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ANALYSIS OF CMX HYDRAULIC DATA FOR THE MARK 22
(Unclassified)

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L. D. Koffman

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ABSTRACT

The original CMX hydraulic data for the Mark 22 assembly, obtained by L. W. Ridenhour in 1972, is analyzed and documented. Comparisons are made to Ridenhour's working notebooks and summary document, and to the Mark 22 hydraulics manual. Several errors in these documents are corrected. Correlations are given in a form suitable for revisions to the hydraulics manual.

The experimental setup and measurements are briefly described, and the original data is compiled in the appendix to this report. An error in the recorded length between channel pressure taps was found in Ridenhour's notebook. This error impacts the channel pressure drop correlations obtained by Ridenhour and used in the hydraulics manual.

The hydraulics of the two purge channels are analyzed based on the geometry of the orifices and on the limited data available. The limited data is shown to be in reasonable agreement with accepted orifice correlations. Purge channel correlations are given, and the purge channel flow splits are shown to be about 1.5% of the total flow.

Three methods for calculating the channel flow splits from channel pressure drop data are presented. Two of these methods were used by Ridenhour. A calculational error by Ridenhour led to incorrect determination of the flow splits by a small percentage. This error is corrected, and it is shown that all three methods give consistent results. The third method shows that theoretical frictional pressure drop calculations using the hydraulic diameter concept are accurate for annular channels with ribs.

The pressure differences down the assembly are correlated as in the hydraulics manual. All of the available data is analyzed, including seven pressure profile tests with single pressure plate end fittings having 10, 20, 32, 40, 50, 60, and 80 shell holes. Ridenhour analyzed only four of these cases, with 10, 20, 32, and 40 shell holes. Numerous plots of the data along with the correlations indicate the accuracy of the correlations. The channel correlations are shown to be consistent with one another as well as with an overall correlation based on all the data. A table of the H_2O correlations is given in the form used in the hydraulics manual. Scaling of the correlations to D_2O is discussed, and tables of D_2O correlations are given in the form used in the hydraulics manual. Comparisons to the hydraulics manual show several errors in the manual correlations. It is recommended that the correlations in this report be used for representing Mark 22 hydraulics.

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We thank Vascoe Whatley for providing the original CMX data sheets and working notebooks of Ridenhour. Vascoe's knowledge of the experimental setup and procedures used at CMX at the time of the Mark 22 experiments is invaluable, and we thank him for sharing his knowledge. Vascoe and George Richardson have both been very helpful in explaining details of the Mark 22 assembly hardware. In addition, we thank George for providing needed drawings and, in particular, for the information on the purge channel orificing hardware.

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1. INTRODUCTION

In the past year, there has been great emphasis on the calculation of flow instability (FI) LOCA limits using refined methods of calculation. Detailed assembly calculations are now performed including detailed analysis of various uncertainties. In many cases, we are dealing with effects that have an impact of only a few per cent and that often require an accurate knowledge of assembly hydraulic behavior in order to carry out the analysis. Considering this situation, it is logical to ask how well we know the hydraulics of assemblies, especially the Mark 22 assembly since future charges will probably be made up of the Mark 22 uniform charge. For some time we have known that the hydraulic correlations for the Mark 22 as given in the hydraulics manual [1] are not self consistent. That is, the flow splits given in the manual are not consistent with the pressure drop correlations. This inconsistency, along with other discrepancies, prompted the present investigation into the data base for the Mark 22.

The hydraulics of SRP assemblies are reported in the form of dimensional correlations in the assembly hydraulic technical manuals [1-3]. The correlations in these manuals are based upon experimental measurements using H_2O in test stations at CMX that were then scaled to D_2O at typical operating temperatures. Unfortunately, the actual data are not documented. Neither are the analysis and scaling of the data documented other than the reporting of final correlations. Fortunately, the original CMX data sheets and working notebooks of L. W. Ridenhour for the Mark 22 tests are still available (thanks to the archival instincts of V. Whatley). In this report, the original data for the Mark 22 is presented along with analysis of this data. Comparisons are made to Ridenhour's original analysis as given in his working notebooks and reported in his summary document [4]. Comparisons are also made to the Mark 22 hydraulics manual, and several inconsistencies are pointed out and corrected.

As we discuss and analyze the data, it is worthwhile to keep in mind that the present study has been done with the objective of ensuring that the hydraulic correlations used in our codes are consistent with the data. The overall pressure drop versus flow rate relationship is of first importance. Next, the flow splits to the channels and the associated frictional pressure drop behavior are important, especially in light of the detailed channel calculations currently being performed. Finally, the breakdown of the pressure drops through the assembly, and the occurrence of minimum pressures, is important with regard to saturation conditions. Because of time limitations, we have not performed rigorous uncertainty analyses, but some uncertainties are discussed and plots of the data communicate the strengths and weaknesses of the data and the associated correlations.

2. DESCRIPTION OF EXPERIMENTS AND DATA

From November 1971 through April 1972, L. W. Ridenhour performed a number of hydraulic tests for the newly designed Mark 22 assembly [5]. Partial descriptions of these tests are available from Ridenhour's working notebooks and from the original CMX data sheets, both of which have been maintained by V. Whatley, and from Ridenhour's summary document [4]. During November and December 1971, tests included flow endurance testing and testing of metering buttons for the two purge channels. January and February 1972 were devoted to calibrations for inlet orifices and for end fitting signals (CMX data sheets K2791-K2847). During March and April 1972, flow distribution tests and pressure profile tests were performed (CMX data sheets K2848-K2860). These last tests are the primary data analyzed in the current study; we also analyze some of the previous end fitting data. We do not address inlet orifice correlations in this report. For the data analyzed in this report, the original data taken from the data sheets are compiled in the appendix.

The hydraulic facility at CMX was designed for full scale flow testing of SRP assemblies using dummy aluminum assemblies manufactured by the same process and to the same specifications as real assemblies. The facility was a once-through system that pumped filtered river water from a clearwell that supplied process water to the TNX area. Because the system was once-through, the temperature of the water was the clearwell supply temperature, which ranged over 10-22°C for these winter tests. Typical reactor assembly flow rates of up to 400 gpm could be obtained during testing. The outlet flow could be diverted to a weigh tank for flow rate measurement and/or meter calibration, although the maximum flow rate was then limited to about 325 gpm.

For the Mark 22 tests, a 2.12" ID orifice meter was calibrated using the weigh tank to collect 1345 gallons over times of 4-7 minutes. An early calibration was based on data set K2791. The measured flow rate F in gpm was correlated to the reading of the height difference in a mercury manometer HF in cm as

$$F = 35.3022 HF^{.4995} \quad (2-1)$$

All flows reported on data sheets K2792-K2847 were obtained from the manometer measurement HF using Eqn. (2-1). Prior to the flow distribution and pressure profile tests, another calibration was performed based on data set K2848, resulting in the correlation

$$F = 35.44182 HF^{.49841} \quad (2-2)$$

All flows reported on data sheets K2851-K2860 are obtained from the manometer measurement HF using Eqn. (2-2). Data sets K2849 and K2850 also give measured flow rate data at lower flow rates. The data from all four of these tests are plotted in Figure 2-1 along with the above fits. Also shown in Figure 2-1 is a fit to all of the data, which agrees with Eqns. (2-1) and (2-2) within 1 gpm. Clearly, the orifice correlations are quite accurate for the available data, and we can expect good accuracy for flow rates up to 400 gpm.

The dummy Mark 22 assembly was instrumented with a number of pressure taps. Taps were located just above the top stem, at the venturi vena contracta, at the pressure plate vena contracta, and about 12" inside the entrance and exit of the three major channels. In addition, the plenum pressure, the tank bottom pressure, and the end fitting signal were measured. Measurements were obtained with pressure gages in psig, and differential measurements were obtained with a mercury manometer. All measurements were taken below the test section so that the water legs in the lines canceled and no hydrostatic correction is necessary to obtain pressure differences. Over the temperature range 10-22°C, the densities of water and mercury change little, with $\rho_{H_2O} \approx 62.4 \text{ lbm/ft}^3$ and $\rho_{Hg} \approx 13.6 \rho_{H_2O}$. Then, the manometer reading ΔH in cm is converted into pressure difference Δp in psi as

$$\Delta p = (\rho_{Hg} - \rho_{H_2O})g \Delta H = \frac{(13.6 - 1)(62.4)}{144} \frac{\Delta H}{(2.54)(12)} = 0.179 \Delta H$$

The various measurements obtained are indicated on the data sheets in the appendix. The only data omitted on the sheets in the appendix are the locations of the venturi vena contracta and pressure plate vena contracta measurements. Typically, the venturi measurement was made about 0.25" below the throat and the pressure plate measurement was made about 0.9" below the plate.

One important dimension that is incorrectly reported in Ridenhour's notebooks is the distance between the channel pressure taps. Apparently, Ridenhour mislabeled the distance between the taps with the total inner channel length of 161.5". The pressure taps are shown to be 12" inside the entrance and exit of this channel. Thus, the correct distance between the channel pressure taps is 137.5". Since Ridenhour used the distance of 161.5" throughout his analysis, there is inherent error in his correlations for channel pressure drop, channel entrance pressure drop, and channel exit pressure drop.

We also note that Ridenhour analyzed only four of the seven pressure profile tests. In the current study, we analyze the data from all seven tests, so the data base for the correlations is strengthened.

3. CALCULATION OF CHANNEL FLOW SPLITS

Knowledge of the channel flow splits is necessary to carry out detailed heat transfer calculations and is thus one of the primary results of interest from the hydraulic tests. The flow splits are not measured directly but must be calculated from the channel pressure drop data using the theoretical functional relation for friction factor. Since we are dealing with noncircular channels, we first calculate the channel hydraulic diameters. Next, we discuss the pressure/flow characteristics of the purge channels in order to estimate the purge channel flow split. We then discuss the two methods used by Ridenhour to calculate channel flow splits and point out a calculational error that led to incorrect results. Next, we discuss a small uncertainty in the recorded water temperatures, and we show how we account for the effect of temperature variation. Finally, we present a method for calculating the channel flow rates, and hence the flow splits, based on the accepted theoretical relation for friction factor, and show that all three methods are in basic agreement.

3.1 Channel Areas and Hydraulic Diameters

Each annular channel in the Mark 22 assembly has four ribs that divide the channel into four subchannels. To account for the ribs in the calculation of area and hydraulic diameter, we use a scheme that is consistent with the results in the Mark 16 hydraulics manual [2]. We assume that each rib extends across the channel and has a uniform width of 0.060". Then, for an annular channel with bounding radii of R_o and R_i in inches, we have

$$\begin{aligned} \text{Area} &= \pi R_o^2 - \pi R_i^2 - 4(R_o - R_i)(0.060) \quad , \\ \text{Perimeter} &= 2\pi R_o + 2\pi R_i - 8(0.060) + 8(R_o - R_i) \quad , \\ \text{Hydraulic Diameter} &= \frac{4 \times \text{Area}}{\text{Perimeter}} \quad . \end{aligned}$$

The following table gives the results of the above equations as applied to the Mark 22 assembly. Also given are the areas from the hydraulics manual [1] and the Mark 22

Geometric Data for Mark 22 Assembly Channels							
	D_o (in)	D_i (in)	Flow Area (in ²)	Perimeter (in)	Hydraulic Diameter (in)	A_{manual} (in ²)	A_{design} (in ²)
Channel 1	4.010	3.700	1.840	24.982	0.2946	1.840	1.84
Channel 2	3.540	3.200	1.759	22.054	0.3190	1.740	1.75
Channel 3	2.892	2.353	2.156	18.154	0.4751	2.142	2.14
Channel 4	1.995	1.590	1.092	12.403	0.3522	1.092	1.08

design document [5], which give slightly different flow areas from those calculated with the above equations. The hydraulic diameters from these documents are in agreement with the above equations to three significant figures. The areas and hydraulic diameters computed from the above equations and given in the following table are used in all calculations in this report. The axial purge channel (channel 5) is a circular pipe of diameter 1.235" with flow area of 1.198 in².

3.2 Hydraulics of the Purge Channels

The Mark 22 assembly has two purge channels: the outer annular channel 1 and the axial circular channel 5. The flow in each of these channels is restricted by orifices, which are shown in Figure 3-1. Channel 1 has two 1/8" diameter button orifices spaced 180° apart and located near the top stem region of the assembly. Channel 5 has the 0.110" diameter orifice, shown in Figure 3-1(b), located in the top stem.

The purging capability of the two button orifices in channel 1 was tested visually in a plexiglas rig. Flow rates were measured for seven different pressure drops as shown in Figure 1 of Reference 4. Two of these data points are noted in Ridenhour's notebook as not having the channel full of water. The remaining five data points follow:

Flow (gpm)	Δp (psid)
1.21	6
1.87	12
2.77	24
3.70	43
4.44	61

These data are plotted in Figure 3-2 along with a square law fit to the data of $\Delta p = 3.12 F^2$. If this correlation is converted to a K-factor loss coefficient based on the area of the two 1/8" holes, the result is $K = 2.705$. Alternatively, this K-factor can be expressed as a discharge coefficient as $C_D = 0.608$. A discharge coefficient of 0.6 is typical of orifices [6], so the above data is consistent with standard correlations.

We are aware of only one data point for flow through the axial purge channel orifice. Drawing ST-MDX3-8313 has a table of flows for different orifice sizes. For the 0.110" diameter nozzle used in Mark 22 assemblies, the rated flow is 2 gpm for a pressure drop of 45 psi. This corresponds to a K-factor of 1.46 or to a discharge coefficient of 0.826. The converging entrance to the orifice, seen in Figure 3-1(b), would tend to reduce the loss as opposed to a sharp edged orifice. Also, the length of the 0.110" diameter hole would tend to recover the behavior of a sudden contraction ($K = 0.42$) followed by a sudden expansion ($K = 1$). Hence, $K = 1.46$ appears to be consistent with standard correlations. Correlating in terms of pressure drop in psi as a function of flow rate in gpm, we have $\Delta p = 11.25 F^2$.

The flow splits to the purge channels are needed in subsequent calculations. The driving pressure for the purge channel flows is essentially the pressure drop between the top

stem and the venturi vena contracta. Given this pressure drop, we can use the preceding correlations for the purge channels to calculate the purge flows. Upcoming in Sections 4 and 5, we correlate this pressure drop in terms of total flow rate. Anticipating these results, we use the correlations in Table 5-1 to obtain the total flow rate for a given pressure drop between the top stem and the venturi vena contracta, and we calculate the flow splits to the purge channels.

For total flow rates ranging from 200-400 gpm, the channel 1 flow is about 1% of the total and the channel 5 flow is about 0.5% of the total, giving a total purge flow of about 1.5%. There is a slight flow dependence, with a total purge flow of 1.55% at 200 gpm and 1.47% at 400 gpm. Ridenhour quotes purge flows of 1.4% and 1.44%, which are in basic agreement with the present estimates. As we will see later, scaling to D₂O at typical operating temperatures changes the purge flow split to about 1.4% instead of 1.5% for cold H₂O.

3.3 Flow Split Calculation Based on Power Law Fit to 1.8 Power

The friction factor for smooth pipes is often correlated as a power law $f = BRe^{-m}$ (usually referred to as a Blasius form). In this case, the Darcy pressure drop equation becomes

$$\Delta p = f \frac{L}{D} \frac{\rho V^2}{2} = \left(\frac{B}{2} \rho L \nu^m \right) \frac{V^{2-m}}{D^{1+m}}$$

A common correlation of this form is $f = 0.184Re^{-.2}$, in which case the pressure drop varies with velocity (or flow rate) to the 1.8 power. This is the form of the channel pressure drop correlations used in the hydraulics manuals. In his working notebook, Ridenhour used this assumed 1.8 power law fit as one method to compute flow splits (although he chose not to use these results).

If we assume that the friction factor in each channel can be represented as $f = BRe^{-.2}$, then there is a simple explicit method for calculating the flow splits. After substitution for average velocity in terms of channel flow rate and area, $V_i = Q_i/A_i$, the channel pressure drop equations become

$$\Delta p_i = \left(\frac{B}{2} \rho L \nu^{.2} \right) \frac{Q_i^{1.8}}{A_i^{1.8} D_i^{1.2}} \quad \text{for } i = 2, 3, 4$$

Assuming that the term in parentheses is constant for a given test, we can take the ratio of this equation for two channels to find

$$\frac{Q_2}{Q_4} = \left(\frac{\Delta p_2}{\Delta p_4} \right)^{5/9} \left(\frac{A_2}{A_4} \right) \left(\frac{D_2}{D_4} \right)^{2/3}$$

$$\frac{Q_3}{Q_4} = \left(\frac{\Delta p_3}{\Delta p_4} \right)^{5/9} \left(\frac{A_3}{A_4} \right) \left(\frac{D_3}{D_4} \right)^{2/3}$$

The third equation needed to solve for the channel flow rates is conservation of mass,

$$Q_T = Q_2 + Q_3 + Q_4 + Q_{\text{purge}} \quad \text{where} \quad Q_{\text{purge}} = Q_1 + Q_5$$

For a given total flow rate Q_T , the purge flow is known from the correlations in Section 3.2. Then, the above three equations can be solved for the flow rates and the flow splits. Alternatively, we can calculate the relative flow splits between channels 2, 3, and 4 without knowing the purge flow explicitly.

To solve for the relative flow splits, it is convenient to first fit the channel pressure drop in terms of total flow rate to the 1.8 power as $\Delta p_i = C_i Q_T^{1.8}$. Then, the ratio of pressure drops becomes the ratio of the fitting coefficients C_i , and the flow rate ratios given above become

$$\frac{Q_2}{Q_4} = \left(\frac{C_2}{C_4} \right)^{5/9} \left(\frac{A_2}{A_4} \right) \left(\frac{D_2}{D_4} \right)^{2/3}$$

$$\frac{Q_3}{Q_4} = \left(\frac{C_3}{C_4} \right)^{5/9} \left(\frac{A_3}{A_4} \right) \left(\frac{D_3}{D_4} \right)^{2/3}$$

With the coefficients C_i known from fits to the data, and with the nominal areas and hydraulic diameters known from the table in Section 3.1, the flow rate ratios are known. The conservation of mass equation can be recast into an equation for the relative flow fraction for channel 4 in terms of the known flow rate ratios,

$$\frac{Q_4}{Q_T - Q_{\text{purge}}} = \frac{1}{1 + \frac{Q_2}{Q_4} + \frac{Q_3}{Q_4}}$$

Then, the relative flow fractions for the other two channels are found from

$$\frac{Q_2}{Q_T - Q_{\text{purge}}} = \frac{Q_4}{Q_T - Q_{\text{purge}}} \cdot \frac{Q_2}{Q_4} \quad \text{and} \quad \frac{Q_3}{Q_T - Q_{\text{purge}}} = \frac{Q_4}{Q_T - Q_{\text{purge}}} \cdot \frac{Q_3}{Q_4}$$

Figures 3-3 to 3-11 show plots of the channel pressure drop data from data sets K2851-K2860. The pressure drops are measured with a manometer and also computed by subtracting gage measurements. Also shown on each figure is the least squares fit for pressure drop as a function of flow to the 1.8 power. In these equations the pressure drop Δp is in psi and the flow rate F is in gpm/100. We see that the data is well fit by this functional form. Note that some points deviate considerably from the rest of the data (usually pressure differences computed by subtracting two pressure gage readings). We have chosen not to eliminate "bad" data points, relying instead on the overall weight of the number of points. Also note that the fitting coefficients vary considerably between the tests. We will show in the next section that this can be accounted for as a temperature effect on viscosity.

The correlations given in Figures 3-3 to 3-11 are used with the above equations to compute the relative flow splits. The results are given in the following table where we see that the calculated flow splits are quite consistent from one test to the next.

Calculated Relative Flow Splits using 1.8 Power Method						
	Coefficient for Fit $\Delta p = CF^{1.8}$			Flow Split		
Test	Ch2	Ch3	Ch4	Ch2	Ch3	Ch4
K2851	2.569693	2.495414	2.846420	0.3054	0.4803	0.2144
K2852	2.577016	2.524593	2.763298	0.3058	0.4833	0.2108
K2854	2.521632	2.521204	2.783162	0.3031	0.4845	0.2124
K2855	2.560979	2.533036	2.804973	0.3043	0.4835	0.2123
K2856	2.540264	2.510078	2.789984	0.3043	0.4832	0.2126
K2857	2.568163	2.526438	2.802810	0.3049	0.4829	0.2122
K2858	2.508692	2.487312	2.749785	0.3041	0.4837	0.2122
K2859	2.490645	2.461765	2.736504	0.3042	0.4832	0.2126
K2860	2.477686	2.432264	2.722406	0.3048	0.4822	0.2130
Average for K2852-K2860				0.3042	0.4833	0.2125
Minimum for K2852-K2860				0.3031	0.4822	0.2122
Maximum for K2852-K2860				0.3049	0.4845	0.2130

One question that arises with respect to the validity of the above method of computing flow splits is whether the friction factor correlation for the three channels is the same. In fact, because of relative roughness effects, there should be some variation. To address this concern, we consider the theoretical friction factors for the channels in a Mark 22 over the total flow rate range from 200-400 gpm. The accepted theoretical relation between friction factor f , Reynolds number Re , and relative roughness e/D is the Colebrook equation [6]

$$\frac{1}{f^{1/2}} = -2.0 \log \left(\frac{e/D}{3.7} + \frac{2.51}{Re f^{1/2}} \right) \quad (3-1)$$

Using the flow splits determined above and considering two representative roughnesses, $e = 3.5 \times 10^{-6}$ ft and $e = 1.13 \times 10^{-5}$ ft, we solve for the channel Reynolds numbers and friction factors. The results are plotted in Figure 3-12 along with the smooth pipe friction factor correlation $f = 0.184 Re^{-.2}$. The following table shows power law fits to these data in which the power is constrained to be -0.2 and the coefficient is the only free parameter. The ratio of each coefficient to 0.184 is also given.

Coefficients for Fit $f = BRe^{-.2}$ to Theoretical Channel Friction Factors				
	$e = 3.5 \times 10^{-6}$	Coef/0.184	$e = 1.13 \times 10^{-5}$	Coef/0.184
Channel 2	$f = 0.1868 Re^{-.2}$	1.015	$f = 0.1937 Re^{-.2}$	1.053
Channel 3	$f = 0.1844 Re^{-.2}$	1.002	$f = 0.1920 Re^{-.2}$	1.043
Channel 4	$f = 0.1859 Re^{-.2}$	1.010	$f = 0.1932 Re^{-.2}$	1.050

From the plot and this table, we see that the coefficients for the friction factor expressions in the three channels are very nearly the same for a given roughness. We can incorporate the small difference in the coefficients into the flow split calculation above. Without showing the details of the calculation, we note that use of the values from the above table results in an impact on flow split of a change of one digit in the third significant digit. Hence, the flow splits calculated above should be good estimates.

3.4 Temperature Effects on Channel Pressure Drop

As we discuss channel frictional pressure drop, it is relevant to note a small uncertainty in the data base regarding the water temperature. The original CMX data sheets give data for three separate runs and give daily temperatures for the days over which the tests were run. Unfortunately, for the seven pressure profile tests, a correspondence between the day (and temperature) and the run is not given for four tests (K2854-K2857), and temperatures are not given for some days in two other tests (K2858-K2859). Hence, in some cases there is an uncertainty of a few degrees in the temperature. While this may seem insignificant, we see in Figure 3-13 that the kinematic viscosity is a strong function of temperature in the range 12-22°C. Since frictional pressure drop varies with the kinematic viscosity to about the 0.2 power, an uncertainty of 4°C leads to about a 2% uncertainty in pressure drop. At a flow rate of 400 gpm, a typical pressure drop is 30 psi, so the uncertainty could be 0.6 psi, which is certainly a measurable difference. To the extent possible, we will account for the temperature effect in subsequent channel pressure drop calculations. For the flow split calculations, the temperature effect is insignificant since the calculations involve one channel relative to another within a single test.

In Table 3-1, we have listed the dates given on the CMX data sheets along with the corresponding recorded temperatures for the pressure profile tests K2854-K2860. Question marks indicate that some daily temperatures and dates were not recorded. On the last three tests, the dates were recorded beside the run number, and we see that there was typically one run per day. We have estimated the dates for the first four tests assuming that there was one run per day, and we have used the corresponding recorded temperature as the run temperature. The unknown temperatures are estimated based on the daily trends and based on the pressure drop data itself. Run 1 of K2855 is

assumed to be at the higher temperature based on the pressure drop data. We have good confidence in the temperatures for 15 of the 21 runs listed, and we have made our best estimate for the other six runs. Based on our estimates, the average temperature for all the runs is about 17.5°C.

At the bottom of Table 3-1 are the reference temperatures we have chosen to represent each test based on the individual run temperatures. We now show that the data scales consistently with these reference temperatures. We will consider the power law fits to the 1.8 power discussed in the last section. Then, the pressure drop is proportional to $\rho\nu^2$. We scale the fit for each test to the reference temperature by multiplying the coefficient by the ratio of properties at the test temperature to those at the reference temperature of 17.5°C,

$$C_{scaled} = C_{fit} \left(\frac{\rho_{test}}{\rho_{17.5}} \right) \left(\frac{\nu_{test}}{\nu_{17.5}} \right)^{0.2}$$

The results of this scaling are given in the following table. (The density and kinematic viscosity of H₂O and D₂O are obtained from the functions used in the FLOWTRAN code [7].) We see that the coefficients are brought closer together as a result of scaling for the small temperature differences between tests. We also see that the average of the coefficients before scaling is very close to the average of the coefficients scaled to 17.5°C, which indicates that 17.5°C is appropriate as an overall average reference temperature. The average of the coefficients scaled to 17.5°C is adopted as the correct representation of the channel friction.

Coefficients from 1.8 Power Law Fits Scaled to 17.5°C							
		Coefficient for Fit $\Delta p = CF^{1.8}$			Coefficients Scaled to 17.5°C		
Test	T _{ref}	Ch2	Ch3	Ch4	Ch2	Ch3	Ch4
K2854	16°C	2.521632	2.521204	2.783162	2.500609	2.500185	2.759959
K2855	15°C	2.560979	2.533036	2.804973	2.525780	2.498221	2.766420
K2856	16°C	2.540264	2.510078	2.789984	2.519086	2.489152	2.766724
K2857	15°C	2.568163	2.526438	2.802810	2.532865	2.491714	2.764287
K2858	18°C	2.508692	2.487312	2.749785	2.515286	2.493850	2.757013
K2859	20°C	2.490645	2.461765	2.736504	2.523813	2.494548	2.772946
K2860	22°C	2.477686	2.432264	2.722406	2.536338	2.489841	2.786851
		Average of coefficients			Average of scaled coefficients		
		2.524009	2.496014	2.769946	2.521968	2.493930	2.767743

The above calculation confirms that the test reference temperatures given in Table 3-1 scale the data in reasonable agreement with theoretical scaling for channel frictional

pressure drop. In subsequent calculations where a reference temperature is required for each test, we will use the reference temperatures given at the bottom of Table 3-1. Finally, we note that the temperature differences are insignificant for scaling square law losses that depend only on the density and not on viscosity.

3.5 Method of Flow Split Calculation Used by Ridenhour

Ridenhour [4] describes his flow distribution calculation as one in which "the actual velocity (flow) exponent determined for each channel was used in the Fanning equation." The details of this calculation are found in his working notebook and proceed as follows.

A least squares power law fit of the data for channel pressure drop Δp_i as a function of total flow rate F_T results in correlation equations of the form

$$\Delta p_i = C_i F_T^{2-m_i} \quad \text{for } i = 2, 3, 4 \quad (3-2)$$

The values of m_i are near 0.2, so flow varies nearly to the 1.8 power. Typically, m_i varies from 0.17 to 0.24 between the three channels. The power law fits to the data in Figures 3-3 to 3-11 are given in Table 3-2.

Based on the common correlation that friction factor f varies as a power law of the Reynolds number, $f = B Re^{-m}$, Ridenhour wrote equations for the channel pressure drops as

$$\Delta p_i = \phi L \frac{V_i^{2-m_i}}{D_i^{1+m_i}} \quad \text{for } i = 2, 3, 4 \quad (3-3)$$

This equation is derived from the Darcy pressure drop equation by substituting the power law approximation for friction factor $f_i = B_i Re_i^{-m_i}$ as

$$\Delta p_i = f_i \frac{L}{D_i} \frac{\rho V_i^2}{2} = \left(\frac{B_i}{2} \rho \nu^{m_i} \right) L \frac{V_i^{2-m_i}}{D_i^{1+m_i}} .$$

We identify ϕ in Ridenhour's equation as the term in parentheses. Under the assumption that ϕ is a constant, ratios of Eqns. 3-3 between the channels eliminates ϕ . Forming such ratios yields two equations for the three unknown velocities. The final equation relating the unknown channel velocities V_i is the equation of mass conservation. The resulting three equations are of the form

$$\begin{aligned} \frac{\Delta p_2}{\Delta p_3} &= \frac{V_2^{2-m_2}}{V_3^{2-m_3}} \frac{D_3^{1+m_3}}{D_2^{1+m_2}} , \\ \frac{\Delta p_2}{\Delta p_4} &= \frac{V_2^{2-m_2}}{V_4^{2-m_4}} \frac{D_4^{1+m_4}}{D_2^{1+m_2}} , \end{aligned} \quad (3-4)$$

$$V_2 A_2 + V_3 A_3 + V_4 A_4 = F_T - F_{\text{purge}} .$$

For a given F_T , the three channel pressure drops are determined from the correlations given by Eqns. 3-2 (see Table 3-2). Similarly, F_{purge} is known from the data correlations given in Section 3.2. Then, the three equations can be solved for the three unknown velocities and the flow splits determined.

The validity of the above method depends on the assumption that ϕ is a constant for all three channels. This assumption implies that $B_i \nu^{m_i}$ is constant. To check this assumption, we again consider the theoretical friction factors for the channels in a Mark 22 over the total flow rate range from 200-400 gpm, which was discussed in Section 3.3. We now fit the data in Figure 3-12 with a power law in which both the coefficient and the power are determined. We take a typical value for kinematic viscosity of $\nu = 1.15 \times 10^{-5}$ ft²/s. For the smooth pipe correlation $f = 0.184 Re^{-.2}$, we find $B \nu^m = 0.184(1.15 \times 10^{-5})^{-.2} = 0.018922$. The following table gives the resulting power law fits and shows that the assumption that ϕ is constant is in reasonable agreement with the accepted theory.

Coefficients for Fit $f = B Re^{-m}$ to Theoretical Channel Friction Factors			
	$e = 3.5 \times 10^{-6}$	$B_i \nu^{m_i}$	$\frac{B_i \nu^{m_i}}{0.018922}$
Channel 2	$f = 0.22397 Re^{-.21728}$	0.018922	1.0000
Channel 3	$f = 0.18635 Re^{-.20095}$	0.018957	1.0018
Channel 4	$f = 0.20963 Re^{-.21120}$	0.018979	1.0030
	$e = 1.13 \times 10^{-5}$	$B_i \nu^{m_i}$	$\frac{B_i \nu^{m_i}}{0.018922}$
Channel 2	$f = 0.17886 Re^{-.19241}$	0.020050	1.0596
Channel 3	$f = 0.14302 Re^{-.17366}$	0.019845	1.0488
Channel 4	$f = 0.16472 Re^{-.18512}$	0.020062	1.0602

The relative flow splits calculated with this method are given in Table 3-2 along with the power law fits to the data. There is insignificant variation in the calculated flow split for a given test as a function of the total flow rate used in the calculation; hence, we give a single result for each test. We see that the flow splits are consistent from one test to the next. The flow splits differ slightly (<1%) from those computed by the method in Section 3.3.

In solving Eqns. 3-4, one must be careful to use consistent units. Ridenhour made a calculational error due to inconsistent units. He solved the equations using length in inches for diameter and area, but he neglected to convert velocity from ft/s to in/s. To indicate the magnitude of the resulting error, we consider channels 2 and 3 of test K2852 (see Table 3-2). The conversion error on the term V^{2-m_2}/V^{2-m_3} in Eqn. 3-4 is the

factor $12^{1.832}/12^{1.805} = 1.07$, which shows that errors of a few per cent are expected. In the following table, Ridenhour's flow splits, given in Table III of Reference 4 and used in the Mark 22 hydraulics manual [1], are compared with the correctly calculated flow splits.

Calculated Relative Flow Splits Using Power Law Method

	Ridenhour	Corrected
Channel 2	31.2%	30.14%
Channel 3	48.4%	48.42%
Channel 4	20.4%	21.43%

3.6 Method of Flow Split Calculation Using Colebrook Equation

The Colebrook equation, Eqn. 3-1, is the accepted equation relating the friction factor f to the Reynolds number Re and the relative roughness e/D . Following Colebrook's work in 1939, there was much activity to bring such theoretical developments into the realm of the design engineer, and, in a time before calculators and computers, the most useful form of information was a chart that could be easily read. The Moody chart, which is probably the most famous figure in hydraulics, is nothing more than a plot of the Colebrook equation, albeit one that has proven very useful for design work. Other forms of plotting the Colebrook equation were suggested depending on the problem to be solved, and one form suggested by Rouse is of use when the pressure drop is known and the flow is to be determined [6].

Since f , Re , and e/D are dimensionless, we can form other dimensionless parameters as combinations of these. Rouse suggested using the parameter

$$\alpha \equiv \frac{1}{2} f Re^2$$

which appears when the velocity squared term in the Darcy pressure drop equation is converted to Re^2 :

$$\Delta p = f \frac{L}{D} \frac{\rho V^2}{2} = (\frac{1}{2} f Re^2) \frac{L}{D} \frac{\rho \nu^2}{D^2} = \alpha \frac{\rho L \nu^2}{D^3}$$

Solving for α , we see that α is known in terms of the geometry, properties, and the pressure drop:

$$\alpha = \frac{\Delta p D^3}{\rho L \nu^2}$$

Now we can eliminate f in the Colebrook equation, Eqn. 3-1, in favor of α and Re as

$$\frac{Re}{\sqrt{2\alpha}} = -2 \log \left(\frac{e/D}{3.7} + \frac{2.51}{\sqrt{2\alpha}} \right)$$

and solve for Re in terms of α

$$Re = -\sqrt{8\alpha} \log \left(\frac{e/D}{3.7} + \frac{2.51}{\sqrt{2\alpha}} \right)$$

Since α is known when the pressure drop is known, we can compute Re directly and then obtain the flow rate from the definition of Reynolds number,

$$Q = Re \frac{A\nu}{D}$$

For our present problem, we know the geometry, properties, and pressure drop, and we want to know the flow rates. The use of α is another method of determining the flow splits. This method will also indicate how well the Colebrook equation applies for the annular geometry with ribs in SRP assemblies. One quantity that is not well known is the roughness e . In lieu of pressure drop measurements in circular pipes, which can be used to estimate e , we must choose a nominal value. For the smooth aluminum walls formed by extrusion, it seems reasonable to use the nominal value for drawn tubing [6], $e = 5 \times 10^{-6}$ ft. As mentioned in Section 3.4, there is some uncertainty in the temperature, which affects the viscosity. We use the reference temperatures given in Table 3-1, which seem to scale the data correctly as discussed in Section 3.4.

At each flow rate in each of the data sets K2854-K2860, the channel pressure drop measurements (manometer and gage independently) are used to calculate channel flow rates using the above equations. The flow rates are summed and compared to the measured total flow rate, and the flow splits are computed. Table 3-3 shows the average and bounding results for these calculations for each data set. We see that the computed flow splits agree very well with the two previous methods. We also see that the computed total flow rate is in good agreement, being high by 1.4-2.0%. As shown in Table 3-4, the computed total flow rate can be brought into almost exact agreement with the measured flow rate if the roughness is increased to $e = 1.13 \times 10^{-5}$ ft. The flow splits for this case remain essentially the same.

An important result of this calculation is the verification of theory for SRP assembly channel geometry. That is, a theoretical calculation of flow versus pressure drop based on the hydraulic diameter concept for annular channels with ribs is in good agreement with data. Figure 3-14 explicitly shows this result. The data for two tests with differing temperatures, K2855 and K2860, are plotted along with computed pressure drops obtained from the Colebrook equation with the two different roughnesses. Clearly, the results of the theoretical calculations are in good agreement with the data.

3.7 Summary of Flow Split Calculations

We have presented three methods for calculating the relative channel flow splits from measured channel pressure drops, and the results are summarized in the following table. The results of the three methods are in good agreement, and we found good agreement in the results from test to test. The flow splits from Ridenhour's summary document [4], which are used in the Mark 22 hydraulics manual, are given for comparison. As discussed in Section 3.4, Ridenhour made a calculational error in obtaining these results; the correct results using Ridenhour's method are given in the table.

Summary of Relative Flow Split Results			
Method of Calculation	Ch 2	Ch 3	Ch 4
1.8 Power Law	0.3042	0.4833	0.2125
Ridenhour's Method	0.3014	0.4842	0.2143
Colebrook ($e = 5 \times 10^{-6}$)	0.3038	0.4846	0.2116
Colebrook ($e = 1.13 \times 10^{-5}$)	0.3041	0.4843	0.2116
Hydraulics Manual	0.312	0.484	0.204

Neither of the three methods for calculating flow splits appears to be preferable over the others, so we could average the results. Subsequently, we present channel correlations as flow to the 1.8 power, which is the form used in the hydraulics manual. For consistency, we recommend the flow splits from the 1.8 power law method. Finally, we note that the relative flow splits given above are relative to the three primary channels. As discussed in Section 3.2, the purge channels account for about 1.5% of the total flow. The flow splits relative to the total flow rate are given in Table 5-1.

4. CORRELATIONS OF PRESSURE DROP DATA

In this section, we correlate the pressure drop data from the pressure profile tests K2854-K2860. The hardware for these tests differs only in the number of shell holes in the bottom fitting insert (BFI). The reference locations for pressure differences coincide with those used in the hydraulics manual [1]. We present pressure difference correlations from plenum to top stem, from top stem to channel entrance, from channel entrance to channel exit, from channel exit to venturi vena contracta, from venturi vena contracta to pressure plate vena contracta, and from pressure plate vena contracta to tank bottom. Also, a correlation is given for the monitor pin signal.

The data consist of pressures measured with gages, pressure differences measured with manometers, and total assembly flow rate, as discussed in Section 2. The measurements available are indicated on the data sheets in the appendix. The correlations in this section are given as a function of the total flow rate, which is consistent with the measurements. Where appropriate, the correlation coefficients are given as a function of the number of shell holes in the bottom fitting insert. As a general rule, we have used all available data in the correlations, and we have not eliminated "bad" data points, but instead have relied on the weight of the number of data points to overpower any spurious data. We clearly indicate when a subset of data has been used in obtaining a correlation. Where calculations are used instead of direct data measurements, we clearly explain how the pressure difference is obtained.

Because the pressure gages and manometers were located below the test section, the hydrostatic head in the lines cancels that in the test section, so that there is no net hydrostatic pressure correction required from the raw data for pressure differences. That is, the measured pressure differences should be the same as if the assembly were tested in horizontal position. However, it is important to note that the measurements and correlations do include pressure changes due to velocity changes (Bernoulli velocity effects). Hence, the measurements and correlations are for pressure differences between points and not for irreversible losses. The hydraulics manuals incorrectly label the pressure difference correlations as "permanent pressure losses." We emphasize this point because significant error can result when applying the correlations if the Bernoulli velocity effects are not accounted for correctly.

4.1 Pressure Difference from Plenum to Top Stem

The pressure difference from plenum to top stem is obtained from the manometer measurement H_{PS} and by subtracting the gage pressures P_S and P_P . Since this pressure difference should be independent of the number of shell holes in the bottom fitting insert, the data from all seven tests yield 124 data points each from the gage and manometer measurements. These data are plotted in Figure 4-1, where the gage and manometer data have been plotted separately. We see that the manometer data correlate well, but the gage data exhibit quite a bit of scatter. We do not understand why the gage data show so much scatter.

Since the primary pressure drop is across the USH holes and permanent sleeve slots, we expect a velocity squared loss. The manometer data correlate with flow to the 1.97 power, in agreement with our expectation. Despite the scatter, the gage data correlate with flow to the 2.12 power. The combined data correlate with flow to the 2.04 power. Forcing a square law fit to the manometer data, we find

$$\Delta p = 0.34129 \left(\frac{F_T}{100} \right)^2 ,$$

and for the combined data we find

$$\Delta p = 0.33004 \left(\frac{F_T}{100} \right)^2 . \quad (4-1)$$

All data, including both the manometer data and gage data, are used in the subsequent correlations discussed in this section. For consistency, we have chosen to recommend Eqn. 4-1, the fit to the combined data, as best representing the plenum to top stem pressure difference.

As a comparison, we refer to the hydraulics manuals for the Mark 16 assembly [2] and the Mark 31 assembly [3], both of which have essentially the same geometry from plenum to top stem as the Mark 22. After scaling from D₂O to H₂O, the corresponding coefficient for the plenum to top stem pressure difference is 0.3354. This value falls between the above values for the Mark 22, and differs from these within 1.8%.

4.2 Pressure Difference from Channel Entrance to Channel Exit

We discussed the channel frictional pressure drops in Section 3, where we have shown that the data matches well with theoretical expressions of the friction factor as a function of Reynolds number and relative roughness. We have also shown that a power law fit to the 1.8 power, as is used in the hydraulics manuals, represents the data well. The recommended power law fits to the 1.8 power are given in Section 3.4 where temperature scaling was addressed.

The correlations in Section 3.4 apply between the pressure taps, which are 137.5" apart. In order to represent the entire channel length as a frictional pressure drop, we assume that frictional pressure drop scales linearly with length, which is true for fully developed flow. That is, we neglect any entrance or exit developing flow effects. Channels 3 and 4 are 161.5" long, while channel 2 is 163" long. For H₂O at 17.5°C, the pressure difference correlations for channel entrance to channel exit become

$$\begin{aligned} \text{Channel 2: } \Delta p &= 2.521968 \left(\frac{163}{137.5} \right) \left(\frac{F_T}{100} \right)^{1.8} = 2.9897 \left(\frac{F_T}{100} \right)^{1.8} , \\ \text{Channel 3: } \Delta p &= 2.493930 \left(\frac{161.5}{137.5} \right) \left(\frac{F_T}{100} \right)^{1.8} = 2.9292 \left(\frac{F_T}{100} \right)^{1.8} , \\ \text{Channel 4: } \Delta p &= 2.767743 \left(\frac{161.5}{137.5} \right) \left(\frac{F_T}{100} \right)^{1.8} = 3.2508 \left(\frac{F_T}{100} \right)^{1.8} . \end{aligned} \quad (4-2)$$

4.3 Pressure Difference from Top Stem to Channel Entrance

There is not a differential measurement between the top stem and the upper channel pressure tap, so we must rely on gage measurements for this pressure difference. As in the last section, we must make a calculational correction from the upper channel pressure tap to the channel entrance. There are a number of different calculations that will give the desired pressure difference. We will use two calculations, one of which involves the plenum to top stem manometer measurement.

Instead of using a correlation to correct from the upper channel pressure tap to the channel entrance, we will use the data directly. For a given flow rate, we compute the channel pressure difference from gage and manometer readings. We then average these to get a channel pressure drop

$$\Delta p_{Ch} = \frac{1}{2}(\Delta p_{gage} + \Delta p_{manometer})$$

which occurs over a 137.5" length. We then correct for the entrance lengths, which are 12" for channels 3 and 4, and 13.5" for channel 2.

The pressure difference from top stem to upper channel pressure tap is obtained directly as $P_S - P_3$ (for channel 2); we will refer to this calculation as "gage" data. Alternatively, we compute this pressure difference as $(P_P - 0.179H_{PS}) - P_3$; we will refer to this calculation as "manometer" data. Combining these calculations with the channel entrance correction, we have the following calculations for the top stem to channel entrance pressure differences:

$$\begin{aligned} \text{Channel 2: } \Delta p_{gage} &= P_S - P_3 - \Delta p_{Ch2} \left(\frac{13.5}{137.5} \right) , \\ \Delta p_{man} &= P_P - 0.179H_{PS} - P_3 - \Delta p_{Ch2} \left(\frac{13.5}{137.5} \right) , \\ \text{Channel 3: } \Delta p_{gage} &= P_S - P_5 - \Delta p_{Ch3} \left(\frac{12.0}{137.5} \right) , \\ \Delta p_{man} &= P_P - 0.179H_{PS} - P_5 - \Delta p_{Ch3} \left(\frac{12.0}{137.5} \right) , \\ \text{Channel 4: } \Delta p_{gage} &= P_S - P_7 - \Delta p_{Ch4} \left(\frac{12.0}{137.5} \right) , \\ \Delta p_{man} &= P_P - 0.179H_{PS} - P_7 - \Delta p_{Ch4} \left(\frac{12.0}{137.5} \right) . \end{aligned}$$

The results of these calculations are plotted in Figure 4-2, which shows the gage and manometer calculated data plotted for each channel. Also shown on this figure are the square law fits to the combined data,

$$\begin{aligned}
 \text{Channel 2 Entrance: } \Delta p &= 0.5841 \left(\frac{F_T}{100} \right)^2, \\
 \text{Channel 3 Entrance: } \Delta p &= 0.5438 \left(\frac{F_T}{100} \right)^2, \\
 \text{Channel 4 Entrance: } \Delta p &= 0.3856 \left(\frac{F_T}{100} \right)^2.
 \end{aligned} \tag{4-3}$$

As with the plenum to top stem data, there is significant scatter in the calculated pressure differences, although the trend of the data is clear. Again we rely on the weight of the number of data points to yield a representative correlation. The gage and manometer data consist of 124 points each, so the correlations are based on 248 points each.

4.4 Pressure Difference from Channel Exit to Venturi Vena Contracta

The channel exit pressure differences are obtained in a similar manner to the channel entrance pressure differences discussed in the last section. We use the same procedure to correct for the 12" distance between the lower channel pressure taps and the channel exits. We again have a gage calculation from the lower channel pressure tap to the venturi vena contracta pressure tap as $P_4 - P_V$ (for channel 2). We also have a manometer calculation since we have the channel exit to tank bottom reading and the venturi vena contracta to tank bottom reading, which can be subtracted as $H_{4T} - H_{VT}$ to represent the desired pressure difference. We have the following calculations for the channel exit to venturi vena contracta pressure differences:

$$\begin{aligned}
 \text{Channel 2: } \Delta p_{gage} &= P_4 - P_V - \Delta p_{Ch2} \left(\frac{12.0}{137.5} \right), \\
 \Delta p_{man} &= 0.179 (H_{4T} - H_{VT}) - \Delta p_{Ch2} \left(\frac{12.0}{137.5} \right), \\
 \text{Channel 3: } \Delta p_{gage} &= P_6 - P_V - \Delta p_{Ch3} \left(\frac{12.0}{137.5} \right), \\
 \Delta p_{man} &= 0.179 (H_{6T} - H_{VT}) - \Delta p_{Ch3} \left(\frac{12.0}{137.5} \right), \\
 \text{Channel 4: } \Delta p_{gage} &= P_8 - P_V - \Delta p_{Ch4} \left(\frac{12.0}{137.5} \right), \\
 \Delta p_{man} &= 0.179 (H_{8T} - H_{VT}) - \Delta p_{Ch4} \left(\frac{12.0}{137.5} \right).
 \end{aligned}$$

The results of these calculations are plotted in Figure 4-3, which shows the gage and manometer calculated data plotted for each channel. Also shown on this figure are the square law-fits to the combined data,

$$\begin{aligned}
 \text{Channel 2 Exit: } \Delta p &= 0.03483 \left(\frac{F_T}{100} \right)^2, \\
 \text{Channel 3 Exit: } \Delta p &= 0.12087 \left(\frac{F_T}{100} \right)^2, \\
 \text{Channel 4 Exit: } \Delta p &= 0.02386 \left(\frac{F_T}{100} \right)^2.
 \end{aligned} \tag{4-4}$$

As with the channel entrance data, there is significant scatter in the calculated pressure differences. Note that these pressure differences are small, so the scatter is somewhat exaggerated. Again we rely on the weight of the number of data points to yield a representative correlation. The gage data consist of 124 points and the manometer data consist of 97 points, so the correlations are based on 221 points each.

4.5 Pressure Difference across Single Pressure Plate

As we begin to discuss correlations in the bottom fitting, it is important to keep in mind that these correlations are hardware dependent. The 1972 CMX pressure profile data for the Mark 22 assembly that we are discussing was taken with a prototypic "A" monitor pin for KC reactors and with a single pressure plate bottom fitting insert. At this time, K reactor still uses the single pressure plate BFI, so this data is directly applicable to K reactor. P and L reactors now have double pressure plate bottom fitting inserts. The double pressure plate BFI pressure drop characteristics for the Mark 22 are available from recent experiments [8-9].

The pressure difference across the pressure plate is available from gage measurements as $P_V - P_{PR}$ and from manometer measurements as $0.179 (H_{VT} - H_{PRT})$. We expect that the pressure difference across the pressure plate is independent of the number of shell holes downstream. For this reason, we have correlated all of the gage and manometer data from all seven tests together (209 points) as

$$\Delta p = 1.027 \left(\frac{F_T}{100} \right)^2 \tag{4-5}$$

which is valid for H_2O at $17.5^\circ C$.

To confirm that there is no apparent effect from the number of shell holes, we have plotted the data for each of the seven tests separately in Figure 4-4. These data include both the gage and manometer data. Also shown in the last frame of Figure 4-4 is a plot of all of the data combined. On each plot the correlation in Eqn. 4-5 is given as a

reference. There does not appear to be any noticeable trend with the number of shell holes within the resolution of this data.

As a matter of interest, we have plotted the manometer and gage data separately for tests K2854 and K2855 in Figure 4-5. Both measurements seem to exhibit about the same amount of scatter.

4.6 Pressure Difference from Venturi Vena Contracta to Tank Bottom

The pressure difference from the venturi vena contracta to tank bottom is available from gage measurements as $P_V - P_T$ and from manometer measurements as $0.179 H_{VT}$. This pressure difference depends on the number of shell holes in the bottom fitting insert, so we must correlate as a function of total flow rate and number of shell holes. Since we expect the pressure difference to correlate with the square of the flow rate, we correlate each test in this form first. The data for each test and the corresponding square law fit are plotted in Figure 4-6. As a general rule, we have not eliminated data points in making these fits. However, we have made one exception to this rule for test K2857. There are only 21 data points for this test, and there is one data point which deviates enough to influence the least squares fit. So we have eliminated this one data point in obtaining the correlation shown in the figure.

The last frame in Figure 4-6 shows the coefficients from the square law fits plotted as a function of the number of shell holes divided by 100. These coefficients are fit very well with a fourth order polynomial. The resulting correlation for pressure difference from venturi vena contracta to tank bottom, in terms of the total assembly flow rate F_T and the total number of shell holes in the bottom fitting insert N_S , is

$$\Delta p = C_{VT}(N_S) \left(\frac{F_T}{100} \right)^2 \quad (4-6)$$

where

$$C_{VT}(N_S) = 4.558 - 16.03 \left(\frac{N_S}{100} \right) + 32.31 \left(\frac{N_S}{100} \right)^2 - 32.76 \left(\frac{N_S}{100} \right)^3 + 13.10 \left(\frac{N_S}{100} \right)^4$$

which is valid for H_2O at $17.5^\circ C$, for 10 to 80 shell holes, and for flows from 195 to 400 gpm.

4.7 Pressure Difference from Pressure Plate to Tank Bottom

The pressure difference from the pressure plate vena contracta to tank bottom is available from gage measurements as $P_{PR} - P_T$ and from manometer measurements as $0.179 H_{PRT}$. As in the last section, this pressure difference depends on the number of shell holes in the bottom fitting insert, so we must correlate as a function of total flow rate and number of shell holes. Again we expect the pressure difference to correlate

with the square of the flow rate, so we correlate each test in this form first. The data for each test and the corresponding square law fit are plotted in Figure 4-7. We have not eliminated any data points in making these fits.

The last frame in Figure 4-7 shows the coefficients from the square law fits plotted as a function of the number of shell holes divided by 100. These coefficients are fit very well with a fourth order polynomial. The resulting correlation for pressure difference from pressure plate vena contracta to tank bottom, in terms of the total assembly flow rate F_T and the total number of shell holes in the bottom fitting insert N_S , is

$$\Delta p = C_{PRT}(N_S) \left(\frac{F_T}{100} \right)^2 \quad (4-7)$$

where

$$C_{PRT}(N_S) = 3.614 - 16.67 \left(\frac{N_S}{100} \right) + 34.19 \left(\frac{N_S}{100} \right)^2 - 35.19 \left(\frac{N_S}{100} \right)^3 + 14.16 \left(\frac{N_S}{100} \right)^4$$

which is valid for H_2O at $17.5^\circ C$, for 10 to 80 shell holes, and for flows from 195 to 400 gpm.

4.8 Monitor Pin End Fitting Signal

The flow out the bottom fitting insert is split between the flow out the shell holes, which goes directly into the moderator tank, and the flow through the baffle plate, which goes onto the monitor pin. The monitor pin at the bottom of the assembly houses four thermocouples and a pressure tap. The pressure signal is used as a flow indicator during normal operation, and as such it is important to know the characteristics of this monitor pin signal.

The monitor pin signal is given on the data sheets as the manometer reading H_E in inches of mercury. We note that the density of H_2O near $10^\circ C$ is about 62.4 lbm/ft^3 and the density of mercury is 13.6 times that of water. To convert to psi,

$$\Delta p = (\rho_{Hg} - \rho_{H_2O})g\Delta H = (12.6)(62.4) \left(\frac{H_E}{12} \right) \frac{1}{144} = 0.455 H_E$$

In addition to the monitor pin signal data available from the pressure profile tests K2854-K2860, there were a number of shell hole calibration tests devoted strictly to calibrating the monitor pin signal. The number of shell holes was varied from 10 to 80, and tests were performed for both "A" and "B" type KC monitor pins. Of these tests, we have considered only the tests K2813-K2819, which used "A" type monitor pins. The monitor pin data for these tests are given in the appendix.

The monitor pin data from tests K2813-K2819 and K2854-K2860 are plotted in Figure 4-8. There is very good agreement in the data between the two series of tests. As

expected, the pressure signal for a given number of shell holes correlates well with the square of the flow rate. The square law fit for each case is given in the figure.

Figure 4-9 shows the coefficients from the square law fits plotted as a function of the number of shell holes divided by 100. A fourth order polynomial fits these coefficients very well. The resulting correlation for monitor pin signal, in terms of the total assembly flow rate F_T and the total number of shell holes in the bottom fitting insert N_S , is

$$\Delta p = C_{MP}(N_S) \left(\frac{F_T}{100} \right)^2 \quad (4-8)$$

where

$$C_{MP}(N_S) = 2.186 - 8.703 \left(\frac{N_S}{100} \right) + 18.05 \left(\frac{N_S}{100} \right)^2 - 18.84 \left(\frac{N_S}{100} \right)^3 + 7.710 \left(\frac{N_S}{100} \right)^4$$

which is valid for H_2O at 10-17.5°C, for 10 to 80 shell holes, and for flows from 195 to 400 gpm.

4.9 Pressure Difference from Plenum to Venturi Vena Contracta

For the consistency checks in the next section, it is convenient to have an overall pressure drop correlation. We have already correlated the pressure drop from the venturi vena contracta to tank bottom, and since the plots in Figure 4-6 show little scatter, we will use this correlation to account for variation in the number of shell holes. The pressure drop from the plenum to the venturi vena contracta should be independent of the number of shell holes, so we can fit all the data with a simple power law form. Manometer measurements are not available for this pressure drop, so we use the 124 data points available from the gage measurements $P_P - P_V$.

Figure 4-10 shows a plot of the 124 data points along with the power law fit

$$\Delta p = 3.903843 F^{1.860348} \quad (4-9)$$

Note that this fit is only useful as a consistency check and in this form can not be scaled to different temperatures or to different fluids.

5. CONSISTENCY OF CORRELATIONS

In the last section, we correlated the pressure difference data between various locations down the assembly. In this section, we examine the consistency of these correlations with one another and recommend the final correlations to represent the Mark 22 hydraulic characteristics. First, we consider the consistency of the correlations down each of the channels with one another and with the overall top stem to venturi correlation. Then we make a minor adjustment to the channel entrance and exit correlations so that the channel correlations are almost exactly consistent. Finally, we examine the consistency between the end fitting correlations.

In anticipation of the final results, we note that the recommended correlations for pressure differences in terms of the total flow rate are given in Table 5-1. The purge channel correlations appear as presented in Section 3.2 since there are no further consistency checks for these. Likewise, the plenum to top stem correlation discussed in Section 4.1, the pressure plate correlation discussed in Section 4.5, and the monitor pin correlation discussed in Section 4.8 appear as previously presented. As mentioned above, we make a minor adjustment to the channel entrance and exit correlations discussed in Sections 4.3 and 4.4, although the channel pressure drop correlations presented in Section 4.2 are unchanged. Finally, we choose to preserve the venturi to tank bottom correlation presented in Section 4.6. Hence, for consistency, we change the pressure plate to tank bottom correlation so that it sums with the drop across the pressure plate to give the venturi to tank bottom correlation.

5.1 Consistency of Channel Correlations

In Sections 4.2 to 4.4 we correlated the pressure differences through each of the channels. Each channel sees the same pressure drop from the top stem to the venturi, so the sums of each of these channel correlations should recover this same pressure drop. We must check that this is the case to ensure consistency in the correlations. At the same time, we will check whether the channel correlations agree with the overall correlation given in Section 4.9.

For a given flow rate F_T , we calculate (for each channel) the pressure difference from top stem to channel entrance using Eqns. 4-3, the pressure difference from channel entrance to channel exit using Eqns. 4-2, and the pressure difference from channel exit to venturi vena contracta using Eqns. 4-4. We then sum the pressure differences down each channel and compare. For the overall correlation, we calculate the pressure difference from plenum to venturi vena contracta using Eqn. 4-9 and subtract the pressure difference from plenum to top stem calculated from Eqn. 4-1. The results of these calculations are given in the following table. We see that there is excellent agreement in the computed pressure drops over the entire flow rate range of the correlations. The flow rate of 303 gpm represents a best fit point for these correlations.

Calculated Pressure Drops from Top Stem to Venturi Vena Contracta			
	200 gpm	303 gpm	400 gpm
Channel 2	12.8864	27.6721	46.1549
Channel 3	12.8589	27.6475	46.1538
Channel 4	12.9579	27.6699	45.9701
Overall	12.8545	27.6703	46.1869

5.2 Modification of Channel Entrance and Exit Correlations

Despite the excellent consistency of the channel correlations demonstrated in the last section, it is numerically convenient if the correlations match almost identically at the best fit flow rate. To this end, we consider a flow rate of 303 gpm and we assume that the overall correlation is correct at this point. We then make minor adjustments to the channel correlations to force the channel pressure drops to equal the overall pressure drop. Since the required modifications are very small, and since the channel entrance and exit pressure differences showed significant scatter, we modify only the entrance and exit correlations (Eqns. 4-3 and 4-4) and leave the channel frictional correlation as presented in Eqns. 4-2. The resulting correlations are given in Table 5-1. Note that the differences between Table 5-1 and Eqns. 4-3 and 4-4 are very small.

5.3 Consistency of End Fitting Correlations

We correlated the pressure difference from the venturi vena contracta to tank bottom by Eqn. 4-6. This same pressure drop must be represented by the pressure difference across the pressure plate, Eqn. 4-5, added to the pressure difference from the pressure plate vena contracta to tank bottom, Eqn. 4-7. The consistency of these correlations is shown in Figure 5-1. The agreement of the correlations is excellent for 20 to 60 shell holes. At 10 and 80 shell holes the difference is only a few percent.

The data for pressure difference from pressure plate vena contracta to tank bottom showed significant scatter. Hence, we recommend that the correlations for pressure difference from venturi to tank bottom, Eqn. 4-6, and for pressure difference across the pressure plate, Eqn. 4-5, be used to represent the end fitting hydraulics. Then, in place of Eqn. 4-7, the pressure difference from pressure plate vena contracta to tank bottom is obtained by subtracting Eqn. 4-5 from Eqn. 4-6. This representation is given in Table 5-1; a plot of this equation compared to the coefficient data is shown in Figure 7-1.

6. SCALING OF CORRELATIONS

The CMX hydraulic tests were performed with H₂O at relatively cold temperatures, but the intended reactor application is with D₂O at hotter temperatures. Thus, it is necessary to scale the correlations through property variations.

First, we convert the correlations in Table 5-1, which are in terms of total flow rate, to correlations in terms of channel flow rates. This is done by using the calculated flow splits given at the bottom of Table 5-1. By definition, the flow split S_i is $S_i = F_i/F_T$ where F_i is the channel flow rate. Substituting for F_T in terms of F_i and S_i , and putting in the values for S_i from Table 5-1, we obtain the correlations given in Table 6-1.

In order to modify the correlations for different temperatures and/or different fluids, we need to know how the pressure differences change with density and viscosity. Since we only have measurements with one fluid over a very small range of temperature, we must rely on theoretical understanding of the effects of property variation. For correlations of the square law form, we have implicitly assumed that

$$\Delta p \propto \rho V^2 \quad ,$$

so the correlation is scaled by a density ratio. For the channel correlations proportional to flow to the 1.8 power, we have assumed that

$$\Delta p \propto \rho \nu^{0.2} V^{1.8} \quad ,$$

as discussed in Section 3.3. In this case, the correlation coefficient is scaled as discussed in Section 3.4,

$$C_{scaled} = C_{ref} \left(\frac{\rho_{scaled}}{\rho_{ref}} \right) \left(\frac{\nu_{scaled}}{\nu_{ref}} \right)^{0.2} .$$

We have applied these scaling laws to scale the correlations to D₂O for a few cases of interest. The density and kinematic viscosity of H₂O and D₂O are obtained from the functions used in the FLOWTRAN code [7]. Correlations for D₂O at isothermal temperatures are given in Table 6-2, for 45°C, and in Table 6-3, for 65°C. A nominal full power case corresponding to the hydraulics manual is given in Table 6-4. A nominal half power case is given in Table 6-5.

7. COMPARISONS TO HYDRAULICS MANUAL

Having discussed the calculation of flow splits, the correlation of the data, and scaling, we now compare the results in this report to the past work of Ridenhour [4] and to the correlations given in the Mark 22 hydraulics manual [2]. We have already mentioned two discrepancies that affect the channel correlations. One is the calculational error that led to incorrect determination of the flow splits, as discussed in Section 3.4. This error has an impact of a few per cent. The other is the incorrect labeling of the distance between the channel pressure taps, as discussed in Section 2. The channel pressure drop was scaled by $185.5/161.5 = 1.149$ when it should have been scaled by $161.5/137.5 = 1.175$, which again has an impact of a few percent. Because these are known errors, we see no reason to compare the channel correlations further. We recommend use of the correlations given in Tables 6-1 to 6-5.

The plenum to top stem correlation given by Ridenhour has a coefficient of 0.331, which agrees with our value of 0.3300. Scaling to D_2O at $38^\circ C$, as in the hydraulics manual, gives 0.365 compared to our value of 0.363.

The pressure difference from the pressure plate vena contracta to tank bottom affects assembly effluent limits. Ridenhour correlated this pressure difference with a quadratic in the number of shell holes valid over the range $10 \leq N_S \leq 40$ as

$$\Delta p = \left[3.43 - 12.85 \left(\frac{N_S}{100} \right) + 14.06 \left(\frac{N_S}{100} \right)^2 \right] \left(\frac{F_T}{100} \right)^2$$

Figure 7-1 shows Ridenhour's quadratic plotted along with the fourth order polynomial recommended in Table 5-1. Ridenhour's fit is very good over its range of validity (the plotted extension outside the range of validity shows the danger in extrapolating correlations). Ridenhour's fit, scaled to D_2O , is reported in the hydraulics manual. However, the hydraulics manual recommends a power law fit valid for D_2O at $100^\circ C$,

$$\Delta p = 0.071 \left(\frac{N_S}{100} \right)^{-1.994} \left(\frac{F_T}{100} \right)^2$$

This correlation, scaled to H_2O by dividing by 1.0636, is plotted in Figure 7-1. Clearly, this correlation is not a good fit and should be discarded in favor of either Ridenhour's quadratic fit or the correlation given in Table 5-1.

The pressure difference from the venturi vena contracta to tank bottom affects channel effluent limits. Ridenhour correlated this pressure difference with a quadratic in the number of shell holes valid over the range $10 \leq N_S \leq 40$ as

$$\Delta p = \left[4.38 - 12.47 \left(\frac{N_S}{100} \right) + 13.51 \left(\frac{N_S}{100} \right)^2 \right] \left(\frac{F_T}{100} \right)^2$$

Figure 7-2 shows Ridenhour's quadratic plotted along with the fourth order polynomial recommended in Table 5-1. Again we see that Ridenhour's fit is very good over its range of validity. Ridenhour's fit is not reported in the hydraulics manual. Instead, a power law fit valid for D_2O at $100^\circ C$ is recommended as

$$\Delta p = 1.062 \left(\frac{N_S}{100} \right)^{-0.610} \left(\frac{F_T}{100} \right)^2$$

This correlation, scaled to H_2O by dividing by 1.0636, is plotted in Figure 7-2. Clearly, this correlation is not a good fit and should be discarded in favor of either Ridenhour's quadratic fit or the correlation given in Table 5-1.

The monitor pin end fitting signal is reported by Ridenhour in a somewhat confusing fashion. The correlation is given as a power law valid for $20 \leq N_S \leq 60$ as

$$\Delta H = 7.484 \left(\frac{N_S}{100} \right)^{-0.884} \left(\frac{F_T}{100} \right)^2,$$

where the pressure head is in inches of H_2O . What is confusing is that the correlation specifies "inches $10^\circ C$ H_2O for $100^\circ C$ D_2O " (i.e. this is not a standard head form in terms of the flowing fluid). What this means is that the manometer reading H_E has first been changed from inches of mercury to inches of H_2O at $10^\circ C$ by multiplying by the density ratio

$$\frac{\rho_{Hg} - \rho_{H_2O}}{\rho_{H_2O}},$$

and then has been scaled to D_2O at $100^\circ C$ by multiplying by the density ratio

$$\frac{\rho_{D_2O @ 100^\circ C}}{\rho_{H_2O @ 10^\circ C}}.$$

Thus, the coefficient 7.484 has already been scaled to D_2O (whereas all the rest of Ridenhour's correlations were for H_2O). However, the "inches" are still referenced to H_2O at $10^\circ C$, so to convert to pressure units we should multiply by $\rho_{H_2O} g$. Converting the correlation to psi, we have

$$\Delta p = (\rho_{H_2O} g) \left(\frac{1}{12 \times 144} \right) 7.484 \left(\frac{N_S}{100} \right)^{-0.884} \left(\frac{F_T}{100} \right)^2 = 0.270 \left(\frac{N_S}{100} \right)^{-0.884} \left(\frac{F_T}{100} \right)^2$$

Scaling back to H_2O for comparison, Ridenhour's correlation becomes

$$\Delta p = 0.2543 \left(\frac{N_S}{100} \right)^{-0.884} \left(\frac{F_T}{100} \right)^2.$$

This equation is plotted in Figure 4-9 where we see that the fit is very good for the range of validity $20 \leq N_S \leq 60$.

The form of Ridenhour's correlation is confusing because a head form is usually given in terms of the flowing fluid. That is, the manometer reading H_E is converted to height of the flowing fluid, light water in this case, as

$$\Delta H = H_E \left(\frac{\rho_{Hg} - \rho_{H_2O}}{\rho_{H_2O}} \right) .$$

Then the pressure drop for light water flowing would be obtained by multiplying by $\rho_{H_2O}g$, whereas the pressure drop for heavy water flowing would be obtained by multiplying by $\rho_{D_2O}g$. Apparently, the nonstandard form given by Ridenhour led to an error in the hydraulics manual because someone assumed that his equation was in standard head form. The hydraulics manual gives the coefficient for D_2O as 0.288 instead of 0.270. In a 1983 memo [10], Whatley pointed out that this error was due to scaling for D_2O a second time. That is, the ratio 0.288/0.270 is the density ratio ρ_{D_2O}/ρ_{H_2O} . Whatley indicated that the correct coefficient is 0.270.

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2. Technical Manual, "Hydraulics and Heat Transfer of the Mark 16-16B Assembly," Savannah River Laboratory, DPSTM-16(H), March 1981.
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5. W. H. Baker, "Mark 22 Assembly for Tritium Production," Savannah River Laboratory, DPST-71-439, October 1971 (Secret).
6. F. M. White, Fluid Mechanics, McGraw-Hill Book Co., 1979.
7. Technical Manual, "FLOWTRAN: An Algorithm for Describing the Thermal-Hydraulic Behavior of SRP Assemblies," Savannah River Laboratory, DPSTM-140, Version 16.1, Revision B, October 1988 (see Appendix A.2 "Fluid Material Properties")
8. V. Whatley, "Bottom Fitting Insert for Mark 22 Assemblies in PL Reactors," Savannah River Laboratory, DPST-86-542, June 1986.
9. V. Whatley, "Bottom Fitting Insert for Mark 22 Assemblies in KC Reactors," Savannah River Laboratory, DPST-86-749, October 1986.
10. V. Whatley, "Mark 22 Bottom Fitting Pressure Drop for KC Type A Monitor Pin," Savannah River Laboratory, Memo to D. W. Pepper, March 1, 1983.

TABLE 3-1. REFERENCE TEMPERATURES FOR TEST RUNS

Test	Date - Temp	Run Date Recorded	Run Date Estimated	Temperature for Run from Date	Temperature for Run Estimated
K2854	3-17-72 12C				
	? ?		1		15C
	? ?		2		17C
	3-22-72 17C		3	17C	
K2855	3-22-72 17C		1	17C	
	3-23-72 13C				
	3-27-72 13C				
	3-28-72 13C		2	13C	
	3-29-72 15C		3	15C	
K2856	3-29-72 17C				
	3-30-72 17C		1	17C	
	4-03-72 16C		2	16C	
	4-05-72 15C		3	15C	
K2857	4-05-72 15C				
	4-06-72 15C		1	15C	
	4-07-72 16C		2	16C	
	4-10-72 15C		3	15C	
K2858	4-11-72 ?	1			17C
	4-12-72 18C	2		18C	
	4-13-72 19C	3		19C	
K2859	4-13-72 19C	1		19C	
	4-14-72 ?	2			19C
	4-17-72 ?	3			22C
K2860	4-17-72 22C	1		22C	
	4-18-72 21C	2		21C	
	4-18-72 22C	3		22C	

Average temperature = 17.5C

REFERENCE TEMPERATURES USED FOR TESTS

Test	Reference Temperature
K2854	16C
K2855	15C
K2856	16C
K2857	15C
K2858	18C
K2859	20C
K2860	22C

TABLE 3-2. Channel Flow Splits Calculated by Ridenhour's Method

Test	Power Law Fits to Channel Data						Relative Flow Splits		
	Channel 2		Channel 3		Channel 4		Ch2	Ch3	Ch4
	Coef	Power	Coef	Power	Coef	Power			
K2851	2.674955	1.767128	2.608010	1.763862	2.804595	1.812277	0.3026	0.4815	0.2159
K2852	2.562209	1.804720	2.427315	1.832175	2.613463	1.846240	0.3052	0.4820	0.2128
K2854	2.631626	1.764839	2.454381	1.822106	2.623001	1.849459	0.2991	0.4853	0.2155
K2855	2.641613	1.774589	2.473967	1.819331	2.642626	1.849771	0.3012	0.4836	0.2152
K2856	2.629907	1.771603	2.401996	1.836012	2.673280	1.835431	0.3011	0.4840	0.2148
K2857	2.765745	1.736913	2.805010	1.710946	2.842911	1.787563	0.3001	0.4861	0.2138
K2858	2.565843	1.781555	2.481087	1.802051	2.705572	1.813447	0.3023	0.4844	0.2133
K2859	2.649914	1.749228	2.459049	1.800904	2.703498	1.810066	0.2998	0.4859	0.2144
K2860	2.537862	1.780344	2.494196	1.779404	2.621599	1.831303	0.3027	0.4823	0.2150
Average							0.3014	0.4842	0.2143
Minimum							0.2991	0.4820	0.2128
Maximum							0.3052	0.4861	0.2155

TABLE 3-3

Flow Splits Calculated from Measured Pressures
Using Colebrook Equation to Compute Flow
(Roughness $e = 5.0e-6$ ft)

	Ch2	Ch3	Ch4	Qcalc/Qmeas
K2854 (32 points)				
average	.3029727	.4857461	.2112812	1.014406
minimum	.2990327	.4822049	.2075634	.993709
maximum	.3065466	.4894806	.2141021	1.025153
K2855 (29 points)				
average	.3037694	.4848788	.2113518	1.016557
minimum	.300356	.4818701	.2073444	.9949318
maximum	.3069527	.4909046	.2141367	1.02987
K2856 (30 points)				
average	.3045452	.4832445	.2122103	1.014259
minimum	.2991102	.4511293	.2097657	.9445903
maximum	.3234836	.4903694	.2253871	1.031103
K2857 (27 points)				
average	.3036335	.4852619	.2111046	1.020235
minimum	.2972087	.4747252	.2056585	.9787909
maximum	.3084918	.4932308	.2176874	1.03976
K2858 (30 points)				
average	.3035604	.4849916	.211448	1.016188
minimum	.2990772	.4806809	.2074382	1.008501
maximum	.3083141	.4907066	.2139056	1.023089
K2859 (30 points)				
average	.3039514	.4842663	.2117823	1.018545
minimum	.3001875	.4713315	.2075167	.9898354
maximum	.3111861	.4905805	.2174824	1.03283
K2860 (30 points)				
average	.3042584	.4837012	.2120403	1.018758
minimum	.3017399	.4772398	.2093406	.9988295
maximum	.3081658	.488119	.2165662	1.027714
TEST AVERAGES				
average	.303813	.4845844	.2116026	1.016993
minimum	.3029727	.4832445	.2111046	1.014259
maximum	.3045452	.4857461	.2122103	1.020235

TABLE 3-4

Flow Splits Calculated from Measured Pressures
Using Colebrook Equation to Compute Flow
(Roughness $e = 1.13e-5$ ft)

	Ch2	Ch3	Ch4	Qcalc/Qmeas
K2854 (32 points)				
average	.3032447	.4854685	.2112867	.998022
minimum	.2994086	.4820152	.2076056	.9813463
maximum	.3067682	.4892305	.2140764	1.009662
K2855 (29 points)				
average	.3040317	.4846119	.2113564	1.00025
minimum	.3007128	.4816513	.2073832	.9827926
maximum	.3071908	.4906411	.2141094	1.014605
K2856 (30 points)				
average	.3048063	.4829867	.2122069	.997626
minimum	.2994545	.4512039	.2097895	.93332
maximum	.3235297	.490006	.2252664	1.018044
K2857 (27 points)				
average	.3038919	.4849969	.2111111	1.004168
minimum	.2974686	.474544	.2057119	.9607276
maximum	.3087144	.4929488	.2176147	1.022476
K2858 (30 points)				
average	.3038383	.4847099	.2114519	.9989456
minimum	.2994293	.4804248	.2074783	.9938527
maximum	.3084925	.4904303	.2138816	1.009702
K2859 (30 points)				
average	.304233	.4839851	.2117819	1.000685
minimum	.3005688	.4711864	.2075575	.9710928
maximum	.3114042	.4902966	.2174094	1.017574
K2860 (30 points)				
average	.3045438	.4834197	.2120365	1.000343
minimum	.3020949	.4769969	.209365	.9769404
maximum	.308449	.4878506	.2165033	1.012757
TEST AVERAGES				
average	.3040842	.4843113	.2116045	1.000006
minimum	.3032447	.4829867	.2111111	.997626
maximum	.3048063	.4854685	.2122069	1.004168

TABLE 5-1

Mark 22 Pressure Differences (psi) in Terms of Total Assembly Flow Rate
(KC Reactor, A pin ; single pressure plate BFI)

Plenum to top stem (H ₂ O at 17.5°C)	$0.3300 \left(\frac{F_T}{100} \right)^2$		
	<u>Channel 2</u>	<u>Channel 3</u>	<u>Channel 4</u>
Top stem to channel entrance (H ₂ O at 17.5°C)	$0.5839 \left(\frac{F_T}{100} \right)^2$	$0.5458 \left(\frac{F_T}{100} \right)^2$	$0.3857 \left(\frac{F_T}{100} \right)^2$
Channel entrance to channel exit (H ₂ O at 17.5°C)	$2.9897 \left(\frac{F_T}{100} \right)^{1.8}$	$2.9292 \left(\frac{F_T}{100} \right)^{1.8}$	$3.2508 \left(\frac{F_T}{100} \right)^{1.8}$
Channel exit to venturi v.c. (H ₂ O at 17.5°C)	$0.03481 \left(\frac{F_T}{100} \right)^2$	$0.12138 \left(\frac{F_T}{100} \right)^2$	$0.02389 \left(\frac{F_T}{100} \right)^2$

Venturi v.c. to pressure plate v.c. (H ₂ O at 17.5°C)	$1.027 \left(\frac{F_T}{100} \right)^2$
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Pressure plate v.c. to tank bottom (H ₂ O at 17.5°C)	$C_{PT}(N_S) \left(\frac{F_T}{100} \right)^2$
--	--

where $C_{PT}(N_S) = 3.531 - 16.03 \left(\frac{N_S}{100} \right) + 32.31 \left(\frac{N_S}{100} \right)^2 - 32.76 \left(\frac{N_S}{100} \right)^3 + 13.10 \left(\frac{N_S}{100} \right)^4$

Monitor pin signal (H ₂ O at 17.5°C)	$C_{MP}(N_S) \left(\frac{F_T}{100} \right)^2$
--	--

where $C_{MP}(N_S) = 2.186 - 8.703 \left(\frac{N_S}{100} \right) + 18.05 \left(\frac{N_S}{100} \right)^2 - 18.84 \left(\frac{N_S}{100} \right)^3 + 7.710 \left(\frac{N_S}{100} \right)^4$

N_S = number of shell holes in BFI ($10 \leq N_S \leq 80$)

F_T = total assembly flow rate in gpm ($195 \leq F_T \leq 400$)

Purge channels	Channel 1	Channel 5
Top stem to venturi v.c. (H ₂ O at 17.5°C)	$31200 \left(\frac{F_1}{100} \right)^2$	$112500 \left(\frac{F_5}{100} \right)^2$

where F_1 and F_5 are purge channel flow rates in gpm

Flow Splits	% of total flow
Channel 1	0.9828
Channel 2	29.9601
Channel 3	47.6098
Channel 4	20.9297
Channel 5	0.5176

Best fit near $F_T = 303$ gpm

TABLE 6-1

Mark 22 Pressure Differences (psi) in Terms of Channel Flow Rates
(KC Reactor, A pin ; single pressure plate BFI)

Plenum to top stem (H ₂ O at 17.5°C)	$0.3300 \left(\frac{F_T}{100} \right)^2$		
	<u>Channel 2</u>	<u>Channel 3</u>	<u>Channel 4</u>
Top stem to channel entrance (H ₂ O at 17.5°C)	$6.5051 \left(\frac{F_2}{100} \right)^2$	$2.4079 \left(\frac{F_3}{100} \right)^2$	$8.8046 \left(\frac{F_4}{100} \right)^2$
Channel entrance to channel exit (H ₂ O at 17.5°C)	$26.173 \left(\frac{F_2}{100} \right)^{1.8}$	$11.140 \left(\frac{F_3}{100} \right)^{1.8}$	$54.276 \left(\frac{F_4}{100} \right)^{1.8}$
Channel exit to venturi v.c. (H ₂ O at 17.5°C)	$0.3878 \left(\frac{F_2}{100} \right)^2$	$0.5355 \left(\frac{F_3}{100} \right)^2$	$0.5454 \left(\frac{F_4}{100} \right)^2$
Venturi v.c. to pressure plate v.c. (H ₂ O at 17.5°C)	$1.027 \left(\frac{F_T}{100} \right)^2$		

Pressure plate v.c. to tank bottom (H ₂ O at 17.5°C)	$C_{PT}(N_S) \left(\frac{F_T}{100} \right)^2$
--	--

where $C_{PT}(N_S) = 3.531 - 16.03 \left(\frac{N_S}{100} \right) + 32.31 \left(\frac{N_S}{100} \right)^2 - 32.76 \left(\frac{N_S}{100} \right)^3 + 13.10 \left(\frac{N_S}{100} \right)^4$

Monitor pin signal (H ₂ O at 17.5°C)	$C_{MP}(N_S) \left(\frac{F_T}{100} \right)^2$
--	--

where $C_{MP}(N_S) = 2.186 - 8.703 \left(\frac{N_S}{100} \right) + 18.05 \left(\frac{N_S}{100} \right)^2 - 18.84 \left(\frac{N_S}{100} \right)^3 + 7.710 \left(\frac{N_S}{100} \right)^4$

N_S = number of shell holes in BFI ($10 \leq N_S \leq 80$)

F_T = total assembly flow rate in gpm = $F_1 + F_2 + F_3 + F_4 + F_5$ ($195 \leq F_T \leq 400$)

F_i = channel flow rates in gpm ($i = 1, \dots, 5$)

Purge channels	Channel 1	Channel 5
Top stem to venturi v.c. (H ₂ O at 17.5°C)	$31200 \left(\frac{F_1}{100} \right)^2$	$112500 \left(\frac{F_5}{100} \right)^2$

where F_1 and F_5 are purge channel flow rates in gpm

Flow Splits	% of total flow
Channel 1	0.9828
Channel 2	29.9601
Channel 3	47.6098
Channel 4	20.9297
Channel 5	0.5176

Best fit near $F_T = 303$ gpm

TABLE 6-2

Mark 22 Pressure Differences (psi) for D₂O at Isothermal 45°C
(KC Reactor, A pin ; single pressure plate BFI)

Plenum to top stem (D ₂ O at 45°C)	$0.362 \left(\frac{F_T}{100} \right)^2$		
	<u>Channel 2</u>	<u>Channel 3</u>	<u>Channel 4</u>
Top stem to channel entrance (D ₂ O at 45°C)	$7.1337 \left(\frac{F_2}{100} \right)^2$	$2.6406 \left(\frac{F_3}{100} \right)^2$	$9.6555 \left(\frac{F_4}{100} \right)^2$
Channel entrance to channel exit (D ₂ O at 45°C)	$26.020 \left(\frac{F_2}{100} \right)^{1.8}$	$11.075 \left(\frac{F_3}{100} \right)^{1.8}$	$53.960 \left(\frac{F_4}{100} \right)^{1.8}$
Channel exit to venturi v.c. (D ₂ O at 45°C)	$0.4253 \left(\frac{F_2}{100} \right)^2$	$0.5872 \left(\frac{F_3}{100} \right)^2$	$0.5981 \left(\frac{F_4}{100} \right)^2$
Venturi v.c. to pressure plate v.c. (D ₂ O at 45°C)	$1.126 \left(\frac{F_T}{100} \right)^2$		
Pressure plate v.c. to tank bottom (D ₂ O at 45°C)	$1.09664 \times C_{PT}(N_S) \left(\frac{F_T}{100} \right)^2$		
where	$C_{PT}(N_S) = 3.531 - 16.03 \left(\frac{N_S}{100} \right) + 32.31 \left(\frac{N_S}{100} \right)^2 - 32.76 \left(\frac{N_S}{100} \right)^3 + 13.10 \left(\frac{N_S}{100} \right)^4$		
Monitor pin signal (D ₂ O at 45°C)	$1.09664 \times C_{MP}(N_S) \left(\frac{F_T}{100} \right)^2$		
where	$C_{MP}(N_S) = 2.186 - 8.703 \left(\frac{N_S}{100} \right) + 18.05 \left(\frac{N_S}{100} \right)^2 - 18.84 \left(\frac{N_S}{100} \right)^3 + 7.710 \left(\frac{N_S}{100} \right)^4$		

N_S = number of shell holes in BFI ($10 \leq N_S \leq 80$)

F_T = total assembly flow rate in gpm = $F_1 + F_2 + F_3 + F_4 + F_5$ ($195 \leq F_T \leq 400$)

F_i = channel flow rates in gpm ($i = 1, \dots, 5$)

Purge channels	Channel 1	Channel 5
Top stem to venturi v.c. (D ₂ O at 45°C)	$34215 \left(\frac{F_1}{100} \right)^2$	$123372 \left(\frac{F_5}{100} \right)^2$

where F_1 and F_5 are purge channel flow rates in gpm

Flow Splits	% of total flow
Channel 1	0.9458
Channel 2	29.9655
Channel 3	47.5766
Channel 4	21.0140
Channel 5	0.4981

Best fit near $F_T = 303$ gpm

TABLE 6-3

Mark 22 Pressure Differences (psi) for D₂O at Isothermal 65°C
(KC Reactor, A pin ; single pressure plate BFI)

Plenum to top stem (D ₂ O at 65°C)	$0.359 \left(\frac{F_T}{100} \right)^2$		
	<u>Channel 2</u>	<u>Channel 3</u>	<u>Channel 4</u>
Top stem to channel entrance (D ₂ O at 65°C)	$7.0679 \left(\frac{F_2}{100} \right)^2$	$2.6162 \left(\frac{F_3}{100} \right)^2$	$9.5664 \left(\frac{F_4}{100} \right)^2$
Channel entrance to channel exit (D ₂ O at 65°C)	$24.171 \left(\frac{F_2}{100} \right)^{1.8}$	$10.288 \left(\frac{F_3}{100} \right)^{1.8}$	$50.125 \left(\frac{F_4}{100} \right)^{1.8}$
Channel exit to venturi v.c. (D ₂ O at 65°C)	$0.4214 \left(\frac{F_2}{100} \right)^2$	$0.5818 \left(\frac{F_3}{100} \right)^2$	$0.5925 \left(\frac{F_4}{100} \right)^2$
Venturi v.c. to pressure plate v.c. (D ₂ O at 65°C)	$1.116 \left(\frac{F_T}{100} \right)^2$		

Pressure plate v.c. to tank bottom
(D₂O at 65°C)

$$1.08652 \times C_{PT}(N_S) \left(\frac{F_T}{100} \right)^2$$

where $C_{PT}(N_S) = 3.531 - 16.03 \left(\frac{N_S}{100} \right) + 32.31 \left(\frac{N_S}{100} \right)^2 - 32.76 \left(\frac{N_S}{100} \right)^3 + 13.10 \left(\frac{N_S}{100} \right)^4$

Monitor pin signal
(D₂O at 65°C)

$$1.08652 \times C_{MP}(N_S) \left(\frac{F_T}{100} \right)^2$$

where $C_{MP}(N_S) = 2.186 - 8.703 \left(\frac{N_S}{100} \right) + 18.05 \left(\frac{N_S}{100} \right)^2 - 18.84 \left(\frac{N_S}{100} \right)^3 + 7.710 \left(\frac{N_S}{100} \right)^4$

N_S = number of shell holes in BFI ($10 \leq N_S \leq 80$)

F_T = total assembly flow rate in gpm = $F_1 + F_2 + F_3 + F_4 + F_5$ ($195 \leq F_T \leq 400$)

F_i = channel flow rates in gpm ($i = 1, \dots, 5$)

Purge channels	Channel 1	Channel 5
Top stem to venturi v.c. (D ₂ O at 65°C)	$33899 \left(\frac{F_1}{100} \right)^2$	$122233 \left(\frac{F_5}{100} \right)^2$

where F_1 and F_5 are purge channel flow rates in gpm

Flow Splits	% of total flow
Channel 1	0.9204
Channel 2	29.9682
Channel 3	47.5494
Channel 4	21.0774
Channel 5	0.4847

Best fit near $F_T = 312.8$ gpm

TABLE 6-4

Mark 22 Pressure Differences (psi) for D₂O at Nominal Full Power
(KC Reactor, A pin ; single pressure plate BFI)

Plenum to top stem (D ₂ O at 38°C)	$0.363 \left(\frac{F_T}{100} \right)^2$		
	<u>Channel 2</u>	<u>Channel 3</u>	<u>Channel 4</u>
Top stem to channel entrance (D ₂ O at 38°C)	$7.1536 \left(\frac{F_2}{100} \right)^2$	$2.6479 \left(\frac{F_3}{100} \right)^2$	$9.6824 \left(\frac{F_4}{100} \right)^2$
Channel entrance to channel exit (D ₂ O at 65°C)	$24.171 \left(\frac{F_2}{100} \right)^{1.8}$	$10.288 \left(\frac{F_3}{100} \right)^{1.8}$	$50.125 \left(\frac{F_4}{100} \right)^{1.8}$
Channel exit to venturi v.c. (D ₂ O at 100°C)	$0.4125 \left(\frac{F_2}{100} \right)^2$	$0.5696 \left(\frac{F_3}{100} \right)^2$	$0.5801 \left(\frac{F_4}{100} \right)^2$

Venturi v.c. to pressure plate v.c. (D ₂ O at 100°C)	$1.092 \left(\frac{F_T}{100} \right)^2$
--	--

Pressure plate v.c. to tank bottom (D ₂ O at 100°C)	$1.06365 \times C_{PT}(N_S) \left(\frac{F_T}{100} \right)^2$
---	---

$$\text{where } C_{PT}(N_S) = 3.531 - 16.03 \left(\frac{N_S}{100} \right) + 32.31 \left(\frac{N_S}{100} \right)^2 - 32.76 \left(\frac{N_S}{100} \right)^3 + 13.10 \left(\frac{N_S}{100} \right)^4$$

Monitor pin signal (D ₂ O at 100°C)	$1.06365 \times C_{MP}(N_S) \left(\frac{F_T}{100} \right)^2$
---	---

$$\text{where } C_{MP}(N_S) = 2.186 - 8.703 \left(\frac{N_S}{100} \right) + 18.05 \left(\frac{N_S}{100} \right)^2 - 18.84 \left(\frac{N_S}{100} \right)^3 + 7.710 \left(\frac{N_S}{100} \right)^4$$

N_S = number of shell holes in BFI ($10 \leq N_S \leq 80$)

F_T = total assembly flow rate in gpm = $F_1 + F_2 + F_3 + F_4 + F_5$ ($195 \leq F_T \leq 400$)

F_i = channel flow rates in gpm ($i = 1, \dots, 5$)

Purge channels	Channel 1	Channel 5
Top stem to venturi v.c. (D ₂ O at 38°C)	$34310 \left(\frac{F_1}{100} \right)^2$	$123716 \left(\frac{F_5}{100} \right)^2$

where F_1 and F_5 are purge channel flow rates in gpm

Flow Splits	% of total flow
Channel 1	0.9158
Channel 2	29.9608
Channel 3	47.5600
Channel 4	21.0811
Channel 5	0.4823

Best fit near $F_T = 312.5$ gpm

TABLE 6-5

Mark 22 Pressure Differences (psi) for D₂O at Nominal Half Power
(KC Reactor, A pin ; single pressure plate BFI)

Plenum to top stem (D ₂ O at 30°C)	$0.364 \left(\frac{F_T}{100} \right)^2$		
	<u>Channel 2</u>	<u>Channel 3</u>	<u>Channel 4</u>
Top stem to channel entrance (D ₂ O at 30°C)	$7.1744 \left(\frac{F_2}{100} \right)^2$	$2.6556 \left(\frac{F_3}{100} \right)^2$	$9.7105 \left(\frac{F_4}{100} \right)^2$
Channel entrance to channel exit (D ₂ O at 45°C)	$26.020 \left(\frac{F_2}{100} \right)^{1.8}$	$11.075 \left(\frac{F_3}{100} \right)^{1.8}$	$53.960 \left(\frac{F_4}{100} \right)^{1.8}$
Channel exit to venturi v.c. (D ₂ O at 60°C)	$0.4224 \left(\frac{F_2}{100} \right)^2$	$0.5833 \left(\frac{F_3}{100} \right)^2$	$0.5940 \left(\frac{F_4}{100} \right)^2$
Venturi v.c. to pressure plate v.c. (D ₂ O at 60°C)	$1.119 \left(\frac{F_T}{100} \right)^2$		

Pressure plate v.c. to tank bottom (D ₂ O at 60°C)	$1.08924 \times C_{PT}(N_S) \left(\frac{F_T}{100} \right)^2$
--	---

$$\text{where } C_{PT}(N_S) = 3.531 - 16.03 \left(\frac{N_S}{100} \right) + 32.31 \left(\frac{N_S}{100} \right)^2 - 32.76 \left(\frac{N_S}{100} \right)^3 + 13.10 \left(\frac{N_S}{100} \right)^4$$

Monitor pin signal (D ₂ O at 60°C)	$1.08924 \times C_{MP}(N_S) \left(\frac{F_T}{100} \right)^2$
--	---

$$\text{where } C_{MP}(N_S) = 2.186 - 8.703 \left(\frac{N_S}{100} \right) + 18.05 \left(\frac{N_S}{100} \right)^2 - 18.84 \left(\frac{N_S}{100} \right)^3 + 7.710 \left(\frac{N_S}{100} \right)^4$$

N_S = number of shell holes in BFI ($10 \leq N_S \leq 80$)

F_T = total assembly flow rate in gpm = $F_1 + F_2 + F_3 + F_4 + F_5$ ($195 \leq F_T \leq 400$)

F_i = channel flow rates in gpm ($i = 1, \dots, 5$)

Purge channels	Channel 1	Channel 5
Top stem to venturi v.c. (D ₂ O at 30°C)	$34410 \left(\frac{F_1}{100} \right)^2$	$124074 \left(\frac{F_5}{100} \right)^2$

where F_1 and F_5 are purge channel flow rates in gpm

Flow Splits	% of total flow
Channel 1	0.9436
Channel 2	29.9630
Channel 3	47.5800
Channel 4	21.0164
Channel 5	0.4969

Best fit near $F_T = 302.8$ gpm

Calibration of Station Orifice for Flow Rate Measurement

Figure 2-1. Data and Correlations for Calibration of Station Orifice

Figure 3-1. Drawings of Orifices for Purge Channels

**(a) Button Orifice for Outer Purge Channel 1
(See drawing ST-MDX4-8444)**

**(b) Cone Spray Nozzle Assembly for Axial Purge Channel 5
(See drawings ST-MDX3-8313 and ST-MDX3-8314)**

Figure 3-2. Data and Correlation for Outer Channel Purge Flow

Figure 3-3. Channel Pressure Drops for Test K2851

Figure 3-4. Channel Pressure Drops for Test K2852

Figure 3-5. Channel Pressure Drops for Test K2854

Figure 3-6. Channel Pressure Drops for Test K2855

Figure 3-7. Channel Pressure Drops for Test K2856

Figure 3-8. Channel Pressure Drops for Test K2857

Figure 3-9. Channel Pressure Drops for Test K2858

Figure 3-10. Channel Pressure Drops for Test K2859

Figure 3-11. Channel Pressure Drops for Test K2860

Friction Factors from Colebrook Eqn for Typical Test Flows (200-400 gpm)

Figure 3-12. Friction Factors for Mark 22 Channels with Typical Total H₂O Flow Rates

Figure 3-13. Kinematic Viscosity for Light and Heavy Water

Figure 3-14. Comparisons of Theoretical Channel Pressure Drops with Data

Figure 3-14. (continued)

Figure 4-1. Pressure Difference from Plenum to Top Stem

Figure 4-2. Pressure Difference from Top Stem to Channel Entrance

Figure 4-3. Pressure Difference from Channel Exit to Venturi

Figure 4-4. Pressure Difference Across Single Pressure Plate. Plots Showing Insensitivity to Number of Shell Holes.

MARK 22 ΔP ACROSS SINGLE PRESSURE PLATE

MARK 22 ΔP ACROSS SINGLE PRESSURE PLATE

MARK 22 ΔP ACROSS SINGLE PRESSURE PLATE

MARK 22 ΔP ACROSS SINGLE PRESSURE PLATE

Figure 4-4. (continued)

Figure 4-5. Pressure Difference Across Single Pressure Plate.
Gage and Manometer Data Plotted Separately

Figure 4-6. Pressure Difference from Venturi to Tank Bottom

Figure 4-6. (continued)

Figure 4-7. Pressure Difference from Pressure Plate to Tank Bottom

Figure 4-7. (continued)

Figure 4-8. End Fitting Signal for KC "A" Monitor Pin

MARK 22 KC "A" MONITOR PIN SIGNAL

MARK 22 KC "A" MONITOR PIN SIGNAL

MARK 22 KC "A" MONITOR PIN SIGNAL

MARK 22 KC "A" MONITOR PIN SIGNAL

Figure 4-8. (continued)

Figure 4-9. Correlation Coefficient for End Fitting Signal as a Function of the Number of Shell Holes.

Figure 4-10. Overall Pressure Difference from Plenum to Venturi

Figure 5-1. Consistency of End Fitting Correlations for Venturi to Tank Bottom, Venturi to Pressure Plate, and Pressure Plate to Tank Bottom

Figure 7-1. Comparison of Hydraulics Manual Correlation with Correlations for Pressure Plate to Tank Bottom Δp

MARK 22 VENTURI VC TO TANK BOTTOM

Figure 7-2. Comparison of Hydraulics Manual Correlation with Correlations for Venturi to Tank Bottom Δp

APPENDIX

Compilation of Original Data Sheets

The hydraulic test data for the Mark 22 assembly were recorded on CMX data sheets K2791-K2860. A subset of this data is analyzed in this report. Those data sheets used for this report are reproduced in this appendix.

Missing entries marked with "-" occur where the pressure differences were out of range of the manometer. A few missing entries are marked with "+", which signifies a bad data point that was struck from the data sheet.

Data Set K2791 1/18/72 Station Orifice Calibration
 2.12" ID orifice, "B" test station, H2O temp 12-14.2C

Run	HF	min	sec	FLOW
1	30.5	6	54.2	194.9
	40.4	5	59.5	224.5
	55.1	5	7.1	262.6
	65.2	4	42.2	285.9
	84.8	4	8.4	324.8
2	30.1	6	56.7	193.7
	39.8	6	2.5	222.6
	54.8	5	8.5	261.6
	65.1	4	46.2	282.0
	84.8	4	8.2	325.1
3	30.2	6	58.5	192.8
	40.3	6	1.4	223.3
	54.4	5	9.6	260.7
	65.2	4	45.6	282.6
	85.1	4	8.9	324.2
4	30.2	6	57.3	193.4
	40.3	6	0.8	223.7
	55.3	5	8.2	261.8
	65.1?	4	38.6	289.7
	85.4?	4	10.3	322.4

HF - station orifice manometer reading (cm Hg)

min,sec - time to collect 1345 gal

FLOW - flow rate calculated from measured time to collect 1345 gal

MONITOR PIN SIGNAL DATA FROM DATA SETS K2813-K2819

The following monitor pin data is supplemental to the pressure profile tests K2854-K2860. As such, the complete data sheets are not compiled here; only the "A" pin data signal and flow are given.

These data sets were part of a series of shell calibration tests for both "A" and "B" monitor pins for KC reactors. The flow was obtained from the station orifice manometer measurement HF, which is not given here. Also given on these data sheets, but not repeated here, were the plenum and tank bottom pressures.

K2813 2/1/72 80 shell holes A pin , 11C		K2814 2/2/72 60 shell holes A pin , 10C		K2815 2/3/72 50 shell holes A pin , 10C	
Flow (gpm)	HE (in Hg)	Flow (gpm)	HE (in Hg)	Flow (gpm)	HE (in Hg)
334.3	6.90	296.0	7.55	296.0	9.2
368.7	8.5	334.3	9.55	334.2	11.50
401.7	10.0	369.0	11.6	370.1	14.05
		402.8	13.85	402.5	16.8
335.6	7.05				
370.1	8.65	295.8	7.45	296.0	9.05
401.8	10.2	334.2	9.4	333.8	11.45
		369.4	11.55	369.7	14.1
335.1	7.10	402.1	13.85	402.9	16.8
369.9	8.55				
402.8	10.2	295.2	7.3	296.4	8.95
		334.5	9.5	333.6	11.45
		368.7	11.55	370.2	14.1
		401.8	13.85	401.5	16.6

K2816 2/3/72 40 shell holes A pin , 10C		K2817 2/3/72 30 shell holes A pin , 10C		K2818 2/4/72 20 shell holes A pin , 9C		K2819 2/4/72 10 shell holes A pin , 10C	
Flow (gpm)	HE (in Hg)	Flow (gpm)	HE (in Hg)	Flow (gpm)	HE (in Hg)	Flow (gpm)	HE (in Hg)
250.6	8.05	250.1	10.3	194.9	8.65	195.3	12.35
295.8	11.25	296.2	14.45	248.9	13.95	250.4	20.4
333.6	14.25	334.7	18.45	296.6	20.0	296.4	28.5
370.1	17.50	369.7	22.55	334.5	26.10		
402.3	20.85	402.8	26.75	353.4	28.20	194.3	12.10
						250.9	20.4
249.9	8.0	248.6	10.2	194.9	8.45	296.4	28.4
296.0	11.25	295.6	14.35	249.9	14.05		
334.0	14.4	334.3	18.35	297.0	20.0	195.3	12.10
369.7	17.4	369.9	22.55	335.6	25.5	250.1	20.25
402.5	20.85	402.5	26.8	353.3	28.15	297.0	28.05
250.4	8.0	249.4	10.0	194.0	8.5		
296.6	11.3	295.8	14.3	251.1	14.20		
334.5	14.35	334.5	18.45	296.4	19.65		
369.4	17.6	369.0	22.5	335.4	25.5		
402.5	20.65	401.5	26.8	353.3	28.3		

Data Set K2848 2/23/72 Station Orifice Calibration
 2.12" ID orifice, "B" test station, H2O temp 11C

Run	HF	min	sec	FLOW
1	30.7	6	54.5	194.7
	50.5	5	20.0	252.2
	70.2	4	34.6	293.9
	74.3	4	25.8	303.6
2	30.2	6	57.8	193.2
	50.4	5	21.8	250.8
	70.2	4	33.0	295.6
	84.7	4	7.8	325.7
3	30.4	6	55.0	194.5
	50.6	5	21.4	251.1
	70.5	4	34.0	294.5
	84.4	4	9.4	323.6
4	30.8	6	53.0	195.4
	50.7	5	21.4	251.1
	70.8	4	32.4	296.3
	84.2	4	11.4	321.0
5	30.2	6	55.7	194.1
	50.8	5	20.5	251.8
	70.4	4	34.9	293.6
	84.0	4	10.6	322.0
6	30.8	6	53.0	195.4
	50.2	5	22.8	250.0
	70.3	4	34.2	294.3
	84.6	4	9.3	323.7
7	30.0	6	59.0	192.6
	50.1	5	22.0	250.6
	70.2	4	34.0	294.5
	84.1	4	9.5	323.4
8	30.6	6	54.7	194.6
	50.5	5	21.0	251.4
	70.7	4	33.5	295.1
	84.4	4	9.3	323.7
9	30.5	6	54.5	194.7
	50.1	5	23.9	249.2
	70.5	4	35.0	293.5
	83.8	4	9.4	323.6

HF - station orifice manometer reading (cm Hg)

min,sec - time to collect 1345 gal

FLOW - flow rate calculated from measured time to collect 1345 gal

Recorded fit to data: $F = 35.44182 \text{ HF}^{.49841}$

Data Set K2849 3/1/72 Mark 22 Flow Distribution Test #1
Flow-Pressure Loss Calibration in Channel #2 , H2O Temp. 14-15C
All other channels blocked

Run	H34	P4	P3	min	sec	Flow	PP	PT	HE	HF
1	25.8	6.4	11.1	10	25.0	64.5	19.0	5.5	0.4	3.1
	41.6	7.2	14.6	7	38.1	88.0	29.0	5.5	0.75	6.0
	58.1	7.8	18.3	6	15.5	107.4	39.9	5.6	1.15	9.0
	77.0	8.7	22.5	5	14.0	128.5	53.8	5.6	1.75	13.1
2	26.3	6.4	11.0	10	38.0	63.2	18.8	5.5	0.4	3.1
	43.1	7.1	14.7	7	36.2	88.4	29.2	5.5	0.75	6.0
	59.3	7.8	18.5	6	13.8	107.9	39.6	5.6	1.15	9.1
	74.6	8.5	21.7	5	23.8	124.6	50.8	5.6	1.55	12.1
	87.0	9.2	24.5	4	50.6	138.8	60.4	5.6	2.0	15.1
3	27.5	6.4	11.2	10	38.1	63.2	18.5	5.5	0.4	3.0
	45.9	7.0	15.2	7	35.4	88.6	29.2	5.5	0.75	6.1
	64.1	7.7	19.1	6	14.8	107.6	39.5	5.6	1.2	9.0
	79.7	8.4	22.3	5	27.0	123.4	50.4	5.6	1.7	12.1
	94.7	9.0	25.8	4	51.6	138.3	60.4	5.6	2.1	15.1

H34 - Pressure difference between taps in channel 2 (cm Hg)
P4 - Bottom pressure in channel 2 (psig)
P3 - Top pressure in channel 2 (psig)
min,sec - time to collect 672.3 gal
FLOW - flow rate calculated from measured time to collect 672.3 gal
PP - Plenum pressure (psig)
PT - Tank bottom pressure (psig)
HE - Endfitting signal (in Hg)
HF - Flow orifice signal (cm Hg)

Distance between the top and bottom channel taps is 137.5".
Endfitting: single pressure plate, KC type A monitor pin, 42 shell holes

Data Set K2850 3/3/72 Mark 22 Flow Distribution Test #1
Flow-Pressure Loss Calibration in Channels 2 & 3 , H2O Temp. 15C
All other channels blocked.

Run	H34	H56	P4	P3	P6	P5	min	sec	Flow	PP	PT	HE	HF
1	26.4	24.4	7.4	12.1	7.5	11.7	12	27.0	108.0	13.8	5.5	1.4	9.2
	43.0	40.0	8.9	16.6	9.0	16.0	9	24.0	143.1	19.4	5.6	2.35	16.2
	58.5	54.0	10.3	20.4	10.4	19.9	7	52.8	170.7	24.7	5.6	3.35	23.1
	74.6	68.2	11.7	24.8	12.0	24.0	6	52.0	195.9	30.4	5.6	4.35	30.5
	87.1	79.5	12.9	28.2	13.2	27.2	6	17.8	213.6	35.0	5.6	5.2	36.3
2	26.0	24.0	7.4	12.0	7.5	11.6	12	34.0	107.0	13.7	5.5	1.4	9.1
	42.9	39.5	8.9	16.6	9.0	15.9	9	22.1	143.6	19.5	5.6	2.35	16.4
	59.4	54.6	10.4	20.9	10.6	20.3	7	47.2	172.7	25.2	5.6	3.4	23.7
	74.6	68.2	11.8	24.9	12.1	24.2	6	51.8	196.0	30.5	5.6	4.35	30.7
	87.3	79.9	13.0	28.4	13.3	27.3	6	16.2	214.5	35.0	5.6	5.2	36.8
3	26.4	24.3	7.5	12.0	7.5	11.7	12	27.6	107.9	13.8	5.5	1.35	9.2
	43.3	39.8	8.9	16.4	9.0	16.0	9	21.2	143.8	19.5	5.6	2.30	16.5
	59.0	54.2	10.3	20.7	10.5	19.9	7	50.0	171.7	25.0	5.6	3.35	23.5
	74.2	67.8	11.6	24.8	11.9	23.8	6	53.0	195.4	30.3	5.6	4.35	30.4
	87.5	79.8	13.0	28.4	13.3	27.4	6	16.0	214.6	35.0	5.6	5.2	36.7
	114.5	104.1	15.6	36.9	16.1	34.5	5	22.1	250.5	45.0	5.7	7.15	49.7
	138.4	126.6	18.4	43.0	18.9	41.3	4	50.0	278.3	54.8	6.1	8.8	62.1

H34 - Pressure difference between taps in channel 2 (cm Hg)

H56 - Pressure difference between taps in channel 3 (cm Hg)

P4 - Bottom pressure in channel 2 (psig)

P3 - Top pressure in channel 2 (psig)

P6 - Bottom pressure in channel 3 (psig)

P5 - Top pressure in channel 3 (psig)

min,sec - time to collect 1345 gal

FLOW - flow rate calculated from measured time to collect 1345 gal

PP - Plenum pressure (psig)

PT - Tank bottom pressure (psig)

HE - Endfitting signal (in Hg)

HF - Flow orifice signal (cm Hg)

Distance between the top and bottom channel taps is 137.5" in both channels.

Endfitting: single pressure plate, KC type A monitor pin, 42 shell holes

Data Set K2851 3/6/72 Mark 22 Flow Distribution Test #1 H2O Temp. 13C
Flow-Pressure Loss Calibration in Channels 2, 3, & 4; Channels 1 & 5 blocked

Run	H34	H56	H78	P3	P4	P5	P6	P7	P8	Flow	PP	PT	HE	HF
1	49.8	48.5	53.7	20.7	11.8	20.7	12.0	21.3	11.7	193.7	24.7	5.7	4.55	30.2
	77.3	74.7	84.0	29.9	16.1	29.6	16.4	30.9	16.1	250.3	36.6	5.9	7.45	50.5
	104.2	100.2	113.3	39.1	20.9	38.7	21.2	40.5	20.4	296.0	48.4	6.3	10.3	70.7
	128.5	124.5	141.4	46.2	23.6	46.3	24.2	48.5	23.3	336.0	59.2	5.0	13.3	91.2
	151.6	146.8	-	55.6	27.6	55.5	28.4	57.4	27.4	369.6	70.1	5.0	16.15	110.4
	-	-	-	62.6	31.8	63.2	32.8	66.3	31.4	401.3	80.1	5.0	19.2	130.2
2	48.8	47.7	53.5	19.7	11.1	19.8	11.4	20.4	11.1	194.3	24.0	4.9	4.45	30.4
	76.1	74.3	83.9	28.8	15.3	28.9	15.7	29.9	15.3	251.0	36.0	5.0	7.35	50.8
	101.8	98.9	112.4	37.5	19.4	37.7	20.0	39.0	19.4	296.6	47.1	5.0	10.35	71.0
	126.6	123.1	140.6	46.1	23.8	46.3	24.3	48.3	23.5	335.7	59.2	5.0	13.25	91.0
	150.7	144.9	-	54.7	27.5	54.3	28.4	57.2	27.4	369.6	70.1	5.0	16.25	110.4
	-	-	-	62.8	31.9	63.0	32.8	66.4	31.6	401.1	81.0	5.0	19.15	130.1
3	48.8	47.2	53.1	19.6	11.2	19.7	11.4	20.4	11.1	195.3	24.1	4.9	4.50	30.7
	75.7	73.2	82.9	28.4	15.3	28.5	15.5	29.9	15.2	250.5	35.6	5.0	7.40	50.6
	102.2	98.3	112.1	37.4	19.6	37.6	19.9	39.5	19.4	297.0	47.3	5.0	10.40	71.2
	125.9	121.5	139.2	45.9	23.6	45.8	24.1	48.2	23.4	335.1	59.2	5.0	13.30	90.7
	150.4	145.2	-	55.1	27.8	54.7	28.5	58.0	27.5	370.8	69.8	5.0	16.35	111.1
	-	-	-	63.0	31.9	63.0	32.7	66.5	31.6	400.3	80.8	5.0	19.2	129.6

H34 - Pressure difference between taps in channel 2 (cm Hg)
H56 - Pressure difference between taps in channel 3 (cm Hg)
H78 - Pressure difference between taps in channel 4 (cm Hg)
P3 - Top pressure in channel 2 (psig)
P4 - Bottom pressure in channel 2 (psig)
P5 - Top pressure in channel 3 (psig)
P6 - Bottom pressure in channel 3 (psig)
P7 - Top pressure in channel 4 (psig)
P8 - Bottom pressure in channel 4 (psig)
PP - Plenum pressure (psig)
PT - Tank bottom pressure (psig)
HE - Endfitting signal (in Hg)
HF - Flow orifice signal (cm Hg)

FLOW - Flow rate (gpm) obtained from flow orifice correlation $F = 35.44182 H^{.49841}$

The distance between the top and bottom channel taps is 137.5" in all three channels.
Endfitting: single pressure plate, KC type A monitor pin, 42 shell holes

Data Sets K2852-K2853 3/16/72 Mark 22 Flow Distribution Test #2 H2O Temp. 16C
 Flow-Pressure Loss Calibration in Channels 2, 3, & 4; Channels 1 & 5 open
 (Run 1 omitted due to leaking pressure tap)

Run	FLOW	H34	H56	H78	PS	P3	P4	P5	P6	P7	P8	PP	PT	HE	HF
2	194.3	47.3	46.7	50.8	23.6	20.7	12.1	20.8	12.4	21.0	12.2	24.5	4.9	5.50	30.4
	250.3	76.2	73.5	80.1	34.5	30.2	17.0	30.2	17.2	31.2	17.0	36.9	4.9	9.30	50.5
	296.2	102.5	98.8	108.1	46.0	39.9	21.9	40.0	22.3	41.3	21.9	49.3	5.0	13.10	70.8
	335.1	127.8	123.2	134.8	57.7	49.3	26.5	49.5	27.3	50.8	26.8	60.8	5.0	16.75	90.7
	368.9	153.0	147.0	-	68.4	58.7	31.4	58.5	32.2	60.2	31.4	72.1	5.0	20.50	110.0
	402.0	-	-	-	79.7	68.3	36.3	68.6	36.5	70.5	36.3	84.9	5.0	24.5	130.7
3	194.7	48.0	47.0	51.2	23.6	20.8	12.2	20.5	12.5	21.2	12.3	24.6	4.9	5.60	30.5
	249.5	75.2	73.1	80.0	34.8	30.2	16.9	30.4	17.4	31.2	17.0	37.2	4.9	9.30	50.2
	295.4	101.3	98.4	107.9	46.0	39.9	21.8	40.0	22.4	40.9	21.8	48.6	5.0	13.15	70.4
	334.6	126.7	123.1	135.6	57.6	49.1	26.7	49.4	27.3	50.9	26.6	61.2	5.0	16.75	90.4
	369.1	150.7	147.0	-	68.8	59.1	31.3	58.8	32.3	60.3	31.5	72.1	5.0	20.50	110.1
	401.4	-	-	-	79.4	67.5	36.3	68.5	37.4	70.5	36.0	85.3	5.0	24.4	130.3
4	195.0	48.4	47.3	51.6	23.8	20.6	12.4	20.9	12.5	21.1	12.4	24.9	4.9	5.70	30.6
	249.8	75.1	73.2	80.1	34.9	30.1	17.1	30.2	17.4	31.2	17.0	37.0	4.9	9.35	50.3
	294.9	101.2	98.6	108.3	46.3	39.8	21.7	40.2	22.4	41.0	21.8	48.8	5.0	13.20	70.2
	336.2	126.7	124.2	136.6	58.5	49.5	26.8	50.0	27.8	51.5	26.9	61.6	5.0	17.00	91.3
	369.4	150.2	147.2	-	68.6	58.5	31.6	59.2	32.4	60.7	31.6	73.5	5.0	20.60	110.3
	401.1	-	-	-	80.0	67.2	36.5	68.5	37.7	70.5	36.3	85.2	5.0	24.45	130.1

H34 - Pressure difference between taps in channel 2 (cm Hg)
 H56 - Pressure difference between taps in channel 3 (cm Hg)
 H78 - Pressure difference between taps in channel 4 (cm Hg)
 P3 - Top pressure in channel 2 (psig)
 P4 - Bottom pressure in channel 2 (psig)
 P5 - Top pressure in channel 3 (psig)
 P6 - Bottom pressure in channel 3 (psig)
 P7 - Top pressure in channel 4 (psig)
 P8 - Bottom pressure in channel 4 (psig)
 PP - Plenum pressure (psig)
 PT - Tank bottom pressure (psig)
 HE - Endfitting signal (in Hg)
 HF - Flow orifice signal (cm Hg)

FLOW - Flow rate (gpm) obtained from flow orifice correlation $F = 35.44182 H^{.49841}$

The distance between the top and bottom channel taps is 137.5" in all three channels.
 Endfitting: single pressure plate, KC type A monitor pin, 42 shell holes

Data Set K2854

3/17/72

Mark 22 Pressure Profile Test #1

32 Shell Holes

H2O Temp. 12-17C

Run	FLOW	PP	PS	P3	P4	P5	P6	P7	P8	PV	PPR	PT	H34	H56	H78	H4T	H6T	H8T	HPRT	HVT	HPS	HE	HF
1	194.7	24.7	23.6	20.5	12.1	20.6	12.5	21.4	12.2	11.5	7.9	4.9	47.6	47.0	51.1	41.4	42.8	41.7	16.3	36.7	7.3	5.7	30.5
	193.7	24.8	23.7	20.5	12.3	20.6	12.4	21.3	12.3	11.4	7.8	4.9	47.8	46.9	51.1	41.5	42.9	41.6	16.4	36.7	7.1	5.65	30.2
	250.0	37.4	35.1	30.5	17.0	30.6	17.6	31.3	17.1	16.0	9.8	4.9	75.1	73.8	80.9	69.1	71.5	69.2	27.0	61.6	11.7	9.50	50.4
	294.7	49.2	46.6	39.9	22.2	40.2	22.6	41.3	22.1	20.3	11.6	5.0	101.4	98.6	108.2	97.4	100.5	97.5	38.3	87.2	16.3	13.45	70.1
	332.7	61.5	60.1	49.2	26.9	49.8	27.7	51.5	27.1	25.2	13.6	5.0	124.5	122.5	134.8	124.0	128.7	124.5	48.9	111.5	20.5	17.2	89.4
	369.6	73.6	69.5	59.0	32.1	60.2	33.2	61.8	32.0	29.5	15.6	5.0	148.3	148.0	-	-	-	-	60.8	138.1	25.4	21.1	110.4
2	400.8	85.2	80.0	67.1	37.1	69.0	38.1	71.1	37.0	33.8	17.6	5.0	-	-	-	-	-	-	71.7	-	30.0	30.2	129.9
	194.0	24.7	23.6	20.4	12.4	20.7	12.6	21.1	12.4	11.5	7.6	4.9	46.8	46.6	50.8	42.2	43.4	42.1	16.6	37.4	7.0	5.8	30.3
	250.0	37.3	35.4	30.4	17.2	30.6	17.7	31.4	17.3	16.0	9.8	4.9	73.9	73.0	80.1	70.2	72.5	70.2	28.1	62.1	11.6	9.75	50.4
	295.6	49.5	46.7	39.9	22.3	40.5	22.9	41.9	22.3	20.4	11.5	5.0	99.2	98.8	108.4	98.2	102.0	98.5	37.4	88.6	16.4	13.60	70.5
	334.0	61.5	58.3	49.4	27.3	50.1	27.9	52.1	27.3	25.2	13.6	5.0	123.3	122.4	135.0	126.0	130.4	126.2	49.8	113.6	20.7	17.40	90.1
	370.4	75.5	70.0	59.1	32.3	60.3	33.2	62.2	32.2	29.8	15.4	5.0	146.8	147.7	-	-	-	-	59.3	141.0	25.8	21.45	110.9
3	401.4	85.8	80.7	67.6	37.3	69.5	38.5	71.8	37.4	34.2	17.1	5.0	-	-	-	-	-	-	69.0	-	30.0	26.15	130.3
	191.8	24.5	23.3	20.3	12.2	20.5	12.4	20.9	12.2	11.5	7.4	4.9	46.3	45.6	49.9	41.5	42.7	41.3	14.3	37.6	6.9	5.7	29.6
	249.8	37.3	35.3	30.6	17.3	30.7	17.7	31.3	17.5	16.0	9.2	4.9	74.3	72.9	80.0	70.3	72.8	70.6	24.5	62.8	11.7	9.75	50.3
	296.0	49.4	46.9	40.1	22.4	40.6	23.1	41.4	22.3	20.7	11.9	5.0	100.1	98.9	108.3	98.4	102.7	99.5	39.5	89.4	16.7	13.65	70.7
	334.0	62.0	58.4	49.5	27.5	49.8	28.1	52.1	27.5	25.3	13.8	5.0	124.2	122.6	134.8	127.3	132.1	127.3	50.3	114.7	21.2	17.45	90.1
	369.4	74.0	69.5	59.0	32.3	60.2	33.6	61.5	32.5	29.7	15.2	5.0	145.7	146.2	-	-	-	-	59.0	140.5	25.8	21.5	110.3
CO	401.9	86.0	80.5	68.0	37.4	69.5	38.6	71.7	37.5	33.6	17.1	5.0	-	-	-	-	-	-	68.9	-	30.2	25.5	130.6

Gage Pressure Readings

PP - Plenum pressure (psig)
 PS - Pressure 4.5" above top stem (psig)
 P3 - Top pressure in channel 2 (psig)
 P4 - Bottom pressure in channel 2 (psig)
 P5 - Top pressure in channel 3 (psig)
 P6 - Bottom pressure in channel 3 (psig)
 P7 - Top pressure in channel 4 (psig)
 P8 - Bottom pressure in channel 4 (psig)
 PV - Minimum venturi pressure (psig)
 PPR - Minimum pressure plate pressure (psig)
 PT - Tank bottom pressure (psig)

Manometer Readings

H34 - Pressure difference between taps in channel 2 (cm Hg)
 H56 - Pressure difference between taps in channel 3 (cm Hg)
 H78 - Pressure difference between taps in channel 4 (cm Hg)
 H4T - Pressure difference between bottom tap in channel 2 and tank bottom (cm Hg)
 H6T - Pressure difference between bottom tap in channel 3 and tank bottom (cm Hg)
 H8T - Pressure difference between bottom tap in channel 4 and tank bottom (cm Hg)
 HPRT - Pressure difference between pressure plate and tank bottom (cm Hg)
 HVT - Pressure difference between venturi and tank bottom (cm Hg)
 HPS - Pressure difference between plenum and tap 4.5" above top stem (cm Hg)
 HE - Endfitting signal (in Hg)
 HF - Flow orifice signal (cm Hg)

FLOW - Flow rate (gpm) obtained from flow orifice manometer reading using the correlation $F = 35.44182 HF^{.49841}$

The distance between the top and bottom channel taps is 137.5" in all three channels.

Endfitting: single pressure plate, KC type A monitor pin.

Data Set K2859

4/13/72

Mark 22 Pressure Profile Test #1

60 Shell Holes

H2O Temp. 19-?C

Run	FLOW	PP	PS	P3	P4	P5	P6	P7	P8	PV	PPR	PT	H34	H56	H78	H4T	H6T	H8T	HPRT	HVT	HPS	HE	HF
1	194.3	22.2	21.2	18.7	10.2	18.6	10.4	19.1	10.2	9.2	5.5	5.0	47.5	46.7	50.9	29.7	31.0	29.6	3.8	24.5	7.3	3.2	30.4
	250.0	34.0	31.9	26.7	13.7	27.1	14.2	28.1	13.8	12.4	5.9	5.0	74.7	73.6	81.1	49.3	51.7	49.3	5.8	41.3	12.1	5.4	50.4
	295.6	44.4	41.6	35.1	17.1	35.0	17.8	36.6	17.2	15.2	6.4	5.0	99.4	98.3	108.0	68.3	72.4	68.6	8.2	58.3	16.9	+	70.5
	335.3	55.0	51.5	42.7	20.8	41.1	21.4	44.7	20.7	18.2	6.7	5.0	123.8	122.6	135.6	87.8	93.2	88.5	10.5	74.7	21.5	9.8	90.8
	369.9	65.4	61.0	50.5	24.1	50.0	25.1	53.0	24.3	21.1	7.1	5.0	146.8	146.4	-	106.6	113.1	107.1	11.4	91.7	26.4	11.9	110.6
	402.0	75.5	70.4	57.6	27.7	59.2	28.8	61.6	27.7	24.3	7.3	5.0	-	-	-	127.4	134.7	127.4	13.0	108.5	30.8	14.5	130.7
2	194.7	22.9	21.3	18.5	10.2	18.8	10.4	19.2	10.4	9.3	5.4	5.0	47.8	47.0	51.3	30.0	31.3	29.9	3.8	25.0	7.3	3.25	30.5
	250.3	33.6	31.6	26.5	13.6	26.9	14.1	27.8	13.5	12.5	5.9	5.0	73.9	72.8	80.1	49.2	51.8	49.0	5.7	43.0	12.5	5.4	50.5
	295.8	43.9	41.6	34.7	17.1	35.3	17.8	36.2	17.1	15.2	6.3	5.0	99.2	97.4	107.6	68.3	72.2	68.3	7.8	57.5	16.5	7.5	70.6
	334.4	54.8	51.2	42.7	20.6	42.8	21.6	44.7	20.8	18.1	6.7	5.0	123.2	121.1	134.4	88.4	93.4	88.9	9.9	75.5	21.3	9.8	90.3
	369.9	66.0	61.4	50.3	24.1	51.4	25.3	53.6	24.2	21.2	7.1	5.0	147.0	145.7	-	107.2	113.4	107.7	11.6	93.4	26.0	12.0	110.6
	401.4	75.1	70.0	57.4	27.5	59.5	28.8	60.8	27.5	24.4	7.2	5.0	-	-	-	126.2	134.3	126.9	13.2	109.6	30.3	14.0	130.3
3	196.3	23.0	21.5	18.8	10.4	18.7	10.5	19.5	10.4	9.3	5.5	5.0	47.7	46.8	51.1	30.0	31.7	30.2	3.8	25.1	7.2	3.35	31.0
	250.5	33.4	31.8	26.7	13.7	27.1	14.3	27.6	13.7	12.3	5.7	5.0	73.3	72.0	79.3	49.5	51.8	49.6	4.8	41.1	11.7	5.40	50.6
	295.6	44.4	41.6	34.5	16.3	35.1	17.8	36.4	17.0	15.1	6.3	5.0	98.4	97.0	107.1	68.2	72.0	68.6	6.5	57.9	16.3	7.55	70.5
	335.3	54.3	51.8	41.9	20.5	42.8	21.4	44.5	20.4	17.8	6.4	5.0	122.0	120.5	133.4	87.4	92.3	87.5	8.3	75.1	21.3	+	90.8
	370.1	65.2	60.8	49.8	23.9	51.2	24.8	52.6	24.0	21.1	6.8	5.0	146.0	144.3	-	106.1	112.4	106.6	11.1	91.2	25.8	11.8	110.7
∞	401.3	75.5	70.4	57.5	27.3	59.1	28.7	60.8	27.5	24.2	7.4	5.0	-	-	-	125.7	133.4	126.1	15.7	107.9	30.8	13.9	130.2

Gage Pressure Readings

PP - Plenum pressure (psig)
 PS - Pressure 4.5" above top stem (psig)
 P3 - Top pressure in channel 2 (psig)
 P4 - Bottom pressure in channel 2 (psig)
 P5 - Top pressure in channel 3 (psig)
 P6 - Bottom pressure in channel 3 (psig)
 P7 - Top pressure in channel 4 (psig)
 P8 - Bottom pressure in channel 4 (psig)
 PV - Minimum venturi pressure (psig)
 PPR - Minimum pressure plate pressure (psig)
 PT - Tank bottom pressure (psig)

Manometer Readings

H34 - Pressure difference between taps in channel 2 (cm Hg)
 H56 - Pressure difference between taps in channel 3 (cm Hg)
 H78 - Pressure difference between taps in channel 4 (cm Hg)
 H4T - Pressure difference between bottom tap in channel 2 and tank bottom (cm Hg)
 H6T - Pressure difference between bottom tap in channel 3 and tank bottom (cm Hg)
 H8T - Pressure difference between bottom tap in channel 4 and tank bottom (cm Hg)
 HPRT - Pressure difference between pressure plate and tank bottom (cm Hg)
 HVT - Pressure difference between venturi and tank bottom (cm Hg)
 HPS - Pressure difference between plenum and tap 4.5" above top stem (cm Hg)
 HE - Endfitting signal (in Hg)
 HF - Flow orifice signal (cm Hg)

FLOW - Flow rate (gpm) obtained from flow orifice manometer reading using the correlation $F = 35.44182 HF^{.49841}$

The distance between the top and bottom channel taps is 137.5" in all three channels.
 Endfitting: single pressure plate, KC type A monitor pin.

Data Set K2860

4/17/72

Mark 22 Pressure Profile Test #1

80 Shell Holes

H2O Temp. 21-22C

Run	FLOW	PP	PS	P3	P4	P5	P6	P7	P8	PV	PPR	PT	H34	H56	H78	H4T	H6T	H8T	HPRT	HVT	HPS	HE	HF
1	195.9	22.1	20.8	18.0	9.6	17.9	9.7	18.5	9.5	8.6	4.7	5.0	47.2	46.3	50.8	26.1	27.7	26.0	-2.1	20.8	7.3	2.35	30.9
	250.5	32.3	30.1	25.5	12.5	25.4	12.9	26.5	12.5	11.0	4.6	5.0	73.0	71.6	78.7	42.2	45.3	42.6	-2.9	34.6	11.9	3.95	50.6
	295.4	42.2	38.7	33.1	15.6	33.2	16.2	34.5	15.6	13.5	4.5	5.0	97.8	96.5	106.3	59.5	63.0	59.6	+	48.4	16.6	5.65	70.4
	334.9	52.0	48.4	40.1	18.5	40.8	19.8	42.3	18.4	16.0	4.6	5.1	121.5	120.0	132.9	75.6	80.5	75.8	-2.6	62.8	21.3	7.10	90.6
	369.8	63.1	58.1	47.3	21.7	47.8	22.5	51.0	21.6	18.6	4.4	5.1	144.9	144.0	-	92.7	93.6	92.6	-2.4	76.3	25.9	8.85	110.5
	401.0	72.3	67.5	55.0	24.3	56.1	25.8	58.1	24.4	21.2	3.8	5.0	-	-	-	109.8	117.7	110.5	-8.2	91.8	30.5	10.30	130.0
2	193.7	21.8	20.5	17.7	9.5	17.8	9.6	18.2	9.4	8.6	4.8	5.0	46.3	45.5	49.9	25.5	26.9	25.6	-1.3	20.7	7.2	2.35	30.2
	250.8	32.6	30.3	25.4	12.5	25.7	13.0	26.6	12.6	11.1	4.6	5.0	73.5	72.2	79.3	42.7	45.2	43.0	-2.8	35.3	12.1	3.95	50.7
	296.0	42.8	40.1	33.0	15.5	33.5	16.2	34.8	15.7	13.6	4.5	5.0	98.9	97.6	107.6	59.9	63.3	59.8	-3.6	48.9	16.8	5.55	70.7
	334.9	52.5	48.7	40.4	18.6	40.6	19.3	42.3	18.6	16.0	4.5	5.0	122.1	120.7	133.7	76.4	81.2	76.7	-2.8	62.5	21.6	7.10	90.6
	369.6	62.5	58.3	47.0	21.3	48.2	22.6	51.0	21.7	18.6	4.5	5.1	145.6	144.1	-	92.7	98.9	92.1	-1.6	77.3	25.8	8.95	110.4
	401.3	73.3	67.1	55.0	24.6	56.0	26.0	58.0	24.7	21.2	3.9	5.1	-	-	-	109.9	117.9	110.3	-4.2	92.0	30.5	10.45	130.2
3	195.3	22.0	20.7	17.9	9.5	17.7	9.7	18.4	9.5	8.7	4.7	5.0	47.3	46.3	50.7	25.8	27.7	26.3	-2.2	21.1	7.3	2.35	30.7
	249.8	32.2	30.1	25.4	12.4	25.6	13.0	26.6	12.5	11.0	4.5	5.0	73.1	71.6	78.7	42.2	45.3	42.5	-3.3	34.7	11.7	3.85	50.3
	295.8	42.1	39.8	32.8	15.5	33.4	16.3	34.7	15.5	13.7	4.4	5.0	98.2	96.2	106.0	59.0	63.1	59.5	-3.1	49.6	16.1	5.45	70.6
	335.7	52.7	49.1	40.2	18.4	40.9	19.4	42.2	18.6	16.0	4.3	5.0	122.5	120.5	133.1	75.8	81.0	76.4	-4.7	62.7	20.8	7.10	91.0
	369.8	62.0	57.8	47.5	21.5	48.2	22.6	50.6	21.4	18.6	4.1	5.0	146.2	143.3	-	92.6	99.2	92.9	-3.2	77.5	26.2	8.70	110.5
CO	401.1	71.6	66.8	54.4	24.5	55.7	27.6	57.1	24.5	21.3	3.8	5.0	-	-	-	109.2	116.7	109.6	-6.5	91.7	29.9	10.30	130.1

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FLOW - Flow rate (gpm) obtained from flow orifice manometer reading using the correlation $F = 35.44182 HF^{.49841}$

The distance between the top and bottom channel taps is 137.5" in all three channels.
 Endfitting: single pressure plate, KC type A monitor pin.