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Influence of Inorganic Salt Additives on the Surface Tension of Sodium Dodecylbenzene Sulfonate Solution

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Abstract: In order to study the effect of inorganic salt additives on the surface tension of a sodium dodecylbenzene sulfonate (SDBS) solution, the surface tension of the mixed system of six common inorganic salt additives, NaCl, $CaCl_2$, $AlCl_3$, Na_2SO_4, Na_2CO_3, and $NaHCO_3$, and SDBS was measured, and the effects of the inorganic salt types, surfactant concentrations and inorganic salt concentrations on the surface tension of the SDBS solution were studied. On this basis, three inorganic salts, NaCl, $CaCl_2$ and Na_2SO_4, were selected, and their effects on the critical micelle concentration (CMC) of the SDBS solution were studied. The experimental results showed that different inorganic salts had different effects on the surface tension of the SDBS solution. The order of effect of the six inorganic salts on the surface tension of the SDBS solution was $CaCl_2$ > NaCl > Na_2SO_4 > $NaHCO_3$ > Na_2CO_3 > $AlCl_3$; when the mass fraction of the SDBS solution is high, the influence of the inorganic salts on the surface tension of the SDBS solution is relatively small; with an increase in the concentration of the preferred inorganic salt additives, the surface tension of the SDBS solution decreases first, then tends to be stable, and then increases; a reduction in the critical micelle concentration by the three selected inorganic salt additives shows the trend of 0.7% NaCl > 0.5% $CaCl_2$ > 0.5% Na_2SO_4.

Keywords: inorganic salt additives; anionic surfactants; surface tension; critical micelle concentration; shield; ionization; static electricity

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1. Introduction

Surfactants are usually organic compounds, and their molecular structures have unique amphiphilic properties. A surfactant's molecular structure is composed of two parts: the group that has no attraction effect with the solvent molecule is called the hydrophobic group, and the group with a strong attraction to the solvent molecule is called the hydrophilic group [1–4]. According to the properties of the main groups of surfactants, they can be divided into four categories: cationic surfactants, anionic surfactants, nonionic surfactants and zwitterionic surfactants [5–7]. The presence of a surfactant in water can significantly reduce the surface tension of the water, and it improve the surface activity of a solution, depending on its unique molecular structure. When a surfactant is dissolved in an aqueous medium, the hydrophobic group and the water molecules in the solution repel each other and the hydrophilic group and the water molecules attract each other so that some surfactant molecules are driven to the gas–liquid interface in the form of hydrophobic groups moving towards the air hydrophilic group, encouraging the solution toward an orderly arrangement and forming an interface monomolecular film adsorption layer. Since the air molecules themselves are non-polar molecules, similar to hydrophobic polarity, this arrangement eliminates the difference between the gas–liquid phases in which the surfaces are in contact with each other, and the repulsion force at the gas–liquid interface decreases and the surface tension of the solution decreases. After being dissolved in water, surfactants can significantly reduce the surface tension of the water; thus, surfactants have a wide range of applications in the chemical, environmental, biological and medical fields [8–12]. Especially in coal mine dust prevention and control, adding surfactants to the spraying dust-suppression water system can effectively improve the dust suppression efficiency [13–20].

After surfactants were added as wetting agents to the field of dust prevention and control, some researchers noticed the excellent chemical properties of inorganic salts. By combining inorganic salts with surfactants, they found that the addition of inorganic salts can not only effectively increase the surface activity of the surfactants also compensate for the shortcomings of the surfactants. For these reasons, many researchers in China and other countries in the field of dust prevention and control began to focus on the use of inorganic salts as auxiliary agents to improve the performance of surfactants. Scholars found that the use of inorganic salts in surfactants can neutralize the charged ions of ionic surfactants with opposite charges, reduce the repulsive force between the ions, and thus improve the activity of surfactants [21,22]. Therefore, Zhang et al. [23] tested the effect of sodium halide on the surface activity of an equimolar mixed system in a relatively high concentration range through surface tension experiments. It was found that for equimolar mixed systems of positive and negative ionic surfactants with equal chain lengths, small concentrations of inorganic salts had little effect on the surface activity. However, high concentrations of inorganic salts have a significant effect which can increase the surface tension and decrease the CMC. Babu et al. [24] synthesized a new polymer surfactant, tested it through surface tension experiments, and found that adding salt to the surfactant had a synergistic effect. Kumar et al. [25] obtained an alkali–surfactant system at an optimal level of salinity via surface tension and other types of experiments. Qin et al. [26] investigated the influence of different inorganic salts (NaCl, $CaCl_2$ and $MgCl_2$) on the surface properties of sulfonate Gemini surfactant DJ using surface tension measurements and other methods. They found that the addition of inorganic salts to the sulfonate Gemini surfactant DJ resulted in a decrease in interfacial tension, followed by a stable trend, demonstrating excellent interfacial activity. The lowest interfacial tension value appeared in a suitable range of salt mass concentration and baryonic surfactant mass concentration. Therefore, the amount of inorganic salt addition and the surfactant mass concentration should be controlled within a certain range. Su et al. [27] used the real bubble method to determine the surface tension and cmc of solutions containing different concentrations of NaCl, $CuCl_2$ and $Fe(NO)_3$ and the surfactant sodium dodecyl sulfate (SDS). They found that the ability of the three inorganic salt ions to reduce surface tension was as follows: $Fe^{3+} > Cu^{2+} > Na^+$. Adding inorganic salts can reduce the cmc value of SDS, and the cmc value decreases with an increase in the concentration of inorganic salt ions. Zhang et al. [28] measured the surface tension of solutions containing different concentrations of KCl, NaCl and the surfactant sodium dodecylbenzene sulfonate (SDBS). They found that the surface tension of the SDBS solution gradually increased with an increasing concentration of inorganic salts, and the influence of Na^+ on the surface tension of the solution was stronger than that of K^+. Chen et al. [29] reviewed the relationship between the phase behaviors of ion headgroups and surfactant aggregates (Hofmeister effect) and the foam properties and their influence on the aggregation performance of ionic surfactants, nonionic surfactants and mixed surfactant systems. It was found that for ionic surfactant systems, the addition of inorganic salts mainly reduces the electrostatic repulsion between charged headgroups of surfactants, thereby promoting aggregation. This promoting effect is related to the Hofmeister sequence. The aggregation behavior of nonionic surfactants is almost unaffected by salts. However, mixed surfactant systems, similar to ionic surfactant systems, are easily influenced by counterions, and the degree of influence is related to the Hofmeister sequence. Amani Pouria et al. [30] measured the equilibrium surface tension (ST) and critical micelle concentration (CMC) of the adsorption layer of SDBS in the presence of NaCl, KCl, LiCl, $MgCl_2$ and $CaCl_2$ through experiments. They found that the ability of salt to reduce the CMC of the ST and SDBS solutions follows $Ca^{2+} > Mg^{2+} > K^+ > Na^+ > Li^+$. Cao et al. [31] studied the interfacial tension (IFT) characteristics of SDS solutions with different concentrations of $MgCl_2$, as well as the adsorption behavior and interfacial features of SDS with and without $MgCl_2$ using molecular dynamics simulations. They found that the adsorption of surfactants involves mixed diffusion-kinetic-controlled adsorption. The addition of $MgCl_2$ can significantly accelerate the adsorption kinetics and increase the amount of SDS adsorbed. This provides new insight into the adsorption kinetics of anionic surfactants in saline environments.

Conclusively, it can be revealed that inorganic salts can enhance some specific properties of surfactants. However, in previous studies, scholars mostly used a single, inorganic salt to improve the performance of surfactant solutions and rarely considered the influence of the type and concentration of the inorganic salt. Therefore, in this paper, six inorganic salts, NaCl, $CaCl_2$, $AlCl_3$, Na_2SO_4, Na_2CO_3 and $NaHCO_3$, were selected and added to an SDBS solution of anionic surfactants. The surface tension experiment was performed to determine the best inorganic salt and the optimal addition amount of the best inorganic salt.

2. Experimental Materials and Schemes

2.1. Experimental Materials

Figure 1 shows the worldwide production of surfactants in 2016 [32]. From Figure 1, it can be seen that the consumption of anionic surfactants in various industries around the world is much higher than that of other ionic surfactants. In addition, since anionic surfactants have good penetration, wetting and emulsification abilities, anionic surfactants were chosen for the experiment. According to the principles of non-toxicity, harmlessness and economy, sodium dodecylbenzene sulfonate (SDBS) was selected for the study. The molecular formula of SDBS is $C_{18}H_{29}NaO_3S$, as shown in Figure 2. In the study, deionized water was used as the experimental preparation water.

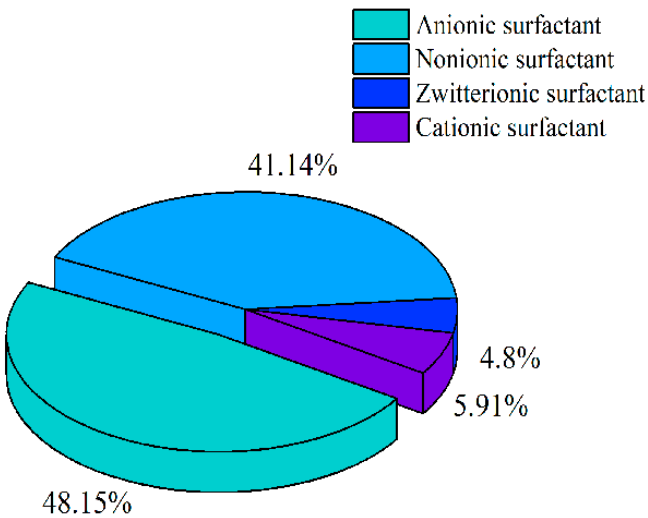

Figure 1. The proportion of surfactant production in the world.

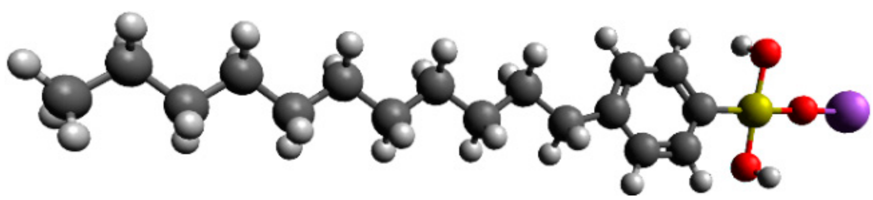

Figure 2. Molecular structure of SDBS.

Based on non-toxic, non-hazardous, non-irritating and environmentally friendly principles, six inorganic salts commonly used in industry were selected: NaCl, $CaCl_2$, $AlCl_3$,

Na_2SO_4, Na_2CO_3 and $NaHCO_3$. The specific parameters of the inorganic salt additives are shown in Table 1.

Table 1. Parameters of inorganic salt additives.

Name	Chemical Formula	Exterior	Purity
Sodium chloride	$NaCl$	Colorless cubic crystal or fine crystalline powder.	Analytically pure
Calcium chloride	$CaCl_2$	White, hard pieces or granules at room temperature.	Analytically pure
Aluminum Chloride	$AlCl_3$	Colorless and transparent crystalline powder.	Analytically pure
Sodium sulfate	Na_2SO_4	White, odorless, bitter crystal or powder.	Analytically pure
Sodium carbonate	Na_2CO_3	White powder.	Analytically pure
Sodium bicarbonate	$NaHCO_3$	Small white particles.	Analytically pure

2.2. Experimental Program

There were three independent variables in this experiment, namely:

A: The mass fraction of the surfactant w_{t1} (3 gradients): 0.00005%, 0.0005% and 0.005%;

B: The types of inorganic salts (6 types): $NaCl$, $CaCl_2$, $AlCl_3$, Na_2SO_4, Na_2CO_3 and $NaHCO_3$;

C: The mass fraction of the inorganic salt w_{t2} (11 gradients): 0, 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9% and 1.0%.

In the SDBS solutions with different mass fractions, inorganic salts of different types and concentrations were prepared, and the Wilhelmy method [33–36] was used to determine the surface tension of the solution after the mixed solution. As the Wilhelmy method is convenient to use, it does not require other correction calculations. It is one of the most commonly used surface tension measurement methods. The operation table was kept stable during the measurement. When the measured liquid was in a state of mechanical balance, after starting the instrument, they were slowly brought into contact in the vertical direction. The wet platinum sheet reached a complete balance when the measured solution and the platinum slices were relatively static. At this time, the instrument was used to determine the minimum tension required for the platinum sheet from the measured solution interface. The instrument used was a KRÜSS-type surface tension meter made in Germany. In order to reduce the experimental error, the average measurement of each group was taken three times. All measurements were performed at a temperature of 25 °C.

The SDBS solution was set within the concentration range of 0.00001–0.1%, and inorganic salt additives that have significantly improved the interfacial tension of the SDBS solution were sequentially added to the solution. The mass fractions of the inorganic salt additives were fixed. The surface tension of the mixed solution was measured, and a surface tension concentration curve was then drawn based on the surface tension value and the corresponding SDBS concentration value. In the curve, the tangents of the curves on both sides of the inflection point were extended until they intersected. The concentration value corresponding to the intersection point is the critical micelle concentration (CMC) of the solution. The specific process is shown in Figure 3.

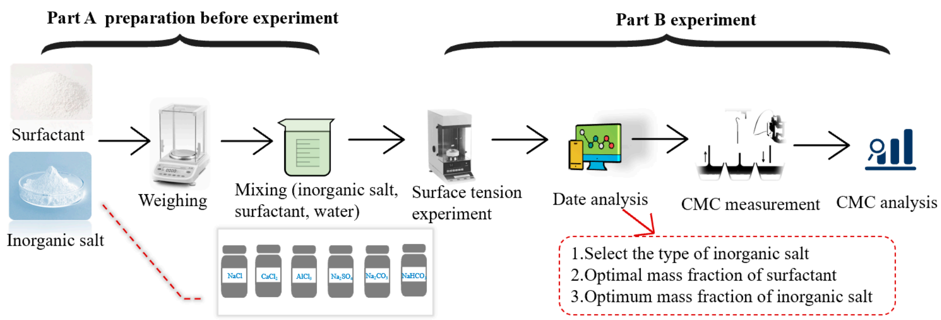

Figure 3. Experimental process.

3. Experimental Results and Analysis

3.1. Influence of the Types of Inorganic Salts

Figure 4 shows a change in the surface tension of the solution with a mass fraction of 0.5% and the SDBS solution. It can be seen from Figure 4 that the surface tension of the combination of the inorganic salt auxiliaries NaCl, $CaCl_2$ and Na_2SO_4 and the SDBS solution was lower than the single SDBS solution, indicating that the inorganic salt assistants NaCl, $CaCl_2$, and Na_2SO_4 show a gain effect on reducing the surface tension of the solution. Essentially, the main reason for the above gain is that after adding the inorganic salt additives to the SDBS solution of the anion surfactant SDBS, the cations (Na^+ and Ca^{2+}) of the inorganic salt electrolytes can reduce the electrostatic exclusion between the hydrophilic group of the surfactant, and the arrangement of the surfactant molecules in the qi–liquid interface is thereby more closely arranged, leading to a greater number of arrangements in the qi–liquid interface, that is, the density of the qi–liquid interface increases, which reduces the surface tension of the SDBS solution. The Hofmeister sequence shows that $Na^+ > Ca^{2+}$, $SO_4{}^{2-} > Cl^-$, and the effect of these three salts on the surface tension of the SDBS solution improves the effect of the improvement effect of $CaCl_2 > NaCl > Na_2SO_4$, which is the opposite of the Hofmeister sequence.

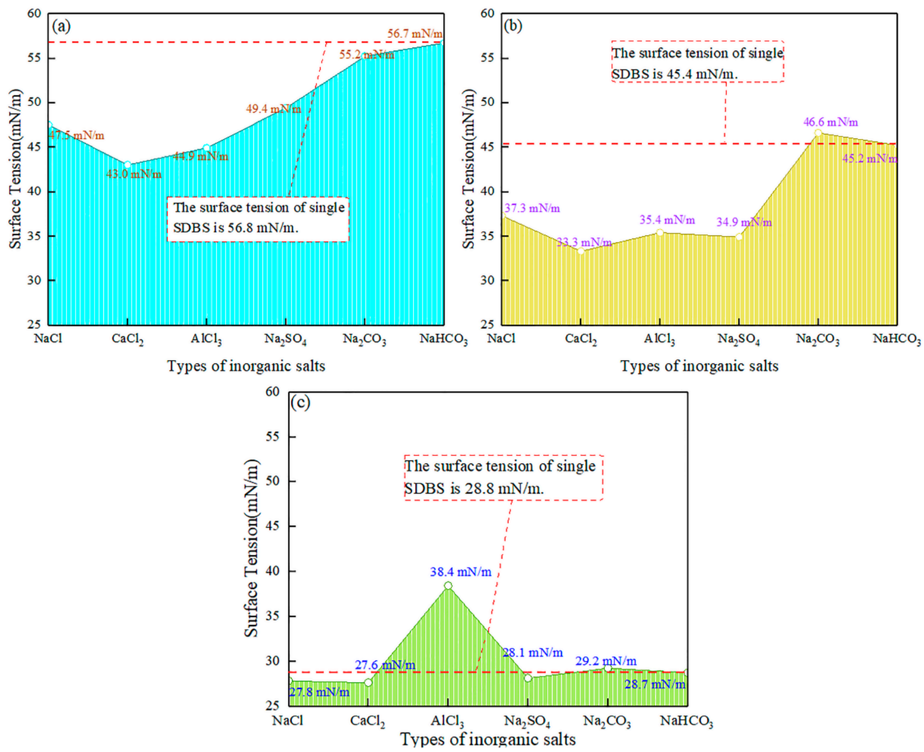

Figure 4. The effect of adding different kinds of inorganic salt additives on the surface tension of SDBS solution: (**a**) w_{t1} = 0.00005; (**b**) w_{t1} = 0.0005; and (**c**) w_{t1} = 0.005%.

From Figure 4, it can also be seen that the inorganic salt additives Na_2CO_3 and $NaHCO_3$ had little overall effect on the surface tension of the solution. For the inorganic salts Na_2CO_3 and $NaHCO_3$, this phenomenon may be due to their strong-alkali weak-acid salts, which generate OH^- during the hydrolysis reaction process, making the solution alkaline. However, SDBS has poor alkali resistance, which hinders the free movement of surfactant molecules to the gas–liquid interface in the mixed solution, The aggregation of surfactant molecules at the gas–liquid interface is affected. When the concentration of the inorganic salt auxiliary $AlCl_3$ is 0.005% of the SDBS, the surface tension of solution increases instead. For the inorganic salt $AlCl_3$, it may be due to the difference between its covalent structure and ionic compound.

Figure 5 shows that when the SDBS concentration is 0.005%, the addition of inorganic salt additives leads to an overall decrease in the surface tension of the SDBS solution. Due to the differences in their chemical properties, different inorganic salt additives have different effects on the surface tension of the SDBS solution. From Figure 5, the surface tension of the SDBS solution mixed with different inorganic salts can be ranked in the order of $CaCl_2$ > NaCl > Na_2SO_4 > $NaHCO_3$ > Na_2CO_3 > $AlCl_3$. When Na_2CO_3, $NaHCO_3$ and $AlCl_3$ are added, the surface tension reduction ratio of the SDBS solution is negative, indicating that the addition of these three inorganic salts affects the surface activity of the surfactant molecules and has a negative effect on the arrangement of the surfactant molecules on the gas–liquid interface. On contrary, the addition of NaCl, $CaCl_2$ and Na_2SO_4 has a beneficial effect on the reduction of the surface tension of the SDBS solution, indicating that the cations ionized by these three types of inorganic salts can reduce the electrostatic repulsion between the hydrophilic groups of the SDBS surfactants and lead to a more compact arrangement of the molecules on the air–liquid interface. As a result, the contact area between the air and the surface of the solution is further reduced, resulting in a further reduction in the surface tension of the SDBS.

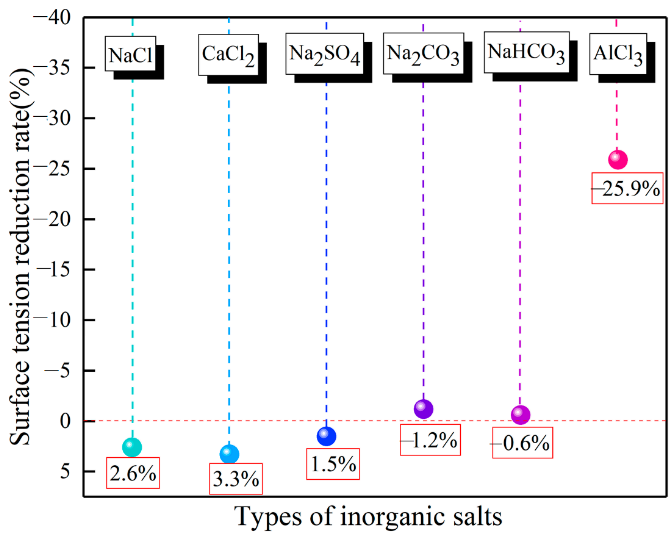

Figure 5. Percentages of the decrease in the SDBS solution surface tension after an inorganic salt is added.

3.2. *Influence of Surfactant Concentration*

Figure 6 shows the change in the solution surface tension after the addition of different concentrations of SDBS. It can be seen from Figure 6 that the two graphs show similar trends, i.e., the surface tension of the SDBS solution decreases with an increase in the surfactant concentration. This is because the decrease in the surface tension of the SDBS solution comes from the arrangement of the surfactant molecules at the air–liquid interface, which increases the interaction between the water and air molecules, reduces the difference between the air and the liquid at the contact interface, and leads to a reduction in the surface tension.

In addition, Figure 6 also shows that different concentrations of the inorganic salt additives reduce the surface tension of the SDBS solution differently. When the surfactant concentration is 0.005%, the addition of an inorganic salt causes almost no change in the surface tension of the SDBS solution, indicating that the degree of reduction in the surface tension of the SDBS solution by the inorganic salt additives is affected by the concentration of the surfactant. This is due to the fact that the CMC of the SDBS solution is 0.005% [37]. When the surfactant concentration is lower than 0.005%, the arrangement density of the surfactant at the gas–liquid interface is relatively small, and the addition of an inorganic salt can greatly shorten the distance between the surfactant molecules, making the arrangement of the surfactant molecules closer. As a result, the surface tension of the SDBS solution has a more obvious reduction. When the surfactant concentration is close to the CMC, the surfactant molecules are already arranged tightly at the gas–liquid interface, so it is difficult for the inorganic salts to reduce the surface tension of the solution.

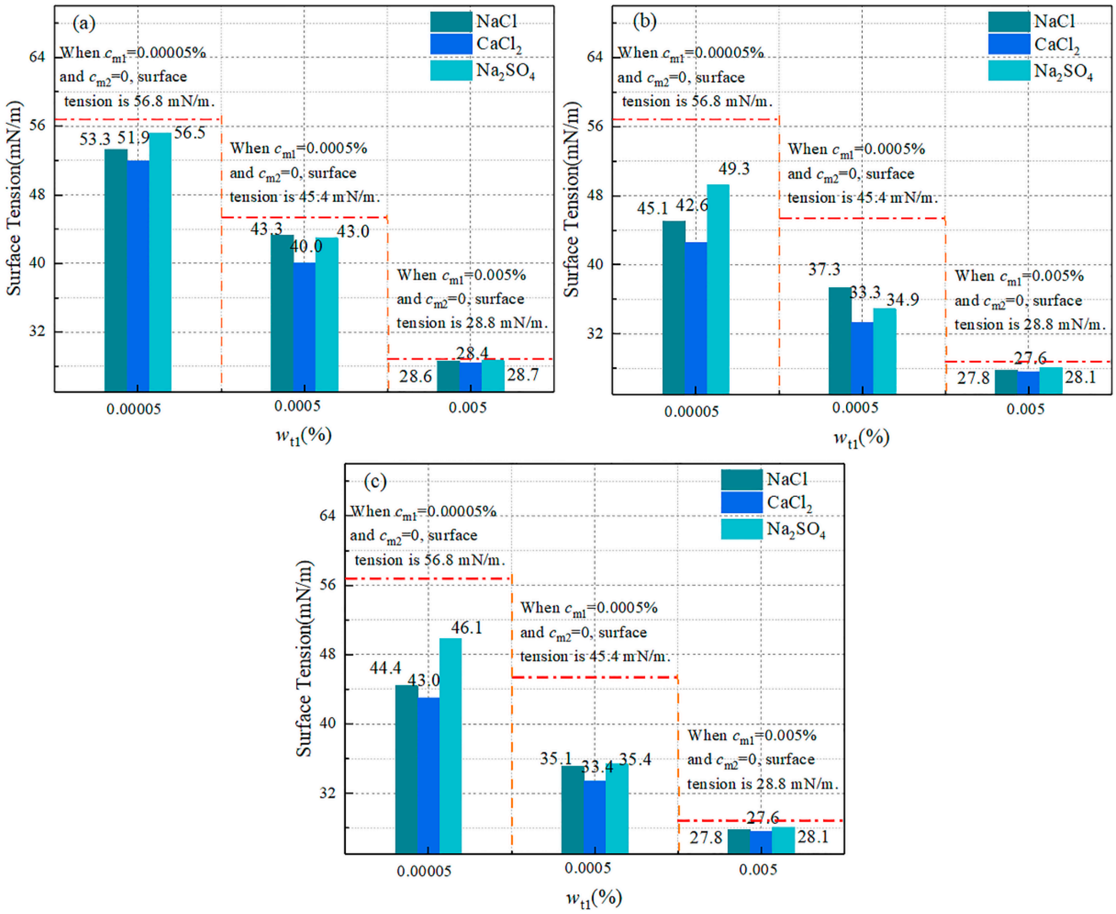

Figure 6. The effect of adding different concentrations of SDBS on the surface tension of the solution: (**a**) w_{t2} = 0.2%, (**b**) w_{t2} = 0.6% and (**c**) w_{t2} = 0.9%.

3.3. Influence of Inorganic Salt Concentration

When the concentration of the SDBS approaches the CMC, the addition of an inorganic salt has little effect on the surface tension of the SDBS solution. Thus, the concentration of the SDBS was set at the other two values, i.e., 0.00005% and 0.0005%, to analyze the influence of the concentration of inorganic salts (NaCl, $CaCl_2$ and Na_2SO_4) on the surface tension of the SDBS solution.

Figure 7 shows the effect of adding inorganic salt additives of different concentrations on the surface tension of the SDBS solution. It can be seen from Figure 8 that the surface tension of the SDBS solution decreases with the increase in the concentration of inorganic salt additives. When the concentration of the inorganic salt additives increases to a certain extent, such as 0.5% $CaCl_2$, the decrease in the surface tension of the SDBS solution becomes smaller and tends toward placidity. This is because when the concentrations of the inorganic salt additives do not reach a certain level, with the addition of inorganic salt counterions, the electrostatic repulsion between the hydrophilic groups of the surfactant decreases, that is, the compression and diffusion of the double electric layer thus increases the molecular density of the gas–liquid surfactant interface, resulting in a reduction in the surface tension of the SDBS solution. The higher the concentration of inorganic salt counterions, the more obvious the reduction in electrostatic repulsion; when the inorganic salt additive reaches a certain concentration, the electrostatic repulsion effect between the hydrophilic groups of the surfactant almost reaches the limit; thus, the surfactant molecules at the gas–liquid interface basically reach saturation, and the surface tension of the SDBS solution basically reaches the lowest value [38–40].

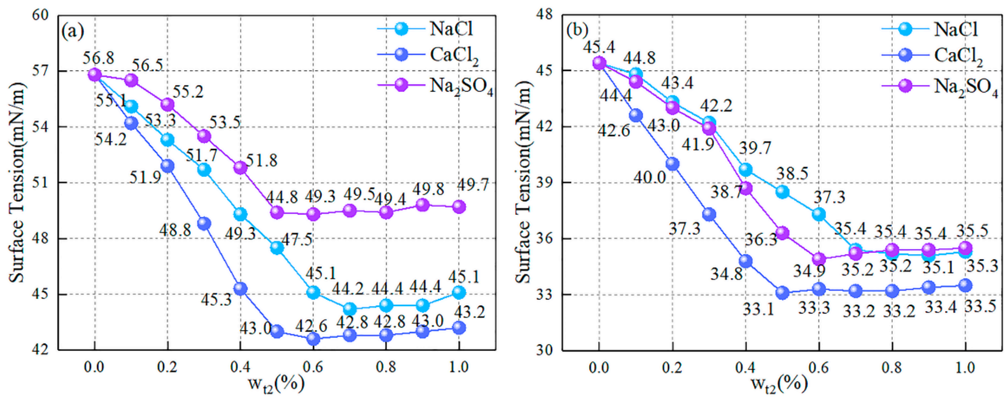

Figure 7. The effect of adding different concentrations of inorganic salt additives on the surface tension of SDBS solution: (**a**) w_{t1} = 0.00005 and (**b**) w_{t1} = 0.0005%.

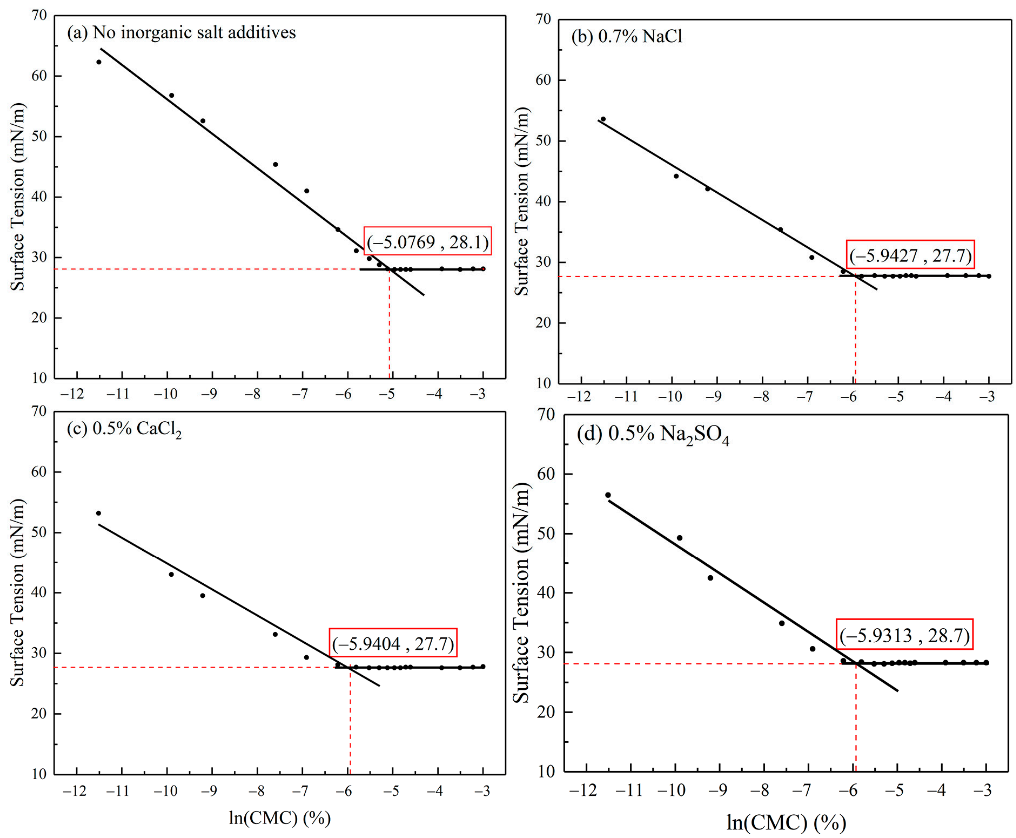

Figure 8. Surface tension curve of the optimal concentration of inorganic salt: (**a**) no inorganic salt additives; (**b**) 0.7% NaCl; (**c**) 0.5% $CaCl_2$; (**d**) 0.5% Na_2SO_4.

It can also be seen from Figure 7 that when the concentration of the inorganic salt additive is low, the reduction in the surface tension of the SDBS solution by $CaCl_2$ is more significant than the reduction caused by NaCl and Na_2SO_4. In addition, when the same concentration of an inorganic salt is added, the SDBS solution with $CaCl_2$ always has a lower surface tension than the SDBS solutions with NaCl and Na_2SO_4. This is because when the concentration of the inorganic salt additives is low, the higher the valence of the cation, the stronger the aggregation ability of the surfactant molecules at the gas–liquid interface is [41] and the lower the surface tension of the SDBS solution is. Therefore, the surface tension of the SDBS solution with Ca^{2+} is lower than the surface tension of the SDBS solution with Na^{+}.

3.4. Influence of Inorganic Salt on the CMC of the SDBS Solution

When the surfactant molecules gradually reach saturation at the gas–liquid interface adsorption, the surfactant molecules will no longer aggregate at the gas–liquid interface. Under the hydrophobic action of the hydrophobic group, the hydrophobic groups of the surfactant molecules attract each other to create cohesion, forming micelles with the hydrophobic group facing inward and the hydrophilic group facing outward in direct contact with the water molecules that are free inside the solution. Therefore, when the interface properties of the surfactant solution tend to be stable and micelles gradually begin to form inside the solution, the concentration of the solution at this time is called the critical micelle concentration (CMC). In surfactant solutions, the addition of an inorganic salt electrolyte usually changes the properties of the solution, causing a change in the critical micelle concentration (CMC) of the solution.

Theories have proved that for anionic surfactants, the influence of inorganic salts on the CMC of the solution is as follows [42–44]:

$$In(CMC) = A' - K_g In(CMC + C_s) \tag{1}$$

where C_s is the concentration of the added inorganic salt electrolyte, mol/L; K_g is the degree of counterion binding (the ratio of the counterion concentration on the surface of the micelle to the concentration of the surfactant forming the micelle); A' is a constant. When C_s is not 0, $CMC + C_s$ is the total counterion concentration of the system, mol/L. When the concentration of external electrolyte is larger, CMC is negligible relative to C_s.

From Equation (1), the influence of an inorganic salt on the surfactant's CMC is related to its concentration. Therefore, based on the surface tension experiment, three types of inorganic salts, i.e., 0.7% NaCl, 0.5% $CaCl_2$ and 0.5% Na_2SO_4, were selected to further analyze the influence of inorganic salts on the CMC of the SDBS solution, as shown in Figure 8. In the figure, the CMC is equivalent to the horizontal coordinate corresponding to the turning point of the surface tension of the curve.

From Figure 8, the curve of the SDBS solution with the addition of inorganic salts shifted downward relative to the single SDBS solution. This indicates that compared with the single SDBS solution, the CMC of the SDBS solution with the addition of the inorganic salt additives is reduced by about 50%. This is mainly because the ions ionized by the inorganic salt reduced the repulsive force between the surfactant ions, altered the intermolecular interaction forces in the system and made it easier for the surfactants to gather to form micelles, thereby reducing the CMC value of the solution.

It can also be seen from Figure 8 that the variation in the surface tension with concentration, the critical micelle concentration and the surface tension of the SDBS solutions with inorganic salt additives are roughly the same. The CMC is mainly concentrated at 0.0026%. The tension is concentrated at 28 mN/m.

Table 2 lists the CMC values of the SDBS solutions with different inorganic salt additives. The smaller the CMC of the solution, the stronger the ability of the surfactant molecules to form micelles in the solution. Therefore, the ability of the SDBS solutions with added inorganic salt additives to form micelles can be ranked from strong to weak as 0.7% NaCl > 0.5% $CaCl_2$ > 0.5% Na_2SO_4.

Table 2. CMC values and surface tension values of SDBS solutions with optimal concentrations of inorganic salt additives.

Type	No Inorganic Salt Additives	0.7% NaCl	0.5% $CaCl_2$	0.5% Na_2SO_4
ln (CMC) (%)	−5.0769	−5.9427	−5.9404	−5.9313
CMC (%)	0.00623	0.00262	0.00263	0.00266
Surface Tension (mN/m)	28.1	27.7	27.7	28.1

4. Conclusions

(1) Different inorganic salts have different effects on the surface tension of an SDBS solution. The inorganic salt additives NaCl, $CaCl_2$ and Na_2SO_4 show a gain effect in reducing the surface tension of the solution. When the mass fractions of the SDBS are 0.00005%, 0.0005% and 0.005%, respectively, the inorganic salt additives to use to increase the surface tension of the solution are $NaHCO_3$, Na_2CO_3 and $AlCl_3$, respectively.

(2) With the increasing concentration of the SDBS solution, the influence of inorganic salts on the surface tension of the SDBS solution is smaller. With the increasing concentrations of the inorganic salts NaCl, $CaCl_2$ and Na_2SO_4, the surface tension of the SDBS solution decreases first and then tends to become stable.

(3) Three inorganic salt additives and their optimum mass fractions were selected: 0.7% NaCl, 0.5% $CaCl_2$ and 0.5% Na_2SO_4. The additions of 0.7% NaCl, 0.5% $CaCl_2$ and 0.5% Na_2SO_4 reduced the critical micelle concentration of the SDBS solution. The three inorganic salts showed a trend reducing the critical micelle concentration of 0.7% NaCl > 0.5% $CaCl_2$ > 0.5% Na_2SO_4.

Author Contributions: B.Z.: data curation; Y.L.: conceptualization and writing—original draft; P.W.: methodology, writing—review and editing, and supervision; R.L.: investigation and visualization; Y.J.: formal analysis. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data that support this study are available in the article and accompanying online Appendix A Table A1.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Different inorganic salts, different concentrations and active surface tension.

w_{t1}	Inorganic Salt	w_{t2} (%)										
		0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0.00005%	NaCl	56.8	55.1	53.3	51.7	49.3	47.5	45.1	44.2	44.4	44.4	45.1
	$CaCl_2$	56.8	54.2	51.9	48.8	45.3	43.0	42.6	42.8	42.8	43.0	43.2
	$AlCl_3$	56.8	53.9	50.2	46.1	45.3	44.9	45.0	45.2	45.6	46.1	45.9
	Na_2SO_4	56.8	56.5	55.2	53.5	51.8	49.4	49.3	49.5	49.4	49.8	49.7
	Na_2CO_3	56.8	56.5	58.2	59.0	56.2	55.2	54.7	54.6	54.2	54.5	54.6
	$NaHCO_3$	56.8	59.0	61.0	60.1	58.3	56.7	55.7	55.3	55.5	55.8	55.1
0.0005%	NaCl	45.4	44.8	43.3	42.2	39.7	38.5	37.3	35.4	35.2	35.1	35.3
	$CaCl_2$	45.4	42.6	40.0	37.3	34.8	33.1	33.3	33.2	33.2	33.4	33.5
	$AlCl_3$	45.4	44	42.6	40.2	34.7	35.2	35.4	35.1	35.0	35.3	35.5
	Na_2SO_4	45.4	44.4	43.0	41.9	38.7	36.3	34.9	35.2	35.4	35.4	35.5
	Na_2CO_3	45.4	46.2	46.5	47.1	46.8	46.3	46.6	46.4	46.1	46.2	46.4
	$NaHCO_3$	45.4	45.8	46.1	46.3	45.9	45.7	45.2	45.0	45.2	45.4	45.3

Table A1. *Cont.*

w_{t1}	Inorganic Salt	w_{t2} (%)										
		0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**
0.005%	NaCl	28.8	28.6	28.6	28.4	28.1	28.0	27.8	27.7	27.7	27.8	27.8
	$CaCl_2$	28.8	28.6	28.4	28.0	27.7	27.6	27.6	27.6	27.7	27.6	27.7
	$AlCl_3$	28.8	32.0	35.7	36.3	35.9	36.6	38.4	37.1	37.1	36.9	36.7
	Na_2SO_4	28.8	28.7	28.7	28.6	28.4	28.1	28.1	28.2	28.2	28.1	28.1
	Na_2CO_3	28.8	29.0	29.4	29.2	29.0	29.1	29.2	29.3	29.2	29.4	29.2
	$NaHCO_3$	28.8	28.9	29.2	29.2	28.9	29.0	28.7	28.7	29.1	29.0	29.3

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