MEBS7014 Advanced HVAC applications

http://ibse.hk/MEBS7014/

Fans and Pumps I

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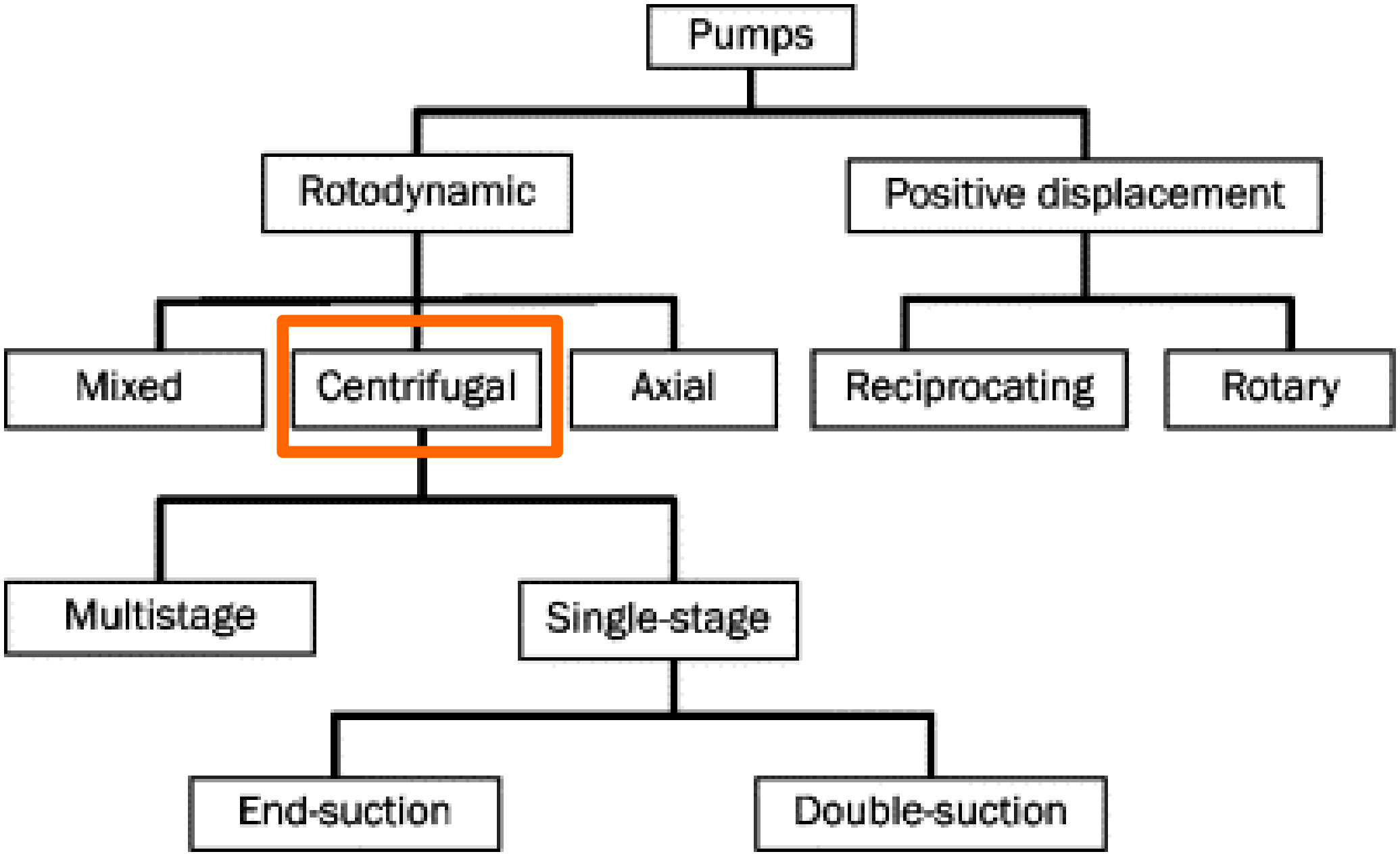
Contents

- Centrifugal Pumps
- Pump Characteristics
- Pump Arrangements
- Matching Pumps to Systems

Classification of pumps

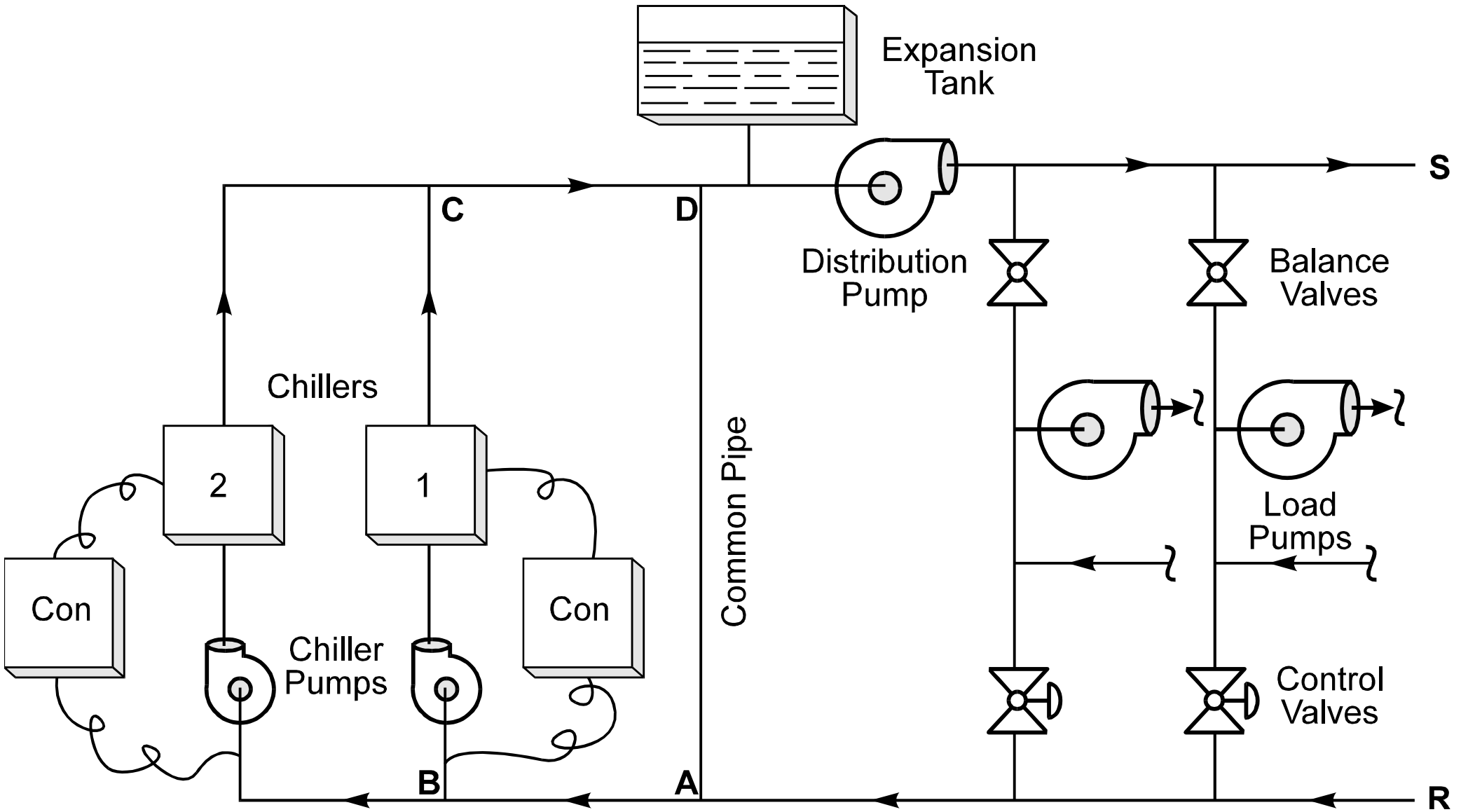


Centrifugal Pumps

- Centrifugal pumps (離心泵)
  - Most widely used in HVAC applications, e .g.
    - Hot water systems
    - Chilled water systems
    - Condenser water systems
    - Boiler feed and condensate return pumps

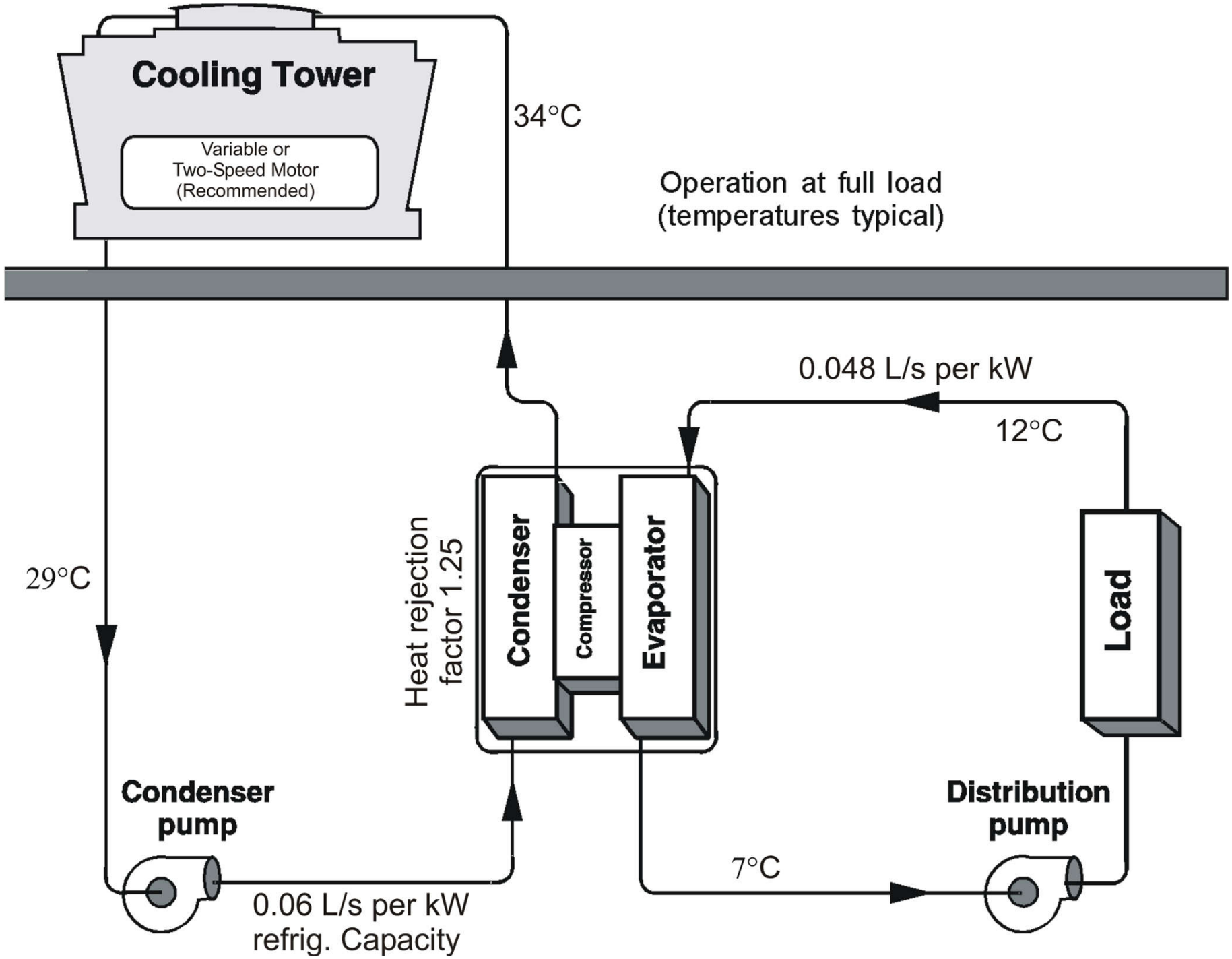
  - Operation
    - Electric motor's output torque => impeller's rotation
    - Coupling to the pump shaft
    - Centrifugal force & tip speed force

Chilled water pumping system



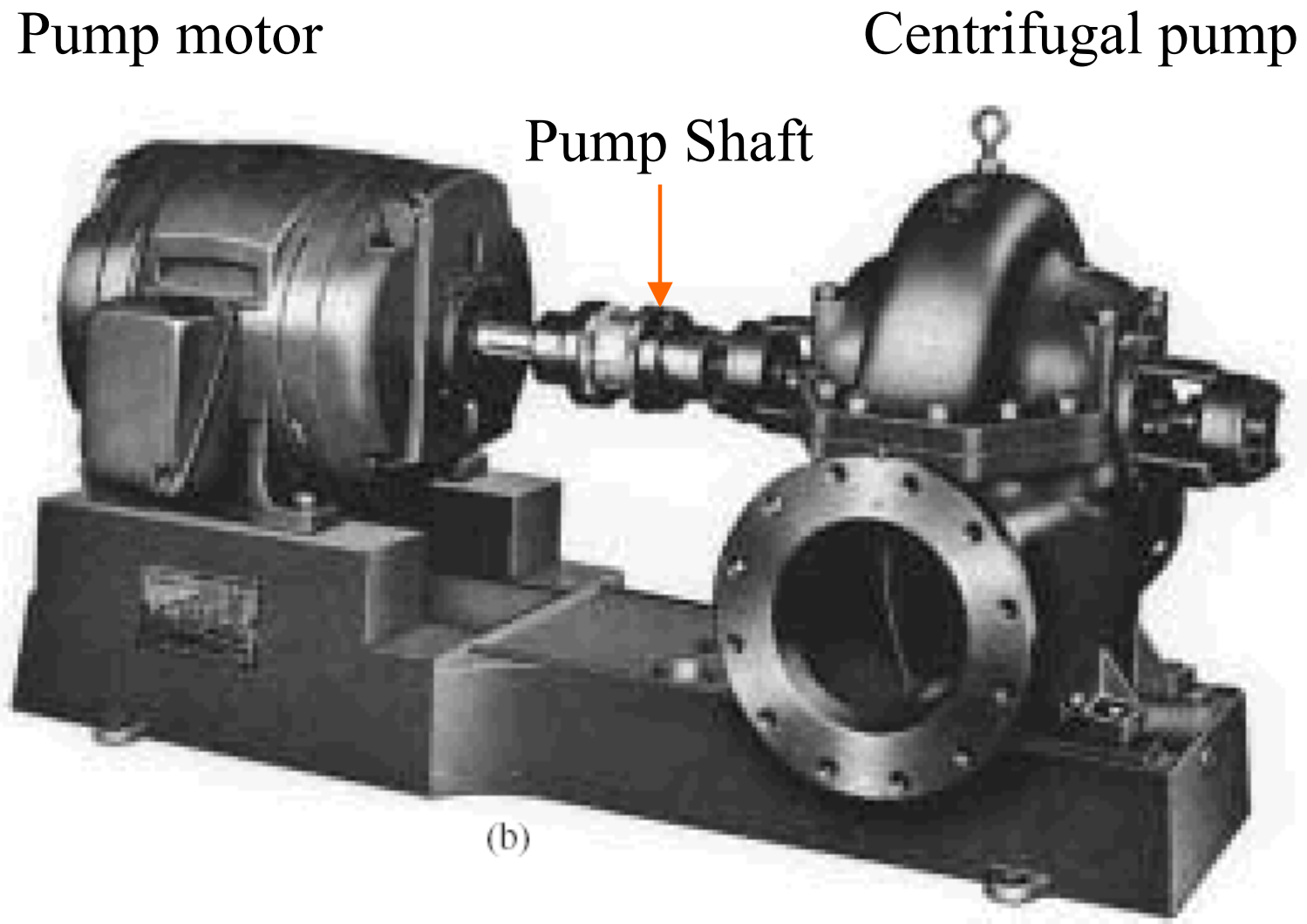
(Source: *Fundamentals of Water System Design*)

Cooling tower pumping system



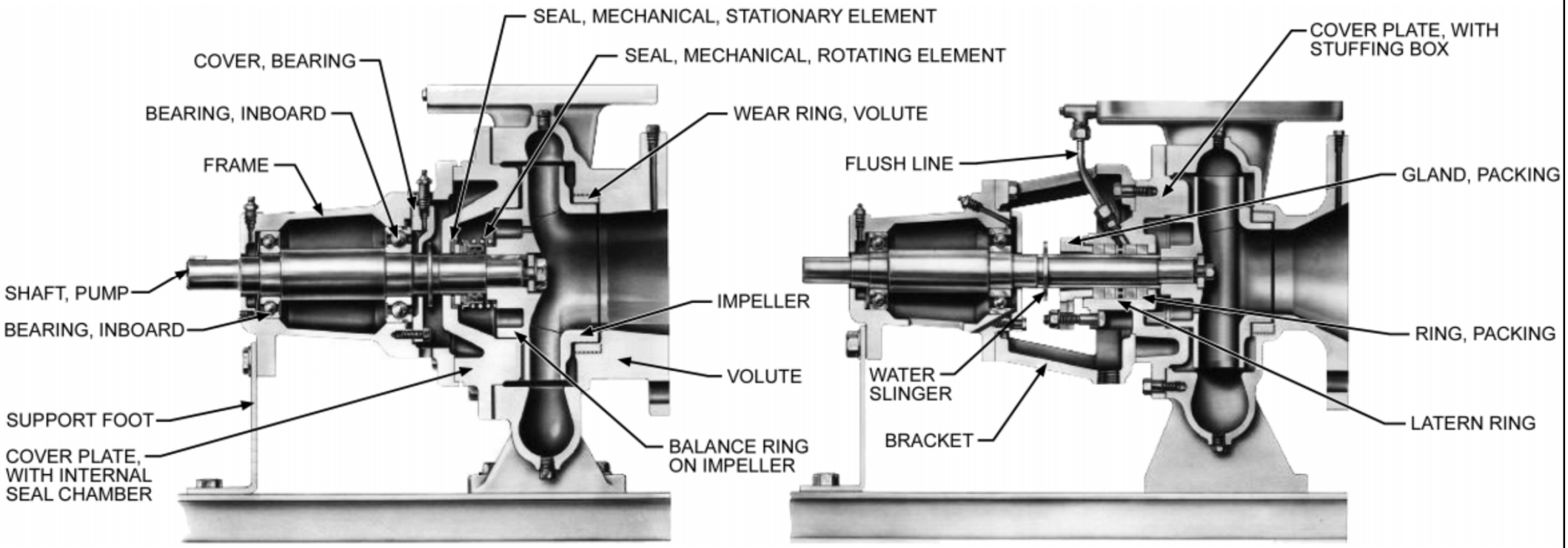
(Source: *Fundamentals of Water System Design*)

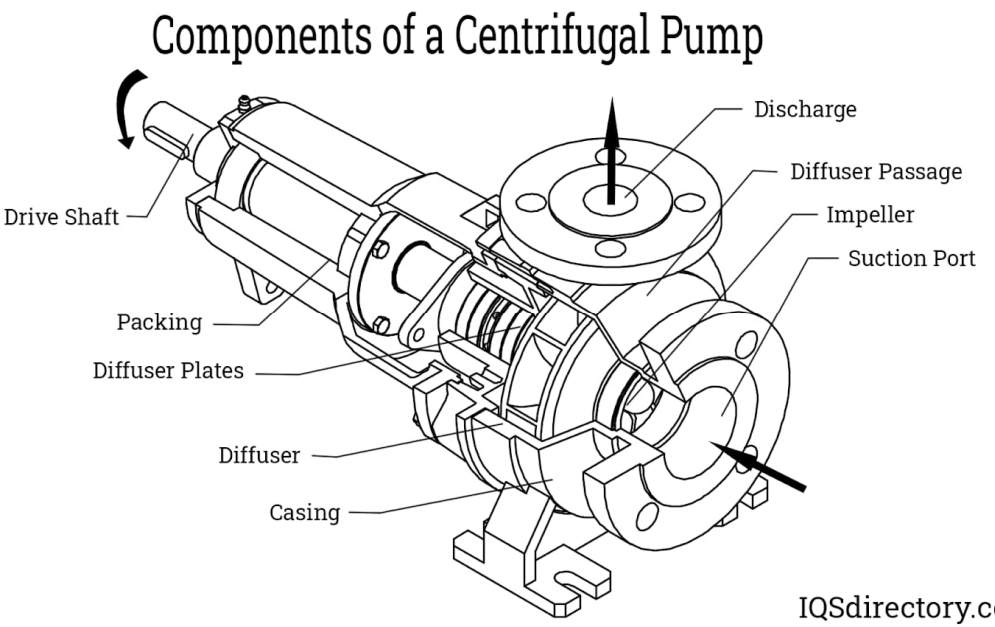
A double-suction, horizontal split-case, single-stage centrifugal pump



(Source: *Wang, S. K., 2001. Handbook of Air Conditioning and Refrigeration*)

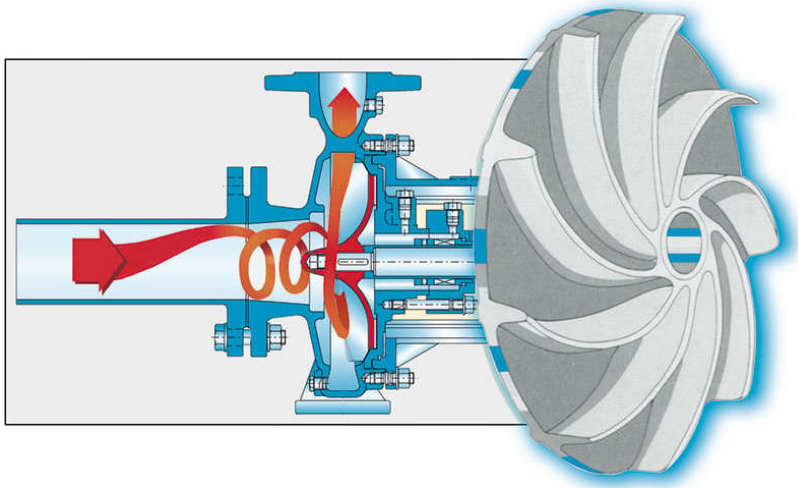
Cross section of typical overhung-impeller end-suction pump





(Source: *ASHRAE HVAC Systems and Equipment Handbook 2020*)

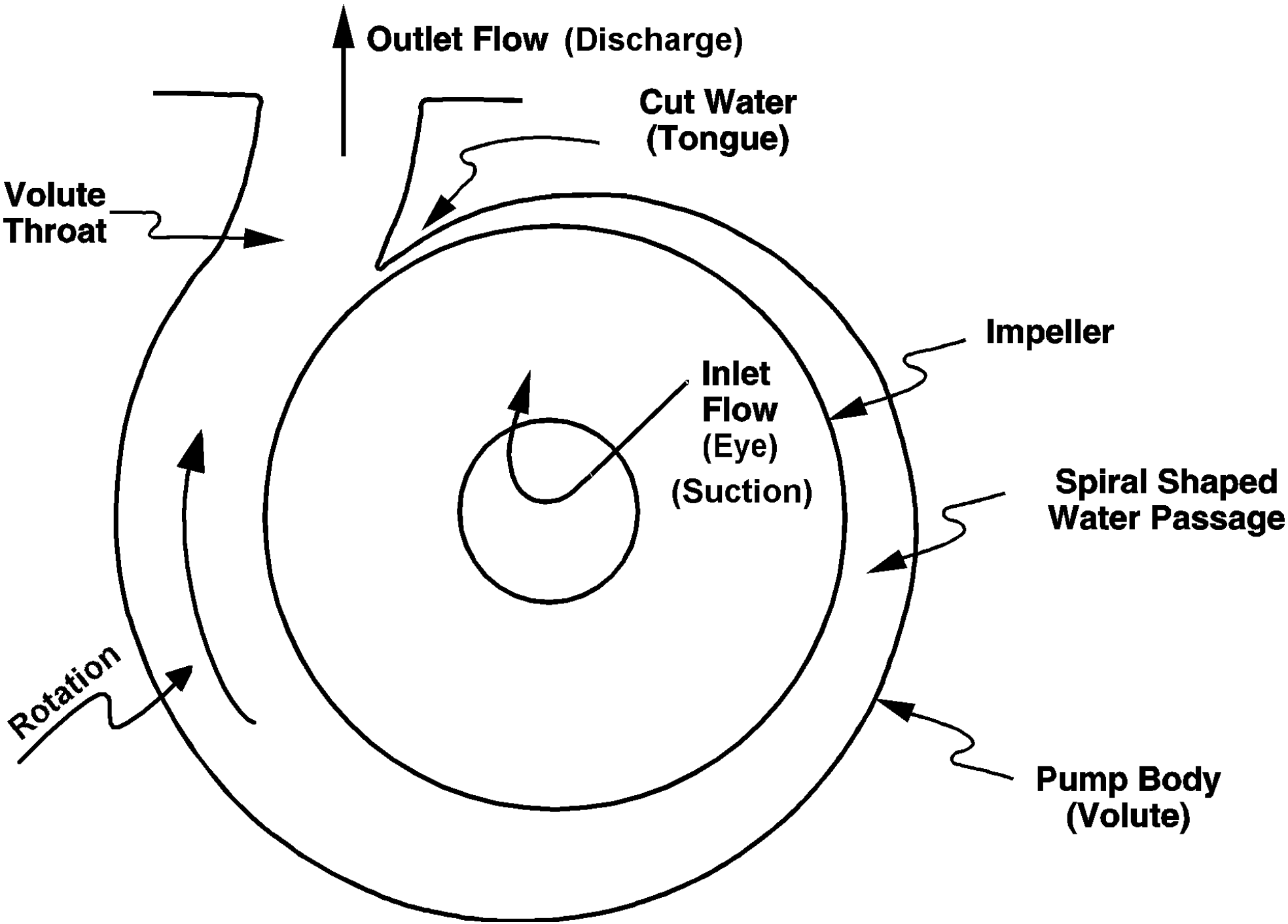
Centrifugal pump



* Video: How does a Centrifugal pump work ? (4:37) https://youtu.be/BaEHVpKc-1Q

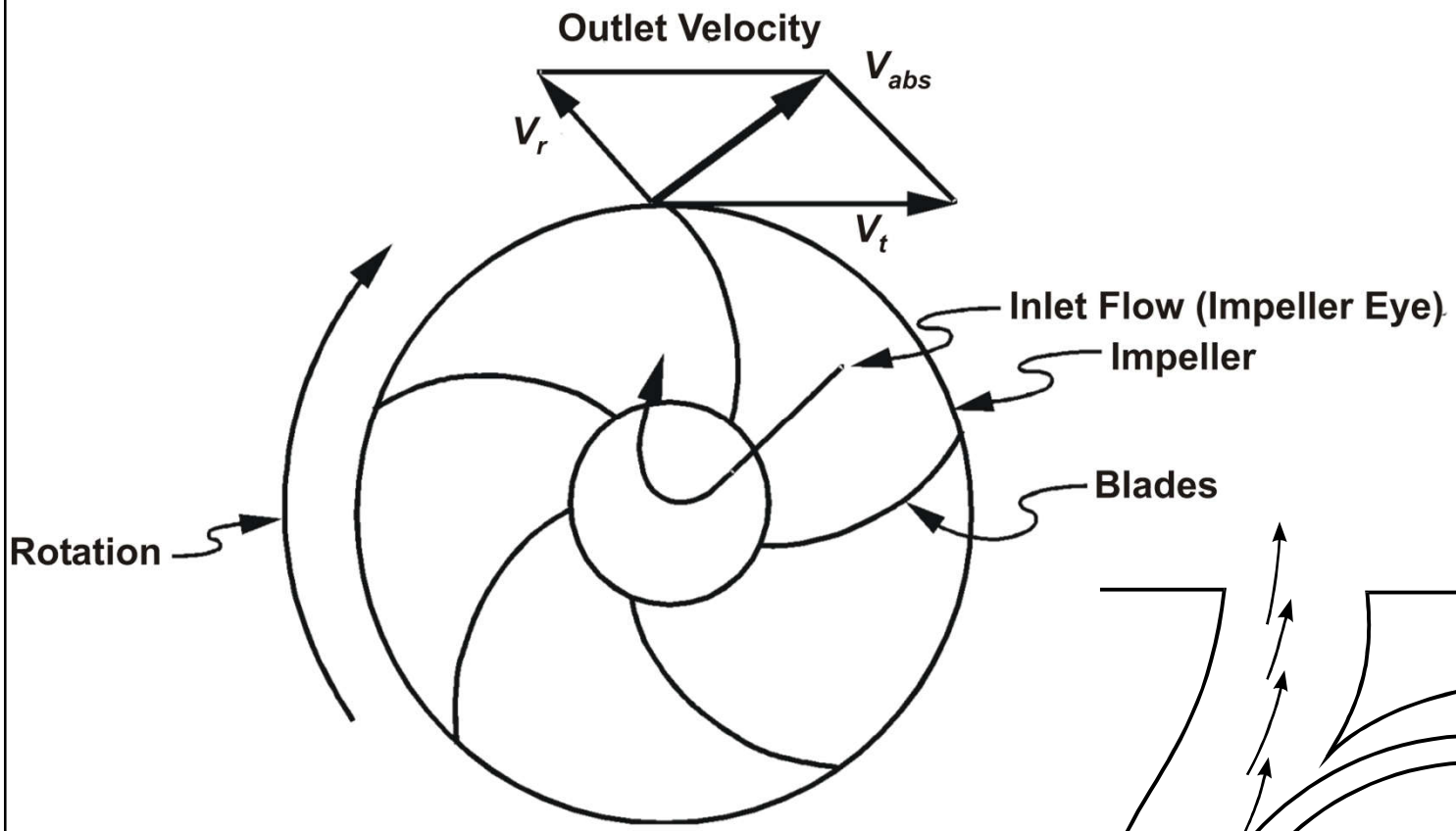
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2012*)

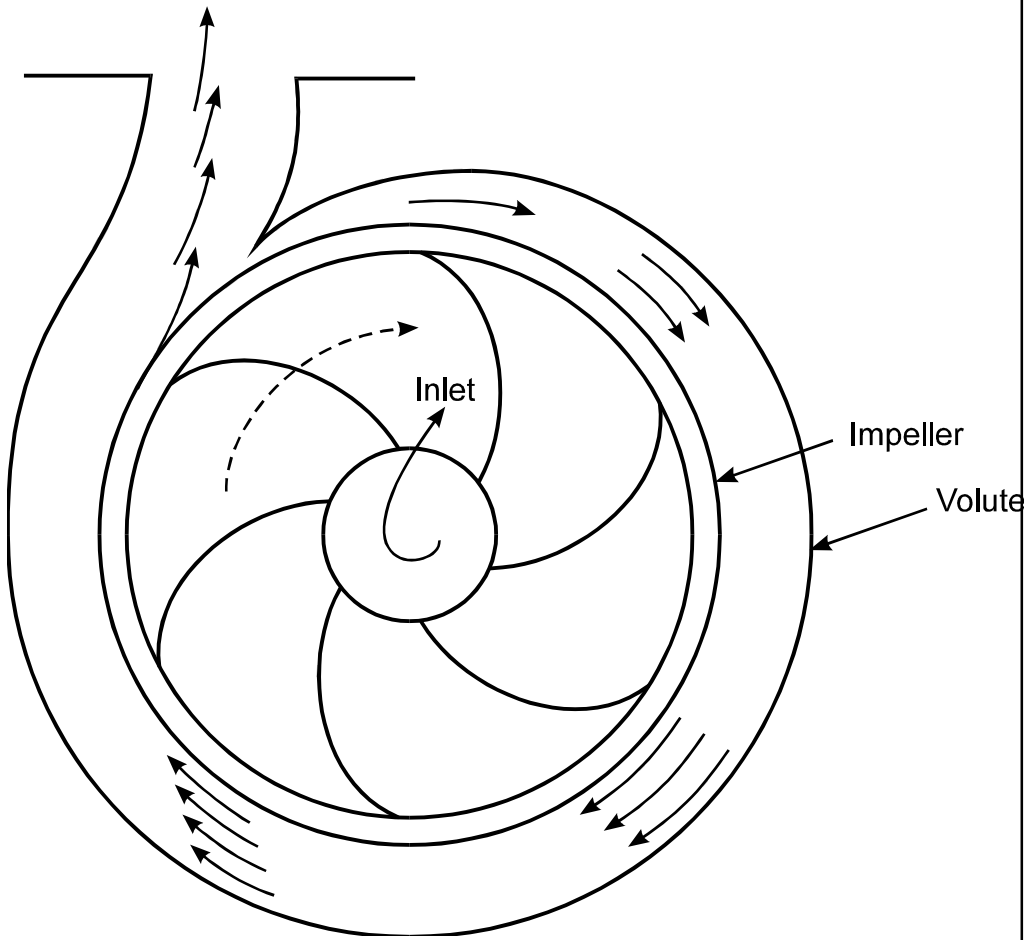
Centrifugal pump, impeller and volute

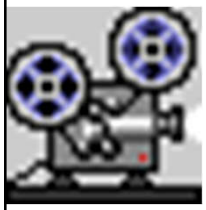


(Source: *Fundamentals of Water System Design*)

Impeller/volute action on fluid



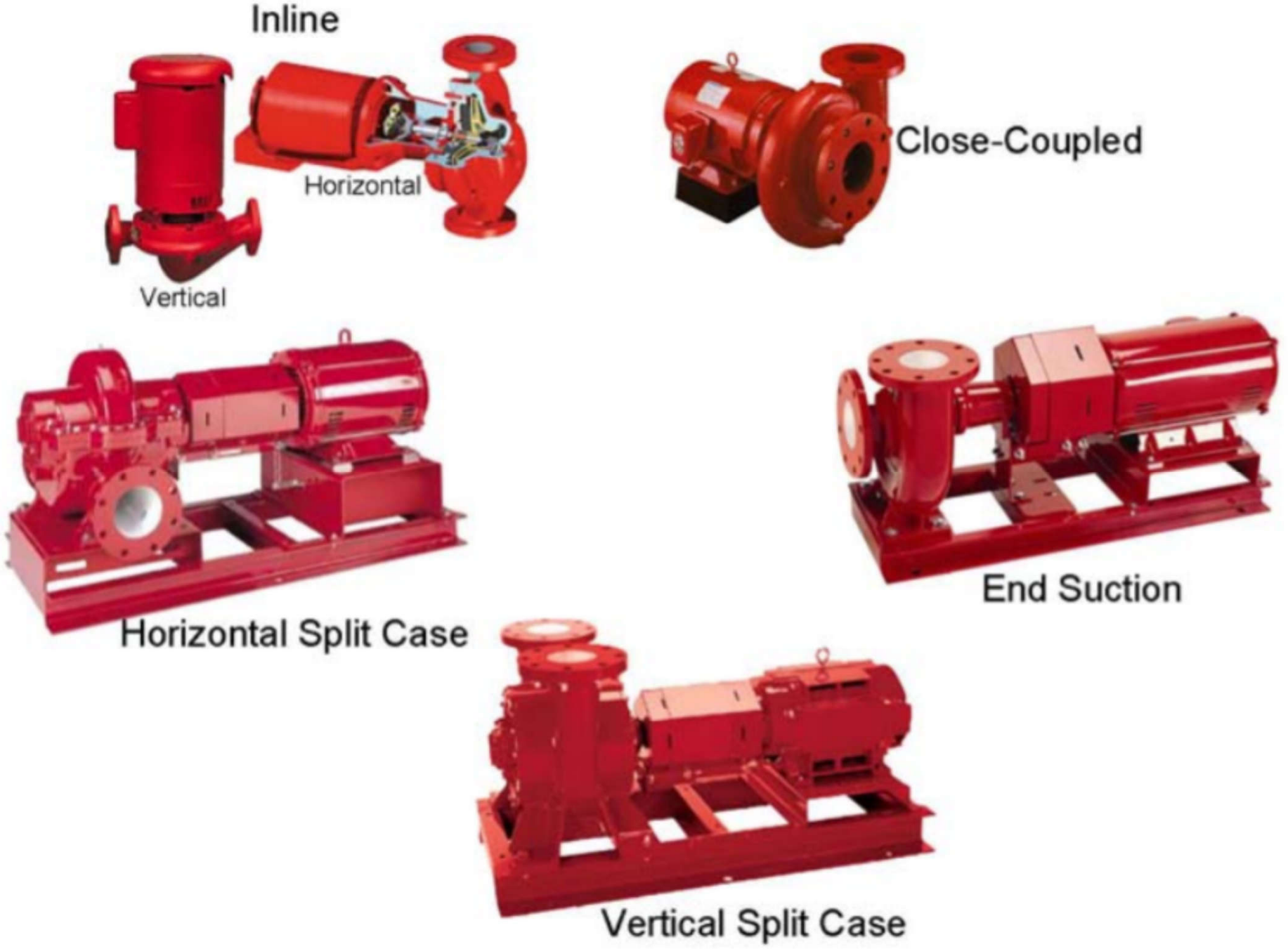




* Video: Centrifugal Pump Working (5:54)
https://youtu.be/IiE8skW8btE

(Source: *Fundamentals of Water System Design*)

Types of centrifugal pumps

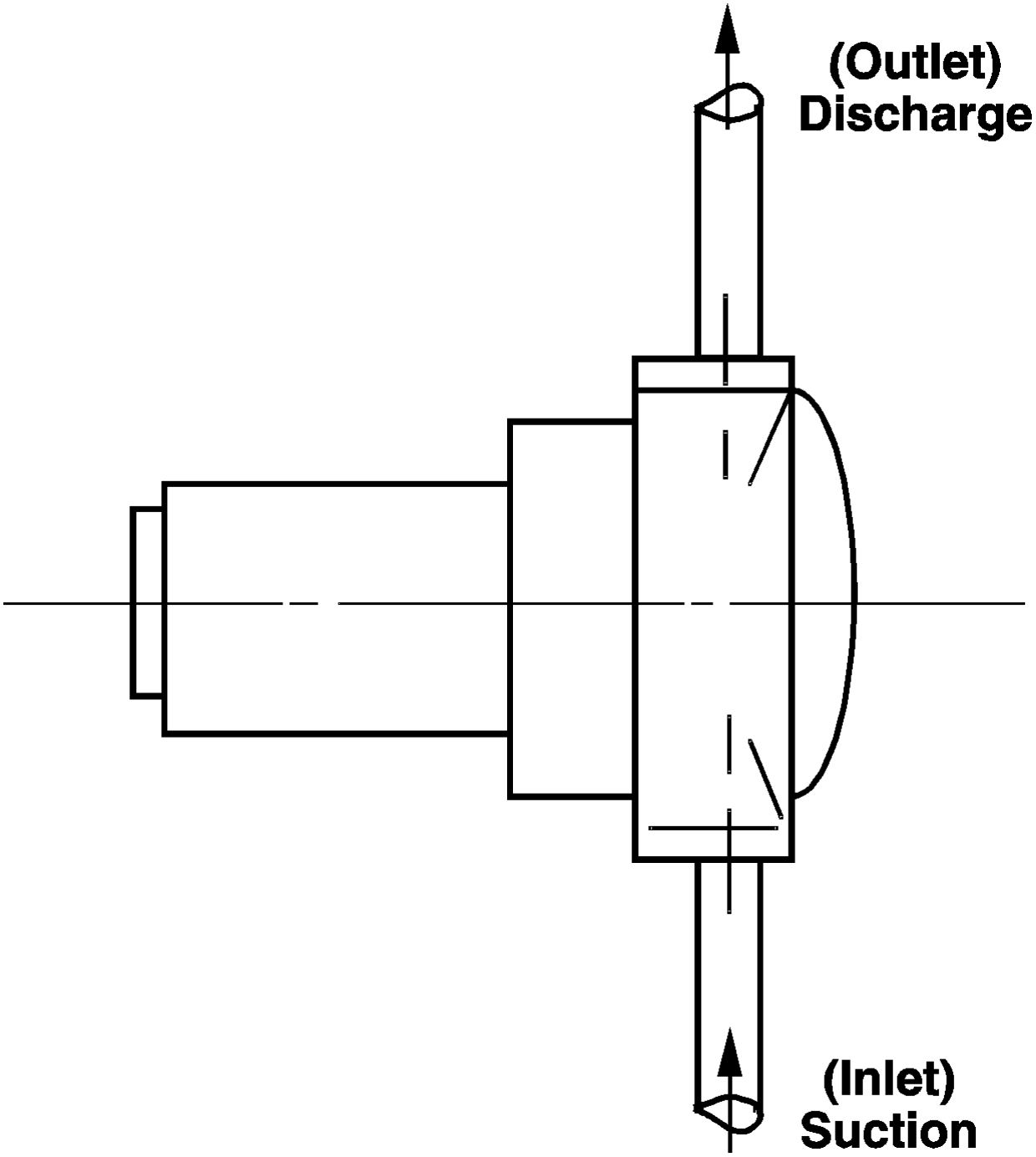


(Source: Carrier Corporation, 2005. *Distribution Systems: Water Piping and Pumps*, Technical Development Program.)

Centrifugal Pumps

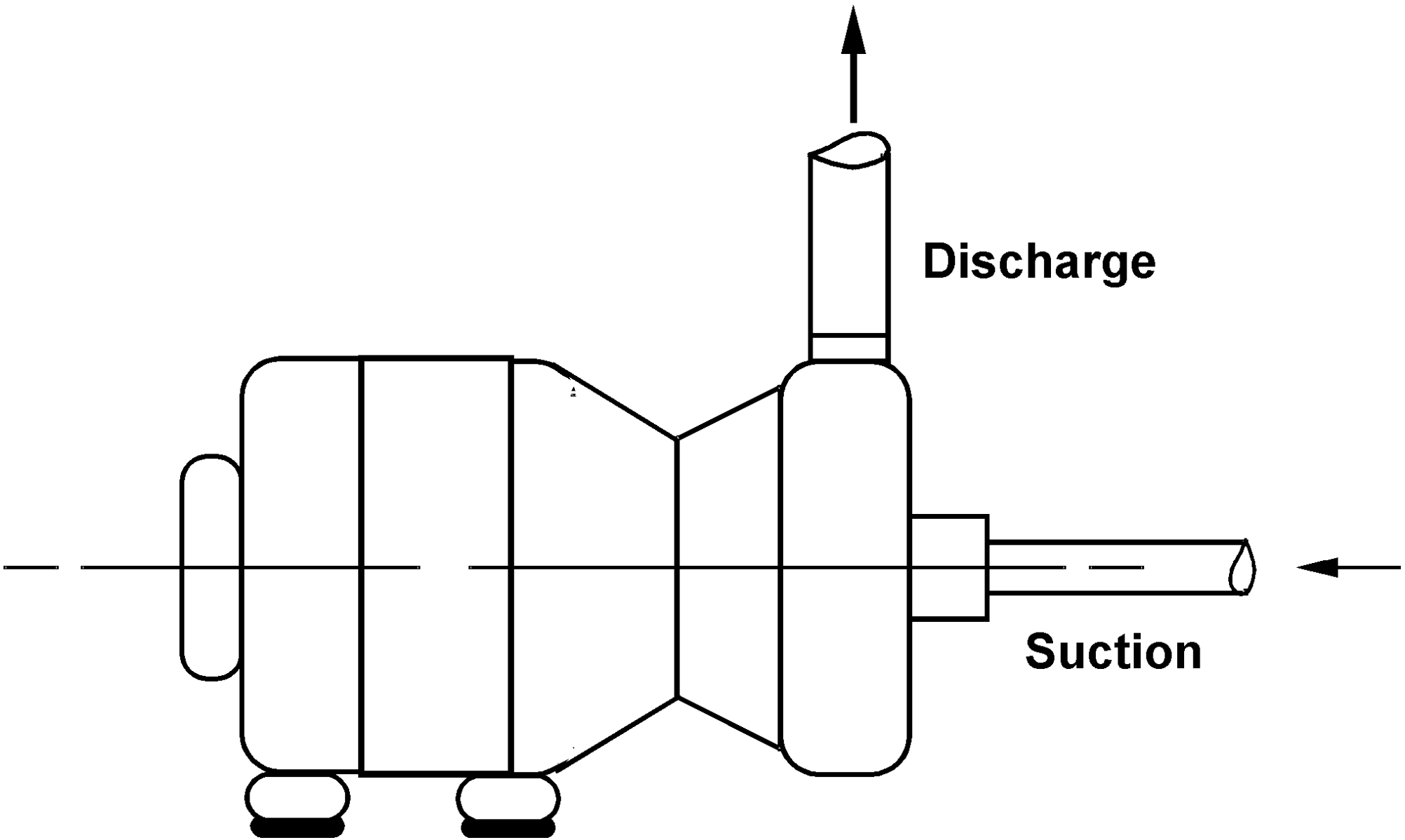
- Types of centrifugal pumps
  - Circulator pump
  - Closed-couple end suction pump
  - Frame-mounted end suction pump
  - Base-mounted horizontal split case pump
  - Vertical inline pump
  - Vertical turbine single or multistage pump

Circulation pump



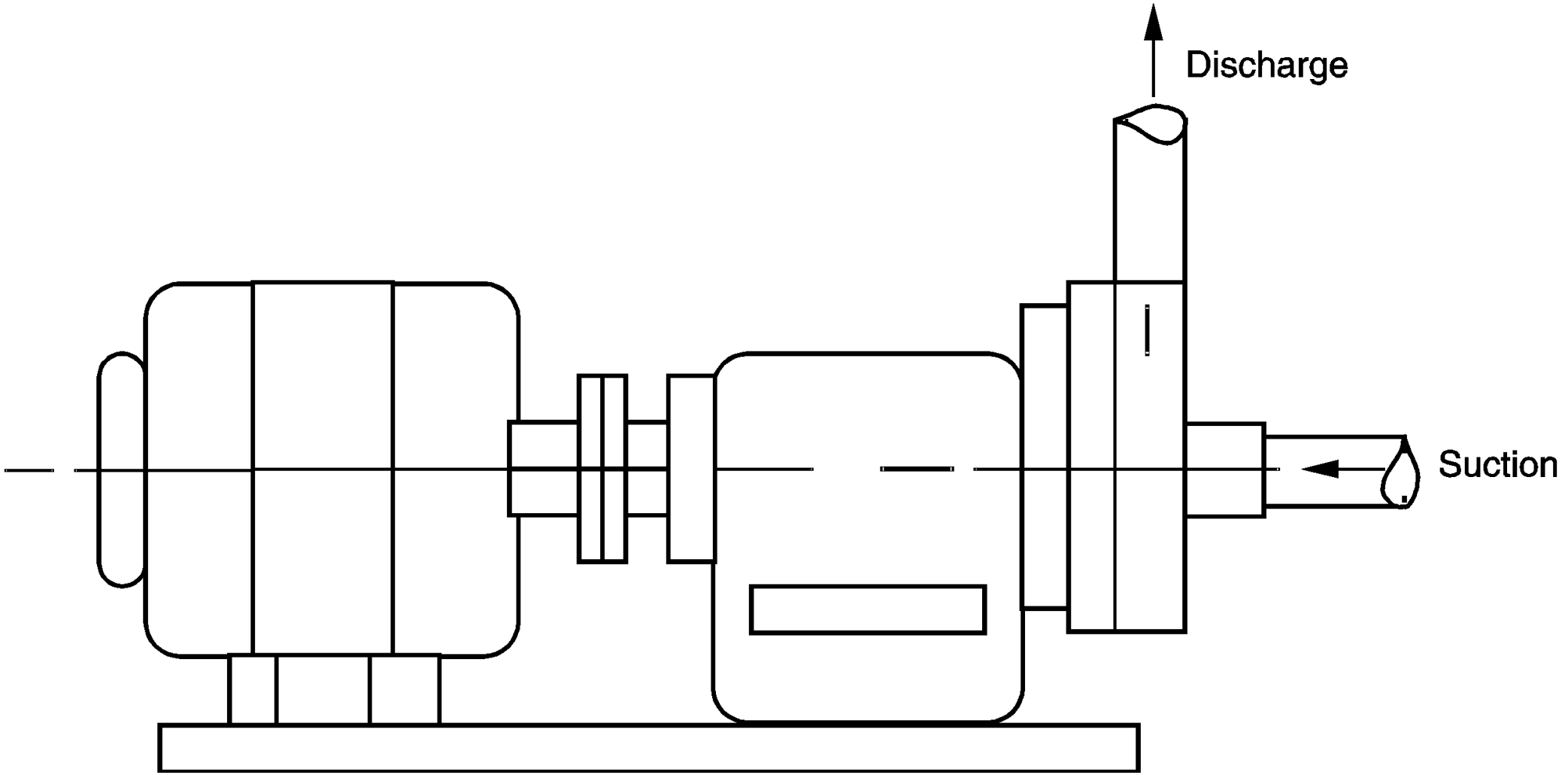
(Source: *Fundamentals of Water System Design*)

Close-coupled end suction pump



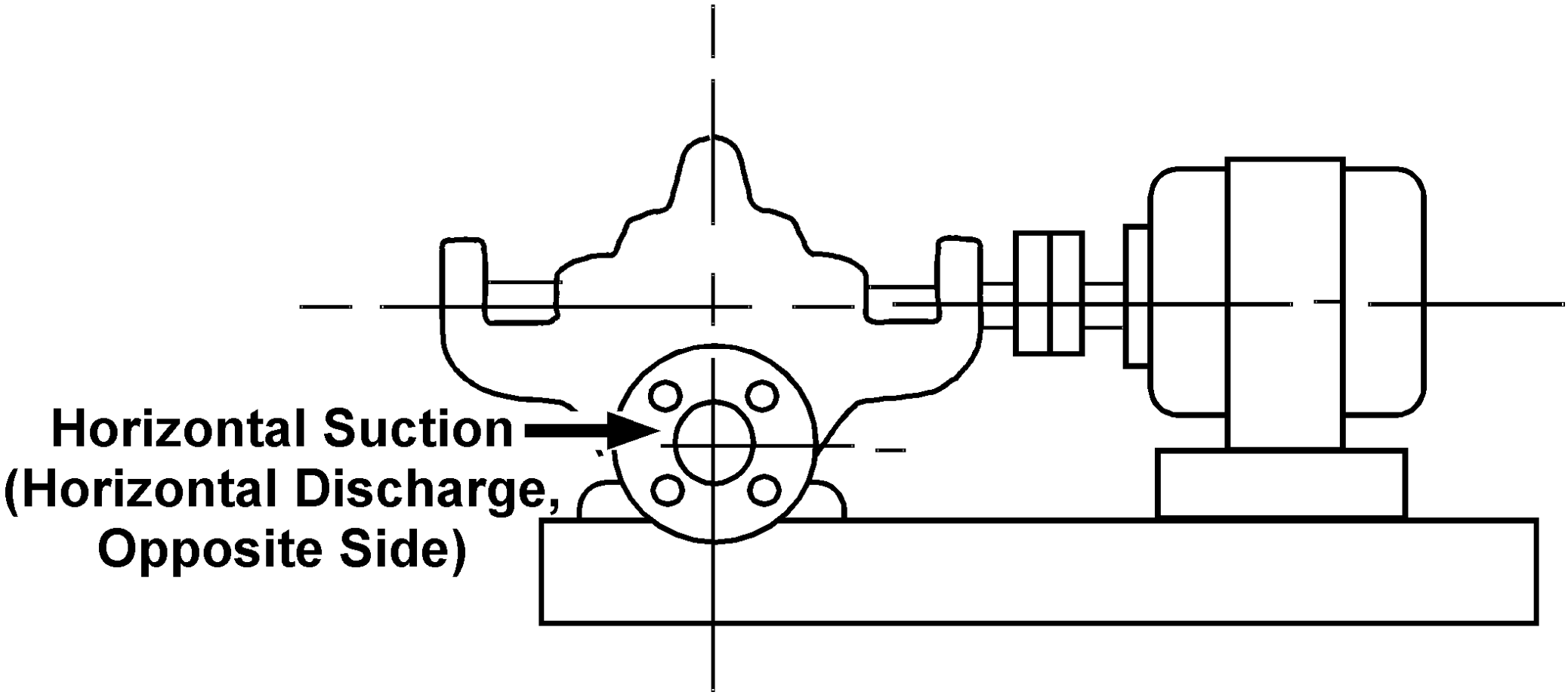
(Source: *Fundamentals of Water System Design*)

Frame-mounted end suction pump



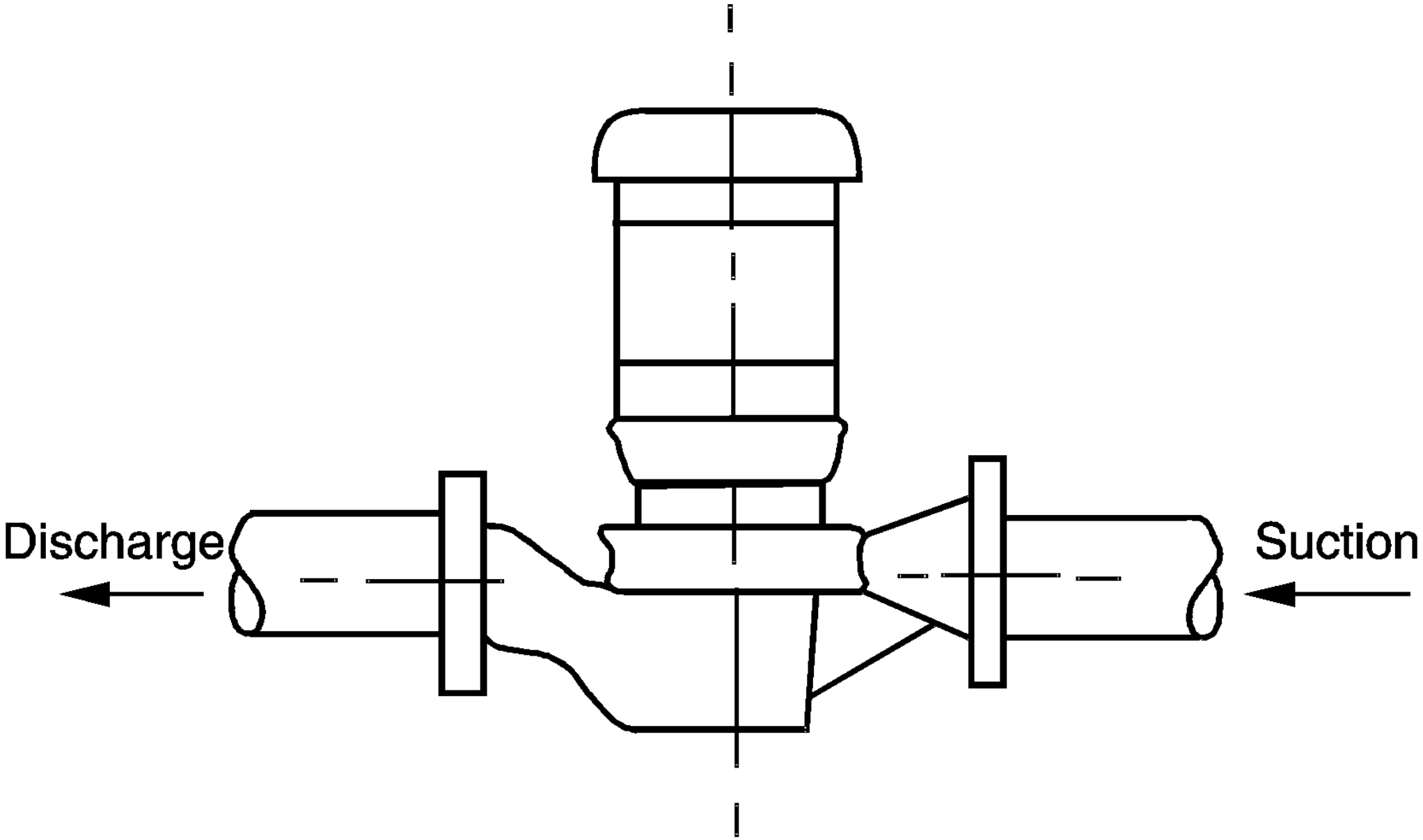
(Source: *Fundamentals of Water System Design*)

Base-mounted horizontal split case pump



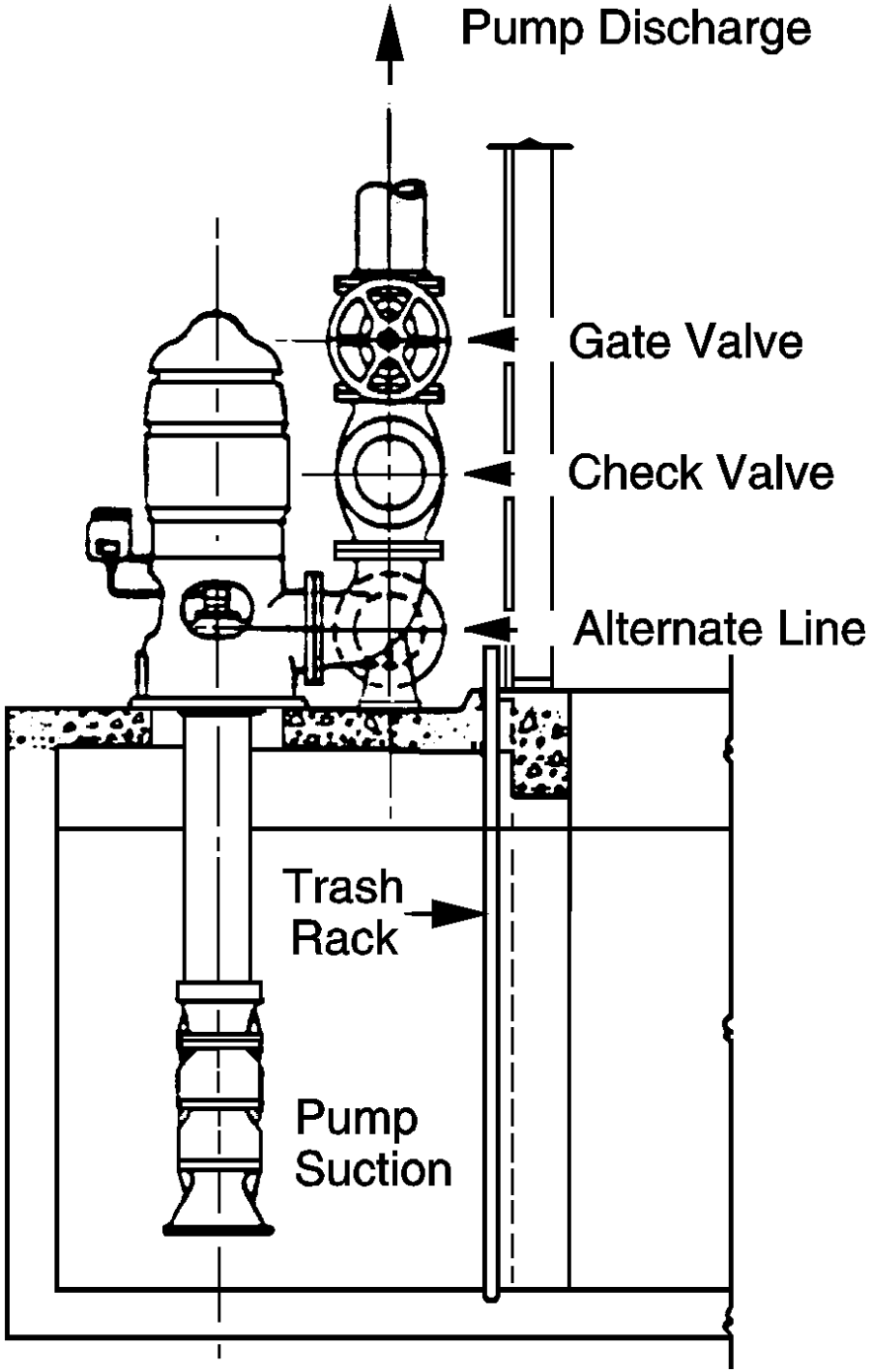
(Source: *Fundamentals of Water System Design*)

Vertical inline pump



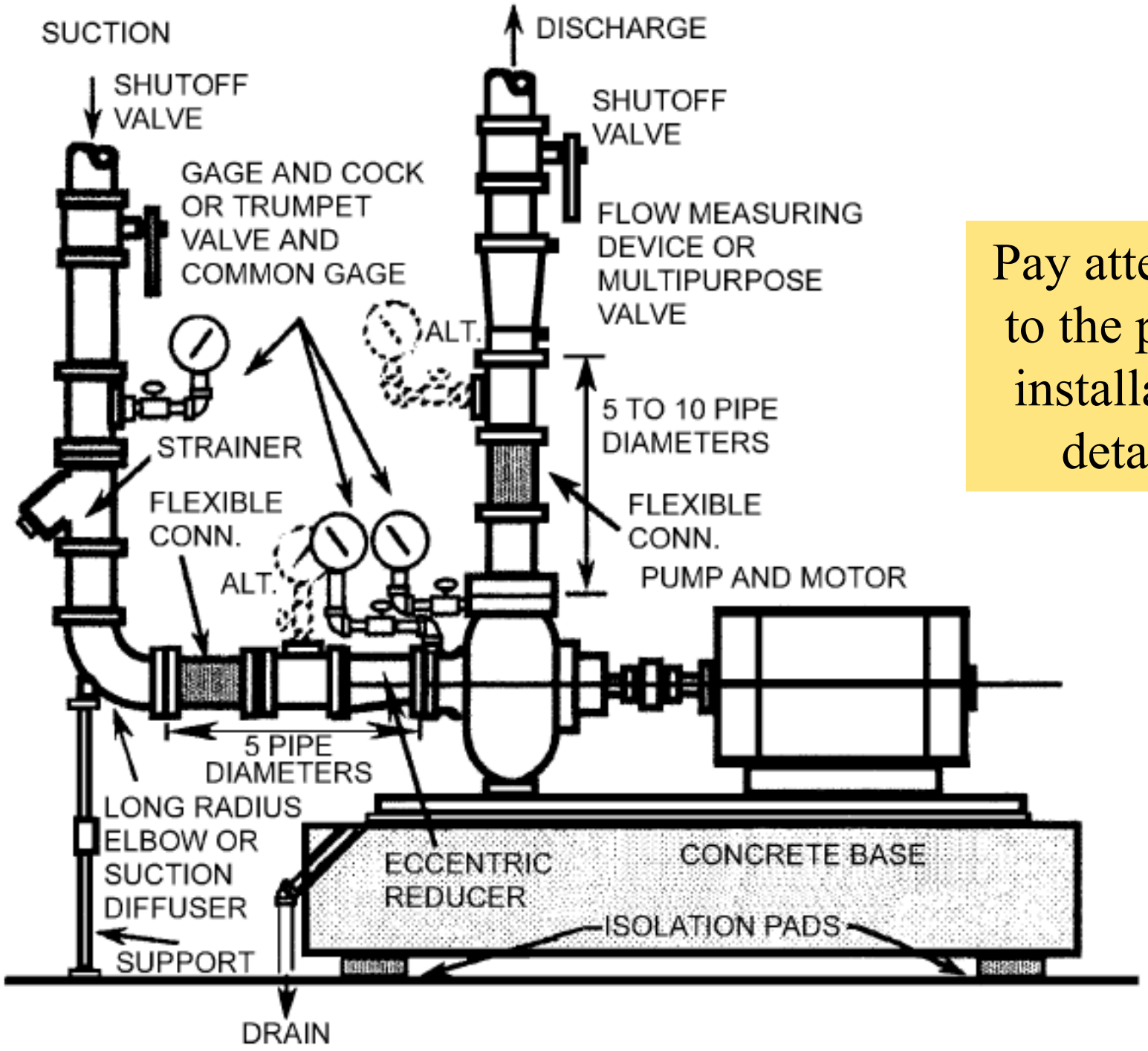
(Source: *Fundamentals of Water System Design*)

Vertical turbine pump, wet sump arrangement



(Source: *Fundamentals of Water System Design*)

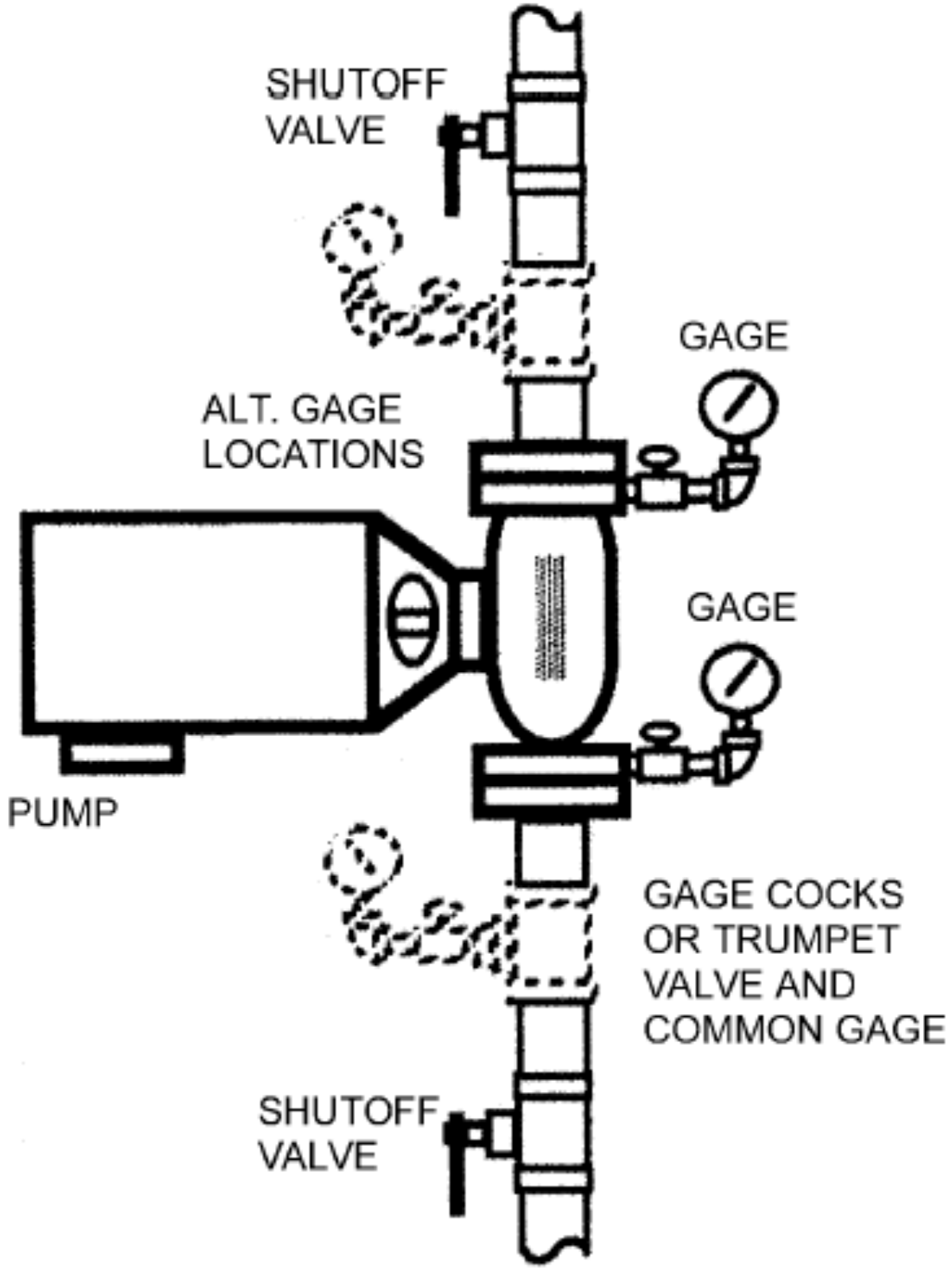
Base plate-mounted centrifugal pump installation



Pay attention to the pump installation details

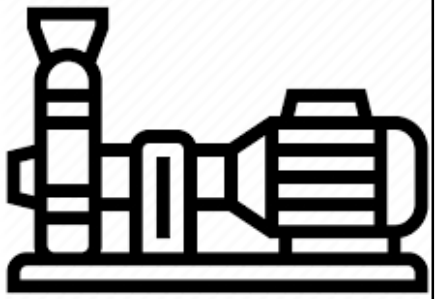
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

In-line pump installation

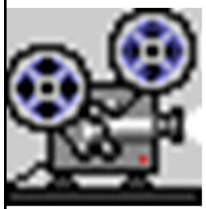


(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Pump Characteristics

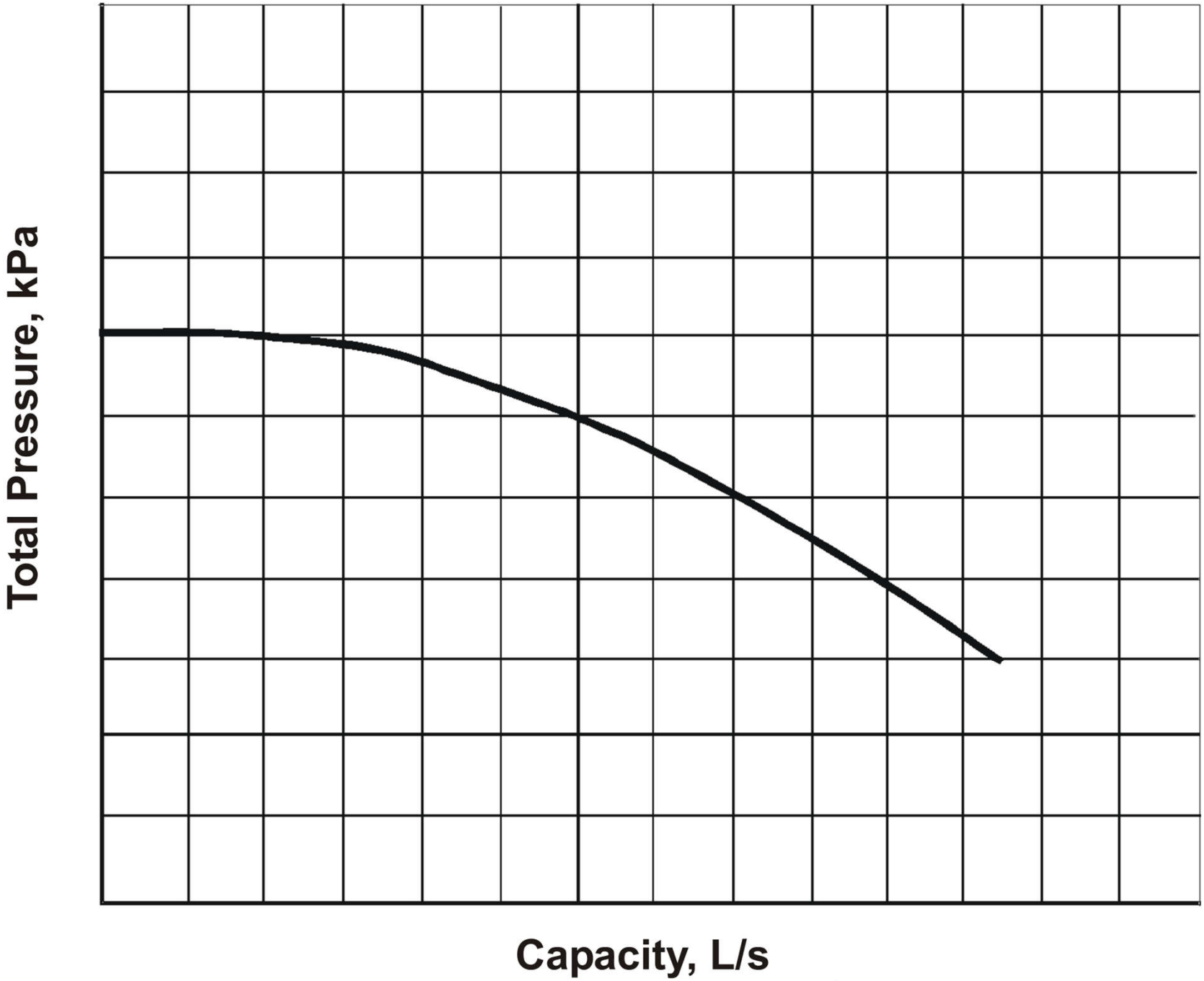


- Centrifugal pump characteristics*
  - Total pressure-capacity curve
    - Flat curve: applied on closed piping systems with modulating valves
    - Steep curve: usually for open piping systems (cooling towers), w/ high pressure, constant flow
  - Family of pump performance curves
- Variable speed pumps
  - Less expensive nowadays; energy saving



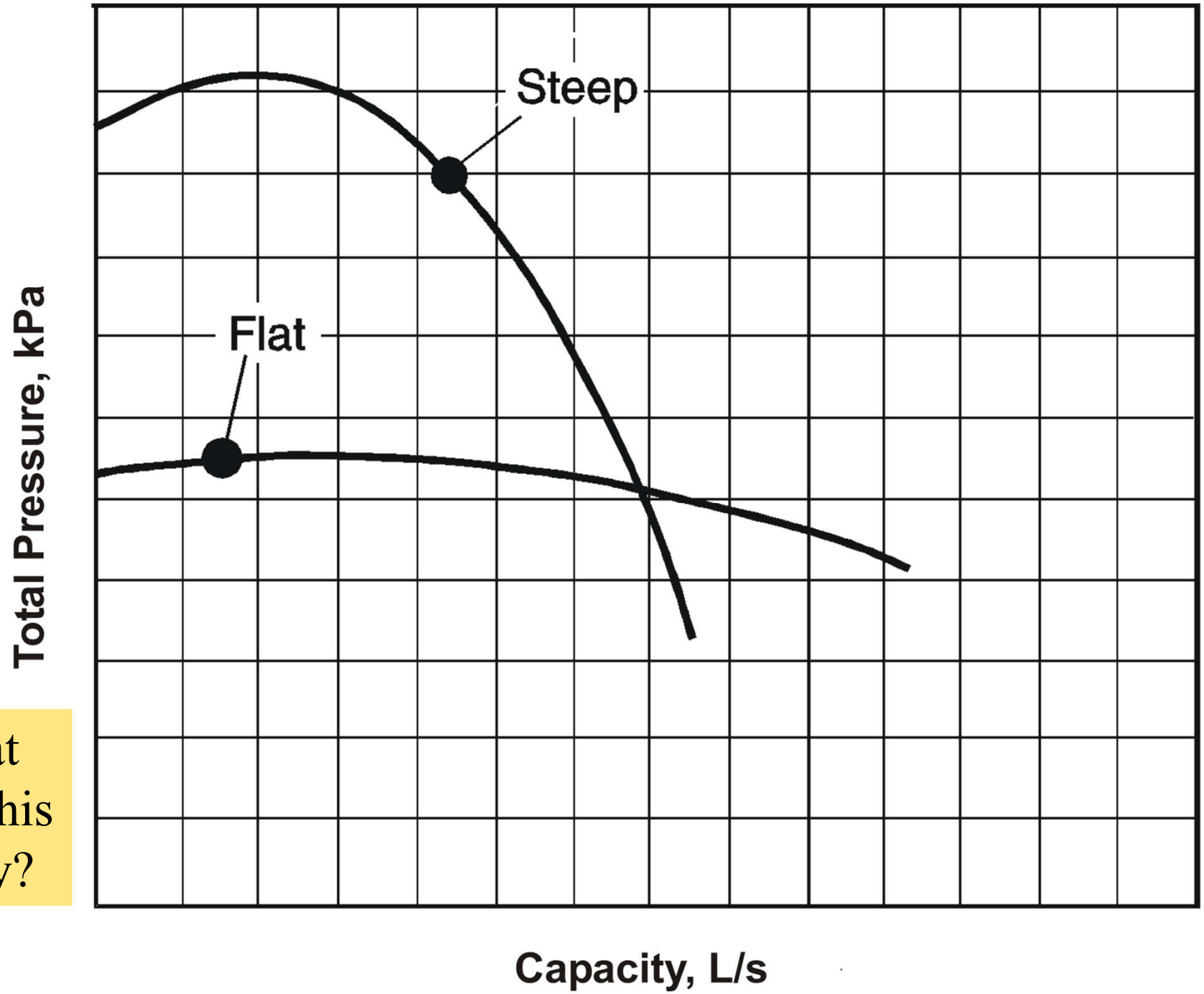
* Video: Centrifugal Pumps | Design Aspects (5:32) https://youtu.be/pWSyrxFJmt4

Total pressure-capacity curve



(Source: *Fundamentals of Water System Design*)

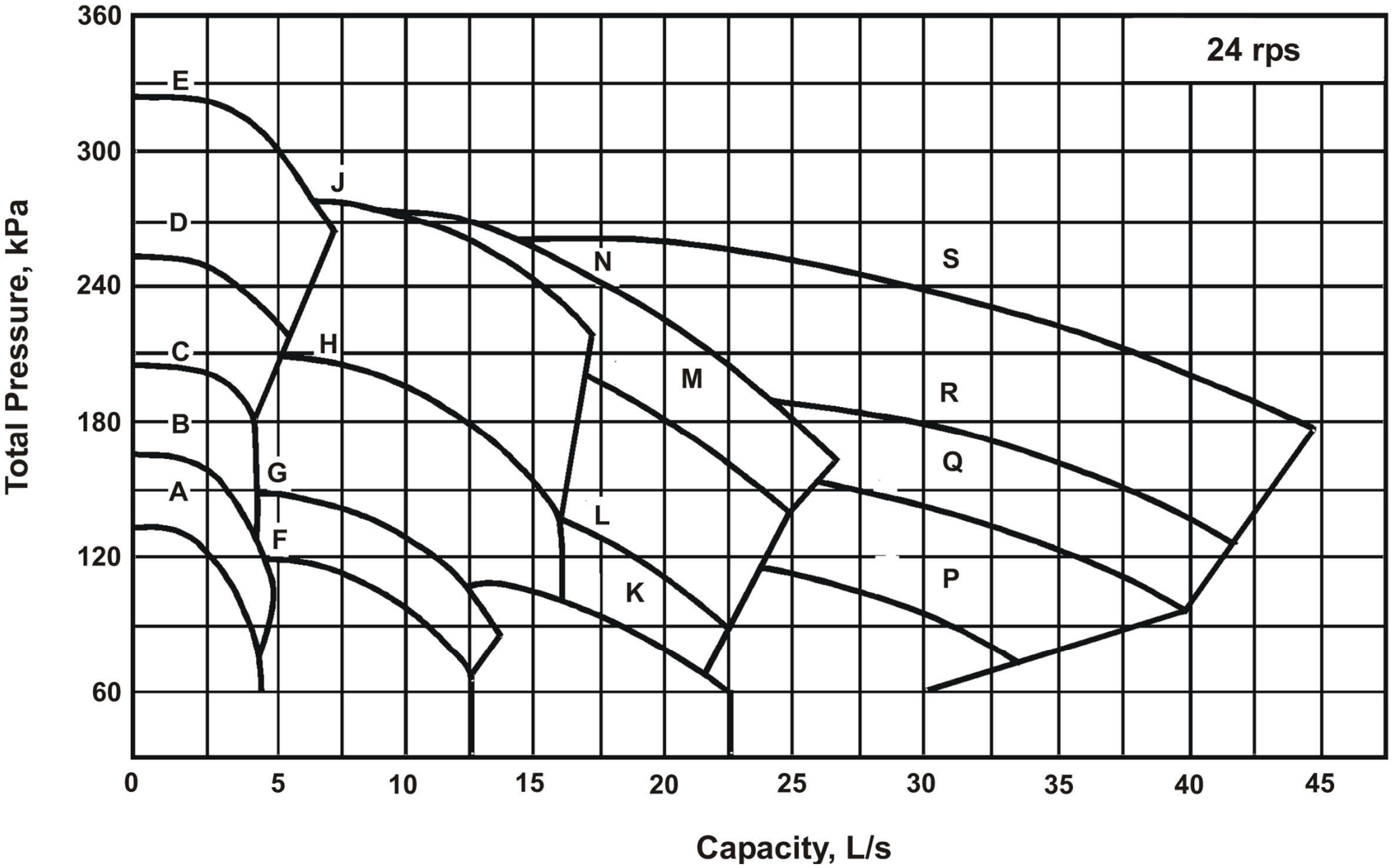
Flat versus steep pump curves



What does this imply?

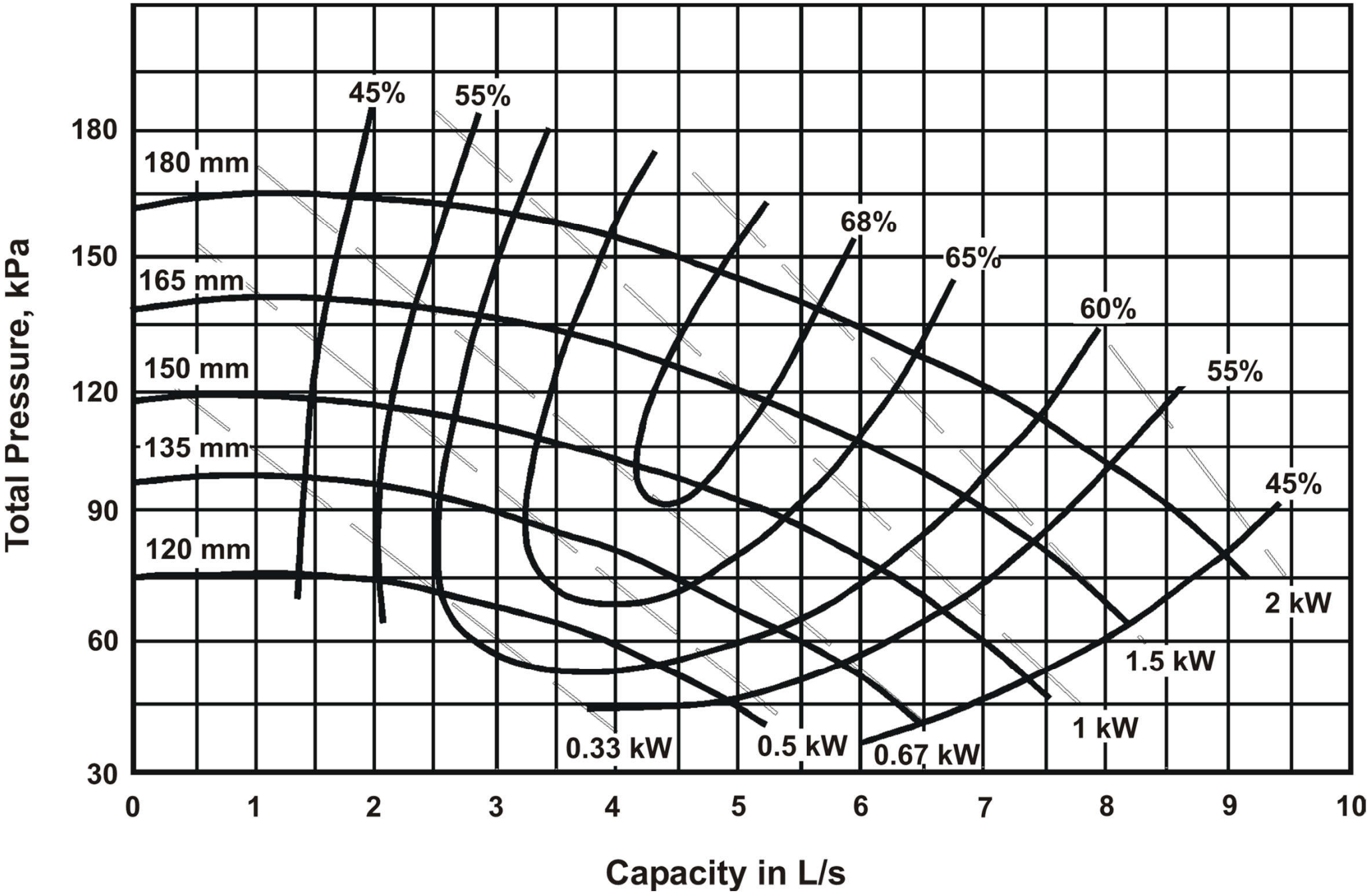
(Source: *Fundamentals of Water System Design*)

Characteristic curves or regions for pump models



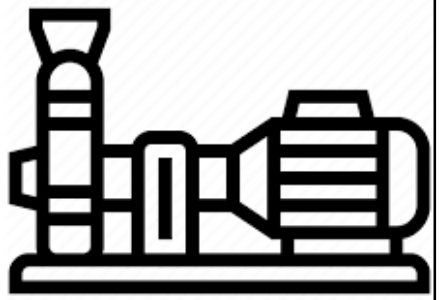
(Source: *Fundamentals of Water System Design*)

Selected pump pressure-capacity curve (with impeller size, power input & efficiency)



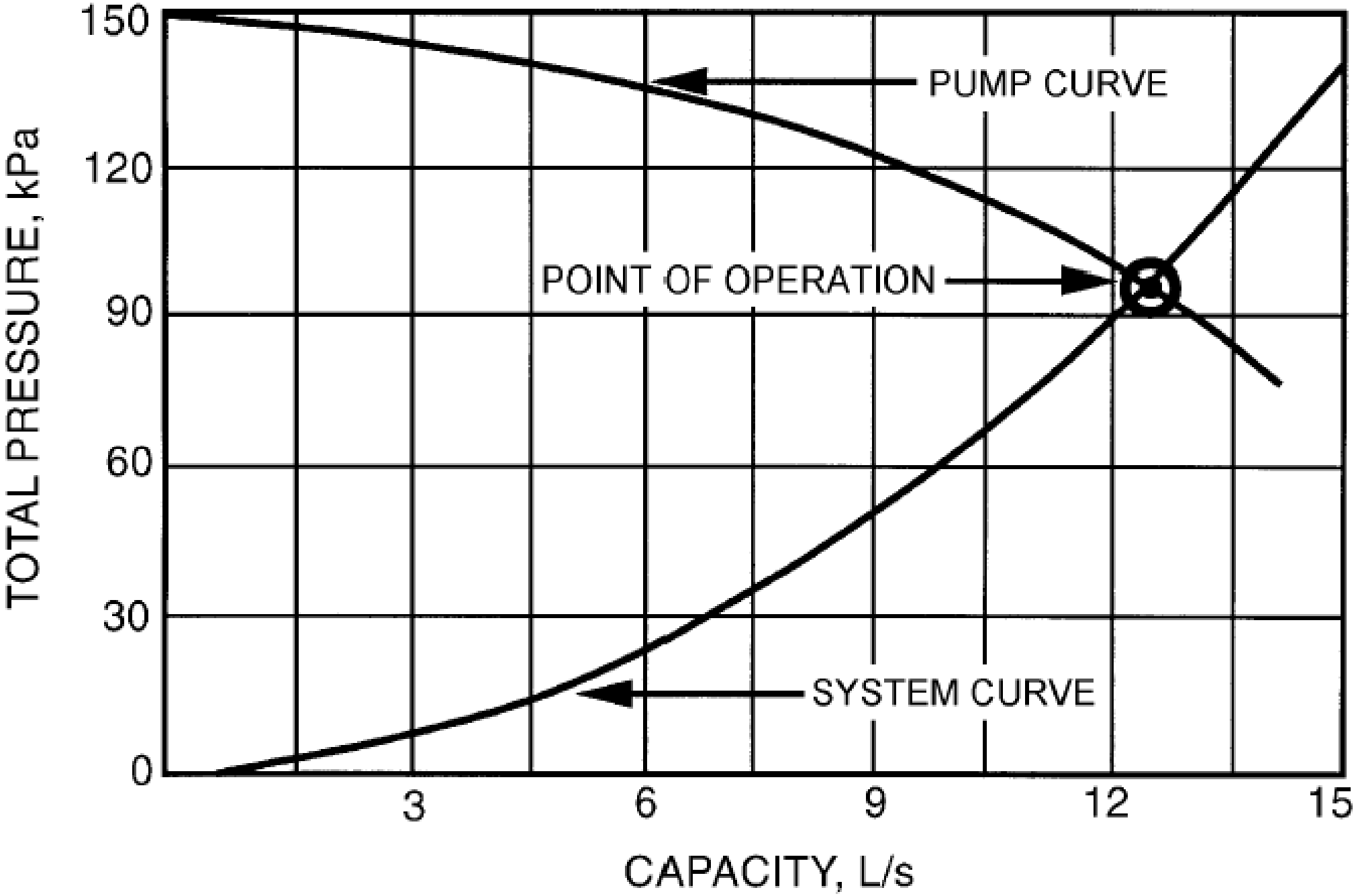
(Source: *Fundamentals of Water System Design*)

Pump Characteristics



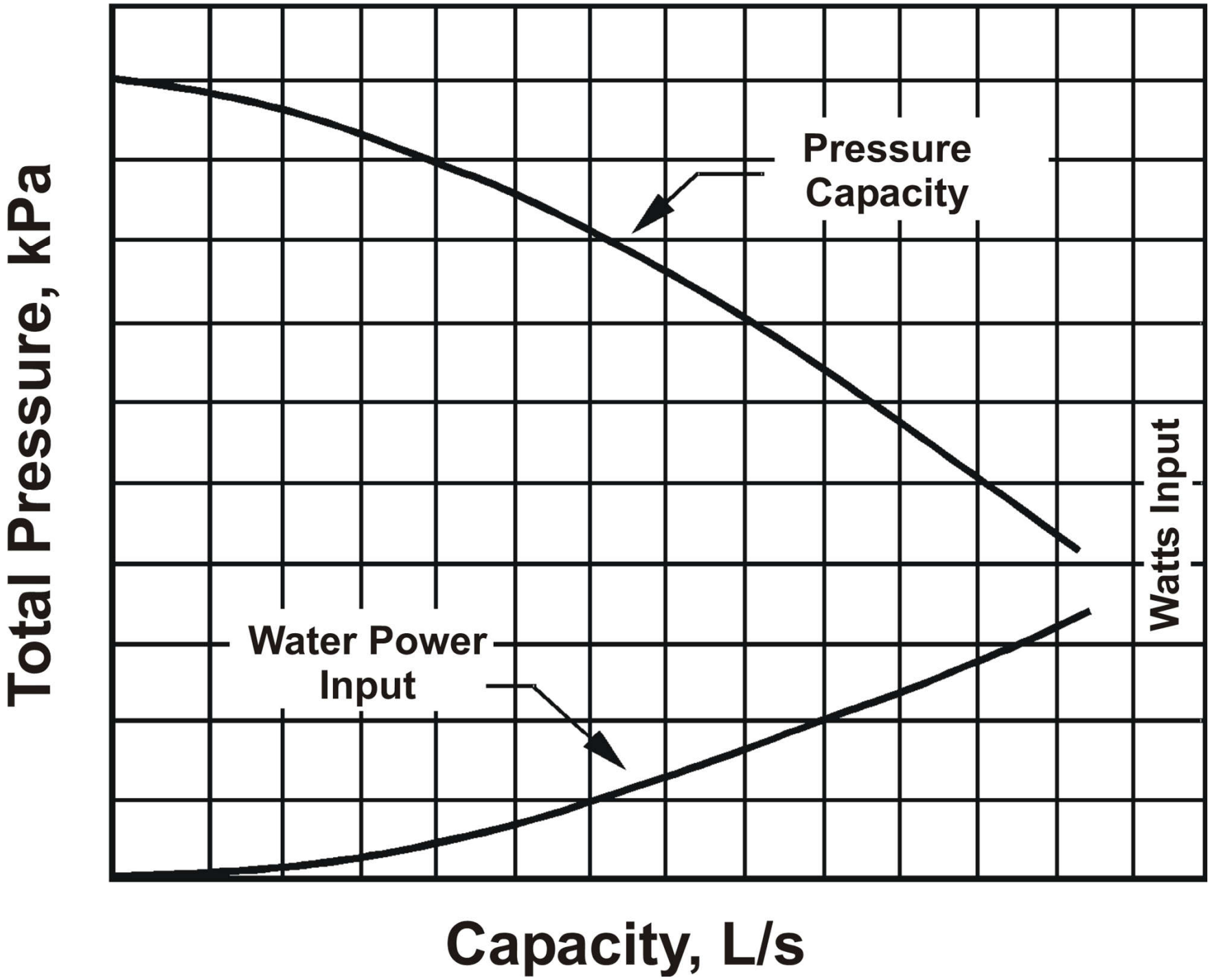
- System pressure characteristic curve
  - Compared w/: fan-duct system characteristics
  - System operating point: intersection of fan curve & system curve
- Pump power (W) = flow (L/s) x pressure (kPa)
  - Pump input power
  - Pump efficiency
    - Matching pump to system curve
    - Best efficiency point (BEP)

Pump curve, system curve and point of operation



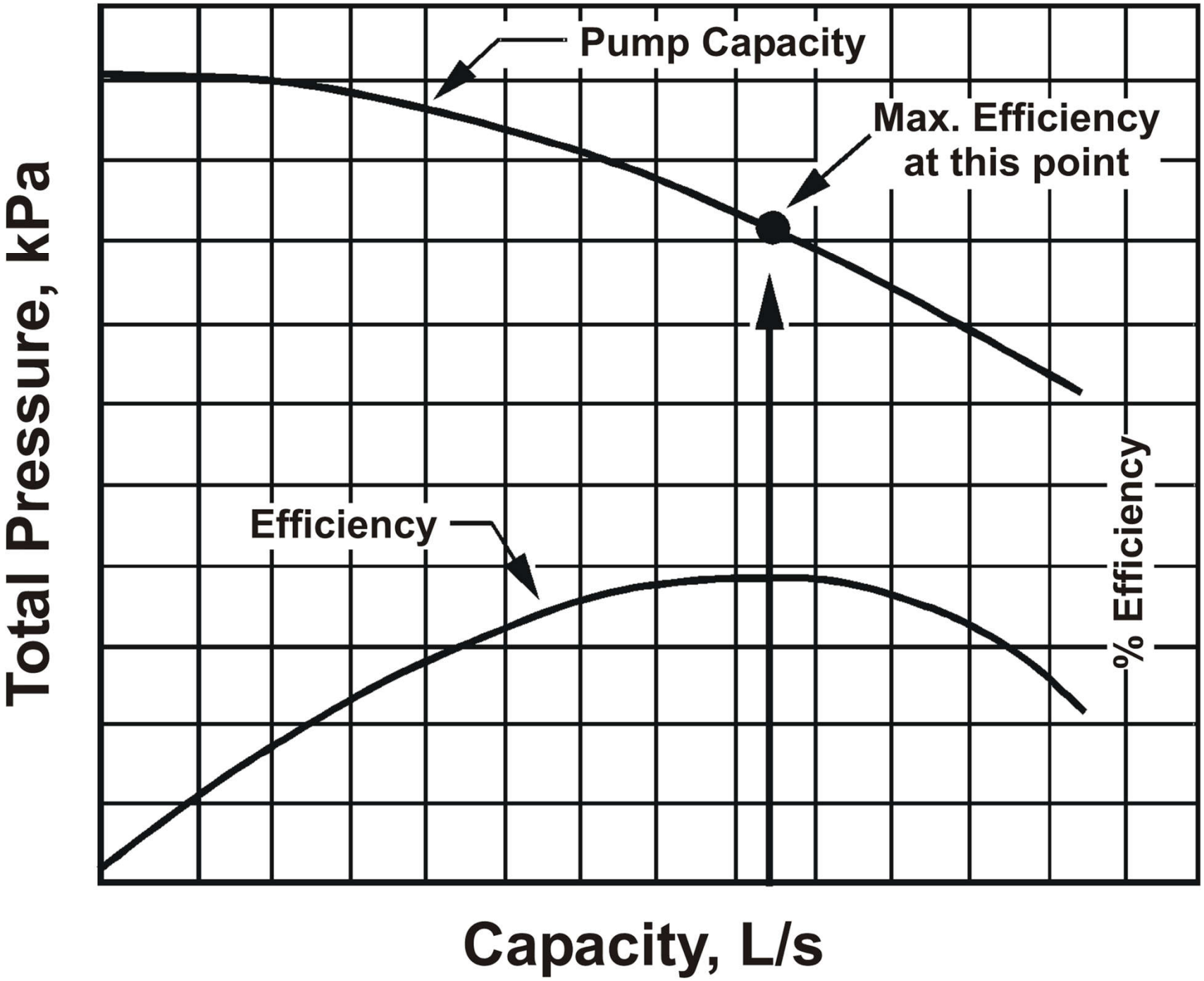
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Increase of pumping power required with pump flow



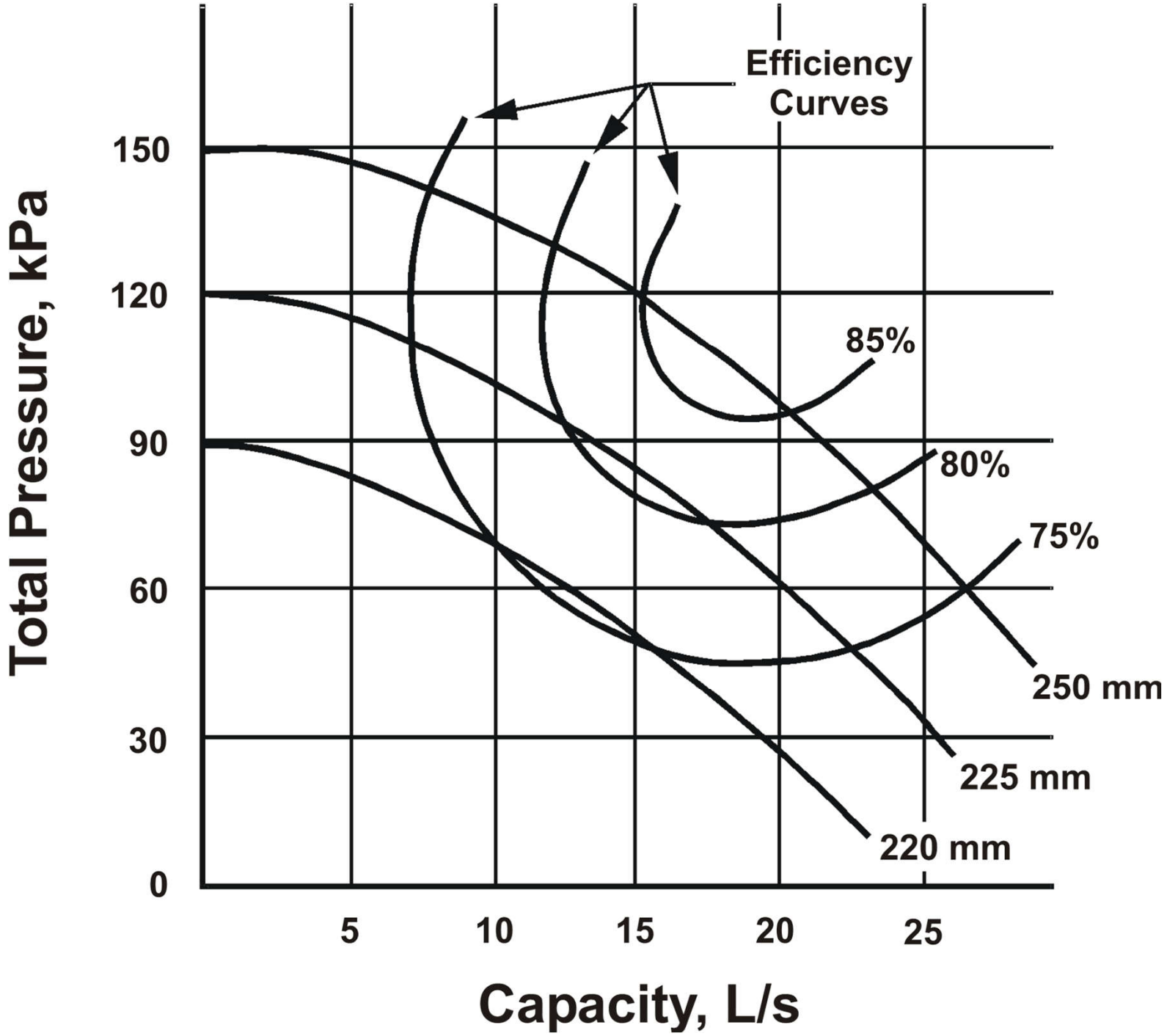
(Source: *Fundamentals of Water System Design*)

Pump efficiency



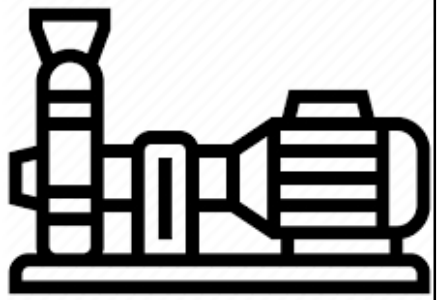
(Source: *Fundamentals of Water System Design*)

Pump efficiency curves



(Source: *Fundamentals of Water System Design*)

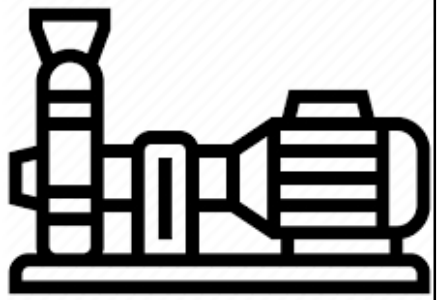
Pump Characteristics



- Similarity relationships
  - Pump affinity laws (c.f. fan laws)

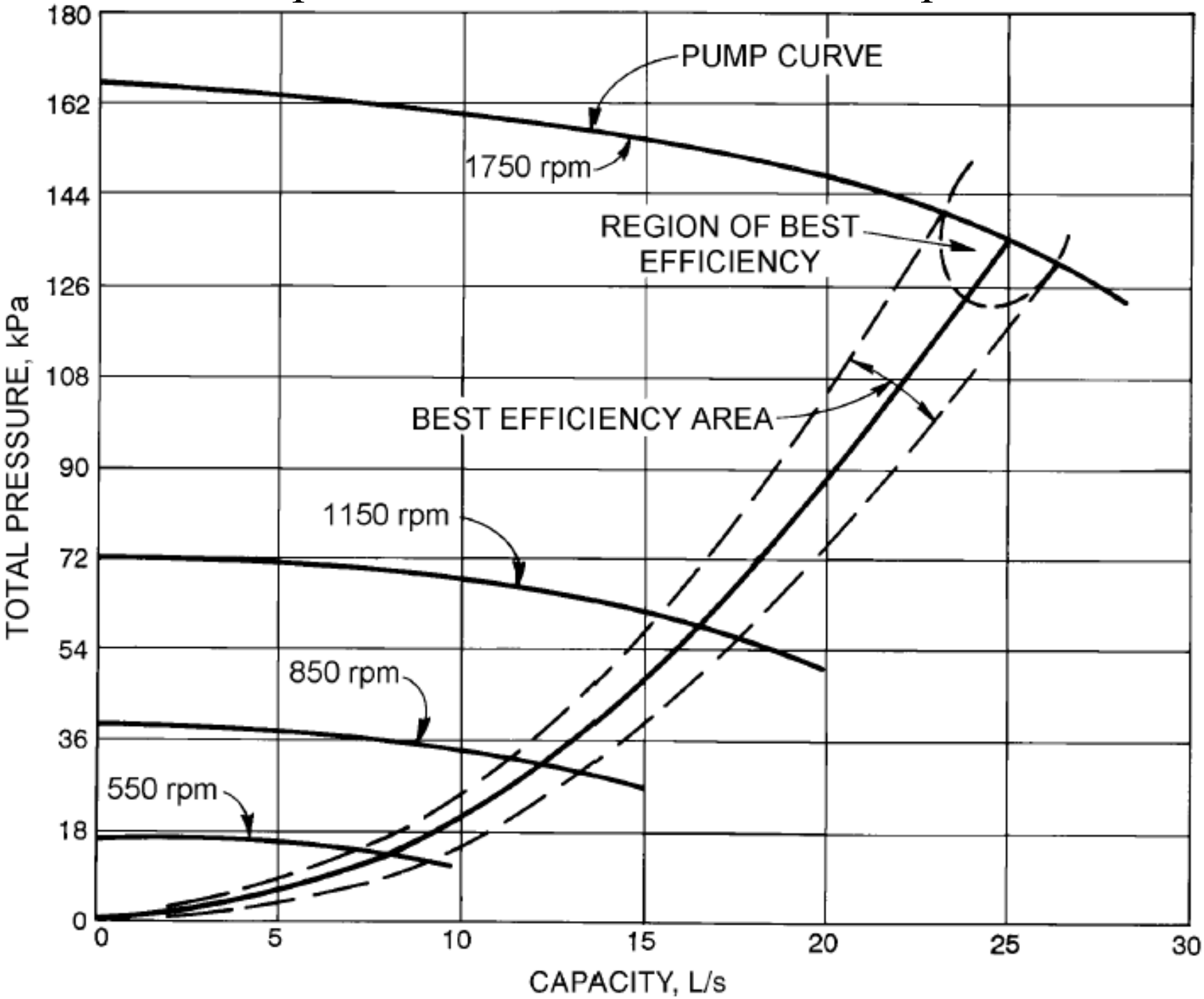
Function	Speed change	Impeller diameter change
Flow	$Q_2 = Q_1 (N_2/N_1)$	$Q_2 = Q_1 (D_2/D_1)$
Pressure	$p_2 = p_1 (N_2/N_1)^2$	$p_2 = p_1 (D_2/D_1)^2$
Power	$P_2 = P_1 (N_2/N_1)^3$	$P_2 = P_1 (D_2/D_1)^3$

Pump Characteristics



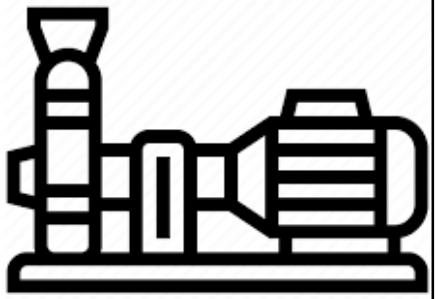
- Pump affinity laws (example)
  - A pump is rated at 15 L/s at 200 kPa with a 24 rpm electric motor. What is the flow and pressure if used with a 16 rps motor? Assume no system static pressure.
  - Solution:
    - Flow: $Q_2 = Q_1 \, (N_2/N_1) = 15 \, (16/24) = \underline{10 \text{ L/s}}$
    - Pressure: $p_2 = p_1 \, (N_2/N_1)^2 = 200 \, (16/24)^2 = \underline{88.9 \text{ kPa}}$

Pump curve variation with rotation speed

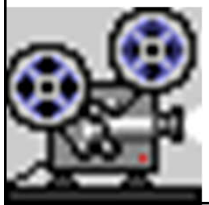


(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Pump Characteristics

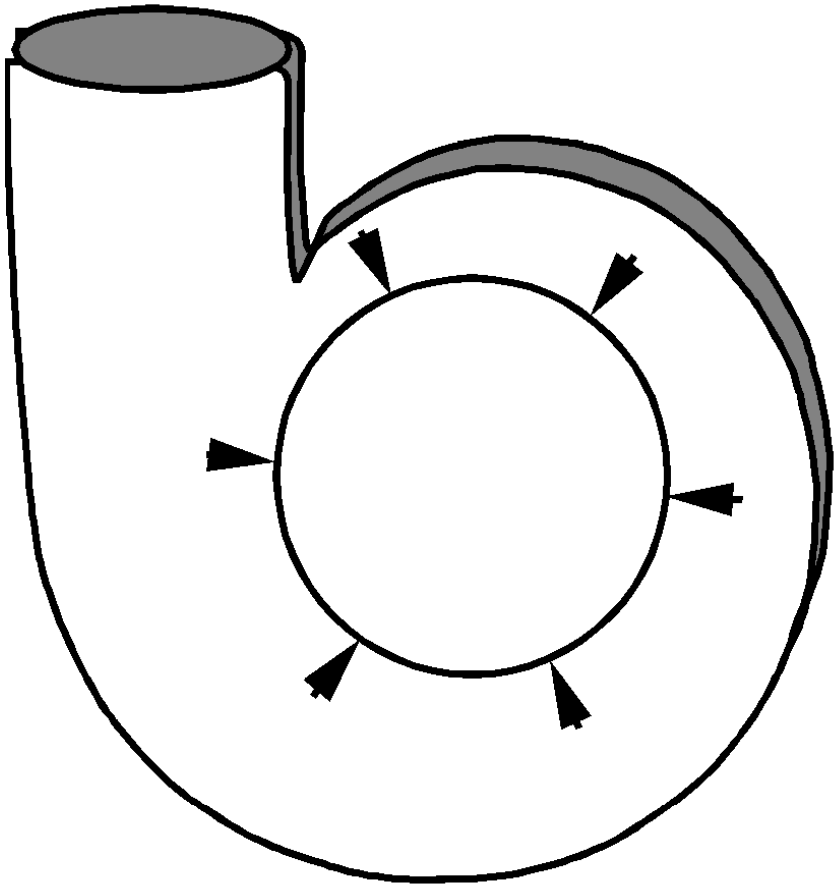


- Radial thrust
  - Non-uniform pressure around impeller
  - Greatest at shutoff
  - Decreases from shutoff to design capacity
  - Increase with overcapacity
- Net positive suction (NPS)
  - Cavitation: vapour pockets form in impeller passages & may cause damages*
  - Net positive suction required (NPSR) - pump

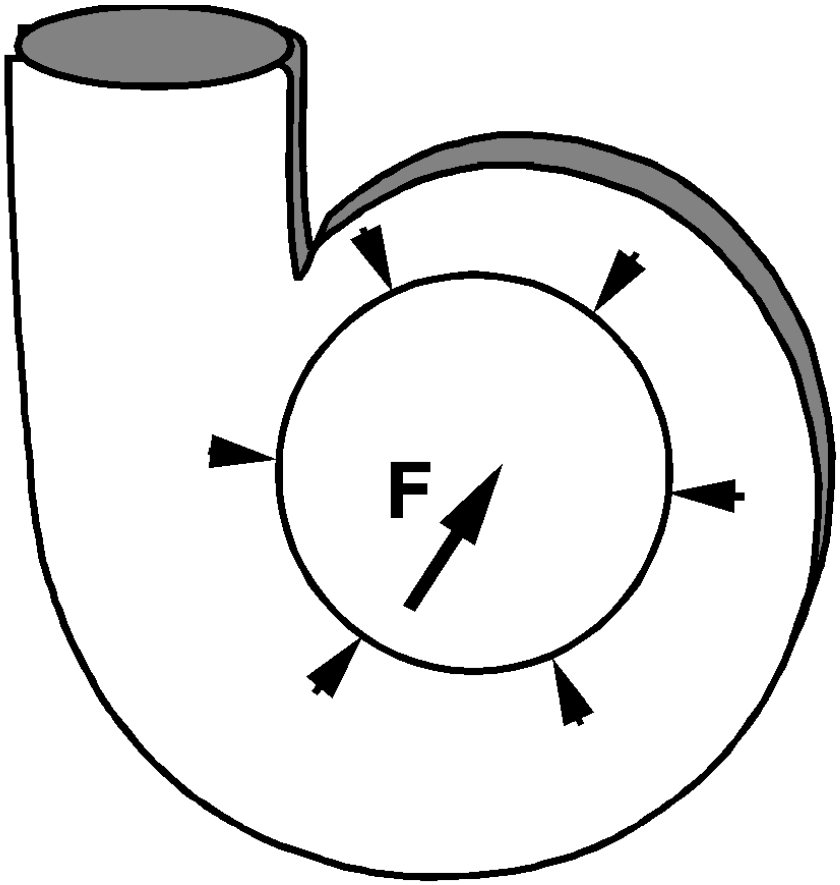


* Video: Cavitation Causes and Effects (16:08) https://youtu.be/oRYYP4F8LTU

Pressures on impeller causing radial thrust



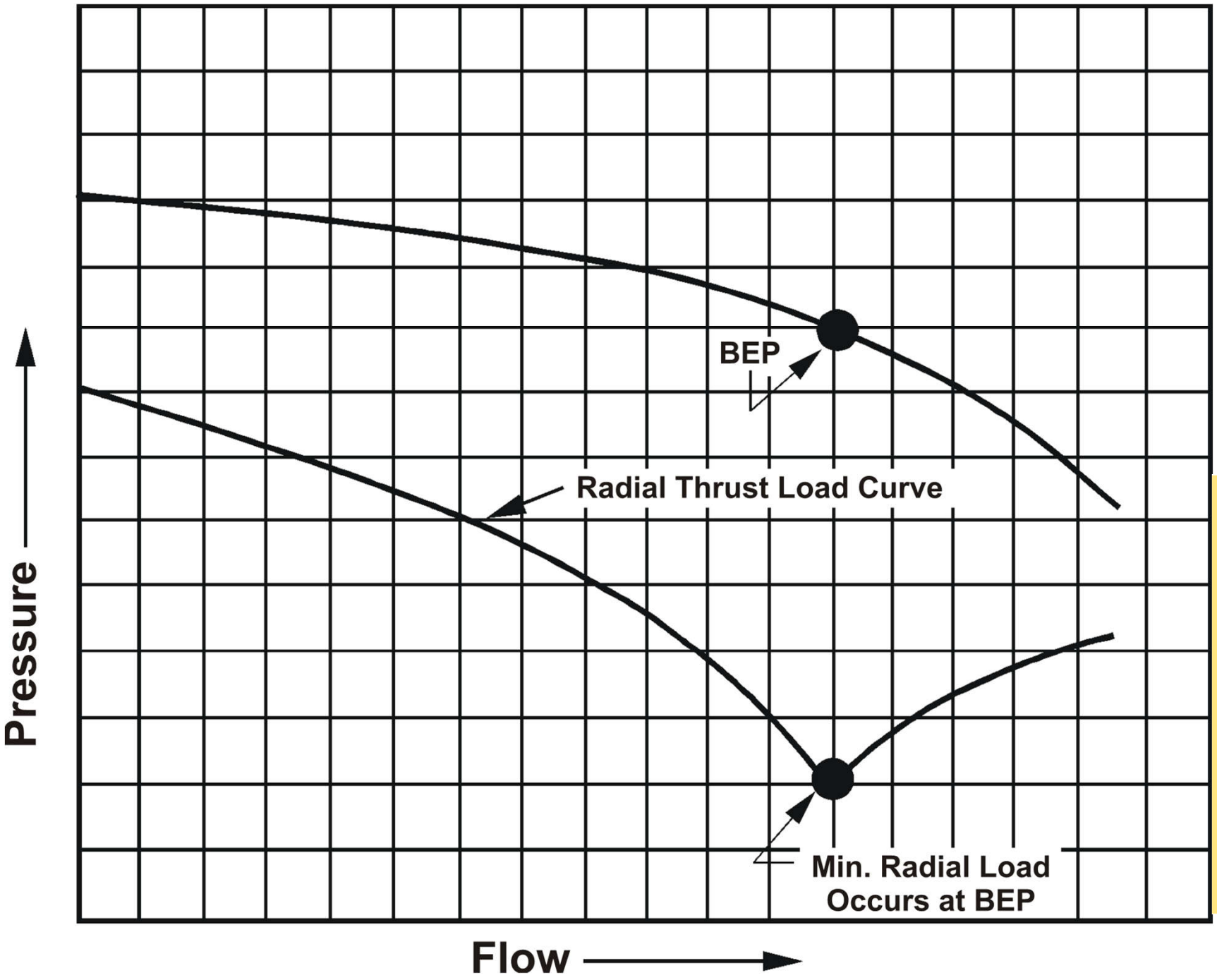
Uniform Pressures Exist at Design Capacity



Non-Uniform Pressures Exist at Reduced Capacities

(Source: *Fundamentals of Water System Design*)

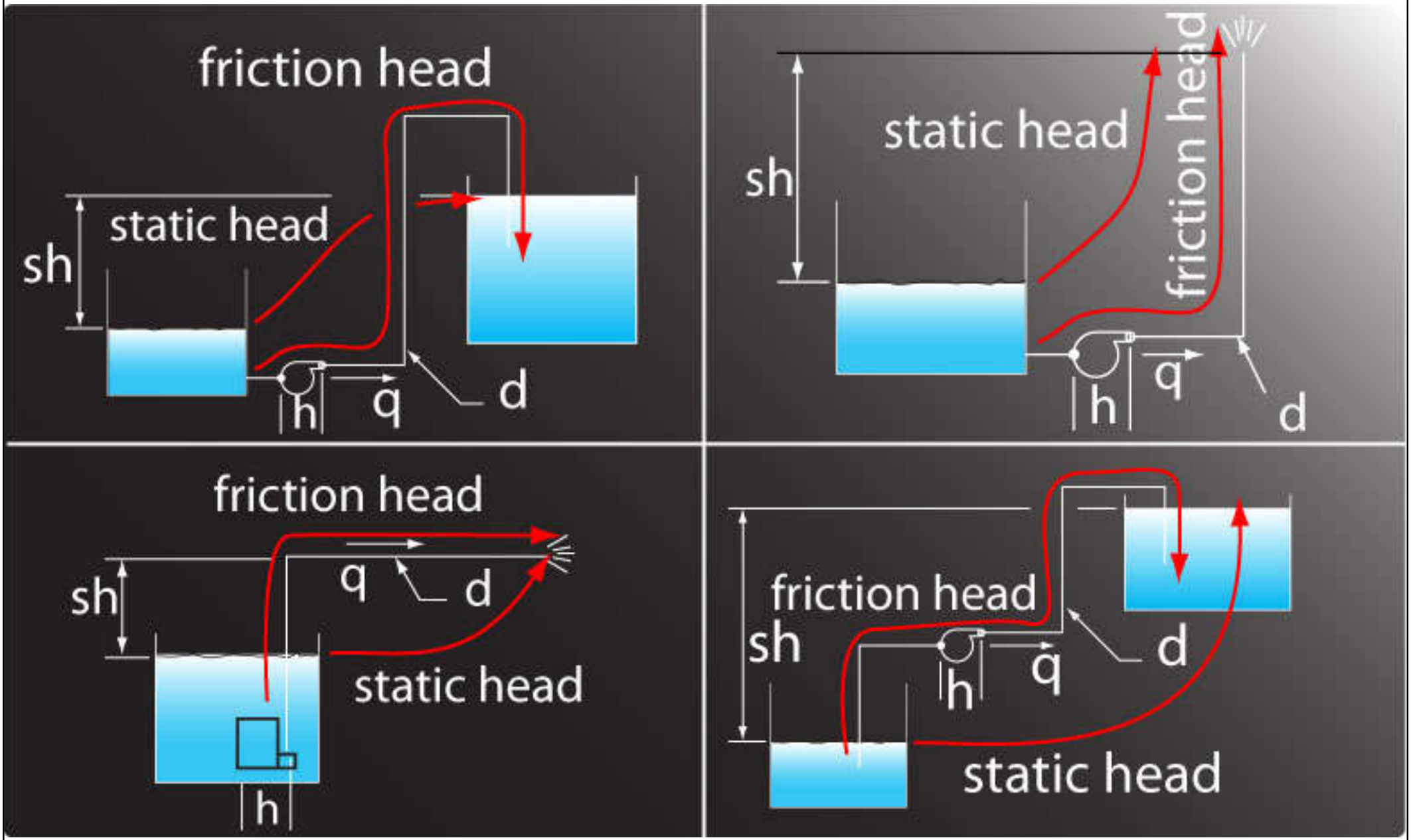
Change in radial thrust versus pumping rate



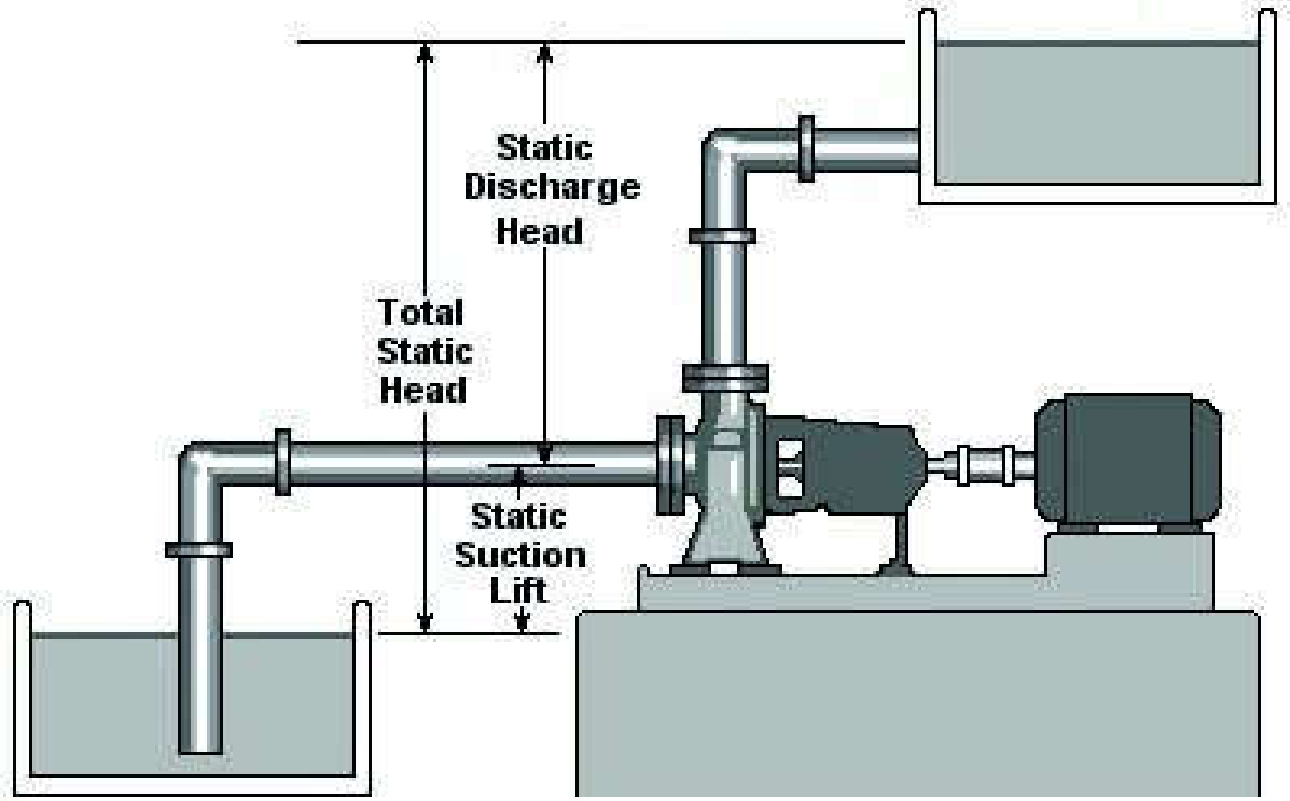
How radial thrust affects pump efficiency ?

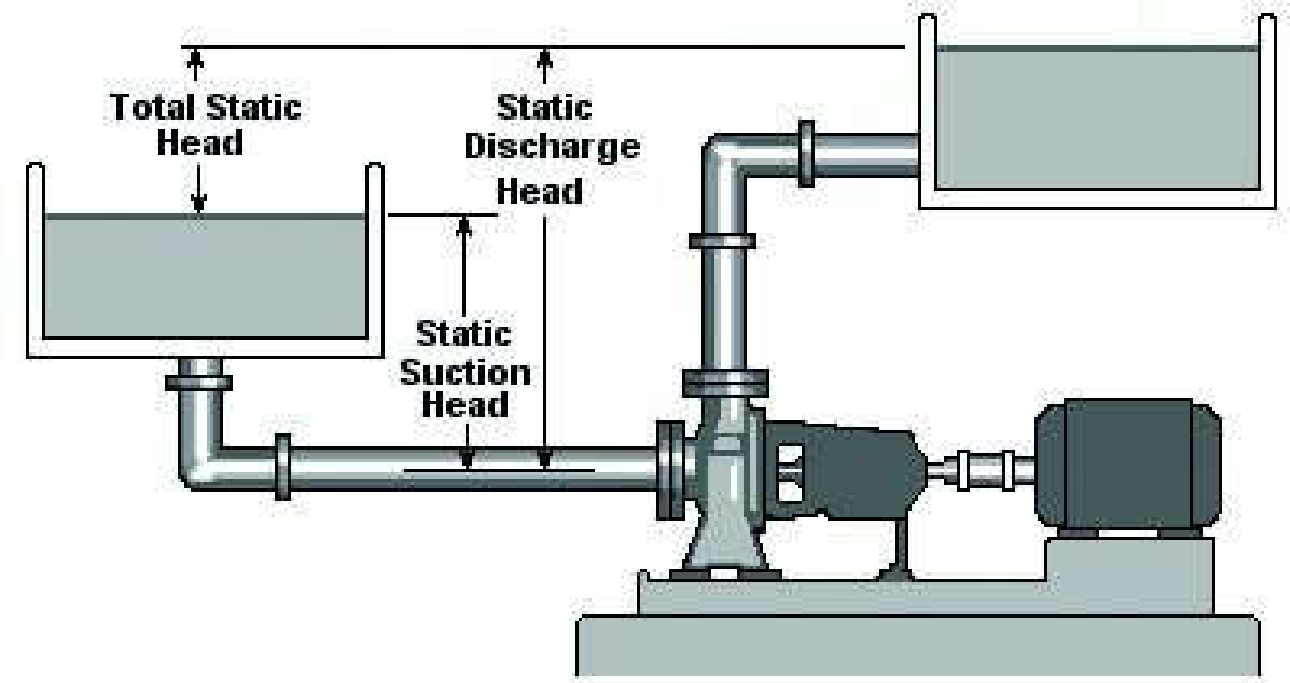
(Source: *Fundamentals of Water System Design*)

Pump head calculation



(Source: https://www.pumpfundamentals.com/php_pages/pump/head-1.php)

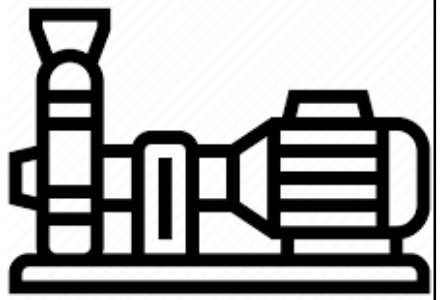




Static discharge head, static suction lift and total static head

(Source: https://www.pumpsandsystems.com/characteristics-centrifugal-pumps)

Pump Characteristics



- Net positive suction available (NPSA)
  - Also known as net positive suction head (NPSH)
  - For the installation
  - Total useful energy above the vapour pressure at the pump suction connection
  - Affected by the location of expansion tank
- If NPSA < Pump's NPSR
  - Cavitation, noise, inadequate pumping, etc.
  - To avoid problem, NPSA > NPSR

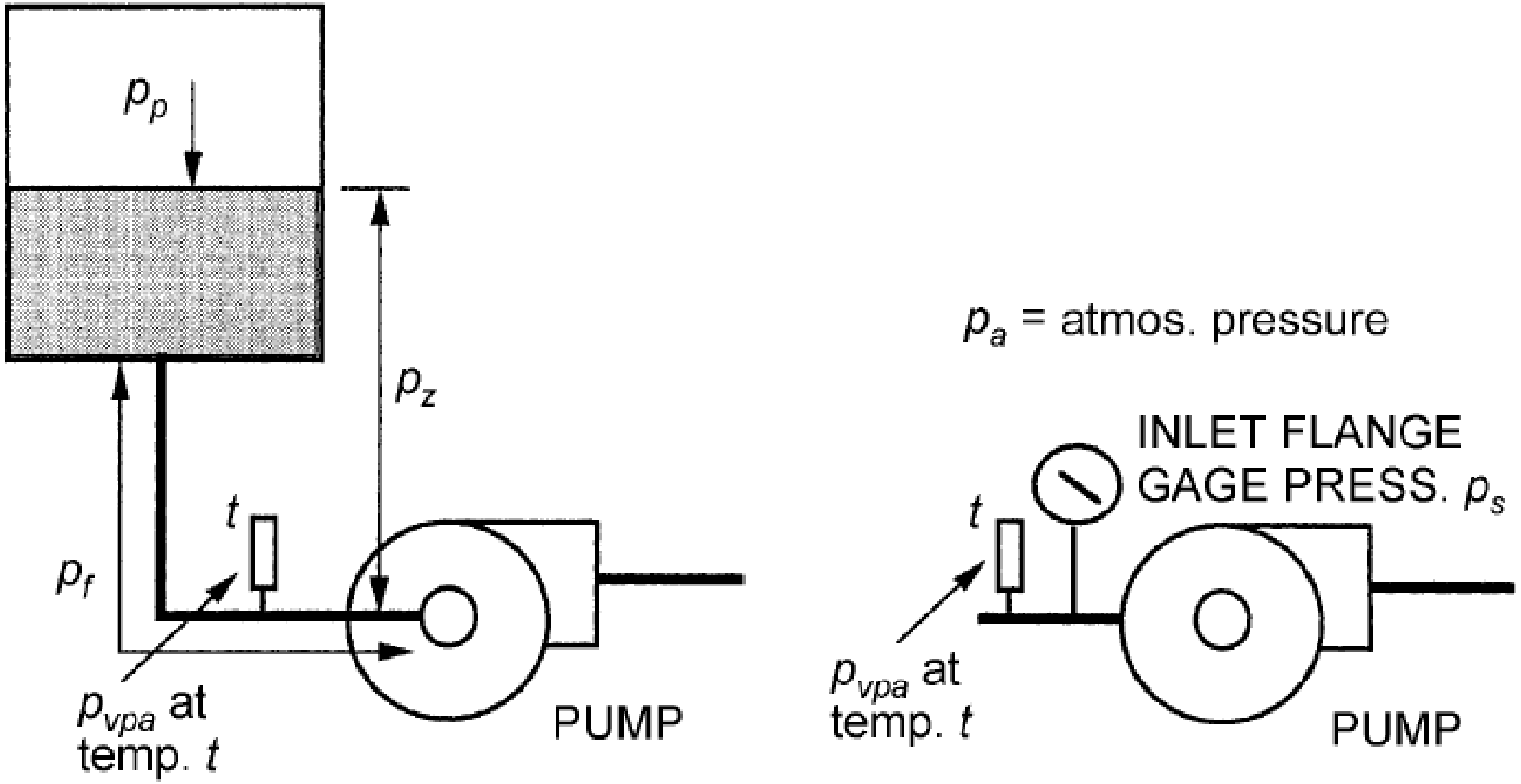
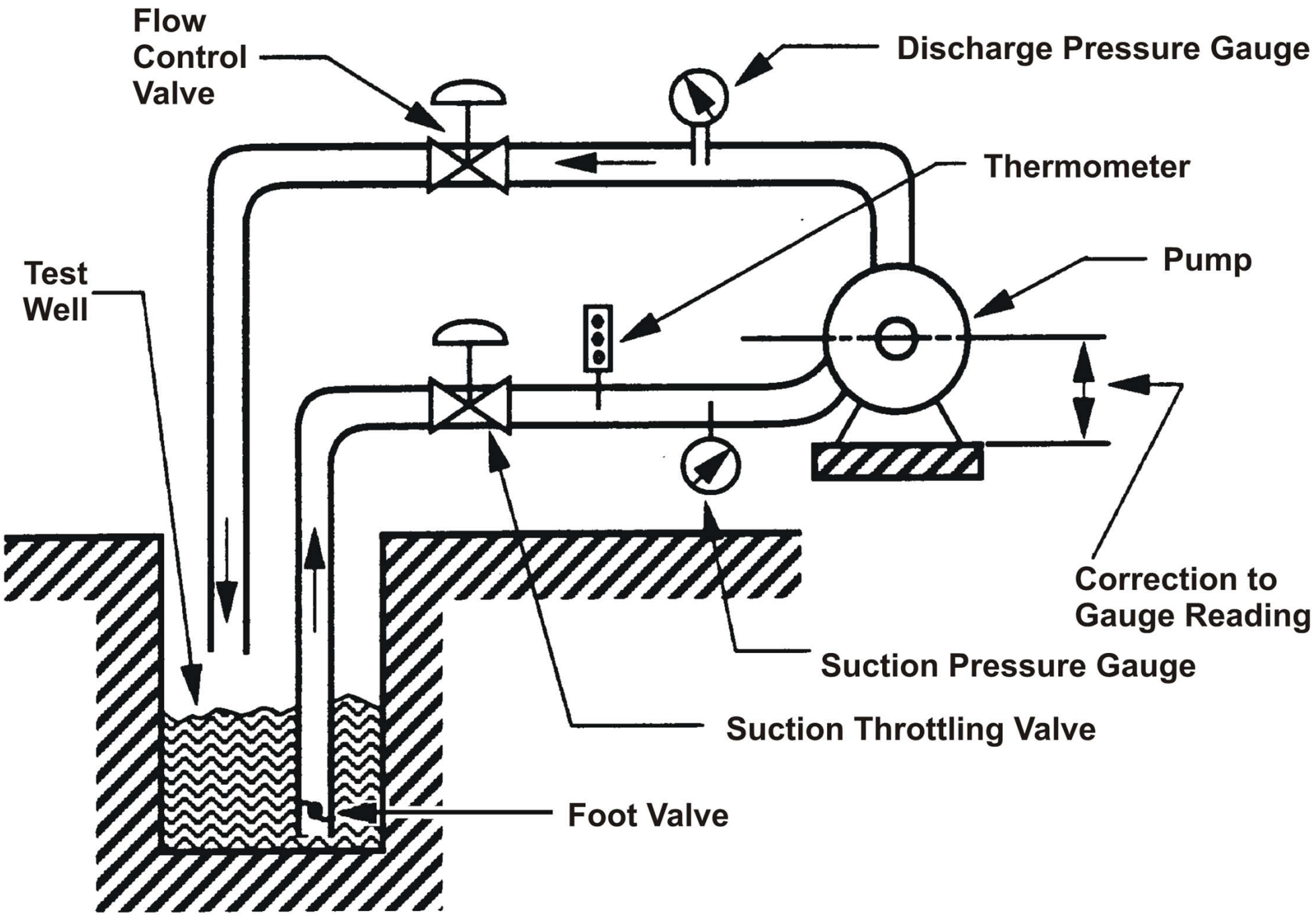


Fig. 29 Net Positive Suction Pressure Available

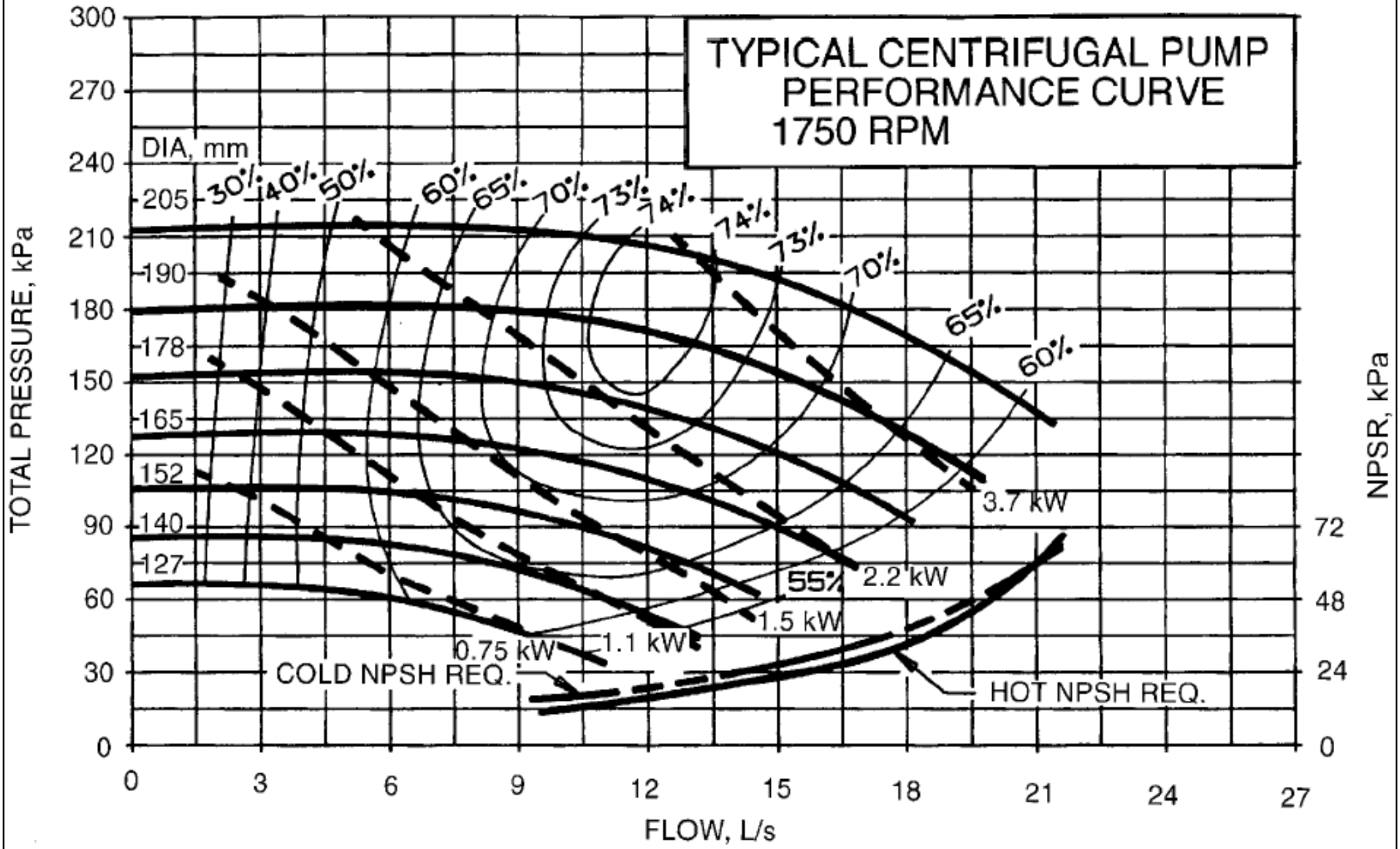
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Test setup to determine pump's NPSR



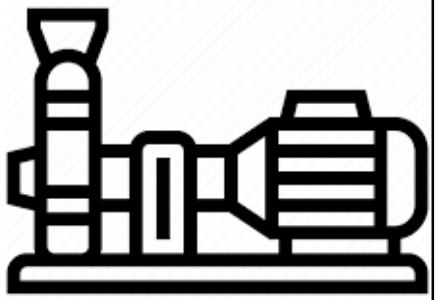
(Source: *Fundamentals of Water System Design*)

Typical centrifugal pump performance curve (with cold & hot NPSH requirements)



(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Pump Characteristics

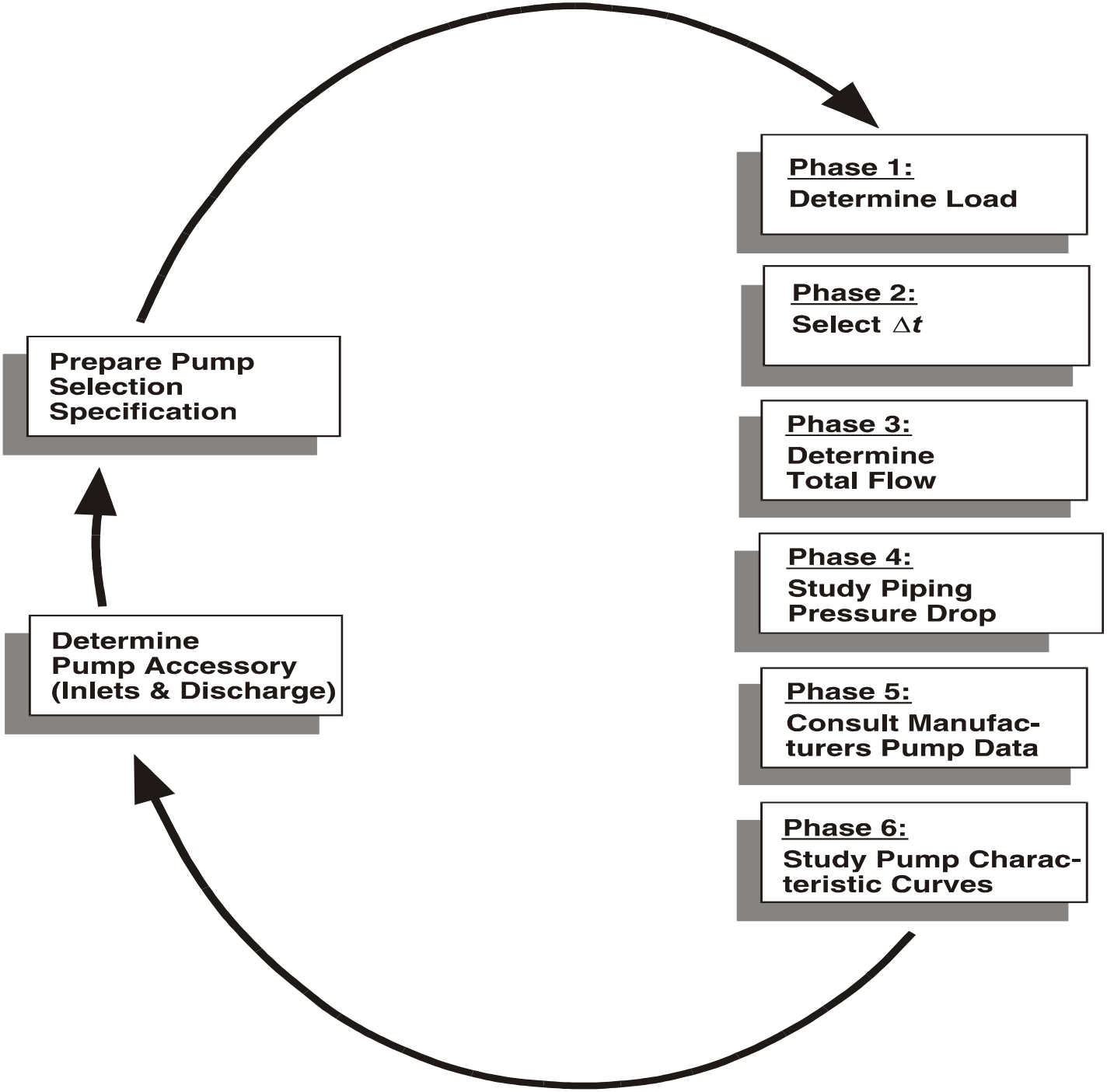


- Videos for illustration & learning:
  - Centrifugal Pump Basics - How centrifugal pumps work working principle hvacr (10:35) https://youtu.be/XpcCUtYzwy0
  - Pump Chart Basics Explained - Pump curve HVACR (13:04) https://youtu.be/U8iWNaDuUek
  - Critical Pump Selection - Three Major Issues (20:25) https://youtu.be/qUONRrP-5pc

Pump Arrangements

- Pump design criteria
  - Design flow & minimum system flow
  - Pressure drop required for the most resistant loop
  - System pressure at maximum and minimum flows
  - Type of control valve—two-way or three-way
  - Continuous or variable flow
  - Pump environment, number of pumps and standby
  - Electric voltage and current
  - Electric service and starting limitations
  - Motor quality versus service life
  - Water treatment, water conditions, and material selection

Pump selection process

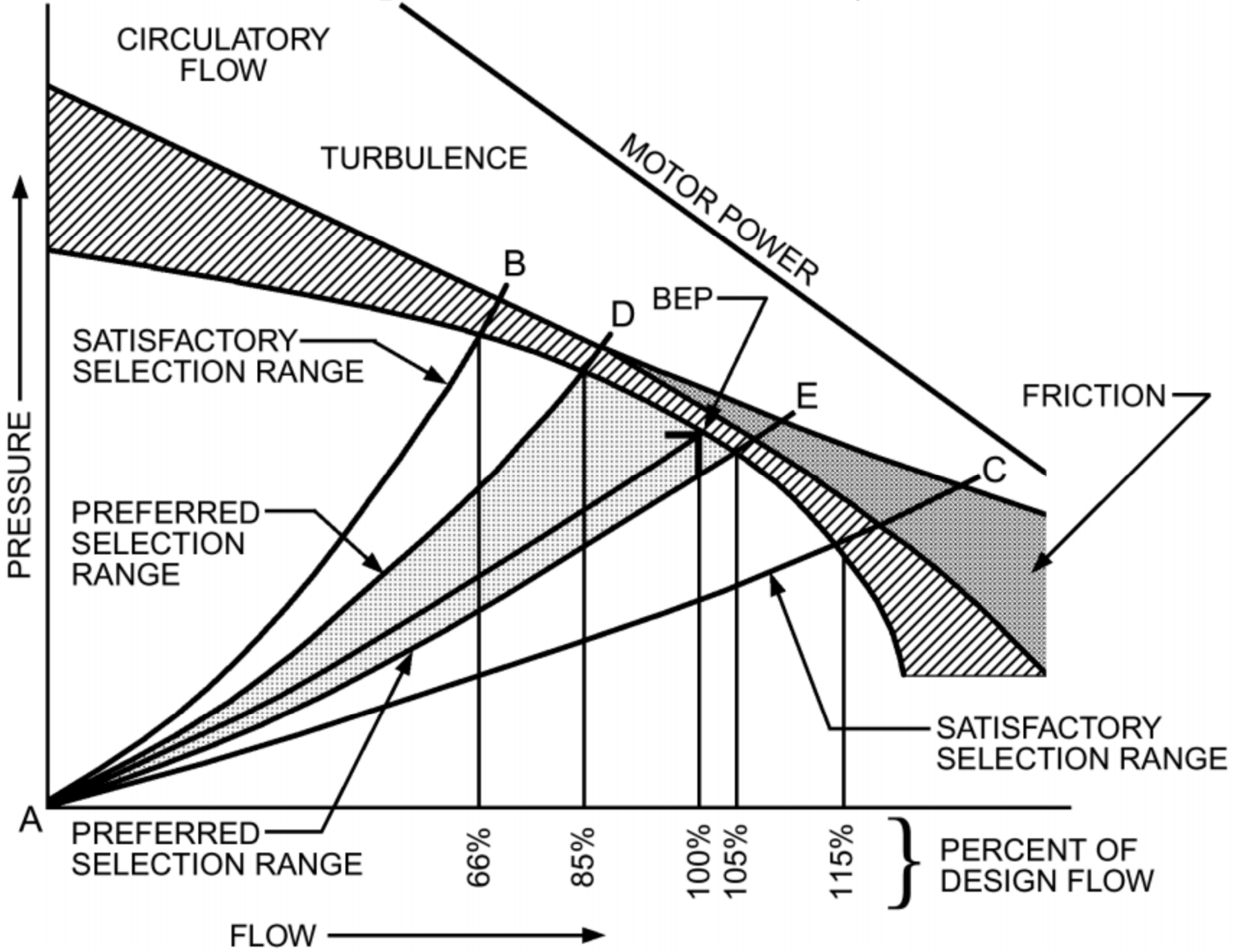


(Source: *Fundamentals of Water System Design*)

Pump Arrangements

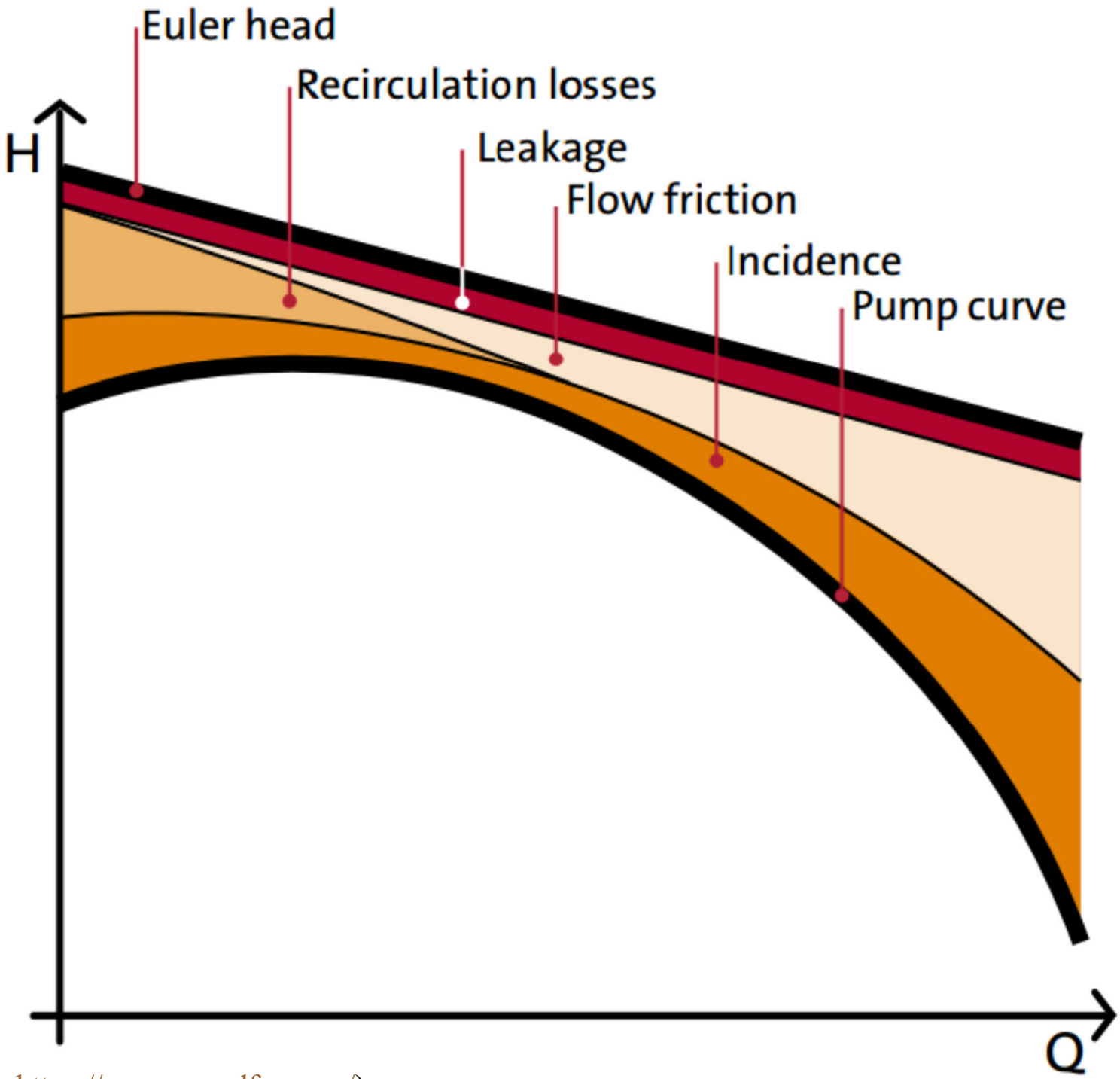
- Pump selection process
  - Determine the load to be pumped
  - Determine design Δt & calculate required flow
  - Sum up the load flows to determine total flow
  - Determine the “critical path” (most resistant)
  - Determine mounting method & support
  - Select a pump from manufacturer
    - Flat curve & steep curve, pump operation & motor
    - Check overflow capacity when staging multiple pumps

Pump selection factors and regions



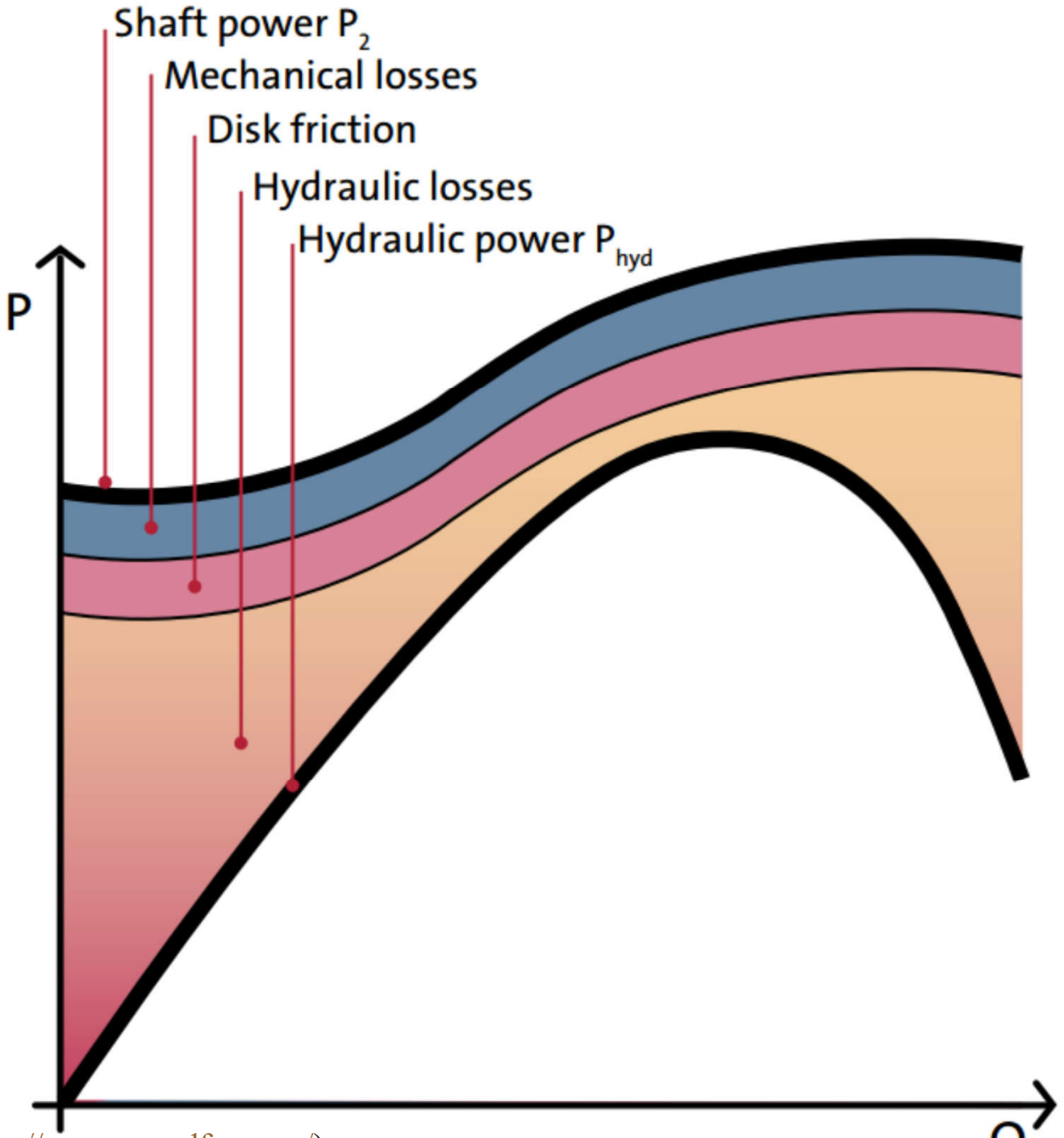
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2020*)

Reduction of theoretical Euler head due to losses



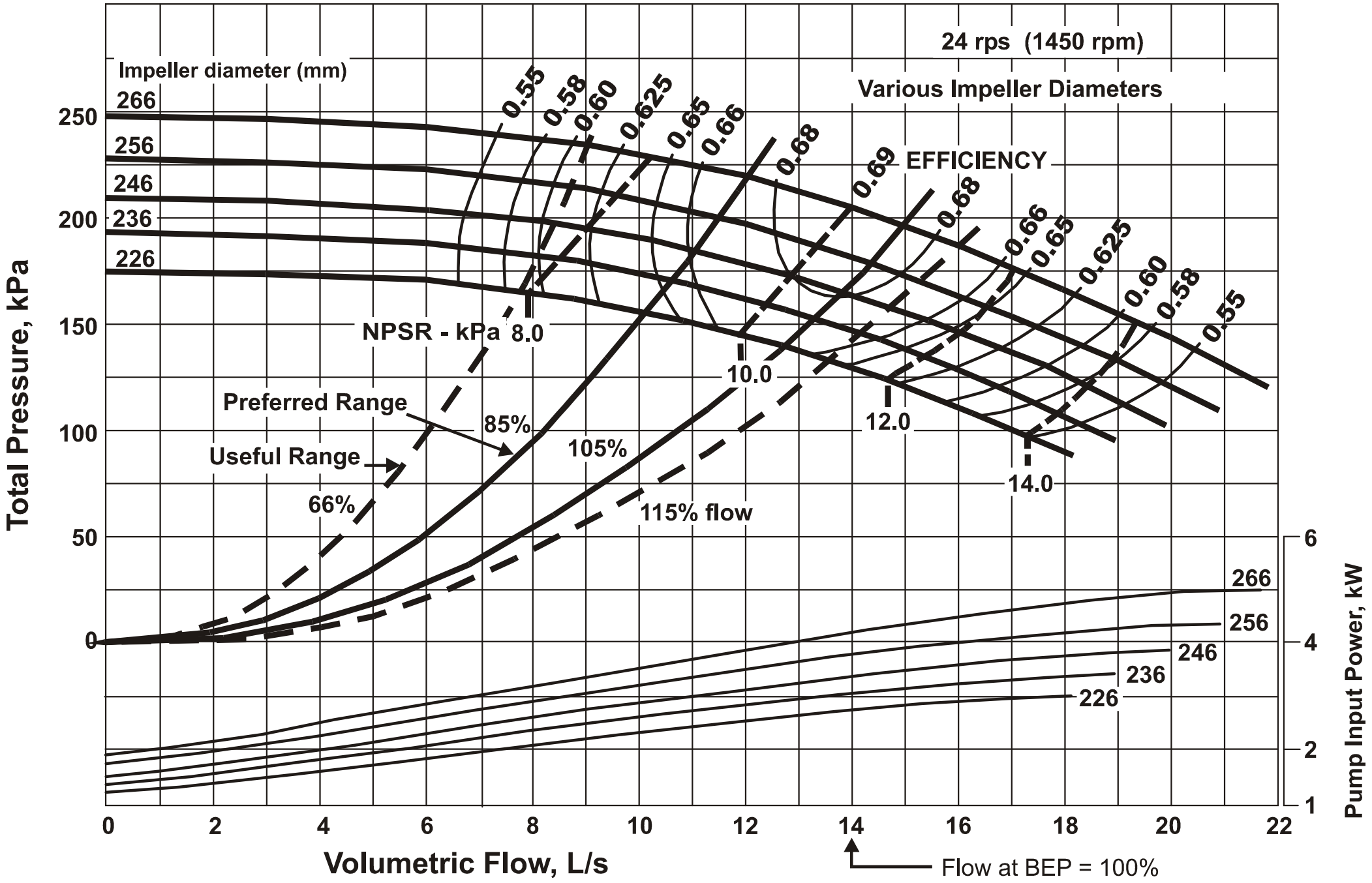
(Source: Grundfos https://www.grundfos.com/)

Increase in power consumption due to losses



(Source: Grundfos https://www.grundfos.com/)

Pump performance data

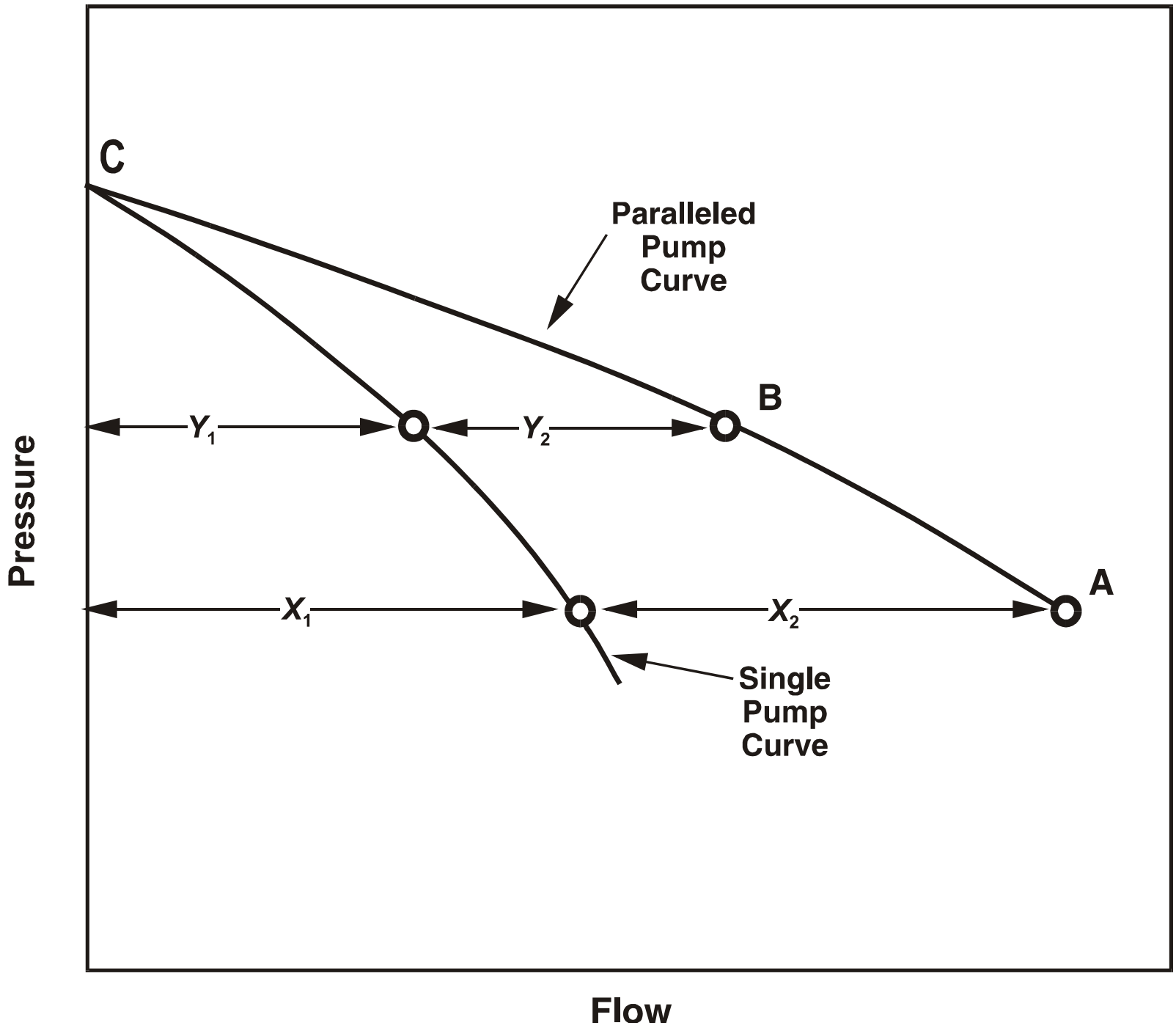


(Source: *Fundamentals of Water System Design*)

Pump Arrangements

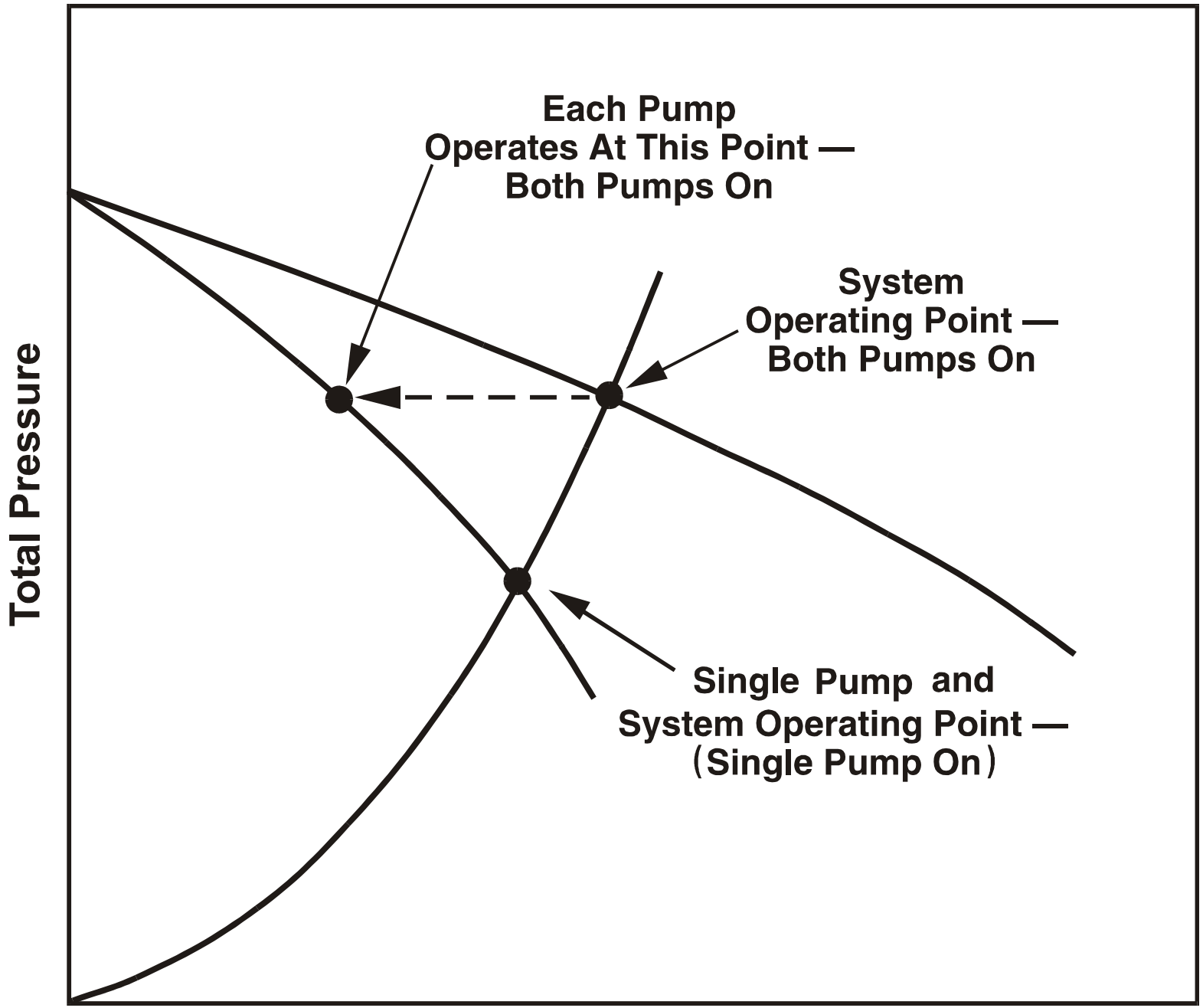
- Pumping arrangements & control scenarios
  - Multiple pumps in parallel or series
  - Standby pump
  - Pumps with two-speed motors
  - Primary-secondary pumping
  - Variable-speed pumping
  - Distributed pumping

Pump curve for parallel operation



(Source: *Fundamentals of Water System Design*)

Operating conditions for parallel pump installation



(Source: *Fundamentals of Water System Design*)

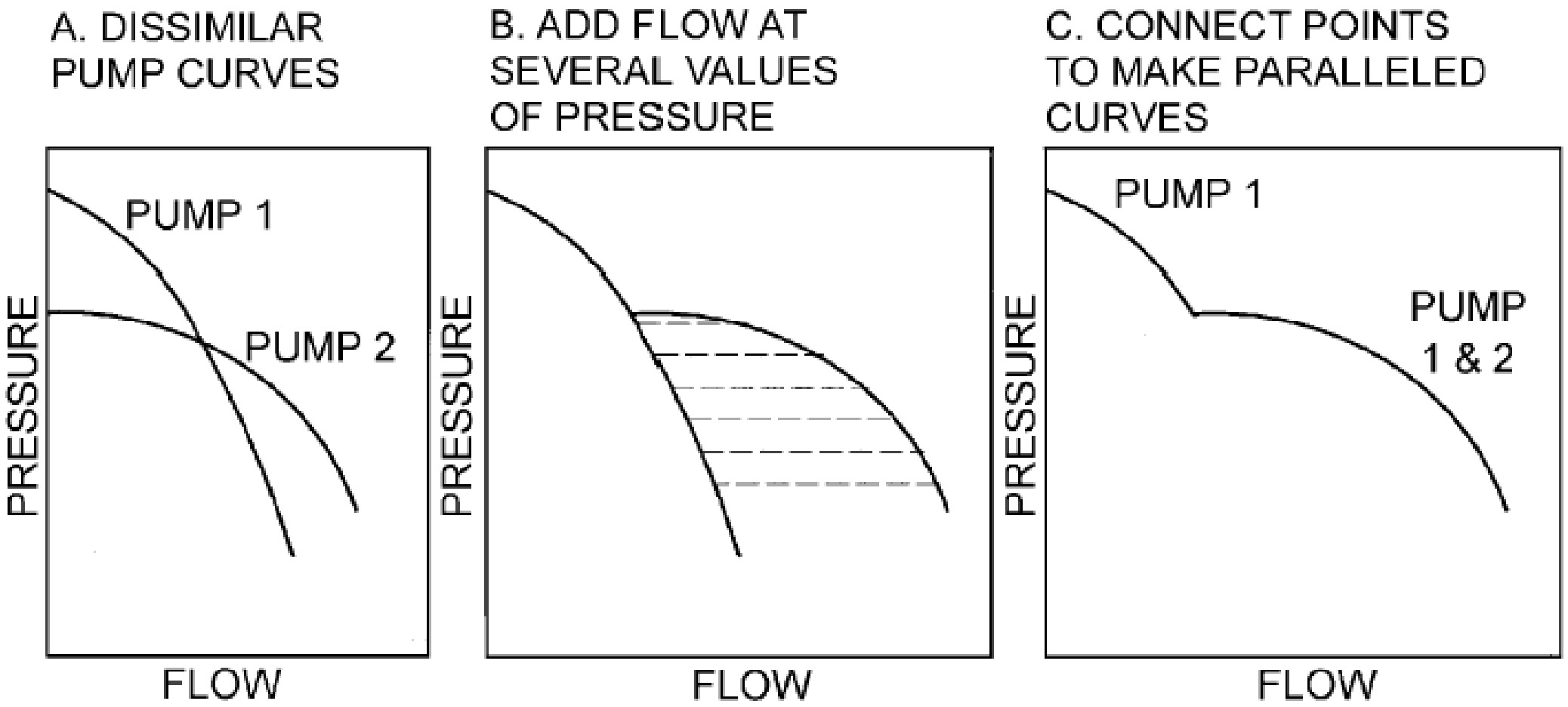


Fig. 34 Construction of Curve for Dissimilar Parallel Pumps

(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

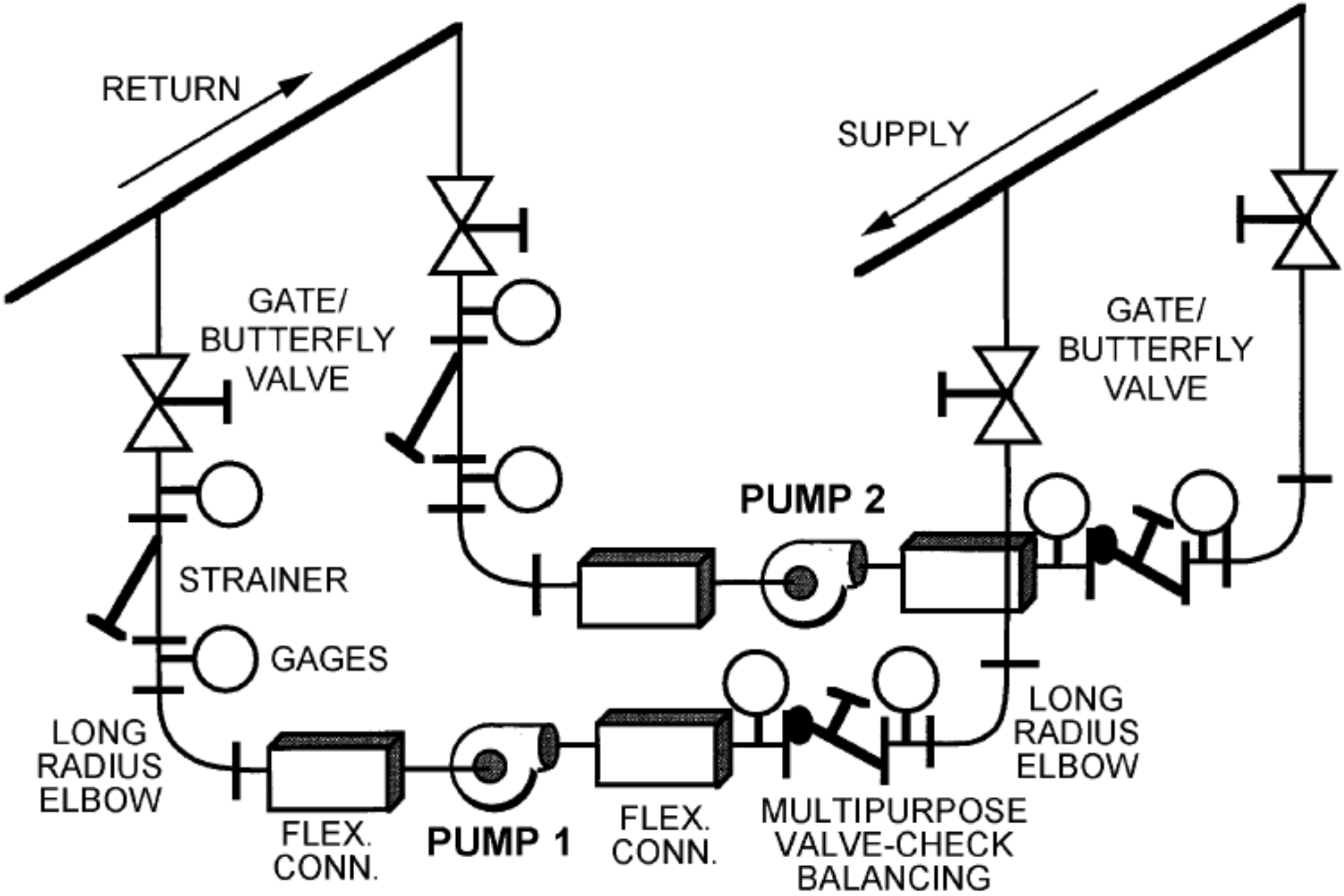
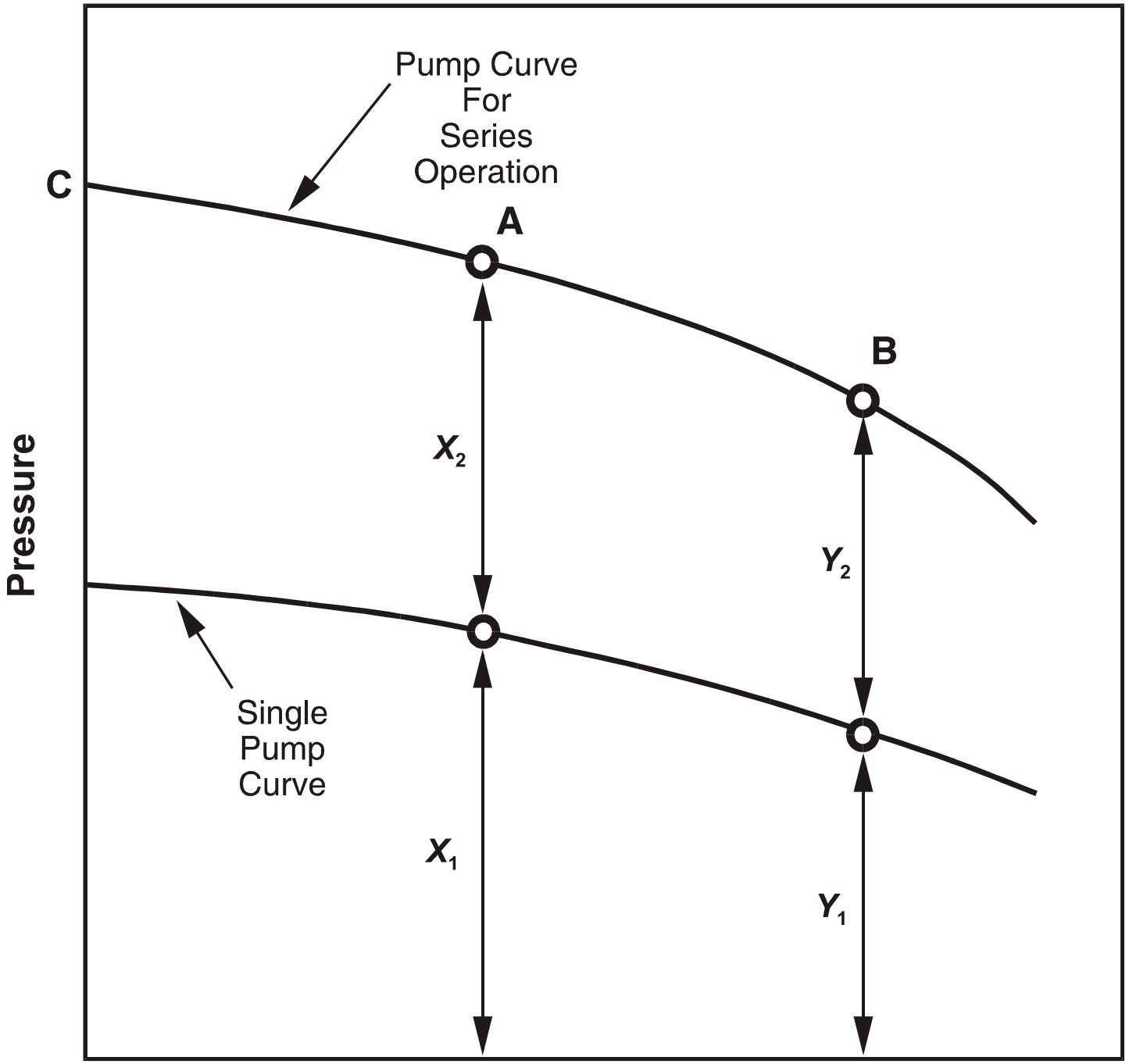


Fig. 35 Typical Piping for Parallel Pumps

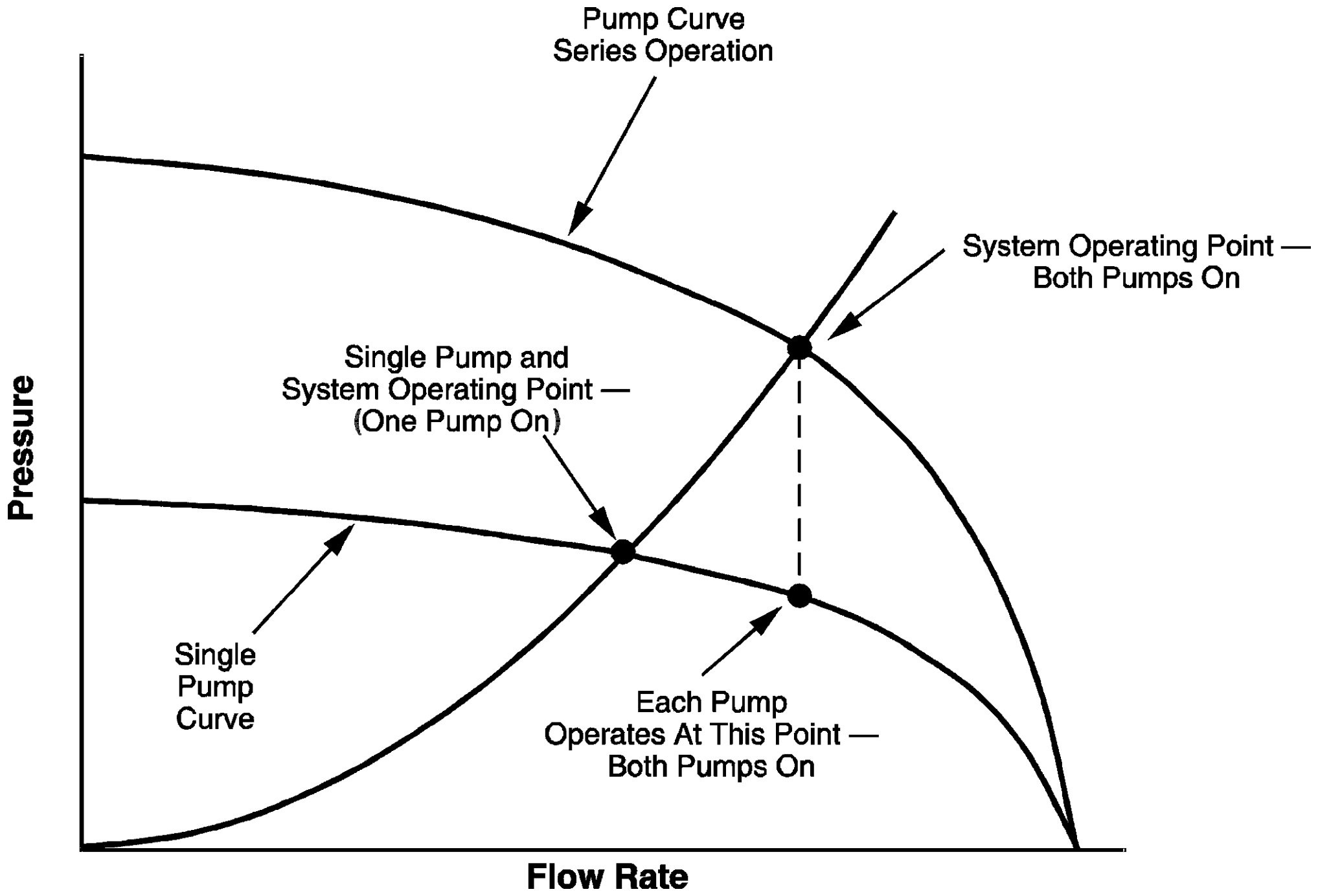
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Pump curve for series operation



(Source: *Fundamentals of Water System Design*)

Operating conditions for series pump



(Source: *Fundamentals of Water System Design*)

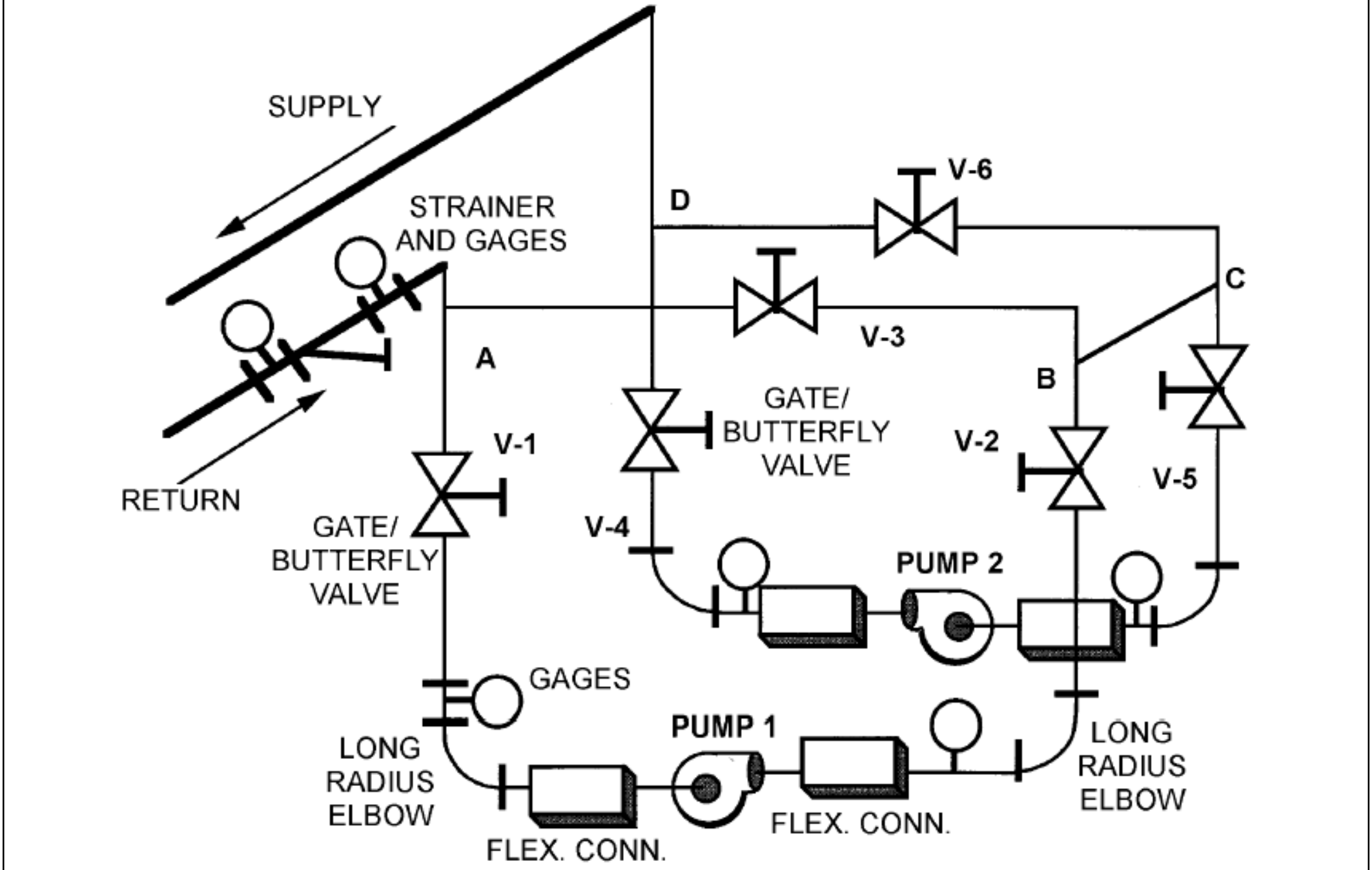


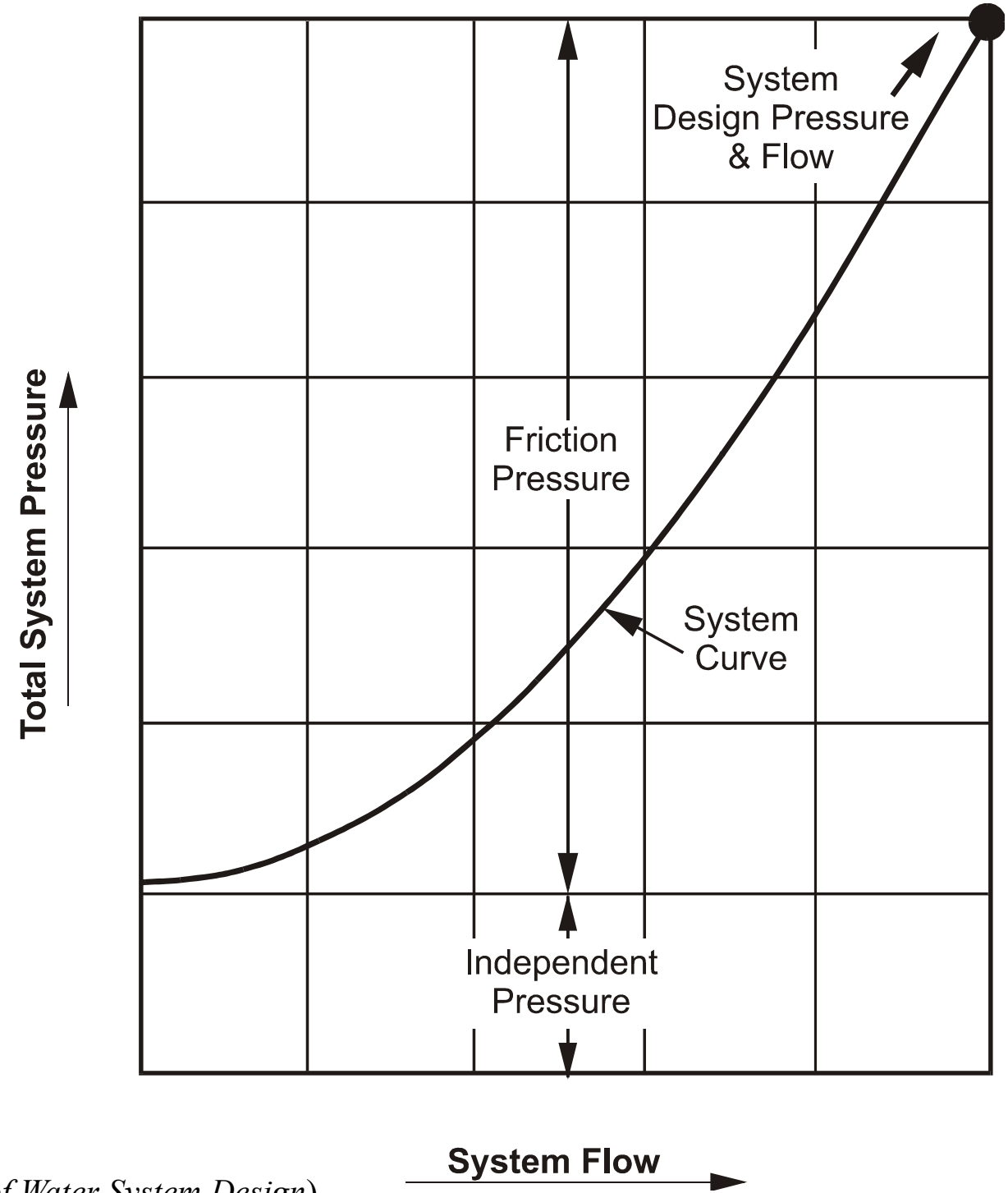
Fig. 38 Typical Piping for Series Pumps

(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Matching Pumps to Systems

- Good piping system design
  - Match system characteristics to pump curve
- Trimming pump impellers
  - To reduce flow
  - To match partload requirments
- Pump control
  - Two-speed pumping & motors
  - Variable speed pumping

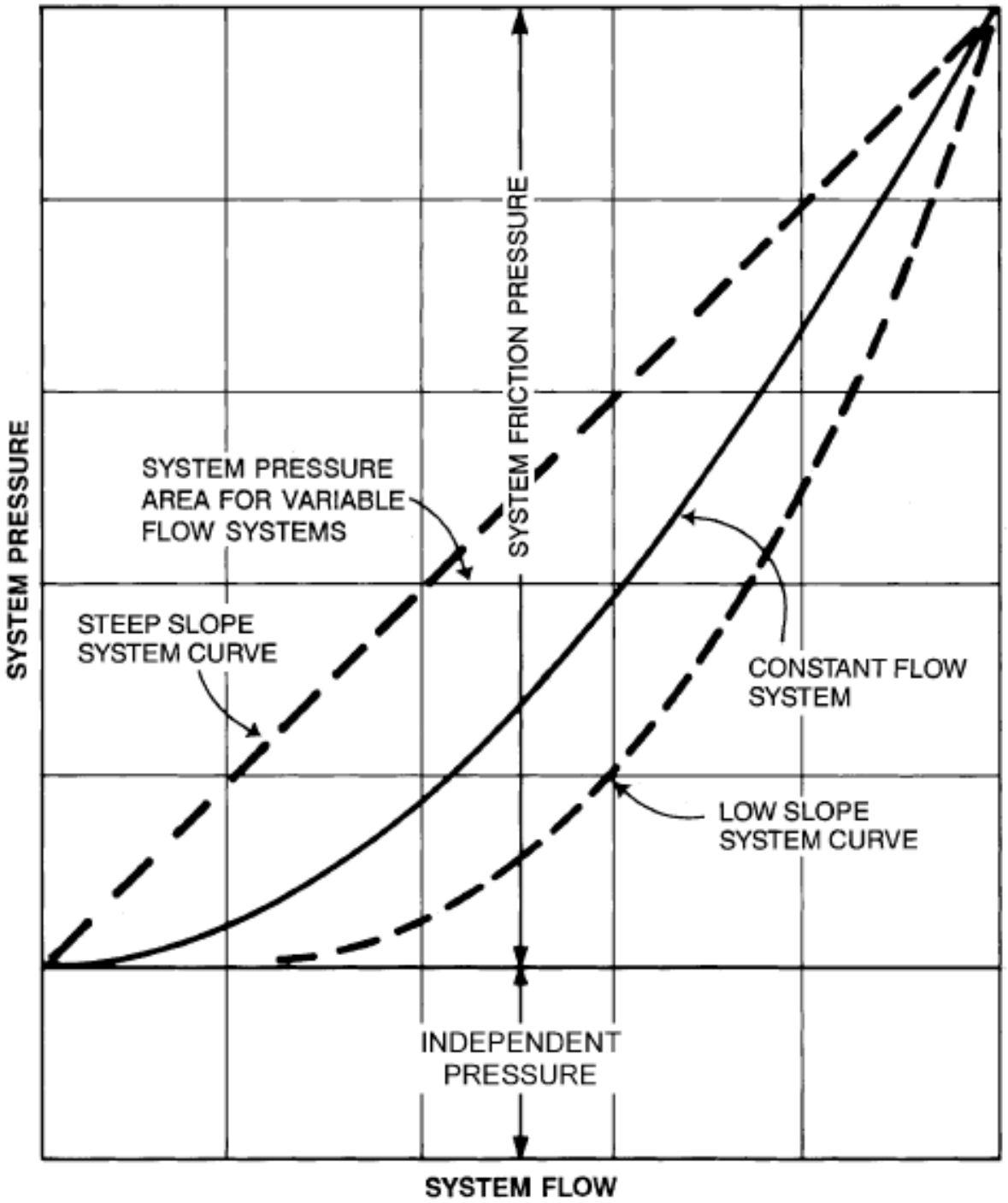
Typical system curve



(Source: *Fundamentals of Water System Design*)

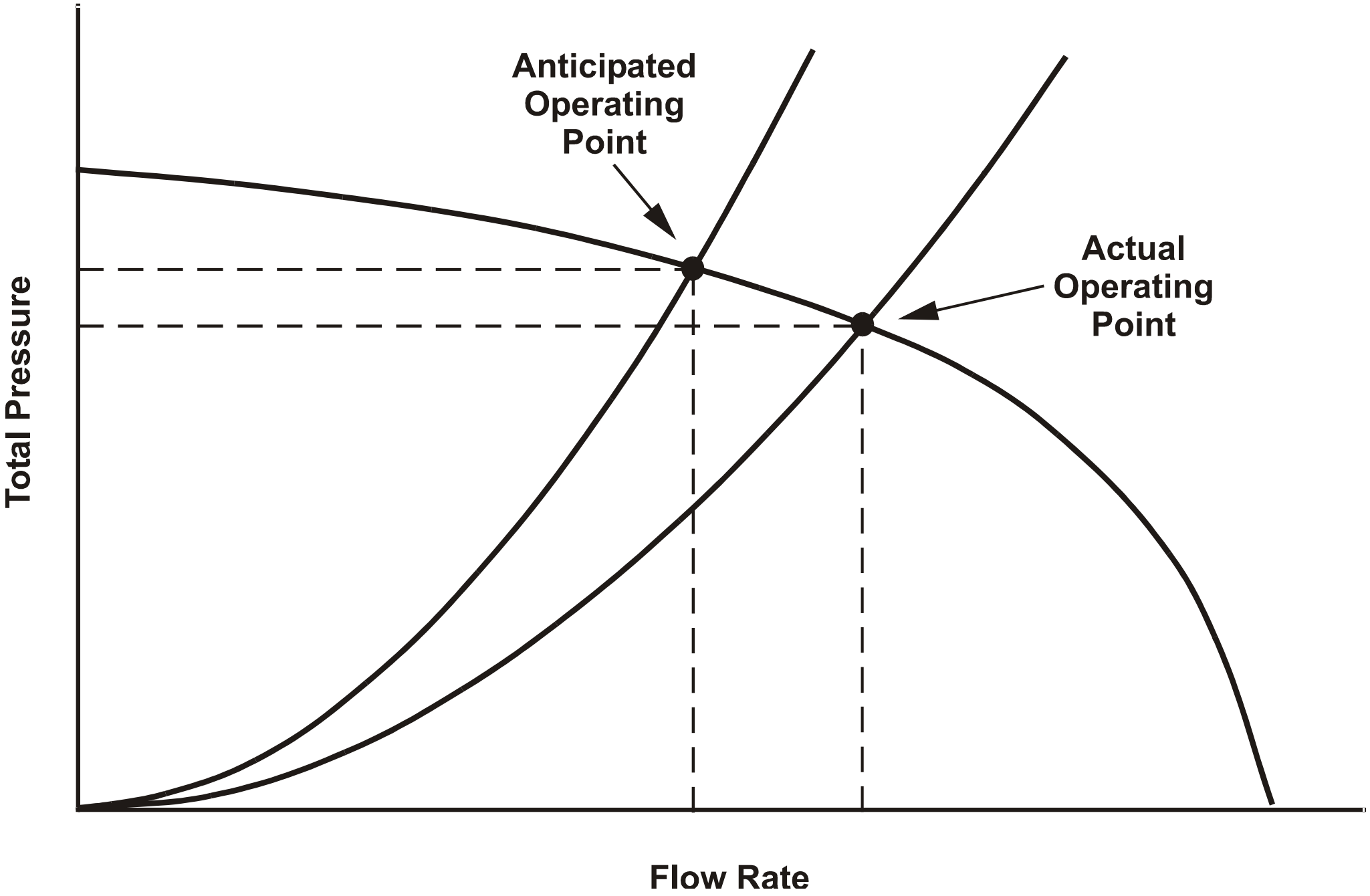
Different types of system curves

How to match the pumps to system curve?



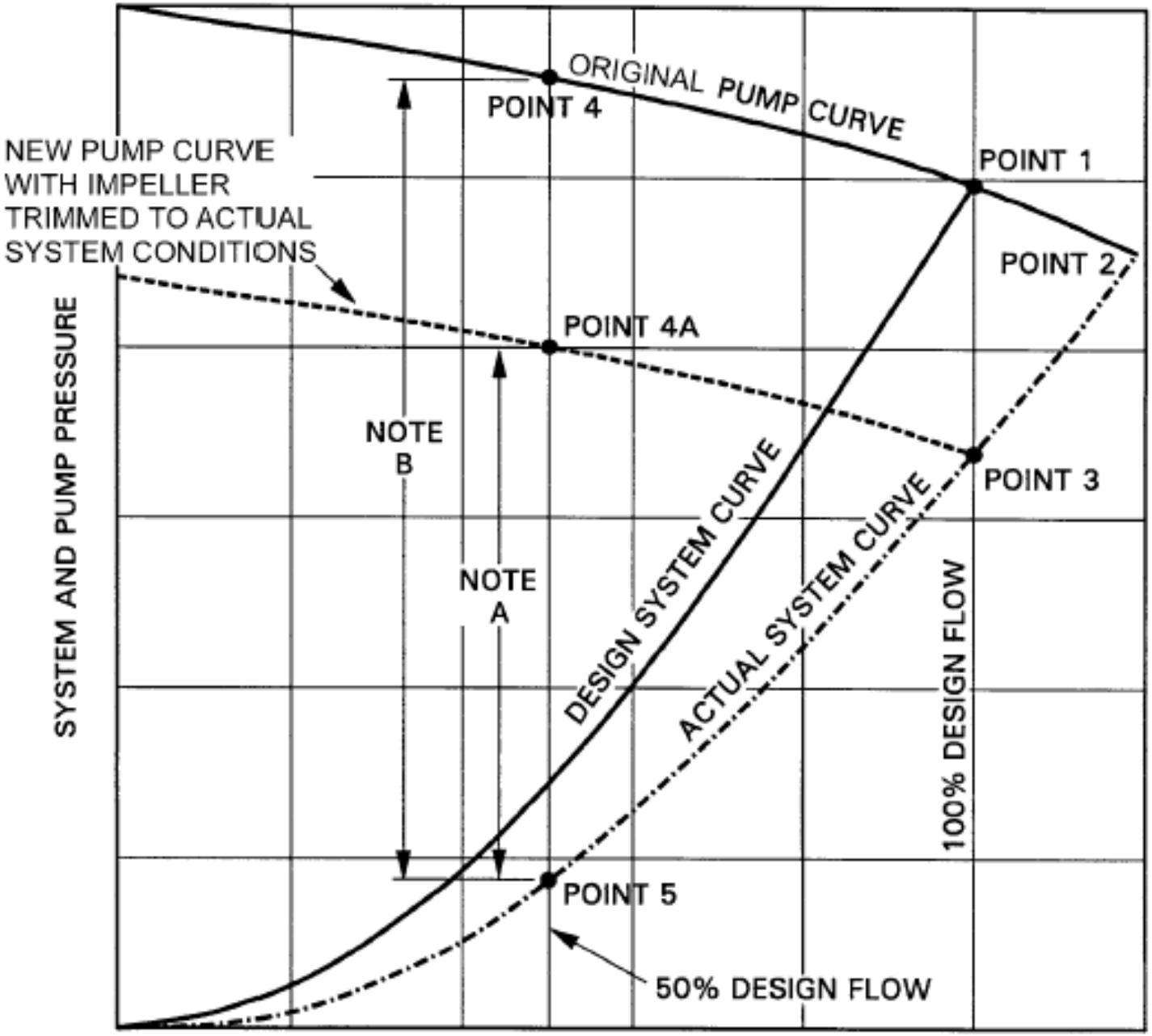
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Shift of system curves



(Source: *Fundamentals of Water System Design*)

Characteristics of pump curve and system curve



A OVERPRESSURE WITH TRIMMED CONSTANT-SPEED PUMP

B OVERPRESSURE WITH CONSTANT-SPEED PUMP

(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

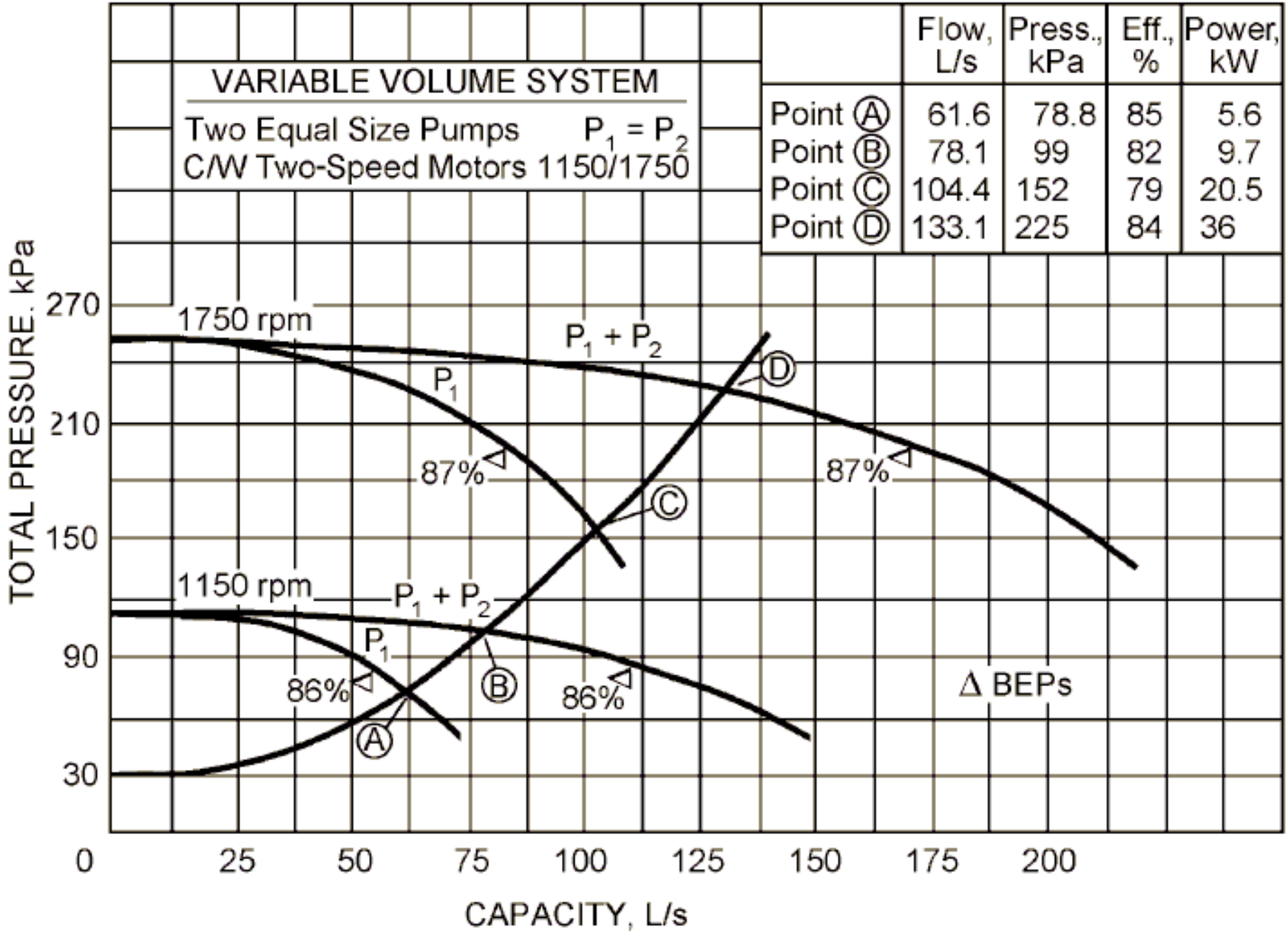


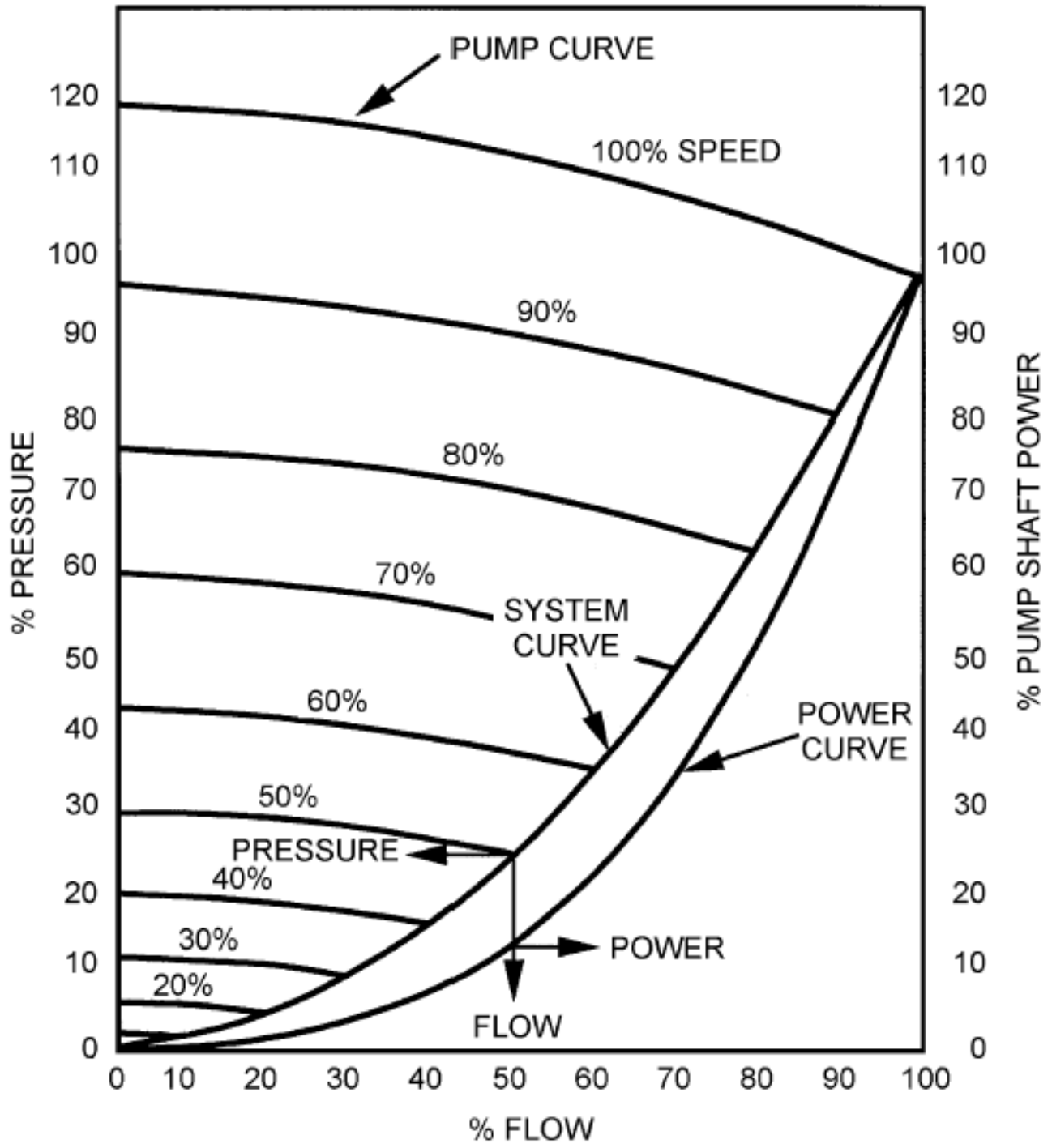
Fig. 39 Example of Two Parallel Pumps with Two-Speed Motors

(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Matching Pumps to Systems

- Modulation of pump-piping systems
  - 1. Throttle volume flow by using a valve
    - Change flow resistance – new system curve
    - Also known as “riding on the curve”
  - 2. Turn water pumps on or off in sequence
    - Sudden increase/drop in flow rate and head
  - 3. Vary the pump speed
    - System operating point move along the system curve
    - Requires the lowest pump power input

Pump curve variation with rotation speed

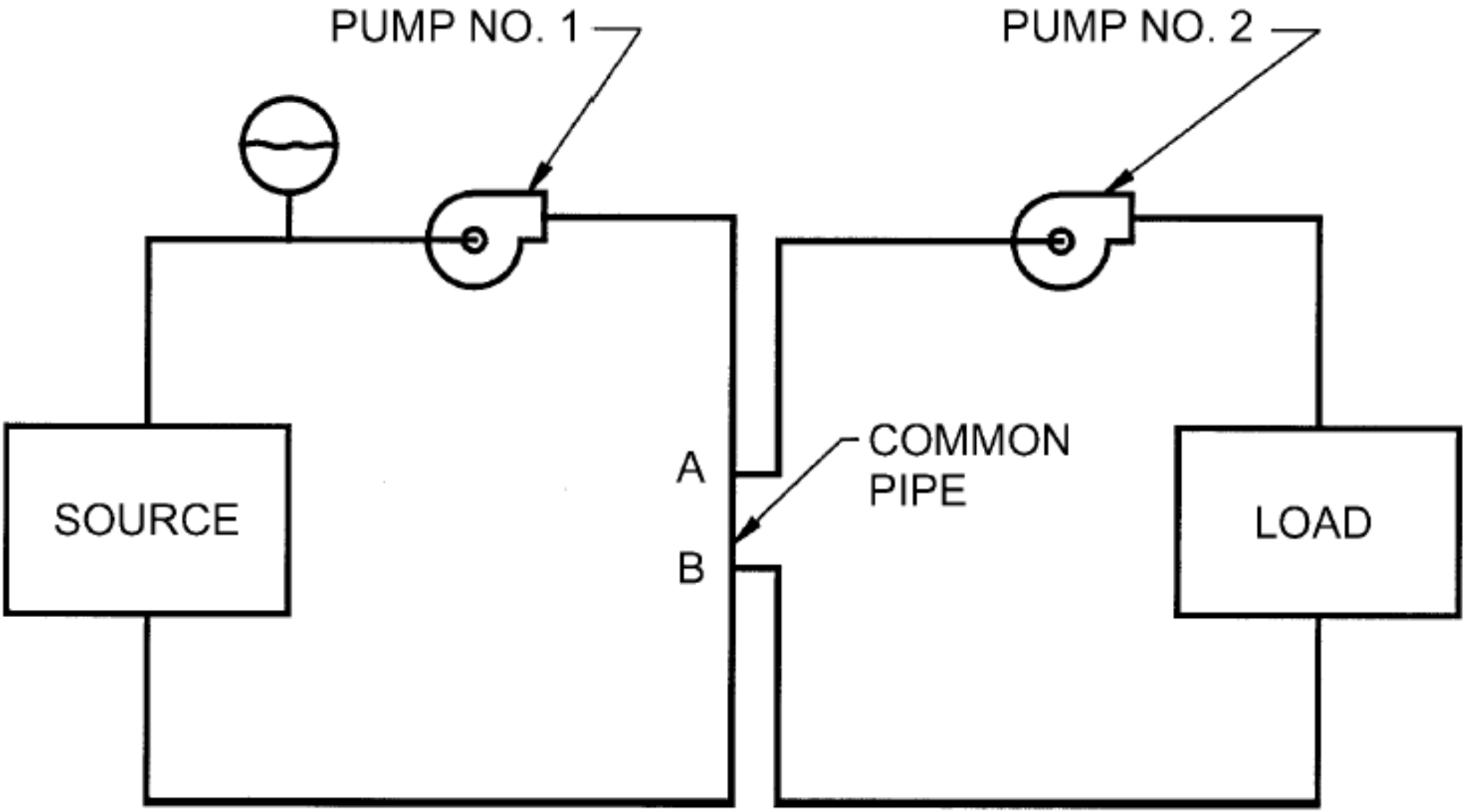


(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Matching Pumps to Systems

- Plant loop (at constant flow) (production loop)
  - To protect evaporator from freezing, a fairly constant-volume water flow is required
- Building loop (at variable flow)
  - For saving energy at partload
  - A differential pressure transmitter is often installed at the farthest end from the pump
- Primary-secondary loop
  - A short common pipe connects the 2 loops

Primary-secondary loop and pumping



(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

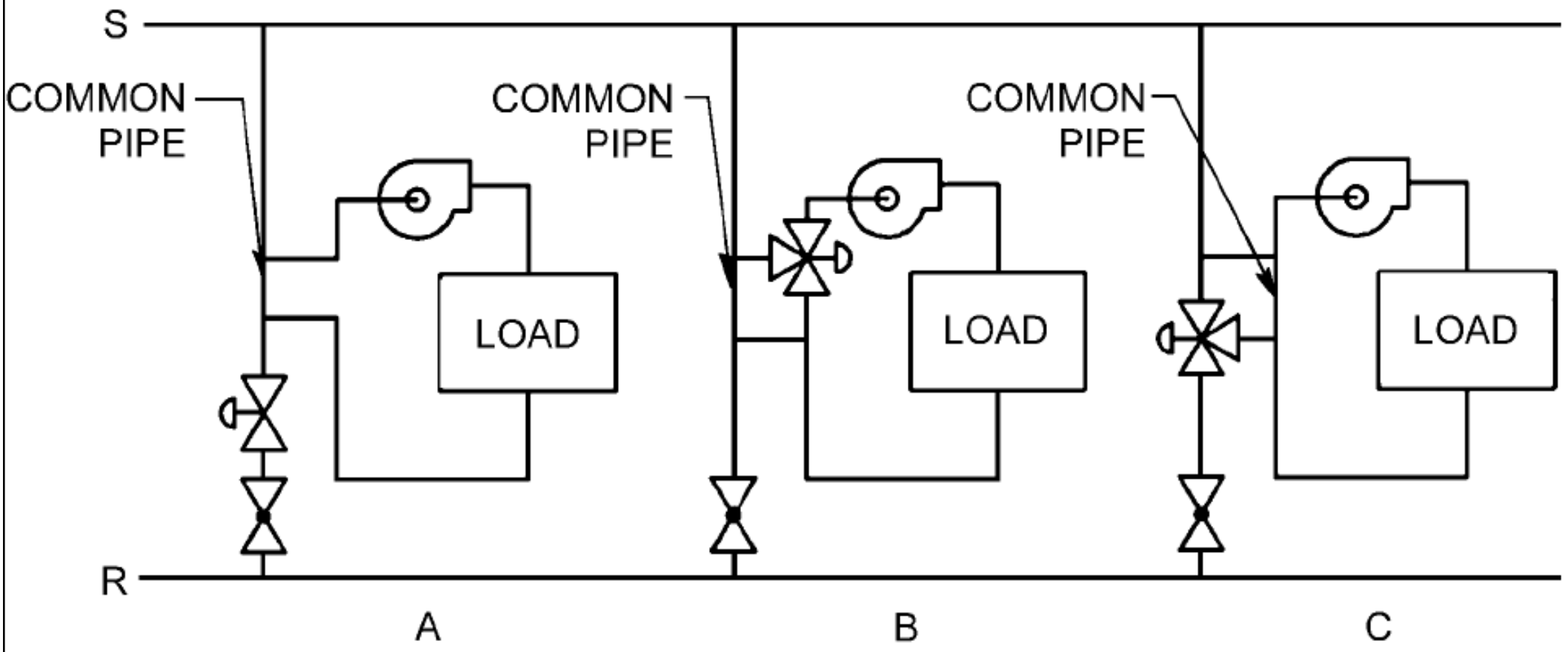
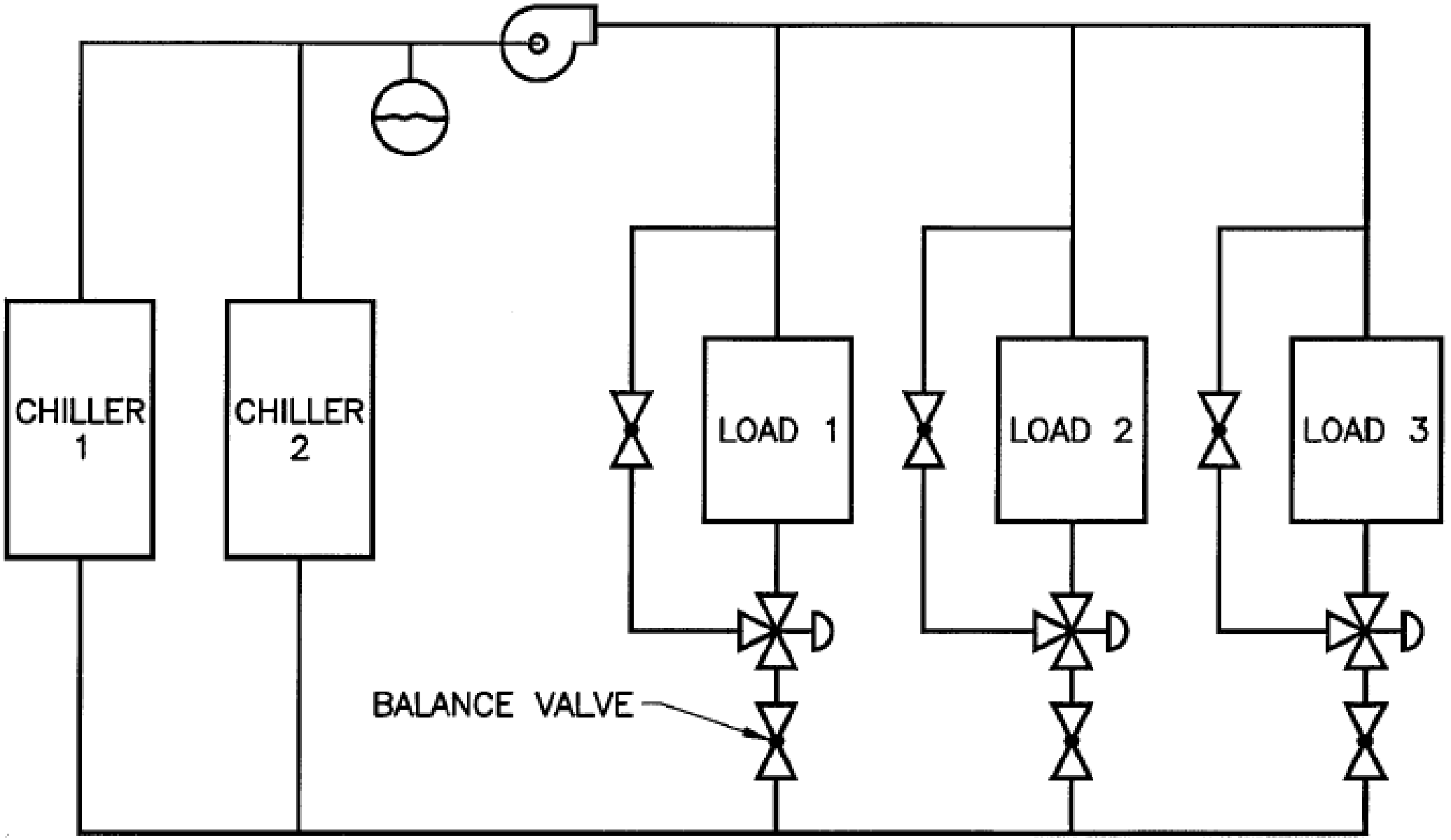


Fig. 40 Primary-Secondary Pumping

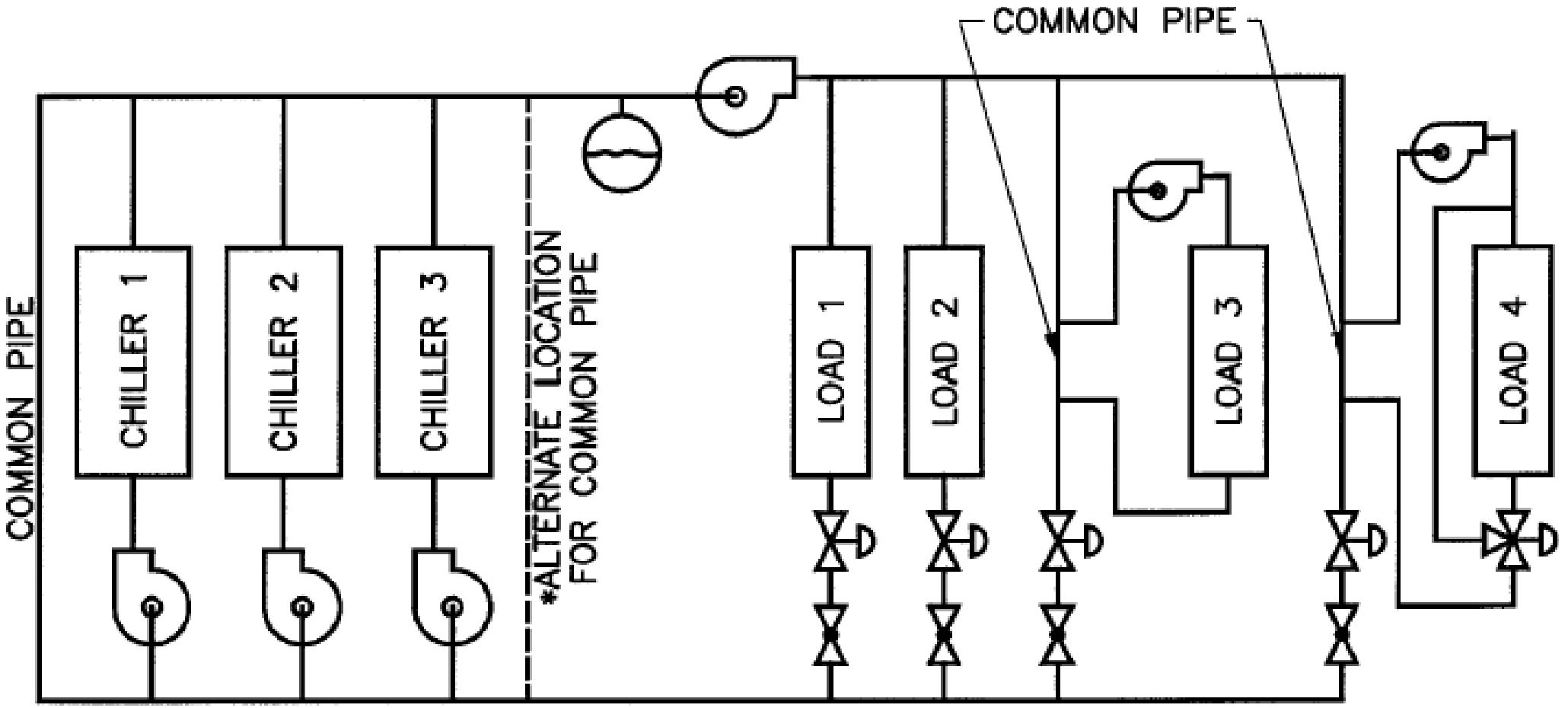
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Constant flow chilled water system



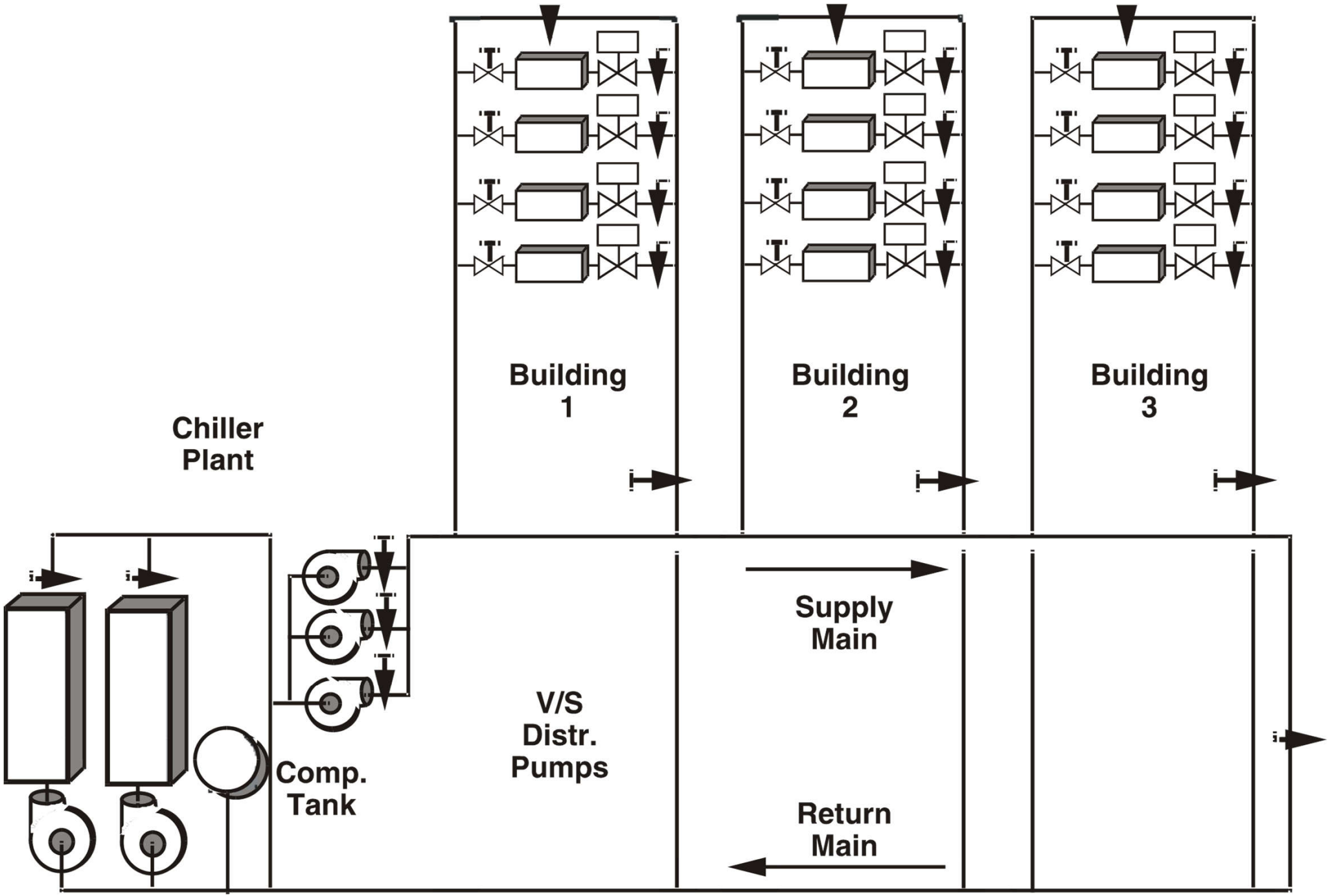
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Variable flow chilled water system (plant-building loop)



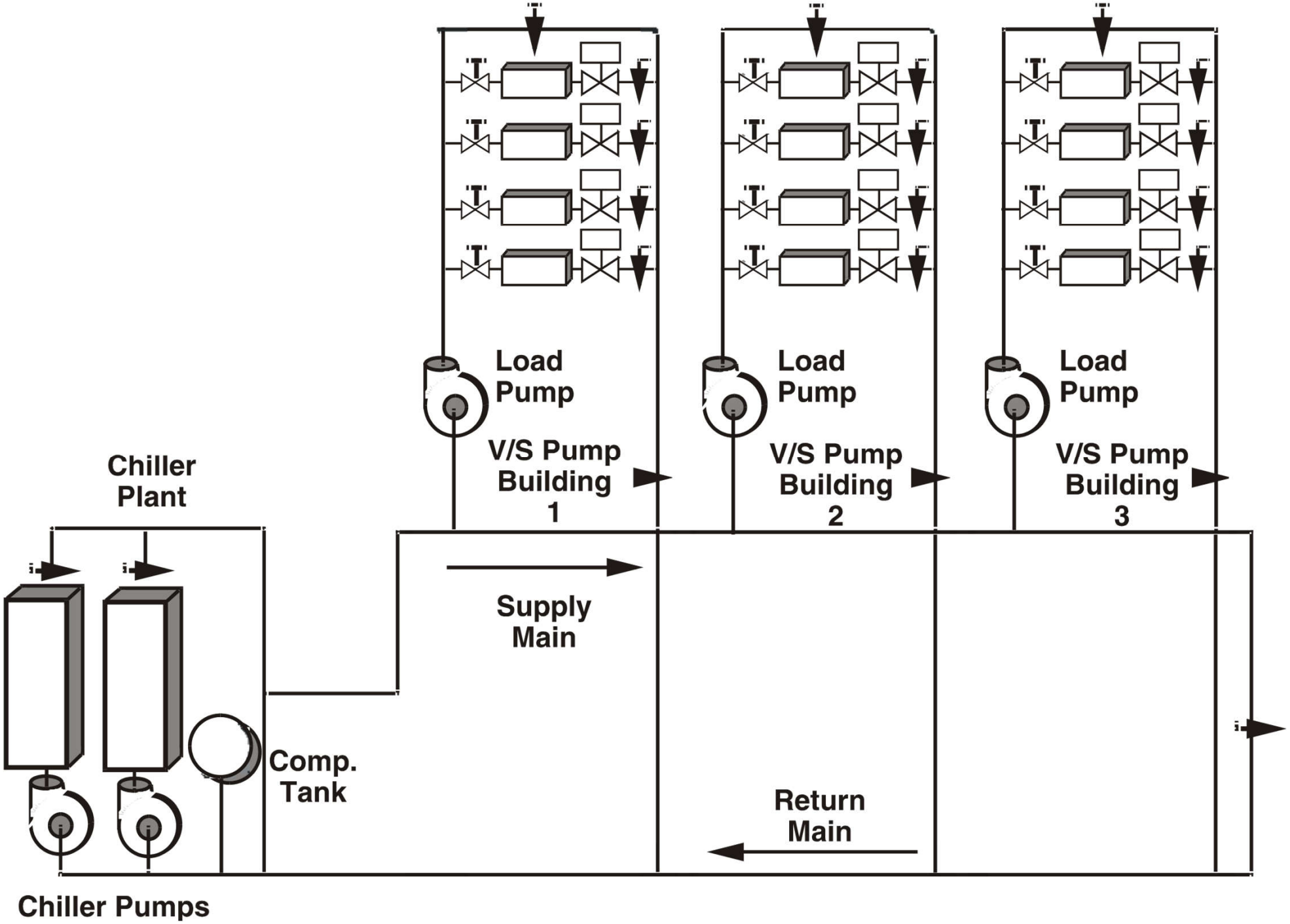
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Primary-secondary variable speed central pumping



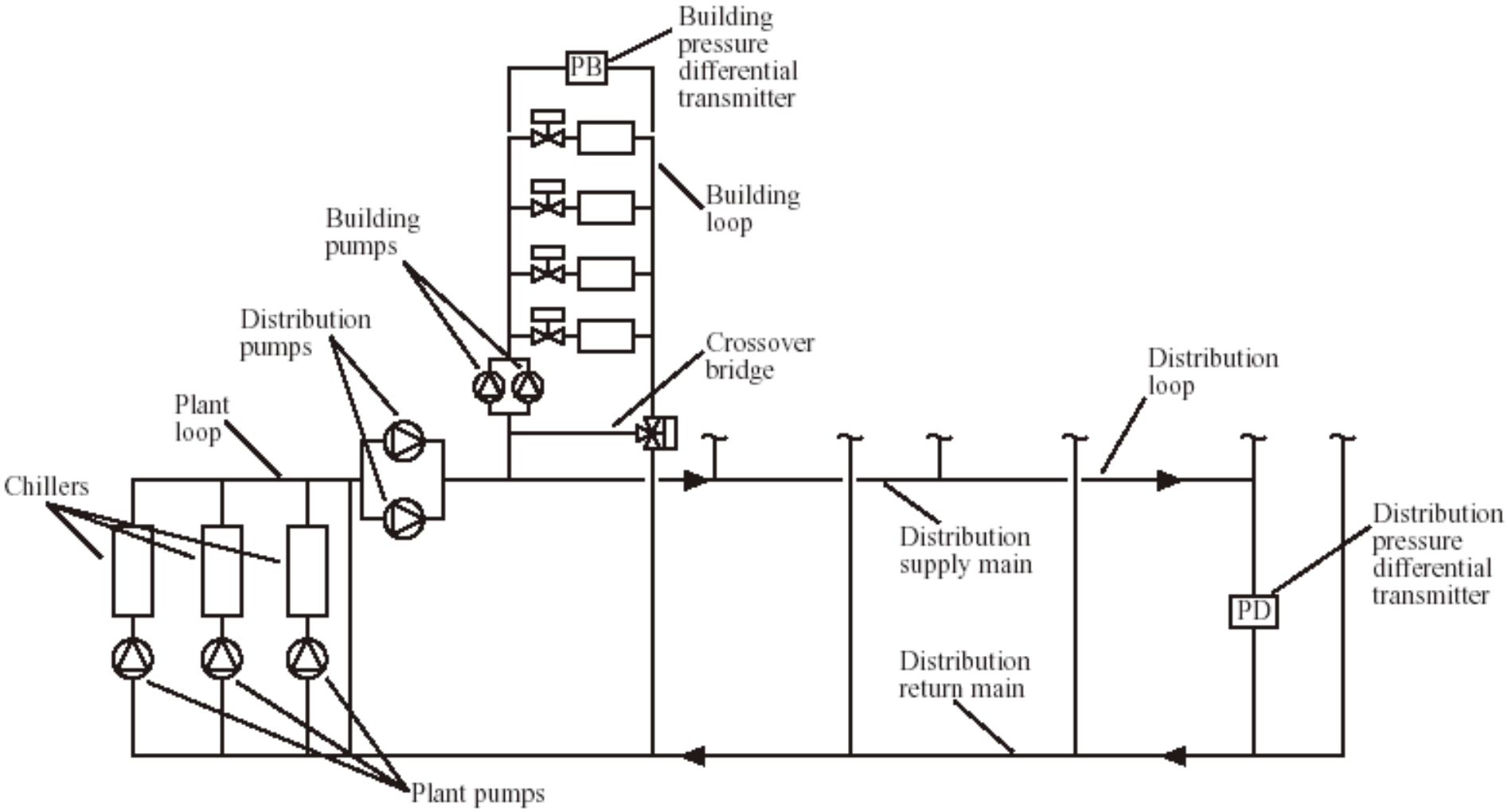
(Source: *Fundamentals of Water System Design*)

Variable speed distributed pumping

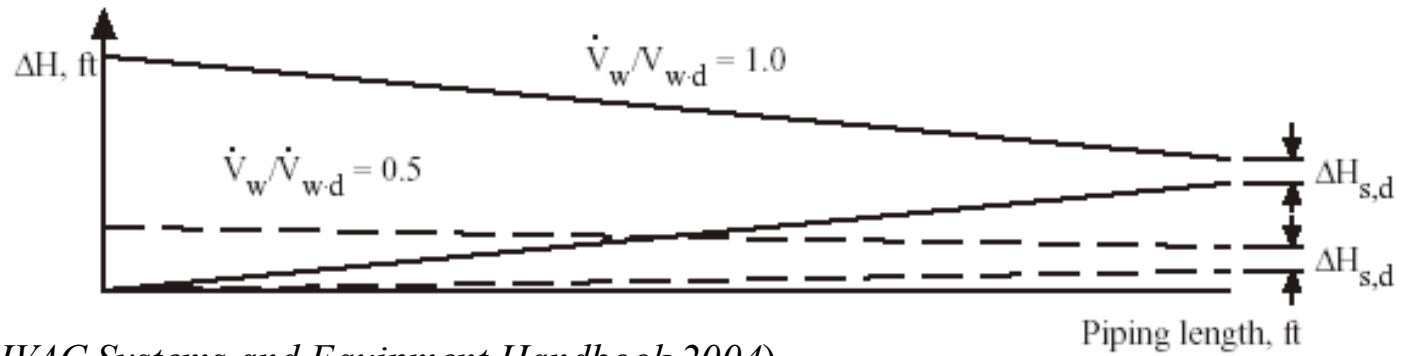


(Source: *Fundamentals of Water System Design*)

Chilled water system using a plant-distribution-building loop

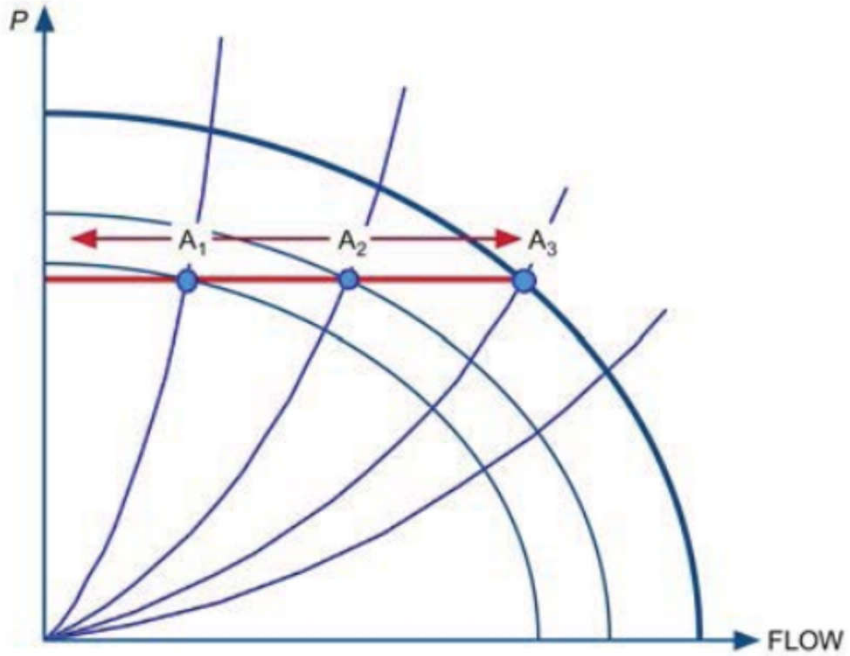


(a)

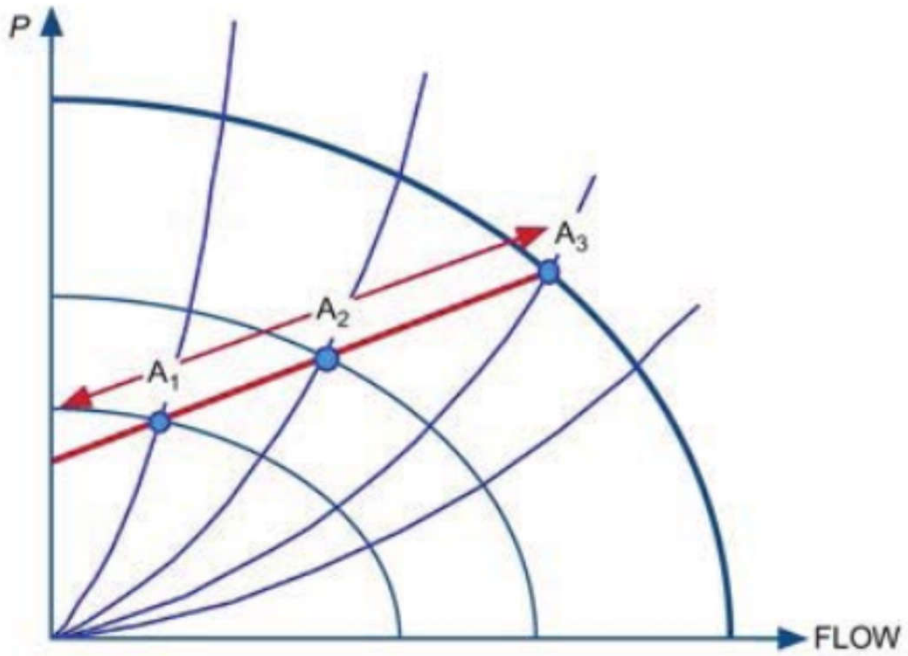


(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

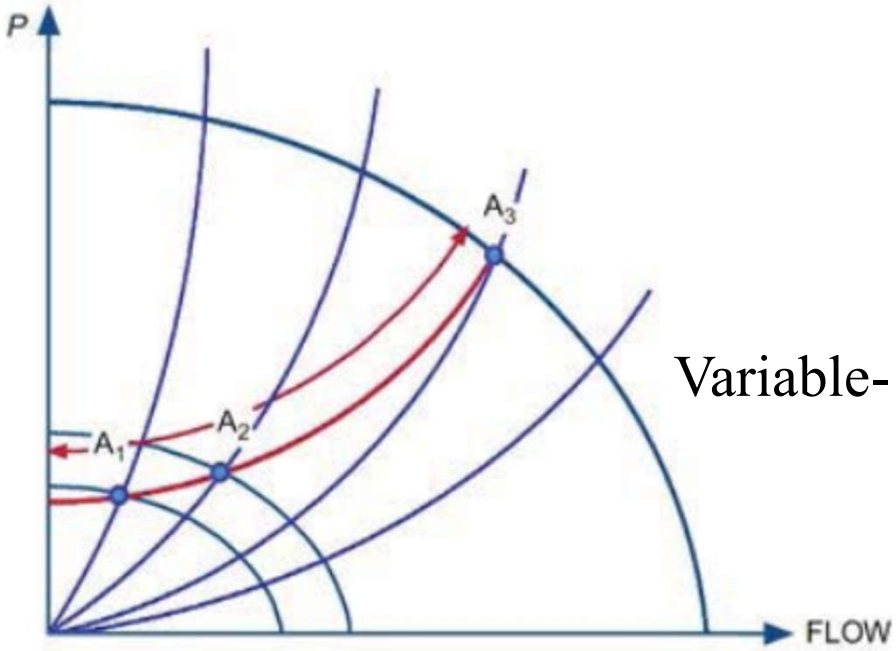
Differential pressure control with predefined control curves



Constant-pressure control



Variable- (Proportional-) pressure control



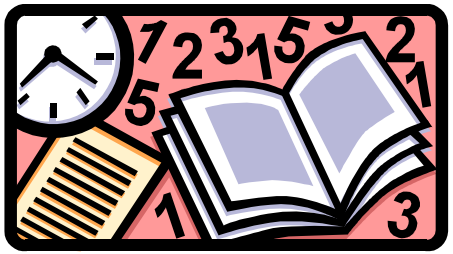
Variable- (Quadratic-) pressure control

(Source: *ASHRAE HVAC Systems and Equipment Handbook 2016*)

Further Reading

- Centrifugal Pumps https://www.iqsdirectory.com/articles/centrifugal-pump.html
- How does a Centrifugal pump work ? https://learnengineering.org/how-does-a-centrifugal-pump-work.html
- ASHRAE, 2020. *ASHRAE Systems and Equipment Handbook 2016*, SI edition, Chp. 44 - Centrifugal Pumps
- Energy Impacts of Chilled-Water-Piping Configuration (HPAC Engineering, Nov 2011, pp. 20-26) http://ibse.hk/MEBS7014/BE_YD_Res_VariablePrimaryFlow.pdf

References



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- Pennycook, K., Churcher, D. and Bleicher, D., 2007. *A Guide to HVAC Building Services Calculations*, 2nd ed., Building Services Research and Information Association, Bracknell, Berkshire, England.
- Trane Company, 2001. *Chilled-water Systems*, Trane Company, La Crosse, Wisconsin. [697.93 A29 T16]
- Wang, S. K., 2001. *Handbook of Air Conditioning and Refrigeration*, 2nd ed., Chp. 7, McGraw-Hill, New York. [697.93 W24 h]