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TITLE

LABORATORY DETERMINATION OF NORMAL
OPERATING FLOW RATES WITH ENLARGED
OUTLET FITTINGS - BDP REACTORS

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February 2, 1960

LABORATORY DETERMINATION OF NORMAL OPERATING FLOW RATES
WITH ENLARGED OUTLET FITTINGS - EDF REACTORS

By E. D. Waters

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LABORATORY DETERMINATION OF NORMAL OPERATING FLOW RATES
WITH ENLARGED OUTLET FITTINGS - BDF REACTORS

INTRODUCTION

By examination of the pressure profile from front header to rear header of a standard BDF reactor process channel, one finds the following relative energy losses (pressure drop) across the various segments of the channel. About 14 per cent of the energy loss occurs in the inlet fittings; 59 per cent of the energy loss occurs along the active fuel charge and 27 per cent of the total loss occurs in outlet fittings. The inlet fittings contain a flow monitor device with which there is necessarily associated some loss. This loss cannot be begrudged, and for the necessary peculiar geometry on the reactor, the loss probably cannot be reduced materially. The energy loss along the fuel charge is expended in creating turbulence which is necessary to effect adequate heat transfer rates from the fuel to the coolant.

There is also value in having some pressure drop in the outlet fittings, although this is not generally realized by persons other than those closely associated with establishing outlet water temperature limits. Therefore, in most studies involving increased flow rates or more efficient pumping methods, efforts are concentrated on reducing the losses in the outlet fittings. While increasing the size of the outlet fittings would not always lead to optimum reactor operation based on heat transfer consideration, it appears that production gains may be possible by increasing the size of the outmoded outlet fittings on the BDF type reactors.

Experiments have been conducted in the Hydraulics Laboratory, at the request of IPD's Mechanical Development-A Operation, to determine the energy losses of various enlarged outlet fitting combinations. These experiments were conducted as steady state runs and allow the determination of the normal operating point (flow rate) of a reactor process channel under selected conditions of front header pressure and fuel charge. No attempt is made to make a mechanical or economic evaluation of the particular fitting combinations, although observations were noted which might bear on this evaluation.

By arrangement of Mechanical Development-A, vibration data were obtained for two of the outlet fitting combinations by P. H. Hutton of Reactor Plant Engineering - IPD. These data, which will be reported separately by Mr. Hutton, should be useful in making a mechanical evaluation of the various outlet fitting assemblies.

It is very important for the reader to bear in mind that changing outlet fittings will definitely affect the reactor tube power limits and outlet water temperature limits. The size of the outlet fittings largely determines the present outlet temperature limits of the old reactors. The flow characteristics of these present fittings cause some degree of pressurization to suppress boiling on the fuel charge and also cause dual Panellit trip protection for certain flow changes and for power surges. Enlargement of the outlet fittings may actually reduce the allowable outlet coolant temperature limits. Since these effects cannot be determined on the apparatus used in these experiments, a complete discussion of this point is not included in this report. However, the seriousness of these effects should be known and carefully analyzed before a final selection of enlarged outlet fittings is made.

This report will be one of a series. New reports in the series will be issued as data are obtained for other such outlet fitting combinations or for new concepts of outlet fitting assemblies such as the new nozzle being developed by C. E. Frantz for use on F-reactor stuck gunbarrel tubes.

The data in this report are directly applicable to B, D, and F reactor outlet assemblies. The data may be used in studies for DR reactor without appreciable error since there is only a very slight difference in the rear header (Parker) fitting for DR. The H-reactor outlet water assembly is significantly different from BDF assemblies and has widely different flow characteristics. Hence, the data of this report would not be applicable to H-reactor studies unless the header (Parker) fittings were completely replaced.

SUMMARY

Data are presented on Figures 1, 2 and 3 to show the flow characteristics of various outlet fitting assemblies with enlarged flow areas as compared to the old-style helical pigtail and outlet nozzle assembly. These data allow the prediction of the normal operating flow rates for these assemblies. Using typical supply curve characteristics for the present BDF reactors with I&E fuel elements in a ribbed tube, the enlarged fittings which were studied will result in normal operating flows up to 15 per cent greater than the present helical outlet assembly. This information is presented in Table I, page 10. These data are for single tube operating point only (i.e., constant front header pressure). Studies of plant expansion must therefore consider the change in front header pressure with total reactor flow.

The discussion in this report does not attempt an economic or mechanical evaluation of the enlarged fitting assemblies studied. However, observations were noted which indicate that the present flare type adapter fittings may not be useful if they are reamed to very large diameters since the flare is then easily crushed.

It is pointed out in this report that the flow characteristics of the outlet fittings materially affect the permissible operating limits of a reactor process channel. Determination of those limits for any particular assembly will probably require experimentation on the electrical heat transfer apparatus.

DESCRIPTION OF THE EQUIPMENT

The experiments were conducted on the process tube mock-up in 189-D. A single tube header-to-header prototype of a BDF process coolant channel was used. The charge consisted of a dummy loading of heavy metal fuel and a standard downstream support charge (three 8-inch expendables, nine 8-inch tubulars or perfs, one 5-inch perf and two 8-inch perfs - front to rear).

Water temperature was measured at the outlet of the heat exchanger (the heat source) and at the end-of-the active-charge, EOAC, which was a point one inch upstream of the junction between the active fuel and the support charge. Pressures were measured at the EOAC and at the rear header as well as intermediate points which could be conveniently fitted with a pressure tap such as rear nozzle barrel and in some cases the pigtail-to-header Y-fitting or slip-nut adapter.

The individual components of the assemblies which were tested are described in Table I, page 10. In general they consisted of the following: 1) a rear nozzle, 2) a nozzle outlet adapter fitting, 3) a pigtail, 4) a pigtail-to-header adapter and 5) a cross header (Parker) fitting which is attached to the rear cross header. The rear nozzles were the standard BDF components except in one case a K rear nozzle was used and in two other cases the standard BDF nozzle was re-bored in the outlet water channel. Standard BDF nozzle outlet fittings were used except in some cases these were re-bored to larger inside diameters. A special nozzle outlet adapter was made to allow use of a 1 inch OD pigtail with the standard BDF nozzle. The pigtails, with exception of the

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helical (DuPont) pigtail test, were J-shaped with an O-ring retainer welded to the downstream end. Such a pigtail is shown on H-1-11735 and is referred to as a J-2 pigtail.

For the J pigtails, two different types of pigtail-to-header adapters were used. One was the cast slip-joint Y-fitting with a 30° convergence taper to the header fitting inlet as shown on H-1-11736 Rev0. The other was the straight slip-joint adapter fitting with a 11° convergence taper to the header fitting inlet (H-1-12091). The downstream bore of these adapters was reamed to various sizes as indicated in the table. The cross-header (Parker) adapter fittings were standard shape and length. Four different bore sizes were used ranging from standard 15/32 (0.469) to 0.650. These fittings were then threaded on the outside to allow attachment to female threads in the wall of a specially fabricated section of "rear cross header". This arrangement allowed easy replacement of the cross header Parker fitting as required for the different component combinations.

DISCUSSION

Normal Operating Flow Rate

Each process flow channel from front cross header to rear cross header on a reactor is made up of many components ranging from inlet fittings to active fuel charge and outlet fittings. Each of these components helps determine the normal operating flow rate for this channel for a given set of conditions of header pressures and temperatures. With a constant supply (front header) pressure and a constant discharge (rear header) pressure, a point can be selected along the flow channel, and the usual supply and demand curves can be drawn for this point if the flow characteristics are known for the portion of the channel on either side of this point. Then the intersection of a supply curve and a demand curve will determine the normal operating flow rate for the channel.

For the present experiments the end-of-active-charge pressure, EOAC, was selected as the point for which to draw supply and demand curves. The supply curve is characterized by the front header pressure, the pressure loss in the inlet fittings, and the pressure loss across the active charge. The demand curves are characterized by the pressure loss across the downstream support charge, the pressure loss across the outlet fittings and the rear header pressure. The pressure loss across the active charge is influenced mildly by water temperature but the pressure loss across the outlet fittings is generally very strongly influenced by outlet water temperature because of critical flow (*) effects present in the EDF type outlet fittings.

Two supply curves were postulated for the present analysis as shown on Figure 1 using the supply curve conditions indicated on the figure. The curves represent two cases of using the present I&E fuel elements in ribbed Al tubes at different front header pressures. These two curves were calculated from previously obtained experimental data for the particular inlet fittings and fuel charges.

The demand curves on Figure 1 represent data obtained during the present experiments. These curves reflect the frictional energy losses and two phase or critical flow energy losses for the respective outlet fitting assemblies while passing water at a given temperature (110°C) to the rear header at a rear header pressure of 30 psig. The temperature and pressure conditions used will approximate the present actual operating conditions on the EDF type reactors and hence the intersection of a suitable supply curve with a demand curve would represent the normal operating point for the particular outlet assembly. A demand curve typical of a complete K reactor outlet assembly and

* Critical flow is defined as a condition of fluid flow through a closed duct wherein the mass flow rate is dependent upon the upstream pressure and temperature but is

rear header fitting is included for comparison purposes. Data points which are shaded indicate critical flow is present at that time while data points which are not shaded indicate non-critical conditions.

The normal operating flow rate was read from Figure 1 and tabulated in Table 1. Comparison was then made of the per cent increase in operating flow which would be achieved by use of any particular outlet assembly as compared to the present (helical pigtail) assembly.

Pressure Drop without Vaporization

Data were obtained and presented on Figure 2 to show the pressure drop across the outlet fitting assembly for high rear header pressures. It is well known that a great deal of the energy loss in the helical pigtail type outlet assembly, presently used on the BDF reactors, occurs because of vaporization and resultant two-phase and/or critical flow pressure drop. The velocity in the small diameter header Parker fitting is so high as to reduce the static pressure at that point to the vapor pressure of the liquid. By increasing the system pressure (as by increasing the rear header pressure), this vaporization could be prevented and the measured pressure drop across the individual tube outlet fittings would be less. Since there has been some study of pressurizing the rear cross headers, data were recorded for the various assemblies under conditions of high back pressure to prevent vaporization.

It is emphasized that a lower pressure drop with high system pressure does not always mean a lower pressure drop (lower demand pressure) for low system pressures, although this is generally so. For example, compare curves C and E on Figure 2 and also on Figure 1. Assembly E presents a lower pressure drop on Figure 2 for high system pressure but it presents a higher pressure drop (demand pressure) on Figure 1 for normal low system pressure (rear header pressure).

Pressure Profile in Outlet Fittings

Data are presented on Figure 3 to show the approximate distribution of losses through the outlet assemblies for a selected low rear header condition. The plot shows static pressure versus pressure tap location and thus is an approximate representation of losses because corrections for velocity head were not made. Also, the actual flow rate varied slightly from 50 gpm for some assemblies.

Notice that the pressure at the pigtail-to-header adapter is quite consistently affected by the inside diameter of the cross-header (Parker) fitting. Then also notice the effect of pigtail size by comparing such curves as C and D or H and M. Such a plot allows one to determine more closely the particular fitting which may be restrictive.

Mechanical Observations

During the course of the experiments there were occurrences which bear on the mechanical evaluation of the component assemblies. First, a cast Y-pigtail-to-header adapter (H-1-11736) of 0.650 inch ID failed during a run by fracturing the bronze near the downstream end where it was recessed for the hex nut retaining wire. This failure occurred during a heating cycle and was probably the result of binding during tube expansion. Second, the header (Parker) fittings and the nozzle outlet adapter fittings with 0.650 inch ID were very easily crushed on the flare end when tightening the mating component to them. The same thing occurred to a lesser extent for the 0.610 inch ID fitting with diameter reductions of 0.015 inch being sustained if extreme care were not exercised in tightening the mating components. It would appear that continued

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reliance on the flare type seal would be questionable if the fittings are reamed to these larger sizes since the mating flare causes the crushing and ID reductions.

General Considerations

Each supply curve on Figure 1 represents a given constant front header pressure. Likewise, the "% Flow Change" numbers in Table I which were taken from Figure 1 assume that the front header pressure remains constant for the various outlet assemblies. On actual reactor application, however, this may not be true. That is, if 2,000 tubes are equipped with enlarged outlet fittings, the total reactor flow would increase and result in a slightly reduced front header pressure as determined by the process pump characteristics. Thus, the total reactor flow would not increase as great a percentage as would be indicated for the single tube data in Table I. This effect would have to be factored in for plant expansion studies when using the data of this report.

When the normal reactor flow rate and operating header pressures have been determined by use of data such as presented in this report, a tentative outlet fitting assembly will have been selected. However, final acceptance of this assembly for full reactor usage will certainly require careful analysis and might require further experimentation with the electrical heat transfer apparatus. This is because the two-phase and critical flow characteristics of the outlet fittings during reactor transients determine, to a large extent, the allowable operating temperature and tube power limits. These transient flow characteristics cannot always be predicted with great accuracy for new geometries by analytical techniques and can be verified experimentally only by use of the high speed controls and high temperatures associated with electrical heating.

Experiments are presently being conducted with the electrical heat transfer equipment for an enlarged fitting assembly corresponding to Assembly J of Table I. This assembly was selected as a probable limiting case; any assembly selected for actual reactor use will probably fall between this case and the present outlet fitting assembly. The data from these preliminary experiments will be useful in establishing reactor outlet water temperature limits for use with the new assembly. The data can also be used for estimating the limits when using intermediate size assemblies.

E. D. Waters
Thermal Hydraulics Operation

E.D.Waters:ag

FIGURE 1 - DEMAND CURVES FOR VARIOUS OUTLET FITTING ASSEMBLIES

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Demand Curve Conditions:
 Outlet water temp. = 111°C
 Rear header pressure = 30 psig
 Shaded symbols indicate presence of critical flow conditions
 Letters refer to assemblies of Table I

Supply Curves:
 J4-C-II-M 1&2 Fuel Elements
 Average coolant temp. = 60°C
 CC-556 Front Fittings with 0.31C Venturi
 Front header pressure as indicated

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FIGURE 2 - ENERGY LOSSES WITH HIGH REAR HEADER PRESSURES

Conditions: Water temperature 10 to 17°C
Rear header pressure - about 100 psig
Non-critical flow
Letters refer to assemblies of Table I

FIGURE 3 - PRESSURE PROFILES

Conditions: Outlet water temperature = 110°C
 Rear header pressure = 14 psig
 Flow rate = 50 gpm (metered at 10°C)

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TABLE I

Outlet assembly	Crs-Hdr Fitting ID	Pigtail-to-Header Adapter ID	Pigtail & QD Inch	Nozzle Outlet Fitting ID	Rear Nozzle Assembly	Effect to Be Studied	Flow Change at 575 psig		Principal Restriction	Remarks
							Pa. Fig. 1	Crit flow in hdr P fitting		
A	0.469	0.500	0.937	0.469	Std HDP	J-assembly	1.5	"	"	30° taper to hdr P fitting
B	0.469	0.500	0.937	0.469	Std HDP	Enlgrd hdr fitting	4.9	"	"	Nozzle outlet fitting easily crushed
C	0.550	0.550	0.937	0.550	Std HDP	Enlarged header	8.8	"	"	
D	0.550	0.550	0.937	0.550 (tapered inlet)	Std HDP	Enlarged and pigtail		"	"	
E	0.469	0.500	0.937	0.469 (tapered inlet)	Std HDP	Enlarged pig-tail & nozzle outlet	4.4	"	"	Nozzle outlet fitting easily crushed
F	0.650	0.650	0.937	0.650	Std HDP	Enlgrd hdr fitting	4.1	"	"	Hdr fitting easily crushed
G	0.650	0.650	0.937	0.650 (t.inlet)	Std HDP	Enlgrd hdr fitting and pigtail	10.6	"	"	Fittings easily crushed
H	0.650	0.650	0.937	0.650	HDP w/hor-Changing nozzle	horizontal* bore	11.3	"	"	
I	0.650	0.650	1.20	0.650 (tapered to 1")	Same as H Larger pigtail above	water chan-nel 3/4"	12.0	"	"	
J	0.650	0.650	1.20	0.650 Std K	Std K	K nozzle	15.0	"	"	
K	0.610	0.610	0.937	0.610 (t.inlet)	Std HDP	Enlarged header and nozzle outlet	8.1	"	"	Very near critical flow at normal flow rate
L	0.610	0.610	0.937	0.610 (t.inlet)	Std HDP	Enlarged header & nozzle outlet	10.3	"	"	Very near critical flow at normal flow rate
M	0.650	0.650	0.937	0.610 (t.inlet)	Std HDP	Enlarged header & nozzle outlet	8.3	"	"	
N	0.469	0.498	0.937**	0.469	Std HDP	noel outlet fits Exit taper from pigtl-hdr adaptor	1.9	"	"	11° taper to header P. fitting
P	0.610	0.610	0.937**	0.610	Std HDP	Enlgrd hdr & noel outlet fittings	8.1	"	"	Very near critical flow
Q	1.125	0.870	0.870	0.870	Std K	Complete K out-let assembly	15.2	"	"	Comparison of complete K assembly

* The horizontal water channel of the HDP nozzle is normally 5/8" bore.

** The pigtail-to-header adapter for assemblies H and P was "in straight slip-on type rather than Y-fitting type. Vibration data were taken by P. H. Hutton for these two assemblies."

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