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SHORTER COMMUNICATIONS

ON THE EFFECT OF HEATING WALL THICKNESS ON POOL BOILING BURNOUT†

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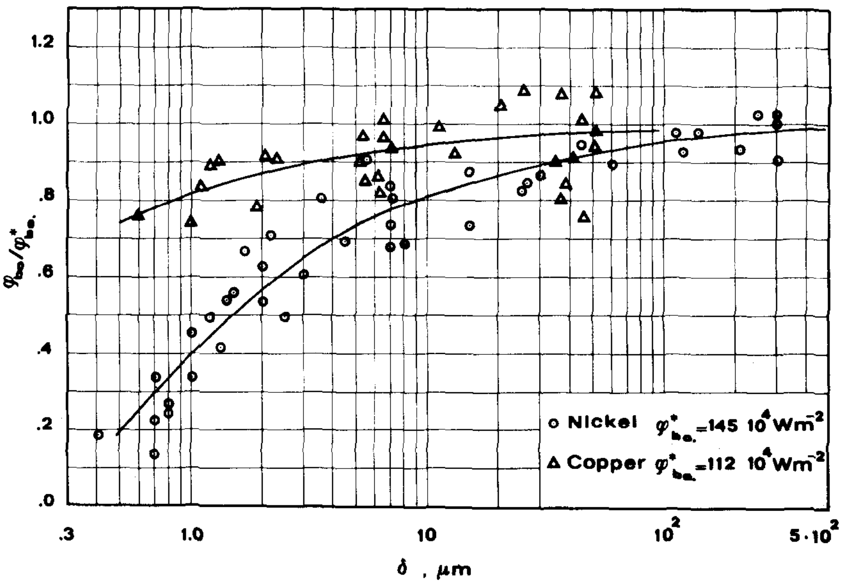

FIG. 1. Normalized burnout heat flux for different thicknesses of copper and nickel heaters in pool boiling of water.

NOMENCLATURE

c, specific heat [J/kg K];
k, thermal conductivity [W/m K].

Greek symbols

α, thermal diffusivity [m^2/s];
δ, thickness of the heating element [m];
δ_l, "limiting value" of the thickness of the heating element [m];
ρ, density [kg/m^3];
$\varphi_{b.o.}$, burnout heat flux [W/m^2];
$\varphi^*_{b.o.}$, asymptotic burnout heat flux [W/m^2].

INTRODUCTION

NUMEROUS experimental investigations have pointed out the effect of the thickness and physical properties of the test section on burnout heat flux in pool-boiling. Such an effect occurs for thin metal layers and results in a drop in the burnout heat flux with decreasing heater thickness. The extent of this effect depends upon the fluid used and upon the test section material. In fact, the physical properties of the heating wall seem to influence both the value of the burnout heat flux and the thickness beyond which the above-mentioned heat flux is no longer dependent on the thickness itself.

This particular aspect has been studied in [1–5] using the thinnest metal strips, and in references [3, 4, 6, 7, 9, 10], using thin walled cylinders and tubes.

The purpose of the present work is to study the effect of the thermal properties of thin heating wall on the range of values of the thicknesses influencing the burnout heat flux.

EXPERIMENTAL SET-UP AND PROCEDURE

The experiments were performed in distilled, degassed and saturated water at atmospheric pressure. The specimens tested were horizontal cylinders, obtained by electrodeposition of thin metal layers on epoxy resin rods (CIBA ARALDITE CW 211) of 10 mm O.D. and 200 mm in length (heated length 120 mm). For each specimen the thickness and surface roughness of the metal layer, held within 0.4 and 0.7 μm, were accurately controlled using the techniques described in reference [10]. Power was supplied from a 1800 A–10V/900 A–20V solid state power unit. Burnout heat flux was evaluated by measuring the electrical power flowing through the heated wall when physical burnout occurs. Each run was first conduced supplying the test section at 40% estimated peak heat flux, for about 30 min, thereafter increasing the power in increments of (2–4)·10^4 W/m^2 at intervals of 2 min. Such a method was employed to remove absorbed gases from the surface and to obtain the burnout values independent of the speed with which the power was increased [8].

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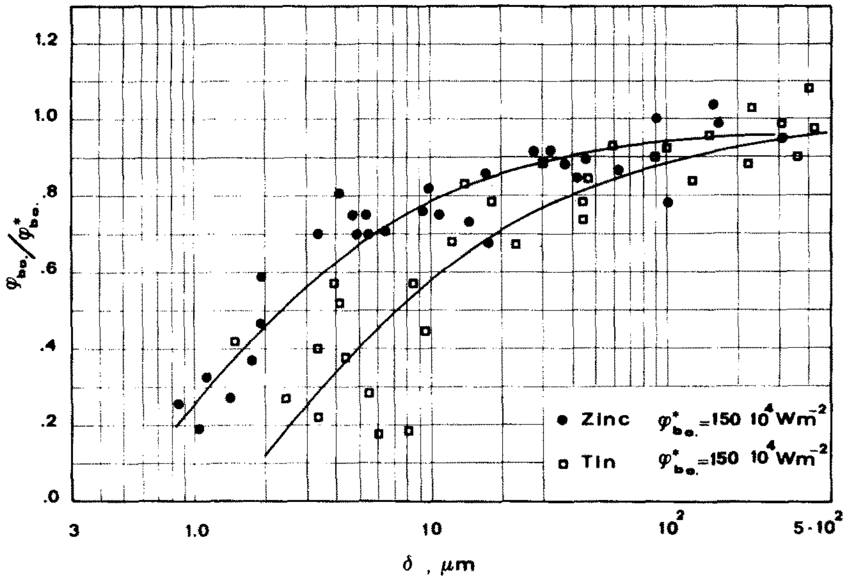

FIG. 2. Normalized burnout heat flux for different thicknesses of zinc and tin heaters in pool boiling of water.

EXPERIMENTAL RESULTS

The tests were performed on metal layers of copper, nickel, zinc and tin. Approximately forty runs were made for each metal, with specimens ranging in thickness from 0.5 to 400 μm.

For all the metals tested the burnout heat flux presented a monotonic decreasing trend with decreasing thickness of the metal. Such behavior has already been pointed out by other authors [1, 5], and has been studied in detail in [9, 10].

An interesting aspect of the phenomenon, not sufficiently analyzed, is that there is a certain range of values for δ, the metal thickness, over which it affects burnout appreciably. When the heater thickness exceeds a certain value, which can be defined as the "limiting value" δ_l the influence of the wall thickness on the burnout heat flux becomes negligible. This limiting value is peculiar to each metal considered.

In order to arrive at a possible relation between δ_l and physical properties of the heating wall, it is suitable to normalize the burnout heat flux with to the asymptotic value $\varphi^*_{b.o.}$ at large thicknesses.

With this method it is possible to separate the effect of thickness of the metal layer from the other variables; above all, from the characteristics of the solid–liquid interface.

The experimental results obtained in such a manner are presented in Figs. 1 and 2. The continuous lines and the values of $\varphi^*_{b.o.}$, reported in the same figures, have been obtained by least squares fit applied to the experimental data.

Referring to Figs. 1 and 2, it may be observed that the effect of the thickness is limited to a range of value of δ, decreasing from tin to copper. This effect seems to be related to a decrease of the parameter $\sqrt{(k\rho c)}$ for the four metals tested (see Table 1). In fact the range of δ is as limited as large as the forementioned parameter of the metal under test. Moreover, the limiting value of the thickness correlates neither with the value of thermal conductivity and diffusivity nor with the thermal capacity.

A simple link seems to exist between the limiting value of the thickness and the parameter $\sqrt{(k\rho c)}$ of the metal layer. To obtain such a relation, one may assume for δ_l, the value of the thickness corresponding to the burnout heat flux equal to 90% of $\varphi^*_{b.o.}$.

From Fig. 3 it may be observed that, the parameter δ_l so defined, is linearly dependent on the parameter $\sqrt{(k\rho c)}$, in logarithmic scale.

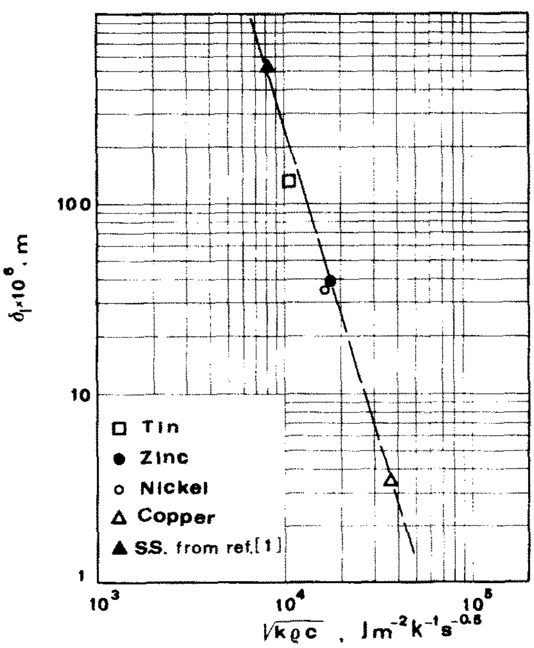

FIG. 3. Plot of δ_l as a function of $\sqrt{(k\rho c)}$ for heaters of different metals.

Table 1

Metal	$c\rho$ $\left[\frac{J}{m^3\,°C}\right]$	α $\left[\frac{m^2}{s}\right]$	k $\left[\frac{W}{mK}\right]$	$\sqrt{(k\rho c)}$ $\left[\frac{J}{m^2 K s^{\frac{1}{2}}}\right]$
Copper	$32.9\cdot10^5$	$1.19\cdot10^{-4}$	393	$3.595\cdot10^4$
Zinc	$28.8\cdot10^5$	$0.38\cdot10^{-4}$	110	$1.778\cdot10^4$
Nickel	$42.8\cdot10^5$	$0.15\cdot10^{-4}$	60.7	$1.639\cdot10^4$
Tin	$17.6\cdot10^5$	$0.34\cdot10^{-4}$	60.6	$1.032\cdot10^4$
Stainless steel	$39.8\cdot10^5$	$0.42\cdot10^{-5}$	16.6	$0.81\cdot10^4$

The thermophysical properties of the metals have been taken from [11, 12].

In the same figure, the value of δ_l obtained by Tachibana *et al.* [1], using stainless steel strips is reported. Finally, the experimental data obtained may be expressed by a simple relation of the form:

$$\delta_l = 2.35 \cdot 10^{-4}\left(\frac{\sqrt{(k\rho c)}}{10^4}\right)^{-3,26}, \text{m}.$$

CONCLUSIONS

The experimental results obtained in the present research point out the considerable effect of the thickness of the walls on burnout heat flux. This effect, however, is present for the values of the thickness δ below a definite limiting value δ_l, characteristic of the metal tested.

Restricted to the experimental conditions here examined, the value of δ_l, defined to correspond to the ratio $\varphi_{b.o.}/\varphi^*_{b.o.}$ equal to 0.9, depends on the parameter $\sqrt{(k\rho c)}$ of the heating wall.

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A CONSIDERATION ON NATURAL CONVECTIVE SWAYING MOTION OF PLUME ABOVE A HORIZONTAL HEATED PLATE

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NOMENCLATURE

- d, heater width;
- f, frequency;
- G_{rd}, Grashof number;
- H, distance from the heated surface to the liquid surface;
- Pr, Prandtl number;
- t, temperature;
- ν, kinematic viscosity;
- τ, period.

1. INTRODUCTION

An oscillation of natural convective flow in a horizontal cylindrical annuli was examined by Bishop *et al.* [1, 2], while the swaying motion of plume rising from a horizontal line heat source was investigated by Forstrom and Sparrow [3], Fujii *et al.* [4]. Miyabe *et al.* [5] observed a plume rising from a horizontal heated cylinder by using a spindle oil. However, the physical understanding on the continuation of such swaying motion of plume or its effect on heat transfer has not been fully made so far.

In this note the swaying motion of plumes rising from a horizontal plate is discussed under an assumption that the motion might be a self-excited oscillation related to a periodical variation of local heat transfer on the surface.

A nondimensional relation between the oscillating frequency of plume and Grashof number is also demonstrated.

2. RESULTS AND DISCUSSION

Measuring procedure

Several kinds of stainless steel foil (400 mm in length, 0.03 and 0.05 mm in thickness, 10, 20 and 30 mm in width) are fixed as heaters on an acryle plate (10 × 100 × 400 mm). The horizontality of every heater placed in oil, which is put into a glass vessel test chamber (300 mm wide, 600 mm long and 360 mm high), is carefully checked. Frequencies of the various swaying motions are evaluated from the results measured with Cu–Co thermocouple of 0.065 mm dia, which is located at a distance s of 30–40 mm vertically above the middle of the width of the heater.

Experiments are carried out for Prandtl number ranging from 80 to 160 under the following conditions, $l = 400$ mm, $H = 95$–300 mm, $Q = 10.5$–53.5 W/m (for $d = 10$ mm), 24.9–47.7 W/m (for $d = 20$ mm), 34.9–80.2 W/m (for $d = 30$ mm), where l is a length of heater, H is a distance from the heated surface to the liquid surface, d is a width of heater and Q is a heat supplied per unit length. Grashof number (based on d) ranges from 6.0×10^3 to 2.0×10^6.