

HEAT TRANSFER CHARACTERISTICS OF A HEATED THIN PLATINUM WIRE AND SURROUNDING LIQUID SUBJECTED TO ELECTROLYTIC CURRENTS

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ABSTRACT

Heat transfer characteristics of a thin heated platinum wire and surrounding conducting liquid have been studied. The enhancement of heat flux and consequent changes in the heat transfer coefficient (h/h_0) for different concentrations of the conducting liquids, at different liquid temperatures and for various temperature differences between the wire and the liquid have been investigated. Suitable explanations of the results have been offered on the basis of induced gravity effects and destabilization of thermal boundary layer surrounding the heated wire.

INTRODUCTION

A DEVIATION from thermodynamic equilibrium for a system causes transfer of heat energy, which is encountered in many scientific experiments and technical applications. A situation where it is necessary to remove heat at a high rate with the lowest possible surface temperature needs special consideration. Pohl¹ discussed several such phenomena in dielectric liquids. Arajs and Legvoid² discussed the same phenomena in gases. Choi³ reported the effects of non-uniform electric field on the motion of dipole molecules. Bonjour⁴ reported the effect of application of an electric field on thermal exchanges in some polar liquids. The technical feasibility of using these effects under conditions close to those, encountered in nuclear reactions and zero gravity environment has been studied by Velkoff⁵. Markels and Durfee⁶ broadened the scope of such investigations under EHD technique. The effect of ionic currents on heat transfer has been well investigated⁷⁻¹³. In the present work, variation of heat transfer from a thin platinum wire to conducting liquids under electrolytic action under different conditions is reported.

EXPERIMENTAL DETAILS

The same experimental set up reported earlier^{8,10} was used with slight modification. A thin platinum wire 10 cm long was stretched horizontally along the axis of a hollow slotted metal cylinder open at both ends. The whole system was immersed in a glass trough containing a weak electrolyte-like water mixed with dilute sulphuric acid or dilute solution of KMnO_4 of different normalities. A temperature difference $\Delta\theta$ was

produced between the wire and the liquid by passing a small current through the wire. The power input to the wire was calculated by measuring the current and the $\Delta\theta$ was determined by measuring the change in the resistance of the wire. Under equilibrium conditions, the heat input to the wire becomes identical to the heat transfer from the wire to the surrounding liquid. Measuring the surface area of the wire, the current density d was calculated.

The system was subjected to a radial electric field by creating a potential difference of a few volts between the wire and the metal cylinder. It produces ionic current in the liquid, which leads to the bubble formation at various points on the wire due to the evolution of gas in the process of electrolysis. Consequently a variation in the value of heat transfer coefficient takes place. This variation has been studied by measuring the value of $(h/h_0)^{10,14}$ for different values of ionic current, where h and h_0 are the heat transfer coefficients in the presence and the absence of ionic current respectively.

RESULTS

The values of (h/h_0) for different ionic current densities and for a fixed value of $\Delta\theta$, were calculated for different normalities of the two solutions. It was found that (h/h_0) increases with $(\log d)$ in low electrolytic current region, reaching a maximum and then decreases rapidly. The values of (h/h_0) increase with concentration as shown in figures 1 and 3. In these experiments the temperature of the electrolyte surrounding the platinum wire was kept almost constant and equal to room temperature.

Experiments were also conducted maintaining the

liquid at temperatures higher than the room temperature and at various temperature differences $\Delta\theta$, at a fixed normality for the two solutions. It was found that (h/h_0) continues to increase as previously, with increasing values of $(\log d)$ in low electrolytic current region and gives two maxima for higher values of $\Delta\theta$ for both the solutions as shown in figures 2 and 4.

DISCUSSION

Gas bubbles formed round the wire play a vital role in enhancing the heat transfer. Initial increase in (h/h_0) for each concentration is due to the increase in the rate of bubble evolution which becomes maximum at a particular ionic current. The contribution of the applied electric field is maximum in giving higher (h/h_0) values upto an optimum value. Beyond the optimum value, due to the formation of a bubble blanket, the (h/h_0) values decrease for higher ionic currents. The bubble blanket acts as a barrier in which heat transfer is more due to conduction than convection.

The thermal boundary layer acts as an electrical double layer, and it is well known that concentration of solvated ions near the double layer is much larger than

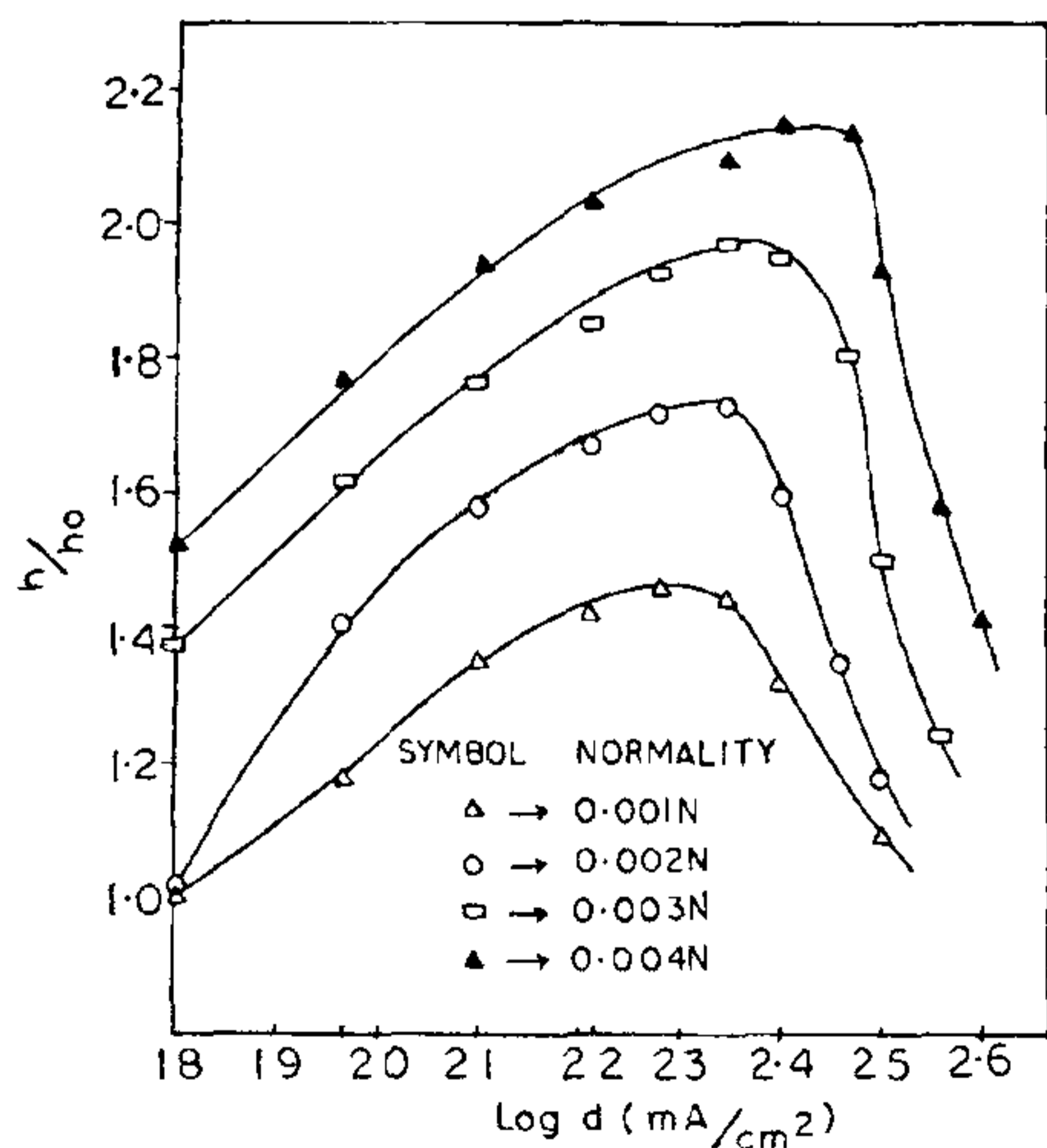


Figure 1. Variation of relative heat transfer (h/h_0) with ionic current density $(\log d)$ for acidulated water at $\theta_B = 23.2^\circ\text{C}$ and $\Delta\theta = 8.1^\circ\text{C}$.

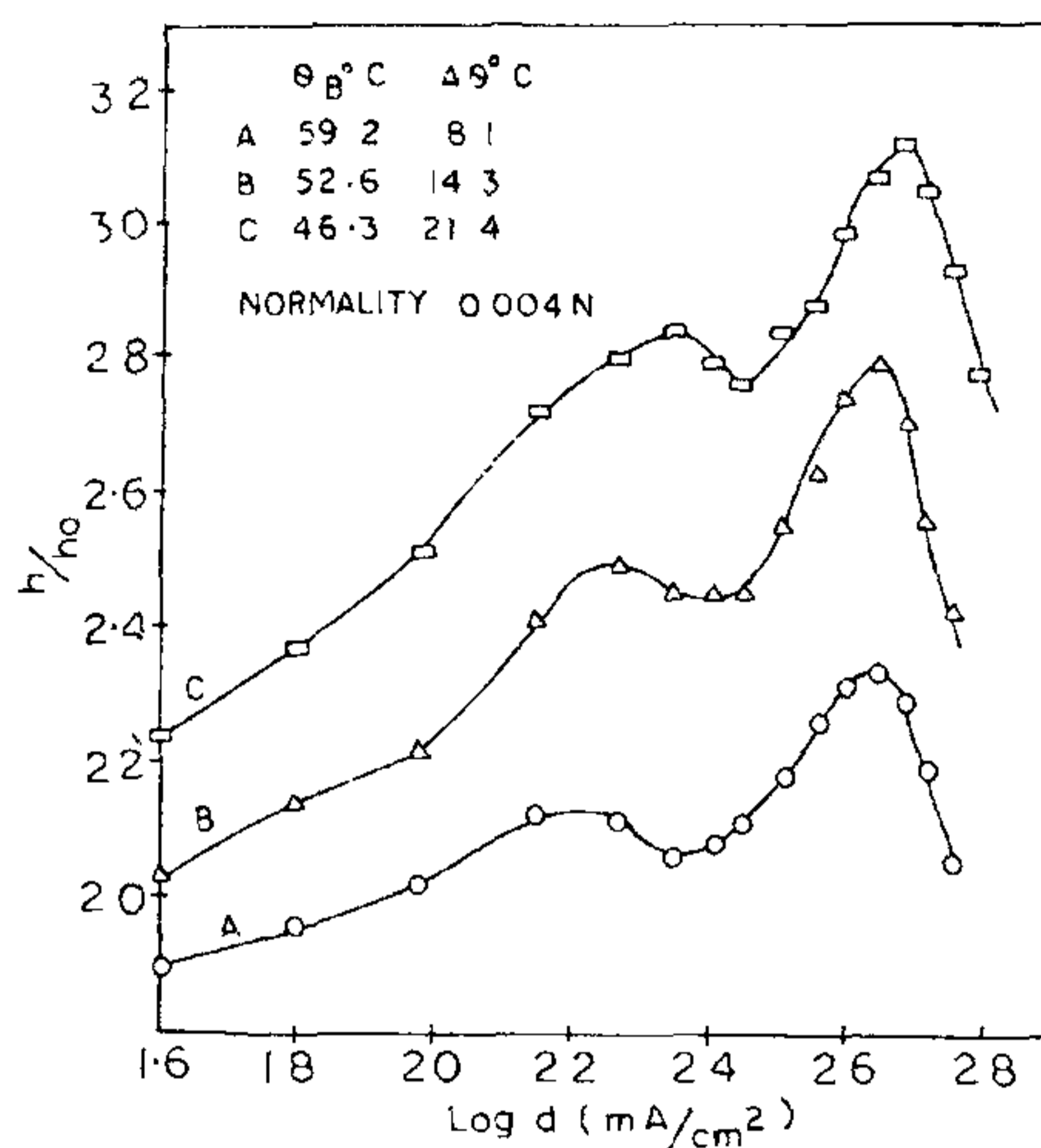


Figure 2. Variation of relative heat transfer (h/h_0) with ionic current density $(\log d)$ for 0.004 N acidulated water.

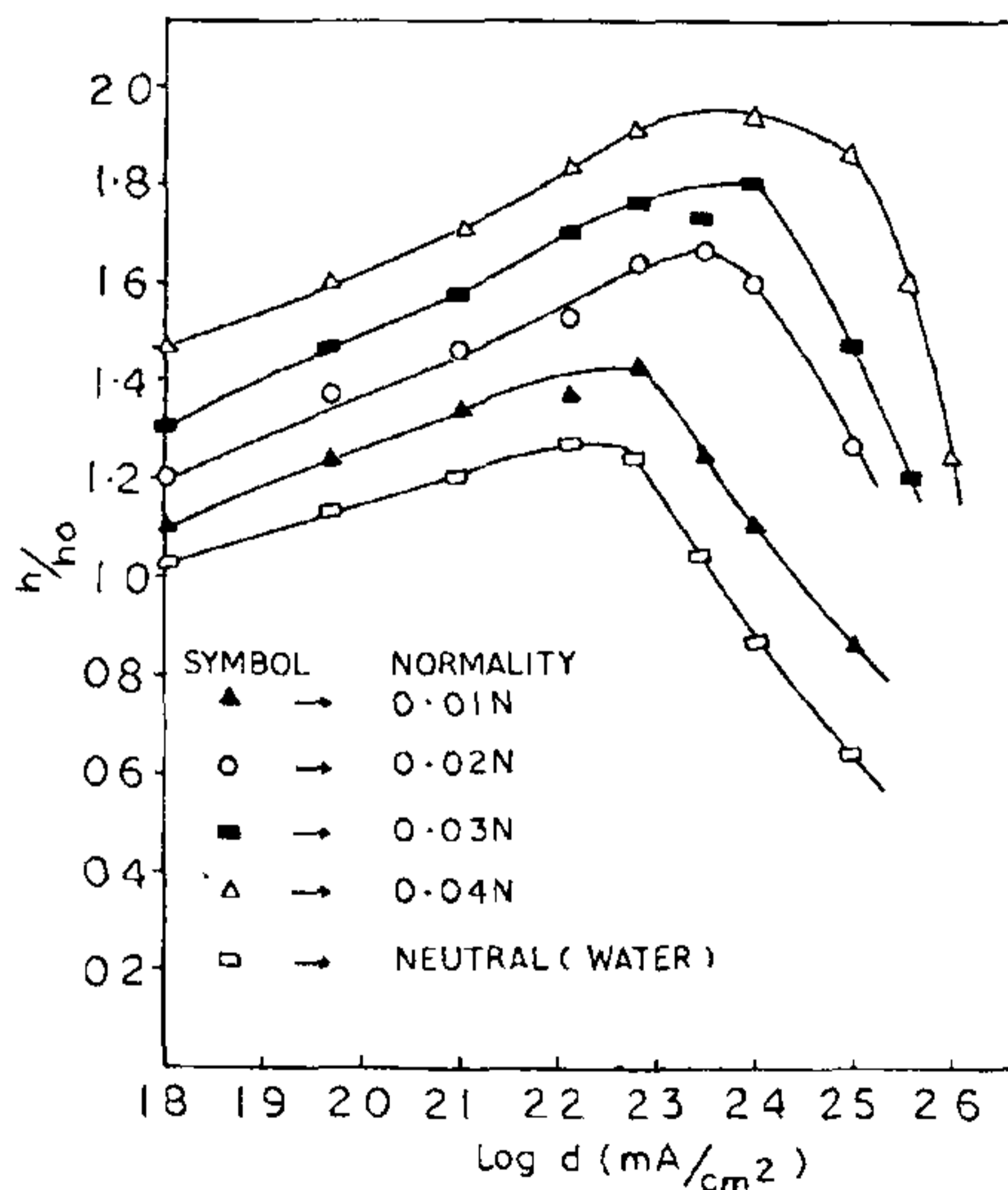


Figure 3. Variation of relative heat transfer (h/h_0) with ionic current density $(\log d)$ for KMnO_4 solution at $\theta_B = 23.2^\circ\text{C}$ and $\Delta\theta = 8.1^\circ\text{C}$.

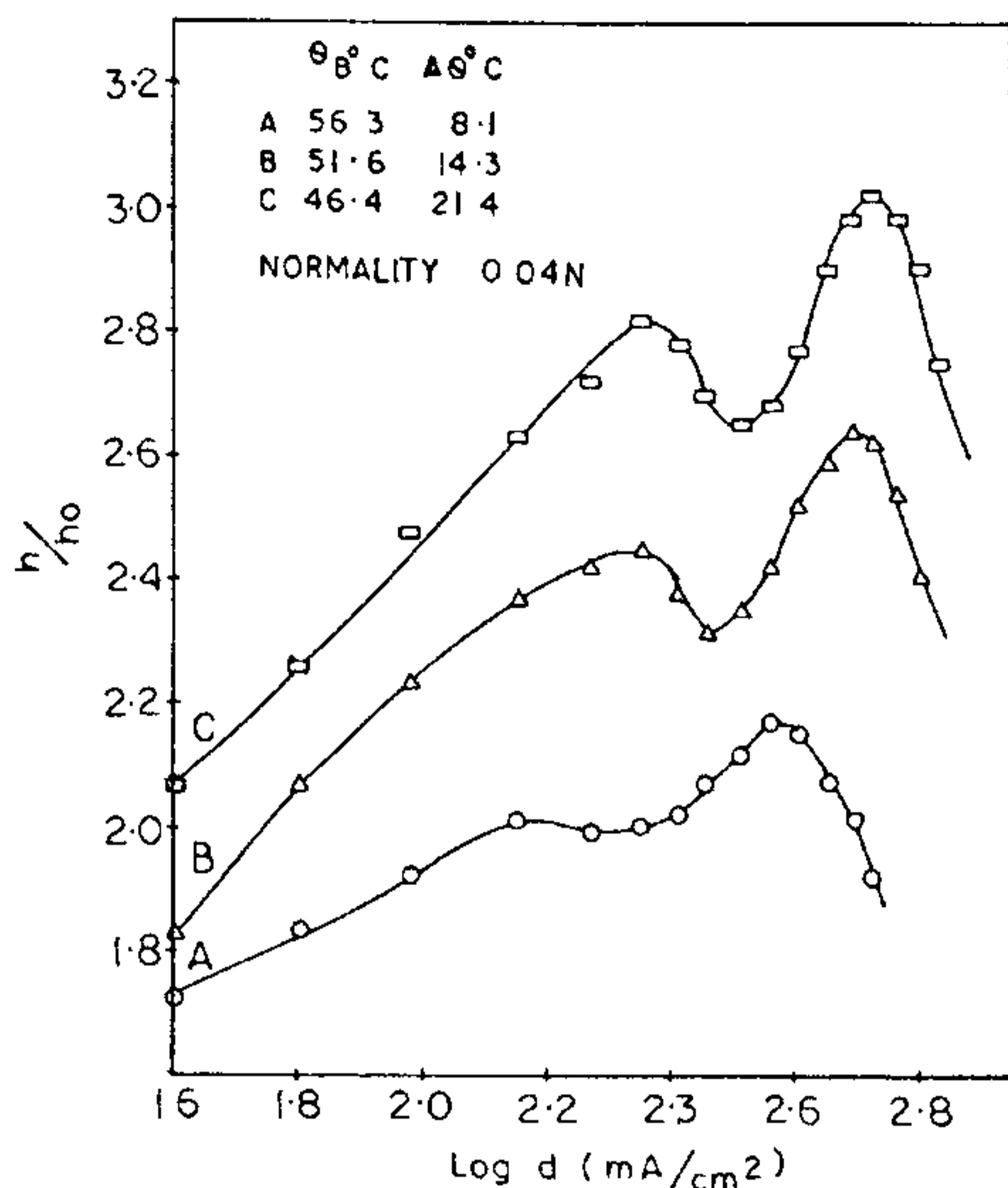


Figure 4. Variation of relative heat transfer (h/h_0) with ionic current density ($\log d$) for 0.04 N KMnO_4 solution.

the bulk solution. The gaseous bubbles and solvated ions near the hot cathode (platinum wire) experience two types of electrostatic forces due to (i) dielectrophoresis in non-uniform electric field and (ii) the condenser action caused by the double layer by Coulombic attraction between charges on the cathode and accumulated ions near it. Dielectrophoresis and apparent local electroviscosity operative within the thermal boundary layer give rise to a large number of tiny bubbles. These induced effects enhance the heat transfer by increasing the bubble nucleation frequency and destabilizing the thermal layer. The bubbles emerging from the hot wire attain maximum strain and approach a minimum size at low ionic current even in a dilute solution. Further increase in concentration does not lead to further reduction in bubble size and consequent increase in heat transfer.

If the initial temperature of the electrolyte is sufficiently higher (> 45 C in the present investigation) than the room temperature and electrolytic currents are created in the electrolyte by applying potential difference, a thin film of vapour appears to be formed on the wire due to the evaporation of liquid. This may

result in the lowering of (h/h_0) in giving first peak on the curve (figures 2 and 4). An increase in the strength of ionic current, further causes greater agitation of the vapour film, which then gradually disappears and there is once again a rise in the value of (h/h_0), with increasing ionic current. This continues until the large value of the ionic current causes almost the whole wire to be covered by a vapour film. The vapour film has a tendency to decrease the heat flux. At this stage the (h/h_0) value is due to conduction through the film and convection becomes almost negligible. This seems to be the main reason for the appearance of a second peak on the curves.

The present study suggests that for systems in which it is desired to remove heat at higher rate and at lower surface temperature, a little addition of an electrolyte in conjunction with an electric field may improve the performance of the system.

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