CRITICAL HEAT FLUXES IN THE BOILING OF ETHANOL AT FLOW SPEEDS OF 50 TO 115 m/sec

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Experimental results are given on the critical heat fluxes for flows of ethanol between 40 and 65 t/m^2-sec and temperature differences corresponding to the conditions for normal boiling crises. The results agree with theoretical calculations.

Theoretical formulas are available for the two limiting cases of boiling in a liquid heated to the saturation temperature (see [1], ch. 8):

$$\frac{q_0}{r\sqrt{\rho''}\,(g^2\sigma(\rho'-\rho''))^{1/4}} = k \approx 0.14 \qquad (1)$$

for $w \to 0$,

$$\frac{q_0}{rw\sqrt{\rho\rho''}} = k_* \approx 0.34c_f \quad \text{for } w \to \infty. \qquad (2)$$

Tests have been done [2] on the boiling of ethanol in tubes at values of the dimensionless speed

$$W = w\left(\frac{\rho^2}{g^2\sigma(\rho'-\rho'')}\right)^{1/4} < 600$$

and for temperature differences at the axis of the flow relative to the saturation point of

$$0 < [(i'-i)/r]\sqrt{\rho/\rho''} < 2,$$

the results being described by a linear interpolation formula:

$$q_0 = \{1 + [(i'-i)/r]\sqrt{\rho/\rho''}\}\times$$
$$\times[0.34c_f rw\sqrt{\rho''\rho} + 0.14r\sqrt{\rho''}\,(g^2\sigma(\rho'-\rho''))^{1/4}] \qquad (3)$$

Here we give results for W > 600, which correspond to linear velocities greater than 50 m/sec for alcohol. The working solution was 96% rectified spirit. These high velocities required a new apparatus, which was made up as a loop constructed of 1Cr18Ni9Ti stainless-steel tubes.

The circulation was provided by two three-piston pumps in parallel, which produced pressures up to 300 bar at 1000 cm^3/sec. The alcohol passed through a high-pressure filter and a regulator to an accessory heater, where it was brought to the required temperature. After this, it passed in sequence through the experimental section, a mixer, and a cooler, being brought to room temperature in the last. From there it passed through control valves to a tank, from which it was drawn through a filter by a centrifugal pump for passage to the main pumps. This centrifugal pump provided the pressure of 2.5 bar necessary for normal operation of the high-pressure pumps.

The tests were done with a tube having an inside diameter of 3 mm, a heated length of 45 mm, and a wall thickness of 0.5 mm. The region of hydrodynamic stabilization was 30 mm long. The power sup-

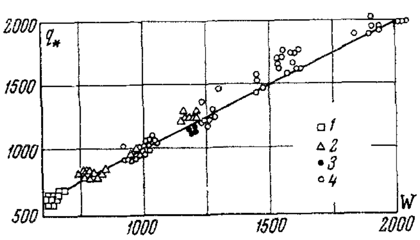

Fig. 1. 1) P = 20 bar, 2) P = 30 bar, 3) P = 40 bar, 4) P = 45 bar.

plied to the heated part was measured by a class 0.2 wattmeter attached to instrument transformers for current and voltage of the same class of accuracy.

The temperature, as averaged over the cross section, was measured past the heated section by chromel-alumel thermocouples in the mixer. The emfs were recorded with a R2/1 semiautomatic potentiometer.

Each series of runs was done with the flow rate and pressure held constant but the temperature variable. The critical heat flux was determined by slowly raising the power input to the heated section.

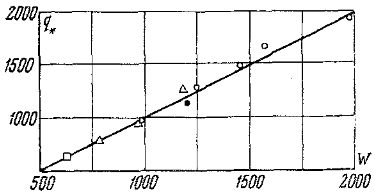

Fig. 2. Relation of average q_* to W.

Although bubble boiling occurred within the experimental tube, the outer surface became red-hot at heat fluxes of 20-30 mW/m^2 on account of large temperature differences across the wall. For this reason, the crisis could be detected only by instruments.

The onset of crisis was detected with a bridge, one arm being formed by the heated section and another by the rheostat, which were defined, respectively, by the point of attachment of the zero lead to the heated tube and by the position of the sliding contact on the rheostat. The bridge diagonal contained a meter in series with Ge diodes. The bridge was balanced before the onset of boiling in the heated part.

There were high pressure gradients in the flow direction, so boiling did not start simultaneously at all parts of the heated section; the uneven change in wall temperature therefore caused the needle of the galvanometer to deflect immediately after the onset of boiling. When the boiling had extended to the entire heated section, the needle returned to the zero position. Further increase in the input power caused superheating of the wall near the exit from the heated part, which produced a fresh deflection, which was recorded as the onset of crisis.

When the crisis at the exit occurred before boiling had extended to all of the heated part, the crisis was detected from the passage of the galvanometer needle through zero, because of temporary balancing arising from the increase in resistance in the exit section of the heated part.

The tests were run in series with constant pressures in the crisis section of 20, 30, 40, and 45 bar and flow rates of 40, 50, 60, and 65 tons/m^2-sec, with variable temperature differences from the saturation point, which corresponded to values of $[(i'-i)/r]\,(\rho/\rho'')^{1/2}$ from 0.3 to 2. These values correspond [3] to the conditions for normal boiling crises.

We measured not only the critical heat flux but also the hydraulic resistance of the heated part as a function of power input. It was found that the hydraulic-resistance coefficients in this range corresponded to the hydraulic-resistance coefficients for isothermal flow of a single-phase fluid in a smooth tube.

Figure 1 shows results for P of 20, 30, 40, and 45 bar (points 1-4, respectively), the ordinate being the dimensionless critical heat flux

$$q_* = \frac{0.41}{c_f}\,\frac{q_0}{[1+(i'-i)/r]\sqrt{\rho''}\,(g^2\sigma(\rho'-\rho''))^{1/4}}.$$

The straight line is derived from (3), in which the values for c_f correspond to the coefficient of friction for isothermal flow in a smooth tube. The maximum deviation of the observed points from the calculated line is 14%.

This graph makes it seem that the experimental points were unevenly distributed (many were coincident), so Fig. 2 shows the averaged q_* as a function of W. These averaged points are uniformly distributed along the straight line with a maximum deviation of 7%. The results thus show that (3) can be used to calculate critical heat fluxes for values of the dimensionless flow speed W from 600 to 2150 and for values of $[(i' - i)/r]\ (\rho/\rho")^{1/2}$ from 0.3 to 2.

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