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NUMERICAL RESULTS OF PRODUCTION TEST IP-326-I,
"LOW-FLOW CALIBRATION TESTS AT B, D, F, AND H
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NUMERICAL RESULTS OF PRODUCTION TEST IP-326-I,
LOW-FLOW CALIBRATION TESTS AT B, D, F, AND H REACTORS

INTRODUCTION

Recent reviews of the last-ditch water backup system at the old reactors had shown that complete adequacy could not be demonstrated at all of the reactors under all conditions⁽¹⁾. However, these conclusions were based in part on conservative calculations using basic data with a sizeable amount of possible error. Subsequently, recommendations⁽¹⁾ were made to run several tests which would increase the accuracy of the basic data and thereby allow an increase in the demonstratable level of last-ditch water backup adequacy.

One of the sources of the aforementioned errors is in the low-flow region of the reactor hydraulic demand curves* where the last-ditch water backup system is operating. The usual method of drawing this reactor hydraulic demand curve is to obtain accurate data at normal high flows and then to extrapolate these data to lower flows by means of the following equation:

$$F^{1.85} = K \Delta P$$

where F = the total reactor flow,

ΔP = the frictional pressure drop through the pile (assumed to be the TORP minus the static head up to the free water surface level in the rear cross-over line or downcomer. All static head corrections used in this document were obtained from reference (4).

and K = a constant determined by substituting normal high flow and pressure data into the equation above and solving for K .

Unfortunately, this relation does not accurately describe the reactor hydraulic demand at low flows, and, in fact, becomes less accurate as the flow goes down. The inaccuracy in the low flow region of the reactor hydraulic demand curve resulting from the use of the above equation occurs because of the drop in the Reynolds number in the reactor flow passages as the flow goes down and corresponding changes in the friction factors which in turn change the exponent in the equation above. These hydraulic changes are discussed in more detail in reference (2).

The water supply capabilities of the last-ditch system are normally measured with a tripout test where reactor riser pressures are recorded over a period of time while the reactor water supply is transferred to the last-ditch system. These riser pressure readings are then converted to reactor flows later by means of a reactor hydraulic demand curve, so the inaccuracy in the low-flow region of these curves result in an inaccurate assessment of the water flow obtained from the last-ditch system during the tripout test.

*The reactor hydraulic demand curve is constructed by plotting the total reactor flow vs. the total friction pressure drop through the reactor.

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A low-flow calibration test where reactor flows and pressure drops are accurately measured in the low-flow region was one of the recommended tests for increasing the accuracy of the data used to assess last-ditch water backup adequacy. A production test⁽³⁾ was written and approved to perform this test at the old reactors, and tests were subsequently run at D Reactor on 7/22/60 and 8/8/60, F Reactor on 9/1/60, B Reactor on 9/3/60, and H Reactor on 9/8/60. These tests were run by supplying water to the reactor from the high tanks and accurately measuring the change in water levels and riser pressures while all other water supply sources to the reactor were shut off. At the same time that this production test was being prepared, work was proceeding on procedures to descale the high tank discharge lines in order to increase the flow from the high tank to the reactor⁽⁵⁾. This work was recommended in reference (1) also because the increased high-tank flow obtained by descaling the high-tank discharge lines would increase last-ditch water backup adequacy. However, a test was needed to assess the actual increase in flow attainable from the descaling operation, so the low-flow calibration test was used for this purpose also. After the descaling work had been completed, the low-flow calibration test was run in two parts. The first part measured the unthrottled full flow capacity of the high tanks to the reactor; thus, data were obtained for calibrating the reactor hydraulic demand and for determining the increased flow available from the high tanks. In the second part of the low-flow calibration test, the discharge line from the high tank was throttled so the measured high-tank flow was about the same as or slightly below the flow that would be obtained from the export line. These two calibration points therefore covered the range of flow where the last-ditch system would be operating, and provided the most useful and accurate data for drawing reactor demand curves and assessing the adequacy of the last-ditch backup system.

An additional purpose of the production test⁽³⁾ was to obtain crossheader differential pressure data during the test that could be used to provide an accurate relation between crossheader ΔP readings and total reactor flow which would be useful during shutdowns.

The purpose of this document is to report the results of the aforementioned low-flow calibration tests at B, D, F, and H Reactors.

SUMMARY

Full high-tank flow and throttled high-tank flow data from the low-flow calibration tests at B and D Reactors were plotted on a graph of total reactor flow vs. total reactor friction pressure drop; curves were drawn through these data points and through normal high flow data as shown in Figures 1 and 2. A similar curve was drawn through H Reactor data except that the throttled high-tank flow data was not used and the lower part of the curve was drawn parallel to the D Reactor curve. The H Reactor throttled high tank low flow calibration data were not used in drawing a reactor hydraulic demand curve because one high tank was inadvertently shut off during this part of the test; therefore, this point would lie on a different reactor hydraulic demand curve (i.e., at the same flow more pressure will be required to supply the reactor from only one side of the reactor than would be required to supply the reactor normally from both sides because of the extra pressure drop through the front risers and crossheaders). A similar curve was drawn for F Reactor parallel to the D Reactor curve and through the F normal high-flow data. The F high tank low flow calibration data could not be used because there was an unknown flow contribution to the reactor

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from 190 building pumps. The experimental reactor hydraulic demand curves obtained as explained above and shown in Figures 1, 2, 3, and 4 are essentially the same as the old theoretical curves from high flow down to roughly 20,000 gpm; however, these experimental curves diverge from the theoretical curves further as the flow drops below 20,000 gpm. The maximum possible errors estimated in obtaining the experimental data were small ($\pm 2\%$ to $\pm 5\%$ of the reactor flow) at the full high tank flow test points, but were more significant ($\pm 7.5\%$ and $\pm 10\%$ of the reactor flow) at the throttled high tank flow test points. (See Table II). The probable errors, however, are considered by the author to be about half these figures. Top-of-riser pressure vs. total reactor flow curves were drawn for B, D, F, and H Reactors from the experimental reactor hydraulic demand curves obtained as described above. The static head corrections needed to convert total reactor friction pressure drops to TORP's were obtained from curves described in reference (4).

The high tank flow capabilities at B, D, F, and H Reactors have been increased by chemically cleaning the line between the reactor and the high tank to the amounts shown below. Calculations to account for differences in the high tank water levels, reactor outlet water temperatures, and possible errors in the data between the test conditions and those of an actual emergency situation resulted in the flows shown in the last column of the table below. It is recommended that these flows be used for assessing high tank water backup adequacy.

TABLE I

REACTOR HIGH-TANK FLOW CAPABILITIES WITH CLEAN
STRAINERS AND HIGH TANK DISCHARGE LINES

Reactor	Test Flow After Line Cleaning	Flow With Hi-Tank Water Level at Critical Point*	Flow With Reactor Bulk Outlet Temp. = 90°C	Maximum Possible Error in Data	Recommended Flow For Assessing Hi-Tank Backup Adequacy
B	9,600	9,900	10,100	$\pm 3\%$	9,800 9.7 (11.1)
D	10,100	10,600	10,800	$\pm 2\%$	10,600 10.6 (11.1)
F	10,000	10,400	10,600	$\pm 5\%$	10,000 10.0 (11.1)
H	11,900	12,300	12,600	$\pm 3\%$	12,200 12.0 (11.1)

Data from the crossheader differential pressure gauges taken during the test did not disclose any correlation of tube flow vs. reactor flow or crossheader ΔP vs. reactor flow that is any better than that already attainable from other data. In fact, the

*The critical point is determined as follows: After all electrical and steam supplies to an area are lost, the reactor will scram and flow to the reactor will drop (as the pump flywheels slow down) and finally be established from the high tanks only. Based on the reactor heat output following a scram, the required flow to prevent boiling in the pile can be calculated for any time after the scram. These required flows can be compared with the flows available from the flywheel energy decay and the last ditch water backup system in assessing backup adequacy, and the places where the required flows most closely approaches the available flows are critical points. For B, D, F and H Reactors, one of these points is about five minutes after the reactor scrams, when flow to the reactor from the high tanks has just been established. Calculations to obtain flows at the critical points are described in the Discussion.

D 12.8 12.6 12.1 (11.1)
C 15.2 15.0 14.2 (11.1)
11.1 10.0

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data from this test were scattered so badly that the author concluded that, although the crossheader ΔP gauges were calibrated just before each test, they were thrown out of calibration during the test. One crossheader ΔP data point indicated a tube or reactor flow which was too high by 30 to 57 per cent (i.e., based on available data, a curve of crossheader ΔP vs. total reactor flow can be drawn with varying degrees of accuracy. The throttled high tank flow data obtained in the second D Reactor test indicated that the total reactor flow was 4700 gpm and the crossheader ΔP reading was 46 inches of H_2O . From the aforementioned crossheader ΔP vs. reactor flow curve, a true crossheader ΔP of 46 inches of H_2O indicates a reactor flow of 3000 gpm to 3600 gpm.

DISCUSSION

A. Description of Test Procedure

Basically the test was performed by drawing down the high tanks while all other water supply sources to the reactor were shut off. As the drawdown proceeded, readings were taken at one minute intervals of the:

1. High tank water levels measured by Hg manometers installed at the base of the high tanks and calibrated in 16ths of an inch of Hg.
2. Reactor TORP's measured by accurate Wallace & Tiernan laboratory pressure gauges located at the top of the riser and calibrated in 10ths of an inch of Hg.
3. Reactor bulk inlet and outlet temperatures with the normal control room instrumentation.
4. Crossheader differential pressure readings on four different crossheaders (usually 38, 40, 44, and 46).

Two flow points were run in each test. The first point was at the maximum flow rate available from the high tanks and the second point was obtained by throttling the high tank discharge valves to obtain a flow of about 4000 gpm.

TABLE II
REACTOR LOW-FLOW CALIBRATION DATA

Total Flow GPM	Near TORP in PSIG	Far TORP in PSIG	Static Head Corr., TORP to Rear Cross Over in PSIG-From Ref. (4)	Avg. ΔP_f (TORP Minus Static Heat Corr.)	X-Hdr. ΔP in H ₂ O	Length of Test in Min.	Maximum Possible Error in % of Flow	Strainer ΔP in PSIG
	17.4	17.0	6.5	10.7	279	13	± 3	9
	8.2	9.4	6.2	2.4	54	35	± 10	1
	--	15.7	6.4	9.3	212	20	--	~ 5
	--	9.9	6.0	3.9	65	30	--	~ 1
	20.0	18.4	6.5	12.7	300+	17	± 2	8
	10.7	9.1	6.3	3.5	46	16	± 7.5	1(near) 3(far)
	21.4	20.1	6.5	14.2	300+	12	$\pm 5^{**}$	< 10
	12.6	11.7	6.3	5.8	100	7	--	1
	23.2	22.9	6.5	16.4	300+	12	± 3	6(near) 4(far)
	10.0	10.2	6.2	3.8	50	9	--	1

these tests obviously did not represent the total reactor flow because
ta. Investigations after the test revealed that some electric pumps
g against closed discharge valves, the valves were probably leaking.
er tests.

btained for full high tank flow to the reactor without the extra
Figure 3.

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C. Calculations

1. High-Tank Flow

The high-tank flow rates were obtained from measurements of the change in high-tank water level from the beginning of each test to the end. The total volume used was then calculated by assuming that the diameter of the tanks were correctly specified in their respective blueprint files (verified by actual measurements of the B and D tanks), subtracting the thickness of the steel shell plus 1/4 inch for scale, and making a simple right cylinder volume calculation. All measurements were made while the water level was on the straight side portion of the tank. The total volume used was then divided by the duration of the test in minutes in order to get the average flow rate that is shown in Table II above.

The full high-tank flow rate obtained could not be used for assessing high-tank backup adequacy because the test conditions were not the same as those that would be obtained in an actual emergency. Three factors were considered in converting the test flows to flows that would have been obtained under emergency conditions.

These were:

- a. The flow rate of water from the high tanks to the reactor will gradually decrease as the high tank drains; this occurs because the water level in the high tanks is going down with a subsequent drop in the static head driving force between the high tanks and the reactor. In each case the effective water levels at which the test flows were obtained were below the water level at the critical point about five minutes after the reactor scrams. (The critical point is defined in the summary). So, calculations were necessary to derive high-tank flows at the critical time and water level from the test flows at lower levels. These calculations were done using the standard equation:

$$F^{1.85} = K\Delta P$$

Where F = the flow to the reactor from the high tanks,

ΔP = the difference in elevation between the water level in the high tanks and the water level in the rear crossover,

and K = a constant determined by plugging the know values of F and ΔP from the test conditions into the above equation and solving for K

The ΔP at the critical time was obtained from the difference in water level in the high tanks at the critical time and the water level in the rear crossover. The ΔP at the critical time and the K so determined were then used in the above equation to solve for the flows at the critical time shown in column 3 of Table I.

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- b. During all test runs, the reactor bulk outlet temperature was about 20°C. During an actual emergency situation where the reactor bulk outlet temperature is increasing, the flow through the reactor from the high tank will be increasing because of the drop in flow resistance through the pile. 90°C is the temperature considered to be the point where boiling in the pile may start, so calculations were necessary to take advantage of the potential flow increase from the 20°C reactor test condition to the 90°C reactor emergency condition. This was done by first drawing a pump supply curve through the full high tank flow test point similar to that shown in Figure 3, for each reactor. A reactor demand curve at a 90°C bulk outlet temperature was then constructed for each reactor by drawing a curve parallel to the 20°C test curve with the distance from the 20°C test curve to the 90°C curve equal to the distance between the 20°C and 90°C curves in the theoretical treatment of reference (2). The intersection of the pump supply curve and the new 90°C reactor demand curve represented the flow which would be obtained in an emergency situation and which are listed in column 4 of Table I.
- c. There were four possible errors inherent in the data taken during the tests and in the calculations made afterwards. These were:
1. Errors in reading and measuring the water level in the tank (which accounts for about half the total error calculated for the full high tank flow test points).
 2. Errors in reading and measuring the riser pressures.
 3. Errors in timing.
 4. Errors in averaging the riser pressures (which accounts for most of the total error calculated for the throttled high tank flow test points). The author estimated the maximum possible error from his observations of the tests for each item listed above and added these errors together to get the total maximum possible errors listed in Table II. The probable errors are considered by the author to be about half these values.

Since the flow figures used to calculate high-tank backup adequacy must represent the minimum available, the flow figures in column 4, Table I were reduced by the estimated maximum possible percentage error in order to obtain the recommended flow figures in column 6.

2. Riser Pressures

Riser pressure readings were obtained in inches of mercury. These were converted to psi, and an elevation correction was made to obtain top-of-riser pressures (TORP's) as listed in Table II. In order to plot the actual friction pressure drop through the pile vs. flow, any static pressure on the pile must be removed from the riser pressure figures. This was done by means of curves obtained from reference (4) which gives the static head

correction from the TORP elevation to the free water surface elevation in the rear. Subtraction of this factor from TORP's will give the actual friction pressure drop through the pile.

3. Riser Pressure on Throttled High Tank Flow Test Points

The flow distribution between the near and far high tanks on the throttled high-tank flow test points during the B and D tests was not balanced as shown in Table II. The flow differences were so large that a simple averaging of the TORP's involved would not be theoretically correct. Unfortunately, no simple method of obtaining the correct or approximately correct TORP for balanced flow from unbalanced data is readily apparent. However, it is apparent qualitatively that at the same flow the pressure drop through the pile will increase with increasingly unbalanced flow due to the extra pressure drop through the front risers and crossheaders. (i.e., the extra pressure drop through the front risers and crossheaders resulting from increased flow on one side of the reactor is greater than the decrease in pressure drop on the other side due to a drop in flow.) This effect of increased total reactor pressure drop due to unbalanced flow is seen in the H throttled high tank flow test point where the flow from one high tank was accidentally shut off. In order to account for this effect partially, but still maintain a conservative estimate of flow at a particular ΔP_f , the TORP's from the B and D throttled high tank flow test points were averaged and then 0.1 psig was subtracted. This was checked as follows: First a reactor hydraulic demand curve was drawn from the test data similar to that shown in Figures 1 and 2 assuming that the averaging technique used above was correct. Then two high tank supply curves were drawn. Each curve represented the supply characteristic from one side of the reactor and intersected the reactor demand curve at the flow value corresponding to the test flow from one high tank. The two individual high tank supply curves were then added together; i.e., at a given ΔP_f the flow from one curve was added to the flow from the other curve to get a total flow which represented a point on a total high tank flow supply curve. Several points so obtained were used to draw a total high tank supply curve which was considered to represent a supply curve with TORP's equal on both sides. The total high tank supply curve so constructed intersected the reactor demand curve at the TORP assumed at the start (i.e., at 0.1 psig below the average TORP of both sides). This procedure roughly confirmed the original assumption.

4. Paralleling High Tank Discharge Line Strainers

One suggestion for improving high-tank flow capabilities has been to parallel both high-tank discharge line strainers in the flow stream, thereby reducing the pressure drop across the strainers. This idea was tested at F Reactor by paralleling both strainers in the flow stream at the end of the full high tank flow portion of the low flow calibration test long enough to obtain an accurate TORP. This TORP was compared to the TORP obtained just prior to repositioning the strainers, and by using the experimental reactor hydraulic demand curve obtained for F Reactor, a flow increase of 5-1/2 per cent was

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noted. This compares favorably with a seven per cent figure obtained in an earlier test⁽⁶⁾.

5. Crossheader Differential Pressure Data

The author made a number of calculations with the crossheader differential pressure gauges in trying to obtain an accurate calibration of gauge reading vs. total reactor flow. However, the data were scattered so badly no matter what adjustments were made that no correlation any better than that already obtainable from previous data could be made. There may be two reasons why this occurred. One would be that the pressure taps on the front and rear crossheaders are not located in the same place, side to side, on the reactor and that the effluent stream discharges into the downcomer at one side of the reactor. These arrangements would mean that the crossheader ΔP gauges are monitoring a ΔP which is not representative of the actual ΔP for an average tube on that crossheader. However, this effect should show up consistently in the data, and it did not. The second possibility is that although the gauges were calibrated prior to each test, they were knocked out of calibration on the full high tank flow portion of the test; this is not even supposed to happen at full reactor flow. After investigating all the crossheader ΔP data from the test and investigating recent reports of crossheader ΔP gauge calibration difficulties⁽⁷⁾, it was concluded that a rapid loss in the accuracy of the gauges was the most likely reason for the large scatter in the data.

Since no correlations of tube flow vs. reactor flow or crossheader ΔP vs. reactor flow were obtained which were any better than those attainable from other data, none of the curves plotted by the author were published.

6. Normal High Flow Data and Use of Experimental Curves

The normal high flow reactor data plotted in Figures 1, 2, 3, and 4 were obtained from the Process Engineers assigned to those reactors. A more accurate use of the experimental curves can be made by plotting all the data on graphs with greatly expanded scales and drawing curves through these data as the author did originally.

Process Engineering Unit
Process Technology Sub-Section
Research and Engineering

JL Benson:md

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Figure - I

ctor Hydraulic Demand at 20°C

⊙ Circled Points Represent
Experimental Test Data

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Figure - 2
Reactor Hydraulic Demand at 20 °C

⊙ Circled Points Represent
Experimental Test Data

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Figure - 3

or Hydraulic Demand at 20 °C

- ⊙ Circled Points Represent Experimental Test Data
- △ Points on High Tank Supply Curve
- Intersection of High Tank Supply Curve & Reactor Demand Curve

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Figure - 4
Hydraulic Demand at 20 °C

⊙ Circled Points Represent
Experimental Test Data

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