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Experimental study of nucleate pool boiling heat transfer to ammonia–water–lithium bromide solution

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ABSTRACT

Visualization of bubble nucleation during nucleate pool boiling outside a vertical cylindrical heated surface was done for ammonia–water binary and ammonia–water–lithium bromide ternary mixture in order to obtain a descriptive behavior of the boiling which was directly compared with the measured heat transfer coefficient at low pressure of 4–8 bar and at low ammonia mass fraction of $0 < x_{NH_3} < 0.3$ and at different heat flux. The lithium bromide concentration of the solution was chosen in the range of 10–50% of mass ratio of lithium bromide in pure water. The effect of concentrations, heat flux and pressure on boiling heat transfer coefficient was studied. Still images taken with high speed camera are used to demonstrate the increase in boiling heat transfer coefficient with the addition of lithium bromide salt to ammonia–water mixture. Further work is required to obtain quantitative information about bubble nucleation parameters.

1. Introduction

Absorption refrigeration systems have attracted increasing research interests in recent years. Unlike mechanical vapor compression refrigerators, these systems cause no ozone depletion and reduce demand on electricity supply. Besides, heat powered systems could be superior to electricity powered systems in that they harness inexpensive waste heat, solar, biomass or geothermal energy sources for which the cost of supply is negligible in many cases. This makes heat powered refrigeration a viable and economic option. The most common absorption systems are H_2O–LiBr and NH_3–H_2O cycles.

The NH_3–H_2O pair possesses very good heat and mass transfer characteristics but requires rectification to remove water vapor from the ammonia rich refrigerant vapor. Lithium bromide, on the other hand, is a non-volatile salt that can act as an absorber for both ammonia as well as water due to ion formation and complexing. Therefore, ternary NH_3–H_2O–LiBr mixtures with high salt concentrations could offer better performance by absorbing ammonia and water thus reducing rectification losses, especially at higher operating temperatures.

The thermodynamic properties of the NH_3–H_2O–LiBr system (principally for a LiBr/H_2O ratio of 60/40 weight percent) have been investigated by Radermacher [1]. McLinden and Radermacher [2] compared the performance of an absorption heat pump operating with NH_3–H_2O and NH_3–H_2O–LiBr mixtures. Although the COP of the heat pump operating with ternary mixture was lower than with the binary system, there were indications of lower water content in the refrigerant vapor entering the rectifier with the ternary mixture.

Peters et al. [3,4] investigated the effects of lithium bromide on the NH_3–H_2O system using a static method to measure vapor–liquid equilibrium data of NH_3–H_2O–LiBr mixtures over temperatures between 303.15 and 423.15 K, and pressures up to 1.5 MPa. They reported reduction in partial pressure of both ammonia and water in the vapor phase compared to respective pressures in binary NH_3–H_2O system. They developed a quasi-chemical reaction model to correlate experimental data. The correlation was in good agreement with the experimental data.

Yuyuan et al. [5] measured vapor–liquid equilibrium (VLE) data for NH_3–H_2O–LiBr system at 10 temperature points between 15 and 85 °C, and pressures up to 2 MPa. The LiBr concentration of the solution was chosen in the range of 5–60% of mass ratio of LiBr in pure water. The VLE for the NH_3–H_2O–LiBr ternary solution was measured statically. It was seen that at the same temperature and ammonia concentration, vapor pressure of ternary NH_3–H_2O–LiBr mixture solution was lower than that of the binary NH_3–H_2O solution. The ammonia content in the vapor phase of ternary NH_3–H_2O–LiBr mixture solution was higher than that in the binary NH_3–H_2O solution without lithium bromide.

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vapor liquid equilibria of the NH_3–H_2O–LiBr system have been established, no information however, is available on the effect of dissolved salt on the boiling heat transfer which is indispensable in the design of these systems. The aim of the present paper is to obtain the nucleate pool boiling heat transfer coefficient of NH_3–H_2O–LiBr ternary system at different mass fraction of ammonia and lithium bromide, at different pressure and at different heat flux. The present investigation also aims at obtaining a visual record of nucleation to study the effect of lithium bromide on bubble parameters.

Boiling heat transfer has been intensively investigated, but it is not yet possible to predict heat transfer coefficients with the accuracy necessary for reliable design of generators/evaporators, particularly, for the boiling of mixtures. Most boiling research has been limited to the behavior of pure components or binary mixtures. Empirical or semi-empirical correlations have been proposed to correlate the heat transfer coefficients. Most correlations represent quite well the experimental data they were developed from, but large discrepancy occurs when they are applied to other data.

There have been relatively few studies on the boiling heat transfer of ammonia/water mixture. Inoue et al. [6], measured the pool boiling heat transfer coefficients of ammonia/water mixture and its pure components on a horizontal platinum wire (diameter of 0.3 mm, 37 mm length) at the pressure of 0.4–0.7 MPa with heat flux varying from 0.4 to 1.5 MW/m^2 and the mass fraction from 0 to 1. Arima et al. [7], obtained data on a horizontal flat circular surface of silver with a diameter of 10 mm for ammonia/water mixture and its pure components at a pressure level from 1 to 15 bar with heat flux varying from 0.1 to 2.0 MW/m^2. It was found by both the authors that the mixture in the range of the mass fraction, 0.2–0.9 gives smaller heat transfer coefficients than its individual components.

Many other previous experimental investigations have also revealed a reduction of heat transfer coefficients in nucleate boiling of mixtures, compared with those for a single component substance of the same physical properties as the mixture, or compared with the linearly interpolated values between the two pure components comprising the mixture. Some physical explanations for the reduction were suggested and reviewed (Fujita and Tsutsui [8]). Deterioration in the heat transfer of mixtures has been recently clarified, but there are few reports on the heat transfer enhancement of binary mixtures. Inoue et al. [9] studied the effect of cationic surfactant on boiling heat transfer enhancement of ethanol/water mixture. They reported increase in boiling heat transfer coefficient in low heat flux range in low ethanol fraction range by the surfactant. They attributed this increase to the decrease in surface tension of the mixture by the addition of surfactant.

The information available on the boiling of inorganic salt solution is very less compared to that available on organic liquid mixtures. Boiling characteristics of aqueous electrolyte solutions are likely to be different from those of organic mixtures because of the differences in surface tension, wetting characteristics and bubble coalescence and breakup behavior (Jamialahmadi et al. [10]). Considerable decrease in heat transfer coefficient at low heat fluxes were observed by Jamialahmadi et al. for aqueous salt solutions. At high heat fluxes the negative effect of the dissolved electrolyte gradually decreased and finally some improvement in heat transfer coefficient was observed.

2. Experimental setup

The schematic diagram of experimental setup is shown in Fig. 1. The unit consists of boiling vessel, water pump, vacuum pump, condenser coil and test section. Boiling vessel 80 mm diameter and 200 mm long made up of SS 316 is fitted with SS 316 flanges at the top and at the bottom as shown in Fig. 1. The vessel is fitted with two sight glasses to observe and record the boiling phenomena. The top flange has provisions for liquid charging, condenser cooling water inlet and outlet, vacuum pump, pressure transducer and thermocouples to measure liquid and vapor temperatures. Bottom flange has provisions for heater rod and drain. The cylindrical stainless steel heater rod of 6 mm diameter and a heating length of 20 mm is mounted vertically within the boiling vessel and is completely immersed in the liquid pool. Boiling takes place

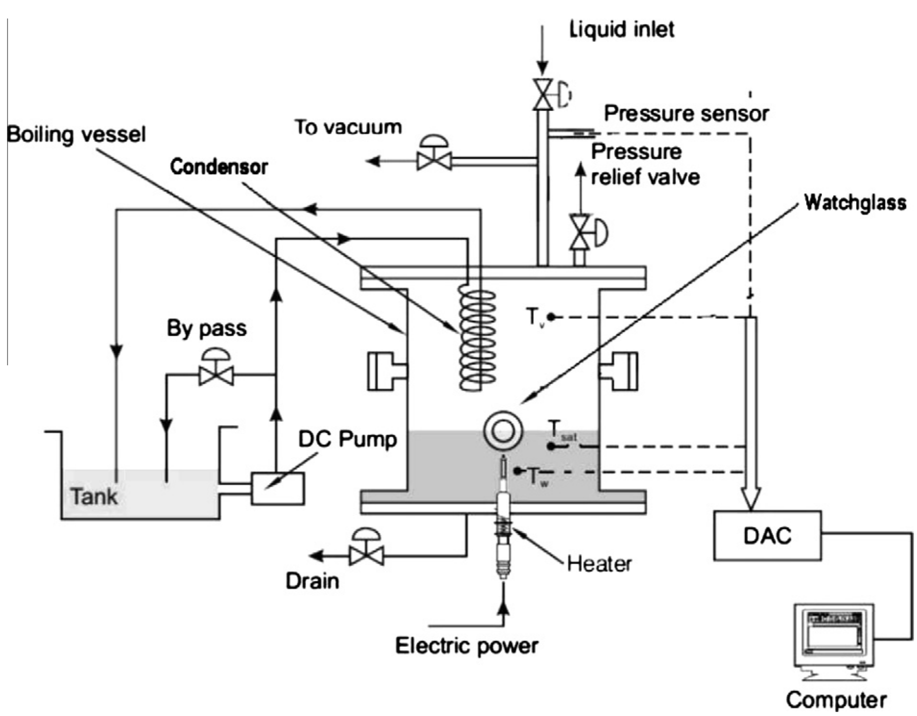

Fig. 1. Schematic diagram of experimental setup.