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HEAT TRANSFER FROM WIRE TO SUBCOOLED AND BOILING WATER

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Abstract—The heat-transfer coefficients from 8×10^3 to 2×10^5 W/m² degC of nucleate and film boiling in subcooled and total boiling distilled water are given. An algebraic numerical equation for film boiling values is enclosed. The heat-transfer results were obtained by a single electrically heated, nickel wire. A brief description of the apparatus used and a simple method for obtaining film boiling are given.

NOMENCLATURE

- q, density of heat flux in watts per unit area of surface (W/m²);
- h, heat-transfer coefficient (W/m² degC);
- R, electric resistance in ohms (Ω);
- T_l, temperature of liquid;
- T_s, temperature at saturation;
- T_w, temperature of the surface of the wire.

1. INTRODUCTION

To illustrate the present knowledge of boiling, the reader is referred, for example, to Grassmann [1] and Rohsenow [2] or Westwater [3].

With the equipment used in this study the equations for nucleate boiling were confirmed. Film boiling is receiving more and more attention. The peak heat flux of nucleate boiling is small. This, however, is not so for film boiling. This and other advantages explain the increased interest in film boiling. Frederking [4] shows in his thesis work the heat transfer during the evaporation of liquefied helium and nitrogen.

If the average liquid temperature is below the saturation temperature we speak of subcooled, local, or surface boiling. Boiling in a liquid at saturation temperature is known as saturated, bulk, or total boiling.

Faneuff [5] gave some aspects of surface boiling pertaining to the growth of vapour bubbles.

The apparatus was used to measure the density of heat flux and heat-transfer coefficient at atmospheric pressure during nucleate, film, subcooled and total boiling. Only the new values of subcooled and film boiling are shown since the results for other regions have been published by other workers in this field.

2. EXPERIMENTAL PROCEDURE

The apparatus is shown schematically in Fig. 1. In principle it was a Thomson bridge. The resistance R_w represented a horizontal heating wire of nickel which was placed about 100 mm in a Dewar glass vessel filled with distilled water. The resistances R_1, R_2, R_4 and R_5 were adjustable decimal resistances up to 10^5 Ω. R_1 and R_4 were adjusted at 10^3 Ω.

R_2 and R_5 served for balancing the bridge in the neighbourhood of 9000 Ω. The resistance R_3 had the fixed value of 0·0303 Ω and was built of constantan wires. The measurements were made with 0·30 and 0·25 mm diameter wires.

Special care was taken to fix the heating wire 100 mm long. It was held by means of two 7 mm diameter brass rods. The wire went through a hole and once around the ends of the rods and back to the entering wire. The rods were polished as clean as possible. Thus, a good contact between wire and rods was guaranteed

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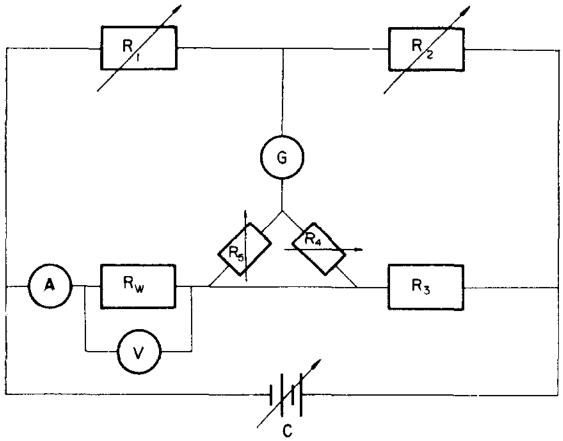

FIG. 1. Schematic of the apparatus connections.

without soldering. It was very important not to injure the wire in any way.

While trying to obtain film boiling it was noticed that film boiling occurred on one half of the 0·30 mm diameter wire, because of a resistance difference that occurred in the wire. The conclusion was to use a combination of two different diameter wires 0·30 and 0·25 mm each having a length of 50 mm. When the wires joined each end was formed into a closed eye hook. A direct current voltage source was produced by silicon rectifiers. The current was adjustable to 60 A (no steps). With this voltage source film boiling on the 0·25 mm diameter wire was easily obtained. At first boiling occurred only on a part of the wire. It could spread out on the whole wire length of 100 mm by increasing the electric current intensity and by lengthening the 0·25 mm diameter wire up to 100 mm. Therefore, one had to pull the 0·30 mm diameter wire through the rod hole by means of a drawing tool.

An immersion heater kept the water at the boiling point but a special shield between wire and heater was installed to keep the bubbles

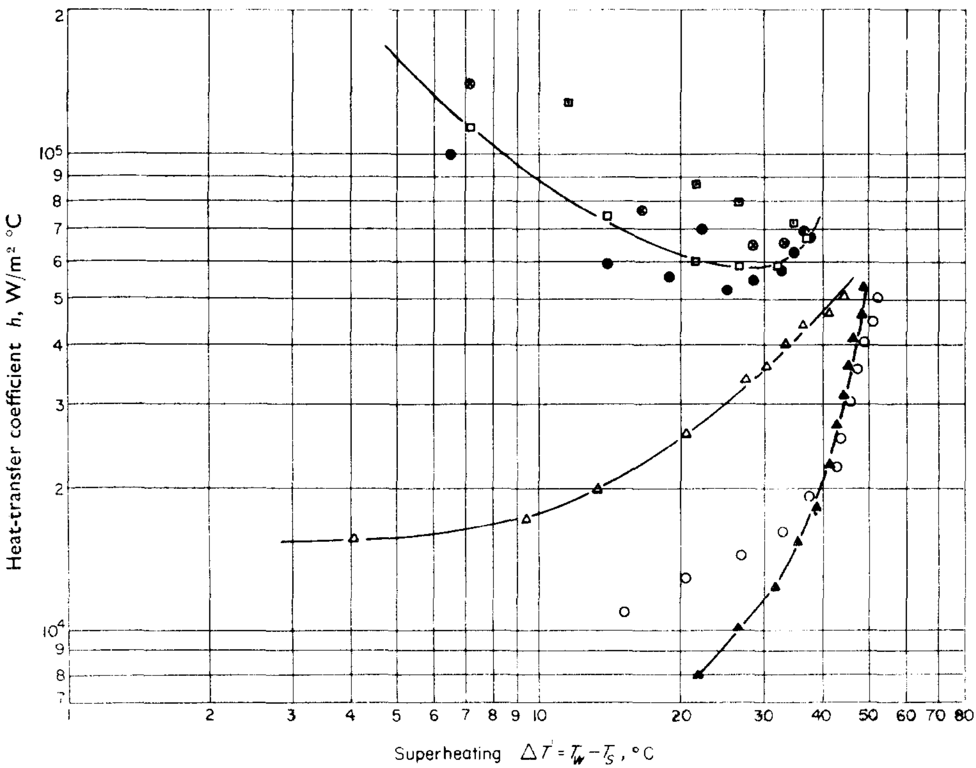

FIG. 2. Subcooled boiling ($T_1 < T_s$) of water at atmospheric pressure. The values of the subcooling amounted to 8°C (▲), 13°C (○), 18°C (△), 28°C (●), 38°C (□), 48°C (⊗) and 63°C (⊡).

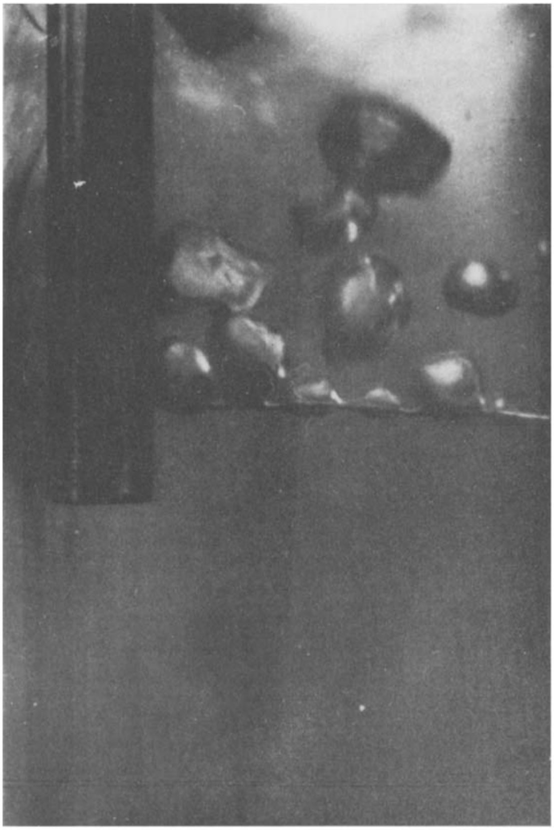

FIG. 5. Photostudy during film boiling.

away from the heater. To hold the water at a constant temperature a normal thermostat was used.

A galvanometer (G), see Fig. 1, served as the balancing apparatus of the Thomson bridge. An ammeter (A) and a voltmeter (V) delivered the necessary values for the calculation of the density of heat flux.

The effect of temperature on wire resistance was found by means of a calibration. An optical pyrometer as well as the voltmeter was used for comparative measurements.

3. RESULTS AND DISCUSSION

The liquid which was evaporated was distilled water. The heat transfer for nucleate boiling in subcooled water and for film boiling during bulk boiling was investigated in relation to the subcooling ($T_s - T_l$) and superheating ($T_w - T_s$) at atmospheric pressure (at Zürich about 710 mm mercury). The boiling point for distilled water was therefore 98°C.

3.1. *Subcooled boiling*

During every measurement the same 0·30 mm diameter wire and the same water were used. Therefore it was necessary not to get over the critical density of heat flux (burn out) therefore the maximum level of the electric current was chosen to be 30 A.

The plots in Fig. 2 show very clearly how the curves turn aside into regions of smaller superheating and higher density of heat flux with increasing subcooling. For a high density of heat flux one can state that there is no influence of subcooling.

3.2. *Film boiling*

With respect to the observation of the film boiling length it was possible to find the characteristic shown in Fig. 3. Since the length could

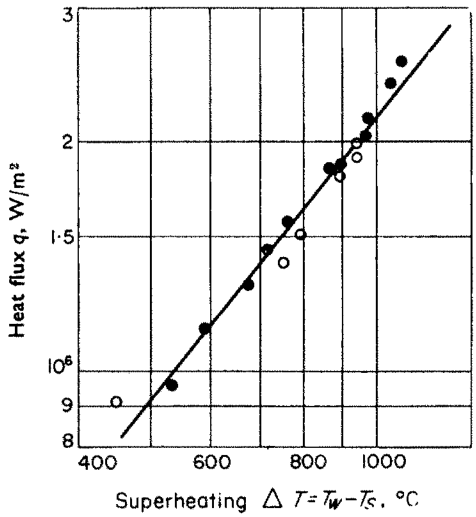

FIG. 3. Film boiling in water at saturation temperature and at atmospheric pressure. Sign ○ represents values measured with a 100 mm long 0·25 mm diameter wire and sign ● a wire combination consisting of two wires of 0·25 and 0·30 mm diameter. (1 W/m² is equal to 0·318 Btu/ft²h.)

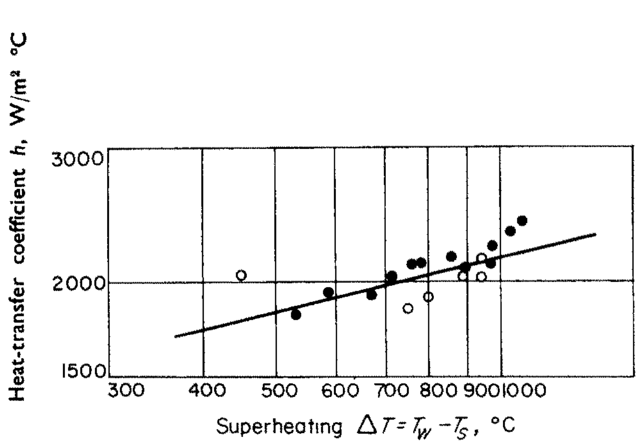

FIG. 4. Representation of heat-transfer coefficients referring to Fig. 3.

only be estimated, the results exhibited more variation than those of the subcooled boiling tests.

The range of density of heat flux increased from $0{\cdot}96 \times 10^6$ to $2{\cdot}56 \times 10^6$ W/m².

Since the reproducibility of the tests was satisfactory only two out of numerous test measurements were plotted in Figs. 3 and 4.

When we attempt to represent the values by a straight line in a double logarithmic plot, such as

$$q = c(\Delta T)^n \quad \text{and} \quad h = q/\Delta T$$

with the constants c and n, we obtain, by using the Gauss method of smallest squares, the following:

$$q = 423{\cdot}4 \times \Delta T^{1{\cdot}235}$$

$$h = 423{\cdot}4 \times \Delta T^{0{\cdot}235}$$

with the units as given in the nomenclature.

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Résumé—Les coefficients de transmission de chaleur de 8×10^3 jusqu'à 2×10^5 W/m² degC de l'ébullition nucléée et l'ébullition de film dans l'eau distillée surfondue et bouillante sont donnés. Une équation algébrique de nombre pour des valeurs de l'ébullition de film est inclue. Les résultats de transmission de chaleur étaient reçus par un simple fil de chauffe de nickel. L'appareil utilisé et une méthode à recevoir très simplement d'ébullition de film sont décrits.

Zusammenfassung—Die Wärmeübergangskoeffizienten von 8×10^3 bis 2×10^5 W/m² degC für Blasen- und Filmverdampfung in unterkühltem und kochendem, destilliertem Wasser wurden gemessen. Eine Zahlenwertgleichung für Werte der Filmverdampfung wird angegeben. Die Resultate wurden mit einem einfachen, elektrisch geheizten Nickeldraht erhalten. Eine kurze Beschreibung der Versuchseinrichtung und eine Methode zur leichten Herstellung von Filmverdampfung wird gegeben.

Аннотация—В статье даются значения коэффициентов переноса тепла от 8×10^3 до 2×10^5 ватт/м² °С для пузырькового и пленочного кипения дистиллированной воды, недогретой до точки кипения и кипящей. Приводится алгебраическое уравнение для численного расчета пленочного кипения. Получены данные о переносе тепла от электрически нагретой никелевой проволоки. Кратко даны описания экспериментальной установки и простого метода получения пленочного кипения.