INVESTIGATION OF FOAM BEHAVIOUR OF ANIONIC, CATIONIC, AND NON-IONIC SURFACTANTS

Arvind B. Madavi[1*], Ganesh A. Bathe[2]

Abstract

The dynamic foam behaviour of anionic, cationic, and non-ionic surfactants with and without nanoparticles (NP's) were investigated. Effect of titanium dioxide (TiO_2) and silicon dioxide (SiO_2) NP's on foam stability of sodium lauryl sulfate (SLS), cetyl trimethyl ammonium bromide (CTAB) and tween-80 (T-80) surfactants were studied. Foam stability was determined by measuring the half-life time ($t_{1/2}$) and normalized foam height (NFH). NP's were attached to the curved foam surfaces and helps to enhance the foam stability. The dynamic foam behaviour of the surfactant solution in the presence of NP's was characterized by transmission electron microscope (TEM), zeta potential value. Results revealed that the more stabilized foam was observed in the presence of NP's. SiO_2 NP's gave more foam stability as compared to TiO_2 NP's. Axial dye displacement through foam section was studied in the presence and absence of NP's.

Keywords: Foam stability; nanoparticles; dynamic foam behaviour; axial dye displacement

[1*]Department of Chemical Technology, Department of Technology, Shivaji University, Kolhapur, India
[2]Chemical Engineering Department, University Institute of Chemical Technology, KBC North Maharashtra University, Jalgaon, India

*Corresponding Author: Arvind B. Madavi
*Department of Chemical Technology, Department of Technology, Shivaji University, Kolhapur, India
Email, arvindmadavi@gmail.com

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1. INTRODUCTION

Gas is passed through a surfactant solution to form aqueous dynamic foam. Dynamic foam stability depends on various factors like water drainage rate from foam section, temperature, surfactant concentration, pH, gas velocity, surface tension, *etc.* [1]. Foam is a gas-liquid system which provides high surface area but thermodynamically and kinetically unstable. Surfactant foams are used for various purposes such as enhanced oil recovery, multiphase combustion system, fire control, floatation, personal care products, pharmaceutical formulation, mining industries, pre-treatment of lignocellulosic materials, *etc* [2-6]. For a dynamic foam generation, gas is trapped into the foam bubbles. Foam size, in dynamic method is larger if compared with the size of bubbles generated in static foam. Foaminess (is the average time of gas retention in foam) and foam stability (refers to the life of bubbles) are the main parameters for dynamic foam behaviour. The combine study of NP's and surfactants with co-surfactant at boundary is a significant area for research, because NP's improves the stability of emulsions and foams [7]. NP's plays vital role in improving the foam properties by reducing liquid drainage rate from the foam section. NP's size differs when added in a surfactant solution due to agglomeration [8]. Many researchers worked on the foam stability in the presence of co-surfactant and NP's [9-12]. In the current study, foaminess and foam stability were investigated for dynamic foam. As well as the dynamic behaviour of air - water and air- water - NP's systems were compared. Axial dye displacement in the foam bed column (FBC) was studied and compared the dye displacement through foam section with and without NP's.

2. MATERIALS AND METHODS

2.1 Materials

SLS was purchased from Thermo Fisher Scientific India Pvt. Ltd., Mumbai. CTAB and T-80 were purchased from Loba Chemie Pvt. Ltd., Mumbai. TiO_2 NP's (Mol. Wt. 79.87, Average Particle Size: 50 nm) and SiO_2 NP's (Mol. Wt. 60.08, Average Particle Size:15 nm) were purchased from Sisco Research Lab. Pvt. Ltd., Mumbai. Methylene blue was purchased from RFCL Ltd., Faridabad.

2.2 Methods

2.2.1 Experimental Set-up

Continuous foam was generated inside the FBC by passing an air through the liquid section. Foam was generated using three different surfactants (SLS, CTAB and T-80) at fixed concentration of 0.04 M. A 10 ml of surfactant solution was introduced into the FBC. (Internal diameter = 6.8 cm and height=115 cm) as shown in figure 1.

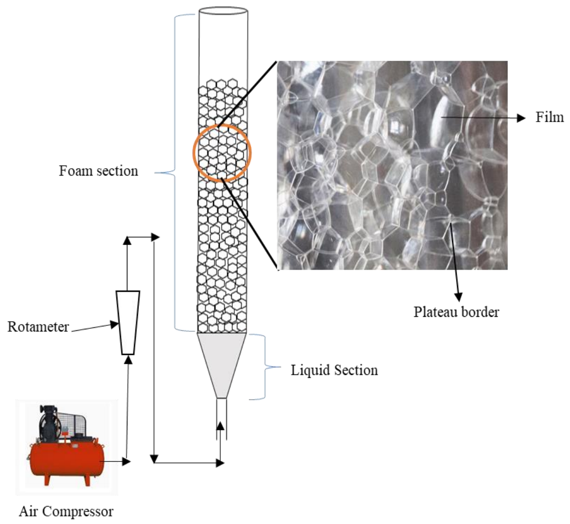

Figure 1: Schematic diagram of FBC.

2.2.2 Foaminess

Foaminess is the average time of gas retention in foam as stated by Bikerman (1973) [13].
Foaminess index (Σ) of foam can be determined by below given formula [5]:

$$\Sigma = \frac{V_f}{U_g} \quad (1)$$

Where, V_f is foam volume (cm^3) and Ug is gas velocity (cm^3s^{-1}).

2.2.3 Foam stability

In the dynamic foam, foam stability was monitored by measuring foam height (in cm) as a function of time (in minutes). Indirectly, stability of foam was measured with the help of half-life ($t_{1/2}$) and NFH.

2.2.4 Foam Half-Life ($t_{1/2}$)

Half-life of foam was calculated by measuring a maximum height of foam decline into half of its initial foam height (air flow was stopped into FBC after reaching a maximum height of foam) [5].

2.2.5 NFH

NFH is nothing but the time required to decrease the foam height into 80% of its maximum foam height. Maximum foam height was achieved at a constant flow rate. After that air flow was stopped for measuring NFH [5]. NFH was calculated by the following equation:

$$\text{NFH} = \frac{\text{Foam height (in cm)at test time (in minutes)}}{\text{Foam height(in cm) at time zero}} \quad (2)$$

2.2.6 Axial Dye Displacement Rate (ADDR)

0.5 ml of (0.01 M) methylene blue (MB) dye was added drop wise using syringe on to the top of foam in FBC. 0.04 M surfactant solution was used for foam generation into FBC. MB dye displacement in axial direction with respect to time from the top of the foam was measured. The unit of axial dye displacement rate was cm s^{-1}[5].

2.2.7 Zeta potential measurement

Dynamic light scattering analyser (Model:Litesizer 500, Anton Paar) was used to determine zeta potential values of SLS, CTAB and T-80 solutions in the presence NP's (TiO_2, SiO_2) at 25 ^{O}C. NP's suspensions was prepared by adding 0.01 g of NP's into 10 ml of 0.04 M surfactant solution. Then, sonicated for 30 minutes before zeta potential measurement.

2.2.8 Transmission electron microscope (TEM)

For TEM image, model: JEM-2100 plus, JEOL, Japan was used. 0.01 g of TiO_2 NP's was dispersed in 10 ml of SLS solution and obtained a homogeneous suspensions. Then, sonicated for 30 minutes before the TEM analysis.

3. RESULTS AND DISCUSSION

3.1 Foaminess

The foaminess was measured for three different surfactant solutions (0.04 M), at 0.15 LPM flow rate of air. More foaminess was observed in SLS and CTAB surfactant solutions. Initially foam height increases with respect to time, after some time rate of foam generation is equal to foam decay rate. Hence, foam height remains constant for certain time. Foaminess provides the information about the maximum foam generated into the FBC. In the presence of NP's, foaminess was slightly affected (*See* figure 2).

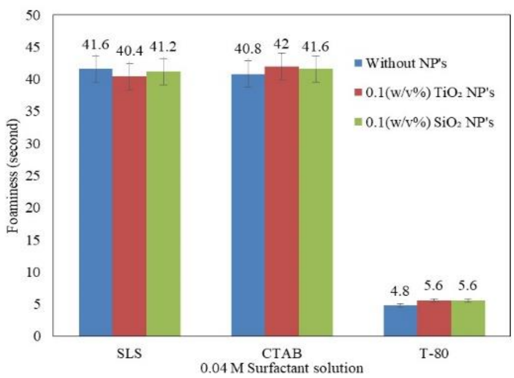

Figure 2: Foaminess of different surfactant solution.

3.2 Foam stability

Half-life ($t_{1/2}$) and NFH terms were used to study the foam stability.

3.2.1 Half-life ($t_{1/2}$) of foam

It was observed that, half-life of CTAB and SLS surfactant solutions were more than T-80. Whereas initial foam height was almost same for SLS and CTAB (*i.e.* 104 cm for SLS and 102-104 cm for CTAB). CTAB and SLS are ionic surfactants. Hence, they can produce more stable foam due to electrostatic attractions and balance van der waals interactions. More foam stability was achieved at pH 6 (if compared with pH 9) (*See* figure 3) [14,15].

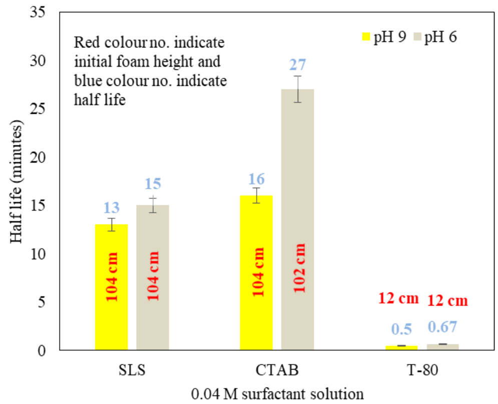

Figure 3: Foam Half-life ($t_{1/2}$) at pH 6 and 9.

3.2.2 NFH

Figure 4 (a), (b) and (c) indicated the NFH values for SLS, CTAB and T-80 with and without NP's. More foam stability was achieved by using SiO_2 NP's. It could be due to the average size of SiO_2 NP's less than the TiO_2 NP's. The water flow towards the lamella is more difficult in the presence of NP's, extending the life of the bubbles. Surfactant and NP's interactions determine the foam stability. NP's helps to hold the more liquid in foam section and prolonged the drainage of foam. It was enhanced the hydrophobicity, surface charges and interfacial properties of surfactant [16]. Dynamic light scattering analyzer was used for measuring the zeta potential values. The zeta potential value of surfactant with NP's were shown in table 1. Zeta potential values showed the direct relation with the foam stability of colloidal solution. Zeta potential is another important factor that can determine the stability of foam in the presence of NP's. A low zeta potential value indicate that NP's agglomeration is more (*see* table 1) and hence, T-80 shows low zeta potential value promotes agglomeration and reducing half-life period. Zeta potential can be used to explain a colloidal system's electro kinetic characteristics. Agglomeration might be occur when the zeta potential value is low due to the attraction of the NP's [17]. Zeta potential value of T-80 surfactant solution is less than SLS and CTAB. Hence, NP's agglomerates more in T-80 surfactant solution. TEM was checked the size of colloidal solution of TiO_2 NP's as shown in figure 5. The TiO_2 NP's sizes were varied from 25.1 nm to 65.1 nm.

Foamability and foam stability was better in SLS and CTAB surfactant solution.

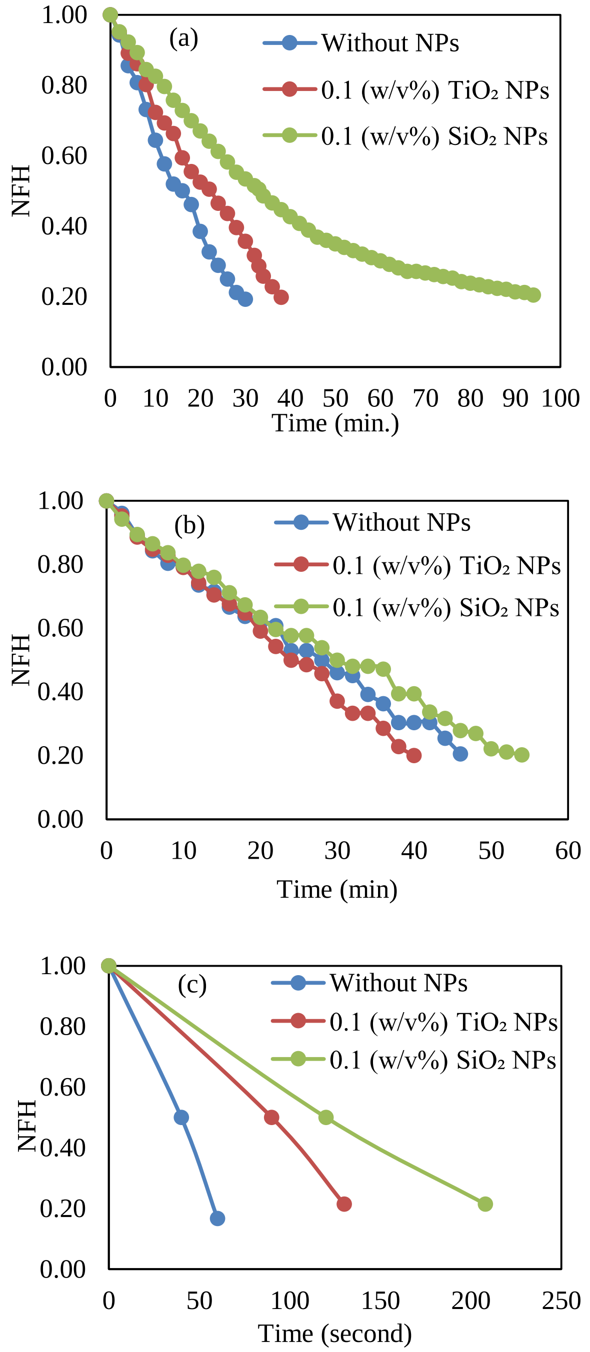

Figure 4: NFH for (a) SLS, (b) CTAB and (c) T-80.

Table 1 Zeta potential of surfactant with NP's.

Surfactants	Zeta potential (mV)
SLS with TiO_2 NP's	-44.5
SLS with SiO_2 NP's	-45.0
CTAB with TiO_2 NP's	30.2
CTAB with SiO_2 NP's	34.0
T-80 with TiO_2 NP's	-17.0
T-80 with SiO_2 NP's	-17.0

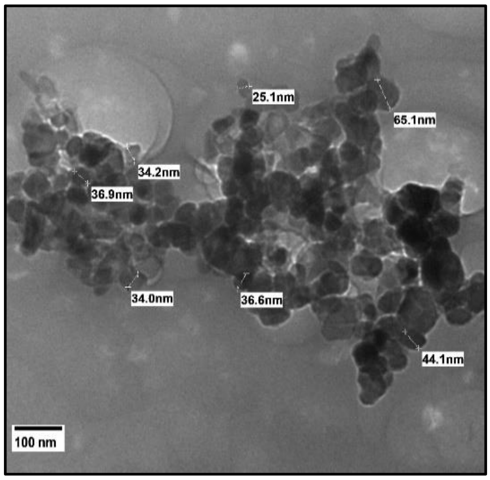

Figure 5: TEM image for 0.1% TiO_2 NP's into 0.04 M SLS solution.

3.3 Axial dye displacement

Axial dye displacement through foam section is the novel method to find foam stability. Figure 6 (a) show, the schematic experimental set-up for the axial dye displacement and figure 6 (b) show, for the foam structure. The shape of the foam was hexagonal. The axial dye displacement through foam section in the presence and absence of NP's were studied (*See* figure 7). NP's were attached to the curved foam surfaces and providing extra resistance to dye displacement through FBC. Hence, the axial dye diffusion rate was slowed in the presence of SiO_2 NP's. Hence, the axial dye displacement rate in FBC is directly proportional to the foam stability. Foam stability is more, if the axial dye displacement rate through the foam section is slow.

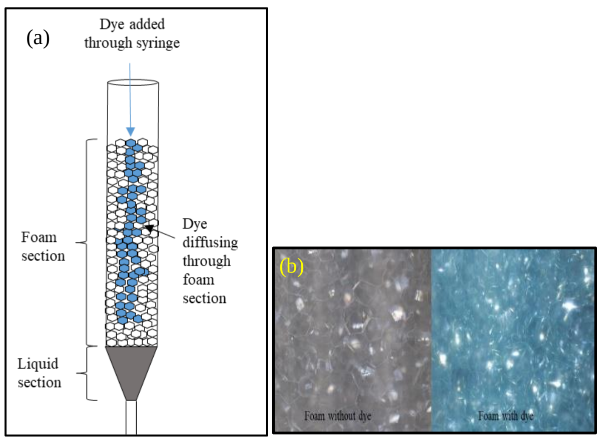

Figure 6: (a) Axial dye displacement; (b) Foam structure.

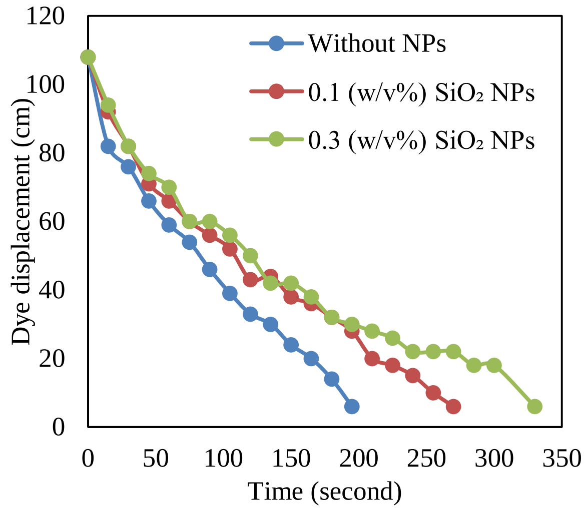

Figure 7: Axial dye displacement through foam section.

4. CONCLUSION

The dynamic foam behaviour of the air-water system was investigated. Stability of foam was studied for pH 6 & 9. It was observed that, more foam stability received at pH 6. NP's increased the foam stability by providing extra resistance to liquid flow through the foam section. More stability of foam was observed in SiO_2 NP's as compared to the TiO_2 NP's. Zeta potential value was low for T-80 surfactant solution with NP's. The more concentration of SiO_2 NP's was slowed down the axial displacement rate in FBC for air-water system. It was found that, NP's reduces axial dye displacement rate and resulting more foam stability.

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