Int. J. Chem. Sci.: 14(3), 2016, 1711-1717
ISSN 0972-768X
www.sadgurupublications.com

AN IN-DEPTH ANALYSIS OF ETHANOL BASED AQUEOUS FOAMS FOR ENVIRONMENTAL APPLICATIONS

PRADIPTA CHATTOPADHYAY* and R. ARUN KARTHICK

Department of Chemical Engineering, BITS-Pilani, PILANI – 333031 (Raj.) INDIA

ABSTRACT

The foamability parameters of surfactant generated aqueous ethanol based foams are critical for remediation of petroleum hydrocarbon contaminated soil. To gain more insight into foams that will be suitable for this application, different aqueous foams were generated by the use of ethanol, surfactant Sodium Lauryl Sulfate (SLS), constant injection of air and then tested for foaming capability, using a Dynamic Foam Analyzer (Kruss GmbH, Germany). The results showed that 30 volume % ethanol solution with 10 mg of SLS added was the best in terms of foamability and thus well suited for soil remediation.

Key words: Aqueous foams, Foamability, Ethanol, Surfactant.

INTRODUCTION

Foams consist of agglomerations of gas bubbles separated by liquid films[1]. Foams[2] help in remediation of contaminated soils by enhancing the oxygen content of soil. This also subsequently reduces the operational costs of cleaning such soils. Aqueous ethanol based foams[3] have shown superior soil remediation performance over aqueous surfactant solutions. It also has been described that while aqueous surfactant solutions are not very successful in removing polyaromatic hydrocarbons from soil, aqueous ethanol based surfactant solutions could eliminate upto 50%[4]. The ethanol based surfactant solutions have been found to remove pollutants efficiently and help in maintaining high hydraulic conductivity in the soil[5]. The aqueous foam plays important role in soil remediation as it reduces contamination in the soil by increasing the sweep efficiency. The problems in delivering water mixture to remove contaminants from soil are also reduced when foam is utilized as delivery system. Foam also reduces the vertical flow of liquid thereby enhancing the preferential spreading of surfactant in the soil layers[6,7].

The aim of this article is to explore in more detail the foaming behavior of aqueous

*Author for correspondence; E-mail: pradipta@pilani.bits-pilani.ac.in

ethanol based Sodium Lauryl Sulfate (SLS) solutions for contaminated soil remediation applications. This is helpful to investigate the better foaming capabilities for such environmental remediation applications. The current research was subdivided into two parts. Firstly, the foamability of different aqueous ethanol + SLS solutions were studied. Next, the foamability of aqueous SLS solutions with no ethanol content were investigated to gain better understanding on the impact of ethanol on the foaming process. The mechanisms for the foam growth and the foam decay for the aqueous ethanol based Sodium Lauryl Sulfate (SLS) solutions were analyzed and discussed. All the foam characterization experiments that have been reported in this article have been performed at surfactant Sodium Lauryl Sulfate (SLS) concentrations below the critical micelle concentration (CMC).

EXPERIMENTAL

Materials

Powdered surfactant Sodium Lauryl Sulfate (SLS) was first weighed and then mixed with aqueous ethanol solution. The ethanol was procured from Varun Industries, India. For all solutions prepared, distilled water was used. The total volume of solutions prepared was 100 mL.

Determination of foam characteristics

Different solutions of aqueous ethanol mixed with surfactant Sodium Lauryl Sulfate (Table 1) were used for the experimental analysis. Also to investigate the role of ethanol on the foaming process, aqueous Sodium Lauryl Sulfate (SLS) solutions with no ethanol were also tested for foamability. All the experiments reported here, were conducted at concentrations of Sodium Lauryl Sulfate (SLS) below the critical micelle concentration (CMC) and at room temperature of 298 ± 2 K. The detailed foam characterization was done using a Dynamic Foam Analyzer DFA 100 (Kruss GmbH, Germany). Foams were generated in a glass column of 0.25 m length and inside diameter 0.04 m by a stream of air that was introduced into the ethanolic solutions through a porous glass filter (pore size: 16-40 μm) with a constant flow rate of 5 mL/s. Both the glass column and the glass filter were supplied by Kruss GmbH, Germany. The air was injected with the above mentioned flow rate for a total duration of 12 s from the start of each experiment. Each foaming experiment was run for a total of 900 s and each run was repeated three times for better accuracy. The volume vs time plots (Fig. 1) as well as the different results for foamability of the solutions, were obtained using the Foam Analysis Software version 1.4.2.3 (Kruss GmbH, Germany).

RESULTS AND DISCUSSION

Foamability and drainage time

The foamability, in terms of maximum foam volume (Table 1), for the different aqueous ethanol + SLS samples were obtained using the Dynamic Foam Analyzer DFA 100 (Kruss GmbH, Germany). Table 1 displayed the variation of maximum foam volume with the different ethanol + SLS solutions. It was observed (Table 1) that for the same ethanol concentration, as the concentration of surfactant SLS was increased steadily, the foamability in terms of maximum foam volume also increased. The plot (Fig. 1), shown for one sample with 10 volume % ethanol + 4 mg of SLS, depicted the variation of foam volumes with time for the run.

Table 1: Foamability data obtained for the different ethanol + SLS solutions tested (Total solution- 100 mL in each case)

Ethanol conc. (Vol. %)	Sodium lauryl sulfate (SLS) added (mg)	Foam capacity	Liquid Vol. fraction of foam	Max foam Vol. (mL)	25% Drainage (s)	50% Drainage (s)
10	2	1.3	0.34	75.2	11.2	35.4
10	4	1.3	0.32	79.9	12.6	37.6
10	6	1.5	0.29	88.8	20.2	59.2
10	8	1.5	0.28	90.9	26.8	83.2
10	10	1.6	0.27	95.5	22.8	83
20	2	1.2	0.35	71.2	9	23.2
20	4	1.3	0.33	79.5	9.8	23.8
20	6	1.3	0.34	82.7	16	44.2
20	8	1.4	0.32	84.4	15.8	47.6
20	10	1.4	0.31	86.5	20.2	71
30	2	1.5	0.3	87.4	19.6	42.4
30	4	1.5	0.29	91.4	31	60.4
30	6	1.5	0.29	93.6	26.8	59.6
30	8	1.5	0.28	95.4	33.6	68
30	10	1.5	0.28	96.2	33.6	72

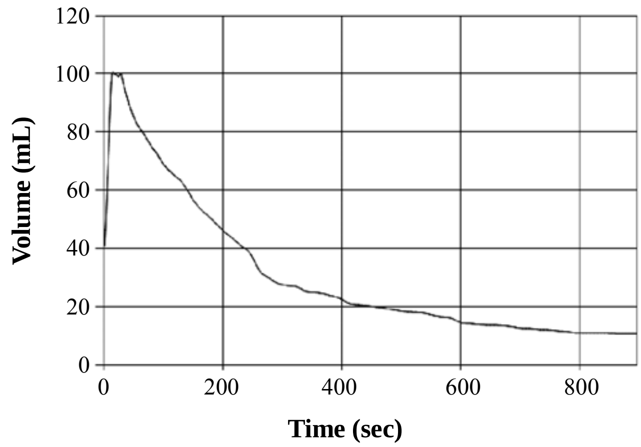

Fig. 1: Foam volume versus time plot obtained for sample with ethanol 10 volume %, Sodium Lauryl sulfate added- 4 mg

The foam volume vs time plots obtained for the other ethanol + SLS samples described in Table 1, have all shown similar trends. Fig. 1 displayed two distinct stages for the foam- foaming, decay phase. During the foaming phase, there was an increase in foam volumes, because of foam growth and during the decay phase, the foam volume decreased because of the foam collapse. It was also clear that the foam did not immediately decay at the end of the air injection period. Foamability was defined[8] as the capability of the surfactant solution to produce the foam. As per literature[9], foamability depended on the surface tension of the solution. As could be seen from Figure 1, the foam volume initially increased with the air injection and the gradual foam decay started from time 27.6 s. Here the development of foam took place with the introduction of air bubbles into the solutions tested. This might have resulted in an increase in surface area. Hence the generation of foam at this stage of air injection would require expenditure of energy against the surface tension forces. The surface tension value relevant for the foam generation process at this stage was thus believed to be dependent on the degree of surface expansion, the rate of surface tension reduction and corroborated by literature[8]. Also it has been reported that greater the rate of surface tension reduction, higher the foamability[10]. Hence the contributory factors for the greater foaming tendencies might be low surface tension, higher rate of surface tension lowering as well as a high rate of micelle disintegration. This might explain the initial trend of increasing foam volumes during the air injection. A gradual decay in the foam volumes after time 27.6 s, after the completion of the air injection was attributed to the increase in micellar stability. Micellar stability has been found to be inversely related to foaming ability[11,12] as because highly stable micelles would be less capable of providing the flux of surfactant SLS required to stabilize the new air-solution interface created during the foaming process. So highly stable micelles would lead to reduction in foaming as observed in Fig. 1.

Also to check specifically the role of ethanol on the foaming of aqueous SLS solutions, foamability data were obtained for different Sodium Lauryl Sulfate (SLS) and water solutions (no ethanol) using the Dynamic Foam Analyzer DFA 100 (Table 2). Fig. 2 showed the comparison plot for maximum foam volumes versus amounts of Sodium Lauryl Sulfate (SLS) added for the different ethanol and non-ethanol solutions.

Table 2: Foamability data obtained for the different aqueous Sodium Lauryl Sulfate (SLS) solutions tested with no ethanol

Volume of water (mL)	Sodium lauryl sulfate added (mg)	Foam capacity	Liquid volume fraction of foam	Max foam volume (mL)	25% Drainage (s)	50% Drainage (s)
100	2	1.1	0.14	63.7	4	9.2
100	4	1.2	0.18	69.3	5.2	14
100	6	1.3	0.21	75.3	6.2	18.8
100	8	1.4	0.26	85.9	7.8	27.6
100	10	1.5	0.26	89.9	8.2	30.2

It was observed from Fig. 2 that as the concentration of SLS increased, the maximum foam volume increased for both ethanol as well as non-ethanol solutions. For 30% ethanol solutions, as the amounts of SLS added increased from 2 to 10 mg, the maximum foam volumes increased from 87.4 ml to 96.2 mL. For the SLS-water solutions (no ethanol), as the amounts of added SLS increased from 2 to 10 mg, the maximum foam volumes increased from 63.7 mL to 89.9 ml. In each case, total solution considered was 100 mL. Similar trends for increase in maximum foam volumes with increasing SLS concentration, were observed for the 10 and 20 volume % ethanol cases, as depicted in Table 1. This increase in foamability in terms of maximum foam volume with increase in surfactant SLS concentration below CMC was found to be consistent with literature[13]. However, this current trend of increase in foamability will be investigated further in future by increasing the surfactant SLS addition to aqueous ethanol solutions. Also, as observed from Table 1, with rise in ethanol volume % in aqueous SLS solution, the maximum foam volume increased. This might be due to the co-surfactant effect where the nonionic ethanol presence in aqueous SLS solution increased the foamability. With increase in ethanol concentration, the micelle producing tendencies including stability of micelles might have decreased and this would explain the increase in foamability in terms of maximum foam volumes, as observed from Table 1.

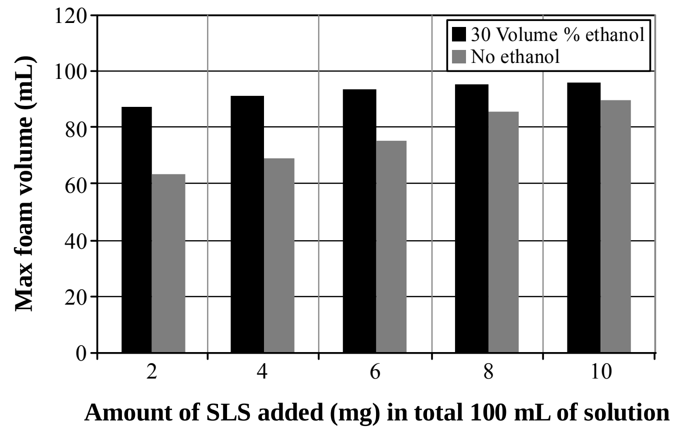

Fig. 2: Comparison of maximum foam volumes obtained from testing aqueous SLS solutions with 30 volume % ethanol and aqueous SLS solutions without ethanol (in all tests, 100 mL of total solution was considered)

The 25% and 50% drainage data (Table 1) clearly shows that there is an increasing trend in the values with increase in surfactant concentration. Drainage time can be affected by the bubble size and size of micelles formed in the foam[14,15]. The increase in drainage time with increase in surfactant concentration may be correlated to the stability of the prepared foam. On comparing the drainage of the foams prepared with only surfactant SLS and SLS-ethanol foams it was found that the drainage time of the ethanolic foam was higher. The highly stable foam had higher drainage time and the variation in stability was observed with increase in concentration of ethanol.

CONCLUSION

Results shown in Fig. 2 indicated that the aqueous SLS solutions with ethanol content are better in terms of foamability, when compared with the aqueous solutions of SLS without any ethanol. These aqueous ethanolic solutions hence will be extremely useful for cleanup of contaminated soils. Also the results shown in Table 1 indicated that for 30 volume % ethanol and 10 mg of SLS added, the maximum foam volume reached is highest at 96.2 mL. So considering the foamability of surfactant generated foams- a chief and critical aspect required for soil remediation applications, the 30 volume % ethanol solution with 10 mg of SLS added was found to be the best choice under the specified conditions.

ACKNOWLEDGEMENT

The authors would like to thank the Department of Science and Technology (DST), India for the financial support of this experimental work (Ref. No. SB/FTP/ETA-208/2012).

REFERENCES

1. H. Azira, A. Tazerouti and J. Canselier, J. Surfactants and Detergents, **11**, 279-286 (2008).
2. M. M. Parnian and S. Ayatollahi, Iranian J. Chem. Engg., **5(2)**, 34-44 (2008).
3. G. N. Sethumadhavan, A. D. Nikolov, D. T. Wasan, V. J. Srivastava, J. J. Kilbane and T. D. Hayes, Ind. Eng. Chem. Res., **42(12)**, 2634-2638 (2003).
4. J. J. Kilbane, P. Chowdiah, K. Kayser, B. Misra, K. A. Jackowski, V. J. Srivastava, G. N. Sethu, A. D. Nikolov, D. T. Wasan and T. D. Hayes, Land Contam. Reclam., **5(1)**, 41 (1997).
5. G. Sethu, A. Nikolov and D. Wasan, Foam Mediated Remediation, Project Reports, Contract No. 5092-253-2336, Gas Research Institute, Mount Prospect, IL (1997).
6. X. Shen, L. Zhao, Y. Ding, B. Liu, H. Zeng, L. Zhong and X. Li, J. Hazard. Mater., **186**, 1773-1780 (2011).
7. Q. Sun, Z. Li, S. Li, L. Jiang, J. Wang and P. Wang, Energy Fuels, **28**, 2384-2394 (2014).
8. R. S. Powale and S. S. Bhagwat, J. Dispersion Sci. Technol., **27(8)**, 1181-1186 (2006).
9. J. J. Bikerman, Foams: Theory and Industrial Applications; Reinhold Publishing Corporation, New York (1953).
10. P. R. Garrett and P. R. Moore, J. Coll. Interface Sci., **159**, 214-225 (1993).
11. D. O. Shah, Micelles, Microemulsions and Monolayers, Marcel Dekker, New York (1998).
12. B. K. Jha, A. Patist and D. O. Shah, Langmuir, **15(9)**, 3042-3044 (1999).
13. L. L. Schramm and F. Wassmuth, Foams: Fundamentals & Applications in Petroleum Industry, DC: Am. Chem. Soc., Washington (1994).
14. A. P. Laheja, S. Basak, R. M. Patil and K. C. Khilar, Langmuir, **14**, 560-564 (1998).
15. I. S. Ranjani and K. Ramamurthy, Mater. Struct., **43**, 1317-1325 (2010).

Accepted : 07.06.2016