EFFECT OF IONIC CURRENTS ON HEAT-TRANSFER

S. C. BHAND, M. S. GAUR AND D. V. GOGATE

PHYSICS DEPARTMENT, MADHAV COLLEGE, VIKRAM UNIVERSITY, UJJAIN

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ABSTRACT. Electrolytic (ionic) currents are produced in a weak electrolyte giving rise to the generation of bubbles and their effect on heat transfer is studied Thin platinum wires were used as heating surfaces and the enhancement of heat transfer under controlled bubble generation was determined for different values of the excess of temperature $\Delta\theta$ of the heating surface over the surrounding liquid Changes in the value of the heat transfer coefficient 'h' resulting from variation in the area of the heating surface and in the excess of temperature $\Delta\theta$ are exhibited graphically and the peak value of 'h' obtained under the above conditions is then determined

INTRODUCTION

Heat transfer between a heating solid surface and a boiling liquid has been the subject of many investigations during recent years (Nukiyama 1934; Drew and Mueller, 1937; Addoms, 1948; Bromley, 1950, Rao, Desai and Gogate, 1960). In the process of heat transfer in boiling liquids, the increase of temperature of the heating surface causes an increase in the rate of bubble evolution and also in the number of bubble nucleation-sites. These two effects can be simulated by electrolytic generation of bubbles and there is the added advantage that it can be controlled independently of the heating surface temperature. It thus offers possibilities of a better understanding of the mechanism by which heat is transferred In our experiments bubbles are produced electrolytically on a heated platinum wire immersed in a dilute electrolyte.

Mixon and du Pont (1959) have investigated the influence of electrolytic bubble evolution on heat-transfer and have concluded that there is a slight but inconclusive evidence that an increase in the ionic current lowers the attainable heat flux in the high current region.

In a preliminary note Edkie, Rao and Gogate (1961) have briefly described the changes in the heat transfer coefficient 'h' resulting from the production of ionic currents under a constant difference of temp. $\Delta\theta$ between a heated platinum wire and the surrounding liquid. It appears from their results that there is a sudden fall in the value of 'h' immediately after the peak value ($h_{max}m$) is reached. But they do not seem to have obtained any definite and reliable observations for the sudden fall in 'h' with increase in the strength of the ionic currents.

The work reported in this paper was undertaken to examine heat transfer enhancement resulting from the controlled bubble generation by means of ionic currents and to investigate the lowering of heat flux in the high ionic current region.

EXPERIMENTAL

A thin platinum wire (about 0.1 m.m. in diameter and 10 cms. in length) was stretched horizontally along the axis of a hollow metal cylinder open at both ends and the system (wire and the metal cylinder) was kept immersed in a through containing a very dilute electrolyte, say water, containing a few drops of dilute sulphuric acid (Fig. 1). A potential difference ranging from 10 to 100 volts

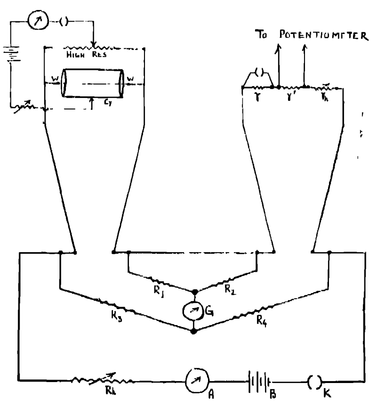

Fig. 1. (a) WW, platinum wire, (b) Cy, cylinder, (C) r, r'—standard low resistances

(using a dry battery) was established between the wire and metal cylinder giving rise to a radial-electric field The ionic (electrolytic) currents generated in this way, were measured by means of milli-ammeter

Measurements of the current flowing through the wire and its resistance are used for determining both the power input and the temperature of the wire. Under equilibrium conditions, the heat input to the wire becomes identical to the heat transfer from the wire to the liquid.

For the accurate determination of the current flowing through the platinum wire the latter was made to form one arm of a low resistance bridge (Kelvin's Double Bridge) as shown in Fig. 1. In the other arm (balancing arm), two standard low resistances r, r' (each fraction of an ohm) are connected in series with a small variable resistance. One of the two low resistances (r) is shunted by a key so that it can be introduced into the circuit when desired. The potential drop across the second low resistance (r') is measured by means of a potentiometer and from this the accurate value of the current passing through the platinum wire can be easily determined.

To start the experiment a very small current of the order of 10m. a. (which does not heat the wire appreciably) is passed through the platinum wire, which is kept in one arm of the low resistance bridge referred to above and a balance is obtained by adjusting the resistances in the other arm of the bridge. The additional standard low resistance (r) is now introduced, and this disturbs the balance previously obtained The current in the platinum wire is now gradually increased to restore the balance The change in temperature $\Delta\theta$, can be calculated by means of the relation $\Delta\theta = (r/R_0\alpha)$, where r, the additional standard low resistance introduced in balancing arm, R_0, the resistance of the platinum wire at 0°C and α, the temp. coefft. of resistance for the wire, are known.

If now some potential difference is established between the platinum wire and the metal cylinder, electrolysis starts in the liquid and ionic currents begin to flow between the wire and the cylinder Bubbles are found to rise from different points on the wire due to evolution of gas in the process of electrolysis and the temp. of the wire is slightly lowered. The wire is now brought back to its initial temperature (temperature before the commencement of ionic currents) by passing a little more current through it from the battery and the heat exchange between it and the surrounding liquid is then measured. The heat flux q/A (A = surface area, $2\pi rl$ of the wire) for unit difference of temperature between the wire and the surrounding liquid is known as the heat transfer coefficient 'h'. We have investigated the variation of 'h' with increasing values of $\Delta\theta$ for different strengths of ionic currents and with platinum wires of different diameters The different values of $\Delta\theta$ could be obtained by choosing suitable values of the additional standard low resistance 'r' in the balancing arm. A typical set of observations showing the variation of the heat transfer coefficient 'h' with the strength of the ionic current 'i' for a fixed value of $\Delta\theta$ is given in Table I.

TABLE I

Wire diameter = 0'10 m.m., $\Delta\theta$ = 6'3°C, h_0 = 0.0873 cal./sq. cm./sec/°C

Sl. No	i in milli-amp	Log i	h Cal./sq cm./°C/sec.	(h/h_0)
1	20	1.30	0.1107	1.268
2	40	1.60	0.1274	1.458
3	60	1.78	0.1348	1.545
4	80	1.90	0.1368	1.567
5	100	2.00	0.1351	1.547
6	120	2.08	0.1310	1.501
7	140	2.14	0.1148	1.314
8	160	2.20	0.1029	1.179
9	180	2.25	0.0983	1.126
10	200	2.30	0.0909	1.041
11	220	2.34	0.0862	0.988
12	240	2.38	0.0726	0.831
13	260	2.41	0.0615	0.705

RESULTS AND DISCUSSION

In studying the variation of 'h' with ionic current, the difference of temp. $\Delta\theta$ between the wire and the surrounding liquid was kept constant by keeping a definite value of 'r', in the balancing arm The values of (h/h_0)*, where h_0 is the heat transfer coefficient in the absence of ionic currents, were then plotted against log i, where 'i' is the strength of ionic current in milliamperes. One such plot is shown in Fig. 2(curve A), where the value of $\Delta\theta$ was maintained constant at 6.3°C.

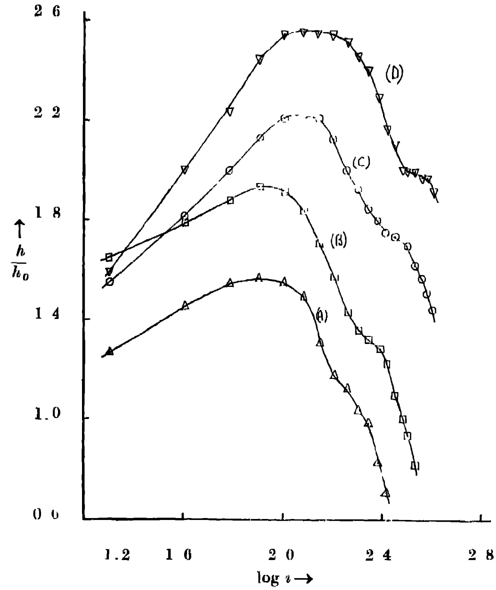

Fig. 2. The plot of (h/h_0) against log i (i, being ionic current in milliamperes) using platinum wire of diameter 0.10 mm., at different values of $\Delta\theta$ (A) 6.3°C, (B) 10.0°C, (C) 15.2°C, (D) 20.1°C.

This process was repeated for the values of $\Delta\theta$ = 10.0°C 15.2°C, and 20.1°C and the resulting graphs B, C, D are shown in Fig. 2. It is obvious from these graphs that there is a definite increase in the peak value of 'h' with increasing values of $\Delta\theta$. For instance, at the value of $\Delta\theta = 6.3$°C, (h/h_0) max^m is equal to 1.567 whereas with $\Delta\theta = 20.1$°C, (h/h_0)max^m comes out to be 2.559.

* It is found more convenient to use the ratio (h/h_0) than 'h' alone, while considering the variation of heat transfer with increase in the ionic currents because, though the values of 'h' may vary for different sets of observations under different conditions of temperature, pressure, humidity etc., the value of (h/h_0) remains sufficiently consistent and uniform.

The effect of varying the diameter of the platinum wire on the rate of heat transfer was then studied. For this purpose, wires of four different diameters were used. The variation of 'h' with ionic currents for these wires of different diameters is depicted in Fig. 3. The different curves of Fig. 3. clearly indicate

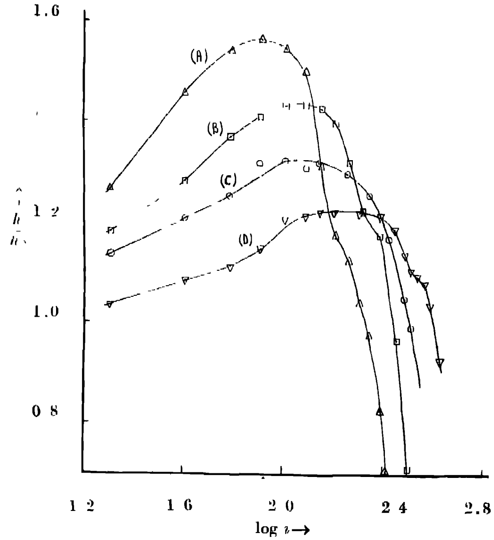

Fig. 3. The plot of (h/h_0) against log i maintaining $\Delta\theta = 6.3°C$ and using platinum wires of different diameters, (A) 0.10mm., (B) 0.19 mm., (C) 0.31 mm., (D) 0.37 mm.

that the maximum rate of heat transfer (h_{max^m}) goes on falling slowly as the diameter of the wire increases though in this case the change in the peak value of 'h' is not very great even when the diameter of the wire is increased to four times its original value.

The variation of the peak value of 'h' with (i) increase in the value of $\Delta\theta$ and (ii) increase in the diameter of the platinum wire is shown in Table II.

TABLE II

Sl No.	Wire diameter – 0.10 mm		$\Delta\theta$ = 6.3°C	
	$\Delta\theta$ in °C	(h/h_0)max^m	wire diameter in mm.	(h/h_0)max^m
1	6.3	1.567	0.10	1.567
2.	10.0	1.938	0.19	1.433
3.	15.2	2.222	0.31	1.323
4.	20.1	2.559	0.37	1.226

Our results indicate very clearly that for every value of $\Delta\theta$ there is a definite enhancement of heat transfer up to a certain value of ionic current and this is followed by a regular decrease in heat transfer in the higher ionic current region.

Moreover the graphs of Fig. 2 and 3 can be taken as a conclusive evidence to show that though 'h' becomes maximum for an optimum value of i, it goes on falling gradually and not suddenly as reported by Edkie, Rao and Gogate (1961) with increasing strengths of ionic currents.

In calculating $\Delta\theta$ we cannot suppose that the temp. of the platinum wire alone is raised up to a certain point by the current passing through it and that the temperature of the surrounding liquid remains constant, though the rise in temperature of the liquid is made negligibly small by employing a large quantity of the liquid and very thin platinum wires. A correction for this very small change in $\Delta\theta$ was however applied by plotting change in $\Delta\theta$ against time and the values of $\Delta\theta$ corrected in this way were used for determining the value of 'h'

In the above experiments the platinum wire was always kept at a positive potential with respect to the cylinder We have checked up that the nature of the phenomena as shown by the graphs of Fig. 2 and 3 remains unaltered by reversing the polarity, though it causes a slight change in the value of 'h'.

CONCLUSIONS

(a) There is an optimum value of 'i' (the strength of the ionic current) for which the heat transfer coefficient 'h' becomes maximum.

(b) The value of 'h' goes on falling gradually after attaining the peak value ($h_{max}{}^{m}$) with increase in the strength of ionic currents.

(c) The enhancement of heat transfer becomes greater when the difference of temperature $\Delta\theta$ between the heating surface and the surrounding liquid is increased.

(d) For a given value of $\Delta\theta$, the rate of heat transfer goes on falling when the area of the heating surface is enlarged.

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