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EXTENDED HYDRAULIC DEMAND CURVES FOR
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EXTENDED HYDRAULIC DEMAND CURVES FOR K GEOMETRY TUBES WITH I&E FUEL ELEMENTS

G. M. Hesson, D. E. Fitzsimmons, and M. F. Kanninen

PURPOSE

The purpose of this report is to present the latest laboratory data relating pressure drop and flow at various tube powers for a K process tube containing I&E fuel elements.

INTRODUCTION

One of the factors determining the maximum allowable outlet water temperature for K reactors is hydraulic instability. Unstable flow, which can lead to excessive fuel temperatures, is encountered under conditions of low flow or high power when the pumps can not supply flow at pressures demanded for steady state heat removal. The determination of conditions for hydraulic instability depends on a knowledge of the pumping characteristics (supply curves) and of the pressure drop in the process tube and fittings at different flows and tube powers (demand curves). This document is concerned only with demand curves as determined experimentally with use of the 189-D heat transfer apparatus. The data are an extension of those previously reported (1)* and differ in that higher tube powers were investigated and that the test section was more nearly prototypical.

SUMMARY

Steady state hydraulic demand curves were obtained for tube powers of 500, 1000, 1500 and 2000 KW with an inlet water temperature of 20°C and a rear header pressure of 25 psig. These curves are shown in Figure 1 and in a generalized form in Figure 2.

The point of initial unstable flow for various tube powers is shown in Figure 4 for a front header pressure of 325 psig. The flow rate that would lead to the initial point of unstable flow as a result of a sudden plug upstream of the Panellit tap is shown in Figure 5.

EXPERIMENTAL PROCEDURE

The experiments were performed on the electrically heated low pressure mock up located in the 189-D laboratory. The equipment was as described in HW-54329 (2) with the modifications as described in HW-56621 (1) except that the heated length was increased from 23.5 to 28.5 feet.

A series of test points were obtained for each tube power by first establishing a flow rate high enough to prevent boiling and then decreasing the flow rate by increments until, with one exception, the boiling burnout point was reached. (The 2000 KW experiment was terminated before boiling burnout conditions were reached because of the high pressures and temperatures incurred.) At the boiling burnout point, the flow and the tube power were increased and a new series of step reductions were started. At each test point, after steady state conditions had been reached, the flow rate and the tube inlet pressure were measured and recorded along with certain other temperatures and pressures.

Boiling burnout is the transition from the nucleate to the film boiling region and it is identified by a sudden rapid rising of the rod temperatures. When this phenomenon is observed during the experiment, the series of tests is immediately terminated to prevent damage to the test section.

* Numbers in parentheses refer to entries in the Bibliography.

For each tube power, one test point was obtained with the flow rate necessary to produce an outlet water temperature of 125°C. The data obtained at this flow rate, which is termed F*, formed the basis for generalizing the boiling curves.

DISCUSSION OF RESULTS

The experimental steady state boiling curves are presented in Figure 1 as plots of the tube inlet pressure versus the flow rate. With the exception of the 2000 KW curve, the terminal points are at conditions of start of film boiling. These terminal points are connected on Figure 1 to give a film boiling line. Operation in the region to the left of this line could result in very high fuel element temperatures. The terminal points were at quite severely reduced flows and were at conditions of gross steam generation. The conditions at the terminal experimental points for each tube power are listed in Table I.

TABLE I

<u>Tube Power, KW</u>	<u>Flow, GPM</u>	<u>Steam Quality, Weight Percent</u>	<u>Tube Inlet Pressure, PSIG</u>	<u>Pressure at end of Heated Section, PSIG</u>
500	4.9	46.1	152	93
1000	11.8	29.3	292	197
1500	19.8	17.9	394	281
2000*	34.7	3.1	424	281

*Not at burnout point.

A more informative method of presenting the data is with a generalized plot. This is done in Figure 2, which is a plot of the generalized Panellit pressure as a function of the square of the generalized flow. The generalizing technique is outlined in HW-42469 C (3). The square of the generalized flow is used because doing so yields straight lines for conditions where boiling does not exist. Figure 3 is a cross plot of Figure 2 and can be used to interpolate between the tube powers experimentally used.

The generalized boiling curves are useful to identify the magnitude of flow reductions which might lead to fuel element melting. They also permit an estimate of the course of Panellit pressures during such flow reductions, and, consequently, a crude estimate of the degree of protection offered by the Panellit system.

The method of identifying the flow reduction which could lead to fuel element melting is illustrated in Figure 6. A supply curve is constructed which is just tangent to the boiling curve. A front header pressure of 325 psig was assumed in this case. A slow plugging incident upstream of the Panellit tap would result in a gradual transition of the supply curve from its normal position to the tangent position. During the course of the plugging incident, the operating points would be the intersections of the slowly changing supply curve and the demand curve. A slight reduction from that giving the tangent point would no longer give an operating point, and the flow would decrease and the pressure increase along the supply curve to a new operating point at a very low flow. This self-induced flow reduction is known as unstable flow. The new point is not shown on Figure 6, but it would be in the film boiling region and fuel element melting might be expected to occur. The flow at the point of tangency, then, is the minimum flow with which a tube can be operated with stable conditions for the given supply curve. These flows were determined for the experimental tube powers and

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plotted in Figure 4. At tube powers less than about 800 KW, the boiling curves exhibit but little pressurization. In these cases, the boiling curve lies below the supply curve; no tangency point exists, and unstable flow will not occur. This is indicated in Figure 4 by a dotted horizontal line at low tube powers.

If the plugging incident were sudden, the outlet water temperatures immediately after the plug would still be at its temperature prior to the flow reduction. In this case, a temporary operating point would be established at the intersection of the extension of the supply curve and the non-boiling demand curve. Then, as the water heats, the flow and pressure would follow the supply curve up to establish the operating point on the demand curve. The flow at the intersection of the tangent supply curve gives the minimum flow after a sudden upstream plugging incident which will not result in unstable flow. These flows are plotted in Figure 5. Since unstable flow cannot occur at tube powers less than about 800 KW, this region is indicated by a horizontal dotted line in Figure 5. A similar analysis for cases of plugs downstream of the Panellit tap would yield unstable flow values about the same as these determined for upstream plugs.

These data are consistent with those obtained earlier with a test section which had a heated section shorter than the active section of a K reactor. The boiling curves from these tests did exhibit one peculiarity. As may be seen in Figures 1 and 2, the boiling curves have a bump upwards at flows a little less than that to give the minimum point on the curve. These bumps arose from an increased pressure drop across the heated section, even though there was no bulk boiling. The reason for this is not known, but it is undoubtedly due to some local boiling phenomenon.

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3. HW-42469 C, Technical Note on Generalization of Boiling Curves, L. H. McEwen, J. M. Batch, and K. G. Toyoda, April 18, 1956. (Secret)

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Figure 7

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Boiling Curves for K Reactors

inlet water temp $\approx 20^{\circ}\text{C}$ 25 psig Rear Header

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Figure

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Generalized Boiling Curves - K Reactors

Crossplot of Generalized Boiling Curves for K Reactors

Figure -9-

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Initial Unstable Flow vs Tube Power

K Geometry

325 psig Front header pressure

Inlet water temp. $\approx 20^{\circ}\text{C}$

25 psig Rear header pressure

Tube Power vs Fast Upstream Plugged Flow WHICH Leads to Unstable Flow

K Geometry

325 psig Front header pressure

inlet water temp $\approx 20^{\circ}\text{C}$

25 psig rear header pressure

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Figure 1

Generalized Boiling Curve for
K Reactor at 2000 Kw Power
20°C inlet water temp 25 psig rear header pressure

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