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LETTERS TO THE EDITORS

ON METHODS OF STUDYING HEAT TRANSFER IN TRANSITION BOILING

THE REPORT by KOVALEV [1] deals with the stability of pool boiling and derives a stability criterion, equation (1), which serves as a basis for measurements in the transition boiling region. This stability criterion as well as the experimental method for measurements during transition boiling have already been presented in earlier papers [2, 3], which apparently were unknown to Kovalev. From the viewpoint of these publications the following remarks concerning the derivation of the stability criterion and some of the conclusions deduced by Kovalev seem appropriate.

1. As Kovalev illustrates a temporary change of surface temperature $\delta\theta_1$ gives rise to a change δq_2 of heat flux across the heating wall and to a change δq_1 of heat flux to the liquid. The further behaviour of the wall temperature is said to depend on the sign of $(q_1 + \delta q_1) - (q_2 + \delta q_2)$. If, for instance, $\delta\theta_1 > 0$ together with $(q_1 + \delta q_1) - (q_2 + \delta q_2) > 0$ then, according to Kovalev, a return to initial conditions is possible because the surface will cool off. Kovalev's suggestion apparently originates in the idea that in this example the surface temperature will decrease together with the internal energy of the heating element which here will decrease because $(q_1 + \delta q_1) - (q_2 + \delta q_2) > 0$. This explanation which may seem reasonable at first sight, is not sufficient for the derivation of a stability criterion. A decrease in internal energy of the heating element does not necessarily imply a decrease of its surface temperature. Any change of surface temperature is influenced not only by the behaviour of the heating element but also by that of the adjacent boiling liquid. It is quite imaginable that the boiling liquid enforces a rise of surface temperature while the internal energy of the heating element is decreasing. Therefore in an investigation of stability the transient behaviour of the boiling liquid may not be neglected as done by Kovalev.

One must principally differentiate between stationary and transient behaviour of the system. The stability of a system is governed by its transient behaviour. This follows directly from the following definition of stability by Franck [4]:

> A stationary state is considered stable if in its immediate vicinity there exist only such states from which the system will return of itself to the initial stationary state after any forced displacement.

When investigating stability, therefore, the capacitive properties of the boiling liquid and of the heating wall must be jointly considered. As we know, capacitive properties become relevant whenever there is a change of heat flux or temperature with time. Their effect is to counteract such changes by either a storage or a release of energy. A more general treatment of stability which includes transient behaviour of the boiling liquid can be found in one of the papers mentioned above [2].

2. From his results Kovalev infers that the region of maximum heat flux q_{max}, i.e. where the derivative $dq_1/d\theta_1$ has a maximum, is the most difficult to investigate. From the viewpoint of stability considerations, however, this is not correct. Stability demands that in the vicinity of a stationary point the reciprocal of the thermal resistance of the heating wall and of the heating medium be less than the reciprocal value of the resistance $d\theta_1/dq_1$ of the boiling liquid. A system is more stable against disturbances of wall temperature or of heat flux, the larger the difference between the reciprocals of these resistances. This difference is smallest at such points where the resistance $d\theta_1/dq_1$ reaches its maximum, i.e. where $dq_1/d\theta_1$ has a minimum. This does not occur at the point of maximum heat flux but rather at a point of inflection on the (q, θ)-curve in the region of transition boiling. This was also found in experiments so far carried out by the contributor. May this be confirmed by Fig. 1 which shows the (q, θ_1)-curve of R 114 boiling on the outside of a horizontal tube mounted inside a large vessel.

3. Commonly, for boiling in systems with fixed wall temperatures, condensing vapour is used as the heating medium. In order to measure in the transition region the vapour temperature must be raised up to 250–300°C, as was the case in the apparatus used by Kovalev, and with steam, pressures up to 100 bar must be coped with. This involves considerable experimental difficulties. A different method, designed to avoid these difficulties, was suggested in one of the mentioned papers [3, p. 115]. It is based on the fact that also in systems with electrical energy-supply, it is possible to obtain stable states, again with the requirement that in a stationary point the reciprocal of the thermal resistance of the heating element and of the heating liquid be less than the corresponding reciprocal of the transfer-resistance to the boiling liquid. In order to produce stable states in the transition region in spite of energy supply by electrical dissipation thermal resistance of the heating wall and that of the fluid flowing along this wall should be kept as low as possible [3, p. 115, section C]. If all the electrically inserted energy is to be transferred to the boiling liquid under stationary conditions, then, as indicated in Fig. 2, the temperature θ_f of the flowing fluid must coincide with the temperature θ_i at the adjacent surface of the wall. In the apparatus this is easily achieved by a simple automatic control which adjusts the fluid temperature so as to make the temperature difference $\theta_f - \theta_i$ vanish. Thereby the flowing fluid does not transfer energy to the heating element as long as a stationary state continues to exist. If however, there is a change $\delta\theta_1$ of wall temperature θ_1 due to some temporary disturbance, also θ_1 will change. The flowing fluid will now oppose such a deviation by some transfer of heat to or from the heating element. Consequently the fluid serves as a stabilizer. This

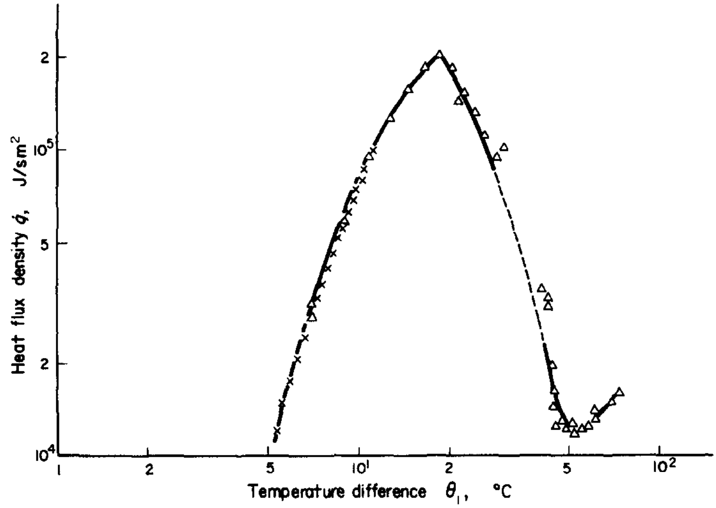

FIG. 1. Refrigerant 114 with stable boiling in transition region.

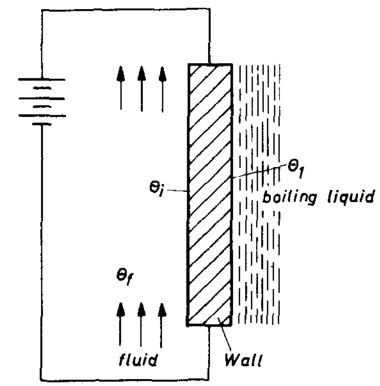

FIG. 2. Stable states with electrical energy supply. Experimental set-up.

method has the advantage of a simple and exact determination of the energy transferred to the boiling liquid by measurements of voltage and current. There is no need for high pressures as in the apparatus described by Kovalev. The measurements of Fig. 1 were obtained by method described above. A more detailed report is in preparation.

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