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EFFECT OF ELECTRIC FIELD ON BOILING HYSTERESIS IN CARBON TETRACHLORIDE

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NOMENCLATURE

E_w, electric field intensity at the wire surface [V/m];
g_e, effective gravitational acceleration [m/s^2];
κ, relative permittivity of the liquid [dimensionless];
r_c, internal radius of the outer cylinder [m];
r_w, outer radius of the heater wire [m];
v, voltage applied between the wire and the outer cylinder [V];
ϵ_0, permittivity of free space [F/m];
ρ_L, density of the liquid [kg/m^3].

INTRODUCTION

THE INCREASE of heat-transfer rate in a fluid, due to the application of an electric field was first pointed out by Senftleben [1]. Ahsmann and Krönig [2] studied the effect of electric field of rectangular waveform on the heat-transfer of some organic liquids. Several workers tried to explain the electro-convectional heat-transfer as due to the change of the electric susceptibility in presence of a temperature gradient. According to Weber and Halsey [3] the heat-transfer rate is suppressed by one of the non-conservative forces in the fluid acting towards the heat source due to the interaction of thermal and electrical gradients. They also concluded that this effect is small compared with the improved heat-transfer due to the motion of the free charges under the action of an electric field.

Allen [4] applied both d.c. and a.c. fields separately and also studied the effect of mixed stresses on the electro-convectional heat-transfer. According to him the alternating stress alone can increase the heat-transfer rate and enhancement of the heat-transfer due to the application of the unidirectional stress, as reported by early workers, was not due to the unidirectional field but due to the "ripples" present in the high voltage supplies. Like Weber and Halsey [3] he also suggested that the increase in heat-transfer is due to the motion of electric charges, present in the liquid bulk, under the action of alternating electric field. Watson [5] experimented with n-hexane. He disregarded the idea that the effect of electric field on the free charges is the reason for enhancement of the heat-transfer. According to him a permittivity gradient is created due to the temperature gradient in the liquid and the increased field strength enhances heat-transfer rate from the heater, since the force on the non-homogeneous dielectric increases with the square of the electric field.

Mascarenhas [6] was of the same opinion that the change in the heat-transfer rate in a liquid dielectric is due to the interaction between the thermal and the electric fields. The thermal conductivity of liquid shows strong variation due to the action of the electric field.

According to Markels and Durfee [7] the increase in the heat-transfer is due to "Dielectrophoresis"—a phenomenon in which there is a movement of the dielectric liquid when placed in a non-uniform electric field and this movement is caused by induced polarization.

Choi [8] investigated the effect of the radial electric field on boiling heat-transfer in a dielectric liquid. He applied d.c. field and found improvement in heat transfer with increasing fields. Choi concluded that, in a non-uniform electric field a dipole molecule tends to align itself in the direction of the field. As the field strength decreases radially outwards, the net force on the dipole molecule is towards the heating surface, producing an effective gravitational acceleration of value

$$g_e = \frac{\varepsilon_0(\kappa - 1)(\kappa + 2)E_w^2}{3r_w\rho_L}. \quad (1)$$

Coulson and Porter [9] made some experimental study on the effect of electric field on natural convection from horizontal cylinders. They found that the effect of electric field was to increase the heat-transfer rates and in most cases to a greater extent than has been reported previously. They discussed the correlation of data in terms of electrostrictive effects.

Lovenguth and Hanesian [10] reported the effect of a non-uniform d.c. field on the peak heat flux in saturated pool boiling for some organic liquids including carbontetrachloride. The electric field was found to have significant effect on peak heat flux. Three fold increases were not uncommon. These authors tried to explain the increase in peak heat flux considering electrically stabilized Helmholtz–Taylor hydrodynamic model.

In the convection rânge, a hysteresis effect is generally observed, with increasing heat flux. Corty *et al.* [11] showed that the nucleation centres on the heater surface behave differently when the heat-flux is increasing than when it is decreasing. They pointed out the existence of an unstable region between natural convection and well defined nucleate boiling. The fact was supported by the work of Mikhail [12] and Sinha [13]. The liquid adjacent to the heater surface is seen to attain a temperature much higher than the normal boiling point of the liquid, without nucleation being started. This instability is known as hysteresis in boiling. The superheating phenomenon greatly reduces the heat-transfer rate. The aim in modern heat transfer equipments is generally to achieve a high rate of heat-transfer at as low a superheat as possible.

Jalaluddin [14] has shown that electric field is a cause of early nucleation and if it be so, this additional nucleation should help to cure the hysteresis effect, thus increasing the rate of heat-transfer.

EXPERIMENTAL ARRANGEMENTS

The heater used in this experiment was of the same form as used by Ahsmann and Krönig [2]. It consisted of a 0·004 cm dia platinum–iridium (90%:10%) wire placed along the axis of a hollow brass cylinder. The end seals of the heater cell were made of bakelite. The detailed construction of the cell is shown in Fig. 1. The wire was screwed at one end to a tapering brass plug, press fitted through the end seal, passing co-axially with the brass cylinder (i.d. = 2 cm). The other end of the heating wire was soldered to a spring which kept the wire straight at elevated temperatures. The tapered brass plug and the spring were the two current terminals. A number of holes were drilled on the outer brass cylinder to provide for free circulation of the liquid.

This heater assembly was placed horizontally in the experimental liquid, taken in a flat bottomed porcelain basin, so that it is well within the liquid. The electric field (both a.c. and d.c.) was supplied between the outer cylinder of the experimental cell and the heater wire. The heater terminal was earthed. The a.c. field was controlled by an auto-transformer, operated from stabilized 230 V 50 c/s (r.m.s.) supply (voltage variation ± 1 per cent). The d.c. field was obtained from the same stabilizer with the help of a rectifier unit (ripple factor = 0·012 per cent).

The heater current was controlled by a gang of rheostats having fine adjustment. The principle of resistance thermometry was used for the measurement of the wire temperature. The temperature of the liquid bulk was measured by a precision mercury-in-glass thermometer.

RESULTS AND DISCUSSIONS

The effect of electric field on boiling hysteresis in carbontetrachloride has been studied, applying both d.c. and a.c. fields. The voltage gradient at the wire surface was calculated assuming cylindrical symmetry of the electric field. The gradient at the wire surface was calculated from the relation,

$$\text{Gradient} = \frac{v}{r_w \log_e r_c/r_w} \; v/\text{m}. \quad (2)$$

Figure 2 shows the effect of an a.c. field and Fig. 3 repre-

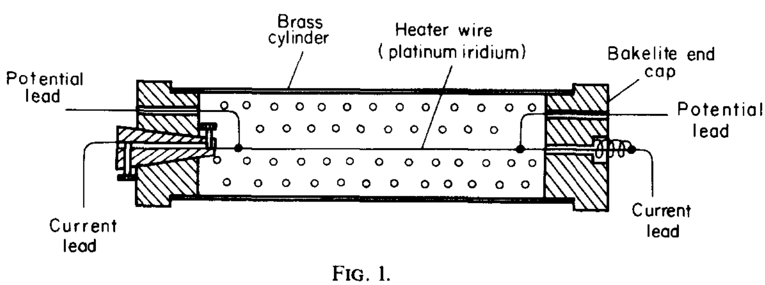

FIG. 1.

sents that of a d.c. field on the convective heat-transfer to

in reducing the hysteresis effect, at a low value of the field gradient.

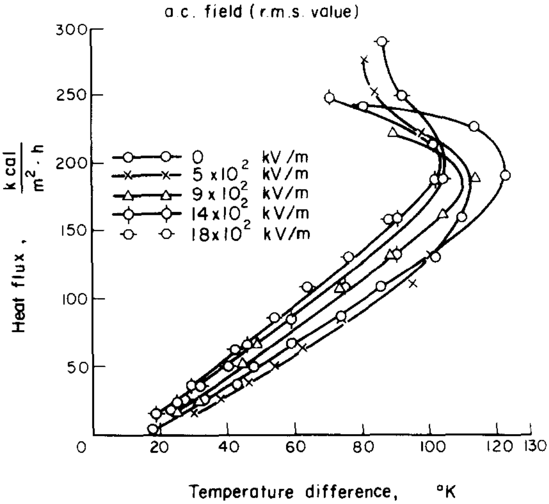

FIG. 2.

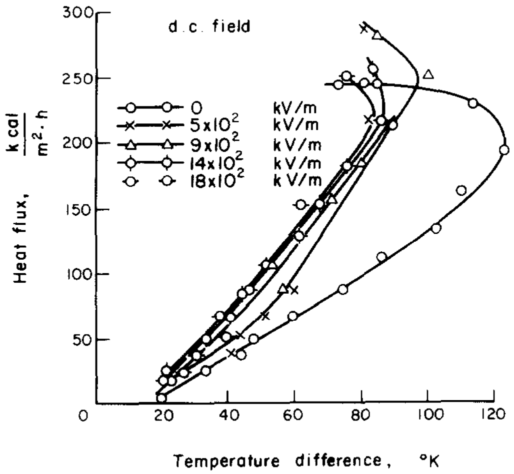

FIG. 3.

In the actual heat-transfer assembly a very thin layer of the liquid adjacent to the heater surface is considerably superheated and it is this interfacial layer of the liquid which acts as the most favourable zone for bubble formation. From the fundamental laws of electricity it is expected that the effect of electric field at an interface would differ qualitatively from that in the bulk.

Any surface phenomenon as in the form of Maxwell–Wagner interfacial accumulation of charge [15], mechanical pressure due to this charge or ionic movement due to any reasons should act as a possible cause of break down of the metastable state at the interface.

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