Lecture 10

Minor Losses & Pressure Requirements

I. Minor Losses

- Minor (or "fitting", or "local") hydraulic losses along pipes can often be estimated as a function of the velocity head of the water within the particular pipe section:

$$h_{ml} = K_r \frac{V^2}{2g} \tag{208}$$

where h_{ml} is the minor loss (m or ft); V is the mean flow velocity, Q/A (m/s or fps); g is the ratio of weight to mass (9.81 m/s^2 or 32.2 ft/s^2); and K_r is a coefficient, dependent on the type of fitting (valve, bend, transition, constriction, etc.)

- Minor losses include head losses through/past hydrants, couplers, valves, pipe elbows, "tees" and other fittings (see Tables 11.1 and 11.2)
- For example, there is some loss when water flows through a hydrant, but also some loss when water flows in a pipe past the location of a closed hydrant
- K_r = 0.3 to 0.6 for flow in a pipeline going past a closed hydrant, whereby the velocity in the pipeline is used to compute h_{ml}
- K_r = 0.4 to 0.8 for flow in a pipeline going past an open hydrant; again, the velocity in the pipeline is used to compute h_{ml}
- K_r = 6.0 to 8.0 for flow from a pipeline through a completely open hydrant. In this case, compute h_{ml} using the velocity of the flow through the lateral fitting on the hydrant, not the flow in the source pipeline.
- For flow through a partially open hydrant, K_r increases beyond the 6.0 to 8.0 magnitude, and the flow rate decreases correspondingly (but not linearly)

- In using Tables 11.1 and 11.2 for hydrants, the nominal diameter (3, 4, 5, and 6 inches) is the diameter of the hydrant and riser pipe, not the diameter of the source pipeline
- Use the diameter of the hydrant for K_r and for computing V_r. However, for line flow past a hydrant, use the velocity in the source pipeline, as indicated above.
- Always use the largest velocity along the path which the water travels – this may be either upstream or downstream of the fitting
- Do not consider velocities along paths through which the water does not flow

- In Table 11.2, for a sudden contraction, K_r should be defined as:

$$K_r = 0.7\left(1 - D_r^2\right)^2 \quad (209)$$

where D_r is the ratio of the small to large inside diameters (D_{small}/D_{large})

- Allen (1991) proposed a regression equation for gradual contractions and expansions using data from the *Handbook of Hydraulics* (Brater & King 1976):

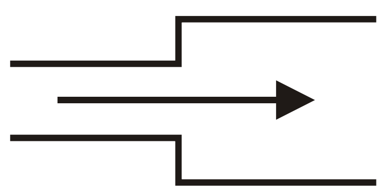
$$K_r = K_f\left(1 - D_r^2\right)^2 \quad (210)$$

where K_f is defined as:

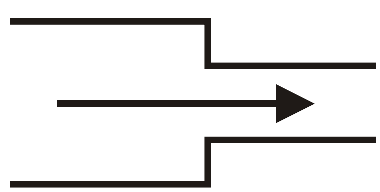
$$K_f = 0.7 - \cos(f)\left[\cos(f)\left(3.2\cos(f) - 3.3\right) + 0.77\right] \quad (211)$$

and f is the angle of the expansion or contraction in the pipe walls (degrees or radians), where $f \geq 0$

- For straight sides (no expansion or contraction), f = 0° (whereby K_f = 0.03)
- For an abrupt change in pipe diameter (no transition), f = 90° (whereby K_f = 0.7)
- The above regression equation for K_f gives approximate values for approximate measured data, some of which has been disputed
- In any case, the true minor head loss depends on more than just the angle of the transition



Expansion



Contraction

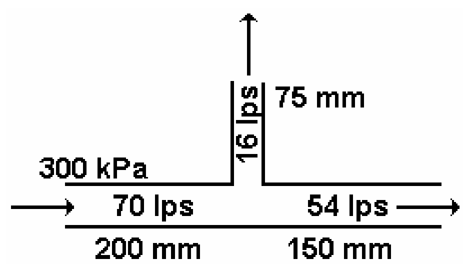
- For a sudden (abrupt) expansion, the head loss can also be approximated as a function of the difference of the mean flow velocities upstream and downstream:

$$h_{ml} = \frac{\left(V_{us} - V_{ds}\right)^2}{2g} \tag{212}$$

- An extreme (albeit unrealistic) case is for V_{ds} = 0 and $h_{ml} = V_{us}^2/2g$ (total conversion of velocity head)
- Various other equations (besides those given above) for estimating head loss in pipe expansions and contractions have been proposed and used by researchers and engineers

Minor Loss Example

- A mainline with an open lateral hydrant valve has a diameter of 200 mm ID upstream of the hydrant, and 150 mm downstream of the hydrant
- The diameter of the hydrant opening to the lateral is 75 mm
- $Q_{upstream}$ = 70 lps and $Q_{lateral}$ = 16 lps
- The pressure in the mainline upstream of the hydrant is 300 kPa



- The mean flow velocities are:

$$V_{200} = \frac{0.070\ m^3/s}{\left(\frac{\pi(0.200\ m)^2}{4}\right)} = 2.23\ m/s \tag{213}$$

$$V_{150} = \frac{0.070 - 0.016\ m^3/s}{\left(\frac{\pi(0.150\ m)^2}{4}\right)} = 3.06\ m/s \tag{214}$$

$$V_{hydrant} = \frac{0.016\ m^3/s}{\left(\frac{\pi(0.075\ m)^2}{4}\right)} = 3.62\ m/s \tag{215}$$

- Note that V_{200} and V_{150} are both above the normal design limit of about 2 m/s
- The head loss past the open hydrant is based on the higher of the upstream and downstream velocities, which in this example is 3.06 m/s
- From Table 11.1, the K_r for flow past the open hydrant (line flow; 6" mainline) is 0.5; thus,

$$\left(h_{ml}\right)_{past} = 0.5\frac{(3.06)^2}{2(9.81)} = 0.24\,m \tag{216}$$

- The head loss due to the contraction from 200 mm to 150 mm diameter (at the hydrant) depends on the transition
- If it were an abrupt transition, then:

$$K_r = 0.7\left[1-\left(\frac{150}{200}\right)^2\right]^2 = 0.13 \tag{217}$$

- And, if it were a 45° transition, K_f = 0.67, also giving a K_r of 0.13
- Then, the head loss is:

$$\left(h_{ml}\right)_{contraction} = 0.13\frac{(3.06)^2}{2(9.81)} = 0.06\,m \tag{218}$$

- Thus, the total minor loss in the mainline in the vicinity of the open hydrant is about 0.24 + 0.06 = 0.30 m (0.43 psi).

- The loss through the hydrant is determined by taking K_r = 8.0 (Table 11.1; 3" hydrant):

$$\left(h_{ml}\right)_{through} = 8.0\frac{(3.62)^2}{2(9.81)} = 5.3\,m \tag{219}$$

- This is a high loss through the hydrant (about 7.6 psi), so it may be advisable to use a larger diameter hydrant.
- The pressure in the mainline downstream of the hydrant is (9.81 kPa/m):

$$\begin{aligned} P_{150} &= P_{200} - \gamma\left(h_{ml}\right)_{past} + \gamma\left(\frac{V_{200}^2 - V_{150}^2}{2g}\right) \\ P_{150} &= 300 - (9.81)(0.24) + 9.81\left(\frac{(2.23)^2 - (3.06)^2}{2(9.81)}\right) = 295\,kPa \end{aligned} \tag{220}$$

II. Total Dynamic Head

- The Total Dynamic Head (TDH) is the head that the pump "feels" or "sees" while working, and is calculated to determine the pump requirements
- It includes the elevation that the water must be lifted from the source (not necessarily from the pump elevation itself) to the outlet, the losses due to "friction", the pressure requirement at the outlet, and possibly the velocity head in the pipeline
- For a sprinkler system, the value of TDH depends on the positions of the laterals, so that it can change with each set. Pump selection is usually made for the "critical" or extreme lateral positions, that is, for the "worst case scenario".
- Keller & Bliesner recommend the addition of a "miscellaneous" loss term, equal to 20% of the sum of all "friction" losses. This accounts for:

    1. Uncertainty in the K_r values (minor losses)
    2. Uncertainty in the Hazen-Williams C values
    3. Aging of pipes (increase in losses)
    4. Wear of pump impellers and casings

- Losses in connectors or hoses from the mainline to laterals, if present, must also be taken into account when determining the TDH
- See Example Calculation 11.2 in the textbook
- The next two lectures will provide more information about TDH and pumps

III. The System Curve

- The system curve determines the relationship between TDH and flow rate
- This curve is approximately parabolic, but can take more complex shapes
- Note that head losses in pipe systems are approximately proportional to the square of the flow rate (Q^2 or V^2)
- For the Hazen-Williams equation, these losses are actually proportional to $Q^{1.852}$ or $V^{1.852}$
- For standard, non-FCN, sprinkler nozzles, the head at the sprinkler is also proportional to Q^2
- Sprinkler systems can have a different system curve for each position of the lateral(s)
- Defining the system curve, or the "critical" system curve, is important for pump selection because it determines, in part, the operating point (TDH and Q) for the system

IV. Valving a Pump

- A throttle valve may be required at a pump:

  (a) Filling of the system's pipes

  - The head is low, and the flow rate is high
  - Pump efficiency is low and power requirements may be higher
  - Water hammer damage can result as the system fills
  - Air vents and other appurtenances can be "blown off"
  - For the above reasons, it is advisable to fill the system slowly

  (b) To avoid cavitation, which damages the pump, pipes and appurtenances
  (c) To control the TDH as the sprinklers are moved to different sets

- Throttle valves can be automatic or manual

Pressure Requirements & Pumps

I. Types of Pumps

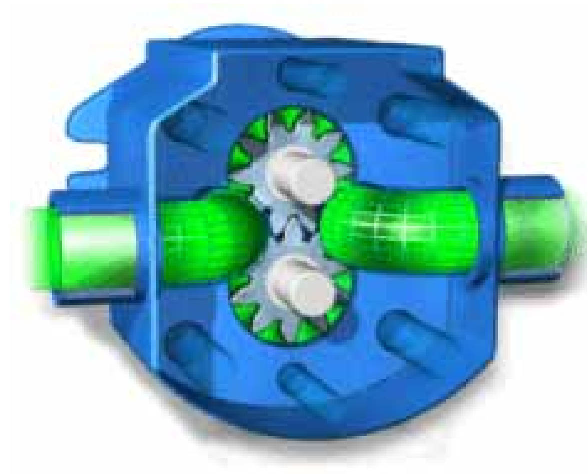
1. Positive Displacement

   - Piston pumps
   - Rotary (gear) pumps
   - Extruding (flexible tube) pumps

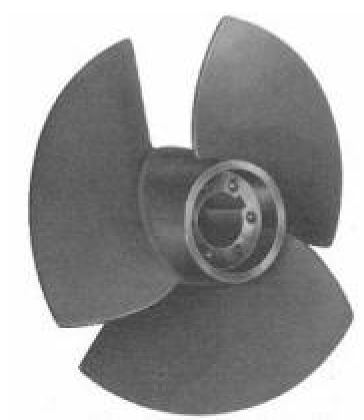
2. Variable Displacement

   - Centrifugal pumps
   - Injector pumps
   - Jet pumps

- The above lists of pump types are not exhaustive
- Positive displacement pumps have a discharge that is nearly independent of the downstream (resistive) pressure. That is, they produce a flow rate that is relatively independent of the total dynamic head, TDH

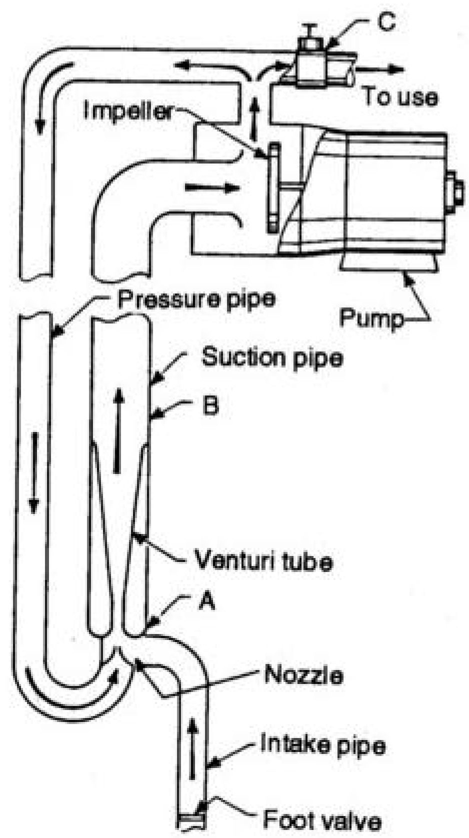


Positive Displacement Pumps



Axial-Flow Impeller

Closed Centrifugal Pump Impeller



Jet Pump

- But, with positive displacement pumps, the required pumping energy is a linear function of the pressure
- Positive displacement pumps can be used with thick, viscous liquids. They are not commonly used in irrigation and drainage, except for the injection of chemicals into pipes and for sprayers
- Piston-type pumps can develop high heads at low flow rates
- Air injection, or jet pumps are typically used in some types of well drilling operations. The air bubbles effectively reduce the liquid density and this assists in bringing the drillings up out of the well. Needs a large capacity air compressor.
- *Homologous* pumps are geometrically similar pumps, but of different sizes

II. Centrifugal Pumps

1. <u>Volute Case</u> This is the most common type of irrigation and drainage pump (excluding deep well pumps). Produce relatively high flow rates at low pressures.

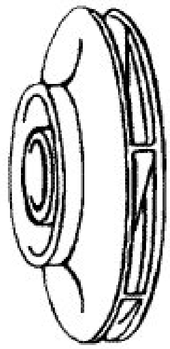
2. <u>Diffuser (Turbine)</u> The most common type for deep wells. Designed to lift water to high heads, typically using multiple identical “stages” in series, stacked up on top of each other.

3. <u>Mixed Flow</u> Uses a combination of centrifugal and axial flow action. For high capacity at low heads.

4. <u>Axial Flow</u> Water flows along the axis of impeller rotation, like a boat propeller. Appropriate for high discharge under very low lift (head). An example is the pumping plant on the west side of the Great Salt Lake.

5. <u>Regenerative</u> The characteristics of these pumps are those of a combination of centrifugal and rotary, or gear, pumps. Shut-off head is well-defined, but efficiency is relatively low. Not used in irrigation and drainage.

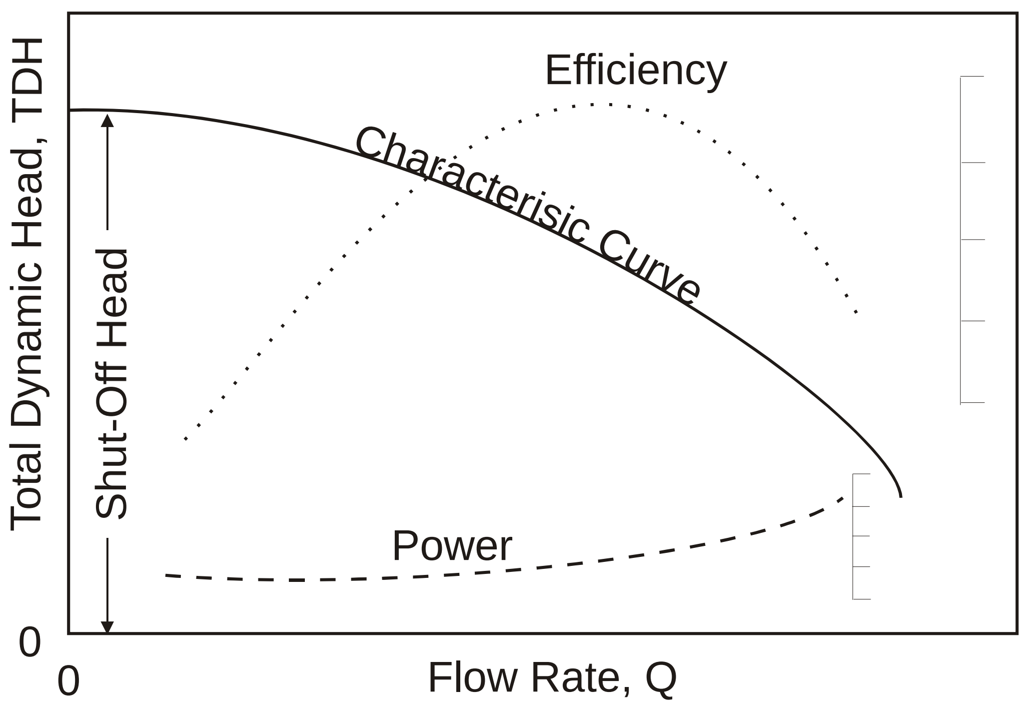
- In general, larger pumps have higher maximum efficiencies (they are more expensive, and more effort is given toward making them more efficient)
- Impellers can be open, semi-open, or closed. Open impellers are usually better at passing solids in the pumped liquid, but they are not as strong as closed impellers
- Double suction inlet pumps take water in from both sides and can operate without axial thrust



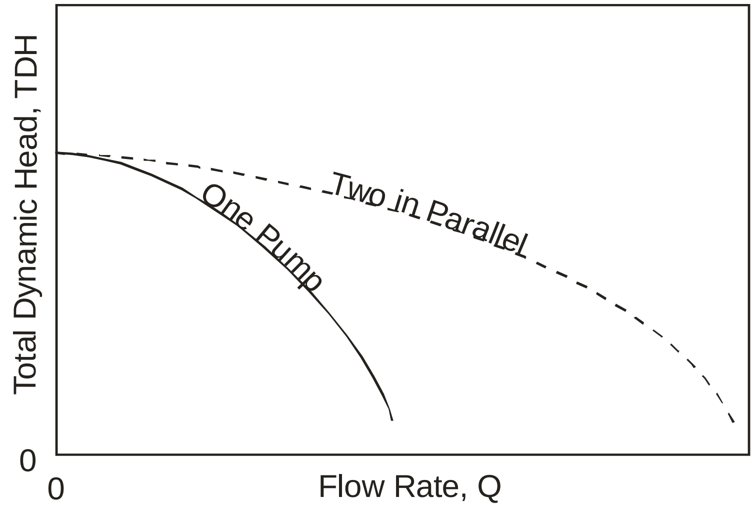
Closed Impeller **Semi-Open Impeller** **Open Impeller**

Characteristic Curve

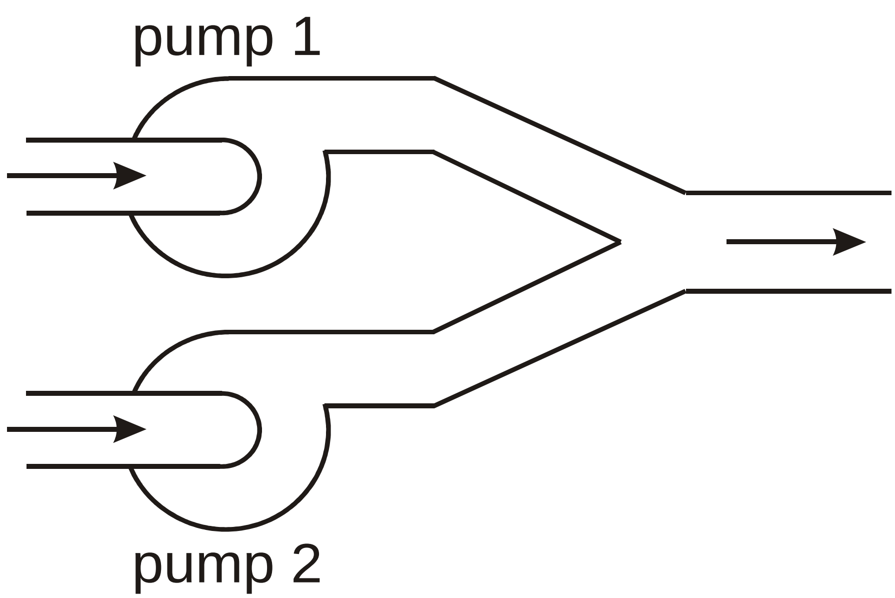
- The pump "characteristic curve" defines the relationship between total dynamic head, TDH, and discharge, Q
- The characteristic curve is unique for a given pump design, impeller diameter, and pump speed
- The characteristic curve has nothing to do with the "system" in which the pump operates
- The "shut-off" head is the TDH value when Q is zero (but the pump is still operating)
- The shut-off head can exceed the recommended operating pressure, or even the bursting pressure, especially with some thin-wall plastic pipes



III. Centrifugal Pumps in Parallel



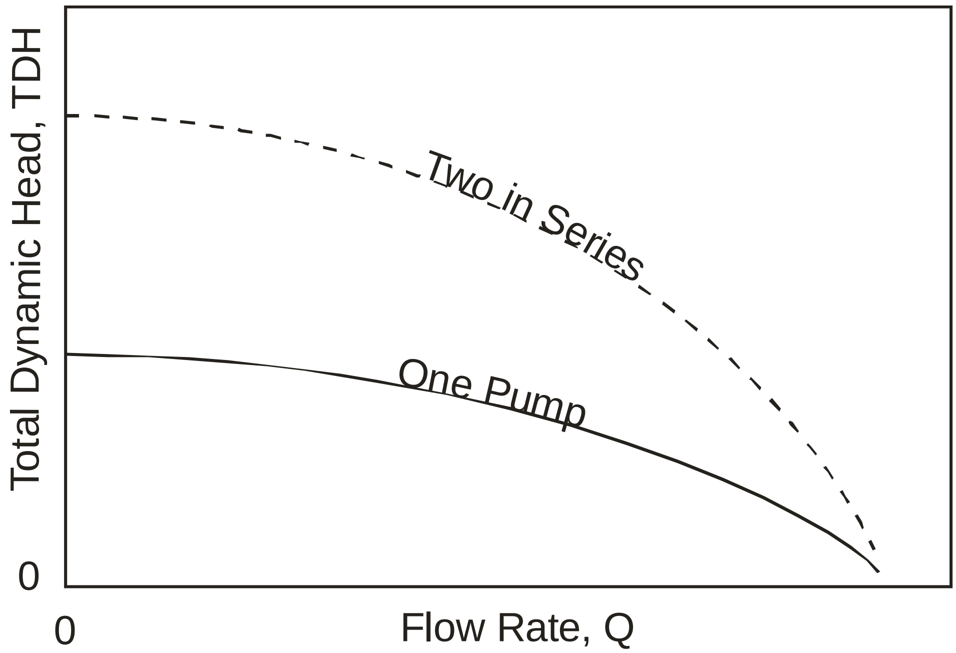
- Pumps in **PARALLEL** means that the total flow is divided into two or more pumps
- Typical installations are for a single inlet pipe, branched into two pumps, with the outlets from the pumps converging to a single discharge pipe
- If only one of the pumps operates, some type of valve may be required so that flow does not flow backwards through the idle pump
- Flow rate is additive in this case



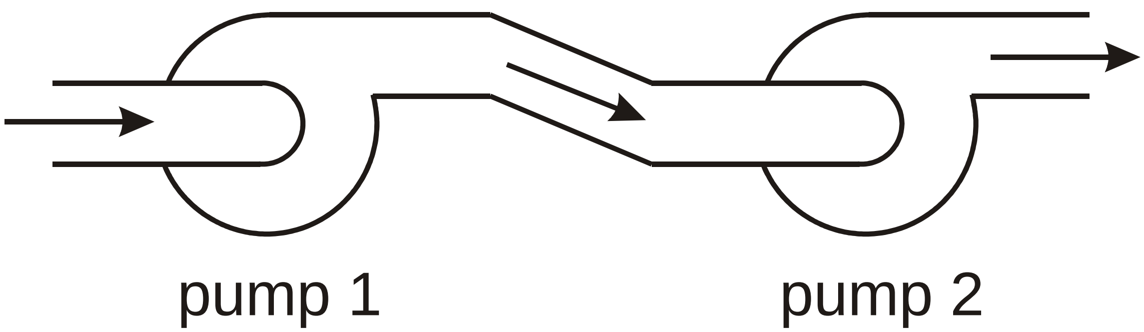
Two Pumps in Parallel

IV. Centrifugal Pumps in Series

- Pumps in **SERIES** means that the total flow passes through each of two or more pumps in line
- Typical installations are for increasing pressure, such as with a booster pump
- Head is additive in this case



- It is common for turbine (well) pumps to operate in series
- For centrifugal pumps, it is necessary to exercise caution when installing in series because the efficiency can be adversely affected
- May need straightening vanes between pumps to reduce swirling
- Note that the downstream pump could cause negative pressure at the outlet of the US pump, which can be a problem



Two Pumps in Series