50

A NOTE ON HEAT TRANSFER AND FILM BOILING

R. D. RAO, H. S. DESAI AND D. V. GOGATE

PHYSICS DEPARTMENT, M. S. UNIVERSITY, BARODA

(*Received May* 31, 1960)

ABSTRACT. Heat transfer between electrically heated metal wires and different boiling liquids has been studied and characteristic boiling curves are obtained by plotting the heat flux q/A against the excess of temperature Δt of the wire over the boiling point. The relation between the heat transfer coefficient h and Δt has also been studied. The values of maximum heat flux and critical temperature difference are calculated for the different wires and liquids used in this investigation.

INTRODUCTION

It is a matter of common experience that when a red hot metal is quenched in water, the metal first cools slowly, then rapidly and then slowly again. This can be taken as a good illustration of the three possible types of boiling, viz.—film boiling, nucleate boiling and natural convection boiling. Film boiling is that type of boiling which occurs when a vapour film exists between a heated surface and a boiling liquid. In nucleate boiling, vapour bubbles originate from different parts of the heated surface. Natural convection boiling takes place when the difference of temperature between the heated surface and the liquid is small. In the operations of jets and rockets, there are frequent contacts between a boiling liquid and a hot surface and this is the condition for film boiling. In an electrically heated boiler or an atomic power plant where the heat input is the controlled variable, there is always a danger that the temperature of the heated object may rise abruptly if the heat input is near the critical heat flux (q/A). This danger becomes much more pronounced if the value of the heat input is above the maximum heat flux $(q/A)_{max}$. If the abrupt temperature rise is sufficiently large, it may give rise to sudden expansion and weakening of certain parts of the system, sometimes causing breakage.

In view of the above importance of film boiling and nucleate boiling, we have tried (1) to investigate the effect of quenching electrically heated wires in different liquids and (2) to study the heat transfer, by means of characteristic boiling curves (incorporating free convection boiling, nucleate boiling and film boiling) between cylindrical metal wires and boiling liquids.

Drew and Mueller (1937) and others have studied heat transfer to boiling liquids by steam condensing method. Nukiyama (1934) succeeded in obtaining almost complete boiling curves by electrically heating thin platinum wires submerged in boiling water. Natural convection boiling and nucleate boiling of water for different pressures have been studied by Addoms (1948) using thin platinum wires. Extensive study of film boiling was made by Bromley (1950) using various organic liquids.

During our study of heat transfer, we have obtained characteristic boiling curves for a number of liquids and the results of our experiments on heat transfer between cylindrical metal wires and boiling liquids have been described in this note. The complete boiling curves [plots of log (q/A) against log Δt] for the vaious liquids used have been obtained for different wires, and the maximum heat flux and the critical temperature difference have been calculated. The heat flux (q/A) for unit difference of temperature between the wire and the surrounding liquid is known as the heat transfer coefficient h. Thus $h = \frac{q}{A \cdot \Delta t}$. The relation between this coefficient h and the temperature difference Δt has also been sutdied for liquids such as water, carbon tetrachloride, turpentine, etc. and some typical results have been graphically illustrated (Fig. 2).

EXPERIMENTAL

The experimental arrangement consisted of a simple Wheatstone bridge with ratio arms of 1000 ohms each. A thin platinum wire which was submerged in the boiling liquid was included in the third arm of the bridge in series with an ammeter, while a small rheostat and a Eureka wire bridge with a sliding contact formed the fourth arm of the bridge.

The platinum wire was allowed to remain in the boiling liquid for some time before passing a current through it so that it attained the temperature of the boiling liquid. The resistance of the wire could then be calculated at this temperature, if R_0, the resistance of the wire at 0°C and α, the temperature coefficient of resistance for the wire are known. A very small current which does not heat the wire appreciably, was then passed through the wire and a balance was obtained by adjusting the rheostat and by sliding the contact on the Eureka wire bridge. The current through the wire was then increased so as to raise its temperature. This increases the resistance of the wire, thus disturbing the balance previously obtained. The contact is now shifted so as to restore the balance. Knowing the value of this shift and also the resistance per unit length of the Eureka wire, the change in resistance ΔR of the platinum wire could be calculated. The excess of temperature of the wire above the boiling point of the liquid could then be determined by means of the relation $\Delta t = \frac{\Delta R}{R_0 \alpha}$.

RESULTS AND DISCUSSION

The input power q is equal to $\frac{C^2R}{J}$ where C is the current passing thrgugh the wire, R is its resistance and J is the mechanical equivalent of heat, The heat

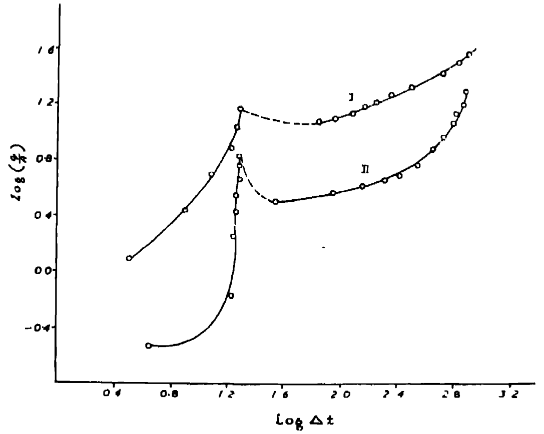

Fig. 1. Curves showing the variation of q/A with the excess of temperature.
Curve I—Platinum-water. Curve II—Platinum-carbontotraphloride.

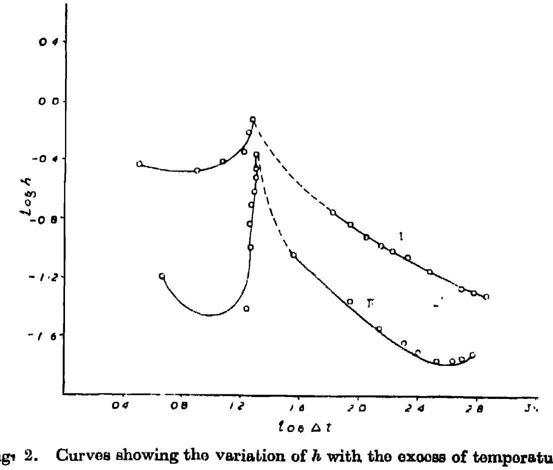

Fig. 2. Curves showing the variation of h with the excess of temperature.
Curve I—Platinum-water. Curve II—Platinum-carbontretrachloride.

flux is given by q/A where A is the surface area $2\pi rl$ of the wire of length l and radius r. Typical curves showing the variation of q/A with the excess of temperature Δt as also the relation between the heat transfer coefficient $h\left(=\frac{q}{A.\Delta t}\right)$ and Δt for water and carbon-tetrachloride are exhibited in Figs. (1) and (2) respectlvely.

The values of the maximum heat flux $(q/A)_{max}$ and critical temperature difference Δt_{crit} for the different wires and liquids used as also the values of the slopes calculated for natural convection boiling and nucleate boiling together with the heat transfer coefficient (h) at the peak value are shown in Table I.

TABLE I

Liquid	Wire	Slopes for		$\left(\frac{q}{A}\right)_{max}$	Δt_{crit}	$(h)_{max}$ cal/cm.^{2} sec°C
		Nat. conv. boiling	Nucl. boiling	cal/sec. cm^2		
Water (B.P. 100°C)	Platinum	0 91	3 25	15.8	19°C	0.800
Turpentine (B.P. 166°C)	-do- r = 0.005 cm.	1 2	3.6	12.02	39.8°C	0 302
	Copper r = 0.0026 cm.	1.0	4.66	10.96	36.3°C	0.302
	Tungsten r = 0.0028 cm.	0.9	1 6	12.6	43.6°C	0.275
Naphthalene (B.P. 215°C)	Platinum	0.77	2.8	11.48	39 8°C	0.288
	Copper	0.83	2.75	10.72	39.8°C	0.263
	Tungsten	1.0	1.7	12.59	38.02°C	0.331
Carbontetrachloride (B.P. 77°C)	Platinum	0.6	2.57	6.9	19.95°C	0 355
	Tungsten	0.71	3.0	8.7	22 9°C	0 355

When the heat flux exceeds $(q/A)_{max}$ the system passes from nucleate boiling regime to film boiling regime after passing through a transient state of unstable film boiling. This unstable (transient) state is shown by the dotted curve in Figs. (1) and (2). In the state of stable film boiling a vapour film is formed between the wire and the liquid. This film acts as a barrier in which the heat flow is due more to conduction than to convection. The formation of this barrier (vapour blanket) naturally diminishes the heat flow from the wire to the liquid and hence the value of heat transfer coefficient h is also decreased as indicated by the graphs in Fig. 2. These graphs also indicate that if the heat flux is still further increased, the value of h goes on decreasing further.

CONCLUSIONS

(a) The material and dimensions of the wire do not seem to affect the value of the maximum heat flux $(q/A)_{max}$ so much as the properties of the liquid, especially the latent heat of vaporisation.

(b) The continued decrease in the value of h with the increase of heat flux in the film boiling regime seems to be due to a slight increase in the thickness of the vapour film.

REFERENCES

Addoms J. N., 1948," Heat Transmission" by William H McAdams, McGraw-Hill Third Edition 1954 page 382 in Asian students' Edition.

Bromley, L. A., 1950, *Chem. Eng. Progr.*, **46**, 221.

Drew, T. B. and Mueller, A. C., 1937, *Trans. Am. Inst. Chem. Engrs.*, **33**, 449.

Nukiyama, S., 1934, *J Soc. Mech. Engrs.*, (*Japan*), **37**. 367., S53-54.