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An analytical a[[rpach to the design and analysis of recycle/branched-flow piping systems

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AN ANALYTICAL APPROACH TO THE DESIGN AND ANALYSIS OF RECYCLE/BRANCHED-FLOW PIPING SYSTEMS

by

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Aug 17, 1979

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ABSTRACT

An analytical approach has been developed for the design and analysis of dual-branched piping systems. It was intended that this technique be a viable alternative to the somewhat tedious graphical methods given in the literature.

A general model of such systems was established and a design equation thereby derived from fundamental physical considerations. In order to prove the validity of this relationship, an experimental study was undertaken. A closed-loop, branch/recycle system was built and used for flowsplit experiments in which flowrates were measured at three different static heads and a variety of pipeline flow resistances. The fraction of total flow recycled was calculated from this experimental data. The recycle fraction given by solving the design equation was also determined and was found to be within 1% of the experimental results. It was concluded that the design equation was an accurate representation of actual flow behavior in branched piping systems of this general type.

For the case of equal static heads, a simple plot is given for the solution of any such problems. For unequal static heads, the design equation must be solved iteratively. In order to avoid this inconvenience, an attempt was made to represent the design equation as either a parametric plot or as a nomograph. It was found that neither of these graphical forms could serve as a useful design tool. However, an analytical procedure, which does not necessarily entail an iterative solution, has been presented for use in any problem solution.

I. INTRODUCTION

The design of fluid piping systems is an area of fundamental importance to all chemical processing industries. Pipes and pumps deliver liquids to and from each process unit within a plant, and thus constitute a vital transportation network. It is important that all piping systems be designed so that the entire installation can operate at the desired production rates, and do so in the most economical manner.

The design and analysis of piping systems is often a problem which can be solved in a rather straightforward manner using the basic principles of fluid flow. However, certain situations arise which require a more complex analysis. One such system is that of simple branched flow; this occurs when a single main-flow pipeline splits into two lines which deliver their flows to different points. Generally, these exit points will be at different elevations and pressures, and it is because of this that a somewhat complicated graphical analysis or a trial-and-error solution to problems of this type is required.

It is quite common that one of the two delivery lines functions as a recycle line, returning its flow to some point in the system prior to the split. Such a branch/recycle system occurs repeatedly in chemical processing and may be regarded as a fundamental unit of some significance. It would indeed be beneficial if a simple, general procedure for the design of such systems were available.

The traditional graphical techniques (1,2) used to study these systems are useful and quite versatile, but are laborious and time-consuming as well. They may also offer some degree of confusion to those not entirely familiar with the more subtle points of such analysis. As an alternative, it may be possible to avoid these undesirable factors with the use of analytical equations. Such an analytical approach would be amenable to machine computation, whereas the graphical procedure is not; this factor could prove to be quite useful in numerous situations.

The objective of this research is to develop an analytical technique which will simplify the design and analysis of branch/recycle piping systems. The proposed analytical method should be an effective and accurate procedure, offering simplification over graphical methods by the use of algebraic equations. It must provide the same flexibility and generality as the graphical approach, and also present the advantages of convenience and speed not inherent in the graphical methods.

So that this technique can be applied to a wide range of problem types, a basic model of the system must first be established. A design equation is then derived from fundamental physical principles using this general flowsplit model. To insure the validity of the design equation, it should be tested and proven true on a real system. Therefore, an experimental investigation spanning as broad a range of operating conditions as possible, is carried out. Comparison of the theoretical and experimental results is made and related to the graphical technique. Then, because it is based on a perfectly general model and by virtue of the experimental verification, the analytical approach can be recommended as a replacement for the graphical approach in solving branch/recycle piping problems.

The branch/recycle flow system is actually a special case of the simple branched pipeline in which both delivery lines exit downstream of the split. While simple branched flow occurs in countless situations, recycle flow in a processing scheme generally serves a special purpose, and may be used for a variety of reasons. In chemical reactors, a recycle stream may be used to increase the yield of a desired product by enabling unreacted components in the reactor exit stream to re-enter the reactor and undergo further reaction. With highly exothermic reactions, part of the exit stream may be cooled externally and readmitted to the reactor as recycle in order to maintain reaction temperatures at a permissible level. Recycle can be used to provide agitation for a process vessel. Also, in an application entirely related to the piping system itself, a recycle or "bypass" stream can be used to provide a certain required minimum flow through the pump when downstream conditions would otherwise restrict the main pumpflow to less than that amount (1). The bypassing of some of the total flow to the suction side of the pump can also serve to regulate the branch flow in situations when automatic flow control is desired.

The types of problems which may be encountered with branched-flow piping systems are too numerous to discuss at length. However, it is important to point out just a few possible examples in order to provide some basis for understanding the implications of this research.

Ordinarily, a "design" problem involves selecting the proper pump to transport fluid through a given piping system. The optimum selection of pumps and piping is usually based upon choosing the combination which can do the job required at the minimum total cost. This total cost consists of fixed costs and operating costs. Fixed costs are the initial and amortized costs of piping, pumps, and perhaps insulation and piping supports as well. A variety of methods is available for estimating the minimum piping cost (3), which can be as much as 80% of the cost of all processing equipment in the plant, and can typically be up to 15% of the total installed plant cost (4). The operating costs are those incurred by operation of the pumps, and are directly related to the pumps and piping chosen, which are in turn dependent on the process units and production rate involved. Operating costs are likely to be a significant part of the total cost of the piping system, and thus, optimal pump selection is important to good design.

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On the other hand, "analysis" problems concern themselves with making the proper modifications in the piping system in order to handle any changes in processing conditions which may be made in the plant. A typical analysis problem might deal with accommodating the changes required by an increase in plant capacity. If, for example, the total production rate is increased, then the flows through each delivery line will change in a certain manner. The primary concern of the branch/recycle system may be to provide a certain fraction of the total flow to, say, a recycle reactor. If the total throughput is changed, then the friction loss in one or both of the delivery lines will have to be modified in order to maintain the same recycle fraction. This may easily be done by adjusting a valve in one or both of the delivery lines. Another solution would be to place an orifice plate of the proper size in one of the lines to restrict the flow accordingly. If the recycle flow is of critical importance, then automatic flow control may be used to compensate for any fluctuations in throughput which may occur. In this case, a control valve of the proper size must be installed in one of the delivery lines.

The manner in which the total flow splits between the two lines is also dependent on the exit pressures and elevations. Similar analysis problems can result if process modifications produce changes in either of these parameters.

Not much work has been published concerning the study of simple branched-flow piping systems. Graphical systems analysis, as detailed by Karassik (1) and Hicks and Edwards

(2), involves examining the energy requirements of the system over the anticipated range of flowrates. The energy/flowrate characteristics of each pump and pipeline are represented as individual curves on a single graph. These separate curves are added graphically in a certain fashion, depending upon whether the pumps and/or pipeline units are arranged in series, or in parallel, or both. A single "system curve" and a single "pump curve" result, which can then be used to examine the behavior of the overall pump-pipeline combination and each of its parts under various operating conditions. It is this feature which lends a great deal of versatility, as well as potential confusion, to the graphical study of piping systems; both of these factors become more significant as the system becomes more complex. Since graphical analysis offers a visual representation of the flow characteristics of all the pipelines, it is often possible to evaluate different designs quite readily. However, since some trial-and-error would likely be involved with examining the various schemes, it would probably be advantageous to use a simpler analytical procedure instead.

II. THEORY

Examination of the energy changes that occur as the fluid moves through the pipeline is the basis of the design procedure.

The amount of energy contained in an element of fluid at any point in a given flow system is always expressed relative to some arbitrary datum plane. Bernoulli's theorem (5) for incompressible fluids in steady flow, without friction losses and without input or output of heat, expresses the total energy as the sum of three types: pressure, velocity, and elevation. Each of these terms is referred to as an energy "head" when expressed in the units of elevation above the datum, e.g. feet of fluid. This relationship for any point in the system is written as follows:

$$H = V^2/2g + P/\rho + Z \qquad \text{(eq. 1)}$$

where, H = total head, (ft)
V = velocity of the liquid, (ft/sec)
P = pressure on the liquid, (lb/ft^2)
Z = elevation of the point above the datum, (ft)
ρ = density of the liquid, (lb/ft^3)
g = acceleration due to gravity = 32.174 ft/sec^2.

The English system of units is used here, since this is still the one most commonly used in industry today.

The velocity head is the kinetic energy per unit mass of fluid, the pressure head is the flow work per unit mass, and the elevation or "static" head is the potential energy per unit mass. Each of these heads can be thought of in terms of a vertical column of liquid. The pressure exerted on the base of this column as a result of the weight of the liquid, can be measured in terms of the height of this column. Such a static head, Z, is equivalent to the pressure head expressed as P/ρ . The velocity head, on the other hand, may be thought of as the distance through which the fluid must fall in order to attain a certain velocity, V.

The energy which must be added to a liquid in order to transport it from some initial point 1 to a second point 2, is equal to the difference in head plus the frictional losses which occur in the flow of real fluids between these points. This is the total energy which must be added by the pump, and is called the total head, H_T:

$$H_T = H_2 - H_1 + H_f \qquad \text{(eq. 2)}$$

where H_f is the energy loss due to friction.

A. Friction Factors

When a fluid flows through any pipe or conduit, the retaining walls in contact with the fluid offer resistance to flow. Because of the viscous nature of real fluids, a velocity gradient exists in the fluid across the flow path so that the velocity of the fluid at the wall is zero. Energy is lost in overcoming the fluid's resistance to motion in the boundary region near the wall. Similarly, any obstructions in the flow path of the fluid offer resistance to flow and, together with the turbulent eddies which form in the wake of obstructions and changes in the flow path, contribute to the overall loss of energy.

The well-known Darcy-Weisbach relation (5) expresses frictional losses in terms of velocity heads and a dimensionless friction factor, viz.

$$H_f = f \cdot L/D \cdot (V^2/2g) \qquad \text{(eq. 3)}$$

where,
L = length of flow path, (in)
D = inside diameter of pipe, (in)
f = Darcy friction factor.

The friction factor has been correlated as a function of Reynolds Number and the pipe size and roughness for turbulent flow, and is graphically presented as the familiar Moody diagram (5).

Several analytical and empirical expressions for both friction factor and head-loss due to friction have been developed as alternatives to use of the Moody diagram (1,6). However, only the recently developed Churchill relation satisfactorily represents the friction factor over the entire flow regime from laminar, through transition flow, to fully turbulent (7). The Churchill friction factor, f_c, is computed as follows:

$$f_c = \left[\left(\frac{8}{Re}\right)^{12} + \frac{1}{(A + B)^{3/2}}\right]^{1/12} \qquad \text{(eq. 4)}$$

where,

$$A = \left[2.457 \ln \frac{1}{\left(\frac{7}{Re}\right)^{0.9} + 0.27\left(\frac{\epsilon}{D}\right)}\right]^{16} \qquad \text{(eq. 5)}$$

$$B = \left(\frac{37530}{Re} \right)^{16} \qquad \text{(eq. 6)}$$

and, ϵ/D = relative surface roughness, (dimensionless)
Re = Reynold's number for flow through pipe.

The Churchill friction factor may then be transformed into the usual Darcy friction factor as

$$f = 8(f_c). \qquad \text{(eq. 7)}$$

B. Velocity Heads and Resistance Coefficients

Flow losses which are attributable to pipe fittings, valves, and obstructions in the flow path can be characterized in terms of the equivalent length of straight pipe which would produce the same loss in total energy. An alternative to this equivalent length concept is to examine these losses directly in terms of the velocity head lost. For turbulent flow, frictional loss is fairly constant for any given fitting, valve, or other obstruction and can be represented by the proportionality:

$$h_f = K\ (V^2/2g). \qquad \text{(eq. 8)}$$

The resistance coefficient K, is equivalent to the quantity fL/D in the Darcy equation, and is thereby defined as the number of velocity heads lost due to the particular obstruction. These resistance coefficients, as well as the equivalent length ratio L/D, are well-documented in the literature for all common types of valves and fittings (6,8).

In selecting a control valve, a parameter known as the flow coefficient is used to specify the size of the valve. For liquids, the flow coefficient C_V is defined as the number of gallons per minute of fluid at $60^{\circ}F$ which will flow through the valve at a pressure drop of 1 psi. The C_V specified by the valve manufacturer is for the valve operating fully open, and is thus a useful measure of the valve's capacity. By relating the definition to the Darcy equation, the following expression results (6):

$$C_V = 29.9\, D'^2/(K)^{1/2} \qquad \text{(eq. 9)}$$

where D' is the inside pipe diameter in inches. This equation allows the resistance coefficient to be determined from the flow coefficient so that the control valve can be regarded the same as any other valve or fitting. This can be of critical importance since, in many cases, the overall piping system is designed so that the control valve takes up from one-tenth to one-third of the total system pressure drop (1).

The total head-loss in a single pipeline is given by the summation of all resistance coefficients and/or all equivalent lengths according to equations 3 and 8. Thus, the general expression for head-loss due to friction is:

$$H_f = (\sum K + fL/D)\ V^2/2g \qquad \text{(eq. 10)}$$

where L includes the total length of straight pipe and the sum of the equivalent lengths of all fittings.

Since the resistance coefficient is related to a particular velocity, it must always be associated with the diameter of pipe in which that velocity occurs. The values of K are additive for several flow losses only when expressed with respect to a common diameter (or common velocity). The continuity principle (conservation of mass) and the Darcy equation provide a relationship which can be used to establish a common basis for resistance coefficients as:

$$K = K'/\beta^2 \qquad \text{(eq. 11)}$$

where K is referred to some common larger diameter, K' is referred to some smaller diameter of significance to the individual obstruction, and β is the ratio of smaller to larger diameter, $\beta = d/D$.

By virtue of its definition, one can determine an equivalent resistance coefficient for any process unit for which the head-loss across that unit can be measured. The head-loss can be determined by measuring the difference in static pressure (ΔP) across the unit and converting this pressure drop to a pressure head-loss. Knowing the velocity through the process unit, a resistance coefficient can be found, viz.

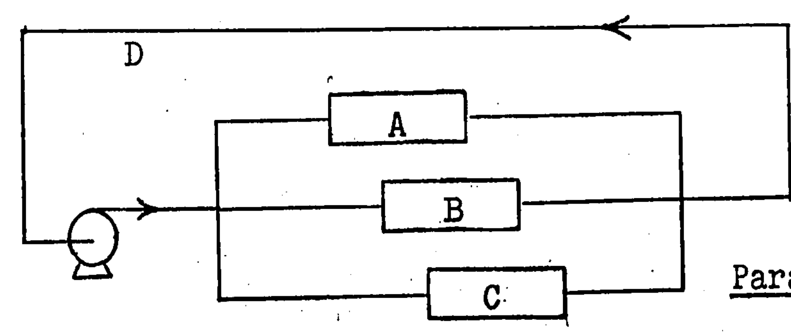
$$H_f = \Delta P/\rho = K\ V^2/2g. \qquad \text{(eq. 12)}$$

Alternatively, if an analytical expression for pressure drop or friction factor in the process unit is available (which is commonly the case with heat exchangers and packed beds), then the resistance coefficient may be calculated directly. Then by choosing an appropriate reference velocity, generally as that which occurs in the main pipeline, the equivalent resistance coefficient for each process unit for that common basis can be found from equation 11. Then, the total head-loss can be determined by summation of the individual resistances in equation 10.

Parallel Piping Arrangement

Networks of parallel pipelines containing various process units or other friction-producing elements may, at times, occur in a piping system. Overall resistance coefficients for a parallel network of pipes may be calculated as follows.

Figure 1 presents a general schematic for a network consisting of three parallel lines with three process units. It is assumed here that the main pipeline, preceeding junction 1 and proceeding junction 2, is the same size although each of the parallel lines may be of different sizes.



Parallel Piping Arrangement

Figure 1

The overall pressure drop across junctions 1 and 2, where the parallel branches split from and recombine with the main line, must equal the pressure drop across each parallel line in order for the flow to be continuous and steady. Since the sum of all branch line flows must equal the total flow to and from each junction, the head-losses through each line can be related to the mainflow velocity as well. The following relation is evident from equation 12:

$$K_{ov}\, Q^2 = \frac{P_2 - P_1}{\rho} = K_a\, Q_a^{\;2} = K_b\, Q_b^{\;2} = K_c\, Q_c^{\;2} \qquad \text{(eq. 13)}$$

where K_{ov} is the overall resistance coefficient for the network based upon the total flowrate Q in the main pipeline. This overall resistance coefficient can then be combined in the usual fashion with other resistances in series with this parallel network throughout the entire pipeline system.

C. Graphical System Analysis

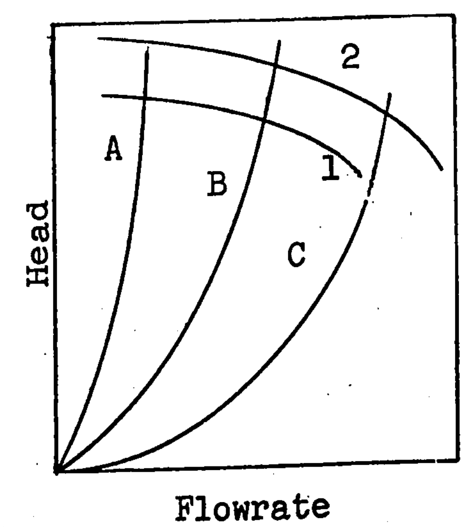
The optimum design for a piping system can be determined only through careful consideration of the hydraulic characteristics of both pumps and piping. While certain maximum and minimum process flowrates or heads may be used to specify a suitable pump for a system, such a method is generally not satisfactory for obtaining the optimum pump selection. The hydraulic characteristics of pumps and piping over the entire range of flowrates anticipated for the process must be evaluated. This can be done most easily by examining graphical plots of head vs. capacity for the piping system and pumps, known respectively as system curves and pump curves.

The pump total head, by definition, is equal to the differential pressure produced between the discharge and suction of the pump, divided by the liquid density. It is common practice that pump curves are expressed in terms of head, usually as feet of water, rather than in terms of differential pressure. At the rated capacity and speed, a centrifugal pump can produce the same head on all liquids of approximately the same viscosity, regardless of the density of the liquid (1). Under these conditions, however, the pump will not produce the same differential pressure, and the power required to drive the pump will be different. If, on the other hand, the pump were rated in terms of differential pressure, the same head would not be produced for one liquid as for another, and a separate curve for each liquid of different density would be required.

The head/flowrate point at which a given pump/pipeline combination will operate under specified conditions is given by the intersection of the pump and system curves. In order to select a pump for a given piping system in an optimal manner, at least one such operating point is needed. Under different operating conditions, such as when a pipeline is throttled by closing down a valve or by placing an orifice plate in the line, a different system curve will be obtained and a different operating point will result. Likewise, when a different pump curve is examined, perhaps for the purpose of obtaining increased efficienty with the use of a different pump, a different operating point will result.

Figure 2 illustrates the basic relationship between pump and system curves. Note that as the line friction increases, the system curve becomes steeper; thus, less flow at a higher head is achieved as the valve is closed down. Also, since pump 2 yields an operating point at a higher flowrate than pump 1, it may prove more suitable for the intended application if the higher flowrate is desirable.

For a system utilizing more than a single pump, either in series or parallel arrangement, a combined pump curve can be prepared which expresses the total performance as that of an equivalent single pump. For pumps in series, the overall performance is obtained by adding the heads at the same capacity. For pumps in parallel, flowrates are added at the same head to give the combined performance pump curve.



Typical System Curves and Pump Curves

A. Valve nearly closed
B. Valve half-open
C. Valve fully-open

1 and 2 are pump curves.

Figure 2

In a complex pipeline, similar reasoning can be applied to determine the combined performance of the various flow elements by construction of an overall system curve. The case of series addition of flow losses has already been alluded to in the discussion of resistance coefficients. If, for example, a pipeline consists of two sections of different-sized pipe in series, the individual heads for each line are added together at the same flowrate. This is the graphical analog of summing all resistance coefficients to determine the head-loss at any particular flowrate. For parallel systems, the flowrates for each individual line are added together at the same head to give the overall curve. For a system where both parallel and series elements occur, the parallel addition is carried out first to determine a combined curve for the parallel network; then, this curve is added in series with all the other sections of the pipeline which are in series to produce the overall system curve.

An alternate version of this procedure involves plotting system curves and pump curves on log-log paper (9). This method may present some simplification in the graphical construction, depending on the type of system being examined. Since the system frictional head-loss varies as the square of the flowrate, the system curve on log-log paper is represented by a straight line with a slope equal to two, viz.

$$H_f = \sum K \cdot V^2/2g = C \cdot Q^2 \qquad \text{(eq. 14)}$$

$$\log H_f = 2 \log Q + \log C \qquad \text{(eq. 15)}$$

The static head and pressure head, when present, are represented by horizontal lines. The result of the series addition of a static or pressure head line with the friction-loss line is a curved total system curve. Also, the pump curve for centrifugal pumps is represented by a curve the same as before.

The simplification presented by this method is that only two points are required for construction of the friction-loss line. When examining situations in which the friction-loss curve changes, as when studying the performance difference between clean and dirty pipe or that of throttled systems, several friction-loss lines may quickly be produced simply by knowing one performance point and constructing parallel lines with a slope of two for each such case (9). This method is particularly helpful in the absence of static and pressure heads when the system curves are all straight lines. Figure 3 illustrates the analysis of the simple parallel network given previously in Figure 1.

<u>Construction of System Curves on Log-Log Paper</u>

A, B, C, D are individual system curves for the units shown in Fig 1.

E results from parallel addition,

T is the overall system curve,

P is the pump curve

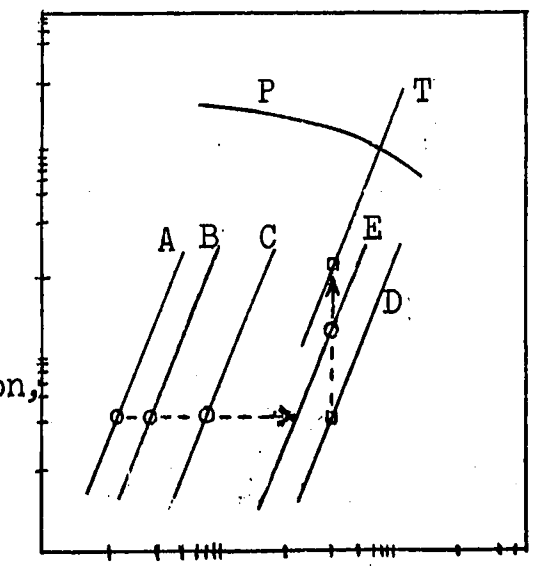


Figure 3

Performance Evaluation of Branched Systems

In the design of a new piping system, the pump is carefully chosen so that anticipated operating conditions will be achieved. However, at some later time, processing demands may require changes in flowrate and/or head that the system can no longer accommodate in its present state. When this occurs, a performance evaluation of the system may be carried out in order to determine what modifications to the system can be made so that the new processing requirements can be satisfied.

In the performance evaluation of existing branched systems, or in the design of new ones, the operating point found at first attempt may not yield the desired distribution of flow in all individual pipelines of the system. It may then be necessary to adjust some part of the system in order to achieve the required operating point or the desired flowbalance. This may be done, perhaps, by throttling or resizing one or more of the lines. A convenient and inexpensive throttling device is the orifice plate, which can be precisely sized to deliver specific flowrates. Alternatively, a control valve or a manually-operated globe or butterfly valve may be used. Addition of a bypass line to the system can also be used to regulate the flow distribution in some instances where no other choice exists (1).

The proper changes to be made to each line can be determined by working backward from the desired operating point to the various individual system curves for each branch, examining the individual flows, and modifying them as necessary. This process enables the appropriate system curve for a particular section to be constructed, from which the required resistance coefficient for that line may be calculated. In order to find the flowrates in each line, it is first necessary to define the head/capacity property of the junction point, which represents said conditions at the node from which the flow splits into separate lines.

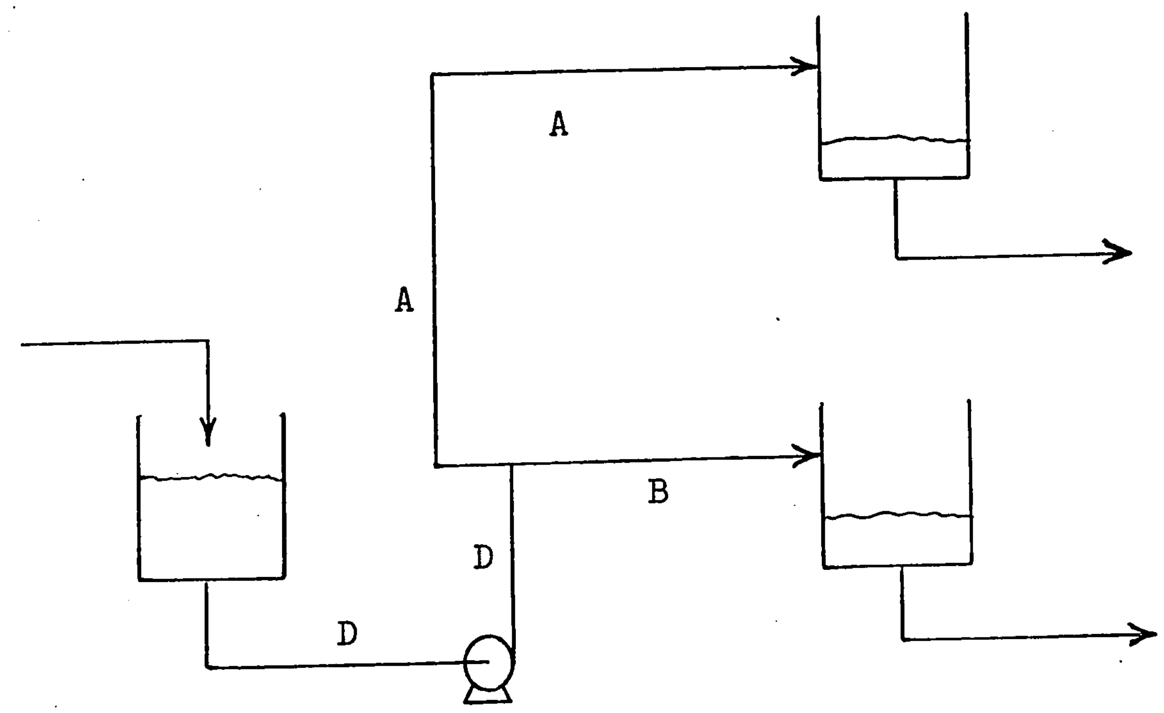
Consider first the example given in Figure 1. In a system where a network of parallel branches splits from and recombines with the main line, the flowrate in each branch is determined by the total head across the two nodes. This is a direct consequence of the requirement that the pressure drop across each line be identical; the flow splits in such a manner as to satisfy this requirement. For each operating point under consideration, a corresponding junction head must be found at the same flowrate; the junction head and the operating point flowrate thereby define the junction point. In this example, the combined frictional head-loss curve for the parallel network determines the junction head by its intersection with the line of constant flowrate equal to that of the operating point. Then, the intersection of each individual branch curve with the horizontal line of constant head given by the junction point specifies the flows through each branch line.

For an open-ended system with branch lines delivering their flows to external points (which is the system being considered in this research), the reasoning is similar. Referring to Figure 4, the general schematic for such a system, one can see that the flow through each branch depends on the total head at the node. The junction head, once again at the operating point flowrate, is equal to the head supplied by the pump minus the frictional head-loss in the pipeline between initial point and the node. A horizontal line of constant head through this junction point determines the individual branch flows by its intersections with the separate branch curves. Figure 5 shows the construction of the junction point and the individual branch flows for the case illustrated in Figure 4.

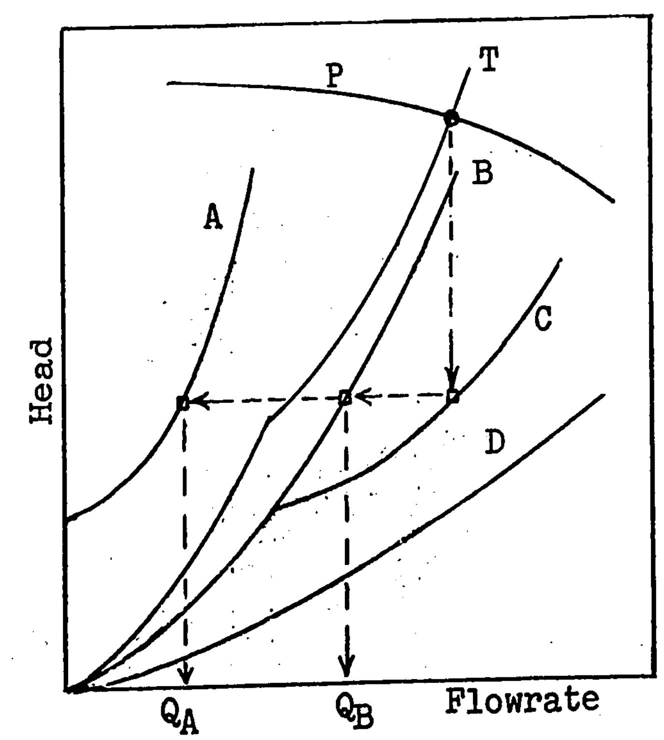
More extensive discussion of these techniques and several illustrations of graphical systems analysis are presented in the "Pump Handbook" (1).

Figure 4

Open-Ended Dual-Branched Piping System



Graphical Determination of Junction Point and Branch Flows



C results from parallel addition of A and B.

T results from series addition of D and C.

P is pump curve.

Figure 5

D. Design Equation for General Branch/Recycle System

Any branched piping system having two delivery lines can be represented by the following model, which is illustrated as a schematic in Figure 6. A supply tank provides continuous feed to the pump, which then delivers fluid through the main line to the node. The recycle line returns its portion of the total flow directly to the supply tank, while the branch line discharges its flow to a collecting tank. The collecting tank then returns the branch flow to the supply tank. Such a closed system enables a steady-state flow situation to be attained with stable operating conditions and conservation of the liquid.

Schematic of

General Flowsplit Model

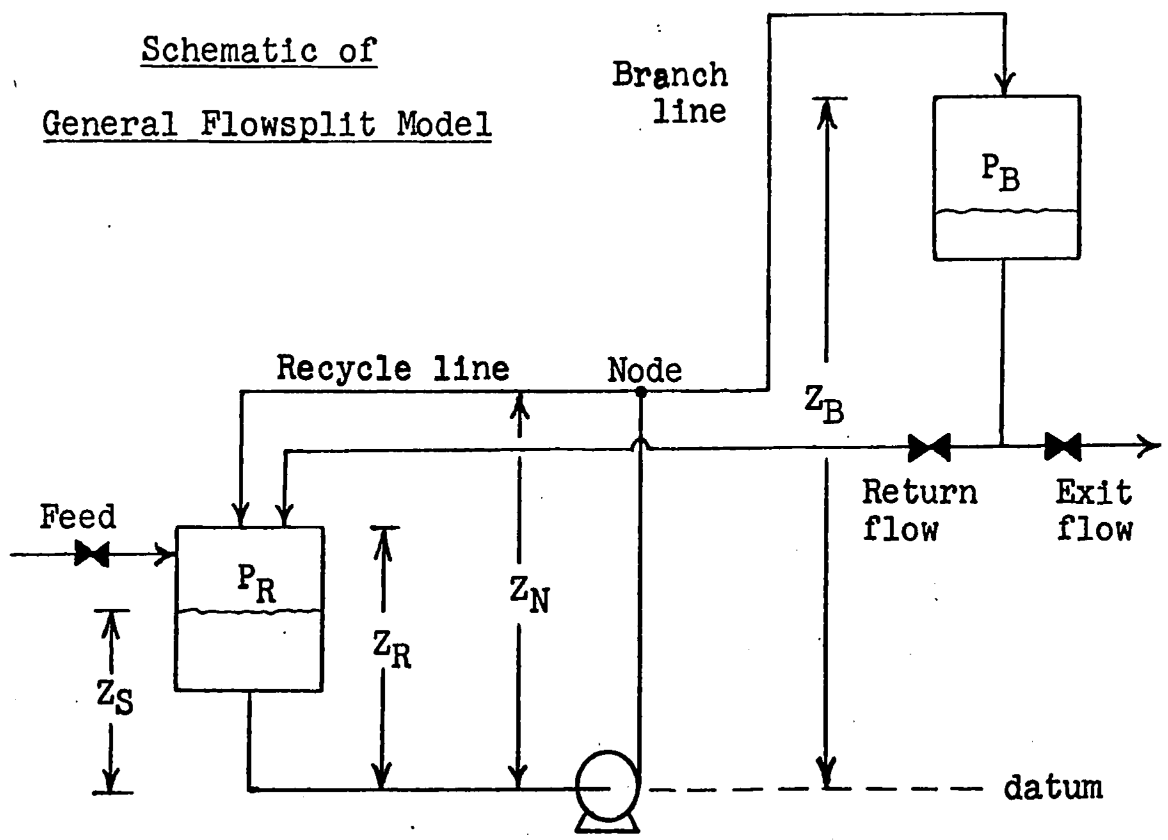


Figure 6

This model is capable of representing both open and closed flow systems. A closed system is one in which all flows return to the pump supply line, as depicted in Figure 6. An open system results if either the recycle or branch line, or both, deliver their flows to points outside the system, and a continuous feed is made available to the supply tank. Such a situation has been shown in Figure 5. Thus, breaking either or both return loops of the closed model results in the simulation of an open system with continuous flow under steady-state conditions. As such, the model can be directly applied as an autonomous pilot unit in the lab for experimental simulation of steady-flow processes of this type.

The model provides for discharge flow at different pressures and static heads. The tanks are enclosed so that they may be pressurized as required by process specifications, denoted by P_B and P_R in Figure 6. Also, the branch line delivers its flow at an elevation different than that of the recycle line.

Figure 6 presents a configuration in which the branch height is greater than that of the recycle line, and the node lies at an elevation between the branch and recycle delivery points. It is evident that a number of other piping arrangements and configurations are possible. "Arrangements" refers to the position of the static heads relative to each other, while "configurations" refers to the position of the flow-split relative to the static heads. Three varieties of each are possible, and can be listed as follows:

Arrangements:

Type 1: $Z_B > Z_R$

Type 2: $Z_B = Z_R$

Type 3: $Z_B < Z_R$

Configurations:

Case a: $Z_N > Z_B$; $Z_N > Z_R$

Case b: $Z_N < Z_B$; $Z_N > Z_R$

Case c: $Z_N < Z_B$; $Z_N < Z_R$

In order to establish a definite frame of reference for the model, the Type 1/Case b system has been chosen, as shown in Figure 6, because it is likely to be the most common situation encountered in industrial practice. When applied to open-ended branched systems where an actual recycle loop does not exist, that branch line which delivers its flow at the lower height will, by convention, be referred to as the recycle line.

Derivation of the Design Equation

Consider an energy balance on each of the delivery lines from a point immediately after the split to the exit point. In the absence of any heat and work inputs, and assuming that flow exists in both lines, the following can be written:

Recycle: $$P_N + Z_N + V_{NR}^2/2g = P_R + Z_R + V_R^2/2g + H_{fR} \qquad \text{(eq. 16)}$$

Branch: $$P_N + Z_N + V_{NB}/2g = P_B + Z_B + V_B/2g + H_{fB} \qquad \text{(eq. 17)}$$

The subscript N denotes the node point, and NR and NB refer to points in the recycle and branch lines, respectively, immediately after the split. The H_{fR} and H_{fB} terms are the frictional losses in the recycle and branch lines, respectively.

Since the velocity in each line is constant throughout at steady-state, then $V_{NR} = V_R$ and $V_{NB} = V_B$. Let STAT be defined as the sum of the total static and pressure heads at points relative to some common ground, such as the pump centerline or the tank level in a supply tank where the liquid height remains constant. Then, since the velocity terms in equations 16 and 17 cancel, these equations may be combined to give:

$$STAT_R + H_{fR} = STAT_B + H_{fB} \qquad \text{(eq. 18)}$$

Expressing the friction-loss in terms of resistance coefficients enables the static heads to be related to the flowrates as follows:

$$H_{fR} = K_R\, V_R^2/2g = K_R\, Q_R^2/C_f \qquad \text{(eq. 19)}$$

$$H_{fB} = K_B\, V_B^2/2g = K_B\, Q_B^2/C_f \qquad \text{(eq. 20)}$$

It is most convenient to work with flowrates, rather than velocities, since this is common industrial practice. The term C_f is a constant which includes the 2g term plus any conversion factors required to make the equation dimensionally consistent. For flowrate expressed in gallons per minute and head expressed in feet,

$$C_f = 466.6 \quad (gpm)^2/(ft\text{-}lbf/lbm) \qquad \text{(eq. 21)}$$

It is now convenient to define the recycle fraction, x, as the fraction of total flow which passes through the recycle line, viz.

$$x = Q_R/Q \qquad \text{(eq. 22)}$$

where Q is the main-flow or total pump flow. Then, the friction loss can be written in terms of the main flowrate:

$$H_{fR} = K_R\, x^2\, Q^2/C_f \qquad \text{(eq. 23)}$$

$$H_{fB} = K_B\, (1-x)^2\, Q^2/C_f \qquad \text{(eq. 24)}$$

Finally, equation 18 may be written as the general design equation:

$$STAT_B - STAT_R = (K_R\, x^2 - K_B(1-x)^2)\, Q^2/C_f \qquad \text{(eq. 25)}$$

The dimensionless design equation is:

$$(STAT_B - STAT_R)\, C_f/Q^2 = K_R\, x^2 - K_B(1-x)^2 \qquad \text{(eq. 26)}$$

It is important to note that for systems where the delivery lines may be of a different size than the main flowline, each of the resistance coefficients, K_R and K_B, must be expressed with respect to the main-line pipe diameter.

Special Cases of the Design Equation

Several limiting cases of the design equation are of interest:

1. Critical Flowrate

The critical flowrate, Q_c, is defined as the main flowrate at which flow just begins in the branch line. Taking the limit of equation 26 as the recycle fraction approaches one,

$$(STAT_B - STAT_R)C_f/Q^2 = K_R\, x^2 \qquad \text{(eq. 27)}$$

and rearranging, gives

$$Q_c = \sqrt{(STAT_B - STAT_R)\ C_f/K_R)} \qquad \text{(eq. 28)}$$

2. Equal Static Heads

A second limiting case arises when the static heads for branch and recycle lines are equal, i.e. both lines discharge at the same elevation. Equation 26 then simplifies to:

$$K_R\ x^2 = K_B(1-x)^2 \qquad \text{(eq. 29)}$$

Solving for the recycle fraction gives:

$$x = \frac{\sqrt{K_B}}{\sqrt{K_R} + \sqrt{K_B}} \qquad \text{(eq. 30)}$$

Since x is a function solely of the resistance coefficients, or rather, since the resistance coefficients depend only on the flowrate, an overall resistance coefficient, K_{ov}, can be used to express the flow losses as follows:

$$\text{Since} \qquad STAT_B = STAT_R$$

$$H_{fB} = H_{fR}$$

$$K_B\ Q_B^2/C_f = K_R\ Q_R^2/C_f = K_{ov}\ Q^2/C_f$$

$$K_R\ x^2\ Q^2 = K_{ov}\ Q^2$$

$$\therefore \quad K_{ov} = K_R\ x^2 \qquad \text{(eq. 31)}$$

One may postulate that the overall resistance coefficient for a parallel piping system is analagous to the total resistance for a system of electrical resistors in parallel. Thus,

$$\frac{1}{\sqrt{K_{ov}}} = \frac{1}{\sqrt{K_B}} + \frac{1}{\sqrt{K_R}} \qquad \text{(eq. 32)}$$

This relationship can be verified as follows:

Rearranging equation 31,

$$x = \frac{\sqrt{K_{ov}}}{\sqrt{K_R}} = \frac{1}{1/\sqrt{K_{ov}} \cdot \sqrt{K_R}}$$

and substituting for K_{ov} in equation 32,

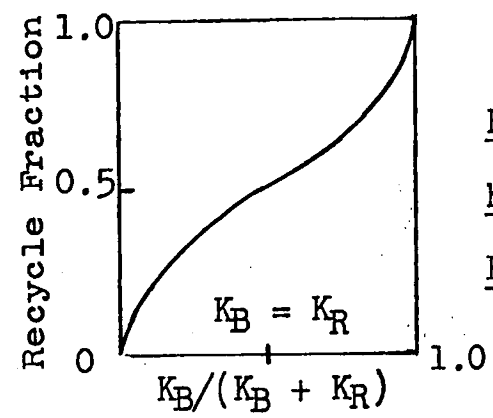
$$x = \frac{1}{\left(\frac{1}{\sqrt{K_B}} + \frac{1}{\sqrt{K_R}}\right) \cdot \sqrt{K_R}}$$

$$x = \frac{1}{\frac{\sqrt{K_R}}{\sqrt{K_B}} + 1}$$

$$x = \frac{\sqrt{K_B}}{\sqrt{K_R}} + 1$$

$$x = \frac{\sqrt{K_B}}{\sqrt{K_R} + \sqrt{K_B}} \qquad \text{Q.E.D.}$$

If the recycle fraction is plotted as a function of the resistance coefficients as $x = f(K_B/(K_B + K_R))$, a symmetrical curve is obtained, as illustrated in Figure 7. The region to the right of $K_B = K_R$ gives recycle fractions greater than 0.5; this is intuitively what would be expected since $K_B > K_R$ here and the least resistance to flow is provided by the recycle line. Similarly, more flow goes to the branch line, $x < 0.5$, when $K_B < K_R$.



Recycle Fraction Behavior for Case of Equal Static Heads

Figure 7

3. Unequal Static Heads

For the case of unequal static heads, the resistance coefficients are no longer simple functions of the flowrate alone but depend on the static heads as well. Therefore, an overall resistance coefficient cannot be determined. Furthermore, the design equation cannot be solved explicitly for the recycle fraction. If the quadratic formula is used, imaginary roots will result when $K_B > K_R$. The only method of solution which will be satisfactory for all cases is to solve the design equation using an iterative technique. The Newton-Raphson method will work well since this function of x is well-behaved over the range of all recycle fractions $x = 0$ to $x = 1$. An algorithm for solution of the design equation using this iteration technique is outlined in Appendix C.

One way to avoid the iterative calculations is through a graphical representation of the design equation, either as a parametric plot or as a nomograph. The form of such a graphical solution is suggested by the recycle behavior for the equal static heads case. Referring to Figure 7, one can deduce that perhaps a family of such curves would in general represent recycle behavior over a wide range of static head differences. In the dimensionless design equation, note that for the case of equal static heads, the left-hand side reduces to zero. As such, equation 26 has become identical to the simplified version of the design equation for equal static heads, equation 29. If this collection of terms, namely $(STAT_B - STAT_R)\ C_f/Q^2$, is denoted by the variable S, then $S = 0$ for the curve presented in Figure 7. For cases where $STAT_B$, the static and pressure heads of the branch line, exceeds that of the recycle line, $STAT_R$, the parameter S is greater than zero. Conversely, S becomes a negative number when $STAT_R$ exceeds $STAT_B$. Since, by convention, the branch exit elevation is always greater than that of the recycle exit, the latter case of negative S can occur only when the recycle delivery pressure exceeds the branch delivery pressure by an amount equal to the difference in exit elevations, viz.

$$S = ((P_B + Z_B) - (P_R + Z_R))\ C_f/Q^2$$

$$S = ((P_B - P_R) + (Z_B - Z_R))\ C_f/Q^2 \qquad \text{(eq. 33)}$$

and for $S<0$, $$|P_R| > P_B + (Z_B - Z_R) \qquad \text{(eq. 34)}$$

Families of curves for this type of parametric plot can be generated as described in Appendix D. However, as an approach to simplified design of branched piping systems in general, this method is not very satisfactory. A series of at least eighteen such parametric plots would be required for good accuracy in design (see Appendix D). The need to interpolate within this unwieldy collection of charts further disqualifies this as a viable simplified design technique. The perfect solution would, of course, arise if all situations could be summarized in a single chart; to this end, a nomograph would be ideal. Unfortunately, the nature of the design equation and the range of variables to be encountered in all design situations would result in perhaps as many as four nomographs (see Appendix E), and this again is an undesirable complication.

Despite the failure of both of these graphical methods to yield a simple design tool, it is still possible to avoid the inconvenience of iteration. A combination of the design equation with the techniques of graphical systems analysis yields a simple procedure for the solution of many types of problems. This method will be documented in detail in the following section of this report.

It is instructive to examine graphically how the recycle fraction changes over the entire range of flowrates for any given combination of resistance coefficients, K_R and K_B.

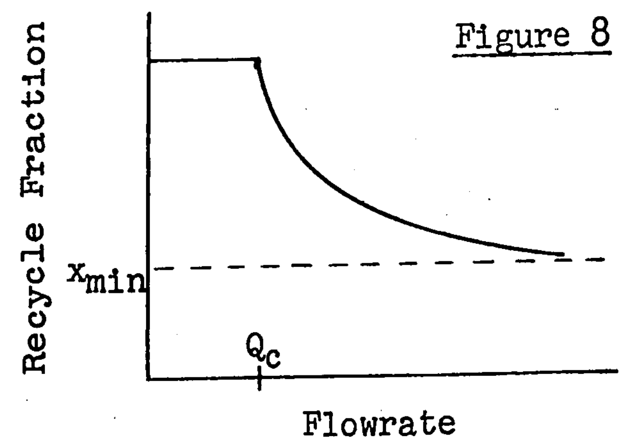
Below the critical flowrate, the recycle fraction is, of course, equal to one. Above Q_c, the recycle fraction decreases asymptotically with increasing flowrate until a minimum recycle fraction is reached. This minimum recycle fraction is that which would be attained for the case of equal static heads with these same recycle and branch line resistance coefficients. This limit can be deduced from the design equation by examining the case of $S = 0$.

Let $\Delta STAT = STAT_B - STAT_R$. Then, it is observed that $S = 0$ is the same situation as given by the following limits:

$$\lim_{Q \to \infty} \frac{\Delta STAT}{Q^2/C_f} = \lim_{\Delta STAT \to 0} \frac{\Delta STAT}{Q^2/C_f} = 0 \qquad \text{(eq. 35)}$$

When $\Delta STAT = 0$, $S = 0$ so that equation 30, for the case of equal static heads, describes the minimum recycle fraction attainable as the flowrate increases toward infinity. This aspect of branched piping systems is illustrated in Figure 8.

Figure 8



Recycle Fraction Behavior for Case of Different Static Heads

Analytical System Analysis

The major advantage of the design equation and the recycle approach in general is that total system losses, as well as branch losses, can be determined without the need for graphical analysis. If it is desired that a system curve be calculated in order to evaluate several pumps under consideration, the design equation greatly simplifies the construction of the overall system curve. For problems related to system analysis, rather than design, only an operating point is required in order to determine all flows for the system. In such cases, a system curve is not really required since the pump curve will give potential operating points, which can then be used to determine the individual delivery flows analytically.

The approach to solving design problems would proceed as follows. Recycle head if given by the following expression:

$$H_R = K_R\, Q_R^{\,2}/C_f = K_R\, x^2\, Q^2/C_f \qquad \text{(eq. 36)}$$

and branch head is given by:

$$H_B = K_B\, Q_B^{\,2}/C_f + \Delta\text{STAT}$$

$$H_B = K_B(1 - x)^2\, Q^2/C_f + \Delta\text{STAT} \qquad \text{(eq. 37)}$$

Because of the recycle fraction parameter, these equations can be used to construct a system curve since the total flowrate and the corresponding head will be known from the operating point. The following equation expresses the flow losses in the main-line, H_M, from the initial suction point to the node:

$$H_M = K_{sn}\, Q^2/C_f \qquad \text{(eq. 38)}$$

where K_{sn} is the resistance coefficient for the main-line piping from the initial point on the suction side of the pump, to the node on the discharge side of the pump. Since flow in the recycle line occurs at all main flowrates, the total system curve results from the series addition of the recycle head and the main-line head at each main flowrate:

$$H_T = (K_{sn} + x^2 \cdot K_R)\, Q^2/C_f \qquad \text{(eq. 39)}$$

It would have been equally valid to add the branch head and main-line head at each main flowrate, but then the total system curve would appear only past the critical flowrate and would not be complete.

In order to calculate the total head, the recycle fraction at a given flowrate must be known. By rearranging the design equation, the iterative problem can be avoided by solving for flowrate as a function of recycle fraction, viz.

$$Q = \sqrt{(\Delta\,\mathrm{STAT}) \cdot C_f/(K_R\, x^2 - (1-x)^2 \cdot K_B)} \qquad \text{(eq. 40)}$$

The data pairs (x,Q) can then be used in equation 39 to solve for several values of the total head, and the points (Q,H_T) plotted as the total system curve.

A consequence of this approach is that a complete system curve need not be constructed since only the operating point is required for the solution of any problem. Thus, only two or three system points need be calculated and plotted so that the system curve crosses the pump curve. As will be shown, all results can be calculated analytically from the operating point. This procedure is much simpler than the traditional graphical approach, which requires a complete system curve for carrying out any systems analysis.

In the graphical approach, the individual delivery-line flows are determined from the intersection of the junction head with the individual system curves. The operating point determines the junction point by the subtraction of the main-line head from the total system head (pump head) at the operating flowrate. This operation is expressed as:

$$H_J = H_T - K_{sn}\, Q^2/C_f \qquad \text{(eq. 41)}$$

where H_j is the junction head at the operating flowrate, Q. By comparison with equation 39, the following can be written:

$$H_T - K_{sn}\, Q^2/C_f = K_R\, x^2\, Q^2/C_f$$

$$H_T - K_{sn}\, Q^2/C_f = K_R\, Q_R^{\,2}/C_f \qquad \text{(eq. 42)}$$

Likewise, the junction head can be expressed in terms of the branch resistance coefficient as:

$$H_T - K_{sn}\, Q^2/C_f = K_B(1 - x)^2\, Q^2/C_f + \Delta\,\text{STAT}$$

$$H_T - K_{sn}\, Q^2/C_f = K_B\, Q_B^{\,2}/C_f + \Delta\,\text{STAT} \qquad \text{(eq. 43)}$$

Equations 42 and 43 will be referred to as the junction equations. In the following discussion, it is assumed that K_{sn} is known for the system and that only K_R and K_B are of interest from a design standpoint.

Either of the two junction equations can be used to solve problems in which only one of the two resistance coefficients is either specified, or is to be determined. For example, equation 42 would be used to solve either of the following problems. Given the recycle resistance coefficient and operating point, determine the recycle fraction which would result. Or, given the desired recycle fraction or recycle flowrate, find the recycle resistance coefficient which will result in a particular operating point. Both of these problems presume that the branch resistance coefficient is already established so that any system modifications necessary will be made by the recycle line. Then, once the recycle flowrate or recycle fraction and the main flowrate are known, the branch flowrate can be determined (or confirmed). Similar reasoning applies for the use of equation 43 when the branch resistance coefficient is of particular interest.

For situations in which both resistance coefficients are to be determined, it is possible to use both junction equations. However, it may be simpler to use the design equation alone to establish several (K_R, K_B) pairs which are capable of achieving the desired recycle fraction at the operating point under consideration. It is also possible to use one of the junction equations to determine one coefficient, and then the design equation to solve for the other. In situations where it might be desirable to solve for recycle fraction at a certain flowrate, it is not necessary to get involved with the iterative solution of the design equation; if an operating point is known, one of the junction equations can be used much more easily.

Of course, the approach to be used depends on the prob- to be solved, but for all cases where the general recy- cle model is applicable, the graphical technique can be re- placed by this simpler analytical approach. The two junction equations, supplemented by the design equation, can be used for the design and analysis of any dual-branched piping sys- tem, or even more complex systems which can be broken down into such elementary units.

III. EXPERIMENTAL

In order to establish the validity of the design equation in practice, an experimental investigation was undertaken. This study was concerned with observing the behavior of water flowing through various branched piping systems of similar configuration. All three parameters affecting the recycle fraction, the main flowrate, piping resistances, and static heads, were varied over as wide a range as physically possible. (The affects of changes in the delivery pressures were not examined directly since the same results would be produced by creating equivalent changes in the static heads). If the experimental results correlate well with the theoretical expectations, then meaningful generalizations for a wide range of possible operating conditions can be inferred.

Apparatus

The experimental apparatus used to obtain flowsplit data was constructed as a closed system in accordance with the general flowsplit model as depicted in Figure 6. Three levels of delivery static head differences comprise the principal basis of the investigation. Each such level in the static head difference between branch and recycle lines is termed a "Stage." Stage 1 refers to flowsplit data obtained at zero static head difference, Stage 2 is for a small static head difference, and Stage 3 is at a moderately large difference in static heads. For all three Stages, the length and configuration of the recycle line remained the same. The changes in static heads were achieved solely by varying the height of the branch line from one Stage to the next.

Open tanks were used for the feed and delivery holding tanks so that, for simplicity, both delivery flows were supplied at atmospheric pressure. Stage 1 utilized only the single feed tank, with identical recycle and branch lines discharging at the same elevation. Downcomer pipes were provided on the exit lines to direct the flow below the tank level in order to eliminate splashing in Stage 1. A shorter downcomer was used to direct the flow out the branch line in Stage 2, while no downcomer at all was used for the branch line in Stage 3. In Stage 3, the branch flow issued directly from the final pipe elbow in order to provide some additional height difference between the exit points.

For each stage, several experimental runs at different piping resistances were made, each one encompassing main flowrates from zero to the maximum allowed by the system. Each such run at a particular combination of recycle and branch line resistances is termed a "Flowsplit." Different piping resistances were obtained by placing orifice plates of various sizes in each line. This was the sole factor in varying the piping resistances for each Flowsplit within the same Stage since the pipe lengths remained the same within each Stage. The orifices also served as metering devices for measuring the water flowrates in each delivery line and in the main pipeline. For each Flowsplit, the three flowrates were determined by the pressure drop across each orifice as measured by mercury-filled manometers. At each main flowrate, an experimental recycle fraction can thereby be determined and compared with a theoretical recycle fraction calculated from the design equation using the physical parameters of the system.

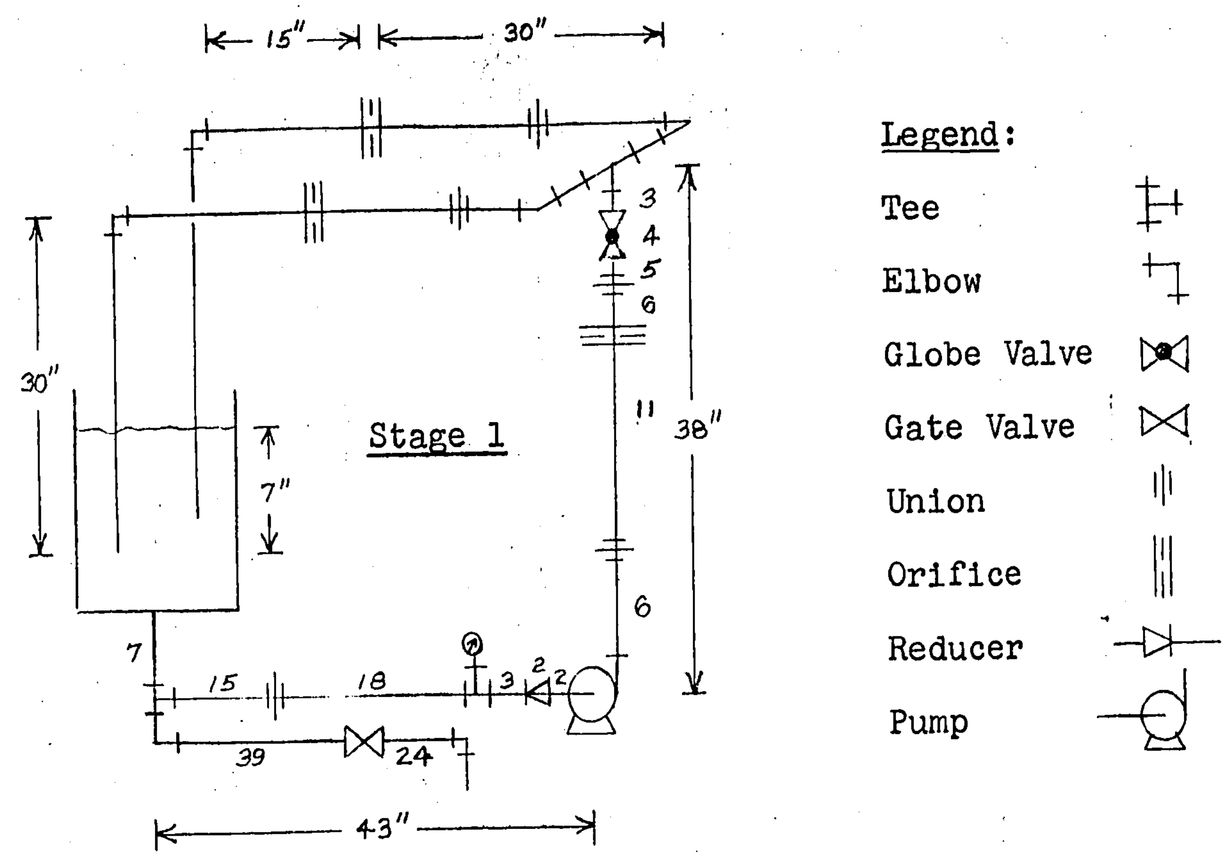
A total of eighteen Flowsplits were studied, four of which were for Stage 1, seven for Stage 2, and seven for Stage 3. Four different orifice plates were used in the two delivery lines: one with a 3/8 inch bore, two with a 1/2 inch bore, and one with a 5/8 inch bore. Another orifice with a 3/4 inch bore was used for measuring the main flowrates. The total number of different combinations possible with the given orifices was eighteen; only four Flowsplits were necessary for Stage 1 since the branch and recycle lines were identical.

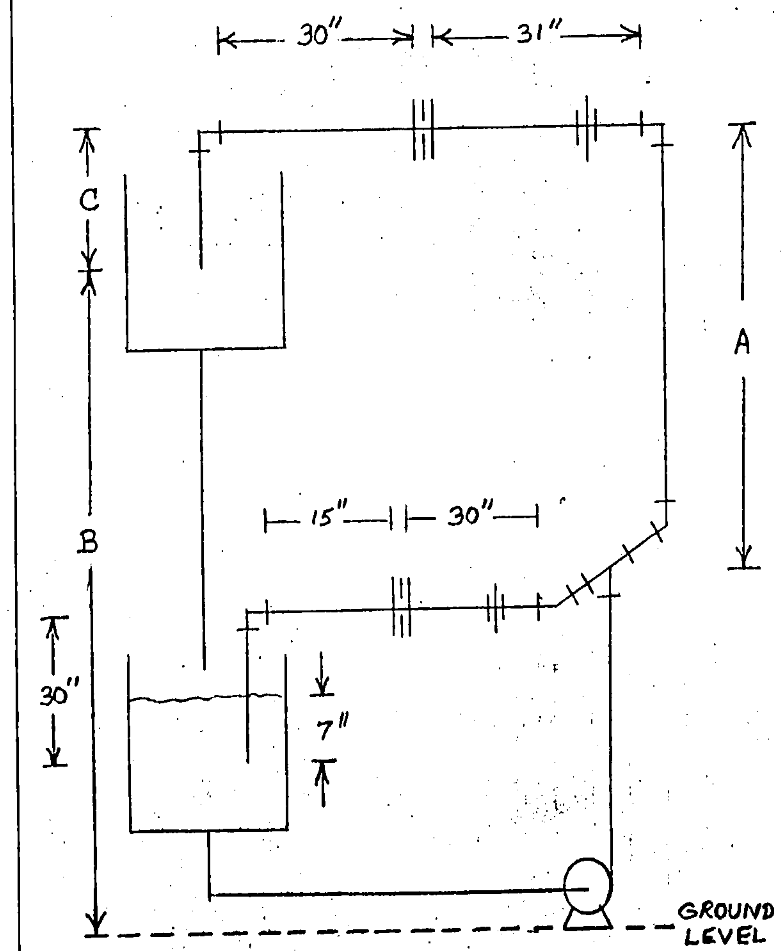
Figure 9 shows the experimental apparatus for the three Stages of operation. A complete tabulation of all system specifications and the details of construction are presented in Appendix A.

Construction of each orifice installation was based upon established guidelines set forth by the ASME (10). However, to insure accurate measurement of flowrates, each orifice was calibrated using a bucket-and-timer technique. A description of the technique, analysis, and resulting calibration curves are presented in Appendix B together with the important specifications for standard orifice installations.

FIGURE 9

Apparatus For Flowsplit Studies





Stage 2

A = 68"

B = 111"

C = 8"

Stage 3

A = 134"

B = 203"

C = zero

Procedure

For each Flowsplit, two sets of data were collected for the entire range of main flowrates studied. Each trial was made under similar operating conditions so that together, they should provide a consistent set of data, presumably free from anomalous errors when compared. Each trial was begun at as low a flowrate as could be indicated on the main-flow manometer, which was 0.1 inch Hg. The flow was then increased at convenient increments as determined by the reading of the main-flow manometer. Flow regulation was provided by the main-flow globe valve located immediately before the node. Manometer readings and estimated uncertainties in these readings due to oscillation of the mercury, were recorded for each orifice at each main flowrate. For Stages 2 and 3, the critical flowrate was noted by observing the point at which flow had begun to trickle out the branch line. At that point, the reading on the branch manometer was indistinguishable from zero, thus necessitating the visual technique. The maximum flowrate attainable was determined by the point at which one of the delivery manometers was at its maximum allowable pressure drop, or at which the main-flow valve was fully open. The latter case occurred only twice, for Flowsplits 8 and 16, and resulted in a maximum flowrate of 43 gpm.

A constant water level in the supply tank at steady state conditions was maintained throughout all trials. With increasing flowrates, the branch flow holdup increased so that it was necessary to add water to the system in order to maintain the level. The height of the water level in the supply tank was established to be seven inches above the exit point in order to insure a constant pump suction head throughout all the experimental runs.

Analysis of Data

Flowrates for the main line and both delivery lines were determined from the orifice head-loss data using the orifice calibration curves. Each such curve is represented by an equation of the form:

$$Q = C'(H_L)^n \qquad \text{(eq. 36)}$$

where C' and n are constants determined from a linear regression analysis of the calibration data. A computer program was used to correlate the data and construct the calibration curves (see Appendix B).

All the data for trials 1 and 2 were averaged at the same readings of the main-flow manometer. The main flowrate used in all calculations was that determined by the addition of the recycle and branch flows, and not that given directly by the main-flow manometer. This was judged to be the better procedure for two reasons: The delivery flows were known more accurately than the main flows since they were measured in tenths of a centimeter, while main flows were measured to tenths of an inch. Also, a consistent set of flowrates would always be obtained in this manner, with recycle fractions below the critical flowrate exactly equal to one.

Each experimental flowrate was used to determine an experimental recycle fraction, given by dividing the recycle flow by the main flow. At the same main flowrate, a theoretical recycle fraction was determined by solving the design equation using the Newton-Raphson iteration technique. The deviation between the two recycle fractions was calculated point-by-point, along with the uncertainties in head-loss measurement and the resultant corresponding uncertainties in flowrate (as described in the Error Analysis section). Velocity, Reynolds numbers, friction factors, and resistance coefficients were also calculated at each main flowrate. A computer program was written and used to perform all the required calculations and data analysis, and is documented in Appendix C along with all the data and results for the eighteen Flowsplits studied.

Graphs of the recycle fraction as a function of flowrate were also prepared with this program. These plots, each for a given combination of branch and recycle resistance coefficients, present both the experimental data points and the theoretical curve as determined by the design equation. This visual representation of the correlation between experiment and theory was considered to be of primary importance is assessing the viability of the design equation in actual situations. These curves are presented in the Results section which follows.

IV. RESULTS AND DISCUSSION

Critical Flowrates

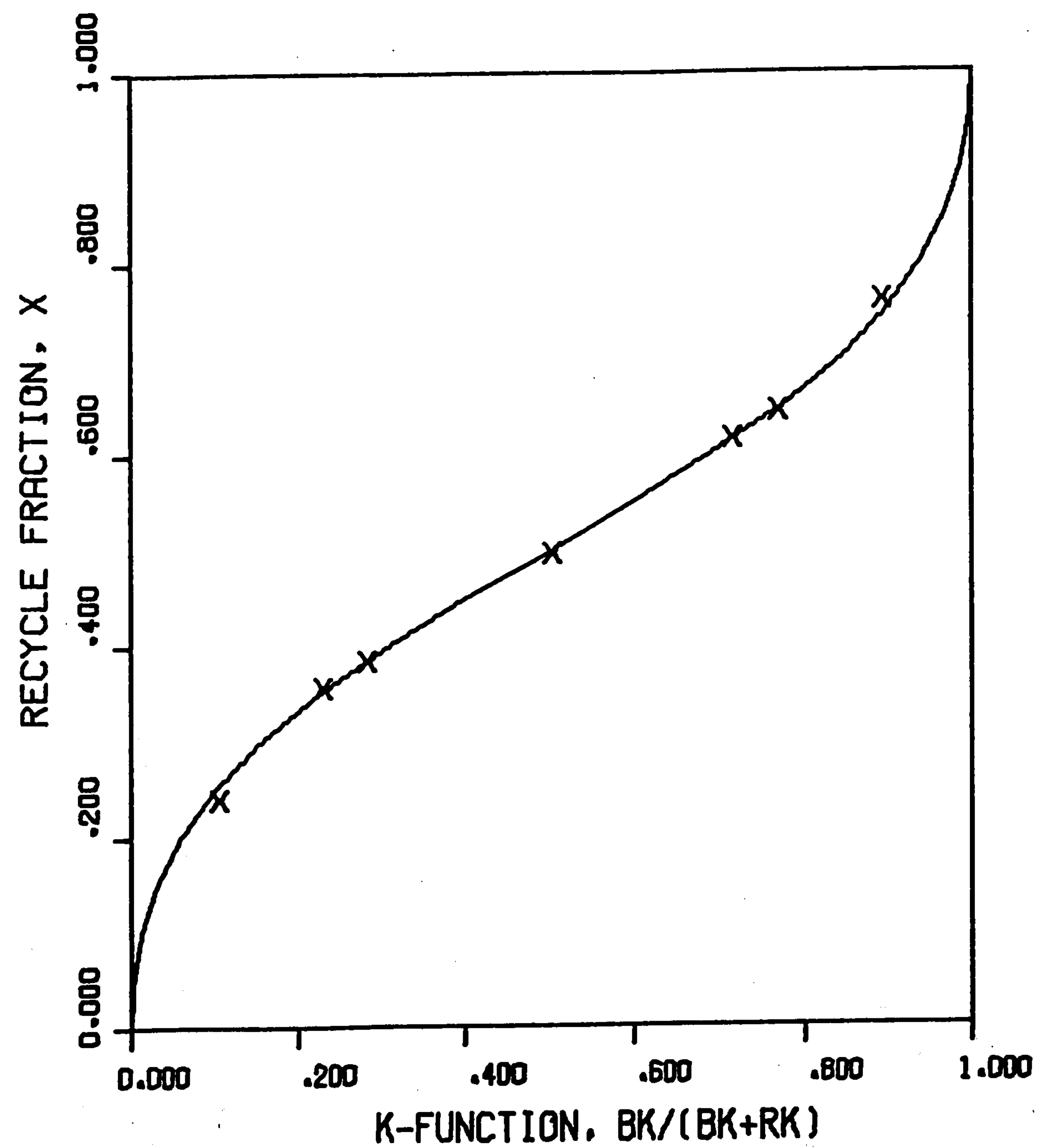
The computer program calculated critical flowrates for each Flowsplit in Stages 2 and 3 using equation 28. Experimental values are given in the Tables of Appendix C as being the very last main flowrate for which the experimental recycle fraction is equal to one. It was at this point that trickle flow out the branch line had just begun to occur. In comparison, the predicted values are always slightly greater than the observed values (by about 0.5 gpm). This is a consistent and reasonable result since actual stream flow did not occur until slightly after the trickle flow, and it is evidently this point that actually defines the critical flowrate. Thus, the excellent agreement between the predicted and experimentally observed values of critical flowrate verifies equation 28 as a dependable expression for this parameter.

Equal Static Heads

Results of the Stage 1 experiments are best summarized by Figure 10, which is a plot of recycle fraction vs. flowrate for Flowsplits 1 to 4. While only four data points were actually obtained in the experiment, three of these are really repeated since the branch and recycle lines are identical and their functions can be reversed in the calculations. The agreement between the experimental points and the curve predicted by equation 30 is seen to be very good. The averaged

Figure 10

FLOWSPLIT BEHAVIOR FOR STAGE 1
AVERAGED DATA



point deviations in the recycle fraction are as follows: Flowsplit 1, 1.4%; Flowsplit 2, 2.4%; Flowsplit 3, 0.5%; Flowsplit 4, -2.0%. These results are on the order of accuracy to be expected considering the degree to which the actual resistance coefficients are known and the actual flowrates are measured. (See Appendix C for all results).

Unequal Static Heads

The results for Stage 2 Flowsplits are presented in Figures 11, 12, and 13 and those for Stage 3 Flowsplits in Figures 14, 15, and 16. Clearly, the agreement between experiment and theory for all of Stage 3 is exceptional, with almost all point deviations less than one percent (see Appendix C). However, the agreement in Stage 2 is excellent only at the higher flowrates.

The results for Stage 2 are unusual in that a definite trend is evident, but not readily explainable. At the low flowrates between the critical and a branch Reynolds number of about 10,000, significant deviations between experimental and theoretical recycle fractions occur, with the highest being about 6.5%. Above this branch Reynolds number, the deviations suddenly and consistently become less than one percent all the way to the highest flowrate for every Flowsplit. There is no other correlation between this behavior and velocities or other Reynolds numbers evident in the Tables of Appendix C.

Such anomalous behavior cannot be explained by anything

Figure 11

FLOWSPLIT BEHAVIOR FOR STAGE 2

5/8" Recycle Orifice

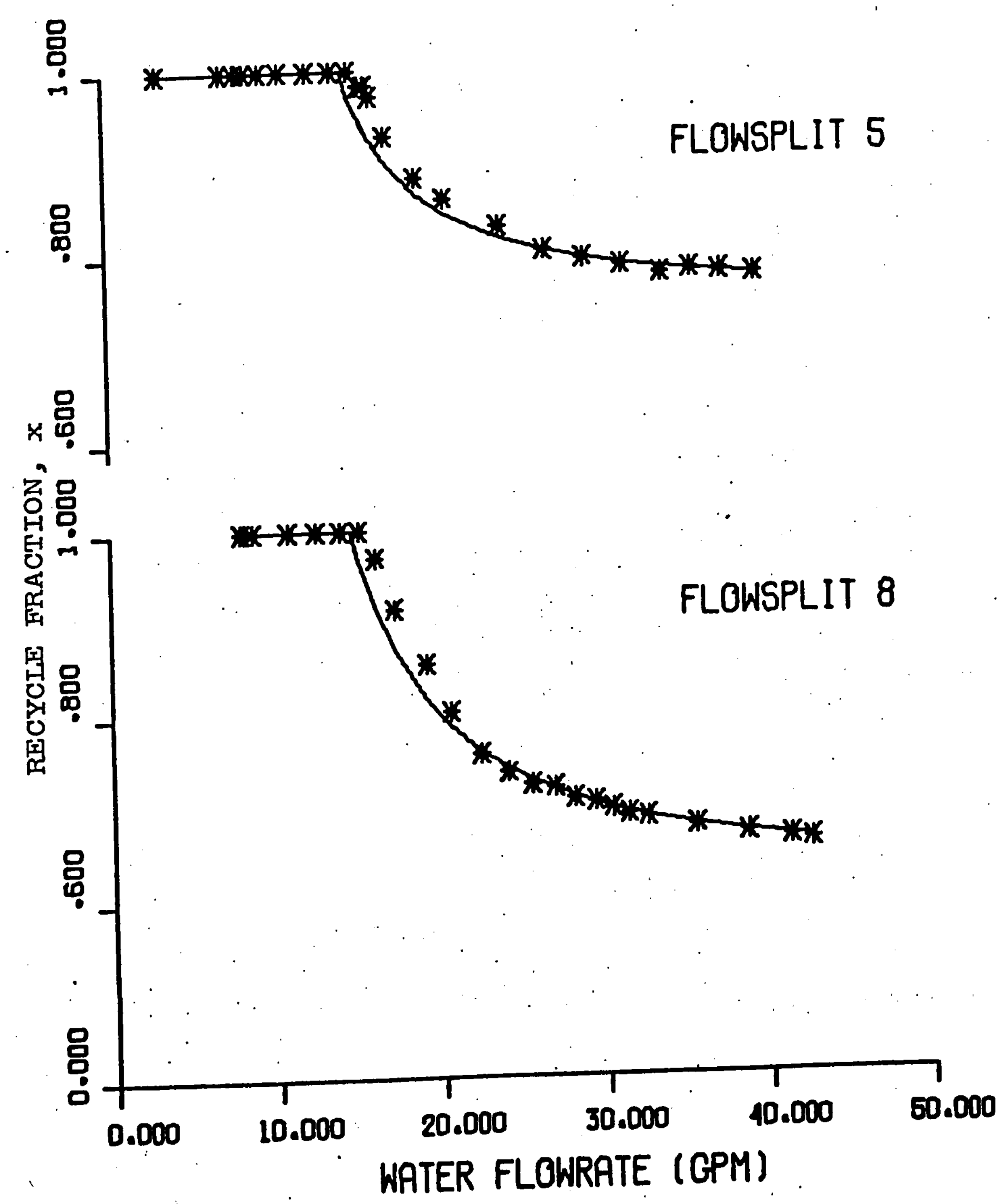


Figure 12

1/2" Recycle Orifice

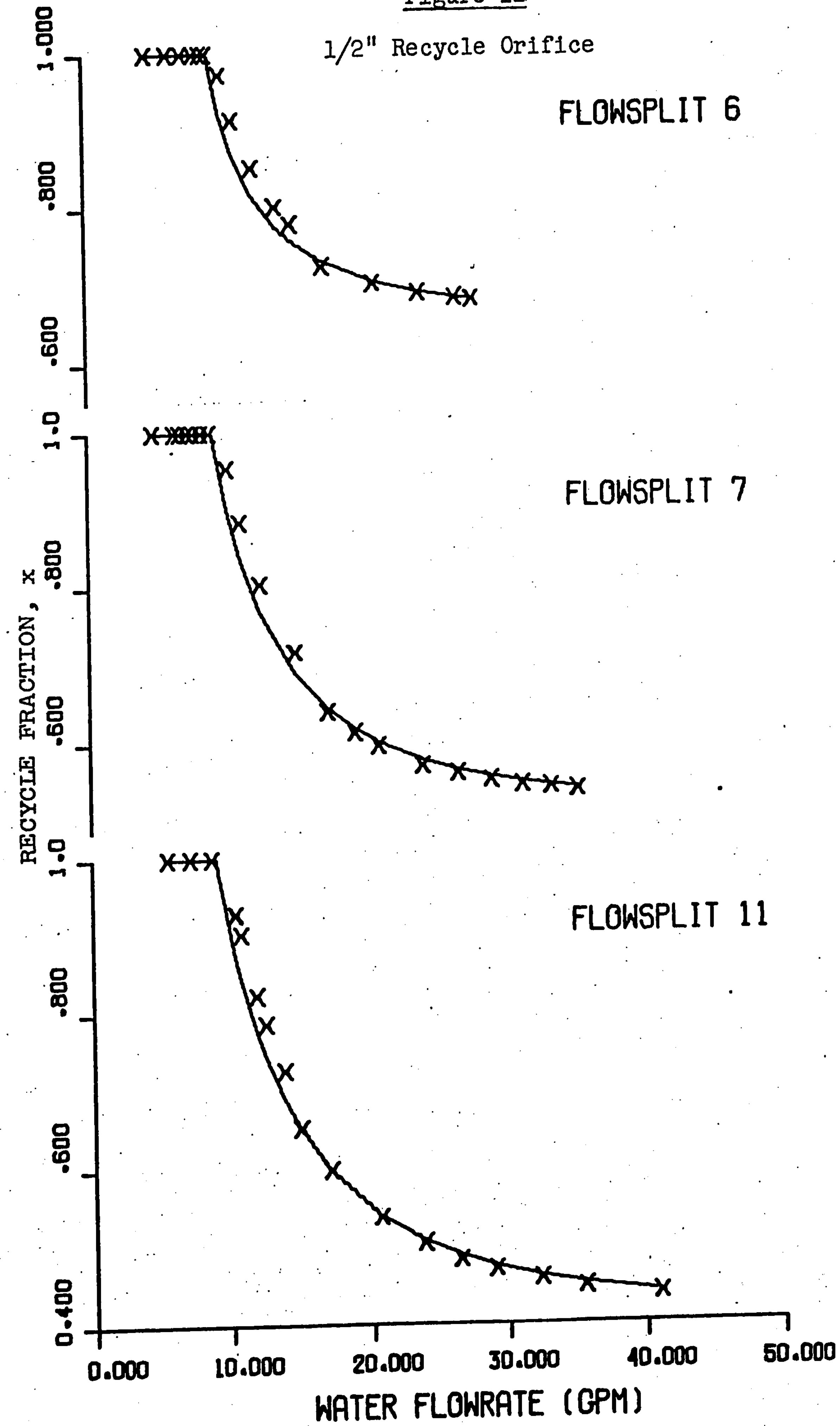


Figure 13

3/8" Recycle Orifice

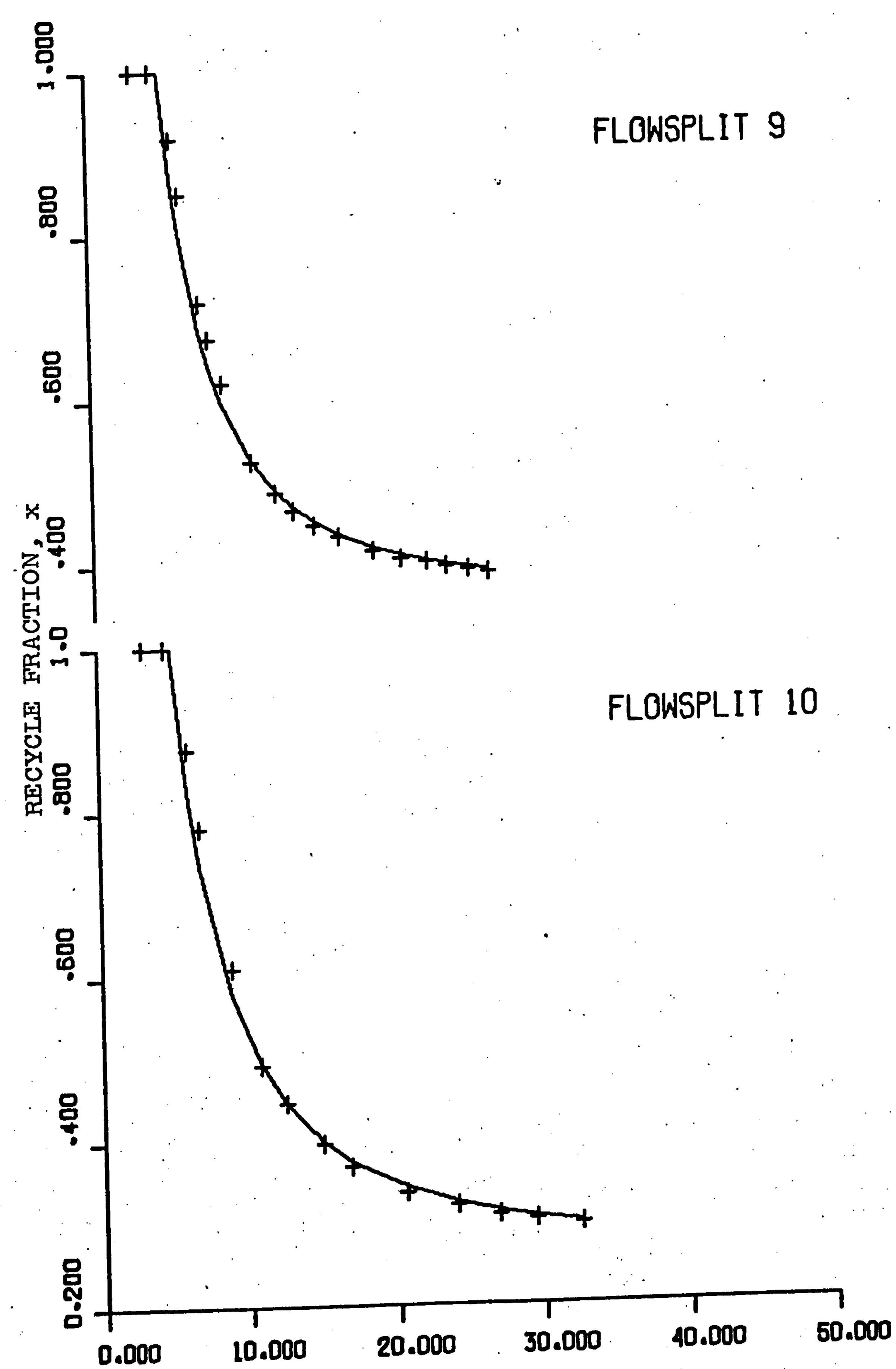


Figure 14

FLOWSPLIT BEHAVIOR FOR STAGE 3

5/8" Recycle Orifice

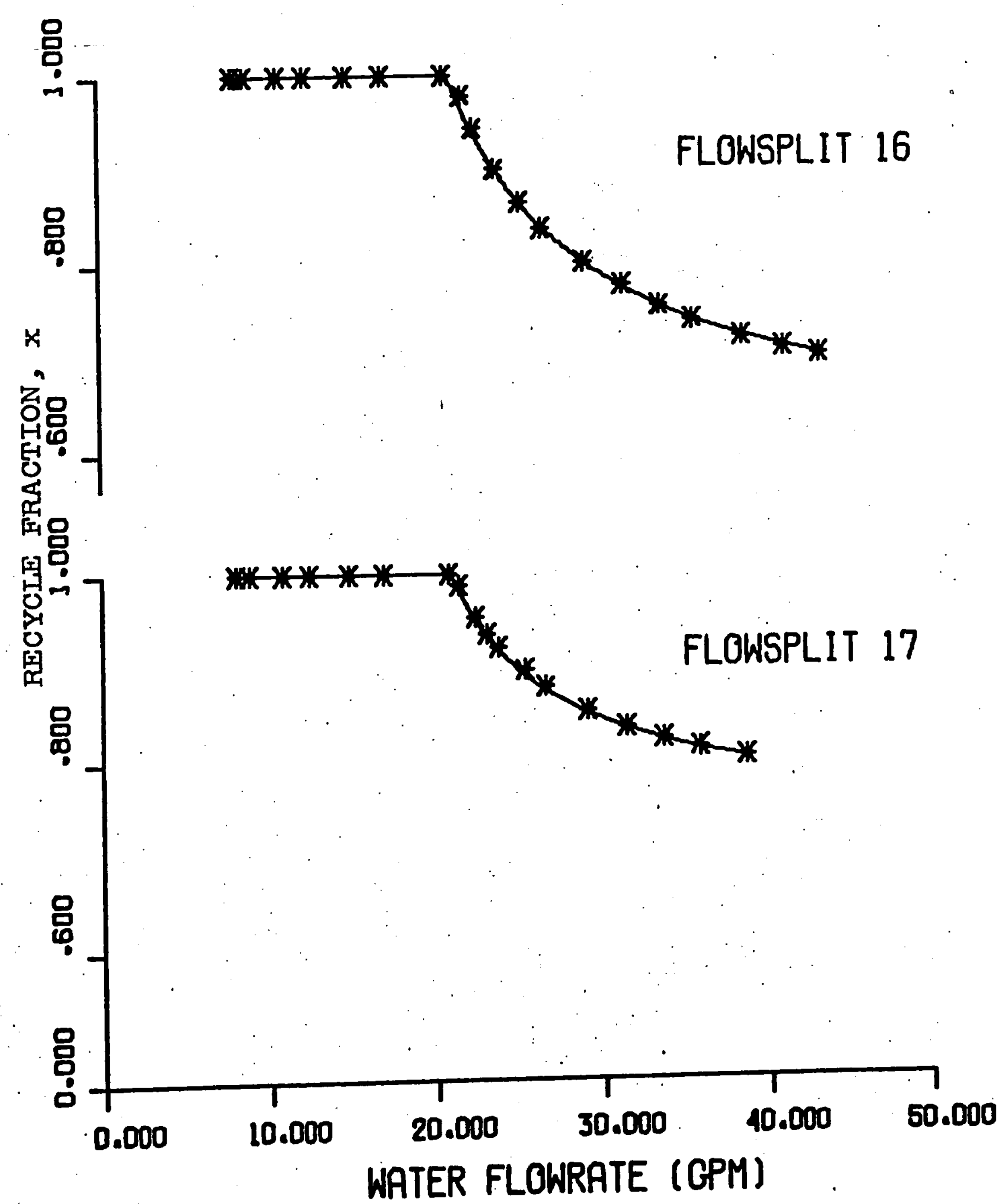


Figure 15

1/2" Recycle Orifice

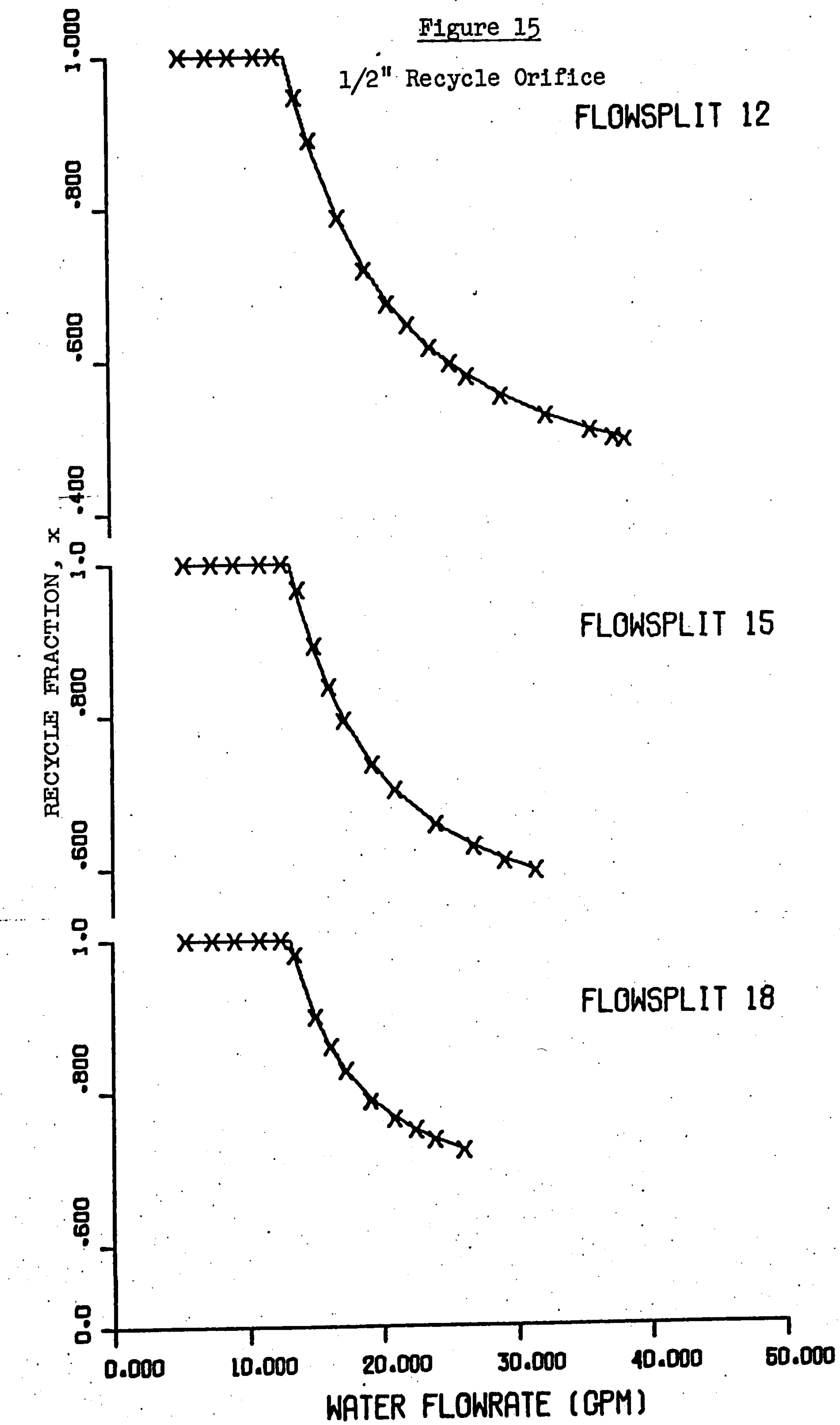
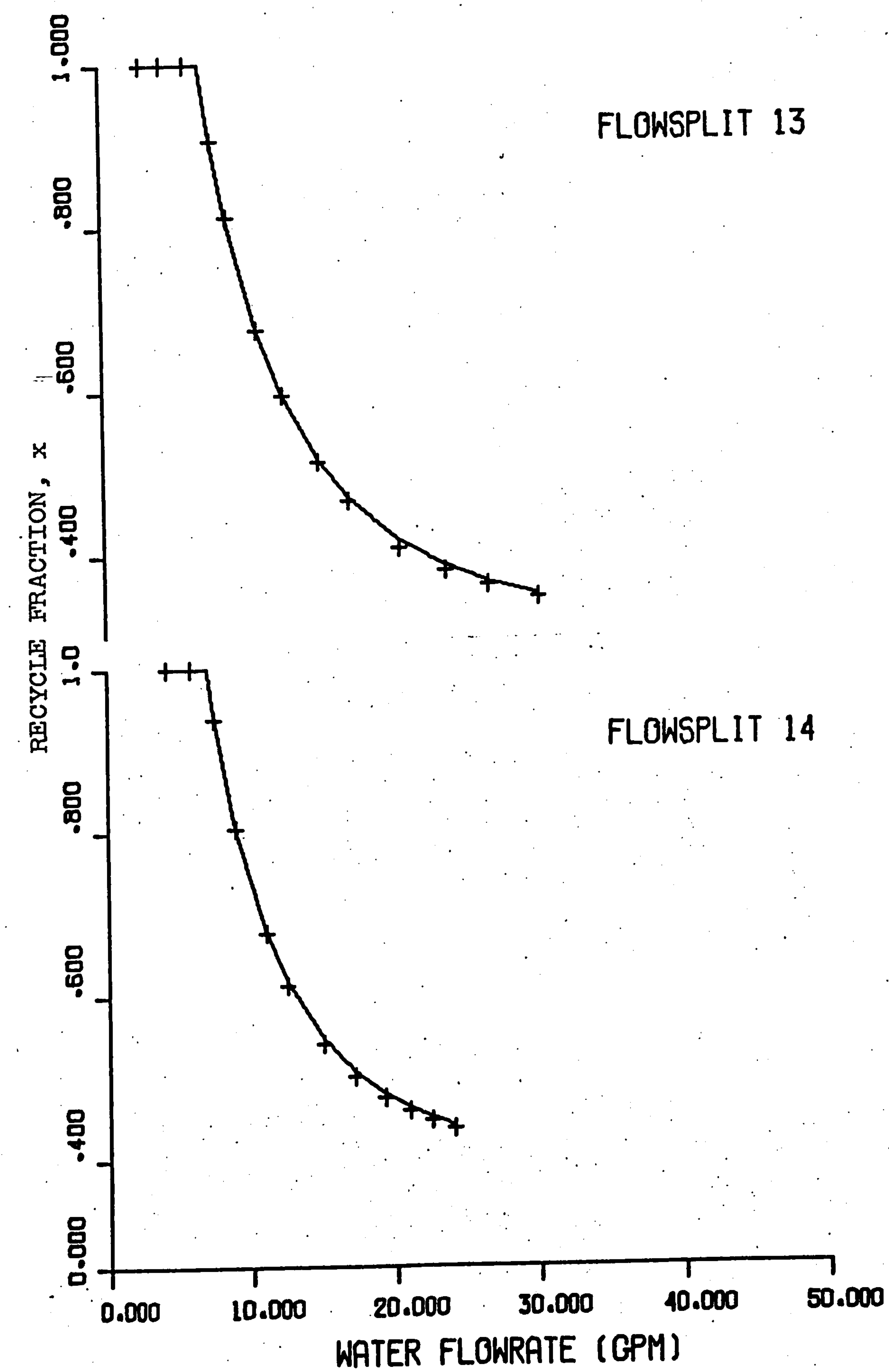


Figure 16

3/8" Recycle Orifice



but an equally anomalous trend which could have produced some significant errors during the course of the experiment. There were, in fact, problems with air leakage into the recycle manometer through the manometer housing during the experimental runs of Stage 2 alone. While taking data, when an air bubble appeared in the downstream pressure tubing at the manometer header, both pressure lines were closed with pinch clamps. The manometer header was then refilled by removing the downstream tubing, opening the vent stopcock atop the header, and adding water with a washbottle until it flowed up and through the vent so that all the air was purged. The vent was then closed, the downstream pressure line reattached, and the experiment resumed once the pinch clamps were opened. This was thought to be an acceptable technique since, with the upstream line blocked, the presiding mercury level in the manometer was maintained and presumably, the experimental trial could be resumed without having to begin all over again from zero flowrate. The only misgiving of this procedure is that the data collected sometime before the air bubble was discovered could very well be in error.

It is recalled that this problem was discovered for each Flowsplit in Stage 2 by about the time of the fourth reading past the start of branch flow. This problem was not corrected until perhaps Flowsplit 9 or so; prior to this, there had been unseccessful attempts to seal the manometer housing with putty and to construct new gaskets for the header wells atop the glass U-tube. Eventually, the housing was sealed better with more putty and the leakage problems no longer occurred by the end of Stage 2.

The consequence of this malfunction is that the recycle flow measured on this manometer, which is used to calculate the experimental recycle fraction, could very possibly be in error. This would explain the deviations noted in the experimental recycle fractions at the lower flowrates in Figures 11, 12, and 13. Although it may seem coincidental that the deviations consistently correct themselves past the point at about which the manometer was refilled, no other explanation for this trend can be offered. By the time Stage 3 had begun, the manometer no longer was leaking air to a noticeable degree and consequently, the results for Stage 3 are consistently as accurate as the last few points in the Stage 2 runs.

System Curves

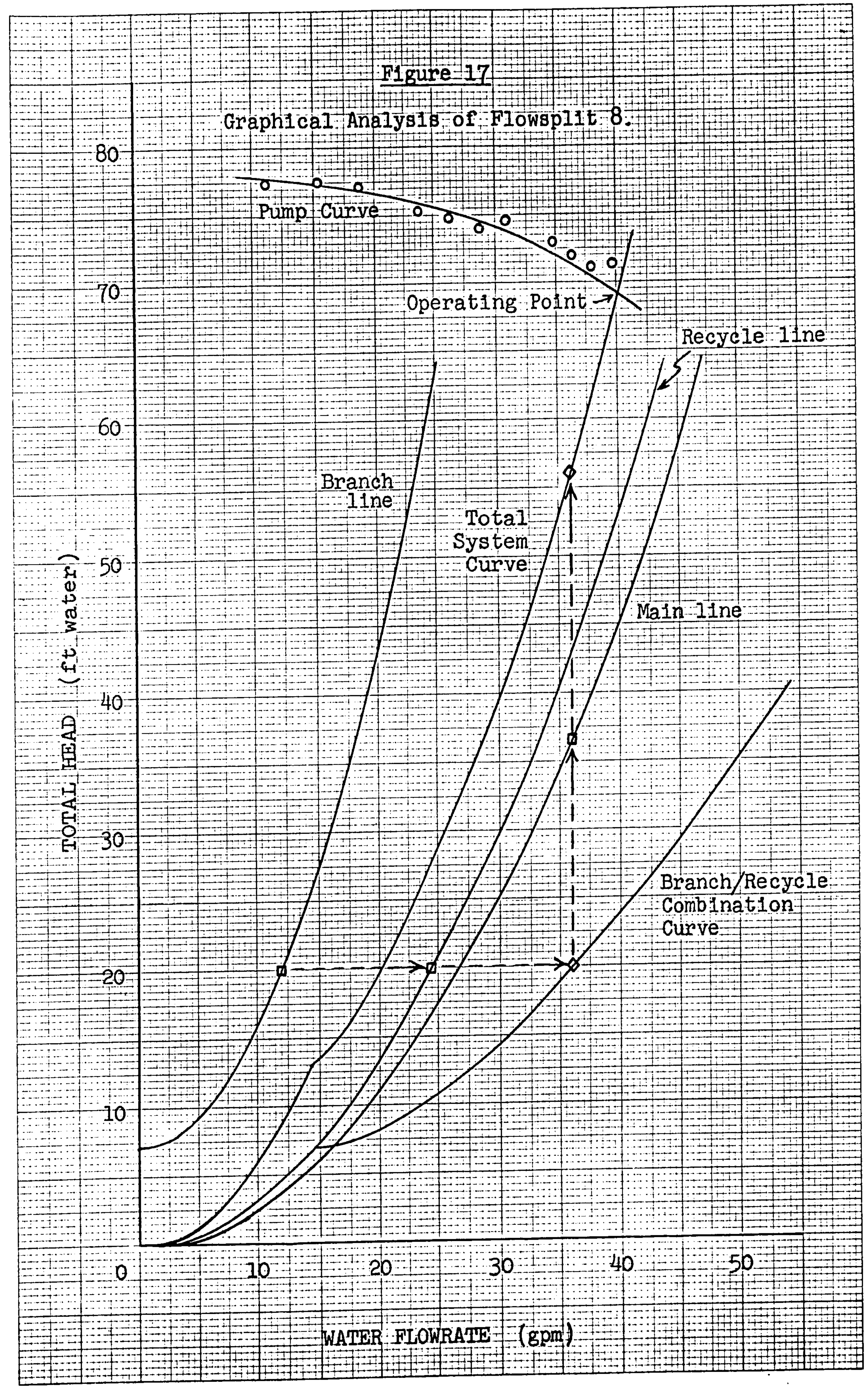
System curves were constructed for Flowsplits 8 and 16, the only two Flowsplits for which data was obtained with the main-flow globe valve fully open. Only for the fully-open valve could a mainline resistance coefficient be calculated and an operating point for the system be determined. The measured flowrate at that point can then be compared with the operating point determined graphically to see how well the design equation checks with the graphical technique.

The resistance coefficient for the globe valve was determined experimentally to be equal to 5.4, as described in Appendix A. This compares with the calculated value of about

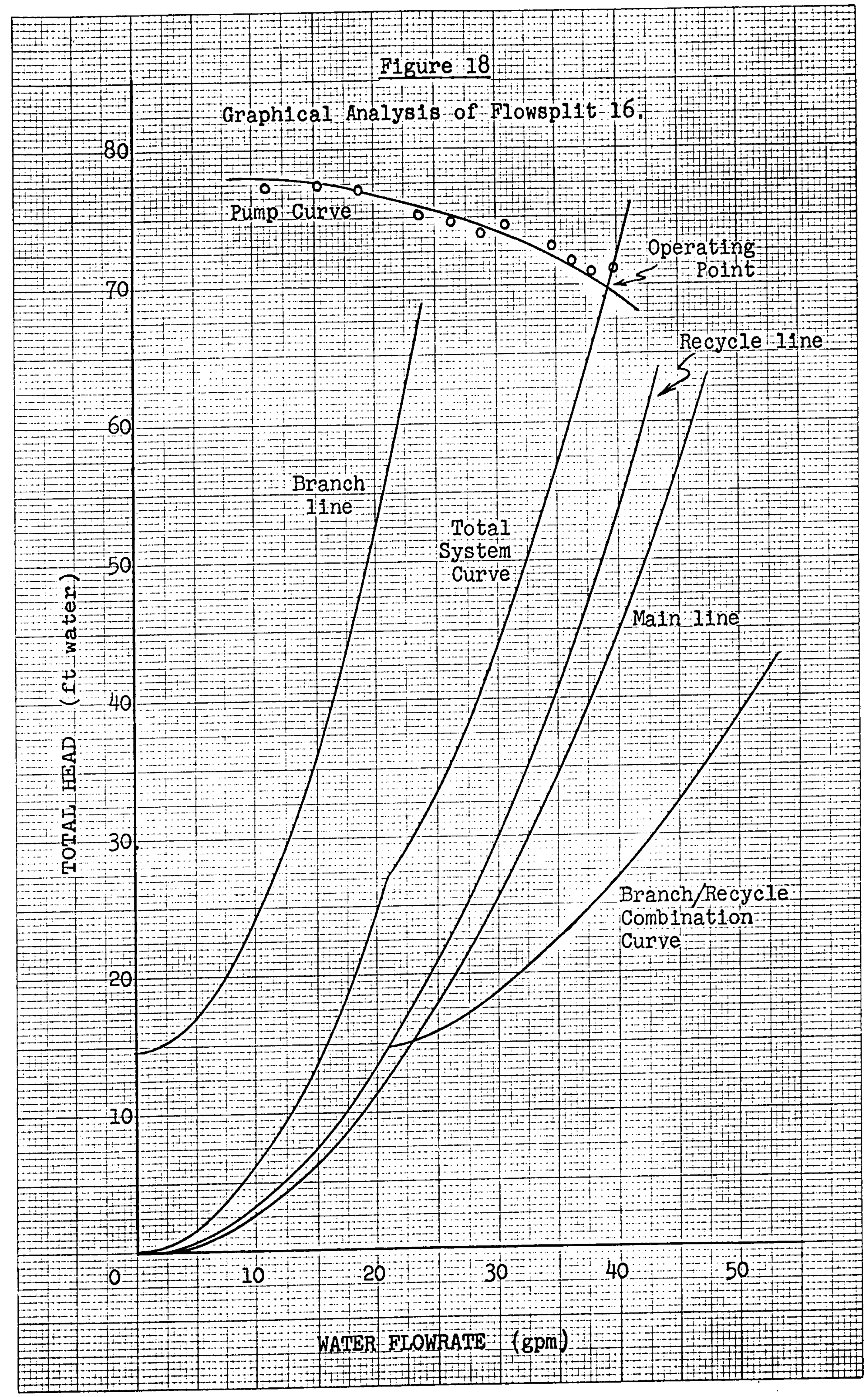
8.8, determined by the standard L/D value (5) of 340 and an average friction factor of about 0.026. While the percentage deviation between these two values is relatively large, the actual difference in values is fairly small since their magnitudes are small. Such a discrepancy should not be surprising since calculated resistance coefficients can sometimes be accurate to only 20 or 30 percent (8). In this case, the difference might be accounted for by the presence of a Teflon seat in the valve, which could possibly offer less flow resistance than a standard seat, to a discernable degree. If a more specific equation for the L/D value were available for this particular type of valve, a better estimate for the resistance coefficient may have been obtained. The consistency in the experimental data implies that the value of 5.4, with a standard deviation of 0.36, is a reliable estimate.

Accounting for flow losses in the main-line from the water level in the supply tank to the node, a main-line resistance coefficient, K_{sn}, equal to 13.2 was determined. Finally, system curves for Flowsplits 8 and 16 were calculated using the graphical addition technique and also, via the design equation. Table A4 summarizes the results of each set of calculations. Figures 17 and 18 show the system curves for each pipeline, the composite curve from the parallel addition of branch and recycle curves, and the complete system curve and pump curve. Figure 17 also illustrates the graphical addition technique for producing the total system curve.

The operating point flowrates determined graphically in



20 Squares to the Inch



20 Squares to the Inch

Figures 17 and 18 are 40 and 39.5 gpm, respectively. The corresponding experimental values, determined as the final flowrate in Flowsplits 8 and 16, are 42 and 42.7 gpm, respectively (which are the averages of the main flowrate and the sum of the delivery flowrates). These are deviations of -5% and -8%, respectively, and considering the absolute differences, are not really serious. While the agreement should have been a little better, a few reasons can be given which might explain the differences. Experimental error, while not large, (see Error Analysis), may have been great enough, say ± 1 gpm, to have an effect here, especially at this, the highest flowrate measured where manometer fluctuations were the greatest. Noting the significant degree of scatter (at the higher flowrates) in the experimental points defining the pump curve, it is easy to imagine that perhaps, the pump curve is actually a little flatter than drawn. Also, in calibrating pressure gague #1 in the pump curve experiment, it was assumed that a deviation of -1.0 psi occurred throughout, even in the vacuum range. If, in fact, the gague read the pressure accurately in the vacuum range (at the higher flowrates), the high end of the pump curve would have been a little flatter. These two factors could easily produce a difference in operating point flowrate of 0.5 gpm towards the experimental value. Considering these potential sources of error, it seems that the agreement between experimentally and graphically determined operating flowrates is rather good after all.

Error Analysis

Excluding the anomalous behavior exhibited in Stage 2, it is necessary to account for potential sources of error in all of the flowsplit data collected, in order to verify that the results are indeed as accurate as they seem to be. The procedure is to examine all the parameters which have an effect on the theoretical and experimental determination of recycle fractions, and to translate any uncertainties in the measured parameters into resultant errors in the calculated results.

Clearly, one source of error may have been the inability to get accurate manometer readings for orifice head-loss. This problem arose at the higher flowrates when oscillation of the mercury in the manometer often became great enough so that an average reading taken was recorded to as much as ± 0.5 centimeter. The significance of such errors in the determination of reliable flowrates is given by the following equations:

$$W_Q = \frac{\partial Q}{\partial(\Delta z)} W_{\Delta z} = \frac{1}{2} \frac{C' W_{\Delta z}}{\sqrt{\Delta z}} \qquad \text{(eq. 45)}$$

$$\frac{W_Q}{Q} = \frac{1}{2}\left(\frac{W_{\Delta z}}{\Delta z}\right) \qquad \text{(eq. 46)}$$

Such uncertainty analysis is based upon calculating a root-mean-squared sum of all the relative uncertainties in the parameters which would affect the variable being calculated from experimental data (11). The term $W_{\Delta z}$ is the uncertainty in reading the manometers, as established by visual judgement, and the term W_Q is the resulting uncertainty in measured flowrate. The relative error, given by W_Q/Q, is tabulated in the results tables of Appendix C for each main flowrate; these errors are, on the average, rather insignificant since they are almost always less than 0.5%.

Since the flowrates are calculated using parameters determined from experimental orifice calibration, rather than from assumed values for "standard installations" (see Appendix B), the calculated values are as good as they could have been. The correlation coefficient for the calibration data was greater than 0.999 for each orifice, indicating very consistent behavior in the data. Examining the calibration curves presented in Appendix B, it is seen that nearly all the data lie well within the 95% confidence band for each orifice, and so are well-represented by the smoothed curve expressed by equation 44. Nevertheless, it is instructive to examine the confidence interval for the y-intercept in the linear plots of Figure B1, since this would determine the confidence limit in the discharge coefficient calculated.

If the confidence level associated with the intercept is added to the value of the intercept, a maximum deviation value is found; this can then be transformed back to nonlinear form as a maximum value for the orifice coefficient, C'. If the difference between the average and this maximum orifice coefficient is regarded as the uncertainty in the value of the coefficient, one can relate this uncertainty to the flowrate as:

$$W_Q = W_{C'} \frac{\partial Q}{\partial C'} = (\sqrt{\Delta z})\, W_{C'} \qquad \text{(eq. 47)}$$

$$\frac{W_Q}{Q} = \frac{W_{C'}}{C'} \qquad \text{(eq. 48)}$$

where W_Q/Q is the relative error attributed to such uncertainty in the coefficient. The relative uncertainties for each orifice are thereby calculated to be as follows:

5/8 inch orifice, 1.6%	0.8 gpm	Max. Errors
1/2 inch orifice, 2.0% ⟹	0.9 gpm	
3/8 inch orifice, 4.2%	1.8 gpm	

The interpretation is that it may be possible for errors in flowrates, as measured by the 3/8 inch orifice, to be as large as 4.2%, to a degree of certainty of 95%. For the maximum flowrate of the experiments, 43 gpm, the maximum possible error in flowrate, due to these uncertainties, is as given above next to the relative errors. It can be seen that only for the 3/8" orifice is this error of any significance at all. However, the 1.8 gpm constitutes a range of 3.6 gpm (± 1.8) in which all flowrates surely will lie; it does not imply that they will all deviate by this amount, but only that almost none will deviate by more than this amount. Since no trends in errors, relating to the particular orifices used in each Flowsplit, are evident in Figures 10 through 16, it would have to be assumed that the uncertainties just discussed are of no consequence.

The confidence intervals associated with the exponent n would not really have any discernable effect on flowrates since all the calculated values of n are very close to the theoretical value of 1/2. Only that of the 3/4 inch orifice differs noticeably (n = 0.469); this is of no consequence, however, since main flowrates as measured by this orifice were not used in any calculations. Therefore, only the deviations in the coefficient C' and in the manometer readings, could have been of any significance. Rigorously, the relative error equation should have been written as:

$$\frac{W_Q}{Q} = \frac{\sqrt{\left(\frac{1}{2}\,\frac{C'\;W_{\Delta z}}{\sqrt{\Delta z}}\right)^2 + \left(W_{C'}\sqrt{\Delta z}\right)^2}}{Q} \qquad \text{(eq. 49)}$$

However, as noted earlier, the magnitude of the errors attributable to manometer readings are negligible and so, equation 48 is a good approximation of the overall relative error in flowrates.

Parametric Plots

As discussed in Appendix D, the idea of representing the design equation by a series of parametric plots failed to substantiate itself as a simplified design technique. Since many charts would be required to represent a wide range in the values of either fixed resistance coefficient for a given system, it would be too laborious to determine accurate solutions to problems.

However, the technique was applied to the experimental apparatus such that one chart would represent one value of the recycle resistance coefficient. To summarize all of the experiments, three charts, one for each of the recycle orifices used, would be required. The plot for the 3/8 inch orifice is presented in Figure 19. A computer program (Appendix D) was used to calculate and plot values of the recycle fraction vs. the resistance coefficient function, f(K), for each of the S curves at convenient intervals. This is a Type A plot, and all characteristics of this particular type, as discussed in Appendix D, apply to Figure 19. This chart has been verified to provide results consistent with the results of the flowsplit experiments, tabulated in Appendix C.

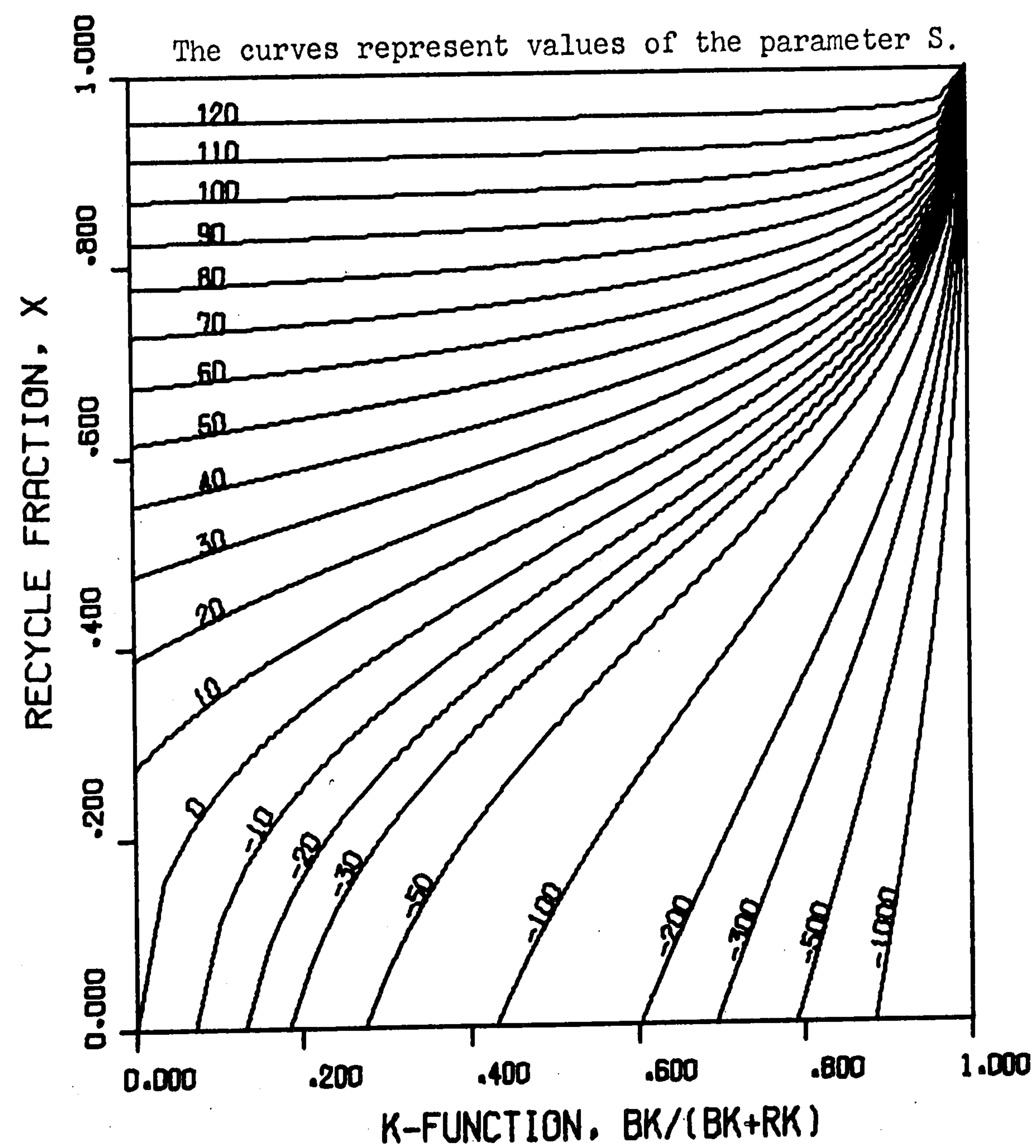
Nomograph

As discussed in Appendix E, the idea of representing the design equation by a nomograph is also one which fails to result in a simplified design technique. Many problems with scaling and construction of the nomograph result, because of the ranges in the variables which should be represented, and due to the form of the design equation. If it were possible to construct such a nomograph in accordance with standart prodedures and formats, it would not be a perfectly general design tool as desired. At least four nomographs would be required to span the ranges in variables to be encountered, and the manipulation necessary to find a solution to a problem would unduly complicate the technique.

Figure 19

PARAMETRIC PLOT OF RECYCLE FRACTION
AS A FUNCTION OF RESISTANCE COEFFICIENTS,
FLOWRATE, AND STATIC-HEAD DIFFERENCE.

$K_R = 132.5$



V. CONCLUSIONS

In view of the results of the experimental study conducted, and regarding the objectives of this research, the following can be concluded:

1. The design equation is a valid representation of actual flow behavior in the experimental apparatus used in this investigation.

2. Because it is based on a perfectly general flowsplit model and since the experimental results represent a fairly wide range of operating conditions, the design equation can be recommended for application to any branched-flow piping system which can be represented by the model.

3. For the case of equal static heads, a simple curve representing all flowrates and any combination of delivery line resistances results; it can be used in the solution of any problems for such a system.

4. For the case of unequal static heads, iterative solution of the design equation is usually necessary.

5. The design equation cannot concisely be represented as either a parametric plot or a nomograph.

6. An analytical system analysis technique has been presented for the solution of any problem with the use of two junction equations and the design equation. In many cases, iterative solution of the design equation may not be necessary.

7. This technique is amenable to machine computation, whereas the graphical system analysis technique is not.

REFERENCES

(1) Karassik, Igor J., et al, eds. Pump Handbook. McGraw-Hill, New York. 1976.

(2) Hicks, Tyler G. and T. W. Edwards. Pump Application Engineering. McGraw-Hill, New York. 1971.

(3) Simpson, Larry L. and M. L. Weirick. "Designing Plant Piping," Chemical Engineering. 85 (8), 1978.

(4) Perry, Robert H. and C. H. Chilton. Chemical Engineer's Handbook. McGraw-Hill, New York. 5th ed., 1973.

(5) Foust, Alan S., et al. Principles of Unit Operations. John Wiley & Sons, New York. 1960.

(6) Flow of Fluids Through Valves, Fittings, and Pipe. Crane Technical Paper no. 410. Crane Co., New York. 1976.

(7) Churchill, Stuart W. "Friction-Factor Equation Spans All Fluid-Flow Regimes," Chemical Engineering. 84 (24), 1977.

(8) Pipe Friction Manual. Hydraulic Institute, Cleveland, 3rd ed., 1961.

(9) Wessel, Roger P. "Graphical Fluid Systems Analysis," Power Engineering. February, April, July, 1975.

(10) American Society of Mechanical Engineers, Howard S. Bean, ed. Fluid Meters: Their Theory and Application. 6th ed., New York, 1971.

(11) Holman, J. P. Experimental Methods for Engineers. McGraw-Hill, New York. 1966.

(12) Franks, Roger G. E. Modeling and Simulation In Chemical Engineering. John Wiley and Sons, New York. 1972.

(13) Benedict, R. P. "Loss Coefficients for Fluid Meters," Transactions of ASME: Journal of Fluids Engineering. March 1977.

(14) Benedict, R. P., et al. "Flow Losses in Abrupt Enlargements and Contractions," Transactions of ASME: Journal of Engineering for Power. January 1966.

(15) Davis, Dale S. Nomography and Empirical Equations. Reinhold, New York. 1955.

APPENDIX A - SYSTEM SPECIFICATIONS AND CALCULATIONS

System Construction

All pipes and fittings used were 1-inch nominal, schedule 40, galvanized commercial steel, previously unused. The holding tanks were constructed from sections of steel 55-gallon commercial chemical drums. The main-flow valve was a brass Stockham globe valve with Teflon seat, union bonnet, threaded ends, and rated at 150 psi service pressure. An Ingersoll-Rand Cameron pump, Type 1-1/4 K-2, Model C, with a 4-3/4 inch impeller was used in conjunction with a Marathon Electric 2-horsepower motor, Model WH137C15, 3-phase, 6-cycle.

The orifice installations were constructed as closely as possible to the specifications set forth by the ASME, as listed in Appendix B. Orifice test sections were fitted with unions at either end to facilitate removal from the pipeline. The recommended minimum lengths of straight pipe before and after the orifice (10) were exceeded in all Stages for all orifice sizes used (see Figure 9).

Orifice plates were cut from 1/8 inch aluminum sheet, and precisely center-drilled so as to be concentric within the pipe installation. A 60^{o} chamfer on the downstream side provided the required sharp, thin upstream edge. All orifice bores were drilled and measured to be within 0.0005 inch of specification, except the 5/8 inch orifice which proved to be larger in diameter by 0.001 inch. Pipe taps on the orifice test sections were constructed of brass tubing of 1/16 inch inside diameter. They were welded in place and smoothed flush to the inner wall of the pipe. Both taps were located as closely as possible to the D-D/2 specification given in Appendix B. They were actually situated at 1 inch upstream and an average of 5/8 inch downstream of the upstream orifice face. Neoprene gaskets were constructed and fitted between the two flanges and each orifice plate so that none of the gasket would extend within the inner walls of the pipe.

Three different mercury-filled manometers were used for measuring orifice pressure drops. The main-flow manometer was calibrated in inches and had a maximum range of 28 inches. The two delivery manometers were calibrated in centimeters and had a maximum range of about 90 centimeters each. Nalgene plastic tubing was used to connect the pipe taps to the manometer taps. All tubing and manometers were filled with water so that no air was present in any of the lines at the start of each experimental trial.

Table A1 lists the differences in construction which occurred for each of the eighteen Flowsplits studied, namely, the various orifice combinations and branch line lengths. A schematic diagram of the apparatus has already been presented in Figure 9 in the Experimental section of this report.

TABLE A1

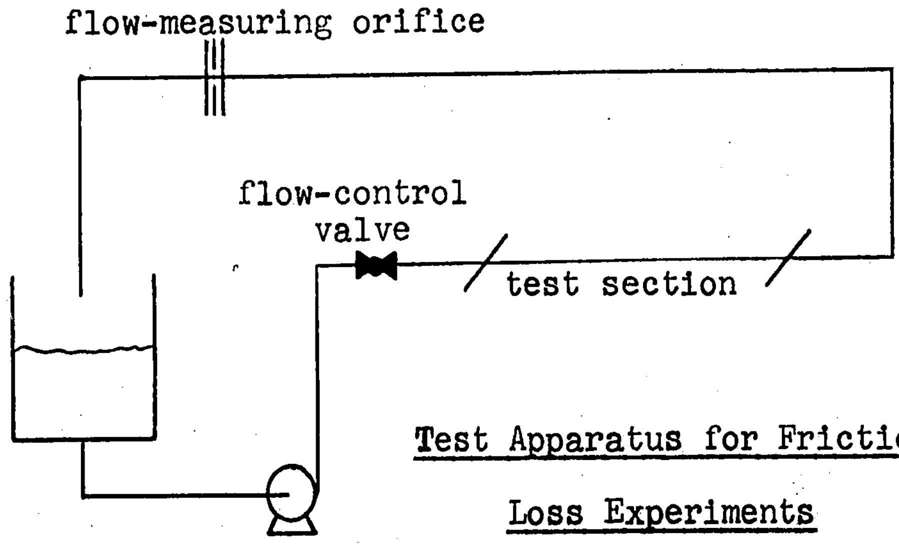
System Specifications for the Flowsplit Apparatus

Stage	1				2							3						
Flowsplit	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Recycle Orifice	1/2	1/2	1/2	5/8	5/8	1/2	1/2	5/8	3/8	3/8	1/2	1/2	3/8	3/8	1/2	5/8	5/8	1/2
Branch Orifice	1/2	5/8	3/8	3/8	3/8	3/8	1/2	1/2	1/2	5/8	5/8	5/8	5/8	1/2	1/2	1/2	3/8	3/8
Branch Length	75 inches				138 inches							196 inches						
Static Head Difference	zero				7.0 feet							14.6 feet						

Globe Valve Resistance Coefficient

In order to experimentally determine the resistance coefficient for the fully-open main-flow globe valve, the apparatus shown in Figure A1 was used. The orifice for measuring flowrates in the system was the same 1/2 inch orifice used in the flowsplit experiments. The test section consists of removable sections of pipe situated between pressure taps at several locations.

The globe valve was placed in a test section containing 20 inches of pipe between the pressure taps. Thus, the pressure drop being measured in this test is that produced by the fully-open globe valve and the 20 inches of pipe. Since this pipe had been in service for some time, it was necessary to evaluate the friction factor for this pipe in order that the pipe friction-loss could be accounted for. This was done in a second test which utilized a straight 82 inch section of this pipe between pressure-measuring stations.



Test Apparatus for Friction-Loss Experiments

Figure A1

The data analysis was performed as follows. The resistance coefficient for any test section can be written as:

$$K_T = \frac{(\Delta P/\rho)_{\text{test section}}}{(V^2/2g)_{\text{flow orifice}}} = \frac{(\Delta P/\rho)_{\text{test}}}{(Q^2/C_f)_{\text{flow}}} \qquad \text{(eq. A1)}$$

Since both numerator and denominator have been measured as pressure drops on two manometers in the experiment, the resistance coefficient can be expressed directly in terms of the manometer readings, Δz. The numerator may be written as:

$$\frac{\Delta P}{\rho} = \frac{\rho_{Hg} - \rho_{H_2O}}{\rho_{H_2O}} (\Delta z)_{\text{test}} = \frac{849 - 62.3}{62.3(30.48)} (\Delta z)_{\text{test}}$$

where $(\Delta z)_{\text{test}}$ is in (cm Hg) as measured. (eq. A2)

Using the orifice calibration equation for the 1/2 inch orifice, the denominator may be expressed as:

$$\frac{Q^2}{C_f} = \frac{\left(2.0607(2.54\ \Delta z_{\text{flow}})^{0.4952}\right)^2}{466.6} \qquad \text{(eq. A3)}$$

where $(\Delta z)_{\text{flow}}$ is in (in. Hg) as measured. The resulting equation for the resistance coefficient is:

$$K_T = 18.083 \frac{(\Delta z)_{\text{test}}}{(\Delta z)_{\text{flow}}^{0.99}} \qquad \text{(eq. A4)}$$

Of course, now the resistance coefficient for the 20 inches of straight pipe, K_P, must be subtracted from this total K_T in order to get the K_V for the valve alone. Using the data from the second test for the 82 inch section of straight pipe, the friction factor can be determined using equation A4, as:

$$f = \frac{K\,D}{L} = \frac{1.049\ K}{82} = 0.2313\ \frac{(\Delta z)_{test}}{(\Delta z)_{flow}^{0.99}} \qquad \text{(eq. A5)}$$

Finally, the equation for the globe valve resistance coefficient is written as:

$$K_V = K_T - K_P = K_T - \frac{f(20)}{1.049} \qquad \text{(eq. A6)}$$

This series of calculations is carried out step-by-step for each experimental flowrate (determined by the flow manometer). The intermediate and final results are presented in Table A2. The final resistance coefficient for the globe valve is obtained by averaging the individual values of K_V.

Pump Curve

In order to determine a pump curve experimentally, the apparatus illustrated in Figure A2 was used. The same 3/4 inch orifice used in the flowsplit experiments was used for measuring flowrates in this system.

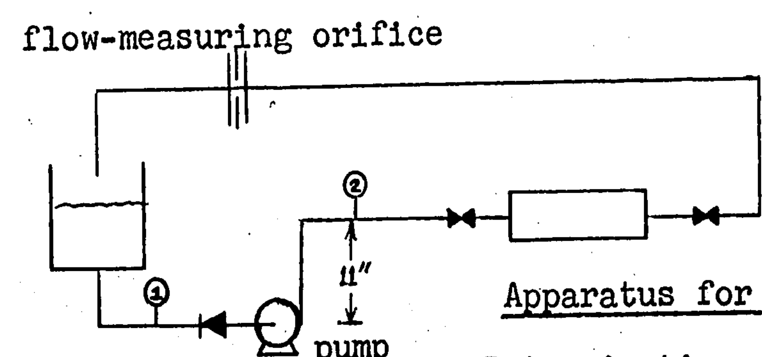
The pressure gagues used to determine the outlet and inlet pump pressures were calibrated with a dead-weight tester. Gague 1 was found to read about 1 psi too high and gague 2 about 2.5 psi too high for the range of positive pressures tested. Because of the location of the pressure gagues, the pressure difference actually measured consisted of the pump

Table A2

Experimental Data for Determination of

Globe Valve Resistance Coefficient

Orifice ΔP (in Hg)	Pipe ΔP (cm Hg)	f	Valve ΔP (cm Hg)	K_T	K_V
1.0	0.1	0.0231	0.35	6.33	5.89
2.0	0.25	0.0291	0.58	5.46	4.91
3.0	0.45	0.0351	0.9	5.48	4.81
4.0	0.55	0.0322	1.2	5.49	4.88
5.0	0.65	0.0305	1.6	5.88	5.29
6.0	----	------	2.0	6.13	5.56
7.0	----	------	2.25	5.92	5.35
8.0	1.0	0.0295	2.65	6.11	5.55
10.0	1.35	0.0319	3.4	6.29	5.68
12.0	1.6	0.0316	4.0	6.17	5.57
15.0	1.85	0.0293	5.0	6.19	5.63
19.0	2.4	0.0301	---	----	----



Apparatus for Experimental Determination of Pump Curve

Figure A2

head developed minus the head-loss of one elbow, one expansion, and a static head of eleven inches. Thus, the equation for pump total head is:

$$H_T = \frac{P_2 - P_1}{\quad} + Z_2 - Z_1 + K\frac{Q^2}{C_f} \qquad \text{(eq. A7)}$$

$$H_T = \frac{144(P_2-P_1)}{62.3} + \frac{11}{12} + (30f + 0.33)\frac{Q^2}{466.6}$$

where P_2 and P_1 are in psi as measured.

Flowrates were calculated using the calibration equation for the 3/4 inch orifice. The Reynolds number for each flowrate was then calculated and the friction factor found from the Moody diagram (5). Table A3 presents the results of these calculations at each flowrate. The (Q, H_T) points have been plotted as the pump curve in Figures 17 and 18.

System Curves

In order to construct system curves for Flowsplits 8 and 16, it is necessary to first determine a resistance coefficient for that part of the system prior to the node. The following is a listing of all flow losses occurring between the initial point, at the surface of the water in the supply tank, and the final point, at the node:

1 exit loss from tank, $K = 0.50$

1 expansion loss, from 1 in. to 1-1/2 in. pipe

$d_1/d_2 = 1.049/1.610 = 0.65$

From reference (5), find $K = 0.33$

1 fully-open globe valve, $K = 5.4$ (by experiment)

1 main-flow 3/4 inch orifice, $\beta = 0.7150$, $C_o = 0.685$

$$K = (1 - \beta^2)((1/\beta^4) - 1)/C_o^2 \qquad \text{(eq. B4)}$$

$$K = 2.9$$

1 tee, flow through run, $L/D = 20$

1 tee, flow through branch, $L/D = 60$

Straight pipe, 34 + 11 + 31 = 76 in., $L/D = 72.4$

The resistance coefficient from surface-to-node is:

$$K_{sn} = \Sigma K + f(\Sigma L/D)$$

$$K_{sn} = (0.50 + 0.33 + 5.4 + 2.9) + (20 + 60 + 72.4)\ f$$

$$K_{sn} = 9.13 + 157.4\ f$$

Since the average friction factor may be taken as $f = 0.026$ (from the data of Appendix C), the resistance coefficient is found to be $K_{sn} = 13.2$.

The system curves in Figures 17 and 18 were calculated by using the design equation and by using the graphical addition technique. The results of these calculations are presented step-by-step in Table A4.

Table A3

Experimental Data for Determination of Pump Curve.

Orifice ΔP (cm Hg)	Pump P_2 reading (psi)	Pump P_2 actual (psi)	Pump P_1 reading (psi)	Pump P_1 actual (psi)	Pump ΔP (psi)	Q (gpm)	f	H_T (ft)
4.0	36.5	34.0	2.0	1.0	33.0	11.16	0.0270	77.50
8.0	36.0	33.5	1.5	0.5	33.0	15.43	0.0260	77.76
12.0	35.5	33.0	1.3	0.3	32.7	18.66	0.0257	77.32
20.0	34.0	31.5	0.8	-0.2	31.7	23.70	0.0251	75.49
25.0	33.3	30.8	0.5	-0.5	31.3	26.32	0.0248	74.86
30.0	32.5	30.0	0.1	-0.9	30.9	28.66	0.0247	74.22
35.0	31.5	29.0	-1.0	-2.0	31.0	30.81	0.0246	74.74
40.0	30.5	28.0	-2.0	-3.0	31.0	32.80	0.0246	75.03
45.0	29.0	26.5	-2.5	-3.5	30.0	34.65	0.0245	73.00
50.0	28.0	25.5	-3.0	-4.0	29.5	36.41	0.0244	72.12
55.0	27.0	24.5	-3.5	-4.5	29.0	38.07	0.0243	71.24
60.0	26.5	24.0	-4.0	-5.0	29.0	39.65	0.0242	71.51

Table A4

Calculations for Construction of System Curves

from: (A) The Design Equation, and

(B) Individual Pipeline Flow Losses

(A)

Flowsplit 8			Flowsplit 16		
x	Q (gpm)	H_T (ft)	x	Q (gpm)	H_T (ft)
1.0	2.0	0.25	1.0	5.0	1.54
1.0	5.0	1.54	1.0	10.0	6.17
1.0	10.0	6.17	1.0	15.0	13.89
1.0	13.0	10.43	1.0	20.0	24.69
1.0	14.43	12.85	1.0	20.92	27.00
0.9	16.31	14.73	0.9	23.66	30.99
0.8	19.80	19.48	0.85	25.77	34.83
0.7	29.16	37.98	0.8	28.83	41.30
0.68	33.69	49.66	0.75	33.71	53.51
0.66	41.54	73.95	0.7	43.20	83.36

(B)

	Flowsplit 8			Flowsplit 16		
Q (gpm)	H_M (ft)	H_R (ft)	H_B (ft)	H_M (ft)	H_R (ft)	H_B (ft)
5	0.71	0.84	9.24	0.71	0.84	17.00
10	2.83	3.34	16.07	2.83	3.34	24.12
15	6.37	7.52	27.45	6.37	7.52	35.99
20	11.32	13.37	43.39	11.32	13.37	52.60
30	25.46	30.09	88.94	25.46	30.09	100.07
40	45.26	53.49	152.70	45.26	53.49	166.53

APPENDIX B - ORIFICE INFORMATION

Orifice Calibration

A bucket-and-timer technique was used to calibrate each of the four sizes of orifice plates used. The time required to collect a given volume of water flowing out of the discharge line was recorded along with the weight of the bucket and water, and its temperature. A constant average weight of bucket and residual water, 2.05 lbs, was subtracted from each collection weight recorded. The temperature of the water was needed to determine the density, from which "weights collected" were transformed to "volumes collected." Three such sets of collection data were taken for each main flowrate. The main flowrate was determined by regulation of the mainflow valve such that clearly discernable readings on the main-flow manometer could be made. Convenient increments of flow, as indicated by the main-flow manometer, were used to regulate the main flow from zero to the maximum attainable. The 3/4 inch orifice was installed as the main-flow orifice; the flowsplit apparatus in the configuration of Stage 1 was used with one or both lines delivering flow with the downcomers removed.

For each set of collection data, the readings of the manometersconnected across the delivery line orifice meter and the main-flow orifice meter were recorded. The three trials, performed for each setting of the main-flow manometer, were averaged to yield a single flowrate/head-loss point. The plot of all such points for each orifice size constitutes the orifice calibration curve. All calculations and calibration curves were carried out by the computer, and are presented in the following pages along with the calibration curves for all four orifice sizes.

Orifice Calibration Computer Program

The flowrates and corresponding manometer head-loss readings were determined as described by the program ORIFIC. Temperature/density data for water (4) was supplied in data statements and the corresponding values of density at the experimental temperatures were found via a data correlation routine, FUN1 (12). Results for the three trials at each main-flow manometer reading were averaged using subroutine AVGY.

The flowrate/head-loss data for each orifice was then correlated via a least-squares linear regression analysis. Equation 44 was first converted to linear form by taking logarithms. A call to subroutine LSLR transforms the data to linear form (by taking the log of each data point) and calculates the slope and y-intercept of the resulting straight line as fitted to the data. Linear results are then transformed back to nonlinear form with the following results:

Slope of line = exponent in equation 44 , $\cong 1/2$

exp(intercept) = constant C' in equation 44.

The discharge coefficient in equation B1 is calculated from C'.

In addition, LSLR establishes the statistical "goodness of fit" by calculating the 95% confidence intervals of the slope, intercept, and regression values of the flowrate at given head-loss readings. Also, the correlation coefficient was calculated to determine the statistical consistency of the data.

Finally, the program plots a linear calibration curve with the 95% confidence envelope, and a smoothed calibration curve, as calculated by LSLR, for each orifice size. Both curves include the original data points for comparison.

It should be pointed out that the orifice calibration equation, given as equation 44, is a concise version of the fundamental orifice equation (5):

$$V_2 = C_o \sqrt{\frac{2g(P_1 - P_2)/\rho}{1 - \beta^4}} \qquad \text{(eq. B1)}$$

where V_2 is the velocity in the pipeline, P_1 is the upstream pressure, P_2 is the pressure downstream of the orifice, and is the ratio of orifice bore diameter to pipe inside diameter. The orifice discharge coefficient, C_o, is a constant precisely determined for orifice installations carefully constructed to ASME specifications (10). It is a function of the beta ratio, but for all orifices in the regime of fully turbulent flow, the value of C_o is 0.61. Note also from equation B1, that the value of n in equation 44 should be approximately equal to 1/2. The results, given in the computer printout, show that all calculated values of n and C_o approximate these.

```
      PROGRAM ORIFIC (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)

C-----------------------------------------------------------------------
C**** ABSTRACT:
C
C          THIS PROGRAM CALCULATES AND PLOTS ORIFICE CALIBRATION CURVES
C          FROM DATA OBTAINED BY BUCKET-AND-TIMER TECHNIQUE.
C          A LEAST-SQUARES LINEAR REGRESSION OF THE ORIFICE HEAD-LOSS/
C          FLOWRATE DATA DETERMINES THE COEFFICIENT AND EXPONENT IN THE
C          ORIFICE EQUATION.
C
C-----------------------------------------------------------------------
C**** NOMENCLATURE:
C
C          A    COLLECTION OF ALL CONSTANTS IN ORIFICE EQUATION
C          ASG  INPUT DATA, SPECIFIC GRAVITIES
C          ATC  INPUT DATA, CELCIUS TEMPERATURES
C          AY   PARAMETER NAMES FOR ORDERING AND AVERAGING SUBROUTINES
C          BETA    RATIO OF D1/D2, WHERE D1=BORE, D2=PIPE ID
C          C    ORIFICE COEFFICIENT IN LINEARIZED ORIFICE EQUATION
C          C12, C38, C58  ORIFICE COEFFICIENTS FOR 1/2, 3/8, 5/8 ORIFICES
C          CGPM    CONVERSION FACTOR, GPM/(CU FT/SEC)
C          CZERO     ORIFICE DISCHARGE COEFFICIENT
C          DEN  WATER DENSITY, (LBM/CU FT)
C          EXDEN   DENSITY OF WATER COLLECTED DURING ORIFICE CALIBRATION
C          EXTF    FAHRENHEIT TEMPERATURE DURING ORIFICE CALIBRATION
C          HLB, HLM  ORIFICE HEAD-LOSS, BRANCH AND MAIN LINES
C          JK   INDEX USED IN COUNTING LOOPS
C          NK   TOTAL NUMBER OF RUNS, EACH AT DIFFERENT MAIN FLOWRATES
C          P    POUNDS OF WATER COLLECTED IN BUCKET
C          QB, QM  BRANCH-LINE AND MAIN-LINE FLOWRATES, (GPM)
C          QBAV    ABERAGE BRANCH-LINE FLOWRATE, (GPM)
C          QRAV    AVERAGE RECYCLE-LINE FLOWRATE
C          RW   WEIGHT OF BUCKET AND RESIDUAL WATER
C          S    NUMBER OF SECONDS TO COLLECT P POUNDS OF WATER IN BUCKET
C          S12, S38, S58  ORIFICE EXPONENTS FOR 1/2, 3/8, 5/8 ORIFICES
C          SG   SPECIFIC GRAVITY OF WATER AT VARIOUS TEMPERATURES
C          TC   CELCIUS TEMPERATURE
C          TF   FAHRENHEIT TEMPERATURE
C          TFNEXT  SUCCEEDING VALUES OF TF IN ARRAY OF TF VS. SG
C          X12, X38, X58 ARE HLBAV VALUES FOR 1/2, 3/8, 5/8 INCH ORIFICES
C          Y12, Y38, Y58 ARE QBAV VALUES FOR 1/2, 3/8, 5/8 INCH ORIFICES
C          YCALC   FLOWRATE USING ORIFICE EXPONENT AND COEFF CALCULATED
C          YR12, YR38, YR58    REGRESSION VALUES OF FLOWRATES IN ORIFICES
C          YLL     LOWER LIMIT FOR 95 PCT CONFIDENCE INTERVAL OF FLOWRATE
C          YUL     UPPER LIMIT FOR 95 PCT CONFIDENCE INTERVAL OF FLOWRATE
C-----------------------------------------------------------------------

3         DIMENSION ATC(21), ASG(21), TF(73), DEN(73)
3         DIMENSION EXTF(3,36), EXDEN(3,36), HLB(3,36), P(3,36), S(3,36),
         .QB(3,36), HLBAV(36), QBAV(36)
3         DIMENSION X12(16), Y12(16), X38(8), Y38(8), X58(12), Y58(12),
         .YREG(75), YR34(36), YR12(16), YR38(8), YR58(12), QRAV(36), QM(36),
         .HLM(36), HLRAV(36), X(75), Y(75), YCALC(75), YUL(75), YLL(75)
3         DIMENSION YP12(200), YP38(200), YP58(200), YP34(200), XP(200)
3         DIMENSION AY(3,75)
3         COMMON X, Y, YCALC, YUL, YLL
3         DATA (ATC(N),N=1,21)/20.,21.,22.,23.,24.,25.,26.,27.,28.,29.,30.,
         .31.,32.,33.,34.,35.,36.,37.,38.,39.,40./
3         DATA (ASG(N),N=1,21)/.99823,.99802,.99780,.99757,.99733,.99708,
         ..99682,.99655,.99627,.99598,.99568,.99537,.99506,.99473,.99440,
         ..99406,.99371,.99336,.99300,.99263,.99225/

      C   **** FORMAT STATEMENTS FOR LITERAL OUTPUT ****
3      25 FORMAT (*1*,6(/),9X,*TEMP (F)*,9X,*DENSITY*,8X,*TEMP (C)*,5X,*SPEC
         .IFIC GRAVITY*,/)
3      50 FORMAT (/,8X,*ORIFICE H-L*,2X,*WATER COLLECTED PER UNIT TIME*,4X,
         .*WATER TEMP*,3X,*WATER FLOWRATE*,/,10X,*(CM HG)*,9X,*(LBS)*,10X,
         .*(SEC)*,11X,*(F)*,11X,*(GPM)*,/)
3     100 FORMAT (/,10X,*1/2 INCH ORIFICE:*,/,10X,*-----------------*)
3     125 FORMAT (/,10X,*3/8 INCH ORIFICE:*,/,10X,*-----------------*)
3     150 FORMAT (/,10X,*5/8 INCH ORIFICE:*,/,10X,*-----------------*)
3     175 FORMAT (*1*,4(/))
3     200 FORMAT (*1*,//,10X,*3/4 INCH ORIFICE:*,/,10X,*-----------------*)
```

```
    3    225  FORMAT (*1*,////,6X,*THE FOLLOWING DATA ARE THE RESULT OF A LINEAR
             . REGRESSION ANALYSIS:*,//)
    3    230  FORMAT (*1*,6(/),12X,*AVG FLOWRATE*,5X,*AVG HEAD-LOSS*,/,16X,*(GPM
             .)*,11X,*(CM HG)*,/)
    3    665  FORMAT (*1*,6(/),10X,*3/4 INCH ORIFICE:*,/,10X,*-----------------*,
             .//)
    3    667  FORMAT (//,10X,*AVERAGED VALUES FOR 3/4 INCH ORIFICE*,/)
    3    668  FORMAT (10X,*HEAD-LOSS*,7X,*MAIN FLOW*,7X,*RECYCLE FLOW*,5X,
             .*BRANCH FLOW*,/,11X,*(IN HG)*,10X,*(GPM)*,12X,*(GPM)*,11X,
             .*(GPM)*,/)

         C      **** DATA INTERPOLATION FOR WATER DENSITY AT FAHRENHEIT TEMPS ****
    3           PRINT 25
    7           TFNEXT = 68.
   11           DO 20  N=1,73
   12           TF(N) = TFNEXT
   15           TC = (TF(N) - 32.)*5./9.
   23           SG = FUN1 (TC,21,ATC,ASG)
   30           DEN(N) = SG*62.4279
   33           TFNEXT = TF(N) + 0.5
   37           IF (TF(N).EQ.85.) PRINT 25
   46           PRINT 300, TF(N), DEN(N), TC, SG
   64    300    FORMAT (10X,F6.2,10X,F7.4,10X,F5.2,10X,F6.4)
   64     20    CONTINUE

         C      **** READ IN ORIFICE CALIBRATION DATA ****
   66           RW = 2.050
   70           CGPM = 448.80
   71           NK = 36
   73           DO 1010  K=1,NK
   74           READ 500,(HLB(J,K),P(J,K),S(J,K),EXTF(J,K),J=1,3),HLM(K),HLRAV(K)
  135    500    FORMAT (3(F5.1,F7.3,F5.1,F5.1),F5.1,F7.3)

         C      **** COMPUTE WATER DENSITY AND ACTUAL FLOWRATE ****
  135           DO 1020  J=1,3
  137           EXDEN(J,K) = FUN1 (EXTF(J,K),73,TF(N),DEN(N))
  156   1020    QB(J,K) = (P(J,K) - RW)*CGPM/(S(J,K)*EXDEN(J,K))

         C      **** COMPUTE AVERAGE FLOWRATE AND ORIFICE HEAD-LOSS ****
  202           HLBAV(K) = (HLB(1,K) + HLB(2,K) + HLB(3,K))/3
  222           QBAV(K) = (QB(1,K) + QB(2,K) + QB(3,K))/3
  243           IF (K.EQ.1) GO TO 400
  245           IF (K.EQ.17) GO TO 410
  250           IF (K.EQ.25) GO TO 420
  253           GO TO 430
  254    400    PRINT 175
  260           PRINT 100
  264           PRINT 50
  270           GO TO 430
  271    410    PRINT 175
  275           PRINT 125
  301           PRINT 50
  305           GO TO 430
  306    420    PRINT 175
  312           PRINT 150
  316           PRINT 50
  322    430    CONTINUE
  322           PRINT 310, (HLB(J,K), P(J,K), S(J,K), EXTF(J,K), QB(J,K), J=1,3)
  363    310    FORMAT (10X,F7.4,4(8X,F7.4))
  363   1010    CONTINUE
  366           PRINT 230
  371           DO 250  K=1,NK
  373           IF (K.EQ.1) PRINT 100
  400           IF (K.EQ.17) PRINT 125
  406           IF (K.EQ.25) PRINT 150
  414    250    PRINT 235, QBAV(K), HLBAV(K)
  431    235    FORMAT (15X,F7.4,10X,F7.4)

         C      **** ASSIGN SEPARATE ARRAYS FOR EACH ORIFICE ****
  431           A = 13.9035
  432           L = 0
  433           DO 1050  K=1,NK
  435           L = L + 1
  437           IF (K.LE.16) GO TO 1030
  442           IF (K.EQ.17) L=1
  446           IF (K.LE.24) GO TO 1040
```

```
            IF (K.EQ.25) L=1
            X58(L) = HLBAV(K)
            Y58(L) = QBAV(K)
            IF (K.EQ.NK) GO TO 1055
            GO TO 1050
      1040  X38(L) = HLBAV(K)
            Y38(L) = QBAV(K)
            IF (K.EQ.24) GO TO 1045
            GO TO 1050
      1030  X12(L) = HLBAV(K)
            Y12(L) = QBAV(K)
            IF (K.EQ.16) GO TO 1035
            GO TO 1050

      C     **** CALL LSLR FOR LEAST-SQUARES LINEAR REGRESSION ANALYSIS ****
      1035  CONTINUE
            PRINT 225
            PRINT 100
            CALL LSLR (X12,Y12,YR12,C12,S12,16)
            C = C12
            BETA = 1./(2.*1.049)
      C     **** PLOT LINEARIZED CALIBRATION CURVE FOR 1/2 INCH ORIFICE ****
            CALL QIKSET (6.0,0.0,.75,8.0,0.0,0.5)
            CALL QIKSAX (3,3)
            CALL QIKPLT (X,YUL,16,24H*LN (HEAD-LOSS (CM HG)) *,27H*LN (WATER FL
           .OWRATE (GPM))*)
            CALL PLOT (-7.0,1.0,-3)
            CALL QLINE (X,YLL,16)
            CALL QLINE (X,Y,-16,3)
            IJ = 2
            GO TO 333
       444  CALL SYMBOL (0.7,8.2,.21,27HLINEARIZED CALIBRATION DATA,0.0,27)
            CALL SYMBOL (0.25,7.9,.21,33HWITH 95 PERCENT CONFIDENCE LIMITS,0.0
           .,33)
            GO TO 1053

      1045  CONTINUE
            PRINT 225
            PRINT 125
            CALL LSLR (X38,Y38,YR38,C38,S38,8)
            C = C38
            BETA = 3./(8.*1.049)
      C     **** PLOT LINEARIZED CALIBRATION CURVE FOR 3/8 INCH ORIFICE ****
            CALL QLINE (X,Y,-8,4)
            CALL QLINE (X,YUL,8)
            CALL QLINE (X,YLL,8)
            GO TO 1053

      1055  CONTINUE
            PRINT 225
            PRINT 150
            CALL LSLR (X58,Y58,YR58,C58,S58,12)
            C = C58
            BETA = 5./(8.*1.049) + 0.001
      C     **** PLOT LINEARIZED CALIBRATION CURVE FOR 5/8 INCH ORIFICE ****
            CALL QLINE (X,Y,-12,11)
            CALL QLINE (X,YUL,12)
            CALL QLINE (X,YLL,12)

      C     **** CALCULATE ORIFICE DISCHARGE COEFFICIENT ****
      1053  CZERO = C*(1. - BETA**4.)**0.5/(A*BETA**2.)
            PRINT 570, BETA,C,CZERO
       570  FORMAT (/,10X,*BETA =*,F6.4,/,10X,*CPRIME =*,F7.4,/,10X,*ORIFICE C
           .OEFFICIENT =*,F6.4,//)
            IF (A.EQ.22.1585) GO TO 1057
      1050  CONTINUE

      C     **** CALCULATE THE SMOOTHED ORIFICE CALIBRATION CURVES ****
            XN = 100.
            NL = 100
            DX = 90./XN
            DO 2000  M=1,3
            XP(1) = 0.
      2100  DO 2000  IP=1,NL
       600  GO TO (12,38,58,34) M
        12  YP12(IP) = C12*XP(IP)**S12
            GO TO 60
```

```
  38     YP38(IP) = C38*XP(IP)**S38
         GO TO 60
  58     YP58(IP) = C58*XP(IP)**S58
         GO TO 60
  34     YP34(IP) = C34*XP(IP)**S34
  60     XP(IP+1) = XP(IP) + DX
2000     CONTINUE
         IF (M.EQ.4) GO TO 700
   C     **** PLOT CALIBRATION CURVES FOR 3/8, 1/2, 5/8 INCH ORIFICES ****
         CALL PLOT (8.0,-1.0,-3)
         CALL QIKSET (6.0,0.0,15.0,8.0,0.0,4.0)
         CALL QIKSAX (3,3)
         CALL QIKPLT (XP,YP12,NL,19H*HEAD-LOSS (CM HG)*, 22H*WATER FLOWRATE
        . (GPM)*)
         CALL PLOT (-7.0,1.0,-3)
         CALL QLINE (X12,Y12,-16,3)
         CALL QLINE (XP,YP38,NL)
         CALL QLINE (X38,Y38,-8,4)
         CALL QLINE (XP,YP58,NL)
         CALL QLINE (X58,Y58,-12,11)
         CALL SYMBOL (0.7,8.2,.21,26HORIFICE CALIBRATION CURVES,0.0,26)
         IJ = 1
 333     CALL SYMBOL (0.5,7.0,.14,13HORIFICE SIZES,0.0,13)
         CALL SYMBOL (0.5,6.5,.14,4,0.0,-1)
         CALL SYMBOL (1.0,6.43,.14,8H3/8 INCH,0.0,8)
         CALL SYMBOL (0.5,6.2,.14,3,0.0,-1)
         CALL SYMBOL (1.0,6.13,.14,8H1/2 INCH,0.0,8)
         CALL SYMBOL (0.5,5.9,.14,11,0.0,-1)
         CALL SYMBOL (1.0,5.83,.14,8H5/8 INCH,0.0,8)
         IF (IJ.EQ.2) GO TO 444
   C     **** CALCULATE FLOWRATES FOR 3/4 INCH ORIFICE ****
         DO 1060  IK=1,NK
         QRAV(IK) = C12*HLRAV(IK)**S12
         QM(IK) = QBAV(IK) + QRAV(IK)
         AY(1,IK) = QM(IK)
         AY(2,IK) = QRAV(IK)
1060     AY(3,IK) = QBAV(IK)
   C     **** ORDER AND AVERAGE THE 3/4 INCH CALIBRATION DATA AT EQUAL HLM
         PRINT 665
         PRINT 668
         CALL ORDER (HLM,AY,36,3)
         PRINT 800, (HLM(K), AY(1,K), AY(2,K), AY(3,K), K=1,NK)
 800     FORMAT (4(10X,F7.4))
         PRINT 175
         PRINT 667
         PRINT 668
         CALL AVGY (HLM,AY,36,3,NJ)
         DO 1070  IK=1,NJ
1070     QM(IK) = AY(1,IK)
         PRINT 175
         PRINT 200
         CALL LSLR (HLM,QM,YR34,C34,S34,NJ)
         C = C34
         BETA = 3./(4.*1.049)
         A = 22.1585
   C     **** PLOT LINEARIZED CALIBRATION CURVE FOR 3/4 INCH ORIFICE ****
         CALL PLOT (8.0,-1.0,-3)
         CALL QIKSET (6.0,-2.0,1.0,8.0,0.0,0.5)
         CALL QIKSAX (3,3)
         CALL QIKPLT (X,YUL,NJ,24H*LN (HEAD-LOSS (IN HG))*,27H*LN (WATER FL
        .OWRATE (GPM))*)
         CALL PLOT (-7.0,1.0,-3)
         CALL QLINE (X,YLL,NJ)
         CALL QLINE (X,Y,-NJ,10)
         CALL SYMBOL (3.0,2.0,.14,16H3/4 INCH ORIFICE,0.0,16)
         IJ = 3
         GO TO 444
1057     CONTINUE
   C     **** PLOT SMOOTHED CALIBRATION CURVE FOR 3/4 INCH ORIFICE ****
         M = 4
         XN = 150.
         NL = 150
```

```
      DX = 30./XN
      XP(1) = 0.
      GO TO 2100
  700 CALL PLOT (8.0,-1.0,-3)
      CALL QIKSET (6.0,0.0,5.0,8.0,0.0,6.0)
      CALL QIKSAX (3,3)
      CALL QIKPLT (XP,YP34,NL,19H*HEAD-LOSS (IN HG)*, 22H*WATER FLOWRATE
     . (GPM)*)
      CALL PLOT (-7.0,1.0,-3)
      CALL QLINE (HLM,QM,-NJ,10)
      CALL SYMBOL (1.5,8.2,.21,21HCALIBRATION CURVE FOR,0.0,21)
      CALL SYMBOL (1.0,7.9,.21,27H3/4 INCH, MAIN-FLOW ORIFICE,0.0,27)
      END

      SUBROUTINE LSLR (XI,YI,YREG,CPRIME,M,LK)

C-----------------------------------------------------------------------
C**** ABSTRACT:
C
C          THIS PROGRAM PERFORMS A LEAST-SQUARES LINEAR REGRESSION
C          ANALYSIS ON THE GIVEN DATA.  IT ALSO DETERMINES THE CORRELATION
C          COEFFICIENT, AND THE 95 PERCENT CONFIDENCE LIMITS FOR THE
C          SLOPE, INTERCEPT, AND PREDICTED VALUES.
C          IT IS NECESSARY TO SUPPLY THE PROPER STUDENT-T VALUES FOR THE
C          NUMBER OF DATA POINTS EXPECTED TO BE ENCOUNTERED.
C-----------------------------------------------------------------------
C**** NOMENCLATURE:
C
C          B     Y-INTERCEPT OF REGRESSION LINE
C          BCONF    CONFIDENCE INTERVAL OF THE INTERCEPT
C          CC    CORRELATION COEFFICIENT
C          CPRIME  COEFFICIENT OF X IN NONLINEAR EQUATION
C          DENOM    QUANTITY USED IN SOLVING FOR REGRESSION PARAMETERS
C          LK    TOTAL NUMBER OF DATA POINTS
C          M     SLOPE OF REGRESSION LINE; EXPONENT OF X IN NONLINEAR EQTN
C          MCONF    CONFIDENCE INTERVAL OF THE SLOPE
C          P     REAL VARIABLE NAME FOR TOTAL NUMBER OF DATA POINTS
C          SDEV     STANDARD DEVIATION OF Y-VALUES FROM REGRESSION LINE
C          T     VALUES OF STUDENT-T FUNCTION, FOR GIVEN NO. OF DATA POINTS
C          VAR   VARIANCE OF Y-VALUES FROM REGRESSION LINE
C          X     LINEARIZED COUNTERPART OF XI
C          XDEV2    SQUARE OF S-DEVIATIONS FROM THE MEAN
C          XI    INPUT VALUES OF FUNCTION X
C          XMEAN    MEAN VALUE OF X
C          XSUM     SUMMATION OF ALL X
C          X2SUM    SUMMATION OF ALL X-SQUARED
C          XYSUM    SUMMATION OF ALL X*Y
C          Y     LINEARIZED COUNTERPART OF YI
C          YCALC    CALCULATED VALUES OF Y IN LINEAR EQUATION
C          YCONF    CONFIDENCE INTERVAL OF Y-VALUES
C          YI    INPUT VALUES OF FUNCTION Y
C          YLL   LOWER LIMIT OF Y CONFIDENCE ENVELOPE
C          YREG     CALCULATED REGRESSION VALUES OF Y IN NONLINEAR EQUATION
C          YSUM     SUMMATION OF ALL Y
C          Y2SUM    SUMMATION OF ALL Y-SQUARED
C          YUL   UPPER LIMIT OF Y CONFIDENCE ENVELOPE
C          ZNUM     QUANTITY USED IN SOLVING FOR REGRESSION PARAMETERS
C-----------------------------------------------------------------------

      IMPLICIT REAL (M)
      DIMENSION XI(75), YI(75), YREG(75)
      DIMENSION X(75), Y(75), YCALC(75)
      DIMENSION YUL(75), YLL(75)
      COMMON X, Y, YCALC, YUL, YLL
      XSUM = 0.
      YSUM = 0.
      XYSUM = 0.
      X2SUM = 0.
      Y2SUM = 0.
      XDEV2 = 0.
C     **** ASSIGN THE PROPER STUDENT-T VALUE FOR NUMBER OF DATA POINTS
      IF (LK.EQ.8) T=2.447
      IF (LK.EQ.10) T=2.306
```

```
      IF (LK.EQ.12) T=2.228
      IF (LK.EQ.16) T=2.145
      IF (LK.EQ.18) T=2.120
      IF (LK.EQ.19) T=2.110
C     **** CONVERT THE INPUT PARAMETERS TO LINEARIZED FORM ****
      DO 99  N=1,LK
      X(N) = ALOG(XI(N))
      Y(N) = ALOG(YI(N))
      XSUM = XSUM + X(N)
      YSUM = YSUM + Y(N)
      XYSUM = XYSUM + X(N)*Y(N)
      X2SUM = X2SUM + X(N)**2.
   99 Y2SUM = Y2SUM + Y(N)**2.
C     **** CALCULATE SLOPE, INTERCEPT, AND CORRELATION COEFFICIENT ****
      P = LK
      ZNUM = P*XYSUM - XSUM*YSUM
      DENOM = P*X2SUM - XSUM**2.
      M = ZNUM/DENOM
      B = (X2SUM*YSUM - XSUM*XYSUM)/DENOM
      CPRIME = EXP(B)
      XMEAN = XSUM/P
      CC = ZNUM/((DENOM)**0.5*(P*Y2SUM - (YSUM**2.))**0.5)
C     **** CALCULATE THE REGRESSION VALUES OF Y AND THE VARIANCE ****
      VAR = (1./(P-2.))*(Y2SUM - B*YSUM - M*XYSUM)
      SDEV = VAR**0.5
      DO 66  N=1,LK
   66 XDEV2 = XDEV2 + (X(N) - XMEAN)**2.
C     **** FIND THE 95  CONFIDENCE LIMITS FOR SLOPE, INTERCEPT, AND
C     CALCULATED Y-VALUES ****
      PRINT 250
  250 FORMAT (//,9X,*X = LN(H-L)*,6X,*Y = MX + B*,7X,*Y-CONFIDENCE*,/)
      MCONF = T*SDEV/(XDEV2**0.5)
      BCONF = T*SDEV*((1./P) + (XMEAN**2./XDEV2))**0.5

      DO 33  N=1,LK
      YCALC(N) = M*X(N) + B
      YCONF = T*SDEV*((1./P) + (X(N) - XMEAN)**2./XDEV2)**0.5
      YUL(N) = YCALC(N) + YCONF
      YLL(N) = YCALC(N) - YCONF
      PRINT 600, X(N), YCALC(N), YCONF
  600 FORMAT (3(10X,F7.4))
      YREG(N) = CPRIME*XI(N)**M
   33 CONTINUE

      PRINT 280
      IF (LK.EQ.NJ) PRINT 275
      IF (LK.EQ.NJ) GO TO 285
      PRINT 270
  285 CONTINUE
  280 FORMAT (/,8X,*ORIGINAL H-L*,6X,*ORIGINAL Q*,6X,*REGRESSION Q*)
  270 FORMAT (10X,*(CM HG)*,11X,*(GPM)*,12X,*(GPM)*,/)
  275 FORMAT (10X,*(IN HG)*,11X,*(GPM)*,12X,*(GPM)*,/)
      DO 44  N=1,LK
   44 PRINT 630, XI(N), YI(N), YREG(N)
  630 FORMAT (5(10X,F7.4))
      PRINT 610, M, MCONF, B, BCONF, CC
  610 FORMAT (/,10X,*SLOPE OF REGRESSION LINE = *,F7.4,/,10X,*CONFIDENCE
     . INTERVAL OF SLOPE = *,F7.4,/,10X,*INTERCEPT = *,F7.4,/,10X,*CONFI
     .DENCE INTERVAL OF INTERCEPT = *,F7.4,/,10X,*CORRELATION COEFFICIEN
     .T = *,F7.4)
      RETURN
      END

      SUBROUTINE ORDER (X,Y,N,NI)

C-----------------------------------------------------------------------
C**** ABSTRACT:
C          THIS PROGRAM ARRANGES THE VALUES OF A SET OF Y-PARAMETERS IN
C          THE ORDER OF INCREASING VALUES OF THE X-PARAMETER.
C-----------------------------------------------------------------------
```

```
C**** NOMENCLATURE:
C
C          N     TOTAL NUMBER OF VALUES FOR THE X AND Y PARAMETERS
C          NI    NUMBER OF DIFFERENT Y-FUNCTIONS TO BE ORDERED
C          X     INPUT VALUES OF X-PARAMETER
C          Y     INPUT VALUES OF Y-PARAMETERS
C-----------------------------------------------------------------------

      DIMENSION X(N), Y(NI,N)
      J = N - 1
      DO 33  K=1,J
      L = N - K
      DO 33  M=1,L
      IF (X(M) - X(M+1)) 33,33,22
   22 XT = X(M)
      X(M) = X(M+1)
      X(M+1) = XT
      DO 55  I=1,NI
      YT = Y(I,M)
      Y(I,M) = Y(I,M+1)
   55 Y(I,M+1) = YT
   33 CONTINUE
      RETURN
      END


      SUBROUTINE AVGY (X,Y,N,NM,NJ)

C-----------------------------------------------------------------------
C**** ABSTRACT:
C          AVERAGE THE VALUES OF THE SET OF Y-PARAMETERS WHEN THE CORRES-
C          PONDING VALUES OF THE X-PARAMETER ARE EQUAL.

C**** NOMENCLATURE:
C          N     TOTAL NUMBER OF VALUES FOR THE X AND Y PARAMETERS
C          NJ    TOTAL NUMBER OF DATA POINTS AFTER HAVING BEEN AVERAGED
C          NM    NUMBER OF DIFFERENT Y-PARAMETERS TO BE AVERAGED
C          X     INPUT VALUE OF X-PARAMETER
C          Y     INPUT VALUE OF Y-PARAMETER
C-----------------------------------------------------------------------

      DIMENSION X(N), Y(NM,N)
      DIMENSION YS(5,50)
      J = 0
      K = 0
 1080 J = J + 1
      K = K + 1
      L = K + 1
      IF (K.EQ.N) GO TO 1070
      IF (X(L).EQ.X(K)) GO TO 1085
 1070 X(J) = X(K)
      DO 20  M=1,NM
   20 Y(M,J) = Y(M,K)
      IF (K.LT.N) 1080,1060
 1085 DO 30  M=1,NM
   30 YS(M,K) = Y(M,K)
      TN = 1.0
 1090 K = L
      L = K + 1
      TN = TN + 1.0
      DO 40  M=1,NM
   40 YS(M,K) = YS(M,K-1) + Y(M,K)
      IF (K.EQ.N) GO TO 1075
      IF (X(L).EQ.X(K)) GO TO 1090
 1075 X(J) = X(K)
      DO 50  M=1,NM
   50 Y(M,J) = YS(M,K)/TN
      IF (K.LT.N) GO TO 1080
 1060 NJ = J
      PRINT 60, ((X(J), (Y(M,J), M=1,NM)), J=1,NJ)
   60 FORMAT (4(9X,F8.4))
      RETURN
      END
```

```
                 FUNCTION FUN1 (A,N,X,Y)
          C-----------------------------------------------------------------------
          C**** ABSTRACT:
          C          THIS PROGRAM CREATES AN ARBITRARY FUNCTION Y FROM WELL-DEFINED
          C          PAIRS OF (X,Y) DATA.

          C**** NOMENCLATURE:
          C          A     X COORDINATE OF INPUT DATA
          C          N     NUMBER OF DATA PAIRS
          C          X     RESULTING X-FUNCTION ABSCISSA POINTS
          C          Y     RESULTING Y-FUNCTION ORDINATE POINTS
          C-----------------------------------------------------------------------

  11             DIMENSION X(100), Y(100)
  11             IF (A - X(1)) 5,5,6
  15          6  IF (A - X(N)) 1,2,2
  21          2  FUN1 = Y(N)
  24             RETURN
  24          5  FUN1 = Y(1)
  27             RETURN
  30          1  DO 3  I=2,N
  32             IF (A.LT.X(I)) GO TO 4
  36          3  CONTINUE
  41          4  FUN1 = Y(I-1) + (A - X(I-1))*(Y(I) - Y(I-1))/(X(I) - X(I-1))
  65             RETURN
  65             END
```

3/8 INCH ORIFICE:

ORIFICE H-L (CM HG)	WATER COLLECTED (LBS)	PER UNIT TIME (SEC)	WATER TEMP (F)	WATER FLOWRATE (GPM)
1.8500	15.2250	62.4000	93.0000	1.5297
1.9000	15.8090	63.3000	93.0000	1.5748
1.8500	14.9640	61.1000	93.0000	1.5313
4.4500	15.1580	38.3000	93.0000	2.4797
4.4000	15.0890	40.4000	93.0000	2.3384
4.4500	14.9750	38.8000	93.0000	2.4135
7.6000	15.1190	30.8000	93.5000	3.0743
7.5000	15.4040	31.5000	94.0000	3.0715
7.3000	15.8060	31.9000	94.0000	3.1243
15.1500	15.4290	22.3000	94.0000	4.3468
15.1000	15.4090	22.5000	94.0000	4.3017
15.1500	15.6180	22.6000	94.0000	4.3497
26.7000	15.2530	16.2000	94.5000	5.9049
27.0000	15.5040	16.3000	94.5000	5.9802
27.0000	15.1150	15.8000	94.0000	5.9911
46.6000	14.4920	11.4000	94.0000	7.9075
46.7000	15.5280	12.3000	94.0000	7.9391
46.7000	15.4420	12.3000	94.0000	7.8885
70.1000	15.8620	10.9000	85.5000	9.1809
70.2000	15.2750	10.4000	86.0000	9.2133
70.1000	15.7620	10.8000	86.5000	9.1988
83.6000	15.4310	9.7000	87.0000	9.9947
83.6000	15.5730	9.7000	87.0000	10.1008
83.6000	14.9710	9.3000	87.5000	10.0662

1/2 INCH ORIFICE:

ORIFICE H-L (CM HG)	WATER COLLECTED (LBS)	PER UNIT TIME (SEC)	WATER TEMP (F)	WATER FLOWRATE (GPM)
4.3000	15.2110	22.6000	77.0000	4.2192
4.3000	16.0630	24.5000	79.0000	4.1440
4.3000	15.3150	22.8000	80.0000	4.2153
9.0000	15.5420	15.9000	81.5000	6.1480
9.0000	15.1660	15.5000	82.0000	6.1309
9.0000	15.2010	15.6000	83.0000	6.1078
12.8000	15.4450	13.1000	84.0000	7.4084
12.8000	15.6490	13.6000	86.0000	7.2447
12.9000	15.3500	13.1000	87.0000	7.3559
19.4000	15.5200	11.0000	87.0000	8.8721
19.6000	15.4410	10.8000	88.5000	8.9834
19.6000	15.2360	10.6000	89.5000	9.0128
21.2000	14.8720	9.8000	78.5000	9.4794
21.3000	15.8800	10.5000	79.5000	9.5430
21.3000	15.6250	10.4000	80.0000	9.4571
26.1000	15.0190	9.0000	81.0000	10.4404
26.1000	15.3380	9.2000	81.5000	10.4647
26.1000	15.1540	9.1000	82.0000	10.4332
34.4000	14.8940	7.9000	75.5000	11.7795
34.5000	15.0400	8.0000	76.5000	11.7645
34.4000	16.0320	8.5000	77.0000	11.9180
37.8000	15.4250	7.8000	92.0000	12.4237
37.9000	16.2640	8.3000	93.5000	12.4077
37.8000	15.2360	7.7000	94.0000	12.4072
42.4000	15.8960	7.6000	86.0000	13.1997
42.3000	15.4340	7.4000	86.0000	13.1041
42.3000	16.0300	7.6000	86.5000	13.3274
51.0000	15.6950	6.9000	82.0000	14.3277
50.8000	16.2800	7.2000	82.5000	14.3194
50.9000	14.9900	6.5000	83.5000	14.4236
53.8000	15.5360	6.5000	94.0000	15.0322
53.8000	16.0730	6.9000	94.0000	14.7246
53.8000	15.9280	6.7000	93.5000	15.0074
60.0000	15.0940	6.0000	88.0000	15.7512
59.7000	15.8320	6.4000	88.0000	15.6022
59.8000	15.2930	6.1000	88.0000	15.7293
68.2000	15.6340	5.9000	88.5000	16.6813
68.5000	15.4800	5.8000	88.5000	16.7765
68.6000	15.4990	5.8000	88.5000	16.8002
71.5000	16.4630	6.1000	94.5000	17.1190
71.0000	15.2040	5.6000	95.0000	17.0186
71.2000	15.5220	5.8000	95.0000	16.8290
76.7000	15.1760	5.3000	88.5000	17.9436
76.6000	16.1170	5.7000	88.5000	17.8805
76.5000	15.6320	5.6000	88.5000	17.5723
85.5000	15.9830	5.6000	96.0000	18.0264
85.7000	15.6250	5.4000	96.0000	18.2137
85.3000	15.4040	5.2000	96.0000	18.6063

5/8 INCH ORIFICE:

ORIFICE H-L (CM HG)	WATER COLLECTED (LBS)	PER UNIT TIME (SEC)	WATER TEMP (F)	WATER FLOWRATE (GPM)
1.6000	15.2320	22.9000	77.0000	4.1706
1.7000	15.6880	23.0000	77.5000	4.2961
1.7000	15.3250	22.7000	78.5000	4.2370
3.2500	15.6420	16.3000	80.0000	6.0416
3.3000	16.1140	16.7000	81.0000	6.1016
3.3000	16.4060	17.4000	81.5000	5.9777
4.3000	14.6170	13.0000	82.5000	7.0039
4.5000	15.3280	13.5000	83.5000	7.1261
4.5000	15.5970	13.8000	84.0000	7.1124
6.9000	15.4530	11.1000	85.5000	8.7485
6.9000	15.2190	11.0000	86.0000	8.6739
6.9000	15.1280	10.7000	86.0000	8.8554
14.0000	15.9490	8.1000	88.0000	12.4323
13.9000	14.9930	7.6000	88.5000	12.3388
13.9000	15.6790	7.9000	88.5000	12.4994
24.5000	14.6560	5.5000	89.0000	16.6061
24.5000	15.1300	5.8000	89.5000	16.3393
24.5000	14.8860	5.7000	89.5000	16.3158
26.1000	16.1150	6.0000	89.0000	16.9841
26.0000	16.2400	6.1000	89.0000	16.8541
26.1000	15.5950	5.8000	89.0000	16.9201
34.0000	15.0580	4.9000	85.0000	19.2339
33.9000	14.9910	4.9000	85.5000	19.1348
34.0000	14.5300	4.8000	86.0000	18.8376
38.6000	16.0160	4.9000	89.5000	20.6504
38.5000	15.5560	4.8000	89.5000	20.3863
38.6000	15.6470	4.8000	89.5000	20.5237
43.5000	14.6000	4.2000	86.0000	21.6495
43.5000	15.8310	4.7000	86.0000	21.2440
43.5000	14.5880	4.2000	86.0000	21.6288
53.9000	15.4550	4.0000	86.0000	24.2806
53.9000	15.2040	3.8000	86.0000	25.0800
53.8000	16.1470	4.3000	86.0000	23.7526
69.5000	14.7740	3.3000	86.0000	27.9359
69.3000	15.4150	3.5000	85.5000	27.6665
69.2000	14.4630	3.2000	85.5000	28.1048

3/4 INCH ORIFICE:

HEAD-LOSS (IN HG)	MAIN FLOW (GPM)	RECYCLE FLOW (GPM)	BRANCH FLOW (GPM)
.2000	4.1928	0.0000	4.1928
.2000	4.4500	2.9047	1.5453
.2000	4.2346	0.0000	4.2346
.4000	6.1289	0.0000	6.1289
.4000	6.0403	0.0000	6.0403
.6000	7.3363	0.0000	7.3363
.6000	7.0653	4.6548	2.4105
.6000	7.0808	0.0000	7.0808
1.0000	8.9561	0.0000	8.9561
1.0000	8.9497	5.8597	3.0900
1.0000	8.7593	0.0000	8.7593
2.0000	12.4129	0.0000	12.4129
2.0000	12.4252	8.0924	4.3328
2.0000	12.4235	0.0000	12.4235
3.0000	14.9214	0.0000	14.9214
4.0000	16.9888	0.0000	16.9888
4.0000	16.9782	11.0194	5.9587
4.0000	16.9194	0.0000	16.9194
4.8000	18.2822	0.0000	18.2822
5.0000	18.9599	9.4667	9.4932
6.0000	20.9092	10.4632	10.4461
6.0000	20.5201	0.0000	20.5201
7.0000	22.2657	14.3540	7.9117
8.0000	23.7617	11.9410	11.8206
10.0000	26.5898	13.3793	13.2104
10.0000	26.4829	17.2852	9.1976
10.0000	26.5267	10.1063	16.4204
12.0000	28.8420	14.4851	14.3569
12.0000	28.9376	18.8837	10.0539
14.0000	31.4293	15.7351	15.6942
14.0000	31.0496	11.9808	19.0688
16.0000	33.5401	16.7874	16.7527
18.0000	35.5940	17.7952	17.7988
18.0000	35.0775	13.5701	21.5074
22.0000	39.3194	14.9483	24.3711
28.0000	44.5529	16.6505	27.9024

AVG FLOWRATE (GPM)	AVG HEAD-LOSS (CM HG)
1/2 INCH ORIFICE:	
4.1928	4.3000
6.1289	9.0000
7.3363	12.8333
8.9561	19.5333
9.4932	21.2667
10.4461	26.1000
11.8206	34.4333
12.4129	37.8333
13.2104	42.3333
14.3569	50.9000
14.9214	53.8000
15.6942	59.8333
16.7527	68.4333
16.9888	71.2333
17.7988	76.6000
18.2822	85.5000
3/8 INCH ORIFICE:	
1.5453	1.8667
2.4105	4.4333
3.0900	7.4667
4.3328	15.1333
5.9587	26.9000
7.9117	46.6667
9.1976	70.1333
10.0539	83.6000
5/8 INCH ORIFICE:	
4.2346	1.6667
6.0403	3.2833
7.0808	4.4333
8.7593	6.9000
12.4235	13.9333
16.4204	24.5000
16.9194	26.0667
19.0688	33.9667
20.5201	38.5667
21.5074	43.5000
24.3711	53.8667
27.9024	69.3333

AVERAGED VALUES FOR 3/4 INCH ORIFICE

HEAD-LOSS (IN HG)	MAIN FLOW (GPM)	RECYCLE FLOW (GPM)	BRANCH FLOW (GPM)
.2000	4.2925	.9682	3.3242
.4000	6.0846	0.0000	6.0846
.6000	7.1608	1.5516	5.6092
1.0000	8.8884	1.9532	6.9351
2.0000	12.4205	2.6975	9.7231
3.0000	14.9214	0.0000	14.9214
4.0000	16.9621	3.6731	13.2890
4.8000	18.2822	0.0000	18.2822
5.0000	18.9599	9.4667	9.4932
6.0000	20.7147	5.2316	15.4831
7.0000	22.2657	14.3540	7.9117
8.0000	23.7617	11.9410	11.8206
10.0000	26.5331	13.5903	12.9428
12.0000	28.8898	16.6844	12.2054
14.0000	31.2395	13.8580	17.3815
16.0000	33.5401	16.7874	16.7527
18.0000	35.3358	15.6827	19.6531
22.0000	39.3194	14.9483	24.3711
28.0000	44.5529	16.6505	27.9024

THE FOLLOWING DATA ARE THE RESULT OF A LINEAR REGRESSION ANALYSIS:

3/8 INCH ORIFICE:

X = LN(H-L)	Y = MX + B	Y-CONFIDENCE
.6242	.4442	.0346
1.4892	.8721	.0251
2.0104	1.1300	.0206
2.7169	1.4795	.0174
3.2921	1.7640	.0185
3.8430	2.0366	.0221
4.2504	2.2381	.0259
4.4260	2.3250	.0277

ORIGINAL H-L (CM HG)	ORIGINAL Q (GPM)	REGRESSION Q (GPM)
1.8667	1.5453	1.5593
4.4333	2.4105	2.3920
7.4667	3.0900	3.0957
15.1333	4.3328	4.3907
26.9000	5.9587	5.8360
46.6667	7.9117	7.6643
70.1333	9.1976	9.3754
83.6000	10.0539	10.2265

SLOPE OF REGRESSION LINE = .4947
CONFIDENCE INTERVAL OF SLOPE = .0135
INTERCEPT = .1355
CONFIDENCE INTERVAL OF INTERCEPT = .0421
CORRELATION COEFFICIENT = .9996

BETA = .3575
CPRIME = 1.1451
ORIFICE COEFFICIENT = .6392

THE FOLLOWING DATA ARE THE RESULT OF A LINEAR REGRESSION ANALYSIS:

1/2 INCH ORIFICE:

X = LN(H-L)	Y = MX + B	Y-CONFIDENCE
1.4586	1.4454	.0123
2.1972	1.8112	.0086
2.5520	1.9869	.0070
2.9721	2.1949	.0055
3.0571	2.2370	.0052
3.2619	2.3385	.0048
3.5390	2.4757	.0047
3.6332	2.5223	.0047
3.7456	2.5780	.0049
3.9299	2.6692	.0053
3.9853	2.6967	.0054
4.0916	2.7493	.0058
4.2259	2.8158	.0063
4.2660	2.8357	.0064
4.3386	2.8717	.0067
4.4485	2.9261	.0072

ORIGINAL H-L (CM HG)	ORIGINAL Q (GPM)	REGRESSION Q (GPM)
4.3000	4.1928	4.2436
9.0000	6.1289	6.1177
12.8333	7.3363	7.2929
19.5333	8.9561	8.9795
21.2667	9.4932	9.3656
26.1000	10.4461	10.3653
34.4333	11.8206	11.8899
37.8333	12.4129	12.4575
42.3333	13.2104	13.1705
50.9000	14.3569	14.4290
53.8000	14.9214	14.8305
59.8333	15.6942	15.6320
68.4333	16.7527	16.7070
71.2333	16.9888	17.0421
76.6000	17.7988	17.6663
85.5000	18.2822	18.6546

SLOPE OF REGRESSION LINE = .4952
CONFIDENCE INTERVAL OF SLOPE = .0056
INTERCEPT = .7231
CONFIDENCE INTERVAL OF INTERCEPT = .0201
CORRELATION COEFFICIENT = .9998

BETA = .4766
CPRIME = 2.0607
ORIFICE COEFFICIENT = .6353

THE FOLLOWING DATA ARE THE RESULT OF A LINEAR REGRESSION ANALYSIS:

5/8 INCH ORIFICE:

X = LN(H-L)	Y = MX + B	Y-CONFIDENCE
.5108	1.4566	.0137
1.1889	1.7948	.0106
1.4892	1.9446	.0093
1.9315	2.1652	.0077
2.6343	2.5157	.0063
3.1987	2.7972	.0066
3.2607	2.8281	.0068
3.5254	2.9602	.0074
3.6524	3.0235	.0078
3.7728	3.0836	.0082
3.9865	3.1902	.0090
4.2389	3.3161	.0100

ORIGINAL H-L (CM HG)	ORIGINAL Q (GPM)	REGRESSION Q (GPM)
1.6667	4.2346	4.2913
3.2833	6.0403	6.0181
4.4333	7.0808	6.9905
6.9000	8.7593	8.7163
13.9333	12.4235	12.3756
24.5000	16.4204	16.3992
26.0667	16.9194	16.9141
33.9667	19.0688	19.3016
38.5667	20.5201	20.5639
43.5000	21.5074	21.8364
53.8667	24.3711	24.2931
69.3333	27.9024	27.5525

SLOPE OF REGRESSION LINE = .4988
CONFIDENCE INTERVAL OF SLOPE = .0054
INTERCEPT = 1.2018
CONFIDENCE INTERVAL OF INTERCEPT = .0162
CORRELATION COEFFICIENT = .9999

BETA = .5968
CPRIME = 3.3261
ORIFICE COEFFICIENT = .6276

3/4 INCH ORIFICE:

X = LN(H-L)	Y = MX + B	Y-CONFIDENCE
-1.6094	1.4451	.0215
-.9163	1.7703	.0176
-.5108	1.9606	.0154
0.0000	2.2003	.0128
.6931	2.5255	.0101
1.0986	2.7158	.0090
1.3863	2.8508	.0087
1.5686	2.9363	.0086
1.6094	2.9555	.0087
1.7918	3.0411	.0088
1.9459	3.1134	.0091
2.0794	3.1760	.0094
2.3026	3.2808	.0100
2.4849	3.3663	.0106
2.6391	3.4386	.0112
2.7726	3.5013	.0118
2.8904	3.5566	.0123
3.0910	3.6507	.0132
3.3322	3.7639	.0144

ORIGINAL H-L (CM HG)	ORIGINAL Q (GPM)	REGRESSION Q (GPM)
.2000	4.2925	4.2422
.4000	6.0846	5.8728
.6000	7.1608	7.1035
1.0000	8.8884	9.0276
2.0000	12.4205	12.4976
3.0000	14.9214	15.1167
4.0000	16.9621	17.3015
4.8000	18.2822	18.8469
5.0000	18.9599	19.2114
6.0000	20.7147	20.9273
7.0000	22.2657	22.4971
8.0000	23.7617	23.9519
10.0000	26.5331	26.5958
12.0000	28.8898	28.9713
14.0000	31.2395	31.1446
16.0000	33.5401	33.1585
18.0000	35.3358	35.0427
22.0000	39.3194	38.5028
28.0000	44.5529	43.1160

SLOPE OF REGRESSION LINE = .4692
CONFIDENCE INTERVAL OF SLOPE = .0063
INTERCEPT = 2.2003
CONFIDENCE INTERVAL OF INTERCEPT = .0128
CORRELATION COEFFICIENT = .9997

BETA = .7150
CPRIME = 9.0276
ORIFICE COEFFICIENT = .6850

Figure B1

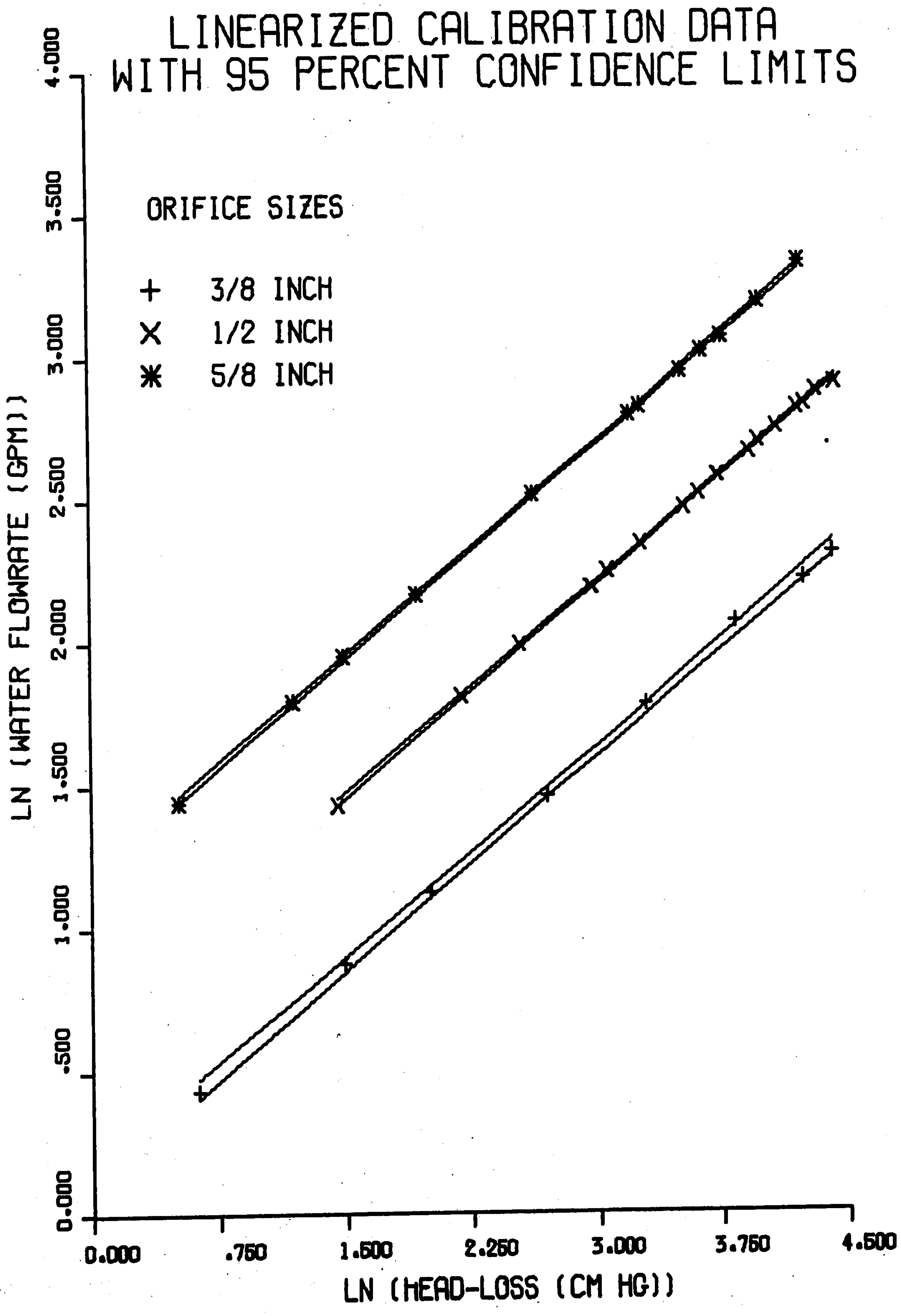

LINEARIZED CALIBRATION DATA
WITH 95 PERCENT CONFIDENCE LIMITS
ORIFICE SIZES
+ 3/8 INCH
X 1/2 INCH
✳ 5/8 INCH
LN (WATER FLOWRATE (GPM))
0.000
.500
1.000
1.500
2.000
2.500
3.000
3.500
4.000
0.000
.750
1.500
2.250
3.000
3.750
4.500
LN (HEAD-LOSS (CM HG))

Figure B2

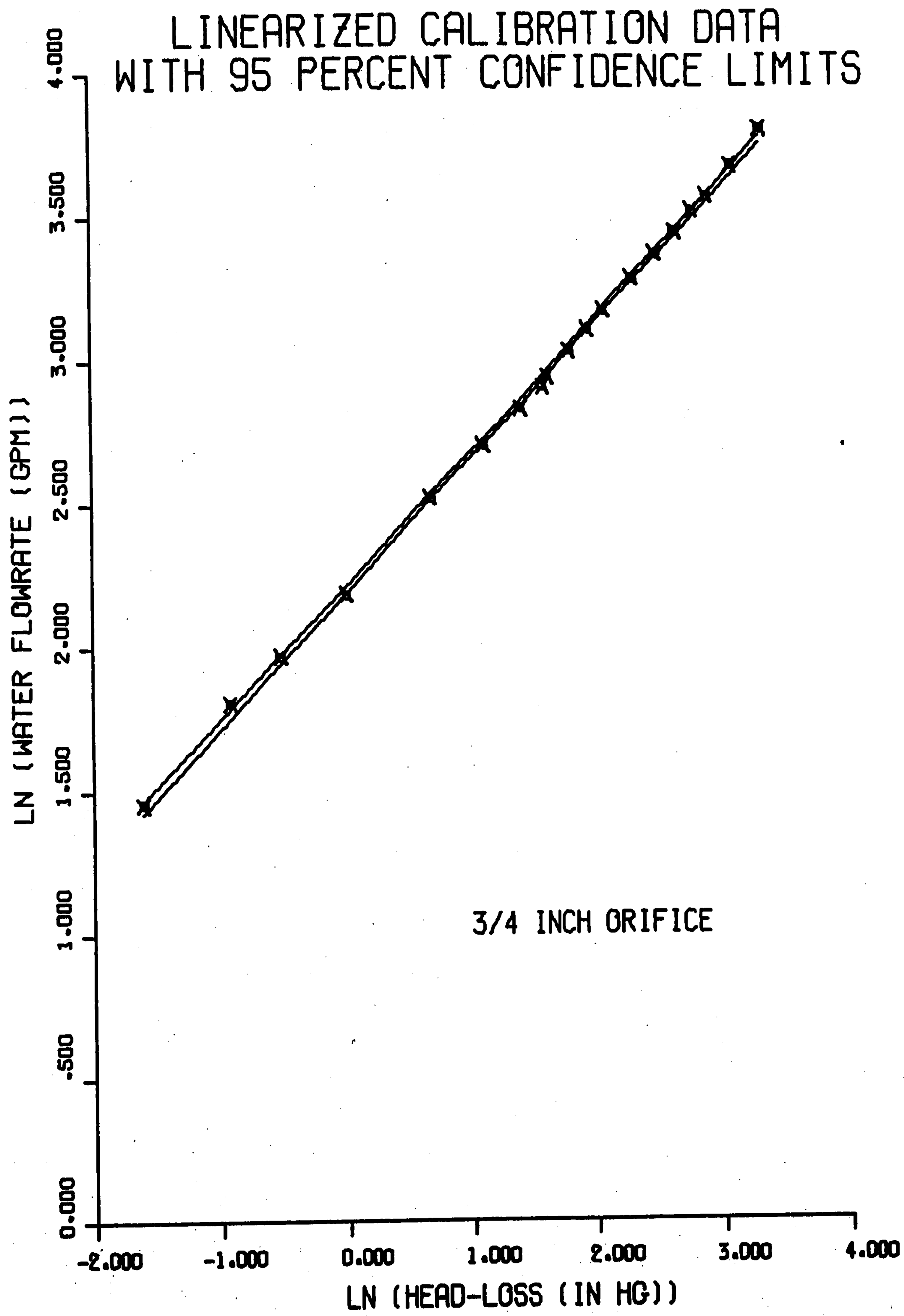
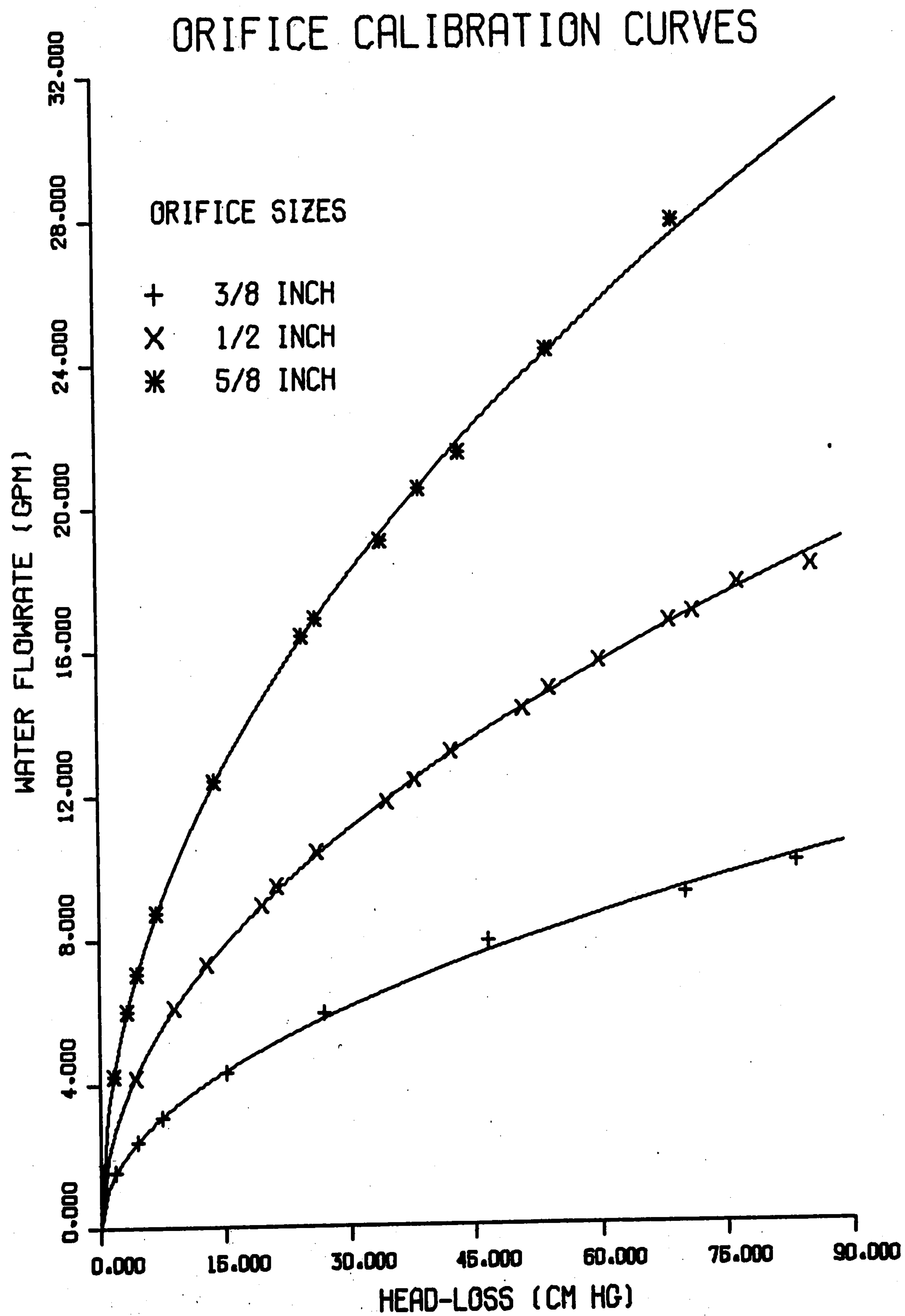
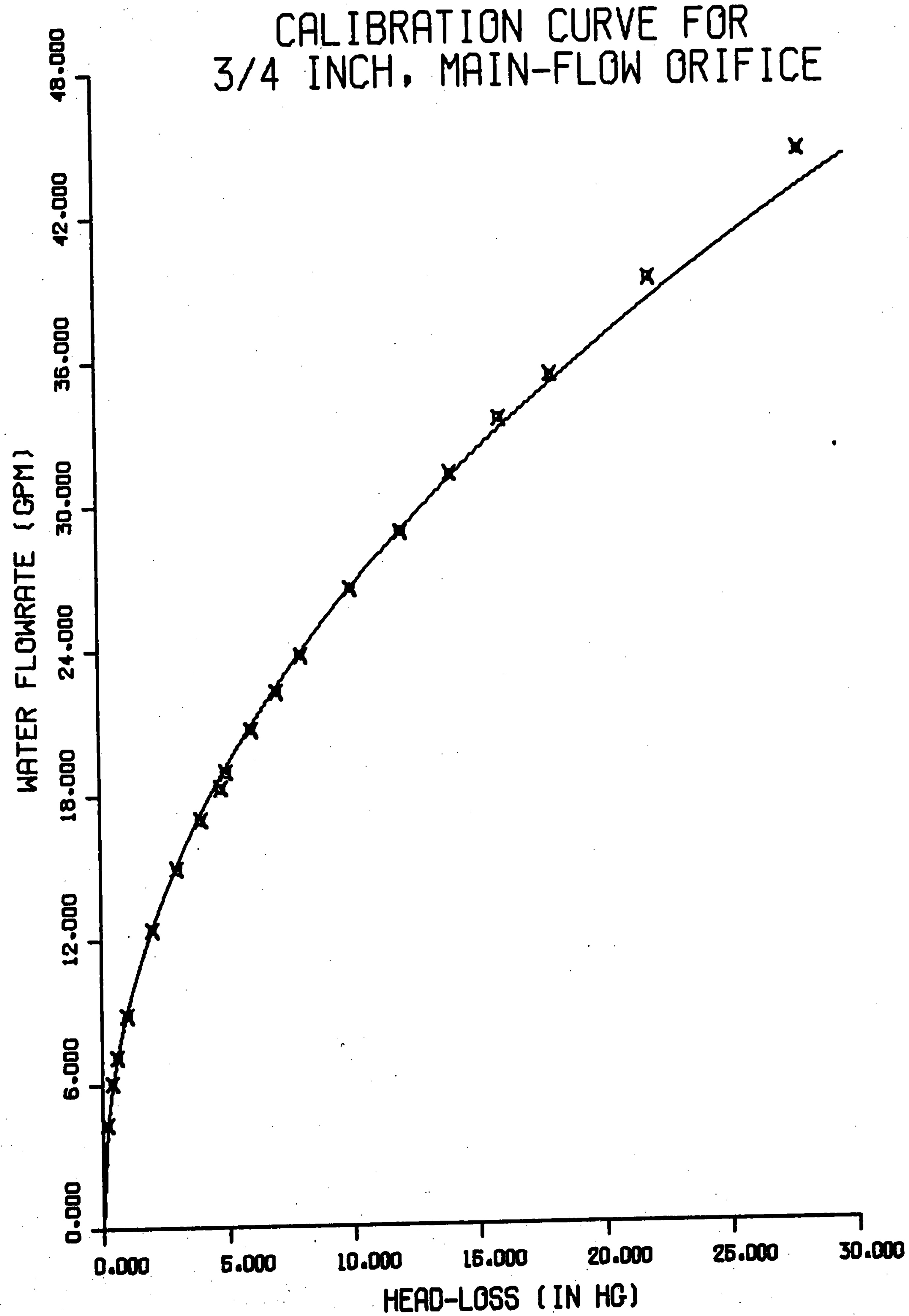

LINEARIZED CALIBRATION DATA
WITH 95 PERCENT CONFIDENCE LIMITS
LN (WATER FLOWRATE (GPM))
4.000
3.500
3.000
2.500
2.000
1.500
1.000
.500
0.000
-2.000
-1.000
0.000
1.000
2.000
3.000
4.000
LN (HEAD-LOSS (IN HG))
3/4 INCH ORIFICE

Figure B3



ORIFICE CALIBRATION CURVES
ORIFICE SIZES
+ 3/8 INCH
X 1/2 INCH
✱ 5/8 INCH
WATER FLOWRATE (GPM)
0.000
4.000
8.000
12.000
16.000
20.000
24.000
28.000
32.000
HEAD-LOSS (CM HG)
0.000
15.000
30.000
45.000
60.000
75.000
90.000

Figure B4


CALIBRATION CURVE FOR
3/4 INCH, MAIN-FLOW ORIFICE
WATER FLOWRATE (GPM)
0.000
6.000
12.000
18.000
24.000
30.000
36.000
42.000
48.000
0.000
5.000
10.000
15.000
20.000
25.000
30.000
HEAD-LOSS (IN HG)

Specifications for Standard Orifice Installations

For orifice meters carefully constructed to established ASME specifications (10), tabulated values of C_o can be used in equation B1 to accurately determine flowrates without the need for calibration of each particular orifice installation. Some of the basic criteria for proper construction of sharp-edged orifice plates are as follows:

The orifice plate should be constructed of a non-corrodible metal, suitable to the liquid being transported at the process conditions. The recommended minimum thickness of the plate, for pipe diameters of three inches or less, is 1/8 inch. The width of the plate at the bore should be D/8 or between 0.01D and 0.02D, whichever is smaller. If the plate is thicker than this figure, the downstream edge of the bore should be beveled at an angle no less than 45^o from the normal to the plate. The inlet edge must be square and sharp, and free from burrs and nicks. The actual diameter of the bore should be precisely determined after all machining of the plate has been done. The center of the orifice, once installed, should not be further than 1/32 inch from the centerline of the pipe. Gaskets placed between the orifice plate and the flanges should not protrude beyond the inner surface of the pipe.

Three types of pressure tap locations may be specified, each of which is subject to certain tolerances:

D - D/2 taps: The center of the inlet pressure tap is located at one pipe diameter from the upstream orifice face, while the outlet tap center is located at one-half pipe diameter from the upstream face of the plate;

Flange taps: The centers of the taps are located 1 inch from the inlet and outlet faces of the orifice plate;

Vena Contracta taps: The center of the inlet tap is located at one pipe diameter from the upstream orifice face and the downstream tap distance from the upstream plate face is given by the location of the vena contracta, which is documented as a function of the beta ratio.

The tap holes in the pipe on either side of the orifice plate should be drilled perpendicular to the pipe wall, with the inside surface free from burrs. The maximum diameter of these holes at the inner surface of the pipe should be 1/4 inch for pipes less than 2 inches in diameter, and 3/8 inch for 2 and 3 inch pipe.

In addition to specifications for construction of the plate and location of the pressure taps, certain minimum lengths of straight pipe preceeding and following the meters have been recommended. These guidelines are based upon what types of fittings occur upstream and, to a lesser extent, downstream of the meter. These minimum lengths of straight pipe serve to insure fully developed pipe flow at the meter.

Resistance Coefficient for Orifice Meters

The resistance coefficient, expressing the number of velocity heads lost by the fluid in passing through an orifice meter, can be derived from equation 12. Substituting for V^2, from equation B1, in the defining equation for the resistance coefficient gives:

$$K_2 = \frac{P/\rho}{V^2/2g} = \frac{1 - \beta^4}{C_o^2} \qquad \text{(eq. B2)}$$

This K_2 is based on the velocity through the orifice; in practice, it must be expressed as the number of main-flow velocity heads based on the main-flow pipe diameter. Using equation 11, the following results:

$$K = K_2/\beta^4 = (1 - \beta^4)/(C_o^2 \cdot \beta^4) \qquad \text{(eq. B3)}$$

However, this equation does not express the actual energy lost since a portion of the orifice pressure drop is recovered. The degree of recovery is specified by the ASME loss parameter (10). This is given in a graph expressing the permanent energy loss as a fraction of the differential pressure drop across the meter, and as a function of the beta ratio. This curve can be satisfactorily represented by the function $(1 - \beta^2)$. Thus, the permanent energy loss is obtained as this fraction of the differenential pressure across the meter, with the result being:

$$K_{orifice} = \frac{(1 - \beta^2)(1 - \beta^4)}{C_o^2 \cdot \beta^4} = \frac{(1 - \beta^2)}{C_o^2}\left(\frac{1}{\beta^4} - 1\right) \qquad \text{(eq. B4)}$$

Recently, a theoretical investigation of loss coefficients for differential-pressure fluid meters was carried out (13). In this work, a completely general expression for the resistance coefficients was derived, accounting for the size and location of the vena contracta, as well as the meter's cross-section, in the analysis. The equation was also used to derive an expression for the ASME loss parameter, which was found to precisely match the data upon which the loss parameter is based.

The resistance coefficient for orifice meters, based upon the orifice area, was derived as:

$$K_2 = (1 - \beta^4)/C_o^2 - 2\beta^2((1/C_c) - \beta^2) \qquad \text{(eq. B5)}$$

where C_c is the contraction coefficient, which accounts for the reduction in the fluid stream's cross-section from the orifice bore to the vena contracta. This factor has been correlated to widely-accepted empirical data from efflux experiments, by the following least-squares equation (14):

$$C_c = 0.61375 + 0.13318\beta^2 - 0.26095\beta^4 + 0.51146\beta^6 \qquad \text{(eq. B6)}$$

The resulting expression for the fluid meter loss parameter, P_{ASME}, for orifice meters is:

$$P_{ASME} = \frac{K_2 \; C_o^2}{1 - \beta^4} \qquad \text{(eq. B7)}$$

While this treatment provides an exact match to the experimental data, the simpler $(1-\beta^2)$ factor yields satisfactory agreement for $\beta<0.7$; hence, this simpler expression is the one used for the 3/4 inch main orifice in the analysis.

APPENDIX C - DATA AND RESULTS OF FLOWSPLIT EXPERIMENTS

The program FLSPLT, documented in the following pages, was used to analyze the experimental flowsplit data, compute experimental and theoretical recycle fractions, and plot these results. The basic structure of the program is as follows:

1. Establish the initial Flowsplit number.
2. Assign equipment specifications to each Stage.
3. Designate orifices used in each Flowsplit and the respective parameters in the orifice calibration equation.
4. Calculate orifice resistance coefficients.
5. Read orifice pressure drop data and print.

6* Arrange the data for trials 1 and 2 in increasing values of main orifice head-loss using subroutine ORDER; average the data at equal values of main orifice head-loss using subroutine AVGY.

7. Calculate all flowrates, using the orifice equation, and their uncertainties using equation 45; calculate the relative flowrate errors and print these results.
8. Calculate Reynolds number, velocity, and friction factor (using the Churchill equation) for each delivery line and print results.
9. Calculate average resistance coefficients and average friction factors for each delivery line, using subroutine AVG, for Reynolds numbers greater than 10,000.

10* Use average resistance coefficients in computing the recycle fraction in the next step.

11. Calculate recycle fraction for Stage 1 using equation 30. For Stages 2 and 3, calculate the critical flowrate and solve the design equation using the Newton iteration procedure. Calculate the experimental recycle fraction by dividing the recycle flowrate by QSUM, the total flowrate given by the sum of recycle and branch flowrates. Calculate the deviation between experimental and theoretical values of recycle fraction.
12. Assign arrays for plotting experimental and theoretical values of x vs. Q for Stages 2 and 3.
13. Plot arrays in step 12.
14. Go to step 17 for Stages 2 and 3.
15. For Stage 1, calculate average recycle fractions for all flowrates in each Flowsplit using AVG. Calculate f(K).
16. Calculate theoretical values of x vs. f(K) from equation 30 and plot these, along with the experimental points, for Flowsplits 1 to 4 on the same graph. Reverse the roles of the recycle and branch lines in Flowsplits 2 to 4 to generate three more experimental points to be plotted (since in Flowsplit 1, both lines are identical with 1/2 inch orifices). Print results.
17. Establish the next Flowsplit number and repeat from step 2 until all flowsplits have been examined.

The two steps designated by * are optional; in the final form of the program which calculated all the results, step 6 was kept and step 10 was abandoned, so that all stepwise results are based upon exact friction factors and represent experimental data which is the average of two trials.

The Newton iteration technique, used in step 11, has been applied to the design equation as follows:

1. Calculate the critical flowrate and experimental x.
2. Set the recycle fraction equal to 1.
3. If the flowrate is less than the critical, go to step 9.
4. If not, calculate f(x), the design eqtn. set equal to zero.
5. Calculate the first derivative of f(x), df(x)/dx.
6. Calculate the next value of recycle fraction, x' as:

$$x' = x - \frac{f(x)}{df(x)/dx} \qquad \text{(eq. C1)}$$

7. Calculate the absolute error as the absolute value of f(x) (since the deviation of this function from zero, at the solution value of x, is a measure of the error).
8. If the error is greater than 0.0001, repeat from step 4 until this is not true.
9. If not, calculate the deviation between experimental and theoretical values of x; print all results. Continue.

The remainder of Appendix C consists of the computer program and all results, as received in output format, for Flowsplits 1 through 18. For simplicity, the tables have not formally been labeled; all data for each Flowsplit is grouped together in several pages, identified by the Flowsplit # heading on the first page. Each line of data is for a different flowrate.

```
      PROGRAM FLSPLT (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C-----------------------------------------------------------------------
C**** ABSTRACT:
C        THIS PROGRAM CALCULATES AND PLOTS THE RECYCLE FRACTION VS.
C        FLOWRATE BEHAVIOR FOR EACH OF 18 DIFFERENT EXPERIMENTAL RUNS.
C        EACH RUN, TERMED A FLOWSPLIT, HAS UNIQUE RECYCLE AND BRANCH
C        RESISTANCE COEFFICIENTS.
C        THREE STAGES, OR LEVELS, WERE EXAMINED WHEREBY EACH STAGE IS AT
C        A SINGLE STATIC-HEAD DIFFERENCE BETWEEN RECYCLE AND BRANCH
C        DELIVERY POINTS.
C        TO CALCULATE RESULTS FOR AVERAGED DATA OF TRIALS 1 AND 2, SET
C        M=3.  OTHERWISE, RESULTS FOR EACH TRIAL WILL BE CALCULATED .
C        BOTH EXPERIMENTAL AND THEORETICAL RESULTS ARE GIVEN.
C-----------------------------------------------------------------------
C**** NOMENCLATURE:
C        A    CONSTANT IN CHURCHILL FRICTION FACTOR EQUATION
C        ABK, ARK  AVERAGE BRANCH AND RECYCLE K-FUNCTIONS (FROM AFR,AFB)
C        AFB, AFR  AVERAGE OF ALL FRA AND FBA
C        AVXEX, AVXTH  AVERAGES OF AXTH AND AXEX FOR TRIALS 1 AND 2
C        AXEX, AXTH  AVERAGES OF ALL XTH AND XEX FOR EACH OF TRIALS 1,2
C        B    DIAMETER RATIO, BETA=D1/D2,  D1 IS BORE, D2 IS PIPE ID
C        BK   TOTAL K-FACTOR FOR BRANCH LINE
C        BL   BRANCH-LINE LENGTH, (FT)
C        BLK  K-FACTOR FOR BRANCH LINE, NO ORIFICE
C        BOK  BRANCH ORIFICE K-FACTOR
C        BRE  BRANCH LINE REYNOLDS NUMBER
C        C    ORIFICE COEFFICIENT
C        C34  COEFFICIENT FOR 3/4 INCH ORIFICE
C        CB, CR    BRANCH AND RECYCLE ORIFICE COEFFICIENTS
C        CF   CONVERSION FACTOR:  (GPM)**2/(CU FT/SEC)
C        CS   CROSS-SECTIONAL AREA OF PIPE, (SQ FT)
C        D    INSIDE PIPE DIAMETER, (IN)
C        DEN  DENSITY OF WATER AT ROOM TEMPERATURE, (LBM/CU FT)
C        DFX  DERIVATIVE OF FX WITH RESPECT TO X, IN NEWTON ITERATION
C        DP   PRESSURE DIFFERENCE BETWEEN POINTS 1 AND 2, (FT)
C        ED   RATIO OF PIPE ROUGHNESS FACTOR (EPSILON) TO PIPE DIAMETER
C        ERR  RELATIVE ERROR IN FX FROM FX=0
C        F    FRICTION FACTOR CALCULATED BY CHURCHILL EQUATION
C        FB, FR    BRANCH AND RECYCLE LINE DARCY FRICTION FACTORS
C        FBA, FRA  FRICTION FACTORS FOR RRE, BRE GREATER THAN 10,000
C        FD   DARCY FRICTION FACTOR
C        FX   FUNCTION F(X)=0 USED IN NEWTON ITERATION TO SOLVE FOR XTH
C        G    CONSTANT IN CHURCHILL FRICTION FACTOR EQUATION
C        HLM  HEAD-LOSS (MANOMETER READING) OF MAIN-FLOW ORIFICE
C        I=1 DENOTES STAGE 1, EQUAL STATIC HEADS
C        I=2 DENOTES STAGE 2, MEDIUM HEIGHT DIFFERENCE
C        I=3 DENOTES STAGE 3, LARGER HEIGHT DIFFERENCE
C        J INDEXES EACH DATA POINT
C        L=1 ASSIGNS THE RECYCLE ORIFICE, L=2 THE BRANCH ORIFICES
C        M INDEXES ALL THE DATA FOR EACH EXPERIMENTAL TRIAL
C        NJ   TOTAL NUMBER OF DATA POINTS
C        NJ1, NJ2  TOTAL NUMBER OF DATA POINTS FOR TRIALS 1 AND 2
C        OK   OVERALL K-FACTOR FOR STAGE 1
C        OKR  SQUARE ROOT OF OVERALL K-FACTOR FOR STAGE 1
C        Q    FLOWRATE USED TO COMPUTE RESULTS
C        Q1   FLOWRATE USED IN PLOTTING EXPERIMENTAL RECYCLE BEHAVIOR
C        Q2   FLOWRATE USED IN PLOTTING THEORETICAL RECYCLE BEHAVIOR
C        QCRIT   CRITICAL FLOWRATE, ABOVE WHICH, BRANCH FLOW BEGINS
C        QL   FLOWRATE USED TO DETERMINE VELOCITY FOR FRICTION FACTORS
C        RE   MAIN-FLOW REYNOLDS NUMBER
C        RK   TOTAL K-FACTOR FOR RECYCLE LINE
C        RL   LENGTH OF RECYCLE LINE, (IN)
C        RLK  K-FACTOR FOR RECYCLE LINE, NO ORIFICE
C        ROK  RECYCLE ORIFICE K-FACTOR
C        RRE  RECYCLE LINE REYNOLDS NUMBER
C        S34  EXPONENT FOR 3/4 INCH ORIFICE
C        SB, SR    BRANCH AND RECYCLE ORIFICE EXPONENTS
C        SKB, SKR  SUM OF K-FACTORS FOR ELBOWS IN BRANCH, RECYCLE LINES
C        UM IS THE UNCERTAINTY IN THE HLM READING FOR MAIN-FLOW ORIFICE
C        V    MAIN-FLOW VELOCITY IN PIPE (FT/S)
C        XEX  EXPERIMENTAL RECYCLE FRACTION, FOR A GIVEN Q
```

```
      C        XTH   THEORETICAL RECYCLE FRACTION, FOR A GIVEN Q
      C        XE2   RECYCLE FRACTION USED IN PLOTTING EXPERIMENTAL BEHAVIOR
      C        XERR     RELATIVE ERROR BETWEEN XTH AND XEX
      C        XT2   RECYCLE FRACTION USED IN PLOTTING THEORETICAL BEHAVIOR
      C        Z     HEIGHT DIFFERENCE BETWEEN POINTS 1 AND 2, (FT)
      C----------------------------------------------------------------------

   3            DIMENSION HLM(25,3), UM(25,3), HLR(25,3), UR(25,3),
               .HLB(25,3), UB(25,3), QM(25,3), QSUM(25,3), QAV(25,3), QR(25,3)
   3            DIMENSION Q(25,3)
   3            DIMENSION QB(25,3)
   3            DIMENSION FR(50), FB(50), AFR(18), AFB(18), ARK(18), ABK(18)
   3            DIMENSION ROK(18), BOK(18)
   3            DIMENSION XEX(25,3), XTH(25,3), RK(50), BK(50), AXTH(50), AXEX(50)
               ., AVXTH(50), AVXEX(50), XH(50), Y(5,50), XDEV(25), QDIF(25,3)
   3            DIMENSION QCRIT(50), AQCRIT(18)
   3            DIMENSION X(50), BR(50), B2(50), F(50), FUNK(18)
   3            DIMENSION AVXEXP(3), FUNKP(3)
   3            DIMENSION XAXIS(2), YAXIS(2), XYAXIS(2)
   3            DIMENSION Q1(30), Q2(30), XT2(30), XE2(30)
   3            DIMENSION FRA(50), FBA(50), RRE(50)
   3            DATA D,ED,DEN,CS,RL/1.049,0.0017,62.3,0.006,75./
   3            CF = 2.*32.174*(CS**2.)*(448.8**2.)
  15            C34 = 9.0421
  16            S34 = 0.4696

      C         **** FORMAT STATEMENTS FOR LITERAL OUTPUT ****
  20      715   FORMAT (/,10X,*MAIN H-L*,4X,*HLM ERROR*,3X,*RECYCLE H-L*,3X,*HLR E
               .RROR*,4X,*BRANCH H-L*,3X,*HLB ERROR*)
  20      716   FORMAT (10X,*(IN HG)*,7X,*(+/-)*,2(7X,*(CM HG)*,7X,*(+/-)*),/)
  20      722   FORMAT (10X,*RECYCLE RE*,6X,*FR*,7X,*RECYCLE-K*,5X,*BRANCH RE*,7X,
               .*FB*,8X,*BRANCH-K*,/)
  20      735   FORMAT (*1*,7(/),10X,*AVERAGED INPUT DATA:*,/)
  20      736   FORMAT (*1*,//,10X,*AVERAGED INPUT DATA:*,/)
  20      740   FORMAT (/,10X,*TRIAL*,I2,/)
  20      745   FORMAT (/,9X,*MAIN FLOW*,5X,*QM ERROR*,3X,*RECYCLE FLOW*,3X,
               .*QR ERROR*,3X,*BRANCH FLOW*,4X,*QB ERROR*,6X,*QR+QB*,9X,*QAV*)
  20      746   FORMAT (11X,*(GPM)*,3(6X,*(+/- PCT.)*,5X,*(GPM)*),8X,*(GPM)*,/)
  20      750   FORMAT (3(/),13X,*XTH*,9X,*XEXP*,7X,*XERR PCT*,6X,*MAIN RE*,4X,*QS
               .UM (GPM)*,3X,*VEL. (FPS)*,/)
  20      755   FORMAT (3(/), 10X,*RESULTS OF AVERAGED DATA:*)
  20      756   FORMAT (*1*,6(/))
  20      800   FORMAT (*1*,5(/),10X,*FLOWSPLIT*,I3,/,10X,*-------------*,/)
  20      801   FORMAT (*1*,3(/),10X,*FLOWSPLIT*,I3,/,10X,*-------------*,/)

  20            NI = 1
  21            NF = 4
  23            DO 2000  N=NI,NF
  25            IF (N.EQ.4) GO TO 803
  27            PRINT 800, N
  35            GO TO 802
  36      803   PRINT 801, N
      C         **** SIGNAL WHICH FLOWSPLITS BELONG TO EACH STAGE ****
  44      802   IF (N.GE.12) I=3
  50            IF (N.LE.11) I=2
  54            IF (N.LE.4) I=1

      C         **** ASSIGN PROPER SYSTEM SPECIFICATIONS FOR EACH FLOWSPLIT ****
  60            SKR = 60.0
  62            GO TO (910,920,940) I
  71      940   SKB = 90.0
  73            BL = 196.
  74            DP = -1.*7./12.
  77            Z = 15.208
 100            GO TO 930
 101      920   SKB = 90.0
 103            BL = 138.
 104            DP = -1.*7./12.
 107            Z = 7.542
 110            GO TO 930
 111      910   SKB = 60.0
 113            BL = 75.

      C         *** ASSIGN RECYCLE AND BRANCH ORIFICE SPECS FOR EACH FLOWSPLIT ***
      C         GIVE SAME PLOTTER SYMBOL TO FLOWSPLITS WITH SAME RECYCLE ORIFICE.
      C         **** CALCULATE THE RECYCLE AND BRANCH ORIFICE K-FACTORS ****
```

```
      930 L = 1
          PRINT 810
      810 FORMAT (10X,*RECYCLE ORIFICE*)
          GO TO (1,1,1,5,5,1,1,5,3,3,1,1,3,3,1,5,5,1) N
       81 PRINT 820
      820 FORMAT (10X,*BRANCH ORIFICE*)
          GO TO (1,5,3,3,3,3,1,1,1,5,5,5,5,1,1,1,3,3) N
        1 C = 2.0607
          S = 0.4952
          B = 0.4766
          CD = 0.6353
          IF (L.EQ.1) NS=4
          PRINT 830
      830 FORMAT (10X,*1/2 INCH*,/)
          IF (L.EQ.1) 82,83
        3 C = 1.1451
          S = 0.4947
          B = 0.3575
          CD = 0.6392
          IF (L.EQ.1) NS=3
          PRINT 840
      840 FORMAT (10X,*3/8 INCH*,/)
          IF (L.EQ.1) 82,83
        5 C = 3.3261
          S = 0.4988
          B = 0.5968
          CD = 0.6300
          IF (L.EQ.1) NS=11
          PRINT 850
      850 FORMAT (10X,*5/8 INCH*,/)
          IF (L.EQ.1) 82,83
       82 CR = C
          SR = S
          ROK(N) = (1. - B**2.)*((1./B**4.) - 1.)/CD**2.
          L = 2
          GO TO 81
       83 CB = C
          SB = S
          BOK(N) = (1. - B**2.)*((1./B**4.) - 1.)/CD**2.
C         **** READ AND PRINT INITIAL ORIFICE HEAD-LOSS DATA ****
          PRINT 715
          PRINT 716
          DO 900 IR=1,2
          READ 700, NJ,M,(HLM(J,M), UM(J,M), HLR(J,M), UR(J,M), HLB(J,M), UB
         .(J,M), J=1,NJ)
      700 FORMAT (2I2/(12F5.1))
          PRINT 740, M
          IF (IR.EQ.1) NJ1=NJ
          IF (IR.EQ.2) NJ2=NJ
      900 PRINT 705, (HLM(J,M), UM(J,M), HLR(J,M), UR(J,M), HLB(J,M), UB(J,M
         .), J=1,NJ)
      705 FORMAT (9X,F8.4,5(5X,F8.4))

C-----------------------------------------------------------------------
C         **** OMIT THIS SECTION IF RESULTS FOR TRIALS 1 AND 2 INDIVIDUALLY
C         **** ARE DESIRED.  APPLIES FOR ALL STAGES. ****

C         **** AVERAGE ALL THE INPUT DATA FOR TRIALS 1 AND 2 AT THE SAME HLM
          IF ((N.EQ.2).OR.(N.EQ.4)) GO TO 738
          PRINT 735
          GO TO 737
      738 PRINT 736
      737 PRINT 715
          PRINT 716
          M = 1
          J = 1
          IF (NJ1.LE.NJ2) 906,908
      906 NUML = 2.*NJ1
          NUMH = 2.*NJ2
          MH = 2
          GO TO 909
      908 NUML = 2.*NJ2
          NUMH = 2.*NJ1
          MH = 1
      909 DNUM = (NUMH - NUML)/2.
```

```
          NUM = NUML + DNUM
          DO 902  K=1,NUM
          XH(K) = HLM(J,M)
          Y(1,K) = UM(J,M)
          Y(2,K) = HLR(J,M)
          Y(3,K) = UR(J,M)
          Y(4,K) = HLB(J,M)
          Y(5,K) = UB(J,M)
          M = M + 1
          IF (M.GT.2) 903,904
    903   M = 1
          J = J + 1
          IF (K.GE.NUML) M=MH
          GO TO 902
    904   IF ((MH.EQ.1).AND.(K.GT.NUML)) 905,902
    905   M = 1
          J = J + 1
    902   CONTINUE
          CALL ORDER (XH,Y,NUM,5)
          CALL AVGY (XH,Y,NUM,5,NJA)
          K = 1
          DO 907  J=1,NJA
          HLM(J,3) = XH(K)
          UM(J,3) = Y(1,K)
          HLR(J,3) = Y(2,K)
          UR(J,3) = Y(3,K)
          HLB(J,3) = Y(4,K)
          UB(J,3) = Y(5,K)
    907   K = K + 1
C         **** M=3 INDICATES THAT RESULTS ARE FOR AVERAGED INPUT DATA ****
          M = 3
C-----------------------------------------------------------------------
          NJ = NJA
          IF (N.EQ.5) PRINT 756
          IF (N.EQ.7) PRINT 756
          IF (N.EQ.8) PRINT 756
          IF (M.EQ.3) PRINT 755
C         **** CALCULATE FLOWRATES AND THEIR UNCERTAINTIES ****
          PRINT 745
          PRINT 746
          IF (M.EQ.3) GO TO 760
          NJ = NJ1
          DO 3000 M=1,2
          PRINT 740, M
    760   DO 3500  J=1,NJ
          QR(J,M) = CR*HLR(J,M)**SR
          WR = 0.5*CR*UR(J,M)/SQRT(HLR(J,M))
          ER = 100.*WR/QR(J,M)
          QB(J,M) = CB*HLB(J,M)**SB
          IF (QB(J,M).NE.0.) GO TO 725
          EB = 0.
          GO TO 730
    725   WB = 0.5*CB*UB(J,M)/SQRT(HLB(J,M))
          EB = 100.*WB/QB(J,M)
    730   QM(J,M) = C34*HLM(J,M)**S34
          WM = 0.5*C34*UM(J,M)/SQRT(HLM(J,M))
          EM = 100.*WM/QM(J,M)
          QSUM(J,M) = QB(J,M) + QR(J,M)
          QAV(J,M) = (QSUM(J,M) + QM(J,M))/2.
          QDIF(J,M) = (QSUM(J,M) - QM(J,M))/QSUM(J,M)
   3500   PRINT 710, QM(J,M), EM, QR(J,M), ER, QB(J,M), EB, QSUM(J,M), QAV(J
         .,M), QDIF(J,M)
    710   FORMAT (10X,F7.4,8(6X,F7.4))
          IF (M.EQ.3) GO TO 765
          NJ = NJ2
   3000   CONTINUE
C         *** CALCULATE DARCY FRICTION FACTORS FROM THE REYNOLDS NUMBERS ***
          DO 4000 M=1,2
          IF (M.EQ.1) NJ=NJ1
          IF (M.EQ.2) NJ=NJ2
          PRINT 740, M
    765   X = 1.0
```

```
C          XTH   THEORETICAL RECYCLE FRACTION, FOR A GIVEN Q
C          XE2   RECYCLE FRACTION USED IN PLOTTING EXPERIMENTAL BEHAVIOR
C          XERR     RELATIVE ERROR BETWEEN XTH AND XEX
C          XT2   RECYCLE FRACTION USED IN PLOTTING THEORETICAL BEHAVIOR
C          Z     HEIGHT DIFFERENCE BETWEEN POINTS 1 AND 2, (FT)
C------------------------------------------------------------------------

      DIMENSION HLM(25,3), UM(25,3), HLR(25,3), UR(25,3),
     .HLB(25,3), UB(25,3), QM(25,3), QSUM(25,3), QAV(25,3), QR(25,3)
      DIMENSION Q(25,3)
      DIMENSION QB(25,3)
      DIMENSION FR(50), FB(50), AFR(18), AFB(18), ARK(18), ABK(18)
      DIMENSION ROK(18), BOK(18)
      DIMENSION XEX(25,3), XTH(25,3), RK(50), BK(50), AXTH(50), AXEX(50)
     ., AVXTH(50), AVXEX(50), XH(50), Y(5,50), XDEV(25), QDIF(25,3)
      DIMENSION QCRIT(50), AQCRIT(18)
      DIMENSION X(50), BR(50), B2(50), F(50), FUNK(18)
      DIMENSION AVXEXP(3), FUNKP(3)
      DIMENSION XAXIS(2), YAXIS(2), XYAXIS(2)
      DIMENSION Q1(30), Q2(30), XT2(30), XE2(30)
      DIMENSION FRA(50), FBA(50), RRE(50)
      DATA D,ED,DEN,CS,RL/1.049,0.0017,62.3,0.006,75./
      CF = 2.*32.174*(CS**2.)*(448.8**2.)
      C34 = 9.0421
      S34 = 0.4696
C
C     **** FORMAT STATEMENTS FOR LITERAL OUTPUT ****
 715  FORMAT (/,10X,*MAIN H-L*,4X,*HLM ERROR*,3X,*RECYCLE H-L*,3X,*HLR E
     .RROR*,4X,*BRANCH H-L*,3X,*HLB ERROR*)
 716  FORMAT (10X,*(IN HG)*,7X,*(+/-)*,2(7X,*(CM HG)*,7X,*(+/-)*),/)
 722  FORMAT (10X,*RECYCLE RE*,6X,*FR*,7X,*RECYCLE-K*,5X,*BRANCH RE*,7X,
     .*FB*,8X,*BRANCH-K*,/)
 735  FORMAT (*1*,7(/),10X,*AVERAGED INPUT DATA:*,/)
 736  FORMAT (*1*,//,10X,*AVERAGED INPUT DATA:*,/)
 740  FORMAT (/,10X,*TRIAL*,I2,/)
 745  FORMAT (/,9X,*MAIN FLOW*,5X,*QM ERROR*,3X,*RECYCLE FLOW*,3X,
     .*QR ERROR*,3X,*BRANCH FLOW*,4X,*QB ERROR*,6X,*QR+QB*,9X,*QAV*)
 746  FORMAT (11X,*(GPM)*,3(6X,*(+/- PCT.)*,5X,*(GPM)*),8X,*(GPM)*,/)
 750  FORMAT (3(/),13X,*XTH*,9X,*XEXP*,7X,*XERR PCT*,6X,*MAIN RE*,4X,*QS
     .UM (GPM)*,3X,*VEL. (FPS)*,/)
 755  FORMAT (3(/), 10X,*RESULTS OF AVERAGED DATA:*)
 756  FORMAT (*1*,6(/))
 800  FORMAT (*1*,5(/),10X,*FLOWSPLIT*,I3,/,10X,*------------*,/)
 801  FORMAT (*1*,3(/),10X,*FLOWSPLIT*,I3,/,10X,*------------*,/)

      NI = 1
      NF = 4
      DO 2000  N=NI,NF
      IF (N.EQ.4) GO TO 803
      PRINT 800, N
      GO TO 802
 803  PRINT 801, N
C     **** SIGNAL WHICH FLOWSPLITS BELONG TO EACH STAGE ****
 802  IF (N.GE.12) I=3
      IF (N.LE.11) I=2
      IF (N.LE.4) I=1

C     **** ASSIGN PROPER SYSTEM SPECIFICATIONS FOR EACH FLOWSPLIT ****
      SKR = 60.0
      GO TO (910,920,940) I
 910  SKB = 90.0
      BL = 196.
      DP = -1.*7./12.
      Z = 15.208
      GO TO 930
 920  SKB = 90.0
      BL = 138.
      DP = -1.*7./12.
      Z = 7.542
      GO TO 930
 940  SKB = 60.0
      BL = 75.

C     *** ASSIGN RECYCLE AND BRANCH ORIFICE SPECS FOR EACH FLOWSPLIT ***
C     GIVE SAME PLOTTER SYMBOL TO FLOWSPLITS WITH SAME RECYCLE ORIFICE.
C     **** CALCULATE THE RECYCLE AND BRANCH ORIFICE K-FACTORS ****
```

```
 930   L = 1
       PRINT 810
 810   FORMAT (10X,*RECYCLE ORIFICE*)
       GO TO (1,1,1,5,5,1,1,5,3,3,1,1,3,3,1,5,5,1) N
  81   PRINT 820
 820   FORMAT (10X,*BRANCH ORIFICE*)
       GO TO (1,5,3,3,3,3,1,1,1,5,5,5,5,1,1,1,3,3) N
   1   C = 2.0607
       S = 0.4952
       B = 0.4766
       CD = 0.6353
       IF (L.EQ.1) NS=4
       PRINT 830
 830   FORMAT (10X,*1/2 INCH*,/)
       IF (L.EQ.1) 82,83
   3   C = 1.1451
       S = 0.4947
       B = 0.3575
       CD = 0.6392
       IF (L.EQ.1) NS=3
       PRINT 840
 840   FORMAT (10X,*3/8 INCH*,/)
       IF (L.EQ.1) 82,83
   5   C = 3.3261
       S = 0.4988
       B = 0.5968
       CD = 0.6300
       IF (L.EQ.1) NS=11
       PRINT 850
 850   FORMAT (10X,*5/8 INCH*,/)
       IF (L.EQ.1) 82,83
  82   CR = C
       SR = S
       ROK(N) = (1. - B**2.)*((1./B**4.) - 1.)/CD**2.
       L = 2
       GO TO 81
  83   CB = C
       SB = S
       BOK(N) = (1. - B**2.)*((1./B**4.) - 1.)/CD**2.

C      **** READ AND PRINT INITIAL ORIFICE HEAD-LOSS DATA ****
       PRINT 715
       PRINT 716
       DO 900 IR=1,2
       READ 700, NJ,M,(HLM(J,M), UM(J,M), HLR(J,M), UR(J,M), HLB(J,M), UB
      .(J,M), J=1,NJ)
 700   FORMAT (2I2/(12F5.1))
       PRINT 740, M
       IF (IR.EQ.1) NJ1=NJ
       IF (IR.EQ.2) NJ2=NJ
 900   PRINT 705, (HLM(J,M), UM(J,M), HLR(J,M), UR(J,M), HLB(J,M), UB(J,M
      .), J=1,NJ)
 705   FORMAT (9X,F8.4,5(5X,F8.4))

C-----------------------------------------------------------------------
C      **** OMIT THIS SECTION IF RESULTS FOR TRIALS 1 AND 2 INDIVIDUALLY
C      **** ARE DESIRED.  APPLIES FOR ALL STAGES. ****

C      **** AVERAGE ALL THE INPUT DATA FOR TRIALS 1 AND 2 AT THE SAME HLM
       IF ((N.EQ.2).OR.(N.EQ.4)) GO TO 738
       PRINT 735
       GO TO 737
 738   PRINT 736
 737   PRINT 715
       PRINT 716
       M = 1
       J = 1
       IF (NJ1.LE.NJ2) 906,908
 906   NUML = 2.*NJ1
       NUMH = 2.*NJ2
       MH = 2
       GO TO 909
 908   NUML = 2.*NJ2
       NUMH = 2.*NJ1
       MH = 1
 909   DNUM = (NUMH - NUML)/2.
```

```
      NUM = NUML + DNUM
      DO 902  K=1,NUM
      XH(K) = HLM(J,M)
      Y(1,K) = UM(J,M)
      Y(2,K) = HLR(J,M)
      Y(3,K) = UR(J,M)
      Y(4,K) = HLB(J,M)
      Y(5,K) = UB(J,M)
      M = M + 1
      IF (M.GT.2) 903,904
 903  M = 1
      J = J + 1
      IF (K.GE.NUML) M=MH
      GO TO 902
 904  IF ((MH.EQ.1).AND.(K.GT.NUML)) 905,902
 905  M = 1
      J = J + 1
 902  CONTINUE
      CALL ORDER (XH,Y,NUM,5)
      CALL AVGY (XH,Y,NUM,5,NJA)
      K = 1
      DO 907  J=1,NJA
      HLM(J,3) = XH(K)
      UM(J,3) = Y(1,K)
      HLR(J,3) = Y(2,K)
      UR(J,3) = Y(3,K)
      HLB(J,3) = Y(4,K)
      UB(J,3) = Y(5,K)
 907  K = K + 1
C     **** M=3 INDICATES THAT RESULTS ARE FOR AVERAGED INPUT DATA ****
      M = 3
C-----------------------------------------------------------------------------

      NJ = NJA
      IF (N.EQ.5) PRINT 756
      IF (N.EQ.7) PRINT 756
      IF (N.EQ.8) PRINT 756
      IF (M.EQ.3) PRINT 755
C     **** CALCULATE FLOWRATES AND THEIR UNCERTAINTIES ****
      PRINT 745
      PRINT 746
      IF (M.EQ.3) GO TO 760
      NJ = NJ1
      DO 3000 M=1,2
      PRINT 740, M
 760  DO 3500  J=1,NJ
      QR(J,M) = CR*HLR(J,M)**SR
      WR = 0.5*CR*UR(J,M)/SQRT(HLR(J,M))
      ER = 100.*WR/QR(J,M)
      QB(J,M) = CB*HLB(J,M)**SB
      IF (QB(J,M).NE.0.) GO TO 725
      EB = 0.
      GO TO 730
 725  WB = 0.5*CB*UB(J,M)/SQRT(HLB(J,M))
      EB = 100.*WB/QB(J,M)
 730  QM(J,M) = C34*HLM(J,M)**S34
      WM = 0.5*C34*UM(J,M)/SQRT(HLM(J,M))
      EM = 100.*WM/QM(J,M)
      QSUM(J,M) = QB(J,M) + QR(J,M)
      QAV(J,M) = (QSUM(J,M) + QM(J,M))/2.
      QDIF(J,M) = (QSUM(J,M) - QM(J,M))/QSUM(J,M)
 3500 PRINT 710, QM(J,M), EM, QR(J,M), ER, QB(J,M), EB, QSUM(J,M), QAV(J
     *,M), QDIF(J,M)
 710  FORMAT (10X,F7.4,8(6X,F7.4))
      IF (M.EQ.3) GO TO 765
      NJ = NJ2
 3000 CONTINUE
C     *** CALCULATE DARCY FRICTION FACTORS FROM THE REYNOLDS NUMBERS ***
      DO 4000 M=1,2
      IF (M.EQ.1) NJ=NJ1
      IF (M.EQ.2) NJ=NJ2
      PRINT 740, M
 765  X = 1.0
```

```
      PRINT 756
      PRINT 722

      DO 4200  J=1,NJ
      DO 631  IJ=1,2
      IF (IJ.EQ.1) QL=QR(J,M)
      IF (IJ.EQ.2) QL=QB(J,M)
      IF (QL.EQ.0.) GO TO 633
      V = QL/(448.8*0.006)
      RE = V*D*DEN/(12.*6.7197E-4)
      A = (2.457*ALOG(1./((7./RE)**0.9 + (0.27*ED))))**16.
      G = (37530./RE)**16.
      F = ((8./RE)**12. + 1./((A + G)**1.5))**(1./12.)
C
C     **** CALCULATE RECYCLE AND BRANCH LINE K-FACTORS ****
      IF (IJ.EQ.2) GO TO 632
      FR(J) = 8.*F
      RRE(J) = RE
  634 RLK = 1.0 + FR(J)*(SKR + RL/D)
      RK(J) = ROK(N) + RLK
      IF (RRE(1).GE.10000.) GO TO 636
      IF (RRE(J).LT.10000.) JR=J
      IF (RRE(J).LT.10000.) GO TO 631
      GO TO 637
  636 JR = 0
  637 FRA(J-JR) = FR(J)
      GO TO 631
  633 FB(J) = 0.
      BRE = 0.
      BK(J) = 0.
      GO TO 631
  632 FB(J) = 8.*F
      BRE = RE
      BLK = 1.0 + FB(J)*(SKB + BL/D)
      BK(J) = BOK(N) + BLK
      IF (BRE.LT.10000.) JB=J
      IF (BRE.LT.10000.) GO TO 631
      FBA(J-JB) = FB(J)
  631 CONTINUE
      PRINT 721, RRE(J), FR(J), RK(J), BRE, FB(J), BK(J)
  721 FORMAT (10X,F7.0,6X,F7.5,5X,F8.4,6X,F7.0,6X,F7.5,6X,F8.4)
 4200 CONTINUE
C
C     **** CALCULATE AVERAGE K-FACTORS ****
      AFR(N) = AVG(FRA,NJ-JR)
      AFB(N) = AVG(FBA,NJ-JB)
      ARK(N) = ROK(N) + AFR(N)*(SKR+RL/D) + 1.0
      ABK(N) = BOK(N) + AFB(N)*(SKB+BL/D) + 1.0
      FD = AFR(N)
      IF (N.EQ.2) PRINT 756
      IF (N.EQ.4) PRINT 756
      IF (N.EQ.5) PRINT 756
      IF (N.EQ.7) PRINT 756
      IF (N.EQ.8) PRINT 756
      PRINT 750

      DO 4500  J=1,NJ
      Q(J,M) = QSUM(J,M)
      XEX(J,M) = QR(J,M)/Q(J,M)
C     **** USE ABK AND ARK FOR COMPUTING X WITH AVERAGE K-FACTORS ****
      BK(N) = ABK(N)
      RK(N) = ARK(N)
      BK(N) = BK(J)
      RK(N) = RK(J)
      V = Q(J,M)/(448.8*0.006)
      RE = V*D*DEN/(12.*6.7197E-4)
C
C     **** CALCULATE THE RECYCLE FRACTION USING NEWTON ITERATION ****
      GO TO (71,72,72) I
   71 OKR = 1./(1./SQRT(BK(N)) + 1./SQRT(RK(N)))
      XTH(J,M) = OKR/SQRT(RK(N))
      QCRIT(N) = 0.
      OK = OKR**2.
      GO TO 74
   72 NR = 0
      QCRIT(N) = SQRT(CF*(Z+DP)/ARK(N))
      X = 1.0
```

```
C        **** SOLVE FOR X WHEN FLOWRATE EQUALS OR EXCEEDS QCRIT ****
         IF (Q(J,M).LT.QCRIT(N)) GO TO 75
   73    FX = (RK(N)-BK(N))*X**2. + BK(N)*(2.*X-1.) - CF*(Z+DP)/Q(J,M)**2.
         DFX = 2.*(RK(N)-BK(N))*X + 2.*BK(N)
         X = X - FX/DFX
         ERR = ABS(FX)
         IF (ERR.GT.0.0001) 76,75
   76    NR = NR + 1
         GO TO 73
   75    XTH(J,M) = X
   74    XERR = (XTH(J,M) - XEX(J,M))*100./XTH(J,M)
         PRINT 720, XTH(J,M), XEX(J,M), XERR, RE, QSUM(J,M), V
  720    FORMAT (10X,F7.4,2(5X,F8.4),6X,F7.0,2(5X,F8.4))
C        **** ASSIGN SPECIFIC ARRAYS FOR PROPER PLOTTING OF X VS. Q ****
         IF (N.LE.4) GO TO 420
         IF (J.EQ.1) GO TO 420
         IF ((XTH(J,M).LT.1.).AND.(XTH(J-1,M).EQ.1.)) GO TO 400
         IF (XTH(J,M).LT.1.) GO TO 410
  420    Q2(J) = Q(J,M)
         XT2(J) = XTH(J,M)
         GO TO 430
  400    Q2(J) = QCRIT(N)
         XT2(J) = 1.
  410    Q2(J+1) = Q(J,M)
         XT2(J+1) = XTH(J,M)
  430    XE2(J) = XEX(J,M)
         Q1(J) = Q(J,M)
 4500    CONTINUE
         RK(N) = ARK(N)
         BK(N) = ABK(N)

C        **** PLOT RECYCLE FRACTION VS. FLOWRATE ****
         IF (N.LE.4) GO TO 4300
         NJP = NJ + 1
         FORMAT = 2HI1
         IF (N.GE.10) FORMAT=2HI2
         CALL QIKSET (5.0,0.0,10.,5.0,0.0,0.2)
         CALL QIKSAX (3,3)
         CALL QIKPLT (Q2,XT2,NJP,22H*WATER FLOWRATE (GPM)*)
         CALL PLOT (-6.0,1.0,-3)
         CALL QLINE (Q1,XE2,-NJ,NS)
   61    CALL SYMBOL (1.0,7.0,.14,28HFLOWSPLIT BEHAVIOR FOR STAGE,0.0,28)
         CALL NUMBER (4.5,7.0,.14,I,0.0,2HI1)
         CALL SYMBOL (3.5,4.5,.14,9HFLOWSPLIT,0.0,9)
         CALL NUMBER (4.7,4.5,.14,N,0.0,FORMAT)
         CALL PLOT (6.5,-1.0,-3)
 4300    CONTINUE

C        **** CALCULATE AVERAGES FOR TRIALS 1 AND 2, STAGE 1 ****
         IF (N.GT.4) GO TO 780
         AXTH(M) = AVG(XT2,NJ)
         AXEX(M) = AVG(XE2,NJ)
         IF (M.EQ.3) GO TO 630
         XDEV(M) = (AXTH(M) - AXEX(M))*100./AXTH(M)
         PRINT 990, AXTH(M), AXEX(M), XDEV(M)
  780    CONTINUE
 000     CONTINUE
         IF (M.EQ.3) GO TO 630

         **** CALCULATE THE AVERAGE PARAMETERS FOR STAGE 1 ****
  610    AQCRIT(N) = AVG(QCRIT,2)
         QCRIT(N) = AQCRIT(N)
  630    FUNK(N) = BK(N)/(BK(N) + RK(N))
         PRINT 960, N
  960    FORMAT (//,10X,*AVERAGE RESULTS FOR FLOWSPLIT *,I2,/,10X,*--------
        .-------------------------*)
         IF (N.GT.4) GO TO 975
         IF (M.EQ.3) GO TO 950
         AVXTH(N) = AVG(AXTH,2)
         AVXEX(N) = AVG(AXEX,2)
         GO TO 955
  950    AVXTH(N) = AXTH(M)
         AVXEX(N) = AXEX(M)
  955    XDEV(N) = (AVXTH(N) - AVXEX(N))*100./AVXTH(N)
         IF (N.EQ.1) GO TO 970
         AVXEXP(N) = 1. - AVXEX(N)
         FUNKP(N) = RK(N)/(BK(N) + RK(N))
```

```
970   PRINT 990, AVXTH(N), AVXEX(N), XDEV(N)
990   FORMAT (/,10X,*THEORETICAL X =*,F6.4,/,10X,*EXPERIMENTAL X =*,F6.4
     .,/,10X,*EXPERIMENTAL DEVIATION OF X =*,F8.4)
975   PRINT 995, RK(N), BK(N), FD, QCRIT(N)
995   FORMAT (/,10X,*RECYCLE K-FACTOR =*,F8.4,/,10X,*BRANCH K-FACTOR =*,
     .F8.4,/,10X,*RECYCLE FRICTION FACTOR =*,F7.5,/,10X,*CRITICAL FLOWRA
     .TE =*,F8.4,* GPM*)
2000  CONTINUE
      IF (NI.NE.1) CALL EXIT
C
      **** CALCULATE THE RECYCLE FRACTION VS. K-FUNCTION FOR STAGE 1 ***
      X(1) = 0.
      F(1) = 0.
      R = 50.
      DO 980 K=2,21
      J = K - 1
      X(K) = X(J) + 0.05
      BR(K) = R*(1. - X(K))/X(K)
      R2 = R**2.
      B2(K) = BR(K)**2.
980   F(K) = R2/(R2 + B2(K))
C
C     **** PLOT FLOWRATE VS. K-FACTOR FUNCTION FOR STAGE 1 ****
      XAXIS(1) = 0.
      XAXIS(2) = 1.
      YAXIS(1) = 0.
      YAXIS(2) = 1.
      XYAXIS(1) = 1.
      XYAXIS(2) = 1.
      CALL QIKSET (5.0,0.0,0.2,5.0,0.0,0.2)
      CALL QIKSAX(3,3)
      CALL QIKPLT (F,X,21,24H*K-FUNCTION, BK/(BK+RK)*,21H*RECYCLE FRACTI
     .ON, X*)
      CALL PLOT (-6.0,1.0,-3)
      CALL QLINE (FUNK, AVXEX, -4, 4)
      CALL QLINE (FUNKP(2), AVXEXP(2), -3, 4)
      CALL QLINE (XAXIS,XYAXIS,2)
      CALL QLINE (XYAXIS,YAXIS,2)
      CALL SYMBOL (-0.2,6.5,.21,30HFLOWSPLIT BEHAVIOR FOR STAGE 1,0.,30)
      CALL SYMBOL (1.25,6.0,.21,13HAVERAGED DATA,0.0,13)
      END


      SUBROUTINE ORDER (X,Y,N,NI)
C--------------------------------------------------------------------------
C**** ABSTRACT:
C          THIS PROGRAM ARRANGES THE VALUES OF A SET OF Y-PARAMETERS IN
C          THE ORDER OF INCREASING VALUES OF THE X-PARAMETER.
C
C**** NOMENCLATURE:
C          N     TOTAL NUMBER OF VALUES FOR THE X AND Y PARAMETERS
C          NI    NUMBER OF DIFFERENT Y-FUNCTIONS TO BE ORDERED
C          X     INPUT VALUE OF X-PARAMETER
C          Y     INPUT VALUE OF Y-PARAMETERS
C--------------------------------------------------------------------------

      DIMENSION X(N), Y(NI,N)
      J = N - 1
      DO 33 K=1,J
      L = N - K
      DO 33 M=1,L
      IF (X(M) - X(M+1)) 33,33,22
22    XT = X(M)
      X(M) = X(M+1)
      X(M+1) = XT
      DO 55 I=1,NI
      YT = Y(I,M)
      Y(I,M) = Y(I,M+1)
55    Y(I,M+1) = YT
33    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE AVGY (X,Y,N,NM,NJ)
C--------------------------------------------------------------------------
C**** ABSTRACT:
C         AVERAGE THE VALUES OF THE SET OF Y-PARAMETERS WHEN THE CORRES-
C         PONDING VALUES OF THE X-PARAMETER ARE EQUAL.
C**** NOMENCLATURE:
C         N    TOTAL NUMBER OF VALUES FOR THE X AND Y PARAMETERS
C         X    INPUT VALUE OF X-PARAMETER
C         NJ   TOTAL NUMBER OF DATA POINTS AFTER HAVING BEEN AVERAGED
C         NM   NUMBER OF DIFFERENT Y-PARAMETERS TO BE AVERAGED
C         Y    INPUT VALUE OF Y-PARAMETER
C--------------------------------------------------------------------------
      DIMENSION X(N), Y(NM,N)
      DIMENSION YS(5,50)
      J = 0
      K = 0
1080  J = J + 1
      K = K + 1
      L = K + 1
      IF (K.EQ.N) GO TO 1070
      IF (X(L).EQ.X(K)) GO TO 1085
1070  X(J) = X(K)
      DO 20  M=1,NM
20    Y(M,J) = Y(M,K)
      IF (K.LT.N) 1080,1060
1085  DO 30  M=1,NM
30    YS(M,K) = Y(M,K)
      TN = 1.0
1090  K = L
      L = K + 1
      TN = TN + 1.0
      DO 40  M=1,NM
40    YS(M,K) = YS(M,K-1) + Y(M,K)
      IF (K.EQ.N) GO TO 1075
      IF (X(L).EQ.X(K)) GO TO 1090
1075  X(J) = X(K)
      DO 50  M=1,NM
50    Y(M,J) = YS(M,K)/TN
      IF (K.LT.N) GO TO 1080
1060  NJ = J
      PRINT 60, ((X(J), (Y(M,J), M=1,NM)), J=1,NJ)
60    FORMAT (9X,F8.4,5(5X,F8.4))
      RETURN
      END


      FUNCTION AVG (ZNUM,NJ)
C
      **** TAKE THE AVERAGE OF NJ VALUES OF ZNUM ****
      DIMENSION ZNUM(50)
      SUM = 0.
      DO 10 J=1,NJ
      SUM1 = ZNUM(J)
10    SUM = SUM + SUM1
      AVG = SUM/NJ
      RETURN
      END
```

FLOWSPLIT 1

RECYCLE ORIFICE
1/2 INCH

BRANCH ORIFICE
1/2 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.2000	-0.0000	.8000	-0.0000	1.2000	-0.0000
.6000	-0.0000	2.7000	-0.0000	3.0000	-0.0000
1.0000	-0.0000	4.3000	-0.0000	4.6000	-0.0000
2.0000	-0.0000	8.8000	-0.0000	9.3000	-0.0000
4.0000	-0.0000	17.4000	-0.0000	17.8000	-0.0000
6.0000	-0.0000	25.9000	-0.0000	25.4000	-0.0000
8.0000	-0.0000	34.6000	-0.0000	35.3000	-0.0000
10.0000	-0.0000	42.7000	-0.0000	43.4000	-0.0000
12.0000	-0.0000	50.1000	-0.0000	51.9000	-0.0000
14.0000	-0.0000	59.5000	-0.0000	60.1000	-0.0000
16.0000	-0.0000	68.3000	-0.0000	69.0000	-0.0000
18.0000	-0.0000	75.8000	-0.0000	76.6000	-0.0000
20.0000	-0.0000	85.5000	-0.0000	86.2000	-0.0000
TRIAL 2					
.2000	-0.0000	.8000	-0.0000	.9000	-0.0000
.6000	-0.0000	2.8000	-0.0000	2.8000	-0.0000
1.0000	-0.0000	4.7000	-0.0000	4.8000	-0.0000
2.0000	-0.0000	9.2000	-0.0000	9.3000	-0.0000
3.0000	-0.0000	13.3000	-0.0000	13.4000	-0.0000
4.0000	-0.0000	17.6000	-0.0000	17.8000	-0.0000
5.0000	-0.0000	22.0000	-0.0000	22.1000	-0.0000
6.0000	-0.0000	25.8000	-0.0000	24.8000	-0.0000
8.0000	-0.0000	34.6000	-0.0000	34.8000	-0.0000
10.0000	-0.0000	42.8000	.1000	43.2000	.1000
12.0000	-0.0000	51.5000	.1000	51.9000	.1000
14.0000	-0.0000	59.5000	.1000	60.0000	.1000
16.0000	.1000	68.0000	.2000	68.4000	.2000
18.0000	.2000	72.6000	.2000	73.1000	.2000
20.0000	.2000	85.3000	.2000	85.8000	.2000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.2000	0.0000	.8000	0.0000	1.0500	0.0000
.6000	0.0000	2.7500	0.0000	2.9000	0.0000
1.0000	0.0000	4.5000	0.0000	4.7000	0.0000
2.0000	0.0000	9.0000	0.0000	9.3000	0.0000
3.0000	-0.0000	13.3000	-0.0000	13.4000	-0.0000
4.0000	0.0000	17.5000	0.0000	17.8000	0.0000
5.0000	-0.0000	22.0000	-0.0000	22.1000	-0.0000
6.0000	0.0000	25.8500	0.0000	25.1000	0.0000
8.0000	0.0000	34.6000	0.0000	35.0500	0.0000
10.0000	0.0000	42.7500	.0500	43.3000	.0500
12.0000	0.0000	50.8000	.0500	51.9000	.0500
14.0000	0.0000	59.5000	.0500	60.0500	.0500
16.0000	.0500	68.1500	.1000	68.7000	.1000
18.0000	.1000	74.2000	.1000	74.8500	.1000
20.0000	.1000	85.4000	.1000	86.0000	.1000

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
4.2465	0.0000	1.8451	0.0000	2.1111	0.0000
7.1136	0.0000	3.4007	0.0000	3.4914	0.0000
9.0421	0.0000	4.3400	0.0000	4.4344	0.0000
12.5208	0.0000	6.1172	0.0000	6.2174	0.0000
15.1470	0.0000	7.4224	0.0000	7.4500	0.0000
17.3379	0.0000	8.5029	0.0000	8.5748	0.0000
19.2533	0.0000	9.5232	0.0000	9.5446	0.0000
20.9744	0.0000	10.3149	0.0000	10.1656	0.0000
24.0082	0.0000	11.9170	0.0000	11.9935	0.0000
26.6606	0.0000	13.2329	.0595	13.3169	.0588
29.0438	0.0000	14.4131	.0501	14.5668	.0491
31.2242	0.0000	15.5868	.0428	15.6579	.0425
33.2448	.1700	16.6704	.0749	16.7369	.0743
35.1354	.3033	17.3876	.0688	17.4628	.0682
36.9176	.2738	18.6412	.0598	18.7059	.0594

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
5553	.03889	41.3118	6354	.03758	41.1391
10235	.03362	40.6186	10508	.03343	40.5936
13062	.03196	40.4001	13346	.03182	40.3822
18411	.02997	40.1389	18713	.02989	40.1278
22340	.02901	40.0130	22423	.02900	40.0107
25591	.02840	39.9328	25808	.02837	39.9281
28662	.02793	39.8709	28727	.02792	39.8697
31045	.02762	39.8297	30596	.02768	39.8371
35867	.02709	39.7604	36097	.02707	39.7575
39827	.02674	39.7140	40080	.02672	39.7113
43380	.02647	39.6785	43842	.02644	39.6742
46912	.02623	39.6476	47126	.02622	39.6458
50174	.02604	39.6223	50374	.02603	39.6209
52332	.02593	39.6071	52558	.02591	39.6056
56105	.02574	39.5829	56300	.02573	39.5817

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
.5000	.4664	6.7200	11907	3.9562	1.4692
.4999	.4934	1.2997	20743	6.8921	2.5595
.4999	.4946	1.0657	26409	8.7744	3.2585
.5000	.4959	.8050	37124	12.3346	4.5806
.5000	.4991	.1840	44762	14.8724	5.5230
.5000	.4979	.4179	51399	17.0777	6.3420
.5000	.4994	.1115	57389	19.0678	7.0810
.5000	.5036	-.7243	61641	20.4805	7.6057
.5000	.4984	.3181	71964	23.9104	8.8794
.5000	.4984	.3148	79908	26.5498	9.8595
.5000	.4973	.5277	87222	28.9800	10.7620
.5000	.4989	.2267	94038	31.2447	11.6030
.5000	.4990	.1981	100547	33.4074	12.4062
.5000	.4989	.2150	104890	34.8504	12.9421
.5000	.4991	.1726	112405	37.3470	13.8692

AVERAGE RESULTS FOR FLOWSPLIT 1

THEORETICAL X = .5000
EXPERIMENTAL X = .4960
EXPERIMENTAL DEVIATION OF X = .7902

RECYCLE K-FACTOR = 39.8869
BRANCH K-FACTOR = 39.8819
RECYCLE FRICTION FACTOR = .02805
CRITICAL FLOWRATE = 0.0000 GPM

FLOWSPLIT 2

RECYCLE ORIFICE
1/2 INCH

BRANCH ORIFICE
5/8 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.2000	-0.0000	.6000	-0.0000	.6000	-0.0000
.4000	-0.0000	1.1000	-0.0000	1.2500	-0.0000
.6000	-0.0000	1.4500	-0.0000	1.6000	-0.0000
1.0000	-0.0000	2.6500	-0.0000	2.6500	-0.0000
2.0000	-0.0000	5.4500	-0.0000	5.1500	-0.0000
3.0000	-0.0000	7.8500	-0.0000	7.4500	-0.0000
4.0000	-0.0000	10.3500	-0.0000	9.7500	-0.0000
5.0000	-0.0000	12.5500	-0.0000	12.4500	-0.0000
6.0000	-0.0000	15.3500	-0.0000	14.7000	-0.0000
8.0000	-0.0000	20.2500	-0.0000	19.4500	-0.0000
10.0000	-0.0000	25.4500	-0.0000	23.9000	.1000
12.0000	-0.0000	30.3000	.1000	28.6000	.2000
14.0000	-0.0000	35.1000	.2000	33.6000	.3000
16.0000	.1000	40.0000	.2000	38.3000	.3000
18.0000	.1000	45.5000	.2000	43.7000	.2000
20.0000	.1000	50.3000	.2000	47.5000	.2000
22.0000	.1000	55.7000	.2000	53.1000	.2000
24.0000	.1000	60.4000	.2000	57.5000	.2000
26.0000	.1500	65.5000	.2000	62.3000	.3000
28.0000	.2000	70.1000	.3000	67.5000	.3000
TRIAL 2					
.2000	-0.0000	.6000	-0.0000	.6000	-0.0000
.6000	-0.0000	1.7000	-0.0000	1.6000	-0.0000
1.0000	-0.0000	2.6500	-0.0000	2.6500	-0.0000
2.0000	-0.0000	5.4000	-0.0000	5.3000	-0.0000
4.0000	-0.0000	9.9000	-0.0000	9.1000	-0.0000
7.0000	-0.0000	17.9000	-0.0000	16.4500	.1000
10.0000	-0.0000	25.5000	-0.0000	24.3000	.1000
13.0000	-0.0000	31.6000	.1000	31.7000	.1000
16.0000	.1000	39.9000	.2000	39.4000	.1000
20.0000	.1000	49.8000	.2000	48.5000	.2000
24.0000	.1000	60.7000	.2000	57.6000	.3000
28.0000	.2000	70.3000	.2000	66.7000	.3000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.2000	0.0000	.6000	0.0000	.6000	0.0000
.4000	-0.0000	1.1000	-0.0000	1.2500	-0.0000
.6000	0.0000	1.5750	0.0000	1.6000	0.0000
1.0000	0.0000	2.6500	0.0000	2.6500	0.0000
2.0000	0.0000	5.4250	0.0000	5.2250	0.0000
3.0000	-0.0000	7.8500	-0.0000	7.4500	-0.0000
4.0000	0.0000	10.1250	0.0000	9.4250	0.0000
5.0000	-0.0000	12.5500	-0.0000	12.4500	-0.0000
6.0000	-0.0000	15.3500	-0.0000	14.7000	-0.0000
7.0000	-0.0000	17.9000	-0.0000	16.4500	.1000
8.0000	-0.0000	20.2500	-0.0000	19.4500	-0.0000
10.0000	0.0000	25.4750	0.0000	24.1000	.1000
12.0000	-0.0000	30.3000	.1000	28.6000	.2000
13.0000	-0.0000	31.6000	.1000	31.7000	.1000
14.0000	-0.0000	35.1000	.2000	33.6000	.3000
16.0000	.1000	39.9500	.2000	38.8500	.2000
18.0000	.1000	45.5000	.2000	43.7000	.2000
20.0000	.1000	50.0500	.2000	48.0000	.2000
22.0000	.1000	55.7000	.2000	53.1000	.2000
24.0000	.1000	60.5500	.2000	57.5500	.2500
26.0000	.1500	65.5000	.2000	62.3000	.3000
28.0000	.2000	70.2000	.2500	67.1000	.3000

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
4.2465	0.0000	1.6001	0.0000	2.5780	0.0000
5.8803	0.0000	2.1603	0.0000	3.7177	0.0000
7.1136	0.0000	2.5805	0.0000	4.2048	0.0000
9.0421	0.0000	3.3389	0.0000	5.4082	0.0000
12.5208	0.0000	4.7609	0.0000	7.5878	0.0000
15.1470	0.0000	5.7168	0.0000	9.0566	0.0000
17.3379	0.0000	6.4846	0.0000	10.1837	0.0000
19.2533	0.0000	7.2121	0.0000	11.7005	0.0000
20.9744	0.0000	7.9685	0.0000	12.7114	0.0000
22.5490	0.0000	8.5986	0.0000	13.4449	.3050
24.0082	0.0000	9.1402	0.0000	14.6167	0.0000
26.6606	0.0000	10.2405	0.0000	16.2662	.2083
29.0438	0.0000	11.1590	.1677	17.7162	.3511
30.1562	0.0000	11.3936	.1609	18.6493	.1584
31.2242	0.0000	12.0019	.2898	19.1988	.4483
33.2448	.3400	12.7963	.2548	20.6407	.2585
35.1354	.3033	13.6478	.2238	21.8881	.2299
36.9176	.2738	14.3074	.2036	22.9371	.2093
38.6074	.2497	15.0856	.1830	24.1220	.1892
40.2176	.2295	15.7224	.1684	25.1100	.2183
41.7581	.3185	16.3462	.1558	26.1232	.2420
43.2369	.3952	16.9169	.1817	27.1084	.2247

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
4816	.04039	41.5084	7759	.03579	16.8719
6502	.03736	41.1108	11189	.03299	16.5025
7767	.03579	40.9036	12655	.03216	16.3940
10049	.03375	40.6363	16277	.03064	16.1940
14329	.03138	40.3246	22837	.02891	15.9667
17206	.03033	40.1864	27258	.02814	15.8650
19517	.02967	40.0994	30650	.02767	15.8034
21707	.02915	40.0308	35216	.02716	15.7361
23983	.02869	39.9703	38258	.02687	15.6986
25880	.02836	39.9265	40466	.02669	15.6744
27510	.02810	39.8928	43992	.02643	15.6400
30821	.02765	39.8334	48957	.02611	15.5986
33586	.02733	39.7912	53321	.02588	15.5676
34292	.02725	39.7813	56130	.02574	15.5499
36123	.02707	39.7572	57783	.02567	15.5401
38514	.02685	39.7285	62123	.02549	15.5166
41076	.02664	39.7009	65877	.02535	15.4984
43061	.02649	39.6814	69035	.02524	15.4844
45404	.02633	39.6603	72601	.02513	15.4698
47320	.02621	39.6443	75574	.02505	15.4586
49198	.02610	39.6296	78624	.02497	15.4479
50915	.02600	39.6170	81589	.02489	15.4381

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
.3893	.3830	1.6312	12575	4.1781	1.5516
.3856	.3675	4.6968	17691	5.8780	2.1829
.3877	.3803	1.8972	20422	6.7854	2.5198
.3870	.3817	1.3607	26326	8.7471	3.2483
.3862	.3855	.1767	37166	12.3487	4.5858
.3859	.3870	-.2840	44464	14.7735	5.4863
.3857	.3890	-.8747	50167	16.6684	6.1900
.3854	.3813	1.0443	56922	18.9127	7.0234
.3853	.3853	-.0170	62241	20.6799	7.6797
.3852	.3901	-1.2633	66345	22.0435	8.1861
.3850	.3847	.0797	71502	23.7569	8.8224
.3849	.3863	-.3710	79778	26.5067	9.8435
.3848	.3865	-.4305	86907	28.8752	10.7231
.3847	.3792	1.4169	90421	30.0429	11.1568
.3847	.3847	.0059	93906	31.2007	11.5867
.3846	.3827	.4933	100637	33.4370	12.4172
.3845	.3841	.1258	106953	35.5358	13.1966
.3845	.3841	.0895	112096	37.2445	13.8311
.3844	.3848	-.0829	118004	39.2075	14.5601
.3844	.3850	-.1669	122894	40.8323	15.1635
.3844	.3849	-.1371	127822	42.4694	15.7715
.3843	.3843	.0198	132505	44.0253	16.3493

AVERAGE RESULTS FOR FLOWSPLIT 2

THEORETICAL X = .3854
EXPERIMENTAL X = .3837
EXPERIMENTAL DEVIATION OF X = .4293

RECYCLE K-FACTOR = 39.8891
BRANCH K-FACTOR = 15.7164
RECYCLE FRICTION FACTOR = .02807
CRITICAL FLOWRATE = 0.0000 GPM

FLOWSPLIT 3

RECYCLE ORIFICE
1/2 INCH

BRANCH ORIFICE
3/8 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.2000	-0.0000	1.7000	-0.0000	1.8000	-0.0000
.4000	-0.0000	3.6500	-0.0000	3.7000	-0.0000
.6000	-0.0000	5.0500	-0.0000	5.1000	-0.0000
.8000	-0.0000	6.3500	-0.0000	6.4000	-0.0000
1.0000	-0.0000	7.5500	-0.0000	7.5500	.1000
1.5000	-0.0000	11.2000	-0.0000	11.3000	-0.0000
2.0000	-0.0000	15.2500	-0.0000	15.2500	-0.0000
2.5000	-0.0000	18.6500	-0.0000	18.7500	-0.0000
3.0000	-0.0000	22.1000	-0.0000	22.1000	.1000
4.0000	-0.0000	30.0500	-0.0000	29.5500	.1000
6.0000	-0.0000	44.5000	.1000	43.0000	.4000
8.0000	-0.0000	57.6000	.2000	53.5000	.4000
10.0000	-0.0000	73.5000	.1000	70.6000	.2000
12.0000	.1000	86.5000	.2000	83.6000	.4000
TRIAL 2					
.2000	-0.0000	1.7000	-0.0000	1.9000	-0.0000
.4000	-0.0000	3.4500	-0.0000	3.5500	-0.0000
.6000	-0.0000	4.9000	-0.0000	4.9500	-0.0000
.8000	-0.0000	6.4000	-0.0000	6.4500	-0.0000
1.0000	-0.0000	7.6500	-0.0000	7.7000	-0.0000
1.5000	-0.0000	11.7000	-0.0000	11.6500	-0.0000
2.0000	-0.0000	15.6000	-0.0000	15.4000	-0.0000
3.0000	-0.0000	22.5000	-0.0000	22.2500	-0.0000
4.0000	-0.0000	29.2000	.1000	27.9000	.1000
6.0000	-0.0000	43.6500	.1000	41.0000	.2000
8.0000	-0.0000	57.5000	.2000	54.0000	.4000
10.0000	-0.0000	73.2000	.3000	70.3000	.3000
12.0000	.1000	86.1000	.3000	80.9000	.4000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.2000	0.0000	1.7000	0.0000	1.8500	0.0000
.4000	0.0000	3.5500	0.0000	3.6250	0.0000
.6000	0.0000	4.9750	0.0000	5.0250	0.0000
.8000	0.0000	6.3750	0.0000	6.4250	0.0000
1.0000	0.0000	7.6000	0.0000	7.6250	.0500
1.5000	0.0000	11.4500	0.0000	11.4750	0.0000
2.0000	0.0000	15.4250	0.0000	15.3250	0.0000
2.5000	-0.0000	18.6500	-0.0000	18.7500	-0.0000
3.0000	0.0000	22.3000	0.0000	22.1750	.0500
4.0000	0.0000	29.6250	.0500	28.7250	.1000
6.0000	0.0000	44.0750	.1000	42.0000	.3000
8.0000	0.0000	57.5500	.2000	53.7500	.4000
10.0000	0.0000	73.3500	.2000	70.4500	.2500
12.0000	.1000	86.3000	.2500	82.2500	.4000

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
4.2465	0.0000	2.6800	0.0000	1.5524	0.0000
5.8803	0.0000	3.8591	0.0000	2.1654	0.0000
7.1136	0.0000	4.5611	0.0000	2.5450	0.0000
8.1425	0.0000	5.1570	0.0000	2.8741	0.0000
9.0421	0.0000	5.6259	0.0000	3.1281	.3314
10.9386	0.0000	6.8918	0.0000	3.8292	0.0000
12.5208	0.0000	7.9877	0.0000	4.4184	0.0000
13.9041	0.0000	8.7752	0.0000	4.8820	0.0000
15.1470	0.0000	9.5873	0.0000	5.3045	.1146
17.3379	0.0000	11.0352	.0858	6.0290	.1772
20.9744	0.0000	13.4344	.1155	7.2755	.3643
24.0082	0.0000	15.3317	.1772	8.2198	.3800
26.6606	0.0000	17.2886	.1392	9.3970	.1815
29.0438	.4494	18.7382	.1480	10.1452	.2489

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
8066	.03547	40.8620	4672	.04072	134.9074
11615	.03273	40.5016	6517	.03734	134.4633
13728	.03164	40.3591	7660	.03590	134.2744
15521	.03091	40.2625	8650	.03490	134.1426
16933	.03042	40.1980	9415	.03424	134.0558
20743	.02937	40.0596	11525	.03278	133.8639
24041	.02868	39.9689	13298	.03184	133.7405
26411	.02827	39.9151	14694	.03123	133.6600
28855	.02791	39.8673	15965	.03075	133.5965
33213	.02737	39.7965	18146	.03005	133.5043
40434	.02669	39.7076	21897	.02911	133.3807
46144	.02628	39.6540	24739	.02855	133.3075
52034	.02594	39.6091	28283	.02799	133.2332
56397	.02573	39.5811	30534	.02768	133.1934

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
.6450	.6332	1.8309	12738	4.2324	1.5718
.6457	.6406	.7867	18132	6.0245	2.2373
.6464	.6419	.6984	21388	7.1061	2.6389
.6461	.6421	.6077	24171	8.0310	2.9824
.6462	.6427	.5417	26347	8.7541	3.2509
.6464	.6428	.5505	32267	10.7210	3.9814
.6465	.6439	.4164	37339	12.4061	4.6071
.6466	.6425	.6342	41104	13.6572	5.0717
.6467	.6438	.4512	44820	14.8918	5.5302
.6468	.6467	.0236	51359	17.0642	6.3370
.6470	.6487	-.2634	62331	20.7099	7.6909
.6471	.6510	-.6033	70884	23.5515	8.7461
.6471	.6479	-.1106	80317	26.6857	9.9100
.6472	.6488	-.2409	86931	28.8834	10.7262

AVERAGE RESULTS FOR FLOWSPLIT 3

THEORETICAL X = .6465
EXPERIMENTAL X = .6440
EXPERIMENTAL DEVIATION OF X = .3797

RECYCLE K-FACTOR = 39.9600
BRANCH K-FACTOR =133.4978
RECYCLE FRICTION FACTOR = .02861
CRITICAL FLOWRATE = 0.0000 GPM

FLOWSPLIT 4

RECYCLE ORIFICE
5/8 INCH

BRANCH ORIFICE
3/8 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.2000	-0.0000	1.6000	-0.0000	.1000	-0.0000
.4000	-0.0000	3.0000	-0.0000	.1000	-0.0000
.6000	-0.0000	3.6500	-0.0000	.7500	-0.0000
.8000	-0.0000	4.3500	-0.0000	1.3000	-0.0000
1.0000	-0.0000	4.4000	-0.0000	3.0000	-0.0000
1.5000	-0.0000	5.9000	-0.0000	5.8500	-0.0000
2.0000	-0.0000	7.9000	-0.0000	8.0000	-0.0000
2.5000	-0.0000	9.5000	-0.0000	9.6000	-0.0000
3.0000	-0.0000	11.4000	-0.0000	11.4000	-0.0000
4.0000	-0.0000	14.6000	-0.0000	14.5000	.1000
5.0000	-0.0000	18.1000	-0.0000	18.0000	.1000
6.0000	-0.0000	21.5000	.1000	21.9000	.2000
8.0000	-0.0000	28.7500	.1000	28.4000	.2000
10.0000	-0.0000	36.4000	.1000	34.8000	.3000
12.0000	-0.0000	43.8000	.1000	43.0000	.2000
14.0000	.1000	50.6000	.2000	48.2000	.4000
16.0000	.1000	58.4000	.3000	57.4000	.3000
18.0000	.2000	65.6000	.3000	64.6000	.4000
20.0000	.2000	72.5000	.3000	72.0000	.4000
22.0000	.2000	80.0000	.4000	79.0000	.4000
24.0000	.3000	87.0000	.4000	86.0000	.4000
TRIAL 2					
.2000	-0.0000	.8500	-0.0000	.8500	-0.0000
.4000	-0.0000	1.8000	-0.0000	1.8000	-0.0000
.6000	-0.0000	2.5000	-0.0000	2.5000	-0.0000
.8000	-0.0000	3.3000	-0.0000	3.3000	-0.0000
1.0000	-0.0000	3.8500	-0.0000	3.7500	-0.0000
1.5000	-0.0000	5.7000	-0.0000	5.7000	-0.0000
2.0000	-0.0000	7.9000	-0.0000	7.8000	-0.0000
2.5000	-0.0000	9.6000	-0.0000	9.4000	-0.0000
3.0000	-0.0000	11.2000	-0.0000	11.1500	-0.0000
4.0000	-0.0000	14.4000	-0.0000	14.3000	-0.0000
5.0000	-0.0000	18.2000	-0.0000	17.9000	.1000
6.0000	-0.0000	21.9500	-0.0000	21.2000	.1000
8.0000	-0.0000	29.2000	-0.0000	27.6000	.2000
10.0000	-0.0000	36.3000	.1000	36.2000	.1000
12.0000	-0.0000	43.3000	.1000	42.8000	.2000
14.0000	.1000	49.9000	.2000	49.2000	.2000
16.0000	.1000	57.8000	.2000	56.6000	.2000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.2000	0.0000	1.2250	0.0000	.4750	0.0000
.4000	0.0000	2.4000	0.0000	.9500	0.0000
.6000	0.0000	3.0750	0.0000	1.6250	0.0000
.8000	0.0000	3.8250	0.0000	2.3000	0.0000
1.0000	0.0000	4.1250	0.0000	3.3750	0.0000
1.5000	0.0000	5.8000	0.0000	5.7750	0.0000
2.0000	0.0000	7.9000	0.0000	7.9000	0.0000
2.5000	0.0000	9.5500	0.0000	9.5000	0.0000
3.0000	0.0000	11.3000	0.0000	11.2750	0.0000
4.0000	0.0000	14.5000	0.0000	14.4000	.0500
5.0000	0.0000	18.1500	0.0000	17.9500	.1000
6.0000	0.0000	21.7250	.0500	21.5500	.1500
8.0000	0.0000	28.9750	.0500	28.0000	.2000
10.0000	0.0000	36.3500	.1000	35.5000	.2000
12.0000	0.0000	43.5500	.1000	42.9000	.2000
14.0000	.1000	50.2500	.2000	48.7000	.3000
16.0000	.1000	58.1000	.2500	57.0000	.2500
18.0000	.2000	65.6000	.3000	64.6000	.4000
20.0000	.2000	72.5000	.3000	72.0000	.4000
22.0000	.2000	80.0000	.4000	79.0000	.4000
24.0000	.3000	87.0000	.4000	86.0000	.4000

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
4.2465	0.0000	3.6804	0.0000	.7923	0.0000
5.8803	0.0000	5.1474	0.0000	1.1164	0.0000
7.1136	0.0000	5.8247	0.0000	1.4560	0.0000
8.1425	0.0000	6.4946	0.0000	1.7290	0.0000
9.0421	0.0000	6.7439	0.0000	2.0902	0.0000
10.9386	0.0000	7.9934	0.0000	2.7264	0.0000
12.5208	0.0000	9.3255	0.0000	3.1835	0.0000
13.9041	0.0000	10.2509	0.0000	3.4876	0.0000
15.1470	0.0000	11.1484	0.0000	3.7960	0.0000
17.3379	0.0000	12.6248	0.0000	4.2844	.1761
19.2533	0.0000	14.1209	0.0000	4.7778	.2828
20.9744	0.0000	15.4458	.1155	5.2300	.3537
24.0082	0.0000	17.8317	.0866	5.9532	.3635
26.6606	0.0000	19.9671	.1381	6.6949	.2871
29.0438	0.0000	21.8506	.1153	7.3522	.2378
31.2242	.3870	23.4672	.1999	7.8282	.3144
33.2448	.3400	25.2294	.2162	8.4620	.2240
35.1354	.6066	26.8045	.2298	9.0025	.3165
36.9176	.5477	28.1755	.2080	9.4987	.2841
38.6074	.4993	29.5935	.2513	9.9449	.2591
[illegible]0.2176	.6884	30.8580	.2311	10.3715	.2381

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
11077	.03306	16.5117	2385	.03246	133.8219
15492	.03092	16.2311	3360	.04441	135.3928
17531	.03023	16.1403	4382	.04144	135.0023
19547	.02966	16.0656	5204	.03956	134.7550
20297	.02947	16.0408	6291	.03767	134.5068
24058	.02867	15.9356	8206	.03533	134.1987
28067	.02802	15.8492	9581	.03411	134.0383
30852	.02764	15.8000	10497	.03344	133.9499
33554	.02733	15.7588	11425	.03284	133.8717
37997	.02690	15.7017	12895	.03204	133.7662
42500	.02653	15.6540	14380	.03136	133.6771
46488	.02626	15.6183	15741	.03083	133.6071
53669	.02586	15.5654	17918	.03011	133.5131
60096	.02557	15.5272	20150	.02951	133.4337
65764	.02535	15.4989	22128	.02906	133.3742
70630	.02519	15.4777	23561	.02877	133.3361
75934	.02504	15.4573	25468	.02842	133.2909
80674	.02491	15.4410	27095	.02816	133.2564
84801	.02482	15.4282	28589	.02794	133.2275
89069	.02472	15.4159	29931	.02776	133.2036
92874	.02465	15.4059	31215	.02760	133.1823

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
.7400	.8229	-11.1894	13462	4.4727	1.6610
.7428	.8218	-10.6295	18852	6.2638	2.3261
.7431	.8000	-7.6645	21913	7.2807	2.7037
.7444	.7898	-6.0946	24751	8.2236	3.0539
.7433	.7634	-2.7024	26588	8.8340	3.2806
.7437	.7457	-.2626	32264	10.7198	3.9809
.7441	.7455	-.1859	37649	12.5090	4.6453
.7444	.7461	-.2405	41349	13.7384	5.1019
.7445	.7460	-.1939	44979	14.9443	5.5497
.7448	.7466	-.2427	50892	16.9092	6.2794
.7450	.7472	-.2879	56880	18.8987	7.0182
.7452	.7470	-.2466	62229	20.6758	7.6782
.7455	.7497	-.5687	71586	23.7849	8.8328
.7456	.7489	-.4367	80245	26.6620	9.9012
.7458	.7482	-.3301	87893	29.2028	10.8448
.7459	.7499	-.5342	94191	31.2955	11.6219
.7460	.7488	-.3845	101402	33.6914	12.5117
.7460	.7486	-.3401	107770	35.8070	13.2973
.7461	.7479	-.2372	113390	37.6743	13.9907
.7462	.7485	-.3102	119000	39.5384	14.6830
.7462	.7484	-.2999	124090	41.2294	15.3110

AVERAGE RESULTS FOR FLOWSPLIT 4

THEORETICAL X = .7447
EXPERIMENTAL X = .7600
EXPERIMENTAL DEVIATION OF X = -2.0603

RECYCLE K-FACTOR = 15.7393
BRANCH K-FACTOR =133.4778
RECYCLE FRICTION FACTOR = .02718
CRITICAL FLOWRATE = 0.0000 GPM

FLOWSPLIT 5

RECYCLE ORIFICE
5/8 INCH

BRANCH ORIFICE
3/8 INCH

TRIAL 1

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.2000	-0.0000	.9500	-0.0000	0.0000	-0.0000
.6000	-0.0000	4.7000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	6.8500	-0.0000	0.0000	-0.0000
1.5000	-0.0000	10.3500	-0.0000	0.0000	-0.0000
2.0000	-0.0000	13.5000	-0.0000	0.0000	-0.0000
3.0000	-0.0000	19.7000	-0.0000	0.0000	-0.0000
3.3500	-0.0000	21.2000	-0.0000	.0500	-0.0000
4.0000	-0.0000	22.2500	-0.0000	1.3500	-0.0000
5.0000	-0.0000	24.8000	-0.0000	4.2000	-0.0000
6.0000	-0.0000	28.5500	-0.0000	7.0000	-0.0000
8.0000	-0.0000	35.5000	-0.0000	14.4000	-0.0000
10.0000	-0.0000	42.0000	.1000	21.7000	.1000
12.0000	-0.0000	48.8000	.1500	28.8000	.1500
14.0000	.1000	56.0000	.1500	35.6000	.1500
16.0000	.1000	63.2000	.1500	42.6000	.2000
18.0000	.1500	70.9000	.2000	50.4000	.2500
20.0000	.2000	77.5000	.2500	56.8000	.3000
22.0000	.2000	85.6000	.3000	64.6000	.4000

TRIAL 2

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.8000	-0.0000	5.9000	-0.0000	0.0000	-0.0000
1.2000	-0.0000	8.3500	-0.0000	0.0000	-0.0000
1.5000	-0.0000	10.7000	-0.0000	0.0000	-0.0000
2.0000	-0.0000	14.3500	-0.0000	0.0000	-0.0000
2.5000	-0.0000	17.3000	-0.0000	0.0000	-0.0000
3.0000	-0.0000	20.3000	-0.0000	0.0000	-0.0000
3.3000	-0.0000	22.0000	-0.0000	.0500	-0.0000
3.5000	-0.0000	22.2500	-0.0000	.1500	-0.0000
4.0000	-0.0000	22.9000	-0.0000	.9500	-0.0000
5.0000	-0.0000	25.7500	-0.0000	3.5500	-0.0000
6.0000	-0.0000	29.2000	-0.0000	6.4000	-0.0000
8.0000	-0.0000	36.2500	-0.0000	12.2000	-0.0000
10.0000	-0.0000	41.3000	-0.0000	22.5000	-0.0000
12.0000	-0.0000	48.5000	.1000	29.0000	.1000
14.0000	.1000	55.2000	.1500	37.8000	.1500
16.0000	.1000	63.2000	.1500	51.8000	.1500
18.0000	.1500	70.4000	.2000	49.9000	.2500
20.0000	.2000	77.5000	.2000	56.8000	.3000
22.0000	.2000	85.1000	.3000	64.8000	.3000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.2000	-0.0000	.9500	-0.0000	0.0000	-0.0000
.6000	-0.0000	4.7000	-0.0000	0.0000	-0.0000
.8000	-0.0000	5.9000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	6.8500	-0.0000	0.0000	-0.0000
1.2000	-0.0000	8.3500	-0.0000	0.0000	-0.0000
1.5000	0.0000	10.5250	0.0000	0.0000	0.0000
2.0000	0.0000	13.9250	0.0000	0.0000	0.0000
2.5000	-0.0000	17.3000	-0.0000	0.0000	-0.0000
3.0000	0.0000	20.0000	0.0000	0.0000	0.0000
3.3000	-0.0000	22.0000	-0.0000	.0500	-0.0000
3.3500	-0.0000	21.2000	-0.0000	.0500	-0.0000
3.5000	-0.0000	22.2500	-0.0000	.1500	-0.0000
4.0000	0.0000	22.5750	0.0000	1.1500	0.0000
5.0000	0.0000	25.2750	0.0000	3.8750	0.0000
6.0000	0.0000	28.8750	0.0000	6.7000	0.0000
8.0000	0.0000	35.8750	0.0000	13.3000	0.0000
10.0000	0.0000	41.6500	.0500	22.1000	.0500
12.0000	0.0000	48.6500	.1250	28.9000	.1250
14.0000	.1000	55.6000	.1500	36.7000	.1500
16.0000	.1000	63.2000	.1500	47.2000	.1750
18.0000	.1500	70.6500	.2000	50.1500	.2500
20.0000	.2000	77.5000	.2250	56.8000	.3000
22.0000	.2000	85.3500	.3000	64.7000	.3500

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
4.2465	0.0000	3.2421	0.0000	0.0000	0.0000
7.1136	0.0000	7.1974	0.0000	0.0000	0.0000
8.1425	0.0000	8.0619	0.0000	0.0000	0.0000
9.0421	0.0000	8.6852	0.0000	0.0000	0.0000
9.8504	0.0000	9.5868	0.0000	0.0000	0.0000
10.9386	0.0000	10.7602	0.0000	0.0000	0.0000
12.5208	0.0000	12.3726	0.0000	0.0000	0.0000
13.9041	0.0000	13.7871	0.0000	0.0000	0.0000
15.1470	0.0000	14.8214	0.0000	0.0000	0.0000
15.8403	0.0000	15.5430	0.0000	0.0000	0.0000
15.9526	0.0000	15.2585	0.0000	.2602	0.0000
16.2841	0.0000	15.6309	0.0000	.2602	0.0000
17.3379	0.0000	15.7444	0.0000	.4480	0.0000
19.2533	0.0000	16.6570	0.0000	1.2271	0.0000
20.9744	0.0000	17.8010	0.0000	2.2380	0.0000
24.0082	0.0000	19.8365	0.0000	2.9343	0.0000
26.6606	0.0000	21.3697	0.0000	4.1192	0.0000
29.0438	0.0000	23.0915	.0603	5.2956	.1150
31.2242	.3870	24.6819	.1291	6.0471	.2202
33.2448	.3400	26.3107	.1355	6.8059	.2083
35.1354	.4549	27.8146	.1193	7.7080	.1892
36.9176	.5477	29.1286	.1423	7.9427	.2545
38.6074	.4993	30.5647	.1459	8.4473	.2698
			.1767	9.0094	.2765

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
9758	.03397	16.6321	0	0.00000	0.0000
21662	.02916	15.9993	0	0.00000	0.0000
24264	.02864	15.9306	0	0.00000	0.0000
26140	.02831	15.8881	0	0.00000	0.0000
28854	.02791	15.8345	0	0.00000	0.0000
32385	.02746	15.7760	0	0.00000	0.0000
37238	.02696	15.7106	0	0.00000	0.0000
41496	.02661	15.6639	0	0.00000	0.0000
44608	.02638	15.6344	0	0.00000	0.0000
46780	.02624	15.6158	0	0.00000	0.0000
45924	.02630	15.6230	783	.08174	147.6627
47045	.02623	15.6137	783	.08174	147.6627
47386	.02621	15.6109	1348	.04747	140.0697
50133	.02604	15.5898	3693	.04344	139.1776
53576	.02586	15.5660	6736	.03704	137.7588
59703	.02558	15.5293	8831	.03474	137.2493
64317	.02541	15.5057	12398	.03229	136.7080
69499	.02523	15.4824	15938	.03076	136.3678
74286	.02508	15.4634	18200	.03003	136.2067
79188	.02495	15.4460	20484	.02943	136.0733
83715	.02484	15.4314	23199	.02884	135.9425
87669	.02475	15.4198	23905	.02870	135.9124
91992	.02466	15.4081	25424	.02843	135.8523
			27116	.02816	135.7918

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
1.0000	1.0000	0.0000	9758	3.2421	1.2040
1.0000	1.0000	0.0000	21662	7.1974	2.6728
1.0000	1.0000	0.0000	24264	8.0619	2.9939
1.0000	1.0000	0.0000	26140	8.6852	3.2253
1.0000	1.0000	0.0000	28854	9.5868	3.5602
1.0000	1.0000	0.0000	32385	10.7602	3.9959
1.0000	1.0000	0.0000	37238	12.3726	4.5947
1.0000	1.0000	0.0000	41496	13.7871	5.1200
.9723	1.0000	-2.8479	44608	14.8214	5.5041
.9344	.9835	-5.2535	47563	15.8032	5.8687
.9445	.9832	-4.1010	46707	15.5186	5.7630
.9248	.9721	-5.1244	48393	16.0789	5.9711
.9004	.9277	-3.0371	51080	16.9714	6.3025
.8641	.8816	-2.0234	56869	18.8950	7.0169
.8412	.8585	-2.0584	62408	20.7353	7.7003
.8153	.8280	-1.5655	72100	23.9557	8.8962
.8012	.8014	-.0218	80256	26.6653	9.9025
.7921	.7925	-.0510	87700	29.1386	10.8209
.7854	.7839	.2008	94770	31.4878	11.6933
.7799	.7734	.8255	102387	34.0187	12.6332
.7768	.7779	-.1399	107620	35.7573	13.2788
.7740	.7752	-.1530	113093	37.5759	13.9542
.7714	.7723	-.1208	119108	39.5741	14.6963

AVERAGE RESULTS FOR FLOWSPLIT 5

RECYCLE K-FACTOR = 15.6247
BRANCH K-FACTOR =136.1069
RECYCLE FRICTION FACTOR = .02631
CRITICAL FLOWRATE = 14.4155 GPM

FLOWSPLIT 6

RECYCLE ORIFICE
1/2 INCH

BRANCH ORIFICE
3/8 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.2000	-0.0000	5.0000	-0.0000	0.0000	-0.0000
.4000	-0.0000	8.7500	-0.0000	0.0000	-0.0000
.6000	-0.0000	11.9000	-0.0000	0.0000	-0.0000
.8000	-0.0000	15.6000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	18.9000	-0.0000	0.0000	-0.0000
1.2500	-0.0000	22.5500	-0.0000	0.0000	-0.0000
1.5000	-0.0000	23.1500	-0.0000	.0500	-0.0000
2.0000	-0.0000	26.0000	-0.0000	.6000	-0.0000
3.0000	-0.0000	32.4000	-0.0000	3.0000	-0.0000
4.0000	-0.0000	36.8000	-0.0000	8.3500	-0.0000
6.0000	-0.0000	51.5000	-0.0000	17.1000	-0.0000
8.0000	-0.0000	66.6000	.1500	30.4000	.1500
10.0000	-0.0000	81.2000	.1500	44.3500	.1500
			.2000	58.0000	.1500
TRIAL 2					
.2000	-0.0000	4.3000	-0.0000	0.0000	-0.0000
.4000	-0.0000	8.8000	-0.0000	0.0000	-0.0000
.6000	-0.0000	12.5000	-0.0000	0.0000	-0.0000
.8500	-0.0000	17.4000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	19.9000	-0.0000	0.0000	-0.0000
1.2500	-0.0000	22.9500	-0.0000	.0500	-0.0000
1.5000	-0.0000	23.8000	-0.0000	.7000	-0.0000
2.0000	-0.0000	26.3500	-0.0000	2.0500	-0.0000
2.5000	-0.0000	30.0000	-0.0000	5.8500	-0.0000
3.0000	-0.0000	32.8000	-0.0000	8.5500	-0.0000
4.0000	-0.0000	37.5500	-0.0000	17.8500	-0.0000
6.0000	-0.0000	51.8000	-0.0000	30.7000	.1000
8.0000	-0.0000	66.8000	.1000	44.3000	.1500
10.0000	-0.0000	80.8000	.1500	57.1000	.2000
11.0000	-0.0000	88.4000	.2000	64.1000	.2000
			.2000		

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.2000	0.0000	4.6500	0.0000	0.0000	0.0000
.4000	0.0000	8.7750	0.0000	0.0000	0.0000
.6000	0.0000	12.2000	0.0000	0.0000	0.0000
.8000	-0.0000	15.6000	-0.0000	0.0000	-0.0000
.8500	-0.0000	17.4000	-0.0000	0.0000	-0.0000
1.0000	0.0000	19.4000	0.0000	0.0000	0.0000
1.2500	0.0000	22.7500	0.0000	.0500	0.0000
1.5000	0.0000	23.4750	0.0000	.6500	0.0000
2.0000	0.0000	26.1750	0.0000	2.5250	0.0000
2.5000	-0.0000	30.0000	-0.0000	5.8500	-0.0000
3.0000	0.0000	32.6000	0.0000	8.4500	0.0000
4.0000	0.0000	37.1750	0.0000	17.4750	0.0000
6.0000	0.0000	51.6500	.1250	30.5500	.1250
8.0000	0.0000	66.7000	.1500	44.3250	.1500
10.0000	0.0000	81.0000	.2000	57.5500	.1750
11.0000	-0.0000	88.4000	.2000	64.1000	.2000

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
4.2465	0.0000	4.4110	0.0000	0.0000	0.0000
5.8803	0.0000	6.0410	0.0000	0.0000	0.0000
7.1136	0.0000	7.1118	0.0000	0.0000	0.0000
8.1425	0.0000	8.0325	0.0000	0.0000	0.0000
8.3777	0.0000	8.4788	0.0000	0.0000	0.0000
9.0421	0.0000	8.9482	0.0000	0.0000	0.0000
10.0410	0.0000	9.6826	0.0000	.2602	0.0000
10.9386	0.0000	9.8342	0.0000	.9253	0.0000
12.5208	0.0000	10.3789	0.0000	1.8107	0.0000
13.9041	0.0000	11.1041	0.0000	2.7438	0.0000
15.1470	0.0000	11.5707	0.0000	3.2912	0.0000
17.3379	0.0000	12.3482	0.0000	4.7148	0.0000
20.9744	0.0000	14.5321	.1233	6.2155	.2083
24.0082	0.0000	16.4938	.1147	7.4721	.1726
26.6606	0.0000	18.1592	.1261	8.5023	.1553
27.8809	0.0000	18.9626	.1156	8.9680	.1595

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
13276	.03185	40.3865	0	0.00000	0.0000
18182	.03004	40.1476	0	0.00000	0.0000
21405	.02922	40.0396	0	0.00000	0.0000
24176	.02865	39.9656	0	0.00000	0.0000
25519	.02842	39.9344	0	0.00000	0.0000
26932	.02819	39.9044	0	0.00000	0.0000
29142	.02787	39.8621	783	.08174	147.6627
29598	.02780	39.8541	2785	.04166	138.7832
31238	.02760	39.8266	5450	.03908	138.2119
33421	.02734	39.7935	8258	.03528	137.3687
34825	.02720	39.7741	9906	.03386	137.0548
37165	.02697	39.7443	14190	.03144	136.5192
43738	.02644	39.6751	18707	.02989	136.1749
49642	.02607	39.6263	22489	.02898	135.9743
54654	.02581	39.5918	25590	.02840	135.8461
57072	.02570	39.5771	26991	.02818	135.7961

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
1.0000	1.0000	0.0000	13276	4.4110	1.6381
1.0000	1.0000	0.0000	18182	6.0410	2.2434
1.0000	1.0000	0.0000	21405	7.1118	2.6410
1.0000	1.0000	0.0000	24176	8.0325	2.9829
1.0000	1.0000	0.0000	25519	8.4788	3.1487
1.0000	1.0000	0.0000	26932	8.9482	3.3230
.9205	.9738	-5.7926	29925	9.9427	3.6923
.8722	.9140	-4.7978	32383	10.7595	3.9957
.8161	.8515	-4.3315	36687	12.1896	4.5267
.7749	.8019	-3.4823	41679	13.8480	5.1426
.7570	.7785	-2.8457	44731	14.8620	5.5191
.7294	.7237	.7879	51355	17.0630	6.3365
.7026	.7004	.3117	62445	20.7476	7.7048
.6890	.6882	.1059	72131	23.9659	8.9000
.6812	.6811	.0169	80244	26.6615	9.9010
.6783	.6789	-.0842	84064	27.9306	10.3723

AVERAGE RESULTS FOR FLOWSPLIT 6

RECYCLE K-FACTOR = 39.8564
BRANCH K-FACTOR =136.0621
RECYCLE FRICTION FACTOR = .02782
CRITICAL FLOWRATE = 9.0258 GPM

FLOWSPLIT 7

RECYCLE ORIFICE
1/2 INCH

BRANCH ORIFICE
1/2 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.2000	-0.0000	5.0000	-0.0000	0.0000	-0.0000
.4000	-0.0000	9.1000	-0.0000	0.0000	-0.0000
.6000	-0.0000	12.4500	-0.0000	0.0000	-0.0000
.8000	-0.0000	16.2000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	18.9000	-0.0000	0.0000	-0.0000
1.2500	-0.0000	22.5500	-0.0000	.0500	-0.0000
1.5000	-0.0000	22.9500	.1000	.3500	-0.0000
2.0000	-0.0000	24.1000	-0.0000	1.4000	-0.0000
3.0000	-0.0000	27.6000	-0.0000	4.3000	-0.0000
4.0000	-0.0000	28.9000	-0.0000	9.0500	-0.0000
5.0000	-0.0000	33.3000	-0.0000	13.1000	-0.0000
6.0000	-0.0000	37.3000	-0.0000	17.2000	-0.0000
8.0000	-0.0000	46.0000	.1000	25.8000	.1000
10.0000	.1000	54.0000	.1500	33.3000	.1500
12.0000	.1000	63.2000	.1500	41.7000	.1500
14.0000	.1500	71.8000	.2000	49.8000	.2000
16.0000	.2000	80.6000	.3000	58.0000	.3000
17.8000	.2000	89.0000	.3000	66.1000	.3000
TRIAL 2					
.5000	-0.0000	10.6000	-0.0000	0.0000	-0.0000
.7000	-0.0000	13.9000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	18.7000	-0.0000	0.0000	-0.0000
1.2000	-0.0000	22.5000	-0.0000	.0500	-0.0000
1.5000	-0.0000	22.9000	-0.0000	.4000	-0.0000
2.0000	-0.0000	23.9500	-0.0000	1.4000	-0.0000
3.0000	-0.0000	27.4000	-0.0000	4.1500	-0.0000
4.0000	-0.0000	29.3000	-0.0000	9.2000	-0.0000
6.0000	-0.0000	37.6500	-0.0000	17.0500	-0.0000
8.0000	-0.0000	45.6000	.1000	25.8000	.1000
10.0000	-0.0000	54.2500	.1000	33.6000	.1000
12.0000	.1000	62.5500	.1000	41.6500	.1000
14.0000	.1500	71.7000	.2000	50.5000	.1500
16.0000	.2000	80.8000	.3000	57.8000	.2500
17.8000	.2000	88.8000	.3000	65.6000	.3000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.2000	-0.0000	5.0000	-0.0000	0.0000	-0.0000
.4000	-0.0000	9.1000	-0.0000	0.0000	-0.0000
.5000	-0.0000	10.6000	-0.0000	0.0000	-0.0000
.6000	-0.0000	12.4500	-0.0000	0.0000	-0.0000
.7000	-0.0000	13.9000	-0.0000	0.0000	-0.0000
.8000	-0.0000	16.2000	-0.0000	0.0000	-0.0000
1.0000	0.0000	18.8000	0.0000	0.0000	0.0000
1.2000	-0.0000	22.5000	-0.0000	.0500	-0.0000
1.2500	-0.0000	22.5500	-0.0000	.0500	-0.0000
1.5000	0.0000	22.9250	.0500	.3750	0.0000
2.0000	0.0000	24.0250	0.0000	1.4000	0.0000
3.0000	0.0000	27.5000	0.0000	4.2250	0.0000
4.0000	0.0000	29.1000	0.0000	9.1250	0.0000
5.0000	-0.0000	33.3000	-0.0000	13.1000	-0.0000
6.0000	0.0000	37.4750	0.0000	17.1250	0.0000
8.0000	0.0000	45.8000	.1000	25.8000	.1000
10.0000	.0500	54.1250	.1250	33.4500	.1250
12.0000	.1000	62.8750	.1250	41.6750	.1250
14.0000	.1500	71.7500	.2000	50.1500	.1750
16.0000	.2000	80.7000	.3000	57.9000	.2750
17.8000	.2000	88.9000	.3000	65.8500	.3000

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
4.2465	0.0000	4.5724	0.0000	0.0000	0.0000
5.8803	0.0000	6.1508	0.0000	0.0000	0.0000
6.5299	0.0000	6.6336	0.0000	0.0000	0.0000
7.1136	0.0000	7.1836	0.0000	0.0000	0.0000
7.6476	0.0000	7.5864	0.0000	0.0000	0.0000
8.1425	0.0000	8.1840	0.0000	0.0000	0.0000
9.0421	0.0000	8.8100	0.0000	0.0000	0.0000
9.8504	0.0000	9.6298	0.0000	.4675	0.0000
10.0410	0.0000	9.6404	0.0000	.4675	0.0000
10.9386	0.0000	9.7194	.1107	1.2679	0.0000
12.5208	0.0000	9.9476	0.0000	2.4343	0.0000
15.1470	0.0000	10.6359	0.0000	4.2065	0.0000
17.3379	0.0000	10.9379	0.0000	6.1592	0.0000
19.2533	0.0000	11.6931	0.0000	7.3669	0.0000
20.9744	0.0000	12.3974	0.0000	8.4122	0.0000
24.0082	0.0000	13.6923	.1112	10.3050	.1968
26.6606	.2681	14.8728	.1177	11.7191	.1900
29.0438	.4494	16.0185	.1014	13.0670	.1527
31.2242	.5805	17.1009	.1423	14.3215	.1778
33.2448	.6800	18.1259	.1898	15.3778	.2422
34.9516	.6132	19.0156	.1724	16.3894	.2324

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
13762	.03163	40.3570	0	0.00000	0.0000
18512	.02994	40.1351	0	0.00000	0.0000
19965	.02956	40.0844	0	0.00000	0.0000
21621	.02917	40.0333	0	0.00000	0.0000
22833	.02891	39.9997	0	0.00000	0.0000
24632	.02857	39.9547	0	0.00000	0.0000
26516	.02825	39.9129	0	0.00000	0.0000
28983	.02789	39.8650	1407	.04549	46.2761
29015	.02788	39.8644	1407	.04549	46.2761
29253	.02785	39.8602	3816	.04306	45.7375
29940	.02776	39.8481	7327	.03629	44.2374
32011	.02750	39.8145	12661	.03216	43.3225
32920	.02740	39.8008	18537	.02994	42.8301
35193	.02716	39.7692	22173	.02905	42.6336
37313	.02696	39.7425	25318	.02845	42.5010
41210	.02663	39.6996	31015	.02762	42.3179
44763	.02637	39.6659	35272	.02715	42.2133
48211	.02616	39.6372	39328	.02678	42.1313
51469	.02597	39.6131	43104	.02649	42.0665
54554	.02582	39.5925	46283	.02627	42.0190
57232	.02569	39.5761	49328	.02609	41.9782

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
1.0000	1.0000	0.0000	13762	4.5724	1.6980
1.0000	1.0000	0.0000	18512	6.1508	2.2842
1.0000	1.0000	0.0000	19965	6.6336	2.4634
1.0000	1.0000	0.0000	21621	7.1836	2.6677
1.0000	1.0000	0.0000	22833	7.5864	2.8173
1.0000	1.0000	0.0000	24632	8.1840	3.0392
1.0000	1.0000	0.0000	26516	8.8100	3.2717
.9002	.9537	-5.9397	30390	10.0972	3.7497
.8994	.9538	-6.0414	30422	10.1078	3.7536
.8393	.8846	-5.4000	33069	10.9873	4.0802
.7687	.8034	-4.5159	37266	12.3819	4.5982
.6893	.7166	-3.9518	44672	14.8424	5.5119
.6444	.6398	.7141	51458	17.0971	6.3492
.6176	.6135	.6714	57366	19.0600	7.0781
.5999	.5958	.6888	62631	20.8096	7.7279
.5769	.5706	1.0987	72225	23.9973	8.9116
.5640	.5593	.8309	80035	26.5920	9.8752
.5547	.5507	.7064	87540	29.0855	10.8012
.5478	.5442	.6595	94573	31.4224	11.6690
.5429	.5410	.3535	100837	33.5036	12.4419
.5392	.5371	.3860	106560	35.4051	13.1480

AVERAGE RESULTS FOR FLOWSPLIT 7

RECYCLE K-FACTOR = 39.8489
BRANCH K-FACTOR = 42.4013
RECYCLE FRICTION FACTOR = .02777
CRITICAL FLOWRATE = 9.0267 GPM

FLOWSPLIT 8

RECYCLE ORIFICE
5/8 INCH

BRANCH ORIFICE
1/2 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.8000	-0.0000	5.9000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	6.9500	-0.0000	0.0000	-0.0000
1.5000	-0.0000	10.7000	-0.0000	0.0000	-0.0000
2.0000	-0.0000	14.0000	-0.0000	0.0000	-0.0000
3.0000	-0.0000	20.1000	-0.0000	0.0000	-0.0000
3.3000	-0.0000	21.7500	-0.0000	.0500	-0.0000
4.0000	-0.0000	22.2000	-0.0000	.4500	-0.0000
5.0000	-0.0000	24.4000	-0.0000	1.8000	-0.0000
6.0000	-0.0000	24.8000	.1000	4.0000	-0.0000
8.0000	-0.0000	28.4000	.1000	9.7500	-0.0000
10.0000	-0.0000	33.8000	.1000	13.7000	.1000
12.0000	-0.0000	38.5000	.1000	18.4000	.1000
15.0000	-0.0000	45.4000	.1000	25.6000	.1000
18.0000	.1000	53.0000	.2000	32.6000	.2000
21.0000	.2000	60.0000	.4000	40.8000	.3000
24.0000	.3000	67.5000	.5000	48.0000	.4000
TRIAL 2					
.8000	-0.0000	5.8000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	6.9000	-0.0000	0.0000	-0.0000
1.5000	-0.0000	10.5000	-0.0000	0.0000	-0.0000
2.0000	-0.0000	13.9000	-0.0000	0.0000	-0.0000
2.5000	-0.0000	17.3000	-0.0000	0.0000	-0.0000
3.3000	-0.0000	21.8000	-0.0000	.0500	-0.0000
4.0000	-0.0000	22.1000	-0.0000	.5500	-0.0000
5.0000	-0.0000	24.0000	-0.0000	1.8500	-0.0000
7.0000	-0.0000	26.2000	-0.0000	7.2000	-0.0000
9.0000	-0.0000	30.6000	-0.0000	12.0000	-0.0000
11.0000	-0.0000	35.6000	.1000	16.4000	.1000
13.0000	-0.0000	40.5000	.1000	20.9000	.1000
14.0000	-0.0000	42.6000	.2000	23.2000	.2000
18.0000	.2000	52.5000	.3000	33.0000	.2000
21.0000	.2000	60.7000	.4000	41.0000	.3000
24.0000	.3000	68.0000	.5000	48.5000	.4000
25.8000	.4000	71.4000	.5000	52.2000	.5000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.8000	0.0000	5.8500	0.0000	0.0000	0.0000
1.0000	0.0000	6.9250	0.0000	0.0000	0.0000
1.5000	0.0000	10.6000	0.0000	0.0000	0.0000
2.0000	0.0000	13.9500	0.0000	0.0000	0.0000
2.5000	-0.0000	17.3000	-0.0000	0.0000	-0.0000
3.0000	-0.0000	20.1000	-0.0000	0.0000	-0.0000
3.3000	0.0000	21.7750	0.0000	.0500	0.0000
4.0000	0.0000	22.1500	0.0000	.5000	0.0000
5.0000	0.0000	24.2000	0.0000	1.8250	0.0000
6.0000	-0.0000	24.8000	.1000	4.0000	-0.0000
7.0000	-0.0000	26.2000	-0.0000	7.2000	-0.0000
8.0000	-0.0000	28.4000	.1000	9.7500	-0.0000
9.0000	-0.0000	30.6000	-0.0000	12.0000	-0.0000
10.0000	-0.0000	33.8000	.1000	13.7000	.1000
11.0000	-0.0000	35.6000	.1000	16.4000	.1000
12.0000	-0.0000	38.5000	.1000	18.4000	.1000
13.0000	-0.0000	40.5000	.1000	20.9000	.1000
14.0000	-0.0000	42.6000	.2000	23.2000	.2000
15.0000	-0.0000	45.4000	.1000	25.6000	.1000
18.0000	.1500	52.7500	.2500	32.8000	.2000
21.0000	.2000	60.3500	.4000	40.9000	.3000
24.0000	.3000	67.7500	.5000	48.2500	.4000
25.8000	.4000	71.4000	.5000	52.2000	.5000

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
8.1425	0.0000	8.0277	0.0000	0.0000	0.0000
9.0421	0.0000	8.7325	0.0000	0.0000	0.0000
10.9386	0.0000	10.7984	0.0000	0.0000	0.0000
12.5208	0.0000	12.3837	0.0000	0.0000	0.0000
13.9041	0.0000	13.7871	0.0000	0.0000	0.0000
15.1470	0.0000	14.8583	0.0000	0.0000	0.0000
15.8403	0.0000	15.4635	0.0000	.4675	0.0000
17.3379	0.0000	15.5958	0.0000	1.4620	0.0000
19.2533	0.0000	16.2998	0.0000	2.7758	0.0000
20.9744	0.0000	16.5001	.2024	4.0941	0.0000
22.5490	0.0000	16.9584	0.0000	5.4773	0.0000
24.0082	0.0000	17.6543	.1768	6.3646	0.0000
25.3736	0.0000	18.3237	0.0000	7.0538	0.0000
26.6606	0.0000	19.2557	.1486	7.5321	.3696
27.8809	0.0000	19.7605	.1411	8.2339	.3090
29.0438	0.0000	20.5477	.1304	8.7167	.2756
30.1562	0.0000	21.0734	.1240	9.2843	.2428
31.2242	0.0000	21.6115	.2358	9.7770	.4376
32.2524	0.0000	22.3087	.1106	10.2654	.1984
35.1354	.4549	24.0425	.2381	11.6058	.3100
37.7732	.5224	25.7121	.3330	12.9461	.3733
40.2176	.6884	27.2391	.3709	14.0502	.4223
41.6070	.8557	27.9615	.3519	14.6085	.4881

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
24161	.02866	15.9331	0	0.00000	0.0000
26282	.02829	15.8850	0	0.00000	0.0000
32500	.02745	15.7742	0	0.00000	0.0000
37272	.02696	15.7102	0	0.00000	0.0000
41496	.02661	15.6639	0	0.00000	0.0000
44720	.02638	15.6334	0	0.00000	0.0000
46541	.02626	15.6178	1407	.04549	46.2761
46939	.02623	15.6145	4400	.04139	45.3684
49058	.02611	15.5978	8354	.03518	43.9925
49661	.02607	15.5933	12322	.03233	43.3616
51040	.02599	15.5833	16485	.03057	42.9704
53135	.02589	15.5689	19156	.02977	42.7925
55149	.02579	15.5559	21230	.02925	42.6794
57955	.02566	15.5391	22670	.02895	42.6107
59474	.02559	15.5306	24782	.02854	42.5217
61843	.02550	15.5180	26235	.02830	42.4673
63425	.02544	15.5101	27943	.02804	42.4091
65045	.02538	15.5023	29426	.02783	42.3632
67143	.02531	15.4926	30896	.02764	42.3211
72362	.02514	15.4708	34930	.02719	42.2209
77387	.02500	15.4521	38964	.02681	42.1380
81983	.02488	15.4368	42287	.02655	42.0797
84157	.02483	15.4301	43968	.02643	42.0530

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
1.0000	1.0000	0.0000	24161	8.0277	2.9812
1.0000	1.0000	0.0000	26282	8.7325	3.2429
1.0000	1.0000	0.0000	32500	10.7984	4.0101
1.0000	1.0000	0.0000	37272	12.3837	4.5988
1.0000	1.0000	0.0000	41496	13.7871	5.1200
.9699	1.0000	-3.1008	44720	14.8583	5.5178
.9164	.9707	-5.9173	47948	15.9310	5.9161
.8720	.9143	-4.8518	51339	17.0578	6.3346
.8166	.8545	-4.6344	57413	19.0756	7.0839
.7862	.8012	-1.9104	61983	20.5942	7.6479
.7583	.7559	.3211	67525	22.4357	8.3317
.7399	.7350	.6596	72290	24.0189	8.9197
.7270	.7220	.6839	76380	25.3775	9.4242
.7159	.7188	-.4082	80624	26.7878	9.9479
.7077	.7059	.2514	84256	27.9944	10.3960
.7002	.7021	-.2767	88078	29.2644	10.8676
.6945	.6942	.0484	91369	30.3577	11.2737
.6897	.6885	.1725	94471	31.3885	11.6564
.6848	.6849	-.0107	98039	32.5741	12.0967
.6743	.6744	-.0215	107292	35.6483	13.2384
.6664	.6651	.1932	116351	38.6582	14.3561
.6609	.6597	.1815	124270	41.2893	15.3332
.6586	.6568	.2687	128124	42.5700	15.8088

AVERAGE RESULTS FOR FLOWSPLIT 8

RECYCLE K-FACTOR = 15.5919
BRANCH K-FACTOR = 42.4992
RECYCLE FRICTION FACTOR = .02606
CRITICAL FLOWRATE = 14.4306 GPM

FLOWSPLIT 9

RECYCLE ORIFICE
3/8 INCH

BRANCH ORIFICE
1/2 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.1000	-0.0000	7.4000	-0.0000	0.0000	-0.0000
.2000	-0.0000	14.0000	-0.0000	0.0000	-0.0000
.3000	-0.0000	21.7500	-0.0000	.0500	-0.0000
.4000	-0.0000	22.0000	-0.0000	.2000	-0.0000
.6000	-0.0000	22.8500	-0.0000	1.0500	-0.0000
1.0000	-0.0000	24.4000	-0.0000	2.7500	-0.0000
1.5000	-0.0000	25.6500	-0.0000	6.4500	-0.0000
2.0000	-0.0000	28.9000	-0.0000	9.6500	-0.0000
3.0000	-0.0000	35.9000	-0.0000	16.9500	-0.0000
4.0000	-0.0000	41.8000	-0.0000	22.2000	.1000
6.0000	-0.0000	57.0000	.2000	37.8000	.1000
8.0000	.1000	70.5000	.3000	51.5000	.2000
10.0000	.2000	86.4000	.5000	66.2000	.4000
TRIAL 2					
.1000	-0.0000	7.0000	-0.0000	0.0000	-0.0000
.2000	-0.0000	14.5000	-0.0000	0.0000	-0.0000
.3000	-0.0000	21.8500	-0.0000	.0500	-0.0000
.4000	-0.0000	22.0000	-0.0000	.2000	-0.0000
.8000	-0.0000	23.6000	-0.0000	1.6500	-0.0000
1.0000	-0.0000	24.5000	-0.0000	2.7500	-0.0000
1.5000	-0.0000	25.8500	-0.0000	6.5000	-0.0000
2.0000	-0.0000	29.4000	-0.0000	10.1500	-0.0000
2.5000	-0.0000	32.1000	-0.0000	13.0000	-0.0000
5.0000	-0.0000	49.6000	.2000	30.5000	.1000
7.0000	-0.0000	64.9000	.2000	44.9000	.2000
9.0000	.1000	78.4000	.4000	59.1000	.3000
10.0000	.2000	85.5000	.5000	66.5000	.4000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.1000	0.0000	7.2000	0.0000	0.0000	0.0000
.2000	0.0000	14.2500	0.0000	0.0000	0.0000
.3000	0.0000	21.8000	0.0000	.0500	0.0000
.4000	0.0000	22.0000	0.0000	.2000	0.0000
.6000	-0.0000	22.8500	-0.0000	1.0500	-0.0000
.8000	-0.0000	23.6000	-0.0000	1.6500	-0.0000
1.0000	0.0000	24.4500	0.0000	2.7500	0.0000
1.5000	0.0000	25.7500	0.0000	6.4750	0.0000
2.0000	0.0000	29.1500	0.0000	9.9000	0.0000
2.5000	-0.0000	32.1000	-0.0000	13.0000	-0.0000
3.0000	-0.0000	35.9000	-0.0000	16.9500	-0.0000
4.0000	-0.0000	41.8000	-0.0000	22.2000	.1000
5.0000	-0.0000	49.6000	.2000	30.5000	.1000
6.0000	-0.0000	57.0000	.2000	37.8000	.1000
7.0000	-0.0000	64.9000	.2000	44.9000	.2000
8.0000	.1000	70.5000	.3000	51.5000	.2000
9.0000	.1000	78.4000	.4000	59.1000	.3000
10.0000	.2000	85.9500	.5000	66.3500	.4000

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
3.0667	0.0000	3.0406	0.0000	0.0000	0.0000
4.2465	0.0000	4.2622	0.0000	0.0000	0.0000
5.1372	0.0000	5.2599	0.0000	.4675	0.0000
5.8803	0.0000	5.2837	0.0000	.9287	0.0000
7.1136	0.0000	5.3837	0.0000	2.1111	0.0000
8.1425	0.0000	5.4704	0.0000	2.6407	0.0000
9.0421	0.0000	5.5670	0.0000	3.4007	0.0000
10.9386	0.0000	5.7116	0.0000	5.1969	0.0000
12.5208	0.0000	6.0730	0.0000	6.4129	0.0000
13.9041	0.0000	6.3696	0.0000	7.3390	0.0000
15.1470	0.0000	6.7321	0.0000	8.3695	0.0000
17.3379	0.0000	7.2584	0.0000	9.5660	.2286
19.2533	0.0000	7.8995	.2058	11.1954	.1666
20.9744	0.0000	8.4620	.1792	12.4506	.1346
22.5490	0.0000	9.0232	.1575	13.5584	.2268
24.0082	.6658	9.4003	.2176	14.5111	.1979
25.3736	.5939	9.9074	.2611	15.5348	.2588
26.6606	1.0725	10.3685	.2978	16.4509	.3076

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
9152	.03446	134.0844	0	0.00000	0.0000
12828	.03207	133.7706	0	0.00000	0.0000
15831	.03080	133.6028	1407	.04549	46.2761
15903	.03077	133.5995	2795	.04184	45.4668
16204	.03066	133.5855	6354	.03758	44.5233
16465	.03058	133.5737	7948	.03559	44.0836
16755	.03048	133.5609	10235	.03362	43.6462
17190	.03034	133.5424	15641	.03087	43.0363
18278	.03001	133.4992	19301	.02973	42.7840
19171	.02976	133.4667	22089	.02907	42.6376
20262	.02948	133.4301	25190	.02847	42.5059
21846	.02912	133.3821	28791	.02791	42.3824
23775	.02873	133.3307	33695	.02731	42.2495
25468	.02842	133.2909	37473	.02694	42.1670
27157	.02815	133.2551	40807	.02666	42.1047
28292	.02798	133.2330	43675	.02645	42.0576
29819	.02778	133.2055	46756	.02624	42.0123
31206	.02760	133.1824	49513	.02608	41.9759

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
1.0000	1.0000	0.0000	9152	3.0406	1.1292
1.0000	1.0000	0.0000	12828	4.2622	1.5828
.8644	.9184	-6.2412	17238	5.7274	2.1269
.8019	.8505	-6.0598	18698	6.2124	2.3071
.6828	.7183	-5.2014	22557	7.4948	2.7833
.6417	.6744	-5.0946	24412	8.1111	3.0121
.5963	.6208	-4.1093	26991	8.9678	3.3303
.5260	.5236	.4657	32831	10.9084	4.0510
.4890	.4864	.5420	37579	12.4858	4.6367
.4687	.4646	.8578	41259	13.7086	5.0908
.4505	.4458	1.0361	45452	15.1016	5.6081
.4335	.4314	.4891	50637	16.8243	6.2479
.4175	.4137	.9114	57471	19.0949	7.0911
.4081	.4046	.8456	62941	20.9126	7.7661
.4013	.3996	.4277	67965	22.5816	8.3859
.3968	.3931	.9311	71967	23.9115	8.8798
.3925	.3894	.7870	76574	25.4422	9.4482
.3892	.3866	.6676	80719	26.8194	9.9597

AVERAGE RESULTS FOR FLOWSPLIT 9

RECYCLE K-FACTOR =133.4418
BRANCH K-FACTOR = 42.4633
RECYCLE FRICTION FACTOR = .02957
CRITICAL FLOWRATE = 4.9327 GPM

FLOWSPLIT 10

RECYCLE ORIFICE
3/8 INCH

BRANCH ORIFICE
5/8 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.1000	-0.0000	6.7500	-0.0000	0.0000	-0.0000
.2000	-0.0000	15.7000	-0.0000	0.0000	-0.0000
.3000	-0.0000	21.8000	-0.0000	.0500	-0.0000
.5000	-0.0000	22.0000	-0.0000	.2000	-0.0000
1.0000	-0.0000	23.2000	-0.0000	1.1000	-0.0000
1.5000	-0.0000	22.2000	-0.0000	2.6500	-0.0000
2.0000	-0.0000	24.3000	-0.0000	4.3500	-0.0000
3.0000	-0.0000	27.8500	-0.0000	7.3000	-0.0000
4.0000	-0.0000	31.3000	-0.0000	10.4000	-0.0000
6.0000	-0.0000	36.6000	.1000	17.1000	.1000
8.0000	.1000	46.1000	.2000	23.8000	.2000
10.0000	.2000	54.0000	.4000	31.0000	.4000
12.0000	.2000	62.5000	.5000	38.8000	.5000
15.0000	.3000	73.0000	.6000	48.0000	.6000
TRIAL 2					
.1000	-0.0000	7.2500	-0.0000	0.0000	-0.0000
.2000	-0.0000	16.7000	-0.0000	0.0000	-0.0000
.3000	-0.0000	21.7000	-0.0000	.0500	-0.0000
.5000	-0.0000	22.0000	-0.0000	.2000	-0.0000
1.0000	-0.0000	22.9500	-0.0000	1.0500	-0.0000
1.5000	-0.0000	22.6000	-0.0000	2.8000	-0.0000
2.0000	-0.0000	24.3500	-0.0000	4.3500	-0.0000
3.0000	-0.0000	27.9000	-0.0000	7.5000	-0.0000
4.0000	-0.0000	29.8000	-0.0000	10.4500	-0.0000
6.0000	-0.0000	38.5000	.2000	16.8000	.2000
8.0000	.1000	46.7000	.2000	24.1000	.2000
10.0000	.2000	55.0000	.4000	31.5000	.4000
12.0000	.2000	62.4000	.5000	38.0000	.5000
15.0000	.3000	73.5000	.6000	47.5000	.6000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.1000	0.0000	7.0000	0.0000	0.0000	0.0000
.2000	0.0000	16.2000	0.0000	0.0000	0.0000
.3000	0.0000	21.7500	0.0000	.0500	0.0000
.5000	0.0000	22.0000	0.0000	.2000	0.0000
1.0000	0.0000	23.0750	0.0000	1.0750	0.0000
1.5000	0.0000	22.4000	0.0000	2.7250	0.0000
2.0000	0.0000	24.3250	0.0000	4.3500	0.0000
3.0000	0.0000	27.8750	0.0000	7.4000	0.0000
4.0000	0.0000	30.5500	0.0000	10.4250	0.0000
6.0000	0.0000	37.5500	.1500	16.9500	.1500
8.0000	.1000	46.4000	.2000	23.9500	.2000
10.0000	.2000	54.5000	.4000	31.2500	.4000
12.0000	.2000	62.4500	.5000	38.4000	.5000
15.0000	.3000	73.2500	.6000	47.7500	.6000

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
3.0667	0.0000	2.9986	0.0000	0.0000	0.0000
4.2465	0.0000	4.5414	0.0000	0.0000	0.0000
5.1372	0.0000	5.2539	0.0000	.7464	0.0000
6.5299	0.0000	5.2837	0.0000	1.4904	0.0000
9.0421	0.0000	5.4099	0.0000	3.4483	0.0000
10.9386	0.0000	5.3310	0.0000	5.4840	0.0000
12.5208	0.0000	5.5529	0.0000	6.9249	0.0000
15.1470	0.0000	5.9401	0.0000	9.0263	0.0000
17.3379	0.0000	6.2155	0.0000	10.7091	0.0000
20.9744	0.0000	6.8834	.2036	13.6473	.4440
24.0082	.6658	7.6431	.2199	16.2156	.4191
26.6606	1.0725	8.2763	.3748	18.5168	.6426
29.0438	.8987	8.8531	.4092	20.5211	.6539
32.2524	1.0858	9.5800	.4190	22.8774	.6312

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
9025	.03457	134.0986	0	0.00000	0.0000
13668	.03167	133.7179	0	0.00000	0.0000
15813	.03080	133.6037	2247	.03026	18.8686
15903	.03077	133.5995	4486	.04117	21.2873
16282	.03064	133.5819	10378	.03352	19.5911
16045	.03072	133.5928	16505	.03056	18.9360
16713	.03049	133.5627	20842	.02934	18.6664
17878	.03013	133.5146	27167	.02815	18.4020
18707	.02989	133.4833	32231	.02748	18.2529
20717	.02937	133.4157	41075	.02664	18.0673
23004	.02888	133.3505	48805	.02612	17.9521
24910	.02852	133.3035	55731	.02576	17.8721
26645	.02823	133.2656	61763	.02550	17.8150
28833	.02791	133.2230	68855	.02525	17.7590

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
1.0000	1.0000	0.0000	9025	2.9986	1.1135
1.0000	1.0000	0.0000	13668	4.5414	1.6865
.8242	.8756	-6.2331	18059	6.0003	2.2283
.7354	.7800	-6.0670	20388	6.7741	2.5156
.5794	.6107	-5.4055	26661	8.8582	3.2896
.4940	.4929	.2257	32550	10.8150	4.0163
.4461	.4450	.2431	37555	12.4779	4.6338
.3981	.3969	.3076	45045	14.9663	5.5579
.3725	.3672	1.4116	50939	16.9246	6.2851
.3422	.3353	2.0355	61792	20.5306	7.6243
.3232	.3203	.8753	71808	23.8587	8.8602
.3121	.3089	1.0129	80640	26.7932	9.9499
.3047	.3014	1.0954	88408	29.3741	10.9084
.2980	.2952	.9643	97688	32.4574	12.0534

AVERAGE RESULTS FOR FLOWSPLIT 10

RECYCLE K-FACTOR =133.4780
BRANCH K-FACTOR = 18.3314
RECYCLE FRICTION FACTOR = .02985
CRITICAL FLOWRATE = 4.9321 GPM

FLOWSPLIT 11

RECYCLE ORIFICE
1/2 INCH

BRANCH CRIFICE
5/8 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.3000	-0.0000	6.9000	-0.0000	0.0000	-0.0000
.6000	-0.0000	12.0000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	17.5000	-0.0000	0.0000	-0.0000
1.2000	-0.0000	22.7000	-0.0000	.0500	-0.0000
1.5000	-0.0000	22.9000	-0.0000	.1000	-0.0000
2.0000	-0.0000	23.4000	-0.0000	.6500	-0.0000
3.0000	-0.0000	23.0000	-0.0000	2.4500	-0.0000
4.0000	-0.0000	25.1000	-0.0000	4.3000	-0.0000
6.0000	-0.0000	30.0000	-0.0000	8.1000	-0.0000
8.0000	-0.0000	35.2000	.1000	12.5000	-0.0000
10.0000	.1000	39.5000	.1500	17.0000	.1000
12.0000	.1500	45.4000	.3000	21.3000	.3000
15.0000	.2000	53.0000	.4000	28.3000	.4000
18.0000	.3000	61.0000	.5000	35.7000	.5000
TRIAL 2					
.3000	-0.0000	7.1500	-0.0000	0.0000	-0.0000
.6000	-0.0000	12.5500	-0.0000	0.0000	-0.0000
1.0000	-0.0000	19.3000	-0.0000	0.0000	-0.0000
1.2500	-0.0000	22.7500	-0.0000	.0500	-0.0000
1.8000	-0.0000	23.1500	-0.0000	.4000	-0.0000
2.5000	-0.0000	24.3000	-0.0000	1.3000	-0.0000
3.0000	-0.0000	22.7000	-0.0000	2.4000	-0.0000
4.0000	-0.0000	24.8500	-0.0000	4.1500	-0.0000
6.0000	-0.0000	29.8500	-0.0000	8.4500	-0.0000
8.0000	-0.0000	34.5000	.2000	12.8000	.1000
10.0000	.1000	39.7000	.2000	17.2000	.1000
12.0000	.2000	45.2000	.3000	22.0000	.3000
15.0000	.2000	53.8000	.4000	28.5000	.4000
18.0000	.3000	61.5000	.4000	35.5000	.4000
24.0000	.4000	78.3000	.5000	49.0000	.5000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.3000	0.0000	7.0250	0.0000	0.0000	0.0000
.6000	0.0000	12.2750	0.0000	0.0000	0.0000
1.0000	0.0000	18.4000	0.0000	0.0000	0.0000
1.2000	-0.0000	22.7000	-0.0000	.0500	-0.0000
1.2500	-0.0000	22.7500	-0.0000	.0500	-0.0000
1.5000	-0.0000	22.9000	-0.0000	.1000	-0.0000
1.8000	-0.0000	23.1500	-0.0000	.4000	-0.0000
2.0000	-0.0000	23.4000	-0.0000	.6500	-0.0000
2.5000	-0.0000	24.3000	-0.0000	1.3000	-0.0000
3.0000	0.0000	22.8500	0.0000	2.4250	0.0000
4.0000	0.0000	24.9750	0.0000	4.2250	0.0000
6.0000	0.0000	29.9250	0.0000	8.2750	0.0000
8.0000	0.0000	34.8500	.1500	12.6500	.0500
10.0000	.1000	39.6000	.1750	17.1000	.1000
12.0000	.1750	45.3000	.3000	21.6500	.3000
15.0000	.2000	53.4000	.4000	28.4000	.4000
18.0000	.3000	61.2500	.4500	35.6000	.4500
24.0000	.4000	78.3000	.5000	49.0000	.5000

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
5.1372	0.0000	5.4110	0.0000	0.0000	0.0000
7.1136	0.0000	7.1334	0.0000	0.0000	0.0000
9.0421	0.0000	8.7167	0.0000	0.0000	0.0000
9.8504	0.0000	9.6721	0.0000	.7464	0.0000
10.0410	0.0000	9.6826	0.0000	.7464	0.0000
10.9386	0.0000	9.7142	0.0000	1.0547	0.0000
11.9164	0.0000	9.7665	0.0000	2.1059	0.0000
12.5208	0.0000	9.8186	0.0000	2.6830	0.0000
13.9041	0.0000	10.0038	0.0000	3.7911	0.0000
15.1470	0.0000	9.7037	0.0000	5.1740	0.0000
17.3379	0.0000	10.1405	0.0000	6.8249	0.0000
20.9744	0.0000	11.0904	0.0000	9.5437	0.0000
24.0082	0.0000	11.9595	.2189	11.7939	.1982
26.6606	.5363	12.7407	.2249	13.7074	.2934
29.0438	.7864	13.6180	.3372	15.4192	.6954
32.2524	.7239	14.7738	.3818	17.6543	.7071
35.1354	.9099	15.8121	.3747	19.7605	.6347
40.2176	.9179	17.8569	.3260	23.1742	.5126

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
16286	.03064	40.2264	0	0.00000	0.0000
21470	.02920	40.0377	0	0.00000	0.0000
26235	.02830	39.9189	0	0.00000	0.0000
29110	.02787	39.8627	2247	.03026	18.8686
29142	.02787	39.8621	2247	.03026	18.8686
29237	.02785	39.8604	3174	.04464	22.0562
29395	.02783	39.8576	6338	.03760	20.4956
29551	.02781	39.8549	8075	.03546	20.0215
30109	.02774	39.8452	11410	.03285	19.4432
29205	.02786	39.8610	15572	.03089	19.0091
30520	.02768	39.8383	20541	.02942	18.6821
33379	.02735	39.7941	28724	.02792	18.3516
35995	.02708	39.7588	35497	.02713	18.1755
38346	.02686	39.7304	41256	.02663	18.0642
40987	.02665	39.7019	46408	.02627	17.9844
44465	.02639	39.6685	53135	.02589	17.9001
47590	.02619	39.6421	59474	.02559	17.8356
53744	.02585	39.5977	69748	.02522	17.7526

XTH	XEXP	XERR PCT	MAIN RE	QSU\ (GPM)	VEL. (FPS)
1.0000	1.0000	0.0000	16286	5.4110	2.0094
1.0000	1.0000	0.0000	21470	7 1334	2.6491
1.0000	1.0000	0.0000	26235	8.7167	3.2370
.8708	.9284	-6.6088	31357	10.4185	3.8690
.8700	.9284	-6.7162	31389	10.4290	3.8729
.8459	.9021	-6.6392	32411	10.7689	3.9991
.7769	.8226	-5.8887	35733	11.8725	4.4090
.7444	.7854	-5.5103	37626	12.5016	4.6426
.6894	.7252	-5.1894	41519	13.7950	5.1229
.6524	.6522	.0259	44778	14.8777	5.5250
.5980	.5977	.0433	51061	16.9654	6.3003
.5384	.5375	.1742	62103	20.6341	7.6627
.5062	.5035	.5321	71492	23.7534	8.8211
.4865	.4817	.9866	79602	26.4481	9.8218
.4723	.4690	.7120	87394	29.0372	10.7833
.4584	.4556	.6241	97600	32.4281	12.0425
.4488	.4445	.9574	107064	35.5726	13.2103
.4369	.4352	.3848	123493	41.0311	15.2373

AVERAGE RESULTS FOR FLOWSPLIT 11

ECYCLE K-FACTOR = 39.8288
RANCH K-FACTOR = 18.3198
ECYCLE FRICTION FACTOR = .02761
RITICAL FLOWRATE = 9.0289 GPM

FLOWSPLIT 12

RECYCLE ORIFICE
1/2 INCH

BRANCH ORIFICE
5/8 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.3000	-0.0000	6.7000	-0.0000	0.0000	-0.0000
.6000	-0.0000	12.5000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	19.1000	-0.0000	0.0000	-0.0000
1.5000	-0.0000	28.6000	-0.0000	0.0000	-0.0000
2.0000	-0.0000	36.9000	-0.0000	0.0000	-0.0000
2.4000	-0.0000	42.0000	-0.0000	.0500	-0.0000
3.0000	-0.0000	42.9000	-0.0000	.2500	-0.0000
5.0000	-0.0000	44.9000	-0.0000	2.6000	-0.0000
7.0000	-0.0000	49.7000	.1000	5.6000	-0.0000
9.0000	-0.0000	54.6000	.1000	9.5000	-0.0000
12.0000	-0.0000	62.0000	.2000	15.2000	.1000
15.0000	-0.0000	70.4000	.3000	21.5000	.2000
18.0000	.1000	78.8000	.4000	28.5000	.2000
21.0000	.1000	86.2000	.4000	34.3000	.3000
TRIAL 2					
.3000	-0.0000	6.4000	-0.0000	0.0000	-0.0000
.6000	-0.0000	12.3000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	19.1000	-0.0000	0.0000	-0.0000
1.5000	-0.0000	29.0000	-0.0000	0.0000	-0.0000
2.0000	-0.0000	37.0000	-0.0000	0.0000	-0.0000
2.4000	-0.0000	42.1000	-0.0000	.0500	-0.0000
3.0000	-0.0000	43.2000	-0.0000	.2500	-0.0000
4.0000	-0.0000	43.6000	-0.0000	1.2000	-0.0000
6.0000	-0.0000	47.0000	-0.0000	4.1500	-0.0000
8.0000	-0.0000	52.0000	.1000	7.6000	-0.0000
10.0000	-0.0000	56.5000	.2000	11.4000	.1000
12.0000	-0.0000	61.4000	.3000	15.5000	.1000
15.0000	-0.0000	70.3000	.3000	21.5000	.2000
20.0000	.1000	83.2000	.4000	32.5000	.3000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.3000	0.0000	6.5500	0.0000	0.0000	0.0000
.6000	0.0000	12.4000	0.0000	0.0000	0.0000
1.0000	0.0000	19.1000	0.0000	0.0000	0.0000
1.5000	0.0000	28.8000	0.0000	0.0000	0.0000
2.0000	0.0000	36.9500	0.0000	0.0000	0.0000
2.4000	0.0000	42.0500	0.0000	.0500	0.0000
3.0000	0.0000	43.0500	0.0000	.2500	0.0000
4.0000	-0.0000	43.6000	-0.0000	1.2000	0.0000
5.0000	-0.0000	44.9000	-0.0000	2.6000	-0.0000
6.0000	-0.0000	47.0000	-0.0000	4.1500	-0.0000
7.0000	-0.0000	49.7000	.1000	5.6000	-0.0000
8.0000	-0.0000	52.0000	.1000	7.6000	-0.0000
9.0000	-0.0000	54.6000	.1000	9.5000	-0.0000
10.0000	-0.0000	56.5000	.2000	11.4000	-0.0000
12.0000	0.0000	61.7000	.2500	15.3500	.1000
15.0000	0.0000	70.3500	.3000	21.5000	.1000
18.0000	.1000	78.8000	.4000	28.5000	.2000
20.0000	.1000	83.2000	.4000	32.5000	.2000
21.0000	.1000	86.2000	.4000	34.3000	.3000
					.3000

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
5.1372	0.0000	5.2266	0.0000	0.0000	0.0000
7.1136	0.0000	7.1693	0.0000	0.0000	0.0000
9.0421	0.0000	8.8794	0.0000	0.0000	0.0000
10.9386	0.0000	10.8819	0.0000	0.0000	0.0000
12.5208	0.0000	12.3111	0.0000	0.0000	0.0000
13.6401	0.0000	13.1251	0.0000	.7464	0.0000
15.1470	0.0000	13.2788	0.0000	1.6658	0.0000
17.3379	0.0000	13.3625	0.0000	3.6428	0.0000
19.2533	0.0000	13.5584	0.0000	5.3570	0.0000
20.9744	0.0000	13.8688	0.0000	6.7642	0.0000
22.5490	0.0000	14.2577	.1025	7.8547	0.0000
4.0082	0.0000	14.5807	.0980	9.1471	0.0000
5.3736	0.0000	14.9373	.0934	10.2241	0.0000
6.6606	0.0000	15.1925	.1805	11.1975	0.0000
9.0438	0.0000	15.8695	.2066	12.9887	.4399
2.2524	0.0000	16.9348	.2176	15.3658	.3268
5.1354	.3033	17.9133	.2592	17.6853	.4668
6.9176	.2738	18.4018	.2455	18.8826	.3523
7.7732	.2612	18.7274	.2370	19.3972	.4635
					.4392

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
15731	.03083	40.2523	0	0.00000	0.0000
21578	.02918	40.0345	0	0.00000	0.0000
26725	.02822	39.9086	0	0.00000	0.0000
32752	.02742	39.8033	0	0.00000	0.0000
37053	.02698	39.7457	0	0.00000	0.0000
39503	.02677	39.7175	2247	.03026	20.5416
39966	.02673	39.7125	5014	.03995	23.2255
40218	.02671	39.7099	10964	.03313	21.3362
40807	.02666	39.7037	16123	.03069	20.6622
41741	.02659	39.6942	20359	.02946	20.3207
42912	.02650	39.6829	23641	.02875	20.1252
43884	.02643	39.6738	27530	.02810	19.9433
44957	.02636	39.6642	30772	.02765	19.8207
45725	.02631	39.6575	33701	.02731	19.7267
47763	.02618	39.6407	39093	.02680	19.5846
50969	.02600	39.6166	46247	.02628	19.4395
53914	.02585	39.5966	53228	.02588	19.3300
55384	.02578	39.5873	56832	.02571	19.2824
56365	.02573	39.5813	58381	.02564	19.2635

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
1.0000	1.0000	0.0000	15731	5.2266	1.9409
1.0000	1.0000	0.0000	21578	7.1693	2.6624
1.0000	1.0000	0.0000	26725	8.8794	3.2975
1.0000	1.0000	0.0000	32752	10.8819	4.0411
1.0000	1.0000	0.0000	37053	12.3111	4.5719
.9457	.9462	-.0484	41750	13.8715	5.1513
.8818	.8885	-.7657	44979	14.9446	5.5498
.7866	.7858	.1013	51181	17.0053	6.3151
.7216	.7168	.6658	56930	18.9154	7.0244
.6763	.6722	.6176	62100	20.6330	7.6623
.6447	.6448	-.0065	66553	22.1125	8.2117
.6156	.6145	.1858	71415	23.7279	8.8116
.5948	.5937	.1921	75729	25.1614	9.3439
.5790	.5757	.5710	79427	26.3900	9.8002
.5527	.5499	.5130	86856	28.8582	10.7168
.5251	.5243	.1585	97216	32.3006	11.9952
.5054	.5032	.4325	107142	35.5985	13.2199
.4972	.4936	.7245	112216	37.2844	13.8460
.4934	.4912	.4526	114745	38.1247	14.1580

AVERAGE RESULTS FOR FLOWSPLIT 12

RECYCLE K-FACTOR = 39.7360
BRANCH K-FACTOR = 19.9029
RECYCLE FRICTION FACTOR = .02691
CRITICAL FLOWRATE = 13.1046 GPM

FLOWSPLIT 13

RECYCLE ORIFICE
3/8 INCH

BRANCH ORIFICE
5/8 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.1000	-0.0000	6.3000	-0.0000	0.0000	-0.0000
.2000	-0.0000	15.2000	-0.0000	0.0000	-0.0000
.4000	-0.0000	29.5000	-0.0000	0.0000	-0.0000
.6000	-0.0000	41.0000	-0.0000	.0500	-0.0000
1.0000	-0.0000	41.4000	-0.0000	.2500	-0.0000
1.5000	-0.0000	42.3000	-0.0000	1.1500	-0.0000
2.0000	-0.0000	43.6000	-0.0000	2.4000	-0.0000
3.0000	-0.0000	46.5000	-0.0000	4.7500	-0.0000
4.0000	-0.0000	49.7000	-0.0000	7.4000	-0.0000
6.0000	-0.0000	55.2000	.2000	13.3000	.1000
8.0000	-0.0000	62.0000	.3000	19.5000	.2000
10.0000	.1000	73.0000	.3000	26.5000	.2000
13.0000	.2000	85.2000	.3000	35.5000	.2000
TRIAL 2					
.1000	-0.0000	6.6000	-0.0000	0.0000	-0.0000
.2000	-0.0000	14.9000	-0.0000	0.0000	-0.0000
.4000	-0.0000	29.3000	-0.0000	0.0000	-0.0000
.6000	-0.0000	40.5000	-0.0000	.0500	-0.0000
1.0000	-0.0000	40.9000	-0.0000	.2500	-0.0000
1.5000	-0.0000	41.5000	-0.0000	1.1000	-0.0000
2.0000	-0.0000	43.4000	-0.0000	2.2500	-0.0000
3.0000	-0.0000	46.5000	-0.0000	4.9000	-0.0000
4.0000	-0.0000	49.5000	-0.0000	7.6500	-0.0000
6.0000	-0.0000	55.2000	.2000	13.6500	.1000
8.0000	.1000	65.2000	.2000	19.8000	.1000
10.0000	.1000	73.2000	.3000	26.0000	.3000
13.0000	.2000	84.8000	.3000	35.6000	.3000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.1000	0.0000	6.4500	0.0000	0.0000	0.0000
.2000	0.0000	15.0500	0.0000	0.0000	0.0000
.4000	0.0000	29.4000	0.0000	0.0000	0.0000
.6000	0.0000	40.7500	0.0000	.0500	0.0000
1.0000	0.0000	41.1500	0.0000	.2500	0.0000
1.5000	0.0000	41.9000	0.0000	1.1250	0.0000
2.0000	0.0000	43.5000	0.0000	2.3250	0.0000
3.0000	0.0000	46.5000	0.0000	4.8250	0.0000
4.0000	0.0000	49.6000	0.0000	7.5250	0.0000
6.0000	0.0000	55.2000	.2000	13.4750	.1000
8.0000	.0500	63.6000	.2500	19.6500	.1500
10.0000	.1000	73.1000	.3000	26.2500	.2500
13.0000	.2000	85.0000	.3000	35.5500	.2500

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
3.0667	0.0000	2.8796	0.0000	0.0000	0.0000
4.2465	0.0000	4.3790	0.0000	0.0000	0.0000
5.8803	0.0000	6.0987	0.0000	0.0000	0.0000
7.1136	0.0000	7.1676	0.0000	.7464	0.0000
9.0421	0.0000	7.2023	0.0000	1.6658	0.0000
10.9386	0.0000	7.2670	0.0000	3.5274	0.0000
12.5208	0.0000	7.4029	0.0000	5.0665	0.0000
15.1470	0.0000	7.6512	0.0000	7.2923	0.0000
17.3379	0.0000	7.8995	0.0000	9.1020	0.0000
20.9744	0.0000	8.3288	.1851	12.1715	.3722
24.0082	.3329	8.9333	.2009	14.6914	.3830
26.6606	.5363	9.5703	.2099	16.9745	.4781
30.1562	.8316	10.3116	.1807	19.7467	.3531

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
8667	.03489	134.1406	0	0.00000	0.0000
13180	.03190	133.7479	0	0.00000	0.0000
18355	.02999	133.4963	0	0.00000	0.0000
21573	.02918	133.3900	2247	.03026	20.5416
21677	.02916	133.3870	5014	.03995	23.2255
21872	.02911	133.3814	10616	.03336	21.3993
22281	.02903	133.3699	15249	.03101	20.7509
23028	.02887	133.3498	21948	.02910	20.2202
23775	.02873	133.3307	27395	.02812	19.9489
25067	.02849	133.2999	36633	.02702	19.6452
26887	.02819	133.2606	44217	.02641	19.4767
28804	.02791	133.2236	51089	.02599	19.3609
31035	.02762	133.1852	59432	.02560	19.2512

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
1.0000	1.0000	0.0000	8667	2.8796	1.0694
1.0000	1.0000	0.0000	13180	4.3790	1.6262
1.0000	1.0000	0.0000	18355	6.0987	2.2648
.9045	.9057	-.1262	23819	7.9140	2.9390
.8104	.8122	-.2155	26691	8.8681	3.2933
.6753	.6732	.3043	32488	10.7943	4.0086
.5954	.5937	.2917	37530	12.4694	4.6307
.5147	.5120	.5145	44976	14.9435	5.5494
.4684	.4646	.7934	51170	17.0015	6.3137
.4150	.4063	2.1069	61700	20.5003	7.6130
.3837	.3781	1.4600	71104	23.6248	8.7733
.3629	.3605	.6474	79893	26.5448	9.8577
.3472	.3431	1.1969	90468	30.0583	11.1625

AVERAGE RESULTS FOR FLOWSPLIT 13

RECYCLE K-FACTOR =133.3685
BRANCH K-FACTOR = 20.0066
RECYCLE FRICTION FACTOR = .02901
CRITICAL FLOWRATE = 7.1530 GPM

FLOWSPLIT 14

RECYCLE ORIFICE
3/8 INCH

BRANCH ORIFICE
1/2 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.2000	-0.0000	15.0000	-0.0000	0.0000	-0.0000
.4000	-0.0000	28.6000	-0.0000	0.0000	-0.0000
.6000	-0.0000	40.6500	-0.0000	.0500	-0.0000
1.0000	-0.0000	41.6000	-0.0000	.7500	-0.0000
1.5000	-0.0000	43.9000	-0.0000	3.0500	-0.0000
2.0000	-0.0000	46.1000	-0.0000	5.7000	-0.0000
3.0000	-0.0000	51.8000	-0.0000	11.3000	-0.0000
4.0000	-0.0000	58.5000	.2000	17.7000	.1000
5.0000	-0.0000	66.2000	.2000	24.7000	.1000
6.0000	-0.0000	72.8000	.2000	30.9000	.1000
7.0000	-0.0000	79.4000	.3000	37.5000	.2000
8.0000	.1000	86.9000	.3000	44.6000	.3000
TRIAL 2					
.2000	-0.0000	14.1000	-0.0000	0.0000	-0.0000
.4000	-0.0000	28.5000	-0.0000	0.0000	-0.0000
.6000	-0.0000	40.7000	-0.0000	.0500	-0.0000
1.0000	-0.0000	41.4000	-0.0000	.7000	-0.0000
1.5000	-0.0000	43.7000	-0.0000	2.9500	-0.0000
2.0000	-0.0000	45.8000	-0.0000	5.5000	-0.0000
3.0000	-0.0000	51.8000	-0.0000	11.4000	-0.0000
4.0000	-0.0000	58.4000	.2000	17.6000	.1000
5.0000	-0.0000	65.9000	.2000	24.5000	.1000
6.0000	-0.0000	72.9000	.2000	31.3000	.1000
7.0000	-0.0000	79.7000	.3000	37.6000	.2000
8.0000	.1000	86.8000	.3000	44.5000	.2000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.2000	0.0000	14.5500	0.0000	0.0000	0.0000
.4000	0.0000	28.5500	0.0000	0.0000	0.0000
.6000	0.0000	40.6750	0.0000	.0500	0.0000
1.0000	0.0000	41.5000	0.0000	.7250	0.0000
1.5000	0.0000	43.8000	0.0000	3.0000	0.0000
2.0000	0.0000	45.9500	0.0000	5.6000	0.0000
3.0000	0.0000	51.8000	0.0000	11.3500	0.0000
4.0000	0.0000	58.4500	.2000	17.6500	.1000
5.0000	0.0000	66.0500	.2000	24.6000	.1000
6.0000	0.0000	72.8500	.2000	31.1000	.1000
7.0000	0.0000	79.5500	.3000	37.5500	.2000
8.0000	.1000	86.8500	.3000	44.5500	.2500

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
4.2465	0.0000	4.3064	0.0000	0.0000	0.0000
5.8803	0.0000	6.0108	0.0000	0.0000	0.0000
7.1136	0.0000	7.1611	0.0000	.4675	0.0000
9.0421	0.0000	7.2326	0.0000	1.7573	0.0000
10.9386	0.0000	7.4281	0.0000	3.5505	0.0000
12.5208	0.0000	7.6063	0.0000	4.8363	0.0000
15.1470	0.0000	8.0709	0.0000	6.8620	0.0000
17.3379	0.0000	8.5678	.1748	8.5389	.2872
19.2533	0.0000	9.1020	.1548	10.0648	.2064
20.9744	0.0000	9.5540	.1404	11.3039	.1634
22.5490	0.0000	9.9791	.1930	12.4097	.2710
24.0082	.6658	10.4220	.1768	13.5059	.2857

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
12961	.03201	133.7619	0	0.00000	0.0000
18091	.03006	133.5064	0	0.00000	0.0000
21553	.02918	133.3906	1407	.04549	48.7912
21768	.02914	133.3844	5289	.03939	47.1026
22357	.02901	133.3678	10686	.03331	45.4192
22893	.02890	133.3534	14556	.03129	44.8598
24291	.02863	133.3181	20653	.02939	44.3340
25787	.02837	133.2838	25700	.02839	44.0562
27394	.02812	133.2504	30292	.02771	43.8703
28755	.02792	133.2244	34022	.02728	43.7501
30034	.02775	133.2018	37350	.02695	43.6597
31368	.02758	133.1799	40649	.02667	43.5823

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
1.0000	1.0000	0.0000	12961	4.3064	1.5992
1.0000	1.0000	0.0000	18091	6.0108	2.2322
.9383	.9387	-.0420	22960	7.6285	2.8329
.8041	.8045	-.0529	27057	8.9899	3.3385
.6781	.6766	.2185	33043	10.9786	4.0770
.6164	.6113	.8333	37449	12.4427	4.6207
.5460	.5405	1.0064	44944	14.9329	5.5455
.5057	.5008	.9572	51487	17.1068	6.3528
.4785	.4749	.7524	57687	19.1668	7.1178
.4615	.4581	.7437	62777	20.8580	7.7458
.4491	.4457	.7508	67384	22.3888	8.3143
.4388	.4356	.7403	72017	23.9280	8.8859

AVERAGE RESULTS FOR FLOWSPLIT 14

RECYCLE K-FACTOR =133.3519
BRANCH K-FACTOR = 44.1914
RECYCLE FRICTION FACTOR = .02889
CRITICAL FLOWRATE = 7.1534 GPM

FLOWSPLIT 15

RECYCLE ORIFICE
1/2 INCH

BRANCH ORIFICE
1/2 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.3000	-0.0000	6.5000	-0.0000	0.0000	-0.0000
.6000	-0.0000	12.5000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	19.5000	-0.0000	0.0000	-0.0000
1.5000	-0.0000	29.1000	-0.0000	0.0000	-0.0000
2.0000	-0.0000	38.0000	-0.0000	0.0000	-0.0000
2.3000	-0.0000	42.8000	-0.0000	.0500	-0.0000
3.0000	-0.0000	43.1500	-0.0000	.6000	-0.0000
3.5000	-0.0000	44.1000	-0.0000	1.6000	-0.0000
4.0000	-0.0000	44.8000	-0.0000	3.0000	-0.0000
5.0000	-0.0000	48.5000	-0.0000	6.2000	-0.0000
6.0000	-0.0000	52.6000	.1000	9.3000	-0.0000
8.0000	-0.0000	60.6000	.1000	16.4000	-0.0000
10.0000	.1000	68.8000	.2000	24.0000	.1000
12.0000	.1000	76.3000	.3000	31.5000	.1000
14.0000	.1000	85.4000	.3000	39.4000	.1000
TRIAL 2					
.3000	-0.0000	6.6000	-0.0000	0.0000	-0.0000
.6000	-0.0000	12.3000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	19.3000	-0.0000	0.0000	-0.0000
1.5000	-0.0000	28.5000	-0.0000	0.0000	-0.0000
2.0000	-0.0000	37.8000	-0.0000	0.0000	-0.0000
2.3500	-0.0000	42.8000	-0.0000	.0500	-0.0000
3.0000	-0.0000	43.1000	-0.0000	.6000	-0.0000
3.5000	-0.0000	44.0000	-0.0000	1.6000	-0.0000
4.0000	-0.0000	44.8000	-0.0000	2.9000	-0.0000
5.0000	-0.0000	48.5000	-0.0000	6.1000	-0.0000
6.0000	-0.0000	52.5000	-0.0000	9.4000	-0.0000
8.0000	-0.0000	60.4000	.1000	16.3000	-0.0000
10.0000	.1000	68.5000	.1000	23.8000	.1000
12.0000	.1000	76.5000	.3000	31.6000	.1000
14.0000	.1000	85.7000	.3000	39.2000	.2000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.3000	0.0000	6.5500	0.0000	0.0000	0.0000
.6000	0.0000	12.4000	0.0000	0.0000	0.0000
1.0000	0.0000	19.4000	0.0000	0.0000	0.0000
1.5000	0.0000	28.8000	0.0000	0.0000	0.0000
2.0000	0.0000	37.9000	0.0000	0.0000	0.0000
2.3000	-0.0000	42.8000	-0.0000	.0500	-0.0000
2.3500	-0.0000	42.8000	-0.0000	.0500	-0.0000
3.0000	0.0000	43.1250	0.0000	.6000	0.0000
3.5000	0.0000	44.0500	0.0000	1.6000	0.0000
4.0000	0.0000	44.8000	0.0000	2.9500	0.0000
5.0000	0.0000	48.5000	0.0000	6.1500	0.0000
6.0000	0.0000	52.5500	.0500	9.3500	0.0000
8.0000	0.0000	60.5000	.1000	16.3500	0.0000
10.0000	.1000	68.6500	.1500	23.9000	.1000
12.0000	.1000	76.4000	.3000	31.5500	.1000
14.0000	.1000	85.5500	.3000	39.3000	.1500

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
5.1372	0.0000	5.2266	0.0000	0.0000	0.0000
7.1136	0.0000	7.1693	0.0000	0.0000	0.0000
9.0421	0.0000	8.9482	0.0000	0.0000	0.0000
10.9386	0.0000	10.8819	0.0000	0.0000	0.0000
12.5208	0.0000	12.4669	0.0000	0.0000	0.0000
13.3702	0.0000	13.2405	0.0000	.4675	0.0000
13.5059	0.0000	13.2405	0.0000	.4675	0.0000
15.1470	0.0000	13.2902	0.0000	1.6001	0.0000
16.2841	0.0000	13.4306	0.0000	2.6007	0.0000
17.3379	0.0000	13.5434	0.0000	3.5210	0.0000
19.2533	0.0000	14.0862	0.0000	5.0660	0.0000
20.9744	0.0000	14.6569	.0485	6.2339	0.0000
24.0082	0.0000	15.7159	.0843	8.2215	0.0000
26.6606	.5363	16.7309	.1115	9.9220	.2124
29.0438	.4494	17.6410	.2005	11.3846	.1611
31.2242	.3870	18.6574	.1791	12.6928	.1942

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
15731	.03083	40.2523	0	0.00000	0.0000
21578	.02918	40.0345	0	0.00000	0.0000
26932	.02819	39.9044	0	0.00000	0.0000
32752	.02742	39.8033	0	0.00000	0.0000
37522	.02694	39.7401	0	0.00000	0.0000
39851	.02674	39.7138	1407	.04549	48.7912
39851	.02674	39.7138	1407	.04549	48.7912
40000	.02673	39.7122	4816	.04039	47.3784
40423	.02669	39.7077	7828	.03572	46.0869
40762	.02666	39.7042	10597	.03337	45.4356
42396	.02654	39.6878	15247	.03101	44.7838
44113	.02642	39.6717	18762	.02987	44.4678
47301	.02621	39.6444	24744	.02855	44.1017
50356	.02603	39.6210	29862	.02777	43.8857
53095	.02589	39.6020	34265	.02725	43.7430
56154	.02574	39.5826	38202	.02688	43.6386

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
1.0000	1.0000	0.0000	15731	5.2266	1.9409
1.0000	1.0000	0.0000	21578	7.1693	2.6624
1.0000	1.0000	0.0000	26932	8.9482	3.3230
1.0000	1.0000	0.0000	32752	10.8819	4.0411
1.0000	1.0000	0.0000	37522	12.4669	4.6297
.9574	.9659	-.8865	41257	13.7080	5.0906
.9574	.9659	-.8865	41257	13.7080	5.0906
.8887	.8925	-.4331	44816	14.8904	5.5297
.8365	.8378	-.1541	48250	16.0314	5.9534
.7981	.7937	.5499	51359	17.0644	6.3371
.7388	.7355	.4421	57643	19.1522	7.1124
.7024	.7016	.1169	62876	20.8908	7.7580
.6568	.6565	.0419	72045	23.9374	8.8894
.6286	.6277	.1450	80218	26.6529	9.8978
.6105	.6078	.4507	87359	29.0256	10.7790
.5961	.5951	.1569	94356	31.3502	11.6422

AVERAGE RESULTS FOR FLOWSPLIT 15

RECYCLE K-FACTOR = 39.7560
BRANCH K-FACTOR = 44.2938
RECYCLE FRICTION FACTOR = .02706
CRITICAL FLOWRATE = 13.1013 GPM

FLOWSPLIT 16

RECYCLE ORIFICE
5/8 INCH

BRANCH ORIFICE
1/2 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.8000	-0.0000	5.8000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	7.0000	-0.0000	0.0000	-0.0000
1.5000	-0.0000	10.3500	-0.0000	0.0000	-0.0000
2.0000	-0.0000	13.8000	-0.0000	0.0000	-0.0000
3.0000	-0.0000	19.9000	-0.0000	0.0000	-0.0000
4.0000	-0.0000	26.6000	-0.0000	0.0000	-0.0000
6.0000	-0.0000	38.7000	-0.0000	0.0000	-0.0000
6.4000	-0.0000	41.7000	-0.0000	.0500	-0.0000
7.0000	-0.0000	40.8000	-0.0000	.4000	-0.0000
8.0000	-0.0000	41.7000	-0.0000	1.4000	-0.0000
9.0000	-0.0000	43.2000	-0.0000	3.0000	-0.0000
10.0000	-0.0000	45.2000	-0.0000	4.6000	-0.0000
12.0000	-0.0000	49.6000	-0.0000	8.2000	-0.0000
14.0000	-0.0000	54.1000	-0.0000	11.8000	-0.0000
16.0000	.1000	58.8000	.1000	16.4000	-0.0000
18.0000	.1000	63.2000	.2000	20.9000	.1000
21.0000	.2000	70.5000	.3000	28.5000	.2000
24.0000	.2000	77.2000	.3000	35.0000	.2000
26.6000	.2000	83.9000	.3000	41.0000	.3000
TRIAL 2					
.8000	-0.0000	5.8000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	6.9000	-0.0000	0.0000	-0.0000
1.5000	-0.0000	10.3000	-0.0000	0.0000	-0.0000
2.0000	-0.0000	13.9000	-0.0000	0.0000	-0.0000
3.0000	-0.0000	20.0000	-0.0000	0.0000	-0.0000
4.0000	-0.0000	26.3000	-0.0000	0.0000	-0.0000
6.0000	-0.0000	39.2000	-0.0000	0.0000	-0.0000
6.4000	-0.0000	41.5000	-0.0000	.0500	-0.0000
7.0000	-0.0000	41.7500	-0.0000	.3500	-0.0000
8.0000	-0.0000	42.2000	-0.0000	1.3000	-0.0000
9.0000	-0.0000	43.8000	-0.0000	2.6000	-0.0000
10.0000	-0.0000	45.2000	-0.0000	4.4000	-0.0000
12.0000	-0.0000	49.6000	-0.0000	7.9500	-0.0000
14.0000	-0.0000	54.5000	.1000	11.9000	.1000
16.0000	.1000	58.6000	.1000	16.8000	.1000
18.0000	.1000	63.2000	.2000	21.4000	.2000
21.0000	.2000	70.6000	.3000	28.4000	.2000
24.0000	.2000	77.4000	.3000	35.4000	.2000
26.6000	.2000	83.9000	.3000	41.5000	.3000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.8000	0.0000	5.8000	0.0000	0.0000	0.0000
1.0000	0.0000	6.9500	0.0000	0.0000	0.0000
1.5000	0.0000	10.3250	0.0000	0.0000	0.0000
2.0000	0.0000	13.8500	0.0000	0.0000	0.0000
3.0000	0.0000	19.9500	0.0000	0.0000	0.0000
4.0000	0.0000	26.4500	0.0000	0.0000	0.0000
6.0000	0.0000	38.9500	0.0000	0.0000	0.0000
6.4000	0.0000	41.6000	0.0000	.0500	0.0000
7.0000	0.0000	41.2750	0.0000	.3750	0.0000
8.0000	0.0000	41.9500	0.0000	1.3500	0.0000
9.0000	0.0000	43.5000	0.0000	2.8000	0.0000
10.0000	0.0000	45.2000	0.0000	4.5000	0.0000
12.0000	0.0000	49.6000	0.0000	8.0750	0.0000
14.0000	0.0000	54.3000	.0500	11.8500	.0500
16.0000	.1000	58.7000	.1000	16.6000	.0500
18.0000	.1000	63.2000	.2000	21.1500	.1500
21.0000	.2000	70.5500	.3000	28.4500	.2000
24.0000	.2000	77.3000	.3000	35.2000	.2000
26.6000	.2000	83.9000	.3000	41.2500	.3000

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
8.1425	0.0000	7.9934	0.0000	0.0000	0.0000
9.0421	0.0000	8.7482	0.0000	0.0000	0.0000
10.9386	0.0000	10.6577	0.0000	0.0000	0.0000
12.5208	0.0000	12.3393	0.0000	0.0000	0.0000
15.1470	0.0000	14.8029	0.0000	0.0000	0.0000
17.3379	0.0000	17.0389	0.0000	0.0000	0.0000
20.9744	0.0000	20.6671	0.0000	0.0000	0.0000
21.6198	0.0000	21.3569	0.0000	.4675	0.0000
22.5490	0.0000	21.2736	0.0000	1.2679	0.0000
24.0082	0.0000	21.4464	0.0000	2.3909	0.0000
25.3736	0.0000	21.8380	0.0000	3.4312	0.0000
26.6606	0.0000	22.2597	0.0000	4.3400	0.0000
29.0438	0.0000	23.3153	0.0000	5.7974	0.0000
31.2242	0.0000	24.3923	.0463	7.0100	.2135
33.2448	.3400	25.3590	.0856	8.2835	.1526
35.1354	.3033	26.3107	.1590	9.3392	.3598
37.7732	.5224	27.7949	.2137	10.8162	.3572
40.2176	.4589	29.0910	.1951	12.0188	.2890
42.2079	.4154	30.3045	.1797	13.0009	.3702

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
24058	.02867	15.9356	0	0.00000	0.0000
26330	.02828	15.8840	0	0.00000	0.0000
32077	.02750	15.7807	0	0.00000	0.0000
37138	.02697	15.7118	0	0.00000	0.0000
44553	.02639	15.6349	0	0.00000	0.0000
51283	.02598	15.5816	0	0.00000	0.0000
62203	.02548	15.5162	0	0.00000	0.0000
64279	.02541	15.5059	1407	.04549	48.7912
64028	.02542	15.5071	3816	.04306	48.1181
64548	.02540	15.5046	7196	.03644	46.2874
65727	.02535	15.4991	10327	.03355	45.4871
66996	.02531	15.4933	13062	.03196	45.0450
70173	.02521	15.4796	17449	.03026	44.5742
73414	.02511	15.4667	21098	.02929	44.3053
76324	.02503	15.4559	24931	.02852	44.0926
79188	.02495	15.4460	28108	.02801	43.9526
83655	.02484	15.4316	32554	.02744	43.7947
87556	.02475	15.4201	36174	.02706	43.6901
91209	.02468	15.4102	39129	.02680	43.6166

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
1.0000	1.0000	0.0000	24058	7.9934	2.9684
1.0000	1.0000	0.0000	26330	8.7482	3.2487
1.0000	1.0000	0.0000	32077	10.6577	3.9579
1.0000	1.0000	0.0000	37138	12.3393	4.5823
1.0000	1.0000	0.0000	44553	14.8029	5.4972
1.0000	1.0000	0.0000	51283	17.0389	6.3276
1.0000	1.0000	0.0000	62203	20.6671	7.6750
.9634	.9786	-1.5746	65686	21.8244	8.1047
.9372	.9438	-.7027	67844	22.5414	8.3710
.8977	.8997	-.2256	71744	23.8373	8.8522
.8629	.8642	-.1488	76054	25.2693	9.3840
.8367	.8368	-.0188	80058	26.5996	9.8780
.7983	.8009	-.3219	87622	29.1127	10.8113
.7721	.7768	-.6020	94513	31.4024	11.6616
.7520	.7538	-.2348	101255	33.6425	12.4935
.7366	.7380	-.1990	107297	35.6499	13.2390
.7202	.7199	.0510	116209	38.6112	14.3387
.7087	.7076	.1501	123730	41.1099	15.2666
.7003	.6998	.0700	130338	43.3054	16.0819

AVERAGE RESULTS FOR FLOWSPLIT 16

RECYCLE K-FACTOR = 15.5613
BRANCH K-FACTOR = 44.2842
RECYCLE FRICTION FACTOR = .02583
CRITICAL FLOWRATE = 20.9407 GPM

FLOWSPLIT 17

RECYCLE ORIFICE
5/8 INCH

BRANCH ORIFICE
3/8 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.8000	-0.0000	5.8000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	7.0000	-0.0000	0.0000	-0.0000
1.5000	-0.0000	10.6000	-0.0000	0.0000	-0.0000
2.0000	-0.0000	13.9000	-0.0000	0.0000	-0.0000
3.0000	-0.0000	20.1000	-0.0000	0.0000	-0.0000
4.0000	-0.0000	26.1000	-0.0000	0.0000	-0.0000
6.0000	-0.0000	39.4000	-0.0000	0.0000	-0.0000
6.4000	-0.0000	41.0000	-0.0000	.0500	-0.0000
7.0000	-0.0000	41.5000	-0.0000	.8000	-0.0000
7.5000	-0.0000	42.5000	-0.0000	1.7500	-0.0000
8.0000	-0.0000	43.7000	-0.0000	2.7000	-0.0000
9.0000	-0.0000	47.4000	-0.0000	5.2000	-0.0000
10.0000	-0.0000	50.2000	.1000	8.2000	.1000
12.0000	-0.0000	56.5000	.1000	14.4000	.1000
14.0000	-0.0000	62.6000	.1000	21.1000	.1000
16.0000	-0.0000	70.0000	.2000	27.8000	.2000
18.0000	.1000	77.6000	.3000	34.9000	.3000
21.0000	.2000	88.0000	.4000	45.2000	.4000
TRIAL 2					
.8000	-0.0000	5.8000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	7.0000	-0.0000	0.0000	-0.0000
1.5000	-0.0000	10.4500	-0.0000	0.0000	-0.0000
2.0000	-0.0000	13.9500	-0.0000	0.0000	-0.0000
3.0000	-0.0000	20.0000	-0.0000	0.0000	-0.0000
4.0000	-0.0000	26.2000	-0.0000	0.0000	-0.0000
6.0000	-0.0000	39.4000	-0.0000	0.0000	-0.0000
6.4000	-0.0000	40.6000	-0.0000	.0500	-0.0000
7.0000	-0.0000	41.6000	-0.0000	.8500	-0.0000
7.5000	-0.0000	42.8000	-0.0000	1.6500	-0.0000
8.0000	-0.0000	43.8000	-0.0000	2.6500	-0.0000
9.0000	-0.0000	47.3000	-0.0000	5.4000	-0.0000
10.0000	-0.0000	50.1000	-0.0000	7.8000	.1000
12.0000	-0.0000	56.2000	.1000	14.1000	.1000
14.0000	-0.0000	62.9000	.1000	21.0000	.1000
16.0000	-0.0000	69.8000	.2000	27.6000	.2000
18.0000	.1000	77.3000	.3000	34.8000	.3000
21.0000	.2000	88.0000	.4000	45.4000	.4000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.8000	0.0000	5.8000	0.0000	0.0000	0.0000
1.0000	0.0000	7.0000	0.0000	0.0000	0.0000
1.5000	0.0000	10.5250	0.0000	0.0000	0.0000
2.0000	0.0000	13.9250	0.0000	0.0000	0.0000
3.0000	0.0000	20.0500	0.0000	0.0000	0.0000
4.0000	0.0000	26.1500	0.0000	0.0000	0.0000
6.0000	0.0000	39.4000	0.0000	0.0000	0.0000
6.4000	0.0000	40.8000	0.0000	.0500	0.0000
7.0000	0.0000	41.5500	0.0000	.8250	0.0000
7.5000	0.0000	42.6500	0.0000	1.7000	0.0000
8.0000	0.0000	43.7500	0.0000	2.6750	0.0000
9.0000	0.0000	47.3500	0.0000	5.3000	0.0000
10.0000	0.0000	50.1500	.0500	8.0000	.1000
12.0000	0.0000	56.3500	.1000	14.2500	.1000
14.0000	0.0000	62.7500	.1000	21.0500	.1000
16.0000	0.0000	69.9000	.2000	27.7000	.2000
18.0000	.1000	77.4500	.3000	34.8500	.3000
21.0000	.2000	88.0000	.4000	45.3000	.4000

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
8.1425	0.0000	7.9934	0.0000	0.0000	0.0000
9.0421	0.0000	8.7795	0.0000	0.0000	0.0000
10.9386	0.0000	10.7602	0.0000	0.0000	0.0000
12.5208	0.0000	12.3726	0.0000	0.0000	0.0000
15.1470	0.0000	14.8399	0.0000	0.0000	0.0000
17.3379	0.0000	16.9422	0.0000	0.0000	0.0000
20.9744	0.0000	20.7859	0.0000	0.0000	0.0000
21.6198	0.0000	21.1511	0.0000	.2602	0.0000
22.5490	0.0000	21.3441	0.0000	1.0411	0.0000
23.2915	0.0000	21.6241	0.0000	1.4888	0.0000
24.0082	0.0000	21.9006	0.0000	1.8631	0.0000
25.3736	0.0000	22.7816	0.0000	2.6130	0.0000
26.6606	0.0000	23.4439	.0501	3.2033	.6319
29.0438	0.0000	24.8474	.0892	4.2622	.3559
31.2242	0.0000	26.2171	.0801	5.1696	.2414
33.2448	0.0000	27.6669	.1438	5.9216	.3674
35.1354	.3033	29.1192	.1947	6.6339	.4386
37.7732	.5224	31.0344	.2285	7.5529	.4505

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
24058	.02867	15.9356	0	0.00000	0.0000
26424	.02827	15.8821	0	0.00000	0.0000
32385	.02746	15.7760	0	0.00000	0.0000
37238	.02696	15.7106	0	0.00000	0.0000
44664	.02638	15.6339	0	0.00000	0.0000
50992	.02600	15.5836	0	0.00000	0.0000
62560	.02547	15.5144	0	0.00000	0.0000
63659	.02543	15.5089	783	.08174	152.1821
64240	.02541	15.5061	3134	.04462	141.9048
65083	.02538	15.5021	4481	.04119	140.9551
65915	.02535	15.4982	5607	.03879	140.2927
68567	.02526	15.4864	7864	.03568	139.4312
70560	.02519	15.4780	9641	.03406	138.9829
74784	.02507	15.4615	12828	.03207	138.4323
78907	.02496	15.4469	15559	.03090	138.1066
83270	.02485	15.4328	17822	.03014	137.8980
87641	.02475	15.4199	19966	.02956	137.7356
93405	.02464	15.4045	22732	.02893	137.5629

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
1.0000	1.0000	0.0000	24058	7.9934	2.9684
1.0000	1.0000	0.0000	26424	8.7795	3.2604
1.0000	1.0000	0.0000	32385	10.7602	3.9959
1.0000	1.0000	0.0000	37238	12.3726	4.5947
1.0000	1.0000	0.0000	44664	14.8399	5.5109
1.0000	1.0000	0.0000	50992	16.9422	6.2917
1.0000	1.0000	0.0000	62560	20.7859	7.7191
.9814	.9878	-.6566	64442	21.4112	7.9513
.9495	.9535	-.4200	67374	22.3853	8.3130
.9312	.9356	-.4741	69564	23.1130	8.5833
.9173	.9216	-.4633	71522	23.7637	8.8249
.8900	.8971	-.7947	76431	25.3947	9.4306
.8739	.8798	-.6748	80201	26.6473	9.8957
.8500	.8536	-.4269	87612	29.1096	10.8102
.8338	.8353	-.1746	94466	31.3867	11.6558
.8219	.8237	-.2235	101092	33.5885	12.4734
.8114	.8145	-.3807	107607	35.7531	13.2773
.8029	.8043	-.1754	116138	38.5873	14.3298

AVERAGE RESULTS FOR FLOWSPLIT 17

RECYCLE K-FACTOR = 15.5656
BRANCH K-FACTOR =137.9471
RECYCLE FRICTION FACTOR = .02586
CRITICAL FLOWRATE = 20.9378 GPM

FLOWSPLIT 18

RECYCLE ORIFICE
1/2 INCH

BRANCH ORIFICE
3/8 INCH

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
TRIAL 1					
.3000	-0.0000	6.6500	-0.0000	0.0000	-0.0000
.6000	-0.0000	12.4500	-0.0000	0.0000	-0.0000
1.0000	-0.0000	19.0500	-0.0000	0.0000	-0.0000
1.5000	-0.0000	28.6000	-0.0000	0.0000	-0.0000
2.0000	-0.0000	37.0000	-0.0000	0.0000	-0.0000
2.4000	-0.0000	42.4000	-0.0000	.0500	-0.0000
3.0000	-0.0000	43.9000	-0.0000	1.9000	-0.0000
3.5000	-0.0000	46.6000	-0.0000	4.1000	-0.0000
4.0000	-0.0000	49.5000	-0.0000	7.2500	-0.0000
5.0000	-0.0000	54.5000	-0.0000	12.7000	-0.0000
6.0000	-0.0000	61.8000	.1000	19.2000	.1000
7.0000	-0.0000	69.2000	.1000	24.8000	-0.0000
8.0000	.1000	74.5000	.2000	31.2000	.1000
9.5000	.2000	85.7000	.4000	41.1000	.3000
TRIAL 2					
.3000	-0.0000	6.5000	-0.0000	0.0000	-0.0000
.6000	-0.0000	12.4000	-0.0000	0.0000	-0.0000
1.0000	-0.0000	19.1000	-0.0000	0.0000	-0.0000
1.5000	-0.0000	28.2000	-0.0000	0.0000	-0.0000
2.0000	-0.0000	37.6000	-0.0000	0.0000	-0.0000
2.4000	-0.0000	42.4000	-0.0000	.0500	-0.0000
3.0000	-0.0000	44.1000	-0.0000	1.6000	-0.0000
3.5000	-0.0000	46.5000	-0.0000	3.9000	-0.0000
4.0000	-0.0000	49.2000	-0.0000	6.5000	-0.0000
5.0000	-0.0000	55.6000	-0.0000	13.0000	-0.0000
6.0000	-0.0000	61.8000	.1000	18.7000	.1000
7.0000	-0.0000	68.6000	.1000	24.8000	.1000
8.0000	.1000	75.6000	.2000	31.0000	.2000
9.5000	.2000	86.0000	.4000	41.1000	.3000

AVERAGED INPUT DATA:

MAIN H-L (IN HG)	HLM ERROR (+/-)	RECYCLE H-L (CM HG)	HLR ERROR (+/-)	BRANCH H-L (CM HG)	HLB ERROR (+/-)
.3000	0.0000	6.5750	0.0000	0.0000	0.0000
.6000	0.0000	12.4250	0.0000	0.0000	0.0000
1.0000	0.0000	19.0750	0.0000	0.0000	0.0000
1.5000	0.0000	28.4000	0.0000	0.0000	0.0000
2.0000	0.0000	37.3000	0.0000	0.0000	0.0000
2.4000	0.0000	42.4000	0.0000	.0500	0.0000
3.0000	0.0000	44.0000	0.0000	1.7500	0.0000
3.5000	0.0000	46.5500	0.0000	4.0000	0.0000
4.0000	0.0000	49.3500	0.0000	6.8750	0.0000
5.0000	0.0000	55.0500	0.0000	12.8500	0.0000
6.0000	0.0000	61.8000	.1000	18.9500	.1000
7.0000	0.0000	68.9000	.1000	24.8000	.0500
8.0000	.1000	75.0500	.2000	31.1000	.1500
9.5000	.2000	85.8500	.4000	41.1000	.3000

RESULTS OF AVERAGED DATA:

MAIN FLOW (GPM)	QM ERROR (+/- PCT.)	RECYCLE FLOW (GPM)	QR ERROR (+/- PCT.)	BRANCH FLOW (GPM)	QB ERROR (+/- PCT.)
5.1372	0.0000	5.2364	0.0000	0.0000	0.0000
7.1136	0.0000	7.1765	0.0000	0.0000	0.0000
9.0421	0.0000	8.8736	0.0000	0.0000	0.0000
10.9386	0.0000	10.8068	0.0000	0.0000	0.0000
12.5208	0.0000	12.3687	0.0000	0.0000	0.0000
13.6401	0.0000	13.1791	0.0000	.2602	0.0000
15.1470	0.0000	13.4231	0.0000	1.5103	0.0000
16.2841	0.0000	13.8028	0.0000	2.2734	0.0000
17.3379	0.0000	14.2079	0.0000	2.9720	0.0000
19.2533	0.0000	14.9982	0.0000	4.0497	0.0000
20.9744	0.0000	15.8823	.0825	4.9077	.2680
22.5490	0.0000	16.7610	.0741	5.6063	.1025
24.0082	.6658	17.4859	.1360	6.2706	.2456
26.0261	1.1272	18.6897	.2380	7.1980	.3722

RECYCLE RE	FR	RECYCLE-K	BRANCH RE	FB	BRANCH-K
15760	.03082	40.2509	0	0.00000	0.0000
21599	.02917	40.0339	0	0.00000	0.0000
26707	.02822	39.9090	0	0.00000	0.0000
32526	.02744	39.8067	0	0.00000	0.0000
37227	.02696	39.7436	0	0.00000	0.0000
39666	.02675	39.7158	783	.08174	152.1821
40400	.02669	39.7079	4546	.04102	140.9104
41543	.02660	39.6962	6842	.03689	139.7671
42762	.02651	39.6843	8945	.03464	139.1422
45140	.02635	39.6626	12188	.03241	138.5246
47801	.02618	39.6404	14771	.03120	138.1909
50446	.02603	39.6204	16874	.03044	137.9801
52628	.02591	39.6051	18873	.02984	137.8147
56251	.02574	39.5820	21664	.02916	137.6254

XTH	XEXP	XERR PCT	MAIN RE	QSUM (GPM)	VEL. (FPS)
1.0000	1.0000	0.0000	15760	5.2364	1.9446
1.0000	1.0000	0.0000	21599	7.1765	2.6651
1.0000	1.0000	0.0000	26707	8.8736	3.2953
1.0000	1.0000	0.0000	32526	10.8068	4.0132
1.0000	1.0000	0.0000	37227	12.3687	4.5933
.9764	.9806	-.4310	40449	13.4393	4.9908
.8984	.8989	-.0463	44946	14.9334	5.5457
.8580	.8586	-.0696	48385	16.0763	5.9701
.8283	.8270	.1510	51707	17.1799	6.3799
.7914	.7874	.5002	57329	19.0478	7.0736
.7668	.7639	.3680	62572	20.7899	7.7206
.7498	.7494	.0623	67320	22.3674	8.3064
.7379	.7360	.2446	71501	23.7566	8.8223
.7234	.7220	.1979	77915	25.8877	9.6137

AVERAGE RESULTS FOR FLOWSPLIT 18

RECYCLE K-FACTOR = 39.7613
BRANCH K-FACTOR =138.0272
RECYCLE FRICTION FACTOR = .02710
CRITICAL FLOWRATE = 13.1004 GPM

APPENDIX D - PARAMETRIC PLOTS

In order to calculate the family of curves for the parametric plots discussed earlier, it is first necessary to examine the constraints and limits on the design equation.

Referring to the equation which defines the abscissa of Figure 7, for the equal static heads case,

$$f(K) = K_B/(K_B + K_R) \quad , \qquad \text{(eq. D1)}$$

it can be noted that the value of f(K) varies from zero to one. If a separate curve does indeed exist for every value of the parameter S, one can plot the values of x vs. f(K) by fixing the values of two out of three variables in equation D1.

Since the objective is to examine the entire range of f(K), either K_R or K_B must be held constant. For a given value of K_R or K_B, the recycle fraction can be calculated for each S curve at each value of f(K). This is possible since both resistance coefficients will be known from equation D1 and the value of S, which gives the flowrate and static heads, is also known.

From a design point of view, perhaps the most useful representation would result if the value of K_R were held constant in such a parametric plot. For the case of a recycle/branch flow system, a control valve might be used to maintain a constant recycle flow in order to satisfy process requirements. The recycle line would then be sized for maximum flowrate and the branch line would contain the control valve. This is necessarily the case since it is the branch flow which varies in direct proportion to the main-flow fluctuations; for an increase in main-flow, the recycle flow drops and the branch flow increases so that for the control valve to do the proper adjustment in flow, it must be located in the branch line.

In general, this reasoning may not apply and depending on the particular piping system, a decision will have to be made regarding the flow regulation. However, in many cases it will probably be true that one delivery line will exhibit a constant flow resistance and the other a variable flow resistance.

For the case of a fixed recycle-line flow resistance, the following limits on equation D1 can be observed:

$$\begin{aligned} &\text{As } f(K) \longrightarrow 0, \quad K_B \longrightarrow 0 \\ &\text{As } f(K) \longrightarrow 1, \quad K_B \longrightarrow \infty \end{aligned} \qquad \text{(eq. D2)}$$

Examining the limits on the recycle fraction x in the design equation, the following is noted:

$$\begin{aligned} &\text{At } x = 0, \quad S = -K_B \\ &\text{At } x = 1, \quad S = K_R \end{aligned} \qquad \text{(eq. D3)}$$

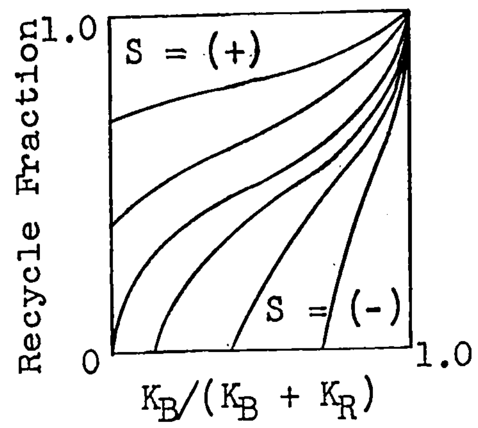
The condition for $x = 0$ defines a locus of points for all values of S, whereas the condition at $x = 1$ defines only a single point for all values of S. Thus, the abscissa on a plot of the form of Figure 7 is the locus of $x = 0$ as determined by the values of K_B for discrete negative values of the parameter S.

Consider also the values of the ordinate at a zero value of the abscissa:

$$\text{At } f(K) = 0, \quad K_B \longrightarrow 0$$

$$\therefore \quad x = \sqrt{S/K_R} \qquad \text{(eq. D4)}$$

and so, this relation can hold only for positive values of S. This equation then defines the locus of points along the ordinate at $f(K) = 0$ for all values of positive S. The values of S, as noted above, can only vary from $-K_B$ to K_R. Thus, all conditions for the variables involved have been established and the parametric plot can be found to exhibit the following form:



Type A Parametric Plot

K_R fixed

Figure D1

For the case of maintaining a constant resistance coefficient for the branch line, a similar analysis can be carried out. The general form of the parametric plot would then be as given in Figure D2.

It was earlier noted in the discussion of Figure 8 that the minimum recycle fraction which can be achieved, for any

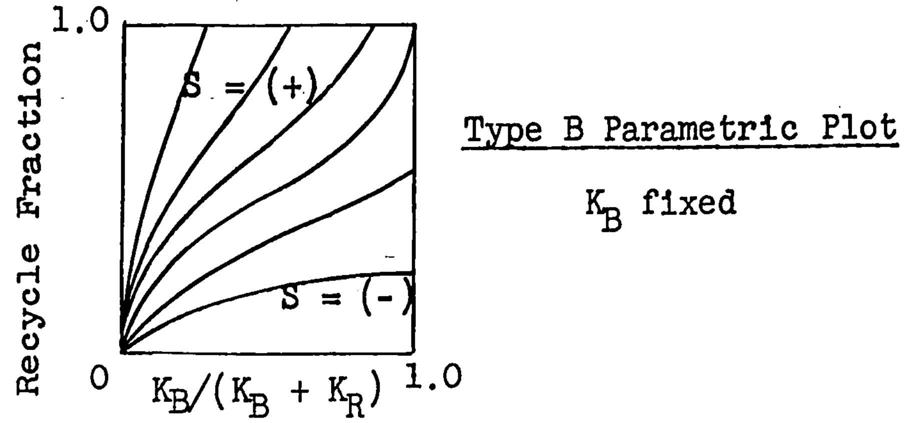


Figure D2

combination of K_B and K_R, is that given by the case of equal static heads, or $S = 0$. This is the situation when S is a positive quantity, and is the situation likely to be encountered in the vast majority of cases. However, for negative values of S, the condition specified by $S = 0$ represents the maximum recycle fraction which could be achieved. This is the case simply because, with respect to the established convention of the general model, flow begins in the branch line when S is negative. As main flowrate increases, a different critical flowrate is reached, at which point recycle flow begins, and then the recycle fraction asymptotically approaches a maximum given by the $S = 0$ case. The critical flowrate in this instance depends on the branch resistance coefficient and can be derived, as done previously, to be:

$$Q_c' = (STAT_R - STAT_B)\ C_f/K_B \qquad \text{(eq. D5)}$$

Such a critical flowrate is not likely to be of any consequence for ordinary recycle/delivery systems since the occurrence of zero recycle would be useless. However, it might occur for a general branched system where the pressure difference between delivery points is sufficiently great such that the static head difference is overcome, and flow does indeed begin in the line of higher delivery point elevation. Of course, by changing the convention of the general model, this situation can be described by the relations given for the case of positive S, which intuitively makes more sense.

It is a matter to be decided upon by the designer whether a Type A or Type B plot is most useful and convenient for a given application. A series of charts would have to be constructed to accommodate the various fixed values of K_R or K_B. However, the construction of such plots entails a great deal of effort; the use of parametric plots as a design tool would be advantageous only if they had been prepared in advance and were readily available for reference.

It can already be imagined that such a collection of charts would be somewhat unwieldy. However, some simplification can be made to greatly reduce the number of such charts required. For each increase in the order of magnitude of the recycle resistance coefficient (for Type A charts), the same S curve results if there is also a corresponding increase in the order of magnitude of each of the S curves. Thus, the same chart may be used for $K_R = 100$ and $K_R = 1000$, when S values for each curve are also increased tenfold in going from the first to the second case. This behavior is a result of the direct relationship between the resistance coefficients and S in the design equation, for fixed values of x and f(K). The consequence of this property is that a set of charts can be used to represent the entire range of possible variations of both resistance coefficients. Sufficient accuracy would probably be attained with a set of 18 charts, covering discrete values of K_R with the following unit values:

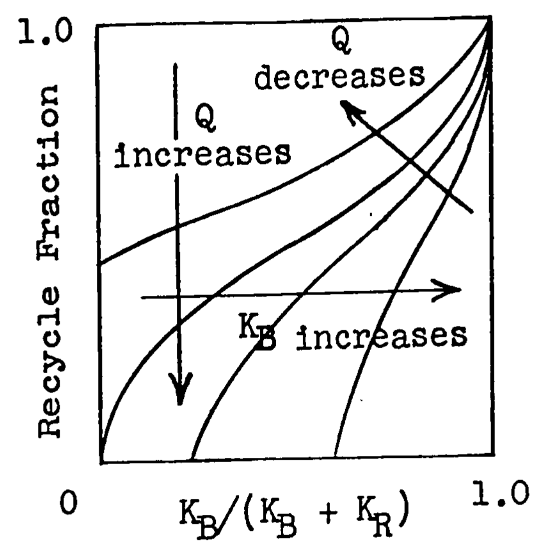
1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0,
5.5, 6.0, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0, 9.5.

A satisfactory estimate of recycle fraction could be obtained by interpolating results given by the two charts which bracket the fixed value of the resistance coefficient. As an example, consider the case for K_R = 1200. Since this is probably an average value, with limits of perhaps $\pm$ 100, one could interpolate the results as given by the 1.0 and 1.5 charts to get a good estimate of the desired result.

Although this sounds fine in principle, in actual practice this procedure would probably be more tedious than the iterative solution of the design equation. Together with the limited precision available with the need for interpolation, this method is not a satisfactory shortcut to the design and analysis of branched piping systems.

However, the general parametric plot is useful for examining some of the behavioral properties of these systems. It is instructive to consider the following types of system analysis, as depicted in Figure D3 for a Type A plot.

For a given piping system with fixed branch resistance as well as recycle resistance, a vertical line at some constant value of f(K) can be established. As the main flowrate increases, the value of S decreases and consequently, the recycle fraction decreases. For an increase in the static head difference of the delivery lines at a given flowrate, the value of S increases and so, the recycle fraction is higher than for the case of less difference in static heads.



System Behavior on a Parametric Plot

K_R is fixed.

Figure D3

For a given recycle fraction to be maintained, a horizontal line at some constant x is established. If the branch resistance is increased, f(K) increases and the line of constant x crosses S curves of a lower value; hence, the main flowrate must increase for a fixed STAT. (The same behavior would result if recycle resistance in a Type B system is reduced). Conversely, if the main flowrate increases, a control valve should respond to increase the branch resistance so that f(K) is increased and x can be maintained. It should be noted that at high recycle fractions, the S curves are nearly horizontal over almost the entire range of f(K); the S curves at low recycle fractions are steeper for a wider range of f(K). For a given change in flowrate, this requires that a much larger increase in branch resistance is required at high recycle fractions than at low recycle fractions in order to maintain a constant recycle fraction. It may then be desirable to design a system so that f(K) is nearly equal to one when dealing with high recycle fractions, so that the slope of the S curve is more steep than flat.

The behavior when maintaining a constant flowrate is given by the span of conditions for a single S curve. Obbiously, recycle fraction increases as branch resistance increases (or recycle resistance decreases) because of an increase if f(K).

Similar behavior results for all these cases when a different plot, based upon a different fixed recycle or branch resistance, is used. However, the extent to which ΔSTAT and Q must change in order to maintain a constant recycle fraction, for example, varies from one plot to the next because of the different values of S in the same region, for all such plots.

A listing of the computer program used to prepare parametric plots for the experimental apparatus, as mentioned in the Discussion, is presented in the following two pages.

```
C**** ABSTRACT:
C     *** THIS PROGRAM CALCULATES AND PLOTS THE DATA PAIRS, (X,Y), GIVEN
C     BY (K-FUNCTION, RECYCLE FRACTION), AS A FAMILY OF CURVES IN THE
C     PARANETER S ****
C-----------------------------------------------------------------------

      DIMENSION FK(50,50), BK(50,50), XTH(50,50)
      DIMENSION XAXIS(2), YAXIS(2), XYAXIS(2)

      I = 1
      L = 1
C     *** THE BASIS OF EACH PLOT IS THE GIVEN RECYCLE K-FACTOR ****
      GO TO (38,12,58) L
   38 RK = 132.5
      SMIN = -1000.
      SMAX = 120.
      GO TO 555
   12 RK = 38.8
      SMIN = -300.
      SMAX = 35.
      GO TO 555
   58 RK = 14.6
      SMIN = -100.
      SMAX = 14.
  555 CONTINUE
      S = SMIN
   20 CONTINUE

      MAX = 30
      AMAX = MAX
      NK = MAX + 1
      FK(NK,I) = 1.
      XTH(NK,I) = 1.
      P = S
C     **** CALCULATE THE INITIAL POINT FOR EACH S-CURVE ****
      IF (S - 0.) 100,200,300
  300 FK(1,I) = 0.
      XTH(1,I) = SQRT(S/RK)
      GO TO 90
  200 FK(1,I) = 0.
      XTH(1,I) = 0.
      GO TO 90
  100 XTH(1,I) = 0.
      FK(1,I) = -1.*S/(RK - S)
C     **** CALCULATE THE VALUES OF X AT EACH INCREMENT OF FK ****
   90 DF = (1. - FK(1,I))/AMAX
      DO 10  K=2,MAX
      J = K - 1
      FK(K,I) = FK(J,I) + DF
   40 BK(K,I) = RK*FK(K,I)/(1. - FK(K,I))
   85 X = 1.0
   73 FX = (RK - BK(K,I))*X**2. + BK(K,I)*(2.*X - 1.) - S
      DFX = 2.*(RK - BK(K,I))*X + 2.*BK(K,I)
      X = X - FX/DFX
      ERR = ABS(FX)
      IF (ERR.GT.0.0001) 73,75
   75 XTH(K,I) = X
   10 CONTINUE
C     **** PLOT THE POINTS (FK,X) FOR EACH VALUE OF S AT A GIVEN RK ****
      IF (S.NE.SMIN) GO TO 50

      CALL QIKSET (5.0,0.0,0.2,5.0,0.0,0.2)
      CALL QIKSAX (3,3)
      CALL QIKPLT (FK(1,I),XTH(1,I),NK,24H*K-FUNCTION, BK/(BK+RK)*,21H*R
     .ECYCLE FRACTION, X*)
      CALL PLOT (-6.0,1.0,-3)
   50 IF (S.EQ.SMIN) GO TO 60
    5 CALL QLINE (FK(1,I),XTH(1,I),NK)
   60 CONTINUE
```

```
C     **** LABEL EACH S-CURVE ON THE PLOT ****
      THETA = (ATAN((XTH(4,I) - XTH(2,I))/(FK(4,I) - FK(2,I))))*180./3.1
     .4159
      IF (S.LT.1000.) FORMAT = 4HF4.0
      IF (S.LT.100.) FORMAT = 4HF3.0
      IF (S.LT.10.) FORMAT = 4HF2.0
      IF (S.LT.0.) FORMAT = 4HF3.0
      IF (S.LE.-10.) FORMAT = 4HF4.0
      IF (S.LE.-100.) FORMAT = 4HF5.0
      IF (S.LE.-1000.) FORMAT = 4HF6.0
      CALL NUMBER (5.*FK(3,I),5.*XTH(3,I),.10,S,THETA,FORMAT)

C     **** SPECIFY THE FORTHCOMING VALUES OF S WITH THE INCREMENT DS ***
      GO TO (380,120,580) L
  380 IF (FK(1,I).LE.1.0) DS=500.
      IF (FK(1,I).LE.0.8) DS=200.
      IF (FK(1,I).LE.0.7) DS=100.
      IF (FK(1,I).LE.0.6) DS=50.
      IF (FK(1,I).LE.0.4) DS=20.
      IF (FK(1,I).LE.0.2) DS=10.
      GO TO 95
  120 IF (FK(1,I).LE.1.0) DS=100.
      IF (FK(1,I).LE..85) DS=50.
      IF (FK(1,I).LE.0.7) DS=20.
      IF (FK(1,I).LE.0.5) DS=10.
      IF (FK(1,I).LE.0.4) DS=5.
      GO TO 95
  580 IF (FK(1,I).LE.1.0) DS=20.
      IF (FK(1,I).LE..75) DS=10.
      IF (FK(1,I).LE.0.6) DS=5.
      IF (FK(1,I).LE.0.4) DS=2.
   95 S = S + DS
      I = I + 1
      IF (S.GT.SMAX) GO TO 500
      GO TO 20
C     **** CONSTRUCT UPPER AXES ON PLOT OF K-FUNCTION ****
  500 XAXIS(1) = 0.
      XAXIS(2) = 1.
      YAXIS(1) = 0.
      YAXIS(2) = 1.
      XYAXIS(1) = 1.
      XYAXIS(2) = 1.
      CALL QLINE (XAXIS,XYAXIS,2)
      CALL QLINE (XYAXIS,YAXIS,2)
      CALL SYMBOL (0.4,7.0,.14,35HPARAMETRIC PLOT OF RECYCLE FRACTION,
     .0.0,35)
      CALL SYMBOL (0.0,6.7,.14,41HAS A FUNCTION OF RESISTANCE COEFFICIEN
     .TS,,0.0,41)
      CALL SYMBOL (0.3,6.4,.14,37HFLOWRATE, AND STATIC-HEAD DIFFERENCE.,
     .0.0,37)
      IF (I.EQ.1) CALL SYMBOL (1.0,5.8,.14,24H3/8 INCH RECYCLE ORIFICE,
     .0.0,24)
      IF (I.EQ.2) CALL SYMBOL (1.0,5.8,.14,24H1/2 INCH RECYCLE ORIFICE,
     .0.0,24)
      IF (I.EQ.3) CALL SYMBOL (1.0,5.8,.14,24H5/8 INCH RECYCLE ORIFICE,
     .0.0,24)
      CALL PLOT (8.0,-1.0,-3)
 1000 CONTINUE
      END
```

APPENDIX E - NOMOGRAPH

In order to construct a nomograph to represent a particular equation, it is necessary to examine the form of the equation and compare it to several standard types of equations (15). Each type of standard equation results in a particular type of nomograph. In certain cases, two different standard forms may together, represent the form of the equation in question. When this occurs, the two different equation types can be used to construct a nomograph which is a composite of the two corresponding standard forms.

Since it is desired to represent the design equation as a nomograph, it must be rearranged to conform to one or more standard equation types. This is evidently not a very simple equation since the variable x is distributed in two terms in a non-separable fashion. The only standard type of equation to which the design equation can conform is the following:

$$f(x) = \psi(x) \cdot F(y) + \phi(z)/\mu(w) \qquad \text{(eq. E1)}$$

in which form the design equation may be written as:

$$2x - 1 = x^2(1 - K_R/K_B) + S/K_B \qquad \text{(eq. E2)}$$

This equation arises simply from expanding the $(1 - x)^2$ term in the design equation and by collecting like terms in x. (Solving for x using the quadratic formula does not result in any useful form of equation. Because of the distributed K_B term, attempting to collect like terms or a collection of terms in K_B and K_R only results in a mess, such as:

$$\alpha = \pm K_B (S + \alpha K_R)/\alpha - x \qquad \text{(eq. E3)}$$

with $\alpha = K_B/(K_R - K_B)$. Here, α is not capable of being collected as in equation E1 and so, this form is of no use.)

Equation E2 is seen to be a combination of two standard equation types, which are the following:

$$f(x) = \Psi(x) \cdot F(y) + \alpha \qquad \text{(eq. E4)}$$

and

$$\phi(z) = \mu(w)/(1/\alpha) \qquad \text{(eq. E5)}$$

The procedure here is to construct two separate nomographs, each one in accordance with the two standard equations E4 and E5. The variable α will be used as a common reference axis to combine the two charts. In preparing the final nomograph, the scales used for the α axis must therefore be the same in each of the two preliminary charts.

The form of the nomograph represented by equation E4 is given in Figure E1, and that of equation E5 is given in Figure E2. If the scaling can be worked out properly, it may be possible to represent the design equation by a nomograph similar to the combined form given in Figure E3.

In order to scale the axes, the anticipated range of each variable and term in the standard equation must be examined:

1. $(1 - 2x)$ ranges from -1 to $+1$,
   x ranges from 0 to 1,
2. $(1 - K_R/K_B)$ ranges from 0 to perhaps -100
   for $K_R > K_B$,

Nonlogarithmic Multiplication Nomograph

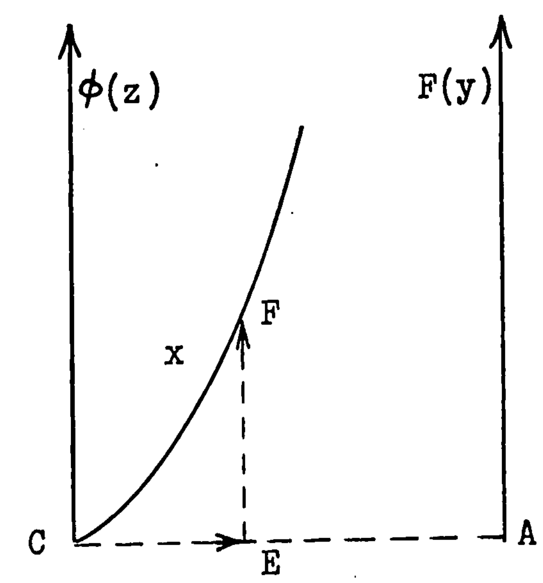


Figure E1

Recurrent Variable Nomograph

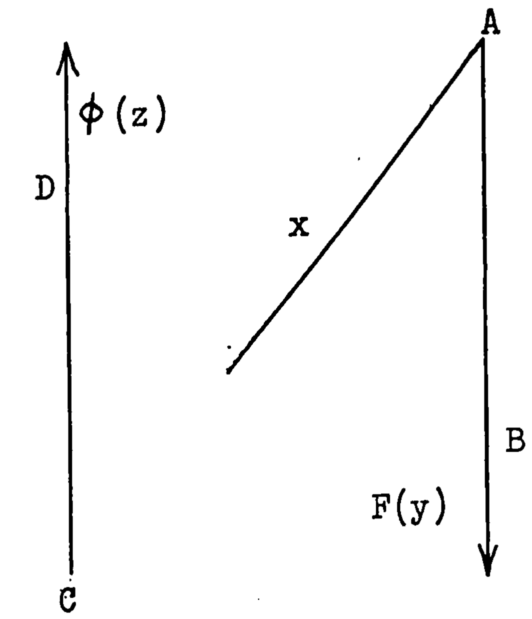


Figure E2

Combination Nomograph

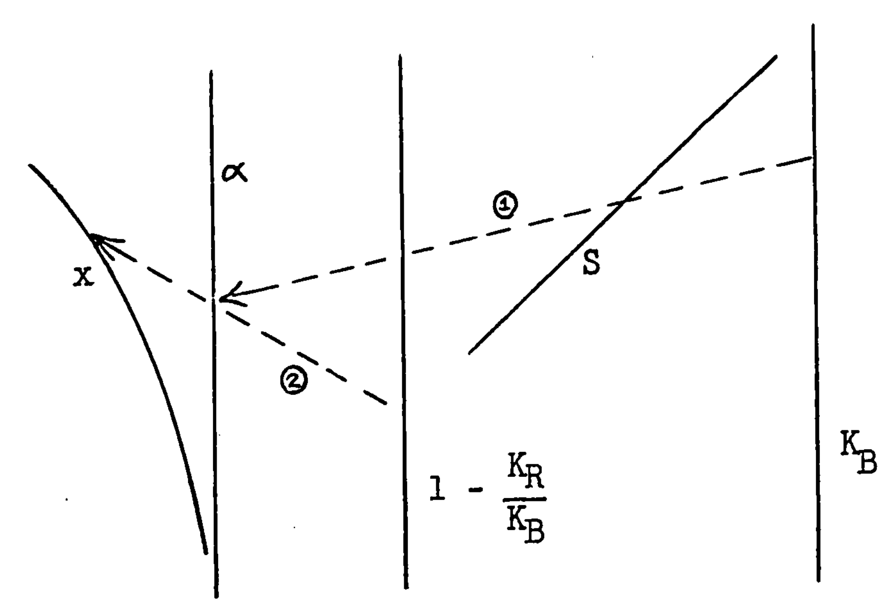


Figure E3

$(1 - K_R/K_B)$ ranges from 0 to 1 for $K_R < K_B$;

3. S ranges from 0 to perhaps 500 to 1000 if

   Z+DP = 100 at most, and Q = 10 at least;

4. K_B ranges from 0 to perhaps a few thousand.

Of course, for a nomograph to be useful as a design tool, it should be perfectly general and should cover as wide a range in all parameters as is realistically possible. It can be seen that several scaling problems arise if the above general ranges in the variables are to be satisfied. In this type of nomograph, it is not permissible to use logarithmic scales due to the nature of the standard equation type. None of the axes (except #1) can be properly scaled to accommodate the desired ranges with adequate precision. It may be possible, however, to limit the ranges of one or more of these terms on a single nomograph and to construct a second nomograph to cover the remaining ranges. For example, one chart could cover the range in K_B from 0 to 500 and another from 500 to perhaps 1000. In addition, the #2 axis must be split onto two charts with one for the $K_R > K_B$ case and another for the $K_R < K_B$ case. Together, at least four nomographs would be required in order to obtain a realistic degree of accuracy.

This alone is reason enough for abandoning the nomograph idea. A nomograph is supposed to be a simple tool for providing quick and easy solutions to problems. Once it becomes necessary to juggle four different charts in order to find, perhaps through trial-and-error, which one chart can yield the desired problem solution, then this technique is no longer the simple tool it was intended to be. Certainly, the iterative solution of the design equation would be less trouble.

However, adding to this concern is another factor which does not permit construction of a workable nomograph. Considering axis #1, the standard chart for equation E4 cannot accommodate the symmetrical function (1 - 2x) with a range of -1 to +1. The only way the chart can be constructed is to split the range from -1 to 0 and from 0 to +1 in two separate charts. Thus, here is another problem which undoubtedly complicates the nomograph idea to the point where any further consideration would be futile.

VITA

The author was born on December 7, 1955 in Brooklyn, New York, as the second son of John and Elaine Nowak. He attended elementary school at Our Lady of Consolation school and high school at St. Francis Preparatory school in Brooklyn, graduating in the top-ten of his class. He pursued undergraduate studies in chemical engineering at The Cooper Union in New York City, and was awarded a Bachelor of Engineering degree on June 1, 1977.

Following a summer of research at Manhattan College in the Bronx, he was lead author of a paper appearing in the Proceedings of the Fourth National Conference on Energy and the Environment, and presented said paper at the conference in October, 1976. The paper was entitled, "A Theoretical Model to Predict Pressure Drop for Flow Through Fabric Filters."

During his graduate studies at Lehigh University, he worked for all four semesters as Teaching Assistant in the Unit Operations Laboratory.