A Vote for Adiutori

In the May 1964 edition of Nucleonics you published an article on thermal stability (New theory of thermal stability in boiling systems by Eugene F. Adiutori, pp. 92–101) which gives rise to some remarkably adverse discussion (NUCLEONICS, Dec. '64, pp. 6, 7).

The essential point of the article is that thermal stability of a heated surface is a function of both the characteristics of the heat source and the heat sink. In particular, if the surface temperature is perturbed slightly by an increase ΔT, an unstable situation will occur if, as a result, the rates of heat removal and heat supply change in such a way that energy tends to accumulate at the surface and cause a magnification of ΔT and a large temperature excursion. For this situation the criterion for stability may be expressed mathematically as

$$\frac{\Delta Q_{\text{in}}}{\Delta T_{\text{surface}}} - \frac{\Delta Q_{\text{out}}}{\Delta T_{\text{surface}}} < 0$$

which is Mr. Adiutori's Eq. 9.

This conclusion is so simple and obvious that it is hard to see why it should have aroused any critical discussion. Furthermore, the applications for this theory are not negligible since one might be able, in a nuclear reactor for example, to operate in a transition boiling regime by designing a suitably negative temperature coefficient of reactivity for the fuel or by adjusting the heat transfer coefficient on the fuel side (e.g. by changing the cladding material and thickness).

Admittedly, some of Mr. Adiutori's remarks and actions have not made him a perfect candidate for a popularity contest, but this is irrelevant as far as an objective assessment of the main contention of his article is concerned.

To test Mr. Adiutori's theory, I have plotted in the graphs the transition boiling data that Berenson obtained.* The data fall into three groups depending on the surface finish and history of the heated wall. For the three cases, one can evaluate the maximum value of $(\Delta Q/\Delta T)_{\text{out}}$ observed by Berenson. Approximately, the results are

For n-pentane (runs 5–9):
-875 Btu/hr/ft²/°F
For carbon tetrachloride:
-800 Btu/hr/ft²/°F
For n-pentane (runs 4, 10, 17, 22, 23):
-780 Btu/hr/ft²/°F

Berenson's "run 5" is omitted on the graphs because the data as tabulated by him are not consistent with his own graphical representation, nor are they consistent within themselves, probably as a result of typographical misplacing of one column of the table.

To evaluate $(\Delta Q/\Delta T)_{\text{in}}$ several methods can be used. The first is to use Berenson's description of his apparatus.

* The apparatus used to obtain the data is described by P. J. Berenson in "Transition Boiling Heat Transfer from a Horizontal Surface," Technical Report No. 17, DSR project 7-8077, Massachusetts Institute of Technology (1960).

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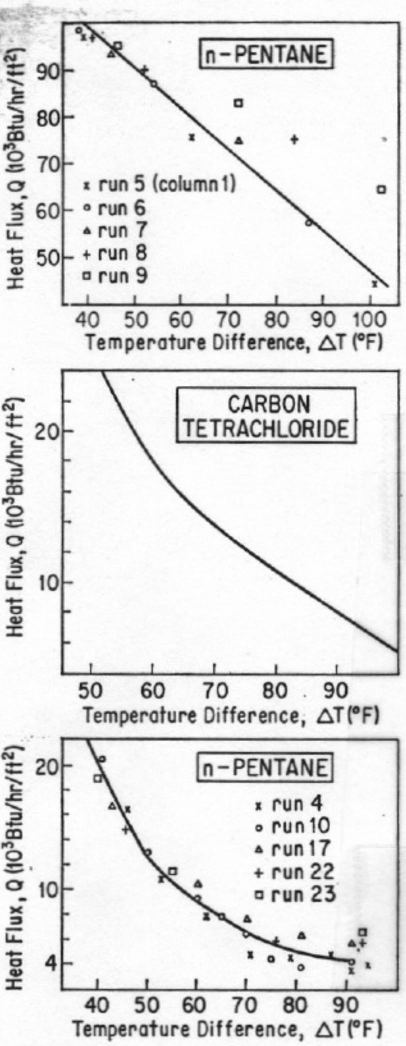

BERENSON'S transition boiling data

The heat source was water condensing on a copper surface covered with many long fins. The heat was then transferred through 2¼ in. of copper to the surface at which boiling took place. Under these conditions the condensing heat-transfer coefficient would be expected to be several thousand Btu/hr/ft²/°F. Assuming pure copper with a conductivity of 220 Btu/hr/ft²/°F, the heat-transfer coefficient across the copper is found to be

$$\frac{220 \times 12}{2.25} \approx 1{,}200 \text{ Btu/hr/ft}^2/^\circ\text{F}$$

The net heat-transfer coefficient would be reduced slightly by the condensing resistance, say to 1,000 Btu/hr/ft²/°F. This is equal to minus $(\Delta Q/\Delta T)_{in}$.

Another way to proceed, since the conductivity of Berenson's copper is unknown, is to use his own sample data calculation on pp. 73 and 74 of his article. The difference in reading between two thermocouples spaced 1⅛ in. apart on the center of the heat-transfer axis in the copper was 0.120 millivolts for a heat flux of 10,200 Btu/hr/ft² and a temperature of about 160°F. Referring to Berenson's thermocouple calibration at this temperature (his Table 1), it is found that the temperature difference corresponding to 0.12 mv is 4°F. Therefore the temperature drop across the entire copper block was 8°F and the heat-transfer coefficient $10{,}200/8 \approx 1{,}250$ Btu/hr/ft²/°F, which is consistent with the previous estimate. Allowing for two-dimensional effects in the copper and some contribution from the condensation resistance it can be seen that $(\Delta Q/\Delta T)_{in}$ is quite close to the three estimates of the maximum value of $(\Delta Q/\Delta T)_{out}$ that were derived from the graphs. Furthermore, since Berenson could only record stable data points, one would expect the magnitude of $(\Delta Q/\Delta T)_{out}$ to be always less than the absolute upper bound given by the magnitude of $(\Delta Q/\Delta T)_{in}$ (both are negative). This is confirmed by the three graphs.

It can be seen, therefore, that the limitation on Berenson's experiments is quite readily and consistently explained, both qualitatively and quantitively, by Adiutori's theory.

At present it is impossible to make use of the theory for reactor design because of the lack of knowledge about $(\Delta Q/\Delta T)_{out}$ on the boiling side of a reactor channel. To date no one has designed a forced-convection system to yield this information. Perhaps it might be worthwhile to try.

I am well aware that Adiutori's theory is not the answer to all aspects of burnout. However it is perfectly valid, if interpreted correctly, and may be useful.

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