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HYDRAULIC DEMAND CURVES FOR B.J.F. GEOMETRY
WITH ENLARGED OUTLET FITTINGS - 25 PSIG REAR HEADER PRESSURE

E. D. Waters and D. E. Fitzsimmons

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HYDRAULIC DEMAND CURVES FOR BDF GEOMETRY
WITH ENLARGED OUTLET FITTINGS - 25 PSIG REAR HEADER PRESSURE

PURPOSE

The purpose of this report is to present steady state hydraulic demand data for a BDF type process assembly with specific enlarged outlet fittings and to compare these data with previous correlations of hydraulic demand for a BDF assembly with standard outlet fittings.

INTRODUCTION

Current IPD production increase (plant expansion) studies generally include the possibility of increasing reactor power levels by increasing the coolant flow rate through the reactors. One method of increasing the coolant flow rate is to lower the flow resistance of the individual process tube outlet fittings by reaming the inside diameter of the present fittings and/or by providing new enlarged flow area fittings.

The possible flow rate gains under normal operating conditions have been studied for individual tubes with various enlarged outlet fittings (1)(2)(3)*. While increasing the size of the outlet fittings would not always lead to optimum reactor operation based on heat transfer considerations, it appears that production gains may be possible by increasing the size of the present fittings on the BDF type reactors.

The flow characteristics of the present fittings result in some degree of pressurization to suppress boiling on the fuel charge and also result in dual Panellit trip protection for certain flow changes and power surges. The effect of enlarged fittings on pressurization and Panellit trip protection must be determined in two steps on the 189-D Heat Transfer Apparatus of the Thermal Hydraulics Operation. First, the hydraulic demand characteristics of the process tube and outlet assembly are determined under steady state operation at constant power for various flow rates. Second, pressure and temperature data are recorded during a transient flow reduction and subsequent power level reduction. Analysis of the combination of these data allows the establishment of maximum outlet water temperature limits such that safe reactor shutdowns are assured for most cases of flow reductions and/or power increases. These limits are commonly called "Trip after Instability" Limits (TAI). The data of this report are of the steady-state demand type. The outlet fitting assembly which was used represents what may be a maximum reasonable enlargement of the present fittings from a mechanical strength standpoint; at least, larger outlet fittings would probably require complete replacement of the rear cross header adapter fittings.

* Numbers in parentheses refer to entries in the Bibliography.

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SUMMARY AND CONCLUSIONS

Steady state hydraulic demand data were obtained for various tube powers ranging from 475 KW to 1700 KW with inlet water temperatures of 17 to 20 C, a rear header pressure of 25 psig, and using a heater rod which simulates a normal charge of O-II I&E fuel elements. For each tube power, the run was terminated when a condition of film boiling was detected by large increases in heater rod temperature readings at some point along the heated section. Tube inlet pressures versus flow rate data are shown on Figure 1. These data are normalized to a (Panellit) pressure of 225 psig at 125 C outlet temperature and presented on Figure 2. The data for a 950 KW tube are compared with the "calculated boiling curve" and with previous data for a standard BDF tube and outlet assembly on Figure 3.

From the data obtained, the following conclusions are drawn:

- (1) The hydraulic demand curves for the enlarged outlet fittings exhibit less pressurization than for the present type BDF outlet fittings, but they exhibit more pressurization than curves for standard K reactor geometry.
- (2) A firm knowledge of protection against plugging incidents requires transient experimentation. However, experience with transient data for standard BDF and K reactor assemblies combined with the steady-state data for the new assembly leads to the preliminary conclusion that the present methods of establishing outlet temperature limits would adequately protect the reactor against plugging incidents while using these enlarged outlet fittings.
- (3) Panellit "high trip backup" protection does not exist at tube powers below about 700 KW per tube for initial Panellit pressures of 225 psig with the enlarged outlet fittings.
- (4) An unstable flow point does not exist for tube powers below about 1100 KW with a front cross header pressure of 550 psig.

EXPERIMENTAL PROCEDURE

The experiments were conducted with the 189-D Heat Transfer Apparatus which is a prototypical mockup of a single reactor process channel with nuclear heat being simulated by d.c. electrical heating in a metal "rod". The "heater rod" used for the current experiments had outside and inside diameters equivalent to those of O-II-N I&E fuel elements and had a heated length of 23.5 feet. Holes were drilled through the wall of the "rod" to allow simulated interjunction flow which can occur in the reactors at the fuel element junctions. "Heater rod" materials were varied along the rod length to give a stepped cosine power distribution with a peak power to average power ratio of 1.39.

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The process tube outlet fitting assembly used in the present experiments was the same as that described as Assembly J, Table I of HW-63756 1. It consisted of the following: (1) a standard K reactor rear nozzle assembly, (2) a K nozzle outlet fitting (0.870" ID), (3) a 1" OD x 0.860" ID J-shaped pigtail, (4) a cast bronze Y pigtail-to-header fitting adapter (0.650" ID discharge), and (5) a standard BDF header Parker fitting which had been reamed to 0.650" ID. This assembly probably represents a maximum enlargement of outlet fittings without replacement of the existing Parker fittings.

A series of data points was obtained for each tube power by beginning with a high flow rate to prevent boiling in the assembly and then decreasing the flow rate through the process assembly by small increments until the boiling burnout point was imminent. (This condition was indicated by a rapid rising of the heater rod metal temperatures with a small flow reduction. When this condition was observed, the particular experiment was terminated to prevent damage of the test assembly.) At each data point, the various temperatures, pressures, and flow rates were read for steady-state operation after changing the flow rate. Rear cross-header pressure for the recirculation system was maintained at 25 psig by an air loaded pressurizer tank riding the pump suction line. For each tube power, one data point was obtained with the flow rate just sufficient to produce an outlet water temperature of 125 C. The data obtained at this flow rate, which is termed F^* , formed the basis for normalizing the hydraulic demand curves.

DISCUSSION

Experimental data are shown on Figure 1 as tube inlet pressure versus flow rate with tube power as the parameter. The terminal points at the left represent conditions where a transition from nucleate to film boiling was indicated by large increases in "heater rod" metal temperatures. Operation in the region to the left of these terminal points could result in excessively high fuel element temperatures and thus cause fuel element meltdown. These terminal points were at severely reduced flow rates and were at conditions sufficient to give bulk steam generation at the end of the heated section as indicated by the following data:

<u>Tube Power</u> <u>KW</u>	<u>Flow Rate</u> <u>GPM</u>	<u>Tube Inlet</u> <u>Pressure</u> <u>PSIG</u>	<u>Pressure at End</u> <u>of Heated Length</u> <u>PSIG</u>	<u>Steam Quality at</u> <u>End of Heated Section</u> <u>Weight per cent</u>
475	4.6	205	123	47.5
710	7.4	307	195	39.2
950	11.0	407	247	29.1
1430	19.5	566	373	14.2
1700	24.4	629	412	9.9

In all cases the film boiling was first indicated by a thermocouple located 2'3" from the downstream end of the 23.5 foot heated length.

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By use of the generalizing technique discussed in HW-42469 C (4), the data for various tube powers may be reduced to a condition of equal upstream (Panellit) pressure at a flow rate which results in a tube outlet temperature of 125 C. This method of presenting the data is shown in Figure 2. These generalized plots allow determination of the course of Panellit pressures during certain plugging or flow reduction occurrences. Hence, they allow an estimate of the degree of protection offered by the Panellit system. Since the technique of generalizing data is well documented (4)(5) and there are examples of use of the generalized curves in determining the course of Panellit pressure during a plugging event (5)(6), the remainder of this discussion will be limited to the most prominent characteristics of the new data.

On Figure 3, generalized data are compared for the new enlarged outlet fitting assembly, the standard BDF assembly, a standard K reactor assembly, and the usual empirically determined hydraulic demand curve (as discussed in HW-53379). One sees that the data for the enlarged outlet fittings fall between that for K reactor and that for BDF reactor with a standard 0.469" ID cross header Parker fitting. Both the new data for enlarged fittings and the data for the K reactor assembly follow the "empirical" hydraulic demand curve reasonably well. The data for standard BDF fittings are for solid fuel elements; however, the generalizing technique would eliminate the effect of this. The reason that the data for the standard BDF fittings fall above the "empirical" curve must be due to the losses associated with the severe critical flow condition which exists in the small diameter Parker fitting and/or increased pressure drops due to local boiling in the heated section with the higher heat flux associated with the solid fuel elements.

By drawing supply curves on Figure 2, one can investigate the unstable flow point for the various tube powers. A supply curve was drawn for a front header pressure of 550 psig and for a tube power of 1430 KW to illustrate the unstable flow point for this tube power during a slow plug incident. Drawing various supply curves from 550 psig front header pressure for the 950 KW case, one finds there is no unstable flow point for this tube power. A slow plugging occurrence to a flow squared ratio of 0.105 would result in a film boiling condition without ever going through a point of unstable flow. Such information is presented on Figure 4 to show the flow rates for various tube powers which will result in either unstable flow or film boiling during slow or fast plugging occurrences. This figure further illustrates the absences of an unstable flow point for low tube powers with a front header pressure of 550 psig.

Again referring to Figure 2 and drawing a line of constant Panellit pressure, it is apparent that Panellit high trip back-up protection during a plugging occurrence is not assured for tube powers less than about 700 KW with a Panellit trip span of 80 psi. Previous experiments with a standard BDF outlet assembly were not carried to low enough flow rates to accurately determine the lower tube power limit which would assure high trip back-up. It is estimated to be about 400 KW. Experimental data (6) indicate that high trip back-up does not exist for K reactor with tube powers less than about 900 KW with a trip span of 80 psi (initial Panellit pressure - 180 psig).

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Although the steady-state data of this report allow determination of suitable Panellit trip limits or allow the determination of Panellit trip assurance with given limits, these data do not give any information concerning the time interval between a flow reduction and Panellit trip or between flow reduction and fuel element damage. Such information can only come from transient type experiments. However, sufficient experience has been gained in the transient experiments with standard BDF, K, and C reactor geometries to indicate that the enlarged BDF outlet fitting assemblies will not be limiting in the transient response respect. There is sufficient confidence in this experience to postpone transient response tests at least until a more firm choice of enlarged outlet fittings has been made, based on mechanical evaluation and water plant capacity considerations.

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Figure 1

Steady-state Hydraulic Demand Data - BDF With Enlarged Rear Fittings

Basis: Inlet water temperature = 17 to 20 C
 Rear header pressure = 25 psig
 O-II I&E fuel pieces (simulated)

Figure 2

Generalized Steady-state Hydraulic Demand -
BDF With Enlarged Rear Fittings

Basis: F^* = flow rate to give 125 C outlet temperature
 F = flow for data point
 Inlet water temperature = 17 to 20 C
 Rear header pressure = 25 psig
 O-II I&E fuel pieces (simulated)

Figure 3

Comparison of Generalized Data For Various Geometries

Basis: F* = flow rate to give 125 C outlet temperature

F = flow rate for data point

Rear header pressure = 25 psig

All curves for 1000 KW tube power (approximate)

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Figure 4

Flow Rates for Unstable Flow or Film Boiling
BDF With Enlarged Rear Fittings

Basis: Front header pressure = 550 psig
 Inlet water temperature = 17 to 20 C
 O-II I&E fuel pieces (simulated)

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