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Investigation of Static Foam Behavior Using Nanoparticles

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ABSTRACT
Static foam behavior of the surfactant in the presence and absence of nanoparticles (NPs) were investigated. The role of TiO_2 and SiO_2 NPs for percentage foamability and foam stability of surfactants (SLS, Tween-80 & CTAB) were studied and checked the effects of temperature, pH, NPs and methanol on foam behavior. The stability of foam was determined by measuring the half-life ($t_{1/2}$) time. Foam stability was more in presence of TiO_2 and SiO_2 NPs.

Keywords - Foamability, Foam stability, Nanoparticles, Static foam, Surfactants

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I. INTRODUCTION

Foam is an important disperse system consisting of gas bubbles (of air, CO_2, N_2 *etc.*) separated by water channels. These foams are both kinetically and thermodynamically unstable system. Foam life time helps to differentiate the transient and metastable foams. The life of transient foam can be for few seconds and metastable foams from minutes to years [1, 2]. Foams are used for various purposes *e.g.* food, pharmaceutical preparations, cosmetics, cleaning, surface treatment, building material, firefighting, mineral flotation due its very large surface area and low density. Surfactants are used in solutions for the production of foam and to reduce the surface tension [2, 3]. Surfactants and NPs are commonly used to stabilize gas-liquid foams and it can influence the dynamic and static behavior of interfaces and strongly affects the surface properties of liquids. Few researchers also studied the behavior of foam along with co-surfactant [4,5]. The most common and simple methods for comparison of foamability of surfactant solutions are Bartsch (shaking test) in which certain amount of surfactants vigorously shaken in locked cylinder and the Ross-Miles (pouring test) in which surfactant solutions present in the cylinder with standard dimensions and poured from the standard distance of upper vessel on to a bed of same surfactant solutions in cylinder [6]. Many industrial applications depend on controlling the foam formation and stability. Foam can be formed inside the column by 1) static and 2) dynamic method. In the static method, firstly foam is generated and then measure the foam volume with respect to time [7]. Foams are destabilized due to the capillary suction and diffusion coalescence. When the foam is form then liquid starts to drain out from its lamellae due to lower the pressure in the plateau borders than in the lamellae and foam films become thinner cause liquid flows towards the plateau border and rupture the foam film and coalescence of the bubbles [8]. NPs are adsorbed at the air-liquid interface becomes irreversible and increases the dilational elasticity leads to the inhibition of bubble coarsening [9, 10]. NPs are slow down the film thinning process due to resistance offer to water flow at bubble surface and increasing the life of foam bubble [11]. F. Ravera *et al.*, 2008 [12] studied the silica NPs dispersion with various amount of CTAB (cationic surfactant). The surface of particle changed from hydrophilic to hydrophobic due to the CTAB adsorption [13]. In the present research work, the effects pH, NPs and methanol presence on foam properties were studied. Comparative analysis was done for the properties of SLS, Tween 80 and CTAB.

II. MATERIALS AND METHODS

2.1. Materials

Sodium Lauryl Sulphate (Molecular weight 288.38) was purchased from Qualigens, Thermo Fisher Scientific India Pvt. Ltd., Cetyl Trimethyl Ammonium Bromide (Molecular weight 364.45) was purchased from Himedia, Tween-80 was purchased from Loba Chemie Pvt. Ltd. and used as anionic, nonionic and cationic surfactants. NPs viz. Titanium oxide mixture of rutile nano-powder (Mol. Wt. 79.87, APS 50nm) and Silicon dioxide nano-powder (Mol. Wt. 60.08, APS 15nm) were purchased from Sisco Research Lab. Pvt. Ltd. Methanol (99.5% extra pure) was purchased from Loba Chemie Pvt. Ltd. and double distilled water.

2.2. Methodology

Static foam was generated by using Bartsch shaking method, where a 10 ml of surfactant solution was vigorously shaken for 30 seconds, 30 times in a 100 ml graduated measuring cylinder by hand and foam volume was measured instantaneously and later up-to 30 minutes with 5 min of interval [6, 14]. Effects of three different surfactants in the presence and absence of NPs on the foamability and foam stability were mainly studied. NPs surfactant solution was prepared by adding defined amount of NPs in surfactant solution and then sonication it for 20 minutes. Percentage foamability is nothing but the foam height (in cm) at 30 minutes divided by the foam height (in cm) at zero minute. Foam stability was studied by monitoring foam height (in cm) as a function of time. Percentage foamability effect (*see* figure 1) with respect to temperature was studied. pH of surfactant solution was varied from 6 to 9 by adding KOH.

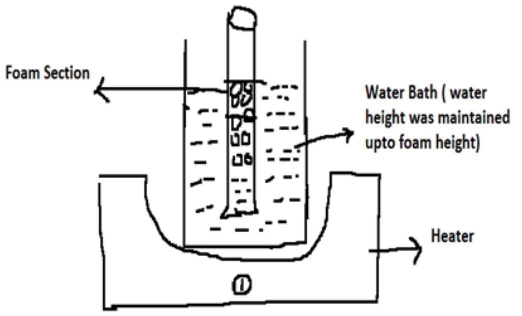


Fig.1 Experimental set-up to measure temperature effect on percentage foamability

III. RESULTS AND DISCUSSION

3.1. Foamability

3.1.1. Effect of temperature on foamability

The foamability of SLS, Tween-80 and CTAB at fixed concentration 0.04 M with and without NPs were investigated by varying temperature from 30±1 ^{0}C to 60±1 ^{0}C as shown in Table 1. Percentage foamability value was more at 30±1 ^{0}C for all three surfactants. If NPs performance was compared for TiO_2 and SiO_2, then SiO_2 showed better values for percentage foamability. Percentage foamability values were better for NPs that displays that NPs increases the life of bubble. Above 50±1 ^{0} C, CTAB shows 0% foamability. Because at high temperature it was observed that decaying rate of bubbles increased suddenly.

Table 1 Foamability of surfactants with and without (0.1 w/v%) NPs at different temperature

		Foamability (%)			
NPs	Surfactants	30±1 °C	40±1 °C	50±1 °C	60±1 °C
0%	0.04 M SLS	79.86	47.82	20.32	2.27
0%	0.04 M Tween-80	60.71	50.00	39.47	25.00
0%	0.04 M CTAB	81.35	39.58	00.00	00.00
0.1 % TiO_2	0.04 M SLS	87.09	60.71	36.51	00.00
0.1 % TiO_2	0.04 M Tween-80	76.92	62.79	42.85	26.31
0.1 % TiO_2	0.04 M CTAB	76.37	52.05	00.00	00.00
0.1 % SiO_2	0.04 M SLS	89.04	60.13	15.34	00.00
0.1 % SiO_2	0.04 M Tween-80	76.92	72.41	31.81	32.00
0.1 % SiO_2	0.04 M CTAB	76.64	52.85	00.00	00.00

3.1.2. Effect of pH on foamability

The foamability of SLS, Tween-80 and CTAB at fixed concentration 0.04M with and without NPs was investigated for pH 6 and 9 as shown in Table 2. It was observed that at pH 9 percentage foamability increases (except CTAB without NPs).

Table 2 Percentage foamability of surfactants with and without NPs at different pH

		Foamability (%)	
NPs	Surfactants	pH 6	pH 9
0%	0.04 M SLS	79.86	85.71
0%	0.04 M Tween-80	60.71	86.20
0%	0.04 M CTAB	81.35	59.05
0.1 (w/v %) TiO_2	0.04 M SLS	87.09	87.17
0.1 (w/v %) TiO_2	0.04 M Tween-80	76.92	91.30
0.1 (w/v %) TiO_2	0.04 M CTAB	76.37	84.55
0.1 (w/v %) SiO_2	0.04 M SLS	89.04	97.27
0.1 (w/v %) SiO_2	0.04 M Tween-80	76.92	66.66
0.1 (w/v %) SiO_2	0.04 M CTAB	76.64%	64.40%

3.1.3. Effect of concentration of NPs on foamability

The foamability of SLS, Tween-80 and CTAB at fixed concentration 0.04M with and without NPs was investigated for varying the concentration of NPs as shown in Table 3. It was observed that the more foamability in the presence of NPs as compared to absence of NPs.

Table 3 Percentage foamability for varying the concentration of NPs

		Foamability (%)			
NPs	Surfactants	0% (NPs)	0.1 w/v% (NPs)	0.2 w/v% (NPs)	0.3 w/v% (NPs)
0	0.04 M SLS	79.86			
0	0.04 M Tween-80	60.71			
0	0.04 M CTAB	81.35			
TiO_2	0.04 M SLS		87.09	77.70	78.43
TiO_2	0.04 M Tween-80		76.92	60.00	64.86
TiO_2	0.04 M CTAB		76.37	84.67	82.20
SiO_2	0.04 M SLS		89.04	88.81	90.00
SiO_2	0.04 M Tween-80		76.92	75.00	72.00
SiO_2	0.04 M CTAB		76.64	86.88	89.14

3.2. Foam stability

Figure 2 shows foam height versus time for 0.04 M concentration of SLS, Tween-80 and CTAB with and without TiO_2 and SiO_2 NPs at room temp. 0.1 w/v% NPs were added into the 10 ml of surfactant. foam height was noted with respective time in the presence and absence of NPs. It was observed that foam stability increased in the presence of NPs. NPs provides extra resistance to water flow towards lamella which increase the life of bubbles. Foam stability depends on the interaction of surfactant with NPs. The liquid hold up was more in foam in the presence of NPs. NPs helps to enhance the hydrophobicity, surface charges and interfacial properties of surfactant [15].

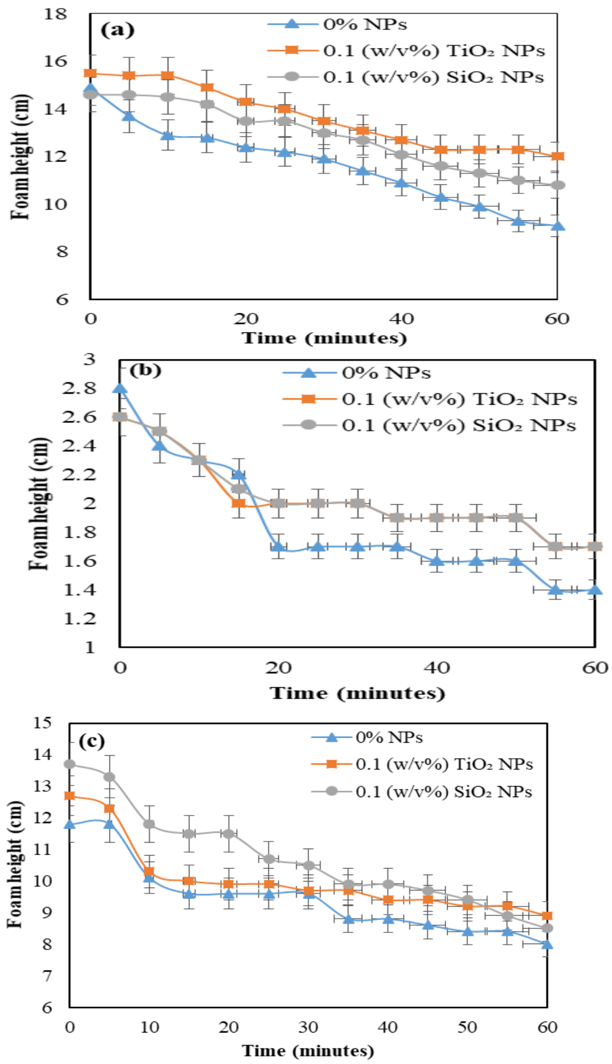


Fig.2 Foam height vs time for different surfactant (a) SLS (b) Tween-80 and (c) CTAB

3.3. Foam half-life ($t_{1/2}$)

Figure 3 shows the half-life ($t_{1/2}$) of foams with and without NPs at different temperatures. It was observed that three surfactants produce more foam stability with 0.1% TiO_2 NPs at 30± 1^{O}C as compared to 0.1% SiO_2 and without NPs. Figure 4 shows foam half-life ($t_{1/2}$) at different concentration of NPs for (a) SLS (b) Tween-80 and (c) CTAB. It was observed that foam stability increased with NPs. Foam stability of surfactants were more at 0.1 (w/v%) TiO_2 NPs. But for SiO_2 foam stability was more for 0.2, 0.3 (w/v%). Figure 5 shows the half-life ($t_{1/2}$) at different concentration of methanol for (a) SLS (b) Tween-80 and (c) CTAB. Foam stability was more at 1% methanol for SLS surfactant while for Tween-80 and CTAB surfactants foam stability was more at 5% methanol. At high concentration of methanol (for 10 %), half-life values reduced for all surfactants.

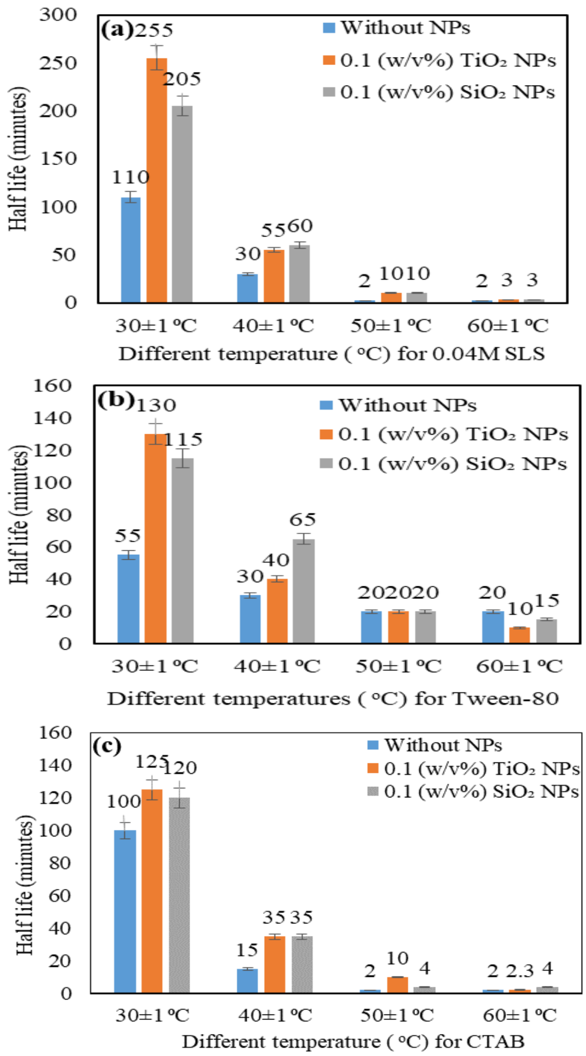


Fig. 3 Foam half-life ($t_{1/2}$) at different temperatures for (a) SLS (b) Tween-80 and (c) CTAB

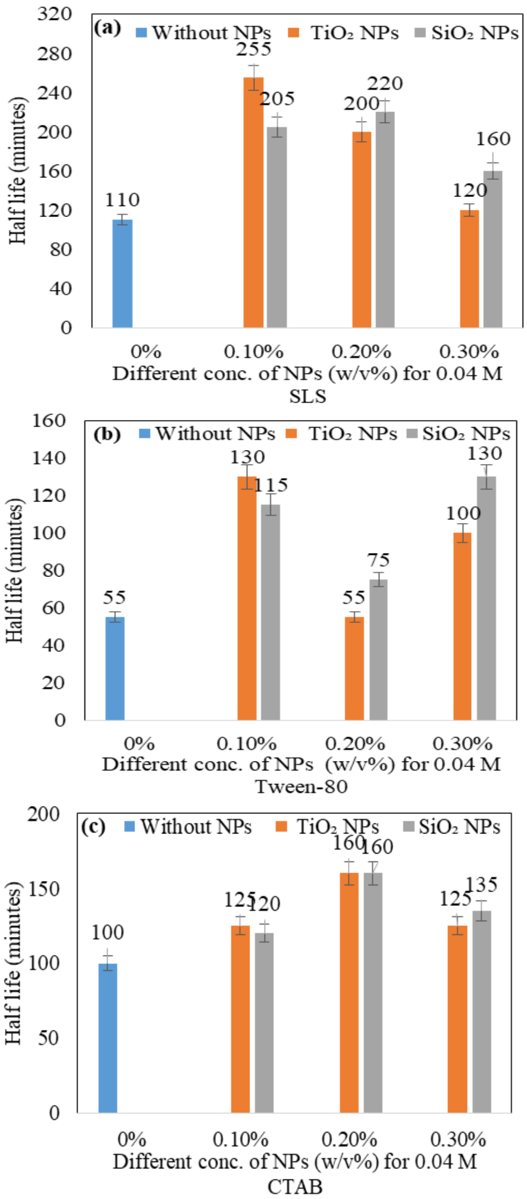
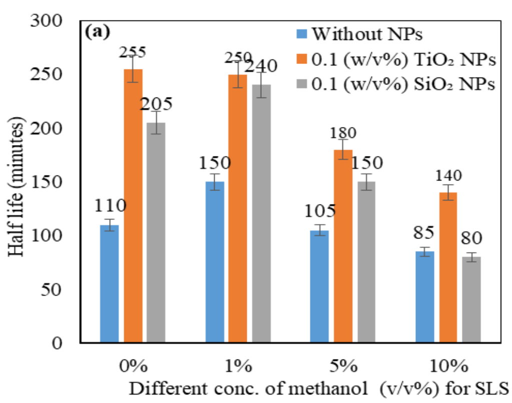


Fig.4 Foam half-life ($t_{1/2}$) at different concentration of NPs for (a) SLS (b) Tween-80 and (c) CTAB



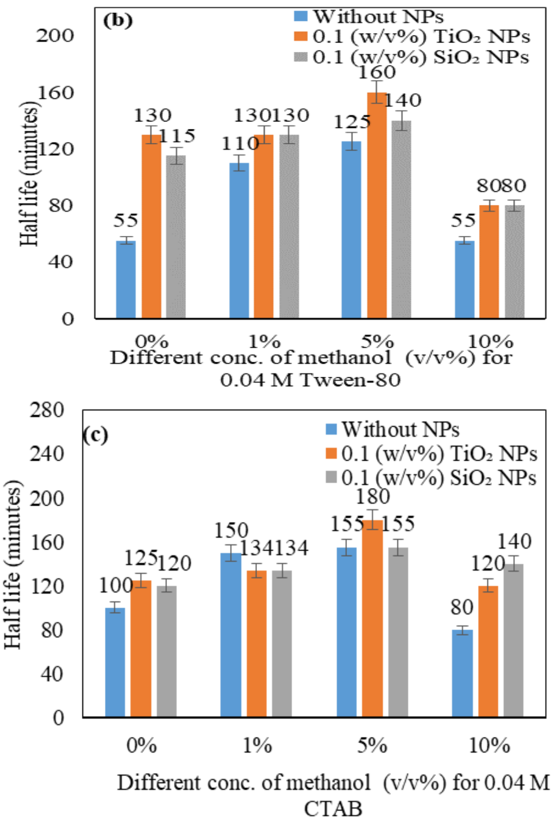


Fig. 5 Foam half-life ($t_{1/2}$) at different concentration of methanol (at 30±1 ^{0}C) for (a) SLS (b) Tween-80 and (c) CTAB

IV. CONCLUSIONS

Foamability and foam stability in presence of different surfactants, NPs and methanol were investigated. These studies concluded that, more percentage foamability was observed for all three surfactants at 30±1 ^{0}C. Percentage foamability value increased for pH 9 surfactant solution if compared with pH 6 surfactant solution. NPs provides extra resistance to water flow towards lamella which prolonged the life of bubbles and eventually increased the stability of foam. Half life ($t_{1/2}$) values of foams were decreased for high temperatures. Methanol effect on half - life ($t_{1/2}$) values were studied. In SLS it was observed that half-life ($t_{1/2}$) values decreased with increasing methanol concentration. For Tween-80 and CTAB half -life ($t_{1/2}$) values increased slightly for 1% and 5% methanol. In general, half- life ($t_{1/2}$) decreased for high concentration of methanol. Methanol was unable to increase the stability of foams due to its high volatility. Methanol may help in generation of foam bubbles in static foam but simultaneously it evaporates form the surface. Due to evaporation of methanol from the surface, upper bubbles decaying rate increases and eventually decreasing stability.

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