Experimental Study of Pool Nucleate Boiling Heat Transfer Characteristics of Lithium Bromide Solution with Additives

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KEYWORDS: Additive; Lithium Bromide Solution; Surface Tension; Nucleate Pool Boiling
ABSTRACT: The pool nucleate boiling heat transfer characteristics of 10%, 20% and 30% lithium bromide solution was studied in the paper with Polyethylene Glycol Octylphenol Ether as an additive. The results showed that the additive can significantly reduce the surface tension of lithium bromide solution and different concentrations of the solution have its own CMC. The additive can enhance boiling heat transfer. The extreme characteristic strengthening effect was shown. The optimum concentration of heat transfer enhancement was about at CMC of the corresponding concentration of lithium bromide solution. With the improving of lithium bromide solution concentration, the additive effect of heat transfer enhancement was slowing and this trend tends to gradually decrease.

INTRODUCTION

Lithium bromide (LiBr) solution is widely used in the absorption refrigeration fields because of its strong water absorption. Lithium bromide absorption chillers use water as refrigerant. It is environmental protection, and can be driven by low-grade heat source, and has great potential in the use of energy-saving and environmental protection [1-2]. However, the unit deeds high degree of vacuum, the solution is easy to crystallize and low heat transfer coefficient and other disadvantages. So looking for additive which can effectively improve the heat transfer and characteristics of lithium bromide solution is an effective way to solve the disadvantages.

Current research on pool boiling heat transfer of lithium bromide solution are mainly concentrated in vacuum conditions [3], high concentration [4-5] area and nano-fluid based [6]. The research on the atmospheric pressure and other types of additives are less studied. Therefore, this article choose 20% LiBr solution to study the regular its boiling heat transfer at atmospheric pressure by the addition of polyethylene glycol octylphenyl ether (Triton X-100), which can be a study reference for the following studies.

Experimental Design

Experimental System

Experimental system consists of a boiling vessel, condensing system, heating system and data acquisition system, as shown in Figure 1.

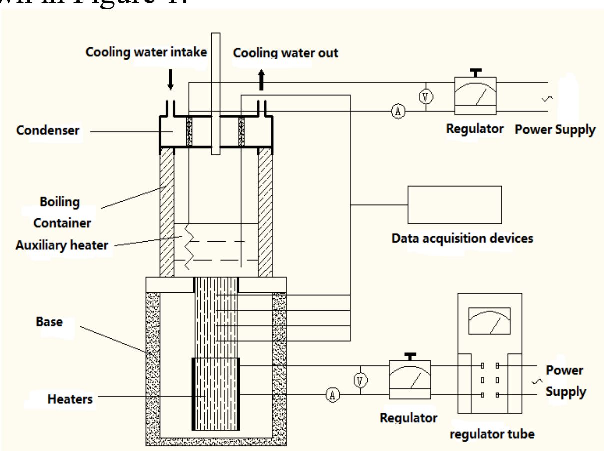

Figure 1. Schematic diagram of the experimental devices

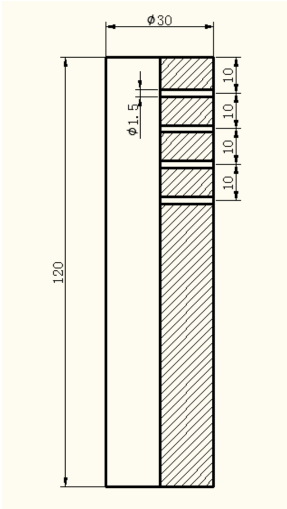

Figure 2. Thermocouple distribution

Boiling vessel is made of tempered glass. Then an upper portion of the vent tube, through the top surface of the condenser and vented to the atmosphere, in order to maintain atmospheric pressure. The condenser condensates steam in order to maintain stable concentration. Heating system made of copper column which is 150mm long, 30mm in diameter. Electric heating coil is wound in its bottom and is connected to a voltmeter, ammeter and voltage regulator. 0.2mm thick of solid grease is laid between the heating coil and copper pillar to enhance the heat exchange and insulation. The end face of copper column was the heating surface. Four holes of 1.5mm diameter were opened on the side face and insert four accuracy of ±0.1 ^{o}C of K-type thermocouples to the center line of copper column, using to measure the temperature to calculate the temperature of the heating surface and heat flux, as shown in Figure 2. The data acquisition was the TC1008 multi-channel temperature measuring instrument. The whole system is strictly insulated by silicate insulation material.

Experimental method

Polyethylene glycol octylphenyl ether (Triton X-100) was chosen as additive and one water-lithium bromide (AR) as drug.

The relationship between lithium bromide and water was:

$$x = \frac{86.85m_1}{18.01m_1 + 104.86m_2} \qquad (1)$$

Where m_1 was the mass of one water-lithium bromide, g; m_2 was the mass of deionized water, g;

The surface tension of LiBr solution was measured by JYW-200B micro-controlled automatic interfacial tension with an accuracy of 0.1mN/m, at condition of 25±0.5 ^{o}C. Each sample was measured three times and taking average value. To avoid boiling lag effect, the test was taken by the way of reducing heating flux mode.

Data Processing

The temperature of heating surface was calculated by the fitting of the temperature of each measuring point with Matlab. The fitting function was quadratic function:

$$T = Ax^2 + Bx + c \qquad (2)$$

So x=0, the heating surface temperature will be drawn:

$$T_w = c \qquad (3)$$

The heating flux:

$$q = -l \left.\frac{dT}{dx}\right|_{x=0} = -l B \qquad (4)$$

Where l was the thermal conductivity of copper, 401W/m·K;
Heat transfer coefficient:

$$h = \frac{q}{T_w - T_{sat}} \quad (5)$$

Where q was the heat flux, W/m·K; T_w was the temperature of heating surface, ^oC; T_{sat} was the solution boiling temperature, ^oC.
According to the transfer analysis method of Moffat [8], the relative error of nucleate pool boiling heat transfer coefficient is:

$$\frac{\Delta h}{h} = \sqrt{(\frac{\Delta q}{q})^2 + (\frac{\Delta T_w}{T_w - T_{sat}})^2 + (\frac{\Delta T_{sat}}{T_w - T_{sat}})^2} \quad (6)$$

The relative error of nucleate pool boiling heat transfer coefficient at experimental conditions can be obtained within 10%.

RESULTS AND DISCUSSION

Surface Tension

Surface tension is considered as an important factor in boiling. Triton X-100 can reduce the surface tension of the solution [9], affect bubble's formation and detachment and thereby influence the boiling heat transfer of solution [10]. When many scholars analyzing the boiling heat transfer of the salt solution, the focuses of the physical properties are on the surface tension change [11-12]. The measurement results of LiBr surface tension with Triton X-100 are shown in the figure 3.

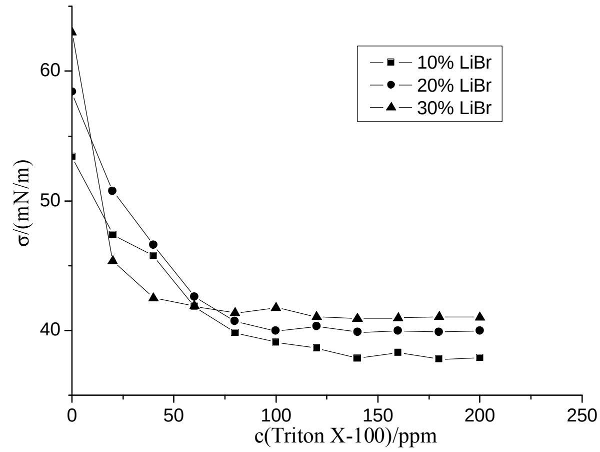

Figure 3. Relationship between surface tension and additive

From Figure 3 we can find little amount of additive can significantly reduce the surface tension of LiBr solution. At lower additive concentration, the surface tension of LiBr solution decreases rapidly with increasing concentration of additive. The downward trend decreases gradually and reaches a stable value. This concentration of the additive is the critical micelle concentration (CMC) of the corresponding LiBr solution. The CMC of 20% LiBr solution is about 100ppm.

Boiling Heat Transfer

The boiling heat transfer curves of LiBr solution with surfactant are shown in the figures 4-9.

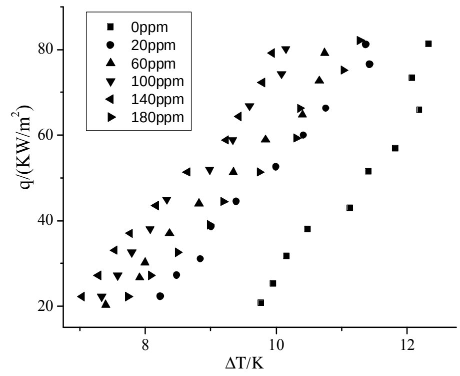

Figure 4. Nucleate boiling curves of 10% LiBr solution

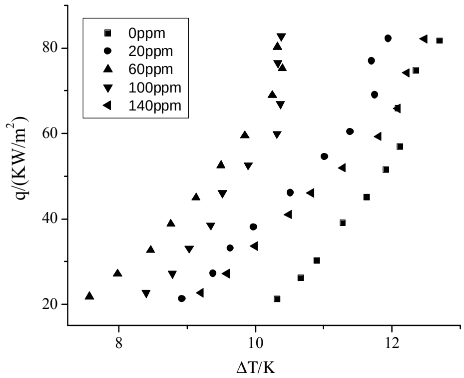

Figure 5. Nucleate boiling curves of 20% LiBr solution

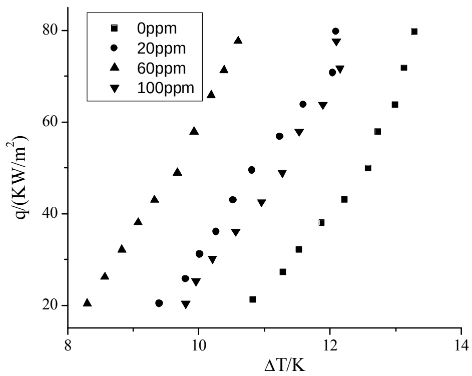

Figure 6. Nucleate boiling curves of 30% LiBr solution

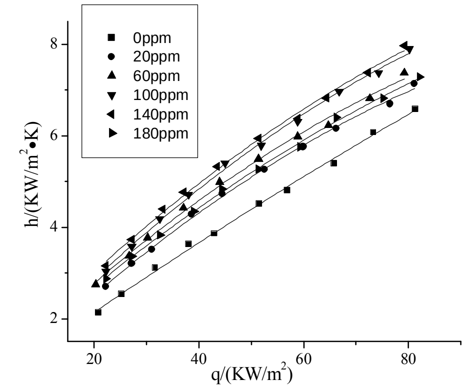

Figure 7. Pool boiling heat transfer coefficients of 10% LiBr solutions

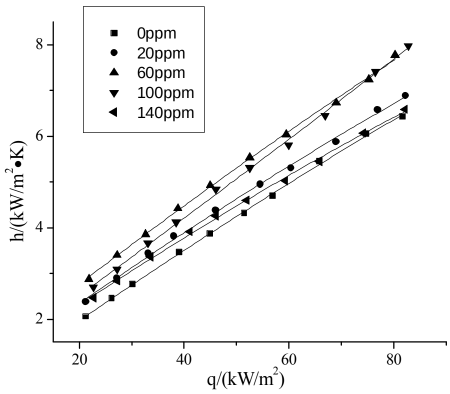

Figure 8. Pool boiling heat transfer coefficients of 20% LiBr solutions

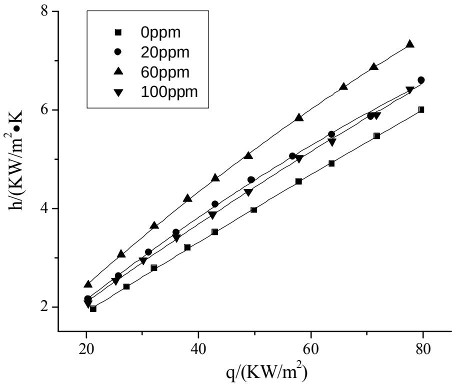

Figure 9. Pool boiling heat transfer coefficients of 30% LiBr solutions

From figures 4-6, we can find that with the gradually improving of additive concentration, LiBr solution boiling curve gradually shifted to the left, showing a trend of strengthening. But when the additive concentration continues to increase, the boiling heat transfer curve shifts to the right, and shows a trend of weakening. Thus, although adding Triton X-100 into LiBr solution can enhance its boiling heat transfer, but it's strengthening effect exhibits extreme value characteristics, its optimal concentration of Triton X-100 is around its CMC. From figures 7-9, we can see that boiling heat transfer coefficients are not all the maximum at CMC. Therefore the relationship between the best effect of heat transfer and CMC needs to be further studied.

From the perspective of surface tension, it can be explained like this: The accumulation of additive at gas-liquid interface reduces the surface tension. Then the bubble generation energy reduces, detachment and cracking frequency increases and the diameter reduces. So the additive can strengthen the solution boiling heat transfer. When the surfactant concentration increased to its CMC, the gas-liquid interfacial tension dropped to the lowest and the bubble diameter down to a minimum. But when the concentration is further improved, the gas-liquid interfacial tension is no longer decreased and the diameter of the bubbles is no longer reduced. At the same time, large number of additives in solution form micelles, which results in deterioration of the solid-liquid interface wettability and increase the difficulty of bubble creation. All those reasons result in the deterioration of boiling heat transfer.

In addition, at the best point of heat transfer, the heat transfer efficient of 10% LiBr solution increases about 34%, 20% lithium bromide solution is about 29% and 30% lithium bromide solution is about 27%. Accordingly, with the improving of lithium bromide solution concentration, the effect of additive is slowing down and the slowdown trend is gradually decreasing. The reason is that with the increasing of LiBr solution concentration, the surface tension of gas-liquid interface increases significantly, the wettability of solid-liquid interface deteriorated. Although additive reduce the surface tension, it still at a high value. All those reasons above affect the formation, detachment and rupture of bubbles.

Conclusion

1) The additive can significantly reduce the surface tension of lithium bromide solution and different concentrations of the solution have its own CMC. At lower additive concentration, the surface tension of LiBr solution decreases rapidly with increasing concentration of additive. The downward trend decreases gradually and reaches a stable value.
2) The additive can enhance boiling heat transfer. The strengthening effect exhibits extreme value characteristics, its optimal concentration of Triton X-100 is around its CMC. The relationship between the best effect of heat transfer and CMC needs to be further studied.
3) With the improving of LiBr solution concentration, the additive effect of heat transfer enhancement was slowing and this trend tends to gradually decrease.

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