SECTION 8.2

BRANCH-LINE PUMPING SYSTEMS

J. P. MESSINA

In some systems, the liquid leaving the pump or pumps will divide into a network of pipes. If the pump is of the centrifugal type, the total pump flow is dependent on the combined system resistance. The total pump flow and flow through each branch can be determined by the following methods. (Review "Pump Total Head and System-Head Curves" in Section 8.1.)

BRANCHES IN CLOSED-LOOP SYSTEMS

Figure 1 illustrates a pump and network of piping consisting of three parallel branches in series with common supply and return headers. Junction points 1 and 2 need not be at the same elevation (provided the liquid density remains constant and the pipes flow full and free of vapor) because, in a closed-loop system, the net change in elevation is zero. Figure

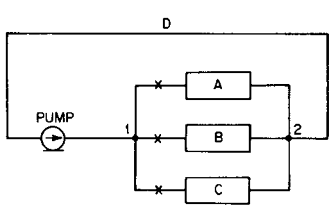

FIGURE 1 Closed loop pumping system with branch lines

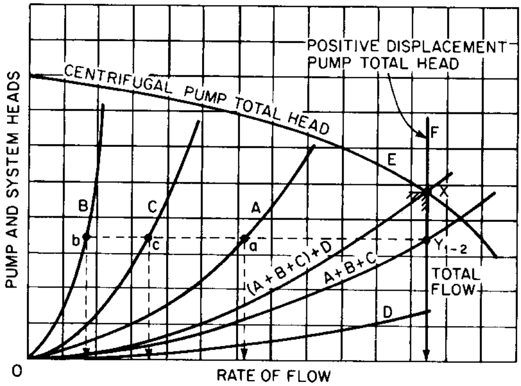

FIGURE 2 System-head curves for pump and branch lines shown in Figure 1 with all valves open

2 shows the system total-head curves for each branch line and header considered independent of the others. These curves are constructed for several flow rates by adding the frictional resistances of the pipes, fittings, and head losses through the equipment serviced from point 1 to point 2. Curves *A, B, C,* and *D* therefore represent the variation in system resistance in feet (meters) versus flow through each branch and header.

If the valves are open in all branches, the total system resistance, total pump flow, and individual branch flows are found by the following method. First observe that (a) the total flow must be equal to the sum of the branch flows, (b) the head loss or pressure drop across each branch from junction 1 to junction 2 is identical, and (c) the flow divides to produce these identical head losses. Therefore, at several head points, add together the flow through each branch and obtain curve $A + B + C$. *Header D* is in series with branches *A, B,* and *C*, and their system heads are added together for several flow conditions to obtain curve $(A + B + C) + D$. On curve *E,* the head-capacity characteristics of a centrifugal pump, point *X* represents the pump flow because at this point the system total head and pump total head are equal. Point Y_{1-2} represents the total head across points 1 and 2, and this head determines the flow through each branch; consequently points *a, b,* and *c* give individual branch flows. Curve *F* represents the head-capacity characteristics of a positive displacement pump (constant capacity) that would produce the same flow conditions.

If valve A is open and valves B and C are closed, Figure 3 shows the construction of the curves required to determine pump flow point X'. Obviously the pump flow and branch *A* flow are the same. Note that the total flow of point *X* is less than when all valves are open as a result of an increase in system head. If all valves were open and the total flow was obtained by a positive displacement pump having a constant capacity curve *F,* closing valves *B* and *C* would not change the flow. The system head would, however, increase to point X'' and the head would be greater than for a centrifugal pump having curve *E*.

Also shown in Figure 3 are the system total-head curves for different combinations of open valves *A, B,* and *C* and the resulting flow caused by a pump having characteristic curve *E*. For these various valve combinations, the head differential across the junction points is found by subtracting the head of the curve *D* from the system total head for the condition investigated, for example, point Y'_{1-2} for only valve A open. The intersection of a horizontal line through point Y'_{1-2} and the individual branch curves gives the branch flow, as illustrated in Figure 2.

BRANCHES IN OPEN-ENDED SYSTEMS

Figure 4 illustrates a pump supplying three branch lines that are open-ended and terminate at different elevations. Figure 5 shows the system total-head curves for each branch

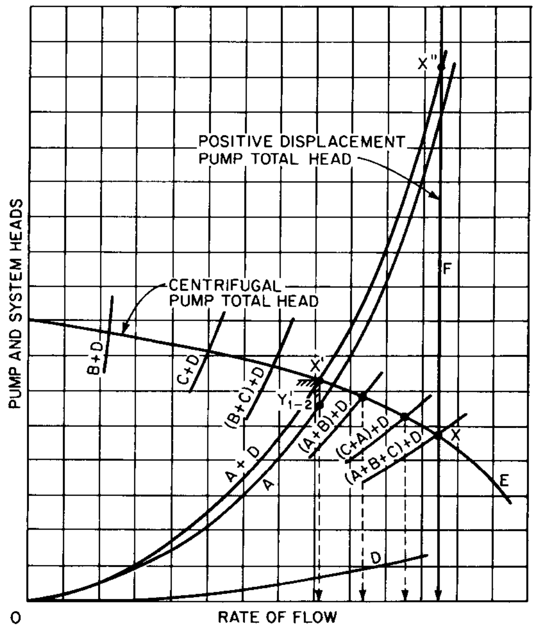

FIGURE 3 System-head curves for pump and branch line shown in Figure 1 with different combinations of open valves

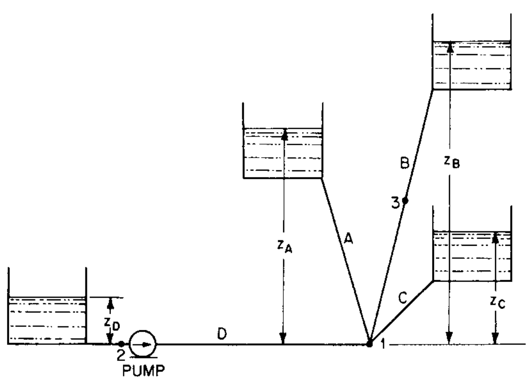

FIGURE 4 Open-ended pumping system with branch lines

line and main supply line considered independently of each other. These curves are constructed by starting at elevation heads Z_A, Z_B, Z_C and Z_D at zero flow. To each of these heads is added the frictional resistances in each line for several flow rates. Frictional losses from the suction tank to junction 1 are included in curve D. Curves A, B, C, and D therefore represent the variation in system resistance in feet (meters) versus flow through each branch and supply line. Note that Z_D is negative because in line D there is a decrease in elevation to point 1.

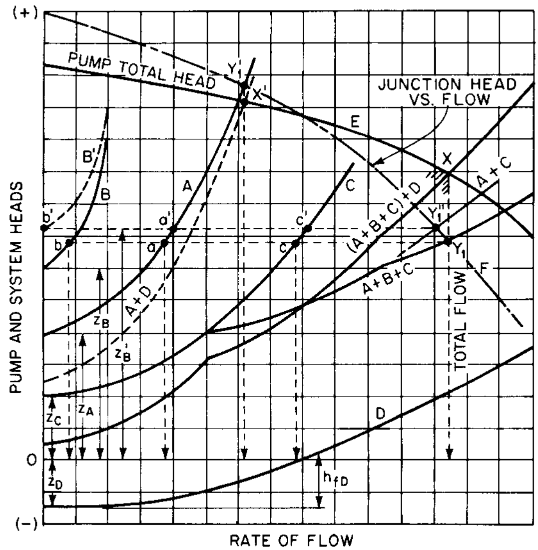

FIGURE 5 System-head curves for pump and branch lines shown in Figure 4

The total head at the junction is the head Z_D in the suction tank measured above point 1 plus the pump total head less the frictional head loss h_{fD} in line D, and it varies with flow, as illustrated by curve F.

The total system resistance, total pump flow, and individual branch flows are found by the following method. First observe that (a) the total flow must be equal to the sum of the branch flows, (b) the frictional resistance plus the elevation head measured relative junction 1 for each branch is identical and (c) the flow divides to produce these identical total branch heads. Therefore, at several head points, add together the flow of each branch to obtain curve $A + B + C$. Supply line D is in series with branches A, B, and C, and their system heads are added algebraically for several flow conditions to obtain curve $(A + B + C) + D$. If curve E is the head-capacity characteristics of a centrifugal pump, point X represents the pump flow because at this point the system total head and pump total head are equal. Point Y_1 represents the total head at junction 1, and this head determines the flow through each branch; consequently points a, b, and c give individual branch flows.

In this example the pump discharges to all tanks, but this should not be assumed. There is a limiting liquid level elevation for each tank, and, if this level is exceeded, flow will be from the tank into the junction. Therefore it is possible for the lower-level tanks to be fed by the higher-level tank and the pump. The limit for the liquid elevation in tank B is Z'_B, and it is found from the intersection of curve $A + C$ with curve F, point Y''_1. The flow in branches A and C is at rates a' and c' when there is no flow in branch B. This is also a condition similar to closing a valve in branch B.

If elevation Z_B is greater than previously found limiting height Z'_B flow in branches A and C is determined in the following manner. Construct a curve for junction head versus flow by adding heads and flows that result when the pump and suction tank are in a series with each other and tank B (less line losses) is in parallel with the pump and suction tank. The intersection of this curve with curve $A + C$ will give the junction head required to determine the individual flows from the pump and tank and the flows to tanks A and C (not illustrated).

If flow to branches B and C is shut off, Figure 5 illustrates the construction of the curves required to determine the pump flow point X' and junction head point Y'_1.

CENTRIFUGAL PUMP BYPASS

Bypass orifices around centrifugal pumps are often used to maintain a minimum flow recommended by the pump manufacturer because of one or more of the following reasons:

- To limit the temperature rise to prevent seizing and cavitation
- To reduce shaft and bearing loads
- To prevent excessive recirculation in the impeller and casing
- To prevent overloading of driver if pump power increases with decrease in flow

Figure 6 illustrates a system that under certain conditions reduces pump flow below the recommended minimum. The pump delivers its flow to either tank *A* or tank *B*. Figure 7 shows the separate system-head curves for flow to tank *A* and for flow to tank *B*. Curve *E* is the head-capacity characteristics of the centrifugal pump. Individual flow rates to each tank are shown as Q_A and Q_B. The recommended minimum flow is Q_R, which is greater than Q_B by the amount shown. In order to maintain the minimum flow, a bypass orifice with necessary pipe, valves, and fittings is required to pass flow Q_c at total head H_R is when the pump discharges to tank *B* only.

Figure 8, (curve *C*) shows the construction necessary to determine the required bypass head versus flow characteristics of the orifice and pipe. The bypass system-head curve *C* includes the pipe, valve, and fitting losses from the pump connection between the suction tank and the end of the bypass piping below the suction water level. These losses must be deducted from the total bypass losses to determine the required orifice head.

Figure 9 illustrates the resultant pump flow with the bypass in operation. Curve *C* is added to curve *B* to obtain curve *B* + *C* by combining flows through each system at the same heads. Note that flow through the piping from the suction tank to junction 1 is the

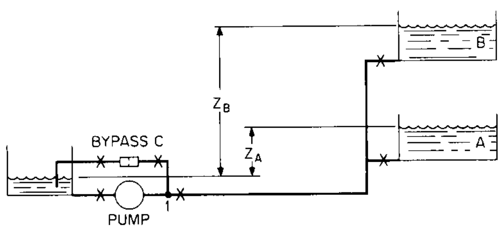

FIGURE 6 Pump with bypass to maintain minimum flow

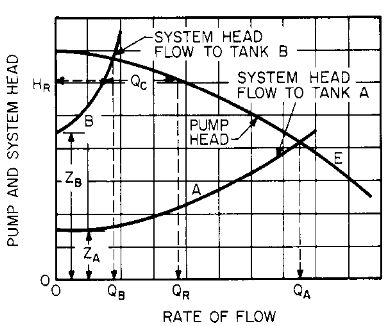

FIGURE 7 System-head curves for pump and tanks shown in Figure 6 with bypass valve closed

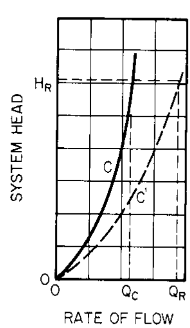

FIGURE 8 Bypass orifice system requirements

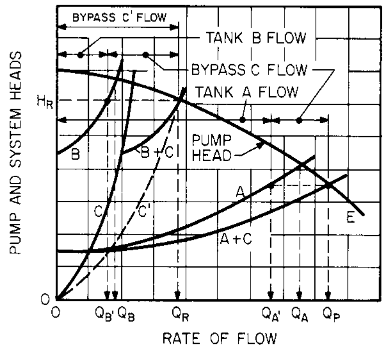

FIGURE 9 System-head curves for pump and tanks shown in Figure 6 with bypass valve open

total from both systems. Therefore, the combined system-head curve $B + C$ should take this into consideration. Similarly, curve C is added to curve A to obtain curve $A + C$. Note that when the flow is directed to tank B with the bypass open, pump flow is increased from Q_B to Q_R and tank flow is decreased from Q_B to Q'_B. When the flow is directed to tank A with the bypass open, pump flow is increased from Q_A to Q_p and tank flow is decreased from Q_A to Q'_A.

If it is desired that there be no reduction in flow or that there be no waste of pumping power when flow is to tank *A*, the bypass can be closed either manually or automatically. If pump flow is monitored, this measurement can be used to open, close, or modulate the bypass valve automatically to maintain desired flow. Refer to Subsection 2.3.4 for more detailed information.

If operating procedures require that the pump occasionally be run with a closed valve (at the pump discharge or at tanks *A* and *B*), the bypass line must be designed to recirculate all of the minimum required pump flow Q_R, dissipating head H_R, shown as curve C' and Figures 8 and 9.

FLOW CONTROL THROUGH BRANCHES

The flow through branches *A, B,* and *C* in Figures 1 and 4 is dependent on the individual branch characteristics. When parallel branches are connected to a pump, the resulting division of flow may not satisfy the requirements of the individual lines. If it is desired that the flow to each branch meet or exceed specified individual line requirements, it is necessary only to select a pump to provide the maximum head required by any one branch. In those branches where this head is more than required, the flow will be greater than the desired amount. A throttling valve or other flow-restricting device may be used to reduce the flow in these branches to the desired quantity. If the flow is controlled in this manner, the pump need be selected to produce only the minimum total system flow at a total head required to satisfy the branch needing the highest head at junction 1 in Figures 1 and 4.

The flow through a branch is sometimes dictated by the requirement of a component elsewhere in the system. For example, in the system shown in Figure 10, the required flow through component *V* could be greater than the sum of the required flows through components *A, B,* and *C*. An additional branch line and control valve *F* around components *A, B,* and *C* may be used to bypass the additional flow needed by component *D*. Individual component throttling valves may also be used, if needed, to adjust the flow in each branch.

The following example illustrates how flow through branches may be controlled and how pump total head is calculated.

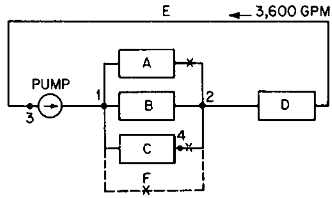

FIGURE 10 Example of a branch-flow pumping system

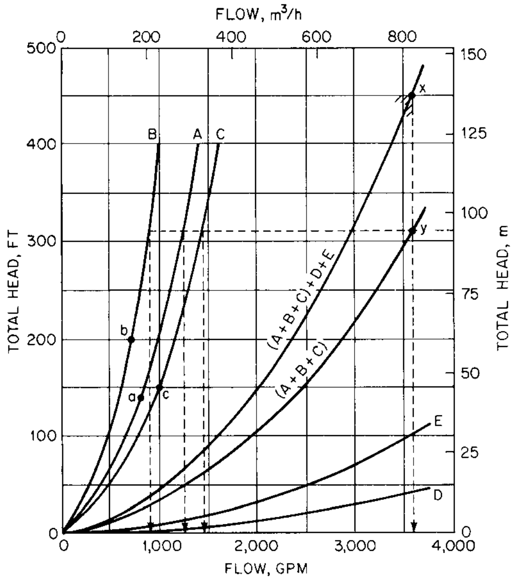

FIGURE 11 System-head curves required for solutions to example problems

EXAMPLE A pump is required to circulate water at a rate of 3600 gpm (817 m³/h) through the system shown in Figure 10. The head versus flow characteristics of the system components *A, B,* C, *D*, and *E* (system pipe and fittings) are shown in Figure 11. The branch pipe and fitting losses from point 1 to point 2 are included in the total heads for components *A, B,* and *C*. Determine

1. The pump total head required and the individual flows through components *A, B,* and *C*
2. The pump total head required if the flow through components *A, B,* and *C* need be only 800, 700, and 1000 gpm (182, 159, and 227 m³/h), respectively, and a bypass *F* is installed

Calculate the individual throttling valve head drops to achieve a controlled branch flow system.

Solution

1. Head versus flow curves *A, B,* and *C* of Figure 11 are added together in parallel, giving curve *(A + B + C)*. Curves (A + *B* + *C*), *D*, and *E* are added together in

series, resulting in curve $(A + B + C) + E + E$. This latter curve indicates that 450 ft (137 m) total pump head is required at 3600 gpm (817 m^3/h), point X. Curve $(A + B + C)$ crosses point Y at 3600 gpm (817 m^3/h) flow through the branches, and this condition requires 310 ft (94.5 m) total head, which is the head across branch points 1 and 2. From each individual component curve, the flow through branches *A, B,* and *C* can be read as 1250, 900, and 1450 gpm (284, 204, and 329 m^3/h), respectively.

2. Because the total flow through components *A, B,* and *C* need be only 2500 gpm (800 + 700 + 1000) [568 m^3/h (182 + 159 + 227)], the bypass should be designed to pass 1100 gpm (249 m^3/h). Component *B* requires the maximum head, 200 ft (61 m) differential (point *b*) across points 1 and 2. Throttling valves are needed in components *A* and *C* and bypass *F* to increase the head in each branch to 200 ft (61 m) at the required flows. Branch *A* (point *a*) requires only 140 ft (42.7 m) total head to pass 800 gpm (182 m^3/h); therefore the throttling valve must be designed for a 60-ft (42.7-m) head loss. Branch *C* (point *c*) requires only 150 ft (45.7 m) total head to pass 1000 gpm (227 m^3/h), requiring a throttling valve for a 50-ft (15.3-m) head loss. The bypass control valve and piping should be designed to produce a 200-ft (61-m) head drop at 1100 gpm (249 m^3/h).

At 3600 gpm (817 m^3/h), the pump is now required to overcome 200 ft (61 m) total head across points 1 and 2, 40 ft (12.2 m) total head through component *D*, and 100 ft (30.1 m) total head through the system pipe and fittings, component *E,* for a total of 340 ft (103.3 m). The reduction in pumping head from 450 to 340 ft (137.1 to 103.6 m), a saving of 110 ft (33.5 m), or 24.4% water power, is the result of decreasing the branch head from 310 to 200 ft (94.5 to 61 m) by bypassing the excess flow.

PUMP TOTAL HEAD IN BRANCH-LINE SYSTEMS

The total head produced is the difference in total heads measured across the suction and discharge connections of a pump. As explained in Section 8.1, the total head is also the difference between the heads at any two points in the pumping system, one on each side of the pump, plus the sum of the head losses between these two points. Confusion sometimes results when the flow through the pump divides into branches in either closed-loop or open-ended systems. The points of head measurement can be in any branch line, upstream or downstream from the pump, regardless of the flow rate in these lines.

In part 2 of the previous example, the pump or system total head could be measured using points 3 and 4 in Figure 10. If the total head measured at the pump suction, point 3, were 25 ft (7.62 m) gage, the head measured at point 4 would be 205 ft (62.48 m) gage above the same reference datum plane, assuming 10 ft (3.05 m) of friction between the pump discharge and point 1. The difference between the head at point 3 and that at point 4 is 180 ft (54.86 m). The loss of head due to friction and the head drop through component *C* is $10 + 150 = 160$ ft ($3.05 + 47.5 = 48.75$ m). The pump and system total head at 3600 gpm (817 m^3/h) is therefore $180 + 160 = 340$ ft ($54.86 + 48.75 = 103.63$ m).

Similarly, the pump and system total head for an open-ended system, such as the one shown in Figure 4, could be found by measuring, for example, the difference between the head at point 2 and that at point 3. Each head measurement would be referred to a common datum plane. The total head loss from 2 to 1 plus the head loss from 1 to 3, at the rate of flow in their respective lines, added to the difference between the head at 2 and that at 3, is the pump and system total head.