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Experimental Study of Pool Boiling Heat Transfer Enhancement with R123 under Non Uniform Electric Field

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Abstract: Experimental investigations are carried out to study the effect of a non uniform electric field on the boiling heat transfer. The study has found that the heat transfer coefficient increases as the electric field strength increases. Enhanced coefficient decreases with heat flux increases and finally reaches a steady value. When the heat flux is small, high voltage has a better enhancement effect. The Onset of Nucleate Boiling (ONB) undergoes a larger increase by applying a high voltage.

Keywords: Electro hydrodynamic, heat transfer enhancement, non uniform electric field

INTRODUCTION

EHD (Electro Hydrodynamic) enhancement of boiling heat transfer is defined in the fluid in an electric field is applied, the use of electric field, flow field and temperature field of the coupling between the three to achieve the purpose of enhanced boiling heat transfer. Achieving higher heat transfer rates through various enhancement techniques can result in substantial energy savings, due both to the increased performance of equipment and the design of smaller systems to meet required loads (Lai and Mathew, 2006). A great deal of research has been conducted primarily on augmentation of convective and condensation heat transfer (Chu *et al*., 2001). The condensation heat transfer is enhanced in the electric field (Butrymowicz *et al*., 2002). Some of this has been directed at practical applications. As for boiling heat transfer, however, due to the complexity of EHD effects during boiling, a qualitative understanding of this effect is lacking (Zaghdoudi *et al*., 2001) and in many cases only experimental data have been reported (Ogata and Yabe, 1993). Under the action of the electric field, the boiling heat transfer is complicated (Pascual *et al*., 2001). The mechanism of enhancement of boiling heat transfer in the electric field has not been explained (Wang *et al*., 2009). In order to further understanding the mechanism of EHD enhancement of boiling heat transfer, this study adopts a linear electrode, studied EHD enhancement of boiling heat transfer effect in the non uniform electric field, hoping to make a little contribution to mechanism research.

EXPERIMENTAL SETUP

The experimental device as shown in Fig. 1 is mainly composed of a boiling chamber, a condensing chamber and the test components, high voltage electric systems, cooling the refrigerant loop and refrigerating system. The boiling chamber and a condensing chamber size is 250×250×400 mm, respectively. A boiling chamber has a test component (i.e., heat exchange plate and the electrode). A condensation chamber has a condensing tube. Refrigerant in the boiling chamber heated to boil, the vapor refrigerant through the connecting tube rises to the condensing chamber. The vapor refrigerant condensed into liquid outside the

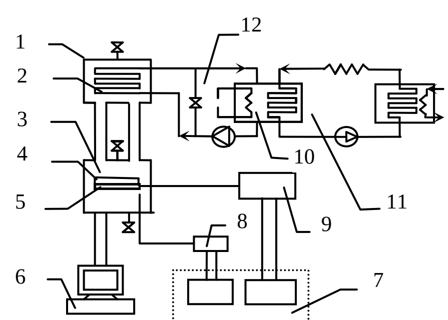

Fig. 1: Schematic diagram of EHD boiling heat transfer enhancement
1: Cooling chamber; 2: Condensing tube; 3: Boiling chamber; 4: Wire electrode; 5: Brass plate; 6: Computer; 7: Control platform; 8: High-voltage supplier; 9: Pressure regulator; 10: Heat exchanger; 11: Cooling system; 12: Water loop

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condenser tube bundle comes back to the boiling chamber through the connected pipe. In order to monitor the system pressure, the boiling chamber is arranged with a pressure gauge. For filling and recovery of the need, the boiling chamber is provided with a liquid feeding valve and a liquid disc haring valve. The upper box body with a condensation tube which is connected with the cooling system. In order to observe the boiling and condensation characteristics, the front and rear side of the box are respectively provided with 185×325 mm window which is made of tempered glass.

The cooling system includes a complete refrigeration system and temperature control system. Refrigeration system consists of a compressor, evaporator, condenser and throttling element. Temperature control system comprises a water tank, stirrer, electric heater, water pump and valve.

High voltage power supply is made by the GLASSMAN Company of America. Its model is ER/DM. It can produce -50~50 kV continuously adjustable high voltage DC power supply.

Heat transfer surface plate is made of brass molded once. The side of the plate is 233×184×20 mm, respectively. The surface of copper plate is treated with sandpaper in order to keep its surface smooth. The surface is wiped cleanly with the acetone prior to each trial.

The high voltage electrode is linear electrode. Its diameter is 2 mm. The material is brass wire. Figure 2 is the linear electrode diagram.

Working medium is R123. Its standard condition boiling point is 27.8C and relative dielectric constant is 3.42. R123 charge relaxation time is 8.9×10-4seconds.General vapor bubble departure time is 0.017 sec. The charge relaxation time is far less than the bubble departure time. The electric field on R123 medium influence evidently, as well as its low boiling point, so R123 is selected as the working fluid.

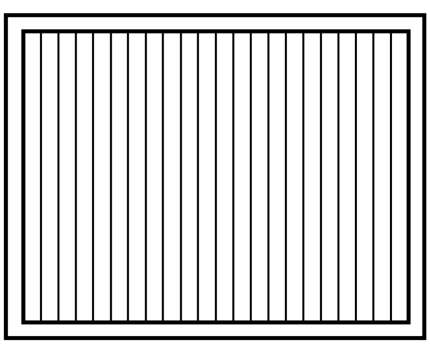

Fig. 2: Schematic diagram of the wire electrode

RESULTS AND DISCUSSION

The influence of electric on the heat transfer coefficients: The flat surface of the boiling heat transfer coefficient is calculated by heating quantity, flat surface area, average wall temperature of the flat surface and liquid body temperature:

$$h = \frac{Q}{A(T_w - T_l)}$$

where,

h = Heat transfer coefficient
Q = Heating quantity
A = Flat surface area
T_w = The wall temperature
T_l = The liquid body temperature

EHD enhancement coefficient k is defined in order to compare the heat transfer coefficient in the electric field and the heat transfer coefficient without electric field in a given experimental condition. It can directly and truly reflect the applied electric field on heat transfer enhancement effect:

$$k = \frac{h_{EHD}}{h_0}$$

where,

k : EHD enhancement coefficient
h_{EHD} : The heat transfer coefficient in the electric field
h_0 : The heat transfer coefficient without electric field

Figure 3 is the relation diagram between the enhancement coefficient and the electric field intensity when the heat flux density is 5 kW/m^2. It can be seen from the figure, enhancement coefficient increases as the field strength increases. Under the experimental conditions, the largest enhancement coefficients can reach 2.9.

From the traditional boiling theory, the formation, growth, departure and movement of the bubble on the surface of heat exchanger plays a decisive role on the boiling heat transfer effect. Buber under the action of electric field force, the thermal boundary effect is enhanced. So it enhanced the boiling heat transfer.

Figure 4 is the relation of EHD enhancement coefficient with heat flux density in the electric field. It can be seen from the figure; enhanced coefficient decreases with heat flux increases and finally reaches a steady value. When the heat flux is small, high voltage has a better enhancement effect.

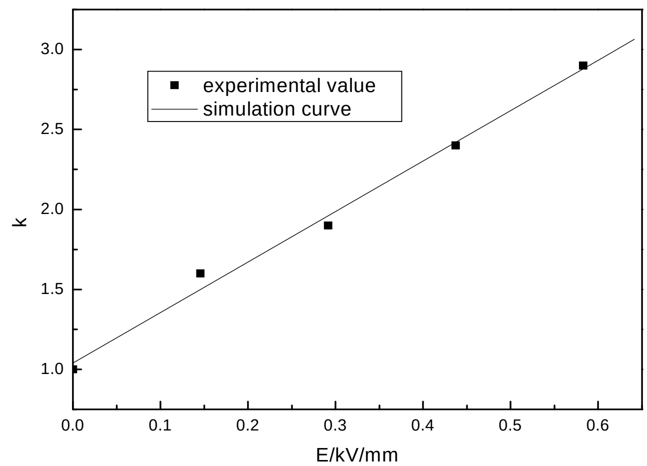

Fig. 3: Relation of EHD enhancement coefficient with electric field strength

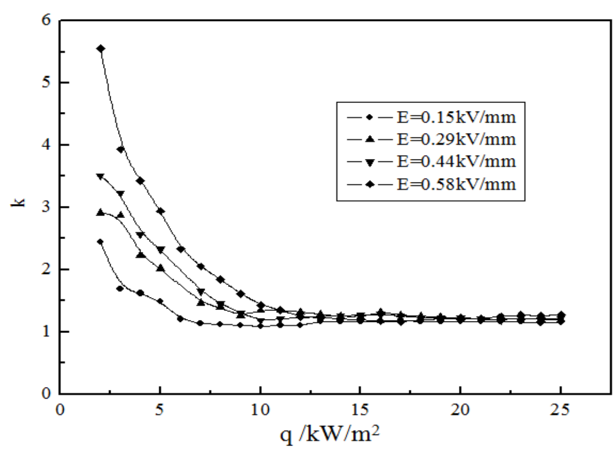

Fig. 4: Relation of EHD enhancement coefficient with heat flux density in the electric field

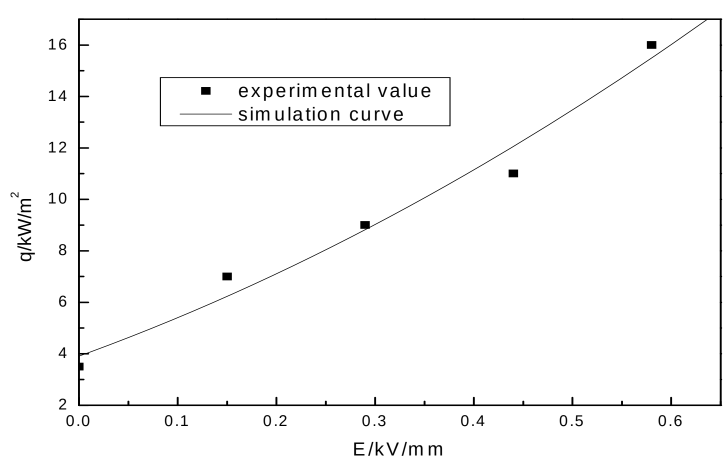

Fig. 5: Relation of ONB with electric field intensity

The influence of electric on the Onset of Nucleate Boiling (ONB): The main part of the experiment platform adopts toughened glass windows. It can observe the generation of bubbles and the law of motion. Under certain conditions, with the heat flux density increases gradually, in a heat flux density it can be observed boiling phenomenon produced on the surface. We call this phenomenon as the initial nucleation boiling point (referred to as the starting boiling point). Corresponding to the heat flux density is known as observed the corresponding heat flux density from the boiling point. Figure 5 is the ONB corresponding to the heat flux density in different electric field intensity. It can be seen from the figure, The Onset of Nucleate Boiling (ONB) undergo a larger increase by applying a high voltage.

CONCLUSION

The study has found that the heat transfer coefficient increases as the field strength increases. Buber under the action of electric field force, the thermal boundary effect is enhanced. So it enhanced the boiling heat transfer. Enhanced coefficient decreases with heat flux increases and finally reaches a steady value. When the heat flux is small, high voltage has a better enhancement effect. The Onset of Nucleate Boiling (ONB) undergoes a larger increase by applying a high voltage.

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