WATER DISTRIBUTION NETWORKS and Design

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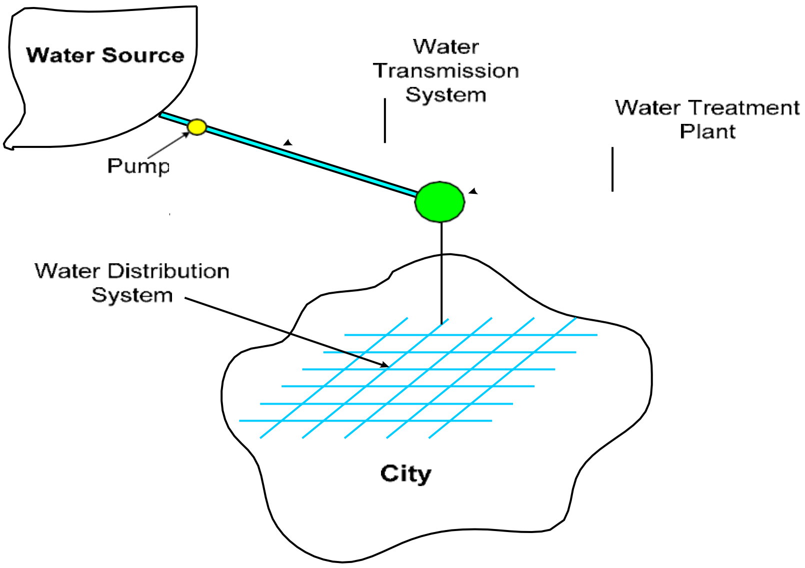
Components of Water Supply System



Water Distribution System

- Water distribution systems are designed to adequately satisfy the water requirements for a combinations of the following demands:
  - Domestic
  - Commercial
  - Industrial
  - Fire-fighting

- The system should be capable of meeting the demands at all times and at satisfactory pressure

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Water Distribution System

- The main elements of the distribution system are:
  - Pipe systems
  - Pumping stations
  - Storage facilities
  - Fire hydrants
  - House service connections
  - Meters
  - Other appurtenances

System Configurations

- Distribution systems may be classified as:
  - Branching systems
  - Grid systems
  - A combination of the above two systems
- The configuration of the system is dictated by:
  - Street patterns
  - Topography
  - Degree and type of development of the area
  - Location of the treatment and storage works.

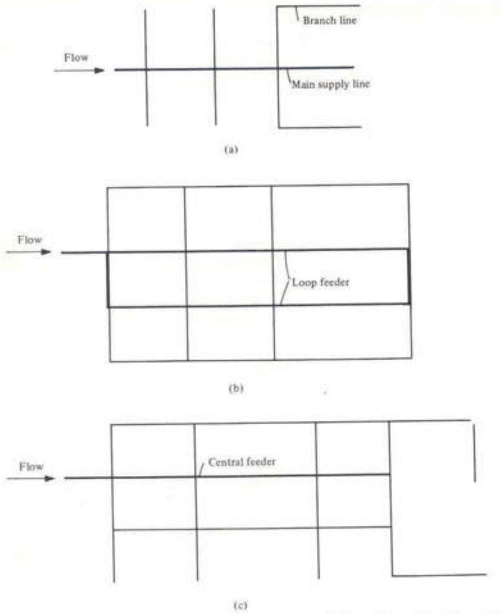


Figure 6.4 Types of water distribution systems: (a) Branching, (b) grid, and (c) combination.

System Configurations

- Branching vs. grid systems:
  - A grid system is usually preferred over a branching system, since it can furnish a supply to any point from at least two directions
  - The branching system has dead ends, therefore, does not permit supply from more than one direction. Should be avoided where possible.
  - In locations where sharp changes in topography occur (hilly or mountainous areas), it is common practice to divide the distribution system into two or more service areas.

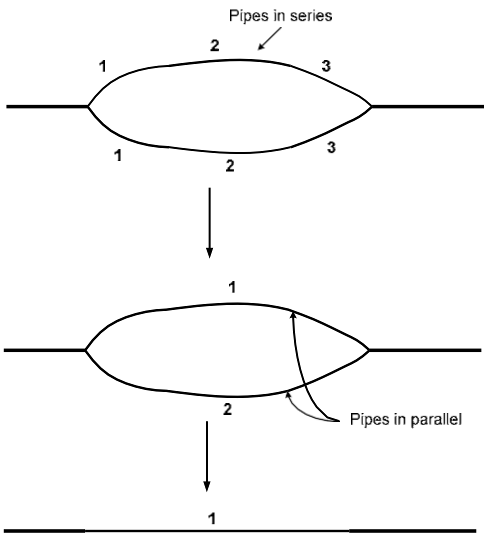
Basic System Requirements

- Pressure:
  - Pressure should be great enough to adequately meet consumer and fire-fighting needs.
  - Pressure should not be excessive:
    - Cost consideration
    - Leakage and maintenance increase
- Capacity:
  - The capacity is determined on the bases of local water needs plus fire-fighting demand.
  - Pipe sizes should be selected to avoid high velocities:
    - Pipe sizes should have selected based on flow velocity of 3-5 fps
    - Where fire-fighting is required, minimum pipe diameter is 6 in.

Hydraulic Design

- The design flowrate is based on the maximum of the following two rates:
  - Maximum day demand plus fire demand
  - Maximum hourly rate
- Analysis of distribution system:
  - Distribution system have series of pipes of different diameters. In order to simplify the analysis, skeletonizing is used.
  - Skeletonizing is the replacement of a series of pipes of varying diameters with one equivalent pipe or replacing a system of pipes with one equivalent pipe.

Skeletonization



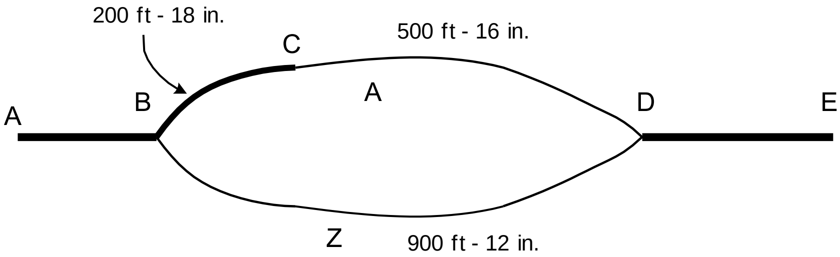
Hydraulic Design

- Example:

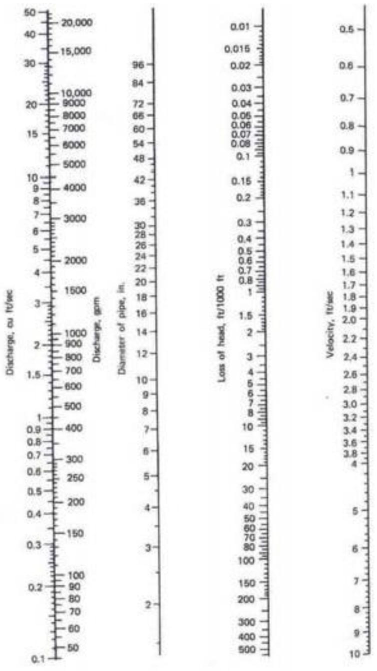
  Consider the piping system shown in the figure, replace (a) pipes BC and CD with an equivalent 12-in. pipe and (b) the system from B to D with an equivalent 20-in. pipe.

- Solution:
  - a) for pipes in series:

    1. assume any value for Q through BCD (8 cfs)
    2. from nomograph with Q = 8 cfs and dia = 18-in, read head loss for BC = 6.1ft/1000ft
    3. from nomograph with Q = 8 cfs and dia = 16-in, read head loss for CD = 11ft/1000ft
    4. total head loss BD = (6.1/1000)*200+(11/1000)*500 = 6.72ft



Nomograph for Hazen
Williams equation



Hydraulic Design

5. the total head loss for 12-in equivalent pipe at 8 cfs is 45ft/1000ft (from nomograph)

6. head loss BCD = head loss BD, therefore;

$$6.72\text{ft} = L_{eq} * (45/1000)$$

$$L_{eq} = 6.72 * (1000/45) = 149 \text{ ft}$$

- b) for pipes in parallel:

1. assume any value of head loss between BD (h_L=5 ft)
2. for the equivalent pipe (L = 149 ft), head loss per 1000ft is;

$$h_L = (5/149)*1000 = 33.5\text{ft}/1000\text{ft}$$

Diameter of equivalent pipe = 12-in

Q_{eq} = 6.8 cfs (from nomograph)

Hydraulic Design

3. for the 900 ft 12-in pipe:

h_L = (5/900)*1000 = 5.5ft/1000ft

Q_{900} = 2.6 cfs (from nomograph)

4. total flow = 6.9 + 2.6 = 9.4 cfs

5. for Q = 9.4 cfs and 20-in pipe:

head loss = 4.8ft/1000ft (nomograph)

6. head loss 12-in pipe = head loss 20-in pipe

5 ft = L * (4.8ft/1000ft)

L = 5 * (1000/4.8) = 1042 ft

Hydraulic Design

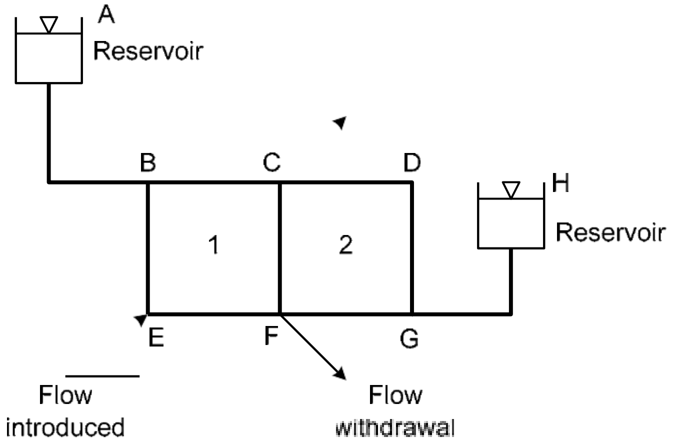
- Pipe networks:
  - Pipe networks are composed of a number of constant-diameter pipe sections containing pumps and fittings.
  - From next figure, following are defined:
    - Node: end of each pipe section. (A, B, C, D, E, F, G, and H)
    - Junction node: points where pipes meet and where flow may be introduces or withdrawn. (B, C, D, E, F, and G)
    - Fixed-grade nodes: points where constant grade is maintained. (A and B)
    - Loops: closed pipe circuits. (1 and 2)
  - From above terminology, we can write the following eq.

    P = J + L + F – 1

Where: P = # pipes, J = # Junction node, L = #loops,

F = # fixed-grade nodes

Pipe Network



Hydraulic Design

- Loop equations:
  - Hydraulic performance of pipe networks are based on mass continuity and energy conservation.
  - **Continuity of mass:**

    $\Sigma Q_{in} - \Sigma Q_{out} = Q_e$ (J number of equations)

    Q_{in} = inflow into node

    Q_{out} = outflow from node

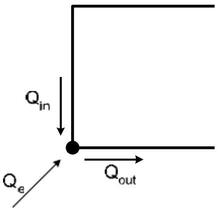
    Q_e = external flow into the system or withdrawal
  - **Conservation of energy:**

    $\Sigma h_L = \Sigma E_p$ (L number of equations)

    h_L = head loss; E_p = pump head

    For fixed-grade nodes, the following can be written:

    $\Delta E = \Sigma h_L - \Sigma E_p$ (F-1 equations)



Hydraulic Design

- Loop equations: (continue)
  - **Frictional losses in pipes:**

    $h_{LP} = K_P\, Q^n$

    Where;

    K_P = constant incorporating pipe size, its roughness, and units used

    n = an exponent

    The Hazen-Williams formula for head loss is given as:

    $h_{LP} = K_P\, Q^{1.85}$
  - **Minor losses:**

    These losses are due fittings, valves, meters, or other insertions that affect the flow. They are expressed as:

    $h_{LM} = K_M\, Q^2$

    Where;

    K_M = minor loss constant

Hydraulic Design

- Node equations:
  - When considering nodes, the principle relationship used is the continuity equation:

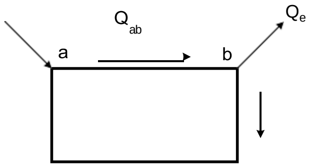
    $Q_{in} - Q_{out} = Q_e$
  - The discharge in pipe ab can be expressed in terms of grade (head) as the following:

    $h_L = KQ^n$

    $h_{Lab} = h_a - h_b = K_{ab}Q^n$

Or

$Q_{ab} = \{(h_a - h_b)/K_{ab}\}^{1/n}$



Hydraulic Design

- Node equations:
  - If pump exist in the line, then junction nodes are specified at the inlet and outlet.

for continuity:

$Q_{ab} = Q_{cd}$

$\{(h_a-h_b)/K_{ab}\}^{1/n} = \{(h_c-h_d)/K_{cd}\}^{1/n}$

$h_a - h_b = (K_{ab}/K_{cd})\,(h_c - h_d)$

The head change across pump is:

$h_c - h_b = P(Q)$

$P(Q)$ = is the head developed by the pump = $(550\ hp)/(\gamma Q)$

hp = horsepower, γ = weight of water, Q = flow

Distribution Reservoirs

- Definition:

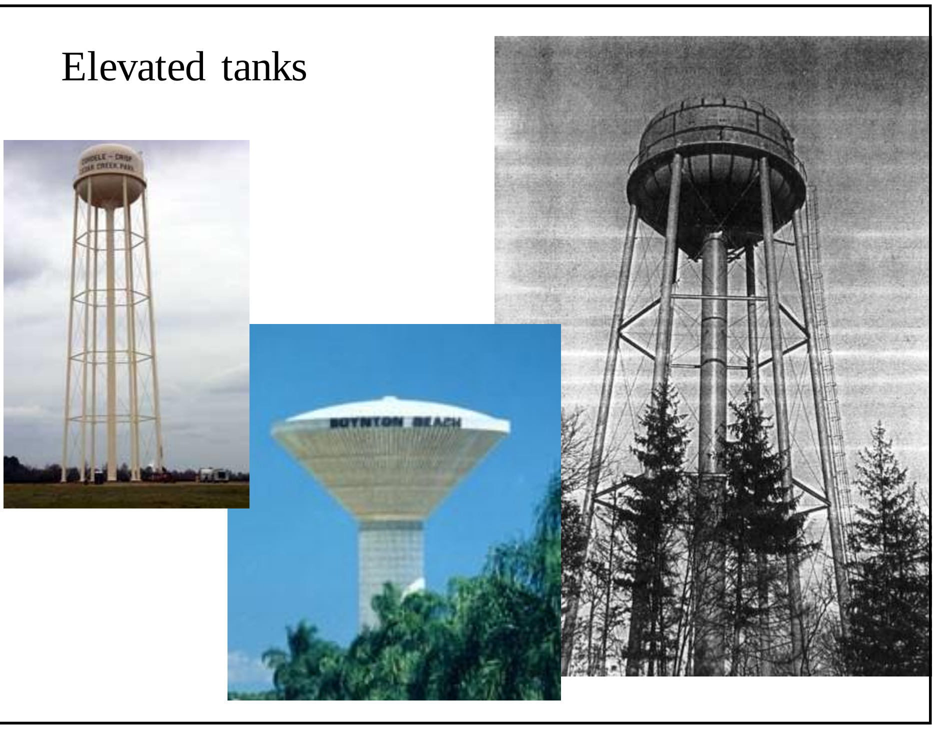
  Distribution reservoirs provide service storage to meet the widely fluctuating demands often imposed on the distribution system, to accommodate fire-fighting and emergency requirements, and to equalize operating pressure.

- Types of reservoirs:
  - Surface reservoir
    - Usually lined with concrete, gunite, asphalt, or membrane.
    - They may be covered or uncovered, but usually covered to prevent contamination.
  - Standpipes or elevated tanks
    - Normally employed where the construction of a surface reservoir would not provide sufficient head.
    - Stand pipes are tall cylindrical tanks whose storage volume includes an upper portion (useful storage) and a lower portion (supporting storage).

Surface Reservoir

Standpipes

Elevated tanks



Distribution Reservoirs

- Location
  - Distribution reservoirs should be located strategically for maximum benefits.
  - Normally the reservoir should be near the center of use.
  - For large areas, a number of reservoirs may be located at key locations
  - A central location decreases the friction losses by reducing the distance to the serviced area.
- Storage function
  - To provide head required head.
  - To provide excess demand such as:
    - fire-fighting: should be sufficient to provide flow for 10-12 hours.
    - emergency demands: to sustain the demand during failure of the supply system and times of maintenance.
  - To provide equalization storage.

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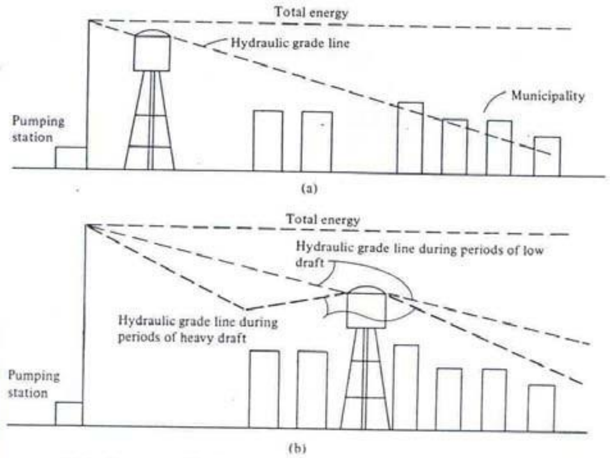


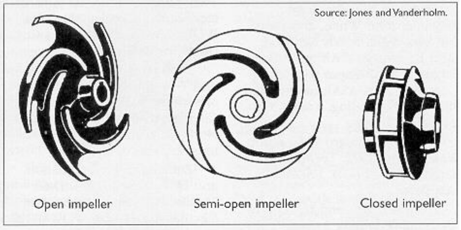
Figure 6.20 Pressure distribution as influenced by the location of a distribution reservoir.

Pumping

- Introduction
  - Pumping is an important part of the transportation and distribution system.
  - Requirements vary from small units (few gallons per minute) to large units (several hundred cubic feet per second)
  - Two kinds of pumping equipments are mainly used; centrifugal and displacement pumps.
- Types of pumps
  - **Low-lift pumps**: used to lift water from a source to the treatment plant
  - **High-service pumps**: used to discharge water under pressure to the distribution system
  - **Booster pumps**: used to increase pressure in the distribution system.
  - **Recirculation pumps**: used within a treatment plant.
  - **Well pumps**: used to left water from wells.

Centrifugal pumps

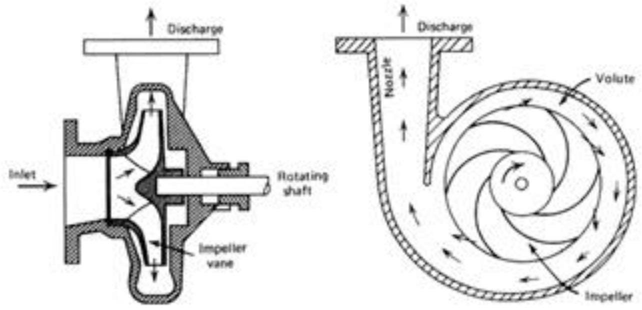
- Used to lift and transport water
- Widely used in water and wastewater applications due to:
  - Simplicity of installation and operation.
  - Compactness.
  - Low cost compared to others.
  - Operate under variety of conditions
- How do they operate:
  - On the principle of centrifugal force; force of pushing outwards.
  - The impeller driven at high speed throws water into the casing
  - Water is channeled through a nozzle to the discharge piping

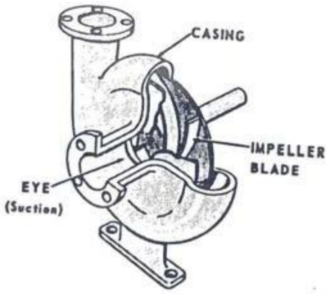


Source: Jones and Vanderholm.

Figure 1. Common impeller types for centrifugal pumps.

Figure 4-9 Cross-sectional diagrams showing the features of a centrifugal pump.





Centrifugal pumps

- Pumping head
  - The pump operates against a certain head called Total Dynamic Head (TDH).
  - TDH is composed of the following:
    - The difference in elevation between the pump centerline and the elevation to which the water is to be raised.
    - The difference in elevation between the level of the suction pool and the pump centerline
    - The friction losses
    - Velocity head

$TDH = H_L + H_F + H_V$

Where;

H_L = total static head

H_F = total friction head

H_V = velocity head ($V^2/2g$)

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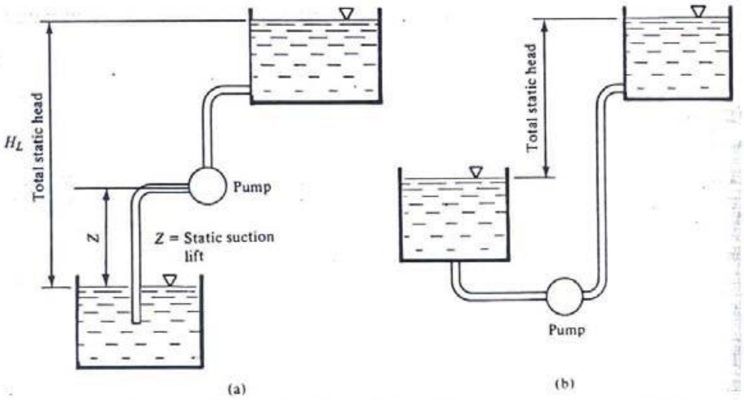

Figure 6.25 Total static head: (a) Intake below the pump centerline and (b) intake above the pump centerline.

Centrifugal pumps

- Power
  - The theoretical horsepower required may be found by using the following equation:

hp = QγH/550

Where;

Q = discharge, cfs

γ = specific weight of water, 62.4 lb/ft^3

H = total dynamic head, ft

The actual hp required is obtained by dividing the theoretical hp by the efficiency of the pump.

Centrifugal pumps

- System head
  - The system head is represented by a plot of TDH vs. discharge for the system being studied.
  - The plot is used to help in selecting the pumping unit.
  - The system head curve will vary with flow since H_F and H_V are both a function of discharge.
  - Since the static head H_L may vary as a result of fluctuating water levels, it is necessary to plot system head curves covering the range of variations in static head.

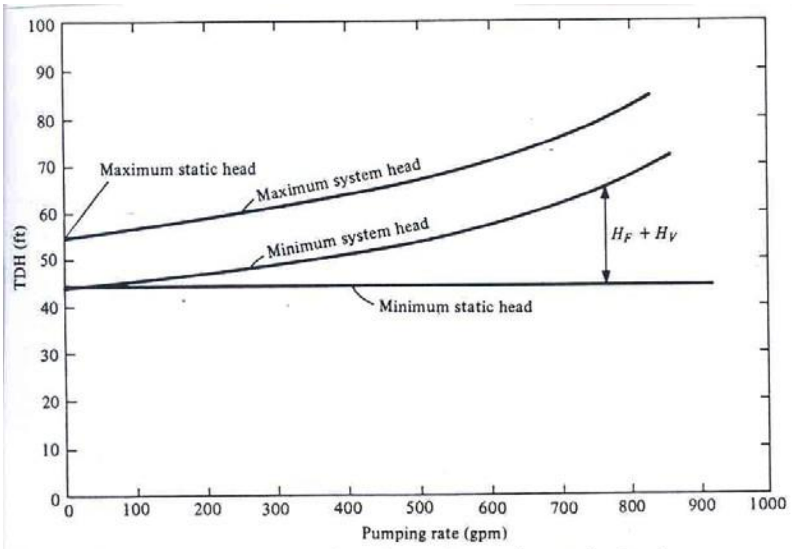

Figure 6.26 System head curves for a fluctuating static pumping head.

Centrifugal pumps

- Pump characteristics
  - Each pump has its own characteristics relative to power requirements, efficiency, and head developed as a function of rate of flow.
  - These relationships are usually given as a set of pump characteristic curves for a specified speed.
  - Pump characteristic curves are used in conjunction with system-head curves to select suitable pumping equipment for a particular installation.
  - As the flow of the centrifugal pump increases, the head will fall.
  - At maximum efficiency, the discharge is known as *normal* or r*ated discharge*.
  - To change the flow, the practical and efficient approach is to provide two or more pumps in parallel so that the flow may be carried at close to the peak efficiency.
  - The normal range of efficiency is between 50-85%.

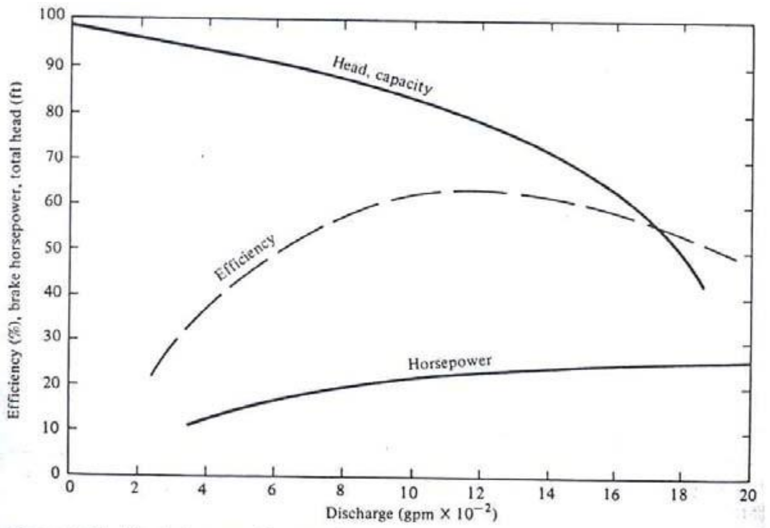

Figure 6.27 Typical pump characteristic curves.

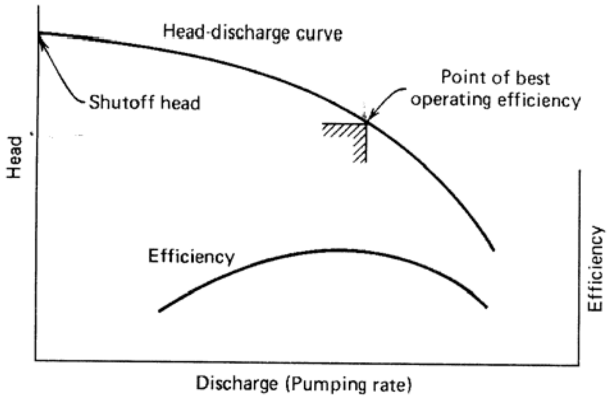

Figure 4-11 Characteristic curves for a centrifugal pump operating at a constant speed.

Centrifugal pumps

- Selection of pumping units
  - Normally the engineer is given the system-head characteristics curve and is required to find a pump or pumps to deliver the required flow.
  - The system-head curve is plotted with the pump characteristics curve.
  - The operating point is located at the intersection of the system-head curve and the pump characteristics curve. This point gives the head and flow at which the pump will be operating.
  - A pump should be selected so that the operating point is also as close as possible to peak efficiency.
  - Pumps connected in series; the total head equals the sum of the heads added by each pump (discharge stay constant).
  - Pumps connected in parallel; the total discharge is the sum of the discharges of each pump at a given head (head stay constant).

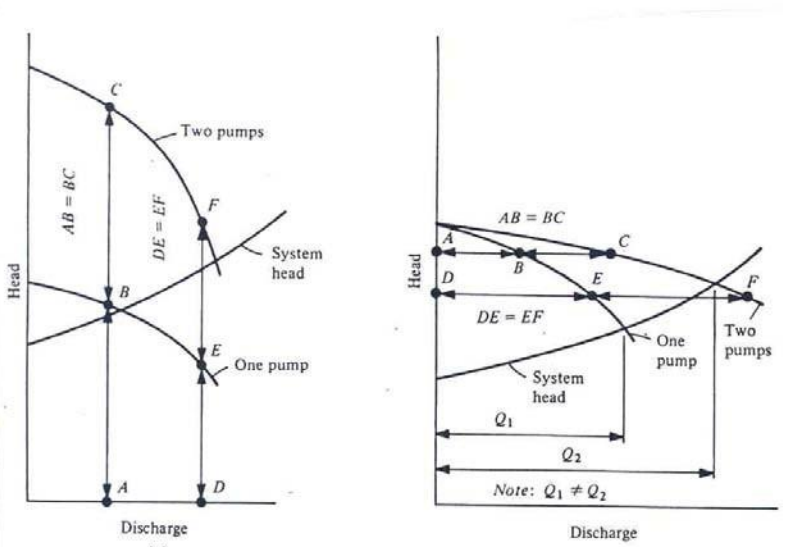

Figure 6.28 Characteristic curves fcr (a) series and (b) parallel pump operations of equal pumps.

References:

1- Water Distribution System Hand Book by Larry W. Mays Editor in Chief Department of Civil and Environmental Engineering Arizona State University Tempe, Arizona

2- Water Distribution Systems by Dragan Savic and John Banyard

3- Design of Water Supply Pipe Networks by Prabhata K. Swamee ‹Ashok K. Sharma,

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