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Experimental and theoretical investigation on the surface tension

of nano-Lithium Bromide solution

Gang Wang [1,2]* Peiwen Dong[1] Yang Lu[3] Min Zeng[2] Qunli Zhang[1]

[1]Beijing Key Laboratory of Heating, Gas, Ventilation and Air Conditioning, Beijing University of Civil Engineering and Architecture, Beijing, 100044, China

[2]Key Laboratory of Thermo-Fluid Science and Engineering, Ministry of Education, Xi'an Jiaotong University, Xi'an, Shanxi, 710049, China

[3]School of Mathematics, Computer Science & Engineering (SMCSE), City University of London, London, EC1V 0HB, UK

E-mail address: 928119081@qq.com (P.W. Dong)

E-mail address: Yang.Lu.4@city.ac.uk (Y. Lu)

E-mail address: zengmin@mail.xjtu.edu.cn (M. Zeng)

E-mail address: zhangqunli@bucea.edu.cn (Q.L. Zhang)

*Corresponding author. Tel.: +86 10 88361620; Fax: +86 10 68322556

E-mail address: wanggang@bucea.edu.cn (G. Wang)

Abstract: To further explore the influence law of nanoparticles on the surface tension of stable nano-Lithium Bromide solution (LiBr), the effects of the concentration of solution, dispersant and nanoparticles on the surface tension were investigated by Wilhelmy plate method under atmospheric pressure. The results demonstrate that the surface tension ascends with the augmentation of solution concentration and the amount of nanoparticles, decreases with increasing temperature and the amount of dispersant. The surface tension of the solution decreases obviously after adding dispersant. However, there is an optimal value for the amount of dispersant, and the surface tension of solution tends to be gentle increased after exceeding the optimal value of the dispersant, which is 2 wt.%. Continue to add nanoparticles, the solution surface tension increases slightly, however, it is still less than pure LiBr. For instance, when the solution temperature is 30°C and the solution concentration is 50 wt.%, the surface tension of nano-LiBr added with 0.01wt.% nanoparticles decreases by 26.20%. The surface tension of nano-LiBr is impacted by coupling of the dispersant and nanoparticles at the same temperature and solution concentration. A surface tension calculation model of nano-LiBr was fitted using experimental data, and the maximum error was 2.78%.

Keywords: Lithium Bromide solution, surface tension, nanoparticles, dispersant

Highlights

1.The surface tension of nano-Lithium Bromide solution was measured by Wilhelmy plate method under steady-state conditions.

2.The effects of temperature, solution concentration, dispersant and nanoparticles on surface tension of stable nano-Lithium Bromide solution are clarified.

3.Based on the experimental data, a semi empirical model of the surface tension of stable nano-Lithium Bromide solution was obtained.

Nomenclature

A_j coefficient of surface tension

B_j coefficient of surface tension

C_j coefficient of surface tension

D_j coefficient of surface tension

d depth of sensing platinum plate immersed in the test solution, m

E_j coefficient of surface tension

F equilibrium of Lithium Bromide tension, N

F_j coefficient of surface tension

g gravitational acceleration, m/s^2

j polynomial degree

L wet perimeter, m

m mass of the sensing platinum plate, kg

n number of data tests

T solution temperature, ℃

t thickness of the sensing platinum plate surface, m

w width of the sensing platinum plate surface, m

x_i data value of the i-th measurement

$\bar{x}$ arithmetic average of each group's experimental data measurement

Greek symbol

α solution concentration, wt.%

β dispersant mass fraction, wt.%

γ nanoparticles mass fraction, wt.%

θ contact angle between the test solution and the platinum plate, °

ρ density of the solution, kg/m^3

σ surface tension of the test solution, mN/m

σ_d surface tension of Lithium Bromide solution with dispersant, mN/m

σ_l surface tension of Lithium Bromide solution, mN/m

σ_p surface tension of pure Lithium Bromide solution, mN/m

$\bar{\phi}$ uncertainty

Subscripts

i   the i-th measurement

l   Lithium Bromide solution

p   pure Lithium Bromide solution

Surface tension represents the tendency of the liquid surface to shrink to the smallest possible surface area, and is one of the significant physical parameters of liquid [1]. The experimental study of enhanced heat and mass transfer in the falling film process of the absorption chiller/heat pump proves that the lower the surface tension of solution, the finer the sprayed droplets, and more readily the solution would form a liquid film on the tube clusters, thus increasing the contact area between gas and liquid and improving the heat and mass transfer effect of solution [2]. Mixing additives into the solution is an effective technique to modify the solution surface tension. The additives could be liquid, gaseous or solid. Earliest, domestic and foreign scholars experimentally measured the surface tension of liquid by adding organic alcohol liquid with 6-10 carbon atoms into the solution [3]. However, there are some discrepancies between the measurement results due to the difference of test methods, experimental conditions, and types of additives. Adding a certain concentration of liquid organic alcohol additives can reduce the surface tension of liquid [2, 4-8], but after reaching an optimal value, the surface tension of the liquid changes only slightly with the amount of additives [4, 9]. Some studies have discovered that the variation range of surface tension with gaseous additives is wider than that of liquid additives [9-11], thus the theory of gas surface activity [9] is put forward. Whereas Gao Hongtao et al. [12] have found that the function of gaseous additives on the surface tension is similar to that of liquid additives. Due to the perplexity of measuring gaseous additives, there are relatively few studies in this area.

In 1995, Choi et al. [13] proposed to suspend nano-scale metal particles in a traditional fluid for the first time to prepare nanofluids with enhanced heat transfer properties. With the wide application of nanofluids in various fields such as solar energy and refrigeration [14,15], the research concerning the intensification of heat and mass transfer of liquids by

nanoparticles [16-22] has also been deepened. Surface tension is a crucial physical parameter of liquids, and the influence of nanoparticles on the liquids surface tension has attracted more and more attention from researchers. Nevertheless, the experimental results of the influence of nanoparticles on the liquids surface tension have demonstrated to be non-uniform. For instance, when studying the surface tension of FeC/H_2O nanofluids in reference [23], it is found that the surface tension of nanofluids climbs with the accretion of the mass concentration of nanoparticles, and the surface tension at low concentration is less than that of water, while the surface tension of high-concentration and temperature range of 10-40℃ is close to that of water. The literature [24,25] also have concluded that the surface tension increases with the accretion of nanoparticles. At the same time, they believed that adding the same nanoparticles, the smaller the size, the smaller the surface tension of nanofluids. However, Cai et al. [26] experimentally drew the opposite conclusion stating that the surface tension of nanofluids diminished with rises in the nanoparticles concentration. Obviously, some researchers have lucubrated the effects of mixed additives on the surface tension of liquids [26-28], and the impact of influencing factors such as temperature and solution concentration. Harikrishnan et al. [28] investigated the surface tension of water-based nanofluids such as Al_2O_3, CuO, Bi_2O_3, and ZnO nanoparticles mixed with SDS, CTAC, and CTAB respectively by using the pendant drop shape analysis method, and found that the surface tension of the liquids mixed with additives decreased with the rising addition of nanoparticles and surfactant, but the influence of nanoparticles was slight, and the surface tension amplified with the augmentation of nanoparticles added separately. The general law of the surface tension of pure liquid or binary solution is that the surface tension descends with the augmentation of temperature or solution concentration [29]. Furthermore, some research results reflect that the surface tension of binary solution attenuates with the addition of solution concentration at the same temperature after adding additives, which may be due to the salting out phenomenon of the solution [7, 28]. The measurement method of liquid surface tension mainly consists of static and dynamic methods. Static methods include the Du Nouy ring method [7, 27], the Wilhelmy plate method [11, 26], the capillary rise method, drop scale method [8-10], maximum bubble pressure method, pendant drop shape analysis method [28], and other methods. Dynamic methods mainly comprise oscillatory jet method and capillary wave method. The operation of dynamic method is complicated and the measurement accuracy is relatively low.

Although it has been confirmed in the literature that additives can intensify the heat and mass transfer effects of the solution, due to complex factors such as type of base liquid , test temperature, type of additives, and addition amount, the strengthening mechanism has not been fully revealed. There is only a limited amount of studies concerning the effects of additives on the surface tension of solution, and there are also some inconsistencies in experimental conclusions. Without considering the stability of nanofluids, the measured surface tension of nanofluids is inaccurate, and the surface tension of nanofluids mixed with dispersant and nanoparticles will also lead to inaccurate experimental results due to stability problems. Therefore, it is of scientific value to verify the function of additives on the surface tension of nanofluids through experiments while accounting for the stability of nanofluids.

In this research, the Lithium Bromide solution (LiBr) in the absorption heat pump was used as the research target to study the effect of temperature, solution concentration, as well as

the addition amount of dispersant and nanoparticles on the surface tension of pure LiBr, LiBr with dispersant (E414), and LiBr with dispersant (E414) + CuO nanoparticles under normal temperature and atmospheric pressure conditions using the Wilhelmy plate method.

1 Experimental equipment and preparation

1.1 Experimental equipment and accuracy analysis

In this research, the surface tension and concentration of solution was principally tested by using an A801 surface tension meter (provided by USA Kino Industry Co., Ltd) and a WBA505 concentration analyzer (provided by Kyoto Electronics Manufaturing (KEM) Co., Ltd (Japan)). Table 1 illustrates the parameters of the test instruments. Fig. 1 and Fig. 2 depict the principle behind the Wilhelmy plate surface tension test and the solution surface tension test system, respectively. The surface tension of the measured solution pulls the sensing platinum plate downward. The surface tension is calibrated by balancing the gravity acting on the sensing platinum plate, the solution buoyancy, the surface tension and the upward tension, as shown in formula (1) [30]. When measuring surface tension, the solution dish to be tested is placed on the lifting platform of the surface tension meter. The lifting platform is a metal platform with a water bath cavity inside, which is connected to a thermostatic water bath. The heating temperature of the lifting platform is controlled by controlling the temperature of the water bath to heat the solution. A high-precision thermocouple (provided by OMEGA Engineering Inc. (USA), accuracy of 0.1K) is immersed in the tested solution, and the other end of the thermocouple is connected to an Agilent data acquisition instrument (provided by Keysight Technologies Co., Ltd (USA)) to test the temperature of the tested solution. Take measurements, when the solution temperature remains stable for more than 30 minutes. Preceding each measurement, the plate should be burned with an alcohol lamp until the color turns red to eliminate the effect of impurities on the platinum plate appearing on the test results [27]. The accuracy of the thermostatic water bath is ±0.1K (provided by Nanjing Xianou Instrument Manufaturing Co., Ltd (China)), and the temperature adjustment range is 25 - 60°C.

$$\sigma = (F - mg + \rho wtdg)/(1000 \cdot L\cos\theta) \tag{1}$$

$$L = 2(w + t) \tag{2}$$

In the above equation, σ is the surface tension of the test solution, mN/m; F is the equilibrium of LiBr tension, N; m is the mass of the sensing platinum plate, kg; g is gravitational acceleration, N/kg; ρ is the density of the solution, kg/m^3; w is the width of the sensing platinum plate surface, m; t is the thickness of the sensing platinum plate surface, m; d is the depth of sensing platinum plate immersed in the test solution, m; L is the wet perimeter, m; θ is the contact angle between the test solution and the platinum plate, °.

Table 1 Parameters of the test instruments

No.	Name	Model	Accuracy	Measuring range
1	Automatic density meter	WBA-505	± 0.00005g/cm^3	0-3 g/cm^3
2	Automatic surface tension meter	A801	±0. 004mN/m	0-999.999 mN/m
3	Electronic balance	DF200A	±0.5mg	0-200 mg
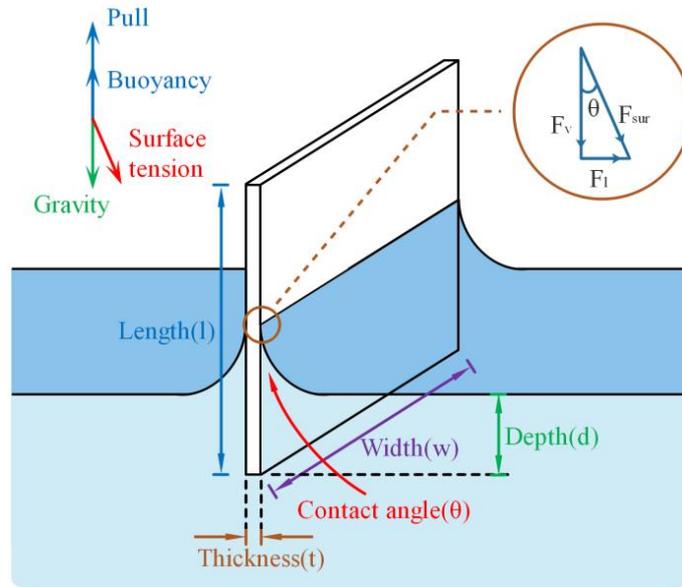
Fig.1 Principle of the surface tension measurement
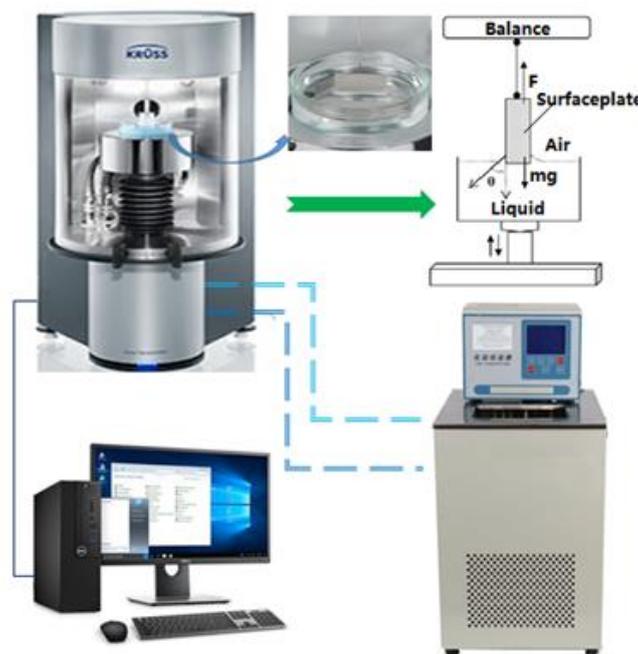
Fig.2 Diagram of the solution surface tension test system

In order to determine the measurement accuracy and precision of the instrument, deionized water and ethylene glycol were selected as standard samples to test the surface tension. The reliability of the instrument test data was verified by comparing the results of five repeated measurements of the sample with the reference values given in the literature. As delineated in Table 2, the maximum values of the test results relative deviations are 3.14% and 2.11%, respectively. Consequently, the test device was determined to possess some degree of reliability.

Table 2 Measurement results of different liquid surface tensions

Test sample	Temperature / ℃	Test value / (mN/m)	Literature value / (mN/m)	Relative deviation / %
deionized water	20	73.64	72.75 [31]	1.22
	30	72.08	71.20 [31]	1.24
	40	68.53	69.60 [31]	1.54
	50	67.35	67.94 [31]	0.87
	60	64.16	66.24 [31]	3.14
ethylene glycol	20	49.76	48.9 [27]	1.76
	30	48.36	48.1 [27]	0.54
	40	47.61	47.1 [27]	1.08
	50	46.87	45.9 [27]	2.11
	60	46.07	--	--

1.2 Experimental materials and nanofluids preparation

This experiment aims at testing the surface tension of pure LiBr, LiBr with dispersant (E414), and LiBr with dispersant (E414) + CuO nanoparticles. Therefore, three types of LiBr are needed to be prepared in the experiment. The materials required for the experiment were pure LiBr (provided by Sinopharm Chemical Reagent Co., Ltd (China)), deionized water, dispersant powder (provided by Sinopharm Chemical Reagent Co., Ltd (China)), CuO nanoparticles (provided by Beijing Deke Daojin Science And Technology Co., Ltd (China)). Fig. 3 is the TEM picture of CuO nanoparticles. The detailed parameters of various materials are outlined in Table 3.
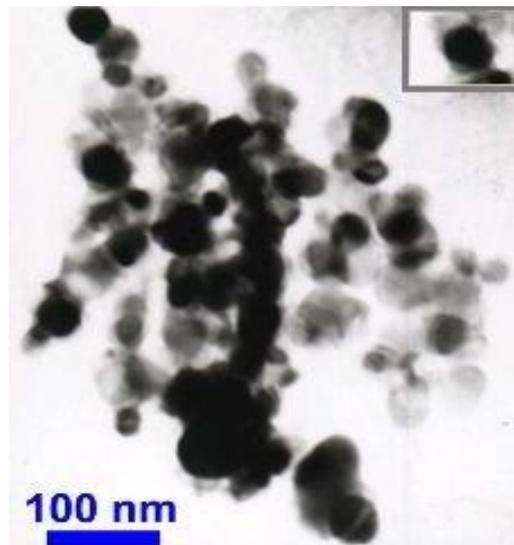
Fig.3 TEM picture of CuO nanoparticles

Table 3 Material information of experiment

Properties	Value		
	Nanoparticle	Dispersant	Solute
Type	CuO	Gum Arabic（E414）	Lithium Bromide
Purity/(%)	99.9	99.0	99.9
Size/(nm)	40	--	--
Color	Black	White	White
Morphology	Nearly spherical	Powder	Crystal
True density/(g/cm³)	6.3–6.49	1.35-1.49	1.57
Added amount/(wt.%)	0.01-0.2	1-5	50-59

According to the required concentration of the solution, pure LiBr (99.9%), deionized water, and dispersant powder (E414) can be mixed according to a certain mass ratio. However, prior to mixing the dispersant with the LiBr, LiBr was prepared first, and then mixed with dispersant when the solution was at normal temperature, so as to avoid the heat of dissolution released by the dissolution of LiBr in deionized water to affect the properties of the dispersant. Considering the stability of nanofluids, the preparation process of LiBr with dispersant (E414) + CuO nanoparticles was relatively complicated. In this research, a two-step method was employed to prepare the nano-LiBr. The preparation process was based on previous research results [32]. Fig. 4 is a process diagram describing the preparation of a nano-LiBr.

Fig. 4 Proposed preparation method of nanofluids

Employing gravity sedimentation method[33], no sediment was observed in the prepared nanofluids suspension after resting for 5 days. Fresh nanofluids had to be prepared for each test to prevent precipitation of the nanofluids suspension during the experiment.

1.3 Uncertainty analysis of experimental data

Uncertainty analysis of experimental data is a necessary process to determine the validity of experimental results [34]. No matter what measures are implemented, errors will always exist during experiments, and errors are generally divided into random errors and systematic errors [34]. Given that the extent of experimental errors is often uncertain, it is more accurate to replace the experimental error with experimental uncertainty. In this study, errors may occur in mass measurement, solution concentration measurement, and surface tension measurement of each component. Hence, this study uses the direct error analysis method and calculates with equation (3). The measurements were performed with equal accuracy repeatedly 5 times to determine the error margin of each measurement link.

$$\overline{\varphi} = [\sum_{i=1}^{n}(x_i - \overline{x})^2 / n(n-1)]^{1/2} \tag{3}$$

In the above equation, $\overline{\phi}$ refers to the uncertainty, n is the number of data tests, x_i is the data

value of the i-th measurement, and $\overline{x}$ is the arithmetic average of each group's experimental

data measurement, and its calculation formula is (4).

$$\overline{x} = \sum_{i=1}^{n} x_i / n \tag{4}$$

The error analysis of the data results reflects that the maximum relative error of surface tension measurement is 1.22%. This confirms that this experiment's results are sufficiently accurate through uncertainty analysis.

2 Experimental results and analysis

In this experiment, the surface tensions of pure LiBr, LiBr with 1 wt.% - 5 wt.% dispersant (E414) which is the appropriate amount of dispersant in nanofluids according to literature research[35-37], and LiBr with 2 wt.% dispersant (E414) + 0.01 wt.% - 0.2 wt.% CuO nanoparticles were tested in the temperature range of 25 - 60℃, concentration range of 50 wt.% - 59 wt.%.

2.1 Effect of temperature and concentration

The surface tension of LiBr is affected by solution temperature and concentration [7]. Fig. 5 reveals the variation trend of surface tension with temperature at different concentrations compared with Jia [38]. This experiment results fit well with those in reference. The surface tension diminishs with the increasing temperature. Fig. 6 reveals the variation of surface tension with solution concentration at different temperatures, and each curve continuously ascends, indicating that the surface tension aggrandizes with the accretion of solution concentration.
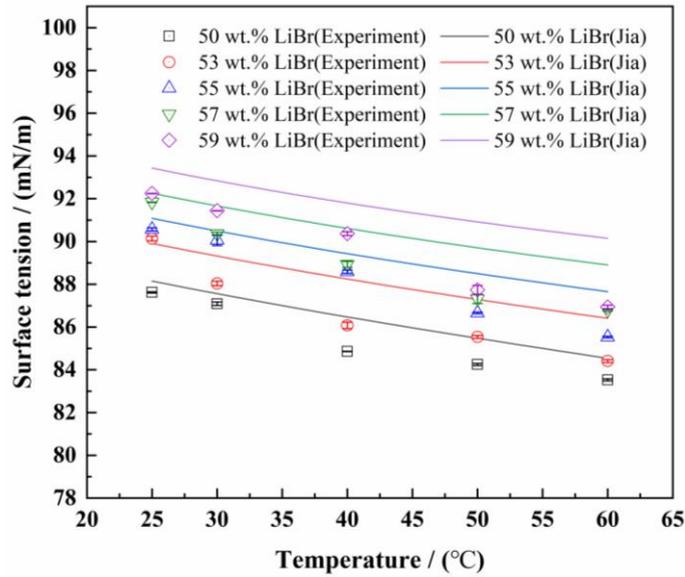
Fig. 5 Surface tension varies with temperature
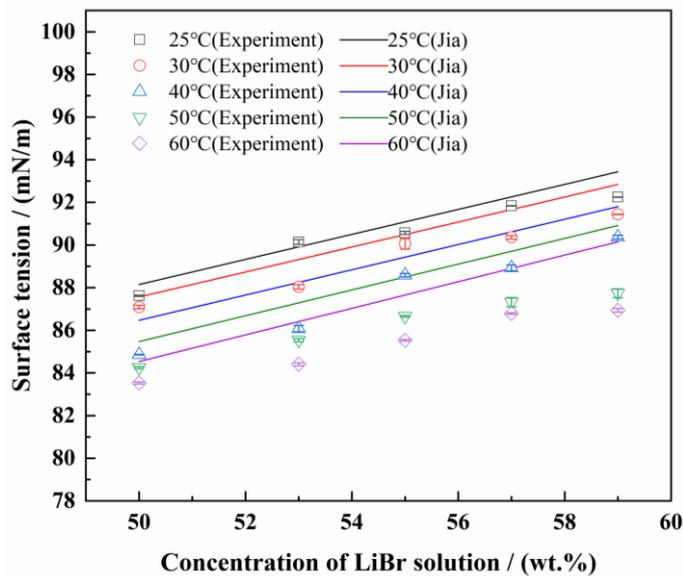
Fig. 6 Surface tension varies with solution concentration

From the perspective of thermodynamics, attractive force potential energy exists in the interaction between molecules in the surface layer, and the average kinetic energy of the molecules inside the liquid are equal to that of those in the surface layer. Therefore, the total energy of the molecules in the liquid surface layer is greater than the total energy of the internal molecules [39]. When the temperature of liquid rises, the attractive force of molecular bonds weakens due to the accretion of molecular thermal kinetic energy. On the other hand, as the average amplitude of the liquid molecules magnifies and the average spacing between molecules expands, the average attractive force potential energy between molecules in the surface layer also declines, resulting in an abatement in the solution's surface tension.

Regarding the analysis of the liquid microstructure, the liquid molecules are closely packed, and the forces on the molecules inside the liquid are balanced and symmetrical. The

spacing between molecules in the surface layer is greater than that in the liquid implying that the forces within the molecules in the surface layer are unbalanced, and its attractive force is greater than the repulsive force, causing the surface molecules to be affected by the internal molecular attraction [29]. The greater the concentration of the solution, the smaller the distance between molecules in the solution, and the greater the attractive force potential energy between molecules. Consequently, the internal molecular attraction effect on the molecules in the solution surface layer climbs, thus, the surface tension of the solution increases.

2.2 Effect of dispersant mass fraction

Dispersant can promote the suspension stability of nanoparticles in nanofluids. Adding dispersant as a surfactant to solution can also alter the physical properties of solution, especially the surface tension. Fig. 7 exhibits the surface tension of LiBr varying with dispersant mass fraction at different concentrations. Generally, the surface tension of the solution after adding dispersant is less than that of the pure LiBr without dispersant. Moreover, with the accretion of dispersant, the surface tension of low concentration LiBr attenuates significantly at first. After the dispersant mass fraction reaches a certain level, the change trend tends to be gentle or slightly increased, which is the best dosage of dispersant; however, the surface tension of high concentration LiBr increases with the augmentation of dispersant addition. For instance, when the temperature is 30℃, the solution concentration is 50 wt.%, and the dispersant mass fraction is 2 wt.%, the surface tension of the solution can decrease by up to 27.83% compared with that of the pure LiBr.
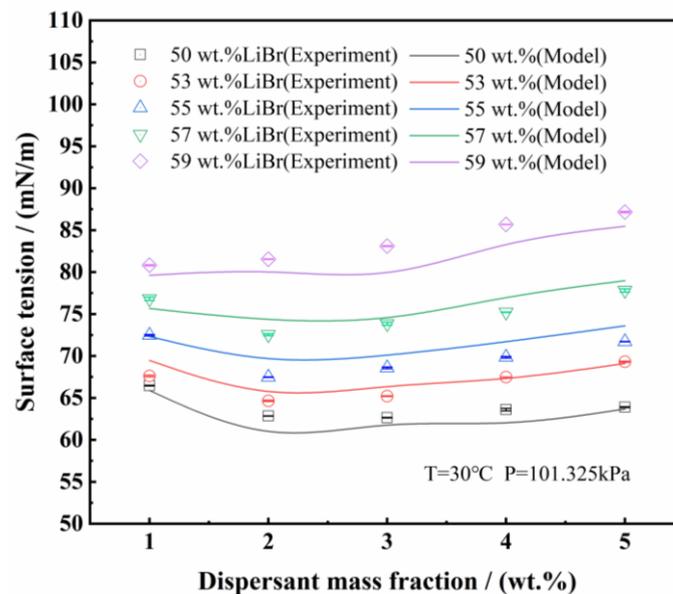
Fig. 7 Surface tension varies with dispersant mass fraction

When the dispersant was added into the low concentration LiBr, some of the dispersant molecules were dissolved, and the remaining part was absorbed by the phase interface [11,40]. Since the hydration force between water molecules and Li^+ and Br^- in LiBr is stronger than the binding force between water molecules and dispersant molecules at the gas-liquid interface,

Li$^+$ and Br$^-$ substitute dispersant molecules to combine with water molecules, so that the released dispersant molecules cannot diffuse in the solution, and adsorb on the surface of the solution immediately, thus lessening the surface tension of the solution. When the gradient of liquid surface tension exceeds a certain critical value, that is, the critical micelle concentration of solution, the surface tension has little range volatility. At this point, the gradient of liquid surface tension causes fluid turbulence in the liquid phase near the interface, namely Marangoni convection [41]. The surface tension gradients become stable due to the convective mixing of the molecules of interfacial dispersion and molecules in liquid phase. In the high concentration LiBr, the solution is nearly saturated result of the concentration corresponds closely to the crystallization concentration of LiBr. With the addition of dispersant, the distribution of Li$^+$ and Br$^-$ in the solution becomes more compact and the relative concentration increases, which accelerates the precipitation of LiBr molecules on the surface of the solution and magnifies the surface tension. After exceeds the critical micelle concentration, a limited amount of LiBr molecules crystallize on the surface of the solution, resulting in the surface tension rising slightly.

2.3 Effects of nanoparticles mass fraction

Stable nano-LiBr solution is prepared by adding dispersant and nanoparticles into LiBr. Introducing two different additives would also modify the solution's surface tension. Fig. 8 points out the influence of nanoparticles mass fraction. The surface tension of the LiBr to which the dispersant was added increases with the augmentation of nanoparticles amount, which was lower than that of pure LiBr, and the change of surface tension approximately ascends linearly. For instance, when the temperature is 30°C, the solution concentration is 50 wt.%, the dispersant mass fraction is 2 wt.%, and the nanoparticles mass fraction is 0.01 wt.%, the surface tension of nano-LiBr can decrease by up to 26.20% compared with that of the pure LiBr.
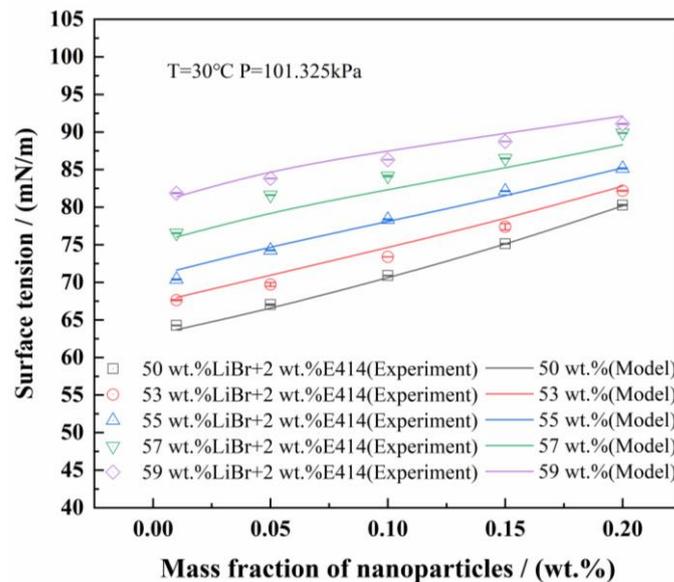
Fig. 8 Surface tension varies with nanoparticles mass fraction

Due to the effects related to the small size of nanoparticles, the addition of nanoparticles to solution narrows the intermolecular distance within the solution and strengthens the attractive force potential energy between the molecules. On the other hand, the Van Der Waals forces between nanoparticles and molecules in the liquid rise, hence raising the attractive force potential energy of the molecules in surface layer, so that the surface tension of solution magnifies [42]. On the contrary, as the addition of nanoparticles increases, the Brownian motion of nanoparticles in the solution plays a leading role. The irregular motion of particles and the collision with molecules both strengthen the kinetic energy of molecules in the liquid, thereby reducing the attractive force potential energy between molecules in the surface layer.

Part of the dispersant dissolved in the solution alters the solution surface tension, whilst the other part modifies the nanoparticles. The Van Der Waals forces between the modified nanoparticles and the liquid molecules diminish, thereby reducing the attractive force potential energy of the surface layer molecules. Whence, the surface tension of nano-LiBr is impacted by the coupling of dispersant and nanoparticles.

2.4 Calculation model of surface tension for nano-LiBr

The surface tension of LiBr is impacted by solution temperature, solution concentration, dispersant mass fraction and nanoparticles mass fraction. Compared with the fitting formula of Jia [38], the experimental results from chapter 2.1 fit well with the calculated values. The average relative error is 1.665%, and the maximum relative error is 3.693%. Therefore, the surface tension σ_p of pure LiBr varying with temperature and concentration can be fitted by Jia's formula, as shown in formula (5).

$$\sigma_p = \sum_0^2 A_j T^j + \alpha \sum_0^3 B_j T^j \tag{5}$$

In the above equation, σ_p is the surface tension of pure LiBr, mN/m; T is the solution temperature, °C; α is the solution concentration, wt.%; j is the polynomial degree; A_j, B_j are the coefficients. The regression coefficients are shown in Table 4.

In order to estimate the surface tension of nano-LiBr, regression analysis was performed on the measured data of surface tension, and the orthogonal polynomial regression method was used for fitting. After adding the dispersant, the calculation equation of the surface tension σ_d for LiBr which introduces dispersant mass fraction and solution concentration is shown in formula (6).

$$\sigma_d = \sigma_p \cdot \left(\sum_0^4 C_j \beta^j + e^{10(\alpha-0.5)} \cdot \sum_0^4 D_j \beta^j \right) \tag{6}$$

In the above equation, σ_d is the surface tension of LiBr with dispersant, mN/m; β is the dispersant mass fraction, wt.%, $0<\beta\leq5\%$; C_j, D_j are the coefficients.

Then the surface tension data of LiBr added with dispersant and nanoparticles were fitted, and the calculation model of surface tension σ_l for nano-LiBr within range of solution temperature $T = 25°C$ - $60°C$, solution concentration $\alpha = 50$ wt.% - 59 wt.%, dispersant mass fraction $\beta = 0$ - 5 wt.%, and nanoparticles mass fraction $\gamma = 0$ - 0.2 wt.% was obtained, as shown in formula (7).

$$\sigma_l = \sigma_d \cdot \left(\sum_0^4 E_j \gamma^j + (\alpha - 0.5) \cdot \sum_0^4 F_j \gamma^j \right) \tag{7}$$

In the above equation, σ_l is the surface tension of nano-LiBr, mN/m; γ is the nanoparticles

mass fraction, wt.%, $0<\gamma\leq0.2\%$; E_j, F_j are the coefficients.

Table 4   The regression coefficients of surface tension equation for nano-LiBr

j	0	1	2	3	4
A_j	60.7 [38]	-4.2061E-2 [38]	-1.3402E-3 [38]		
B_j	62.07 [38]	-0.2536 [38]	5.013E-3 [38]	-1.171E-5 [38]	
C_j	1.84614	-209.303	11755.6	-2.698E5	2.168E6
D_j	-0.53489	110.896	-6398	149940	-1.22E6
E_j	1.06153	90.9	61073.9	-3.55683E7	9.08245E9
F_j	-0.727	929.026	-2.2618E6	1.22217E9	-2.56989E11

The fitting results are convergent. Compared with the measured data above, the average relative error of surface tension calculated by formula (7) is 1.07%, and the maximum relative error is 2.78%, as shown in Fig. 9. This surface tension calculation model for nano-LiBr can provide reference for predicting the surface tension under more working conditions.
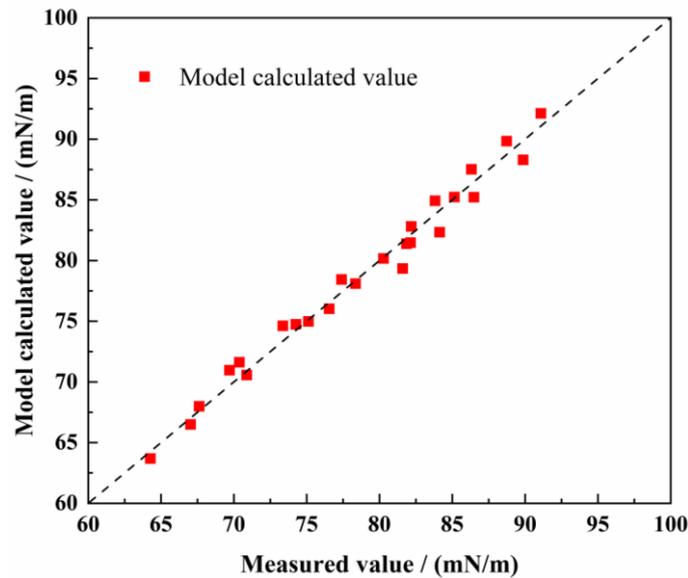
Fig. 9 Error range between calculated value and measured value of surface tension

3 Conclusion

In this research, pure LiBr, LiBr with dispersant (E414) as well as LiBr with dispersant (E414) + CuO nanoparticles with different concentrations were prepared, and the stability of the nano-LiBr was analyzed via the gravity sedimentation method. The surface tension of the three types of LiBr was measured using the Wilhelmy plate method under normal temperature and pressure conditions, and conclusions regarding the effects of temperature, solution concentration, dispersant mass fraction, and nanoparticles mass fraction on the surface tension were drawn.

(1) The surface tension of pure LiBr increases with diminishing temperature and increasing solution concentration, respectively.

(2) With the augmentation of dispersant addition, the surface tension of low concentration LiBr attenuates significantly at first. After reaching a certain amount of addition, the change trend tends to be gentle or slightly increased, which is the best dosage of dispersant.

However, the surface tension of high concentration LiBr amplifies with the augmentation of dispersant addition. When the temperature is 30℃, the solution concentration is 50 wt.%, and the dispersant mass fraction is 2 wt.%, the surface tension of the solution can decrease by up to 27.83% compared with that of the pure LiBr.

(3) The surface tension of the nano-LiBr magnifies with the augmentation of nanoparticles addition. It is also worth mentioning that the surface tension of nano-LiBr is impacted by the coupling of dispersant and nanoparticles at the same temperature and concentration of the solution. When the temperature is 30℃, the solution concentration is 50 wt.%, the dispersant mass fraction is 2 wt.%, and the nanoparticle mass fraction is 0.01 wt.%, the surface tension of nano-LiBr can decrease by up to 26.20% compared with that of the pure LiBr.

(4) A surface tension calculation model of stable nano-LiBr is put forward, which provides reference for calculating the surface tension under more working conditions, and the maximum error was 2.78%.

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