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## **INFLUENCE OF ELECTROLYTE PRESENCE ON BUBBLE MOTION IN SOLUTIONS OF SODIUM N-ALKYLSULFATES (C8, C10, C12)**

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**Abstract.** Influence of sodium chloride (NaCl) addition on bubble velocity in solutions of sodium n-octylsulfate (SOS), n-decylsulfate (SDS) and n-dodecylsulfate (SDDS) was studied. The NaCl concentration was varied from 0.0001 to 0.05 M. Profiles of the bubble local velocity, that is, variations of the bubble local velocity with distance from the point of the bubble formation (capillary), were determined. At low sodium n-alkylsulfates concentrations the bubbles, after the acceleration stage, reached a maximum velocity followed by a deceleration stage tending to attain their terminal velocity. The maximum disappeared at high SOS, SDS and SDDS concentrations. Electrolyte alone did not affect the bubble velocity. However, addition of even small amounts of NaCl into solutions of sodium n-alkylsulfates affected the bubble motion. The effect was especially significant at low concentrations of the surfactants studied, where the bubble terminal velocity was lowered from ca. 30-34 cm/s (no electrolyte) down to ca. 15 cm/s in 0.01M NaCl presence. The electrolyte affected the bubble motion via its influence on state of the Dynamic Adsorption Layer formed over surface of the bubbles rising in sodium n-alkylsulfates solutions.

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*keywords:* sodium n-octyl-, n-decyl-, n-dodecylsulfates, bubble velocity, adsorption coverage, electrolyte, surface tension, surface fluidity, dynamic adsorption layer

### **1. Introduction**

Sodium n-alkylsulfates are typical anionic surfactants and some of them (n-dodecylsulfate) are used in froth flotation of various metals, salts, as frothers or/and collectors (Laskowski, 1998, 2010; Ceylan and Kucuk, 2004; Hu et al., 2005 and 2008; Watasharing et al., 2009; Rujirawanich, 2010). As sodium n-alkylsulfates adsorb strongly at solution/gas interfaces so their adsorption at surface of the rising bubbles affects (lowers) the bubble velocity. Adsorption of surface active substances (frothers) at bubble surface prevents also their coalescence, assures a froth layer formation and facilitates the grain attachment to bubbles (Laskowski, 1998; Nguyen and Schulze, 2004; Leja, 1982). Lower rise velocity means that the contact time between the colliding bubble and particle is longer and therefore, the probabilities of

the three phase contact (TPC) and stable bubble-grain aggregate formation are increased. Moreover, the bubble residence time and corresponding gas holdup are higher in the flotation column when the bubble rise velocity is smaller (Azgoni et al., 2007).

Presence and state of adsorption layer at the rising bubble surface can slow down in a great extent the bubble velocity as a result of retardation of fluidity of the gas/liquid interface (Clift et al., 1978; Sam et al., 1996; Krzan and Malysa, 2002ab; Krzan et al., 2007; Krzan and Malysa, 2009). When the bubble is formed in surfactant solution then adsorption coverage is uniform over its surface. Motion leads to inducement of uneven distribution of adsorbed molecules over the bubble surface as a result of viscous drag exerted by fluid on surface of the rising bubble. When the bubble starts to rise with a constant velocity (terminal velocity) it indicates that the dynamic architecture of adsorption layer (DAL) is established over the bubble interface. Establishment of the DAL means that the adsorption coverage is at minimum on the bubble top pole, while on the bottom the coverage is higher than the equilibrium one. It means that the surface tension gradient is induced over interface of the rising bubble, which retards mobility of the bubble interface. As a result of the bubble interface immobilization the hydrodynamic drag for the bubble motion is increased and the bubble rising velocity can be reduced, even by over 50%. For complete immobilization of interface of the rising bubbles a definite degree of adsorption coverage is needed, which magnitude is different for various surface active substances (Krzan and Malysa, 2002ab; Krzan et al., 2007). In the case of ionic surfactant their degree of adsorption coverage at solution/gas interface is strongly affected by the electrolyte presence, due to the electrolyte influence on electrostatic interaction in the adsorption layer formed.

Adsorption of ionic surfactant is affected by the properties of electric double layer (EDL) at the solution/gas interface. Electrostatic interactions (repulsive) in the EDL hinder the adsorption of further surfactant ions and facilitate the counterions adsorption. Davies and Rideal applied the Frumkin adsorption isotherm by considering the ionic interactions in the diffuse part of EDL under the assumption that the surfactant ions are adsorbed in the Stern layer (Davies and Rideal, 1963). However, their model overestimated the diffuse layer potential. Kalinin and Radke (1996) assumed that part of the counterions can form a pair with surfactant ions in the Stern layer, while another (not bonded part) is located in the diffusive region of EDL. Their model was applied successfully to describe experimental data of several authors concerning the dependence of the surface tension of air/aqueous and oil/aqueous solutions. Most recently an alternative model was proposed by Warszynski et al. (1998a), which assumes a penetration of counterions into the Stern layer and formation of the “surface quasi-two-dimensional electrolyte” (STDE). According to the STDE model the electroneutrality condition is not fulfilled at the interface, which bears a surface charge originating from the difference in surfactant ion and counterion surface concentrations. A good agreement between experimental data and theoretical calculations was obtained under an assumption that the ion specific effect is caused by

the difference of size of hydrated counterions. Warszynski et al. (1998a) showed that due to neutralization of the surface charge of adsorbed ionic surfactant molecules by counterions adsorbed in the Stern layer the surface tension of SDDS solutions can be shifted towards lower concentrations by more than order of magnitude. It was also shown recently (Krzan and Malysa, 2009) that addition of 0.05M of some inorganic electrolytes (NaCl/KCl/HCl/NaOH) and/or the pH variation caused significant diminishing the local velocity in low concentrations of SDDS solutions.

The paper presents results of studies on influence of sodium chloride (NaCl) addition on bubble motion in solutions of sodium n-octylsulfate, n-decylsulfate and n-dodecylsulfate of different concentrations. Variations of the bubble local velocity with distance from the point of the bubble formation (capillary) and the terminal velocity values were determined. The electrolyte (NaCl) concentration was varied from 0.0001 to 0.05M and it was found that NaCl presence even at so small amount as 0.001M can significantly affect motion of the rising bubbles. It is showed that the electrolyte affected the bubble motion via its influence on state of the Dynamic Adsorption Layer formed over surface of the bubbles rising in sodium n-alkylsulfates solutions.

## 2. Experimental

The experimental setup and procedures of the measurements were described in details elsewhere (Krzan and Malysa, 2002a; 2009). Single bubbles were formed in a controlled way at the capillary of inner diameter 0.075 mm and their motion after detachment was monitored over approximately 500 mm distance from the capillary using the Moticam 2000 camera and stroboscopic illumination (100 Hz). Values of the local velocity  $U$  of the bubble, at the given distance  $L$  from the capillary, were calculated as:

$$U = \frac{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}}{\Delta t}$$

where  $(x_2, y_2)$  and  $(x_1, y_1)$  are coordinates of the subsequent positions of the bubble bottom pole, and  $\Delta t$  is the time interval (10 ms) between the stroboscopic lamp flashes. The distance  $L$  was measured as a distance between the capillary orifice and the bottom pole of the rising bubble. Bubble shape deformations were determined by measurements the horizontal and vertical diameters of the rising bubble.

Sodium n-octylsulfate (SOS), n-decylsulfate (SDS) and n-dodecylsulfate (SDDS) were the commercial reagents (Sigma-Aldrich and Fluka) and were used as received. Sodium chloride was heated up to 550°C in order to get rid of any surfactant contaminations. The solutions were prepared immediately before experiment to avoid any long term hydrolysis. Distilled water (Millipore – surface tension 72.4 mN/m, conductivity 0.05  $\mu$ S) was used for solution preparation.

The measurements were carried out at room temperature  $22 \pm 1^\circ\text{C}$ .

### 3. Results and discussion

Figure 1 presents the dependencies of the bubble local velocity on distance from the capillary for sodium n-octylsulfate (Fig. 1A), n-decylsulfate (Fig. 1B) and n-dodecylsulfate solutions of different concentrations. The dependence for the bubble local velocities in distilled water is presented as a reference to show effect of the surfactants studied on the velocity profiles. As seen in pure water the bubble terminal velocity,  $V_{\text{term}}$ , that is, the bubble constant velocity, was  $34.8 \pm 0.3$  cm/s for the bubbles of diameter  $1.48 \pm 0.03$  mm, formed at the capillary used in the study (inner diameter 0.075 mm). It is worthy to add here that the bubble terminal velocity depends on the bubble size as documented by Clift et al. (1978). In our previous studies (Zawala et al., 2007ab, Malysa et al., 2011) we showed that when the bubble diameter varied from 1.22 to 1.66 mm (capillaries of inner diameters 0.05–0.1mm) then magnitude of the bubble terminal velocity varied from  $31.5 \pm 0.2$  to  $36.7 \pm 0.2$  cm/s, but character of variations of the local velocity profiles was similar. As seen in Fig. 1 the velocity profiles are varying with n-alkylsulfates concentration, in a similar way as in the case non-ionic and ionic surfactants studied earlier (Krzan and Malysa, 2002ab and 2009; Krzan et al., 2004 and 2007; Malysa et al., 2005 and 2011). Immediately after detachment the bubble accelerates rapidly over a distance of ca. 20mm, depending on the solution concentration. In distilled water the bubble acceleration was ca.  $925 \text{cm/s}^2$  (Krzan et al., 2007) and after the acceleration stage the bubble achieved its terminal velocity of  $34.8 \pm 0.3$  cm/s at the distance ca. 2–3 cm from the capillary. In low concentrations of sodium n-alkylsulfates the bubbles reached, after the acceleration stage, a maximum velocity followed by a deceleration stage tending to attain their terminal velocity (see Fig. 1). A general tendency can be easily noted in Fig. 1 that position, height and width of the maximum depend on concentration of the sodium n-alkylsulfates solutions. Higher solution concentration caused lowering the maximum height and width. Finally, the maximum disappeared and the bubbles attained their terminal velocity immediately after the acceleration stage at concentrations high enough.

Presence of the maximum on the velocity profiles is an indication that the dynamic architecture of the adsorption layer (DAL) hasn't yet been fully established (Krzan and Malysa, 2002ab and 2009; Krzan et al., 2004 and 2007; Malysa et al., 2005 and 2011). The maximum disappearance means that the DAL has been established at the acceleration stage of the bubble motion. Variations of the maximum velocity with concentrations of sodium n-octylsulfate, n-decylsulfate and n-dodecylsulfate are compared in Fig. 2A. As seen there and in Fig. 1 the concentration of the maximum disappearance was the lowest in the case of sodium n-dodecylsulfate solutions, due to its highest surface activity. Figure 2B presents the dependencies of the bubble terminal velocity on concentrations of these solutions and again here the reagent of highest surface activity (sodium n-dodecylsulfate) lowered the bubble terminal velocity at lowest solution concentrations. It needs to be added here that values of the terminal velocity for low concentrations of sodium n-octylsulfate should be treated with a

caution (as approximates only) because at these concentrations, as can be observed in Fig. 1A, the bubble local velocities were still not constant even at distances 25-30 cm from the capillary orifice. Note please (Figs. 1 and 2) that at high concentration of sodium n-octylsulfate, n-decylsulfate and n-dodecylsulfate the bubbles terminal velocity was similar, ca. 15 cm/s, that is over 50% smaller than in distilled water. Moreover, the bubble terminal velocity practically stopped to depend on the solution concentration above a “threshold” concentration, which value depends on the reagent type.

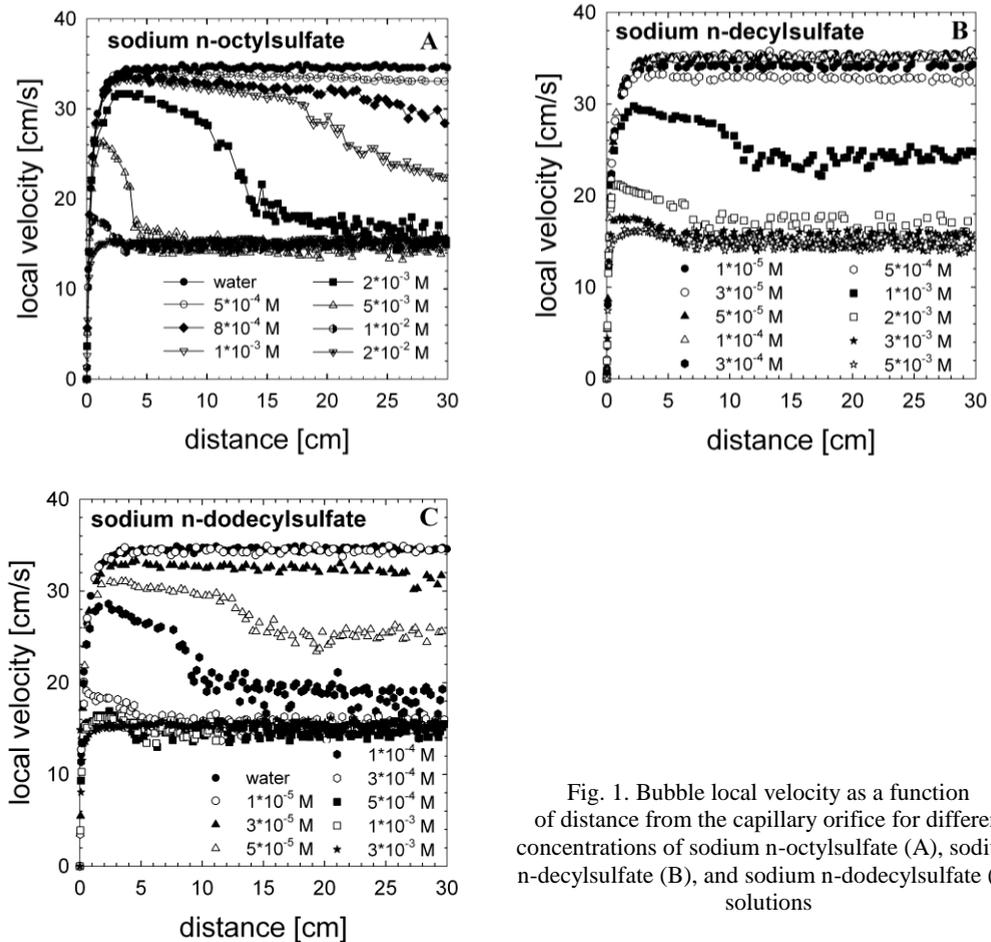


Fig. 1. Bubble local velocity as a function of distance from the capillary orifice for different concentrations of sodium n-octylsulfate (A), sodium n-decylsulfate (B), and sodium n-dodecylsulfate (C) solutions

Lowering of the bubble terminal velocity in surfactant solutions is caused by retardation fluidity of the bubble surface due to formation a dynamic architecture of the adsorption layer (DAL) over surface of the rising bubble. As surface tension of solutions of ionic surfactants (Warszynski et al., 1998a and 2002; Adamczyk et al., 1999ab; Para et al., 2005; Jarek et al. 2010), that is adsorption coverage under equilibrium condition, is strongly affected by electrolyte presence so the velocity

profiles of the rising bubbles should also depend on the electrolyte contents in their solutions. It has already been shown that the addition of 0.05M of electrolyte (NaCl or KCl) strongly affected the parameters of the bubble motion in sodium n-dodecylsulfate solutions (Krzan and Malysa, 2009). In presence of 0.05M NaCl or KCl the bubble local velocities were significantly diminished even in low concentrations of the SDDS solutions. As there is a lack of systematic studies on influence of electrolyte concentration so we studied effect of sodium chloride on the bubble velocity in SOS, SDS and SDDS solutions of different concentrations to find a minimum electrolyte concentration, which can affect the bubble motion. Photos of Figs. 3 and 4 illustrate clearly that increasing concentration of inert electrolyte can significantly affect velocity of the bubbles rising in solutions of  $1 \cdot 10^{-3}$ M sodium n-decylsulfate (Fig. 3) and  $3 \cdot 10^{-5}$  M sodium n-dodecylsulfate (Fig. 4). As all these experiments were carried out under identical frequency of the stroboscopic illumination (100 flashes/sec) so changes in distances between positions of the subsequent images show immediately influence of electrolyte concentration on the bubble velocity. The effect is really huge and it is clearly seen that at constant concentrations of the anionic surfactants the bubble velocity decreases quickly when the electrolyte concentration is increasing. It needs to be noted and underlined here that in  $1 \cdot 10^{-3}$ M SDS and  $3 \cdot 10^{-5}$ M SDDS solutions there were a distinct maximum (see Figs. 1B and 1C) indicating that fluidity of the bubble interface was not fully retarded in these solutions. Lower velocity in the SDS and SDDS solutions containing sodium chloride is an indication that the electrolyte presence caused higher retardation of the bubble surface fluidity.

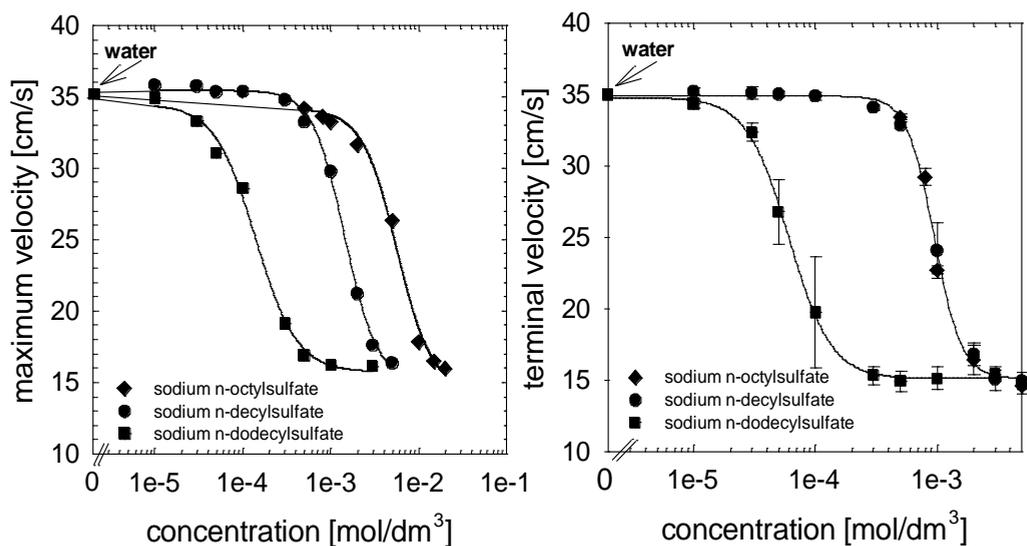


Fig. 2. Variations of the bubble maximum and terminal velocity with concentration of sodium n-alkylsulfates

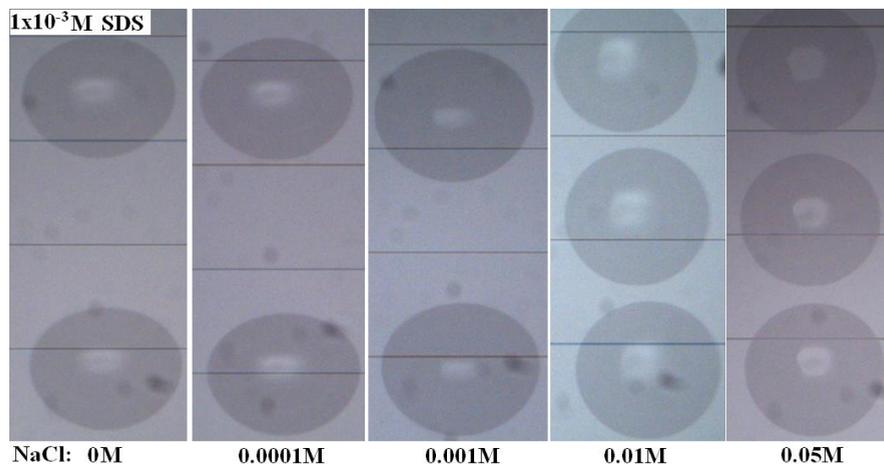


Fig. 3. Images of the bubbles rising in  $1 \cdot 10^{-3}$  M SDS solutions containing different amounts of sodium chloride (distance 1cm from the capillary orifice). Strobe frequency-100 flashes per second

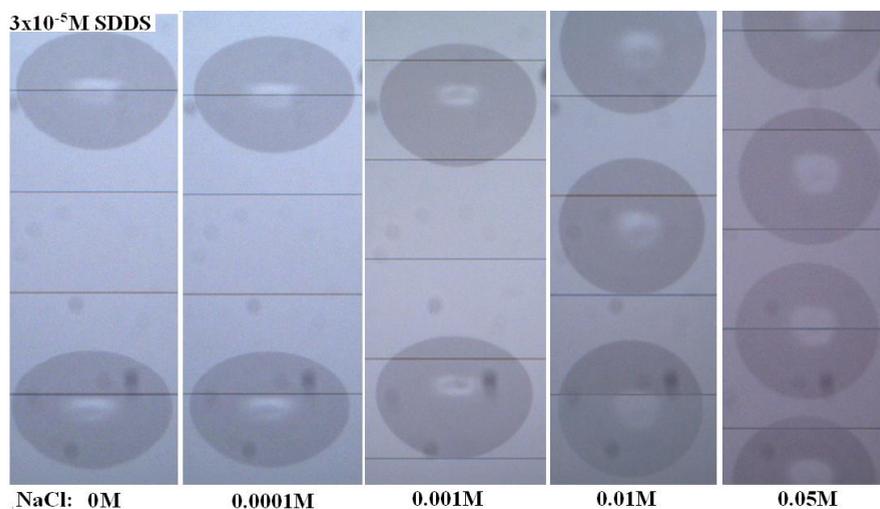


Fig. 4. Images of the bubbles rising in  $3 \cdot 10^{-5}$  M SDDS solutions containing different amounts of sodium chloride (distance 1cm from the capillary orifice). Strobe frequency-100 flashes per second

Figures 5A-5D present the quantitative data on influence of sodium chloride addition on profiles of the bubble local velocity in solutions of  $5 \cdot 10^{-4}$  M sodium n-octylsulfate (Fig. 5A),  $1 \cdot 10^{-3}$  M sodium n-decylsulfate (Fig. 5B),  $3 \cdot 10^{-5}$  M sodium n-dodecylsulfate (Fig. 5C) and  $1 \cdot 10^{-4}$  M sodium n-dodecylsulfate (Fig. 5D). The sodium chloride concentration was varied from 0.0001 to 0.05 M. The dashed lines in Figs. 5A-5D refer to the bubbles motion in solution of 0.05M NaCl without any surfactant

added. As seen the profiles of the bubble local velocity in 0.05 M NaCl and in distilled water (compare Figs. 5 and 1) are identical – after the acceleration stage the bubbles attained their terminal velocity of  $34.8 \pm 0.3$  cm/s at the distance ca. 2-3 cm from the capillary. Identical values of the terminal velocity for distilled water and 0.05 M NaCl solution shows two important things: i) presence of inert electrolyte alone does not affect the bubble motion, and ii) there was no even traces of surface active contaminations in the sodium chloride used. When SOS, SDS or SDDS was present then the situation was completely different (see Figs. 5A-D). With increasing NaCl concentration the local velocity profiles in solutions of  $5 \cdot 10^{-4}$  M SOS,  $1 \times 10^{-3}$  M SDS,  $3 \cdot 10^{-5}$  M SDDS and  $1 \times 10^{-4}$  M SDDS were changed very significantly. Values of the maximum velocity in solutions containing  $5 \cdot 10^{-4}$  M SOS,  $1 \cdot 10^{-3}$  M SDS,  $3 \cdot 10^{-5}$  M SDDS and  $1 \cdot 10^{-4}$  M SDDS were clearly decreasing with increasing NaCl concentration. The bubbles terminal velocity was also changed. For example in  $1 \cdot 10^{-3}$  M SDS and  $3 \cdot 10^{-5}$  M SDDS the bubble terminal velocities were lowered from  $24.1 \pm 0.7$  cm/s and  $31.4 \pm 0.6$  cm/s to  $15.2 \pm 0.5$  cm/s and  $14.6 \pm 0.5$  cm/s, respectively (see Figs. 5B and 5C), when the electrolyte concentration was changed from 0 to 0.05 M. Thus, the increasing electrolyte concentration affected the bubble motion parameters in a similar way as increasing surfactant concentration in solutions without inert electrolyte. Explanation of these findings is rather obvious and consistent with literature data on influence of inert electrolytes on surface tension isotherms of ionic surfactants (Kalinin and Radke, 1996; Warszynski et al., 1998a and 2002; Adamczyk et al., 1999ab; Para et al., 2005; Jarek et al., 2010) – surface activity of the sodium n-alkylsulfates studied was increased due to the electrolyte presence as a result of damping electrostatic interactions in their adsorption layers.

When molecules of the ionic surfactant are adsorbed at solution/gas interface, the electrical double layer (EDL) is built and, as a result, an energetic barrier of electrostatic origin appears. Due to repulsive interactions between the adsorbed ionic surfactant molecules within the adsorption layer the adsorption coverage is significantly lower than in the case of similar but nonionic surfactants. Addition of electrolyte can increase the ionic surfactant adsorption. For example in the case of the SDDS solutions the surface tension isotherm can be shifted towards lower concentrations by more than order of magnitude (Warszynski et al., 1998a). This effect of lowering of surface tension of ionic surfactant solutions in electrolyte presence is due to neutralization of the surface charge of adsorbed ionic surfactant molecules by counterions adsorbed in the Stern layer (Kalinin and Radke, 1996; Warszynski et al., 1998a and 2002; Adamczyk et al., 1999ab; Para et al., 2005; Jarek et al., 2010). The counterions adsorption in the EDL region causes that interface is almost “neutral” for the adsorbing surfactant, and thus, the surface activity of the ionic surfactant almost approaches the surface activity of nonionic surfactant with the same carbon chain length. In other words the electrolyte presence means that at identical bulk concentration the surface tension of sodium n-alkylsulfates solutions is lowered.

Presence of the maximum on the local velocity profiles is an indication, as showed elsewhere (Krzan and Malysa, 2002ab; Krzan et al., 2007), that dynamic structure of the adsorption layer, i.e., uneven, steady state distribution of the surfactant molecules over the bubble surface, has not been established at the acceleration stage of the bubble motion.

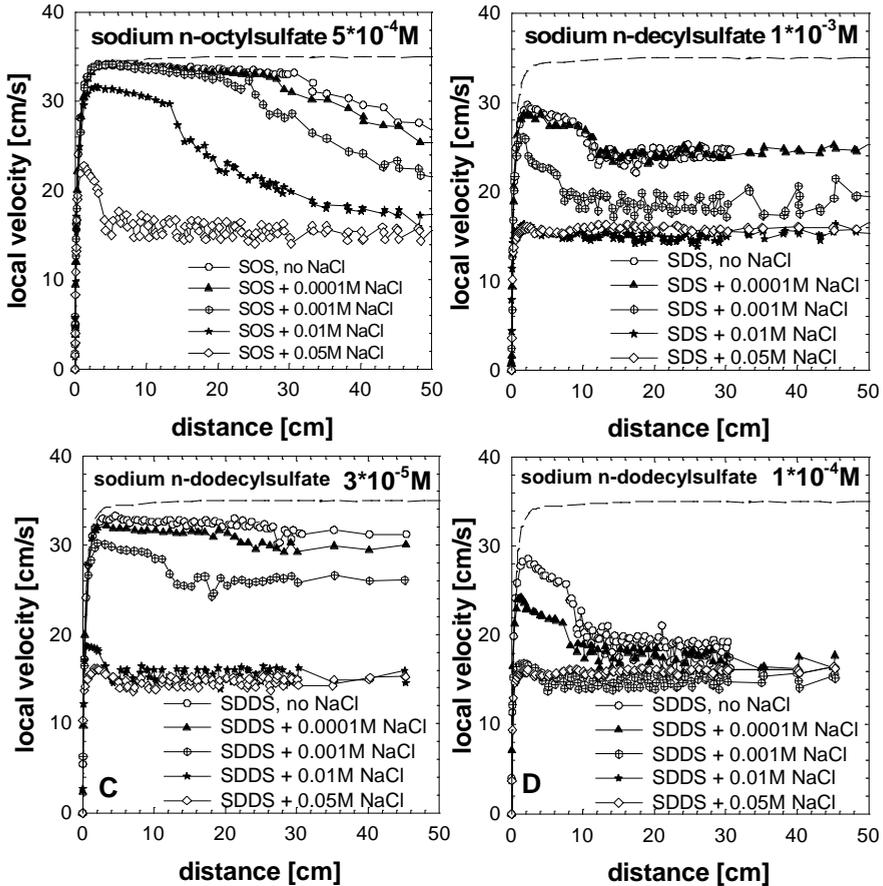


Fig. 5. Influence of sodium chloride concentration on local velocity profiles of the bubbles rising in  $5 \cdot 10^{-4} \text{ M}$  sodium n-octylsulfate (A),  $1 \cdot 10^{-3} \text{ M}$  sodium n-decylsulfate (B),  $3 \cdot 10^{-5} \text{ M}$  (C) and  $1 \cdot 10^{-4} \text{ M}$  sodium n-dodecylsulfate (D) solutions. The dashed line shows the bubble local velocities in 0.05 M NaCl solution, without any surfactant

The maximum is observed at low concentrations of various surfactants and diminishes with increasing surfactant concentration (see Figs. 1 and 2A). It has also been showed (Krzan and Malysa, 2002a; Krzan et al., 2007) that when a maximum is observed on the bubble velocity profiles then there are observed shape pulsations of the rising bubbles. These shape pulsations mean variations of the interfacial area and adsorption-desorption processes, counteracting expansion of the interfacial area, and

are strong confirmation that there was not yet established a steady state distribution of the adsorbed surfactant molecules. The bubble shape pulsations are decreasing, similarly as the height and width of the maximum on the velocity profiles, when the surfactant concentration is increasing. As discussed above the electrolyte presence in solution causes an increase of n-alkylsulfates surface activity as a result of damping electrostatic interactions in the adsorption layers. Increased surface activity means that there is higher adsorption coverage at a given solution bulk concentration. Thus, there should also exist a correlation between variations of the bubble shape and the local velocity values when the electrolyte concentration is increasing at the constant n-alkylsulfate concentrations.

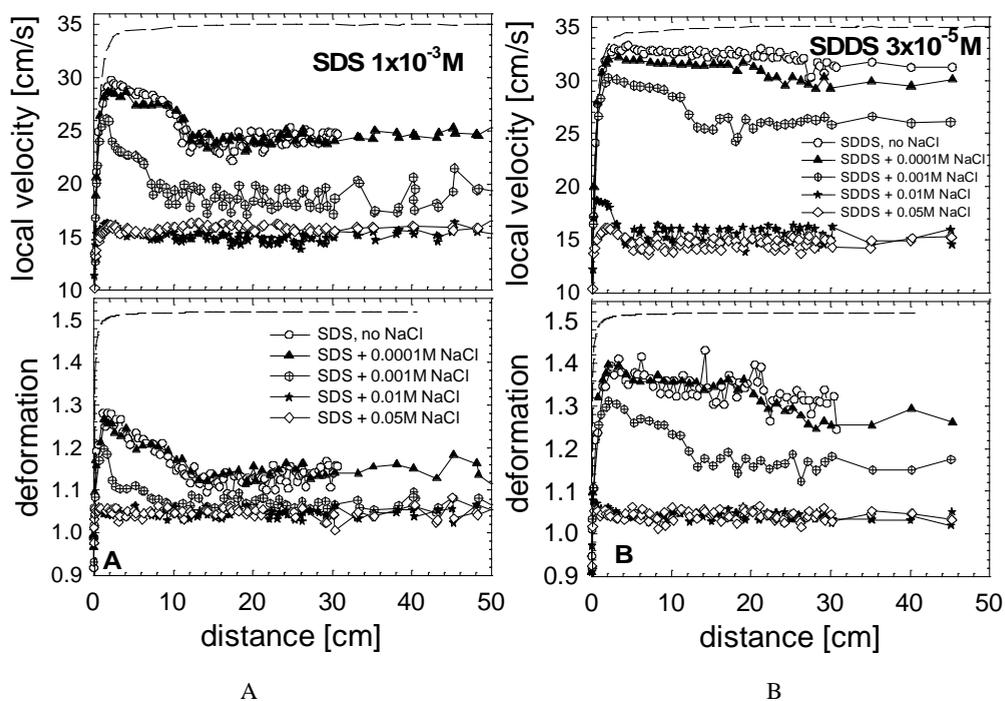


Fig. 6. Influence of sodium chloride concentration on local velocity and degree of the shape variations with distance from the bubble detachment in  $1 \cdot 10^{-3}$  M SDS (Fig. 6A) and  $3 \cdot 10^{-5}$  M SDDS (Fig. 6B) solutions. The dashed line shows the bubble local velocities and deformations in 0.05 M NaCl solution, without any surfactant

Figures 6A and 6B present a comparison of variations of the bubble local velocity and the bubble shape deformations with distance from the capillary in  $1 \cdot 10^{-3}$  M SDS and  $3 \cdot 10^{-5}$  M SDDS solutions. The bubble shape variations are expressed as a ratio ( $d_h/d_v$ ) of the horizontal ( $d_h$ ) and vertical ( $d_v$ ) diameters. A good correlation between variations of the bubble shape and the local velocity values can be observed there.

Both parameters show maxima at similar distances from the capillary and in a similar way the maxima are changing and shifting with changes of the solution concentration. Shape pulsations mean variations of the interfacial area and variations in surface tension gradients induced, which affect fluidity of the bubble interface. Consequently, these variations in the bubble surface fluidity lead to changes of the bubble velocity. Existence of correlations between local velocity changes and shape variations shows that electrolyte presence caused, indeed, variations of adsorption coverage over surface of the rising bubbles. Influence of electrolyte concentration on degree of adsorption coverage over surface of the bubble growing at the capillary orifice can be determined using the convective-diffusion model elaborated by Warszynski et al. (1998b). In calculations the available literature data (Warszynski et al., 1998a) on influence of electrolyte on adsorption isotherms of sodium n-dodecylsulfate were used. Table 1 presents data on degree of adsorption coverage at the moment of the bubble detachment from the capillary in  $3 \cdot 10^{-5}$  M and  $1 \cdot 10^{-4}$  M sodium n-dodecylsulfate solutions without and containing 0.01 M NaCl. As seen the adsorption coverage at the detaching bubble ( $\theta_{det}$ ) was ca. 5–6 fold higher in SDDS solutions containing 0.01 M NaCl. In  $3 \cdot 10^{-5}$  M SDDS solution the adsorption coverage was increased from 1% to 6% in presence of 0.01 M NaCl. Simultaneously, as showed above, the bubble maximum and terminal velocities were lowered from 33.3 and 31.4 cm/s to 18.7 and 15.4 cm/s, respectively. Thus, the data presented in Fig. 4 and Table 1 show straightforward that electrolyte presence affects the bubble velocity as a result of variation of the adsorption coverage of the anionic surfactants over surface of the rising bubbles.

Table 1. Adsorption coverage on bubble growing in sodium n-dodecylsulfate solutions without and containing 0.01 M NaCl. Time of the bubble growth 1.6 s

Conc.	No electrolyte			0.01M NaCl		
	$\theta_{det}$	$V_{term}$	$V_{max}$	$\theta_{det}$	$V_{term}$	$V_{max}$
$3 \cdot 10^{-5}$ M	0.01	31.4±0.6	33.3	0.06	15.4±0.7	18.7
$1 \cdot 10^{-4}$ M	0.036	17.7±1.3	28.6	0.2	15.9±0.3	16.5

Figure 7 presents influence of NaCl concentration on the bubble maximum (7A) and terminal (7B) velocities in SOS, SDS and SDDS solutions. As seen the electrolyte presence, even at so low concentrations as 0.0001 and 0.001M, affect the bubble motion in solutions of sodium n-alkylsulfates. In the case of lowest concentrations of sodium n-alkylsulfates solutions the terminal velocities are lowered from ca. 30-35 cm/s (no electrolyte) down to ca. 23-28 cm/s (0.001M NaCl). When the electrolyte concentration was increased to 0.01 M NaCl then the bubble terminal velocity was reduced to the level of ca. 15cm/s in all SOS, SDS and SDDS solutions studied, what means that fluidity of the bubble surface was practically fully retarded. At higher SOS,

SDS and SDDS concentrations the electrolyte caused also lowering the bubble velocity but the effect was less spectacular because the “starting point” was lower, that is, the bubble velocity in solutions without any electrolyte was lower. Nevertheless, the data obtained show clearly how strongly the electrolyte presence can lower the bubble velocity in solutions of anionic surfactants. As lowering of the bubble velocity is advantageous for probability of the grain attachment to the bubble in every flotation system (lower velocity means a longer contact time during their collisions) so a practical implication from these studies is the following – lower dosage of ionic frother can be applied when electrolyte is present in flotation system.

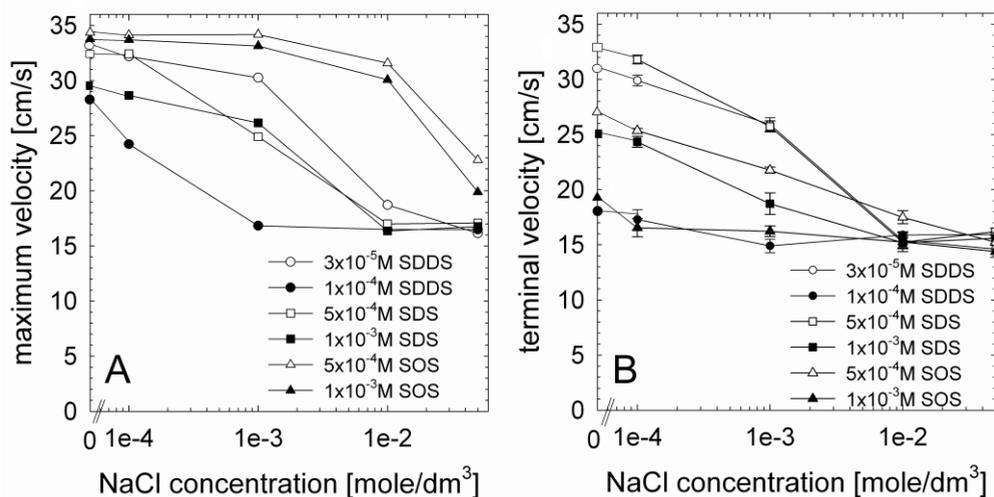


Fig. 7. Influence of electrolyte concentration on maximum (Fig. 7A) and terminal (7B) velocities of bubbles in SDDS, SDS and SOS solutions.

#### 4. Conclusions

Presence of electrolyte (sodium chloride) in sodium n-alkylsulfate solutions affects strongly motion of the rising bubbles. Electrolyte alone, i.e. without any sodium n-alkylsulfate presence, has no effect on the bubble motion and the bubble terminal velocity in 0.05M NaCl was identical as in distilled water ( $34.8 \pm 0.3$  cm/s). At low sodium n-alkylsulfates concentrations the effect of electrolyte addition is huge and even at very low NaCl dosage (0.0001 and 0.001M) the bubbles terminal velocity was lowered from ca. 30-34 cm/s (no electrolyte) down to ca. 23-28 cm/s (0.001M NaCl). When the electrolyte concentration was increased to 0.01M NaCl then the bubble terminal velocity was reduced to the level ca. 15 cm/s in all SOS, SDS and SDDS solutions studied. It was found that increasing electrolyte concentration affected the bubble motion parameters in a similar way as increasing concentration of sodium n-alkylsulfates, what shows that due to the electrolyte presence the degree of adsorption

coverage over the bubble surface was increased. Higher adsorption coverage means an increased retardation of the bubble surface fluidity and lower bubble velocity. Minimum adsorption coverage needed for complete retardation of the bubble surface mobility was determined for sodium n-dodecylsulfate solutions without electrolyte and with 0.01M NaCl. It was found that the SDDS adsorption coverage over surface of the rising bubble was ca. 5–6-fold higher when 0.01 M of NaCl was added.

In flotation systems the bubble velocity lowering is advantageous because lower velocity means a longer contact time during collisions of the bubbles and grains and increased probability of formation a stable bubble-grain aggregates. Thus, a practical implication can be drawn from these studies that lower dosage of anionic frother can be applied when electrolyte is present in flotation system.

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