MEBS7014 Advanced HVAC applications

http://ibse.hk/MEBS7014/

Fans and Pumps I

Ir Dr. Sam C. M. Hui

Department of Mechanical Engineering

The University of Hong Kong

E-mail: cmhui@hku.hk

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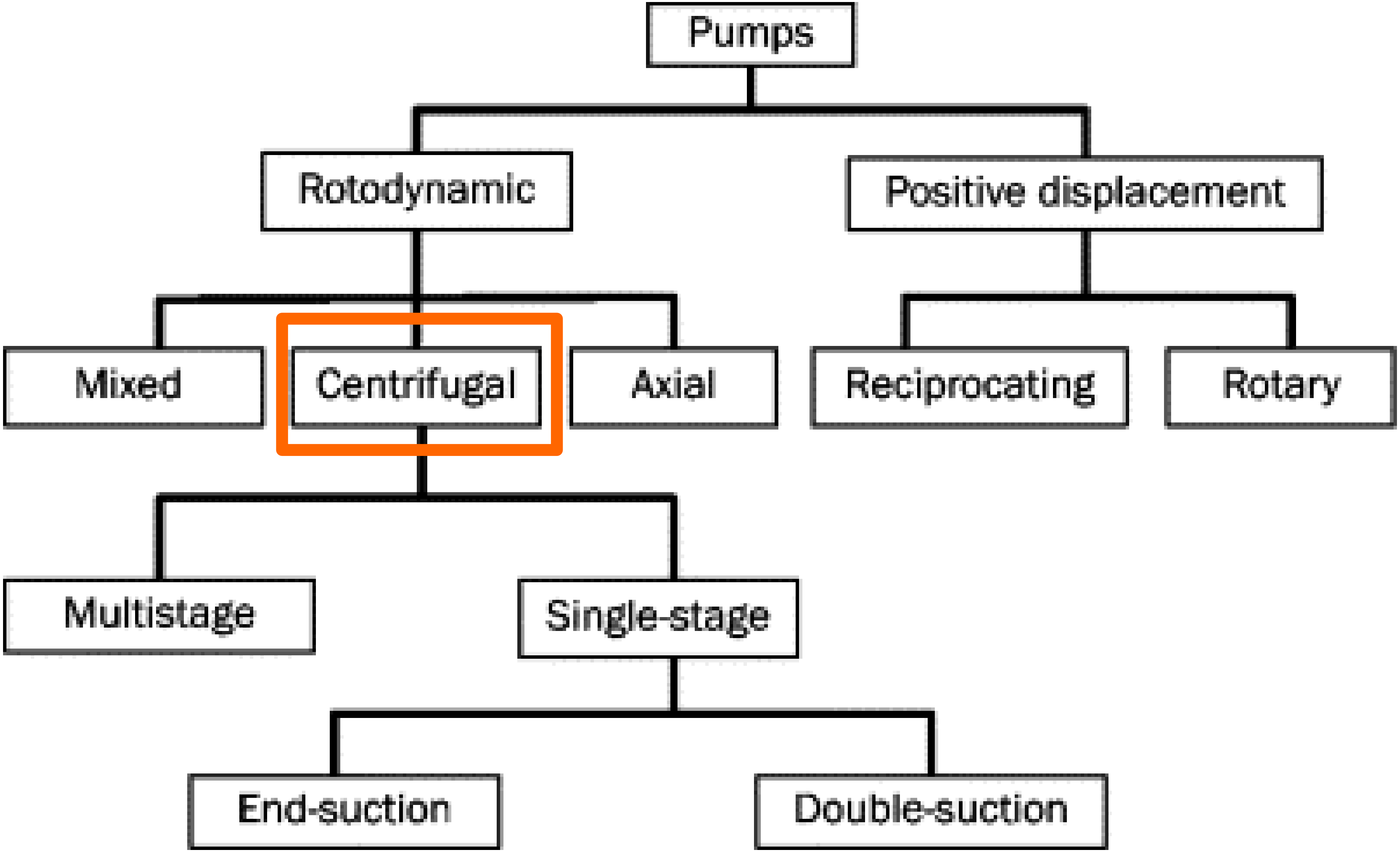
- Centrifugal Pumps
- Pump Characteristics
- Pump Arrangements
- Matching Pumps to Systems

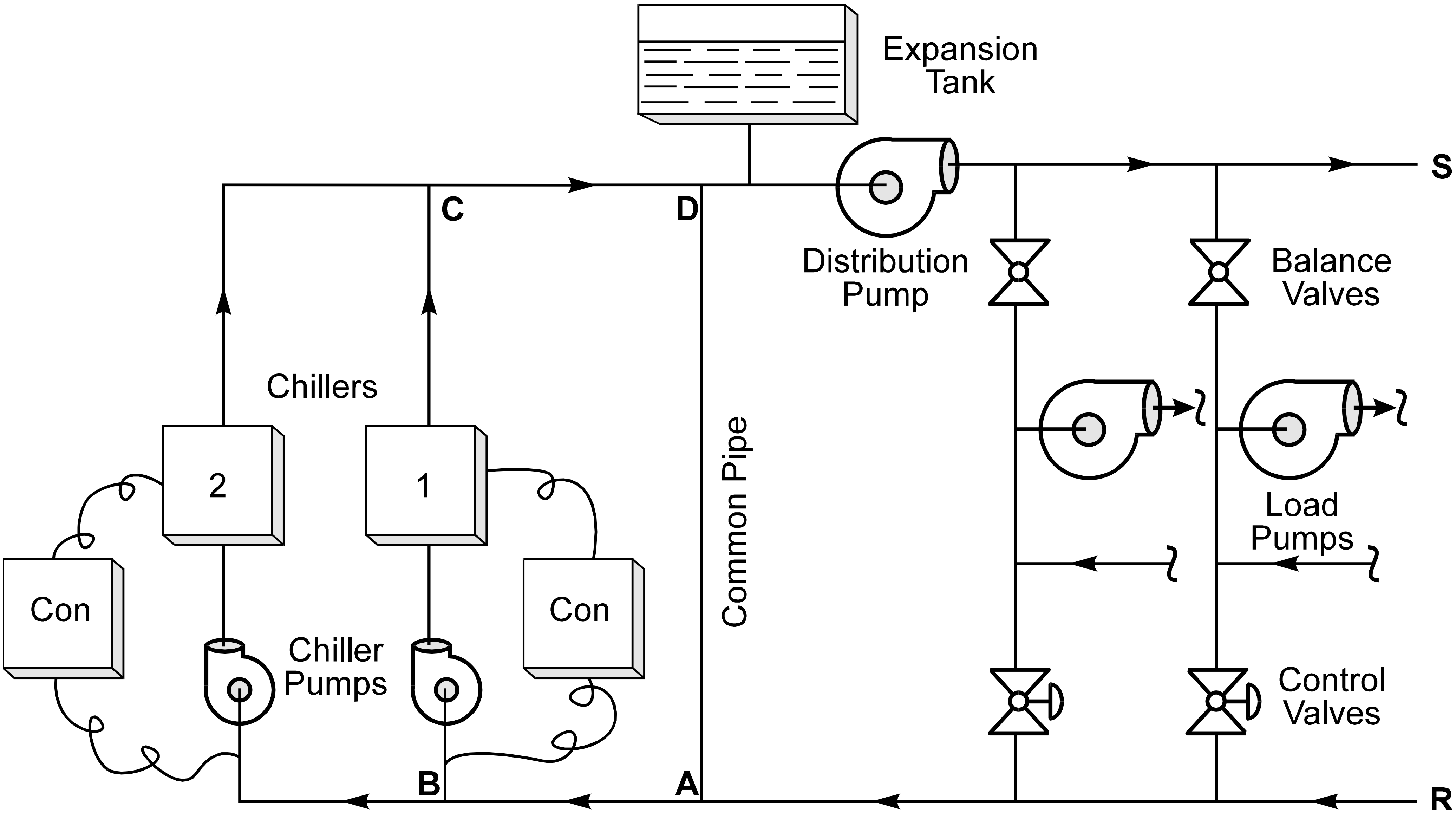
Classification of pumps



Centrifugal Pumps

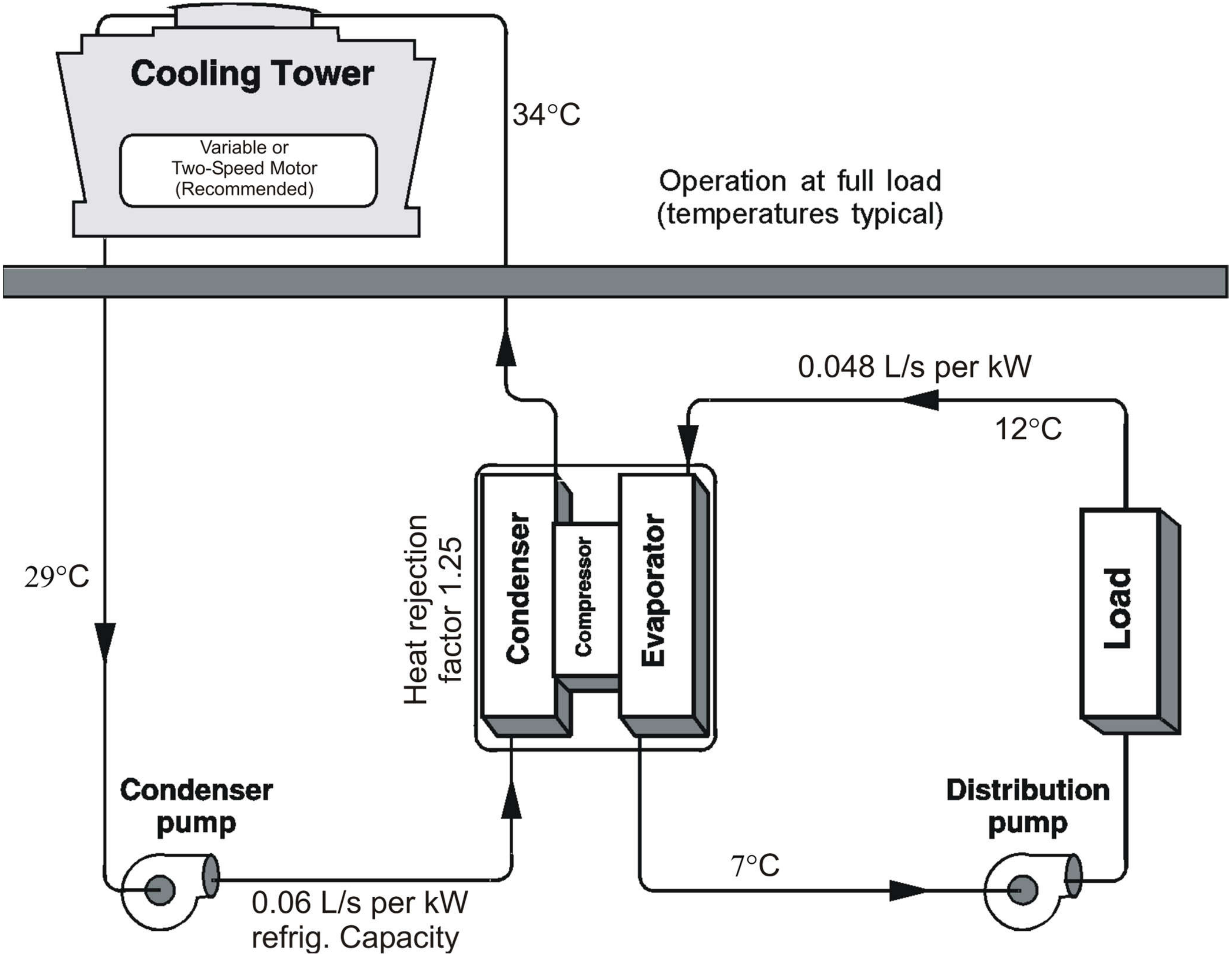
- Centrifugal pumps
  - Most widely used in HVAC applications, e .g.
    - Hot water systems
    - Chilled water systems
    - Condenser water systems
    - Boiler feed and condensate return pumps
  - Operation
    - Electric motor's output torque => impeller's rotation
    - Coupling to the pump shaft
    - Centrifugal force & tip speed force

Chilled water pumping system



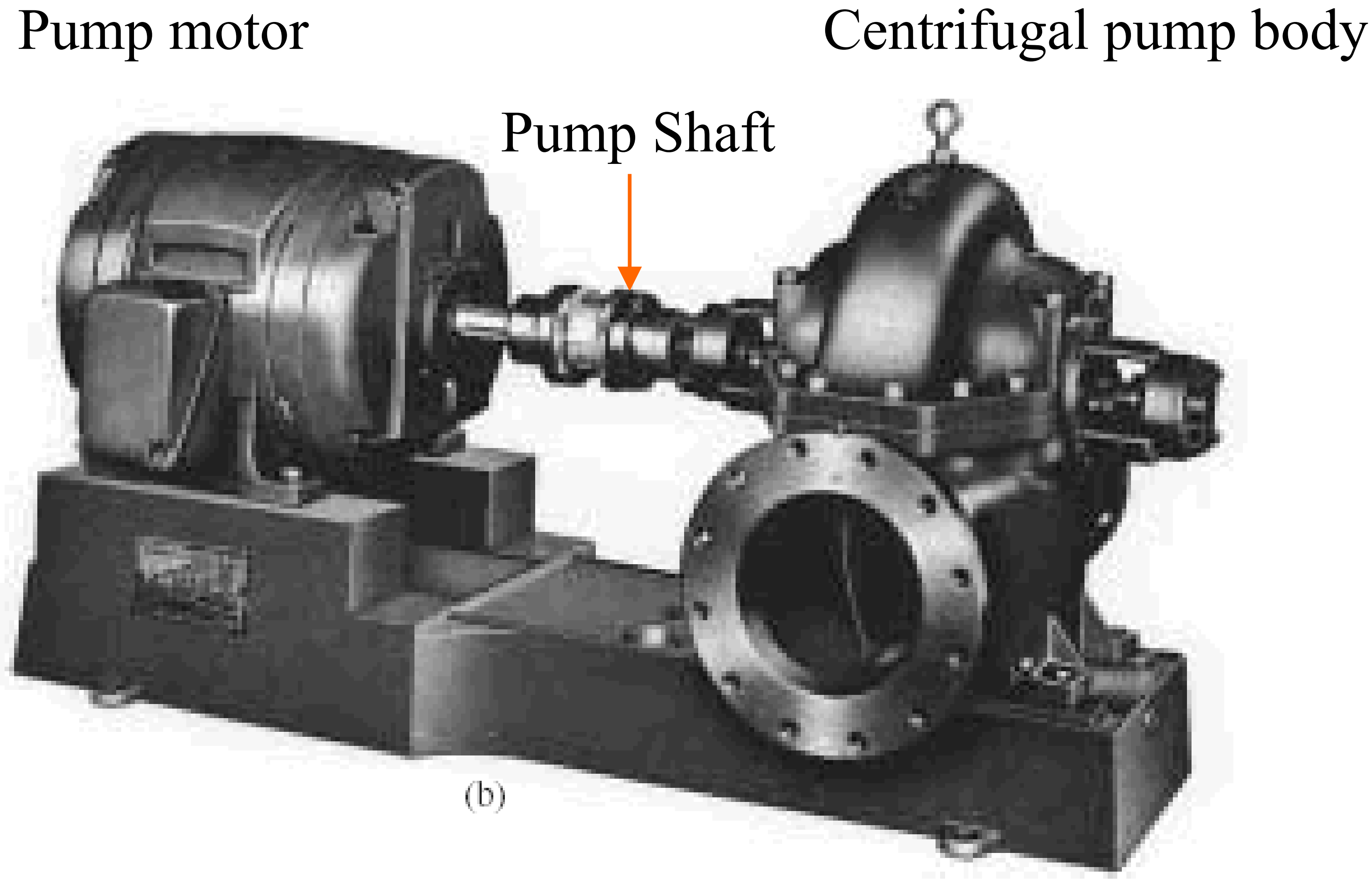
(Source: *Fundamentals of Water System Design*)

Cooling tower pumping system



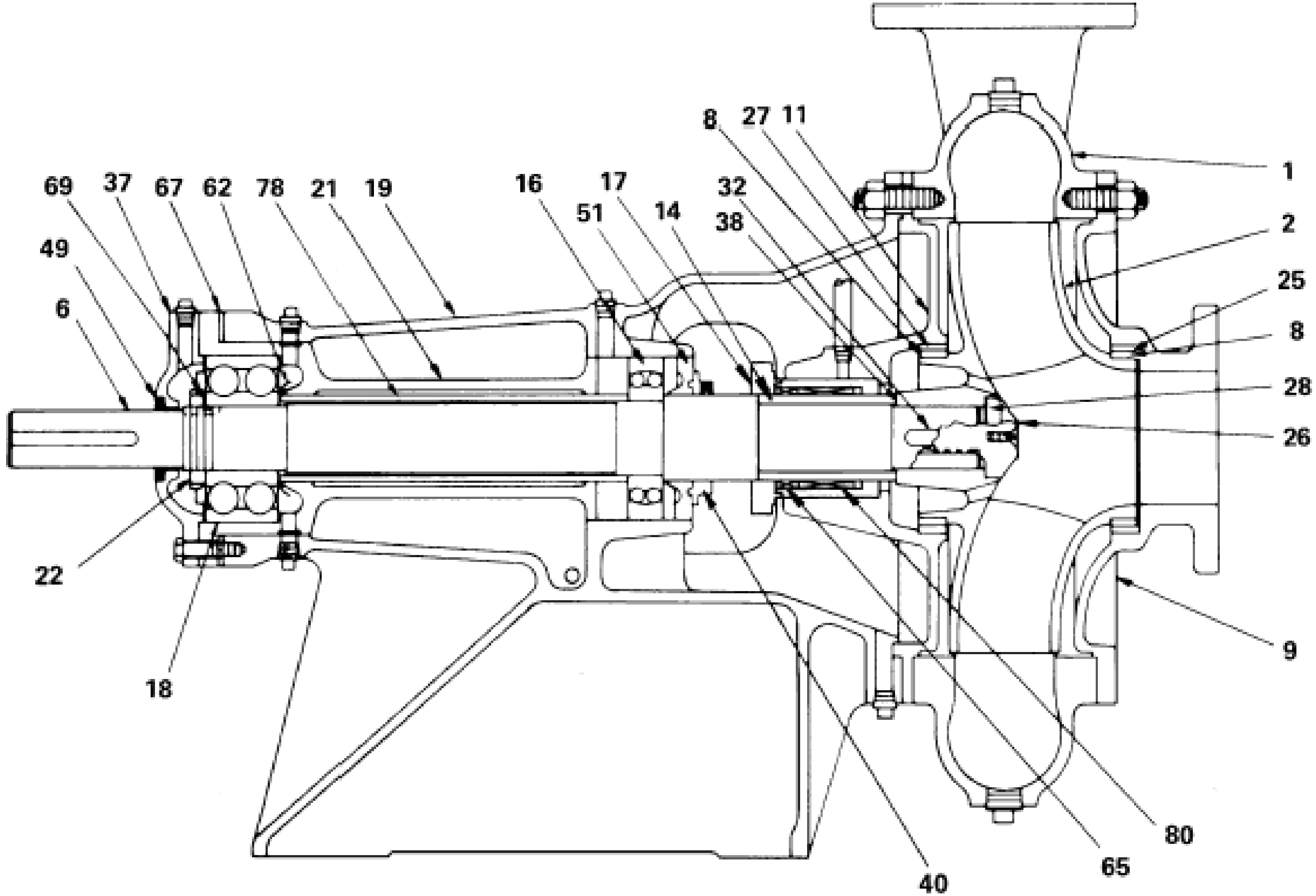
(Source: *Fundamentals of Water System Design*)

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



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

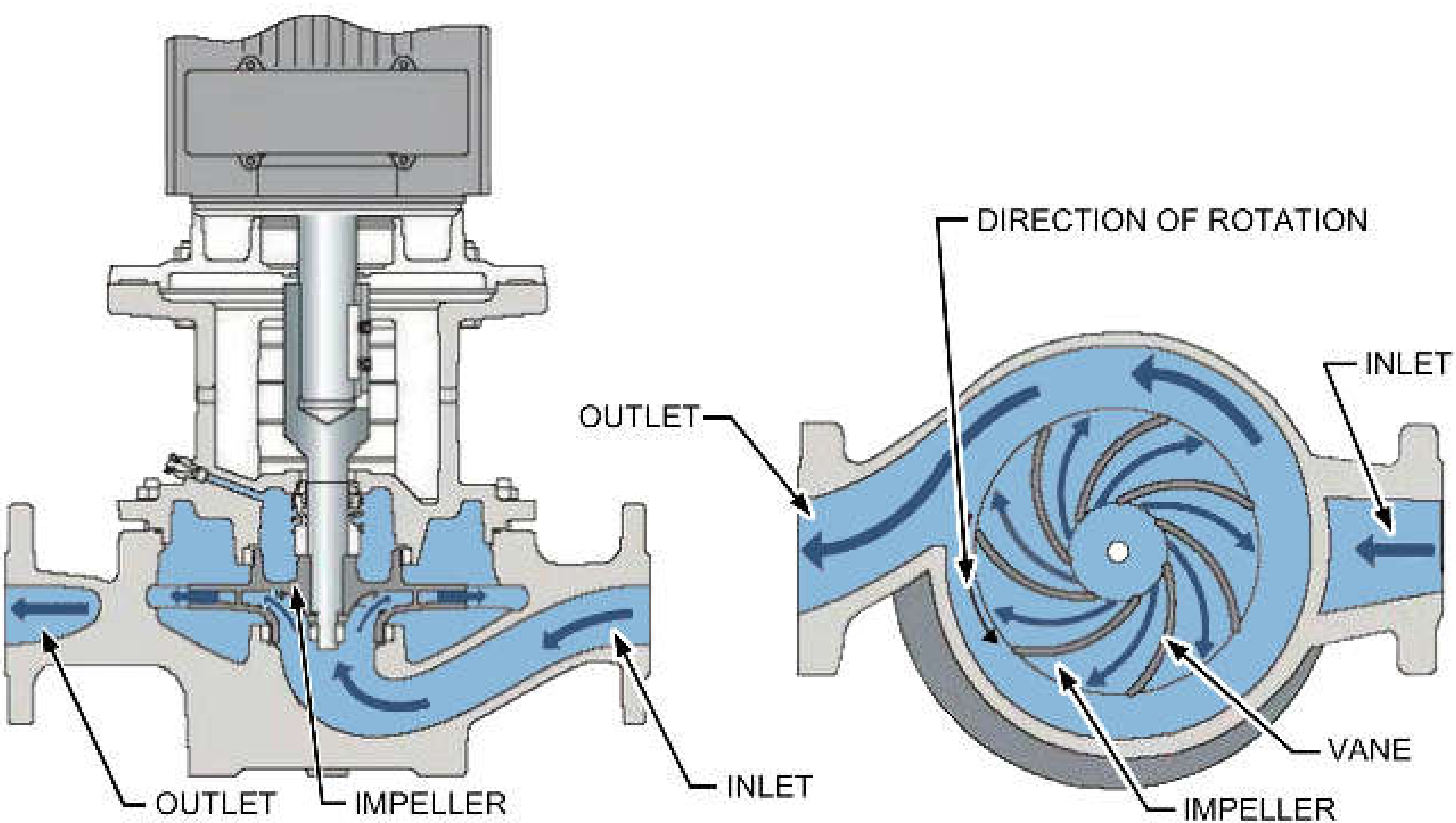
Typical overhung-impeller end-suction pump

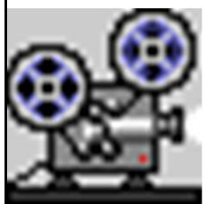


1 Casing	17 Gland	28 Gasket, impeller screw	62 Thrower, oil or grease
2 Impeller	18 Bearing, outboard	32 Key, impeller	65 Seal, mechanical, stationary element
6 Shaft, pump	19 Frame	37 Cover, bearing, outboard	67 Shim, frame-liner
8 Ring, impeller	21 Liner, frame	38 Gasket, shaft-sleeve	69 Lock washer
9 Cover, suction	22 Locknut, bearing	40 Deflector	78 Spacer, bearing
11 Cover, stuffing box	25 Ring, suction cover	49 Seal, bearing cover, outboard	80 Seal, mechanical, rotating element
14 Sleeve, shaft	26 Screw, impeller	51 Retainer, grease	
16 Bearing, inboard	27 Ring, stuffing box cover		

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

Centrifugal pump

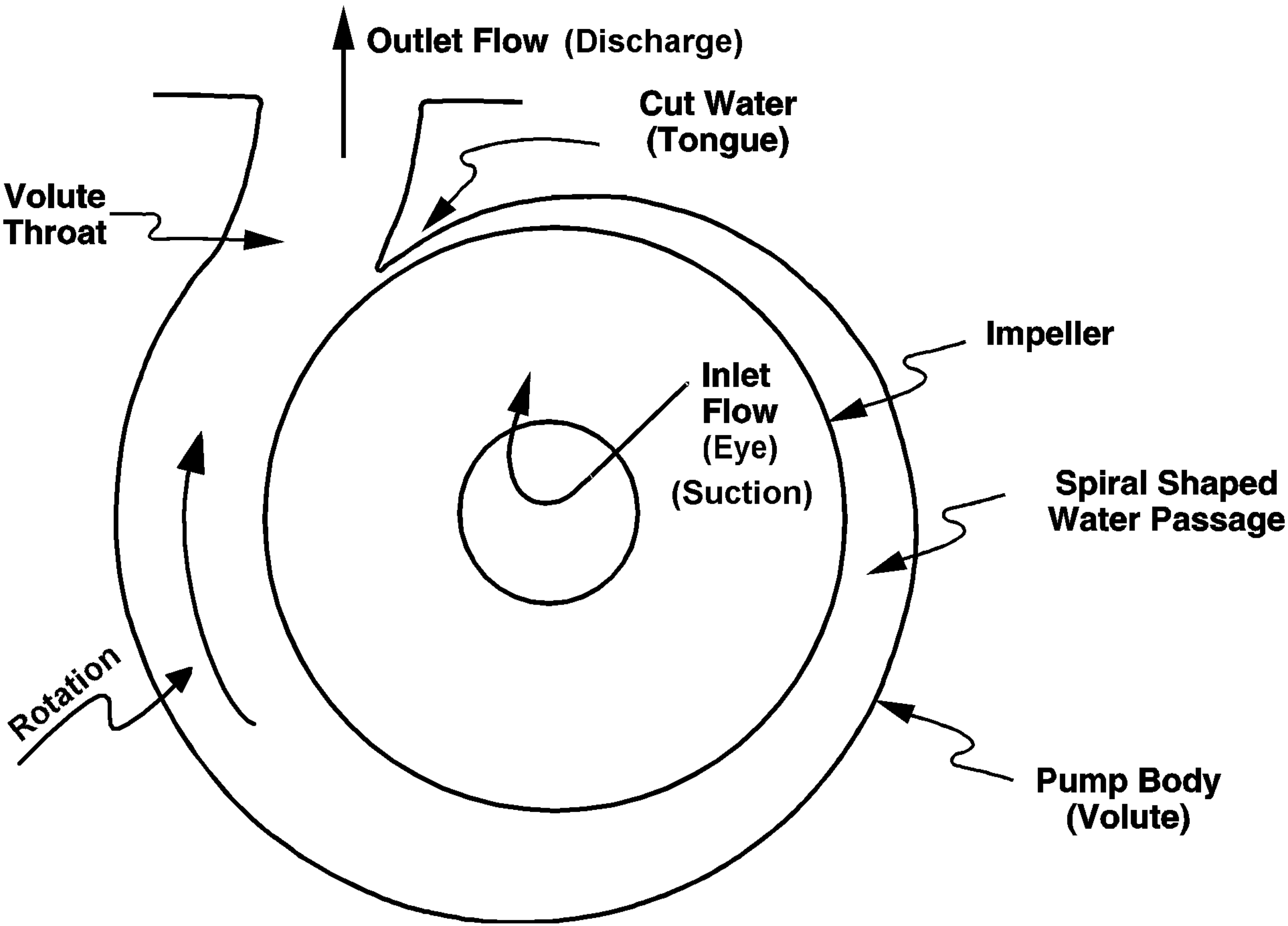




* Video: How does a Centrifugal pump work ? (4:37) https://youtu.be/BaEHVpKc-1Q

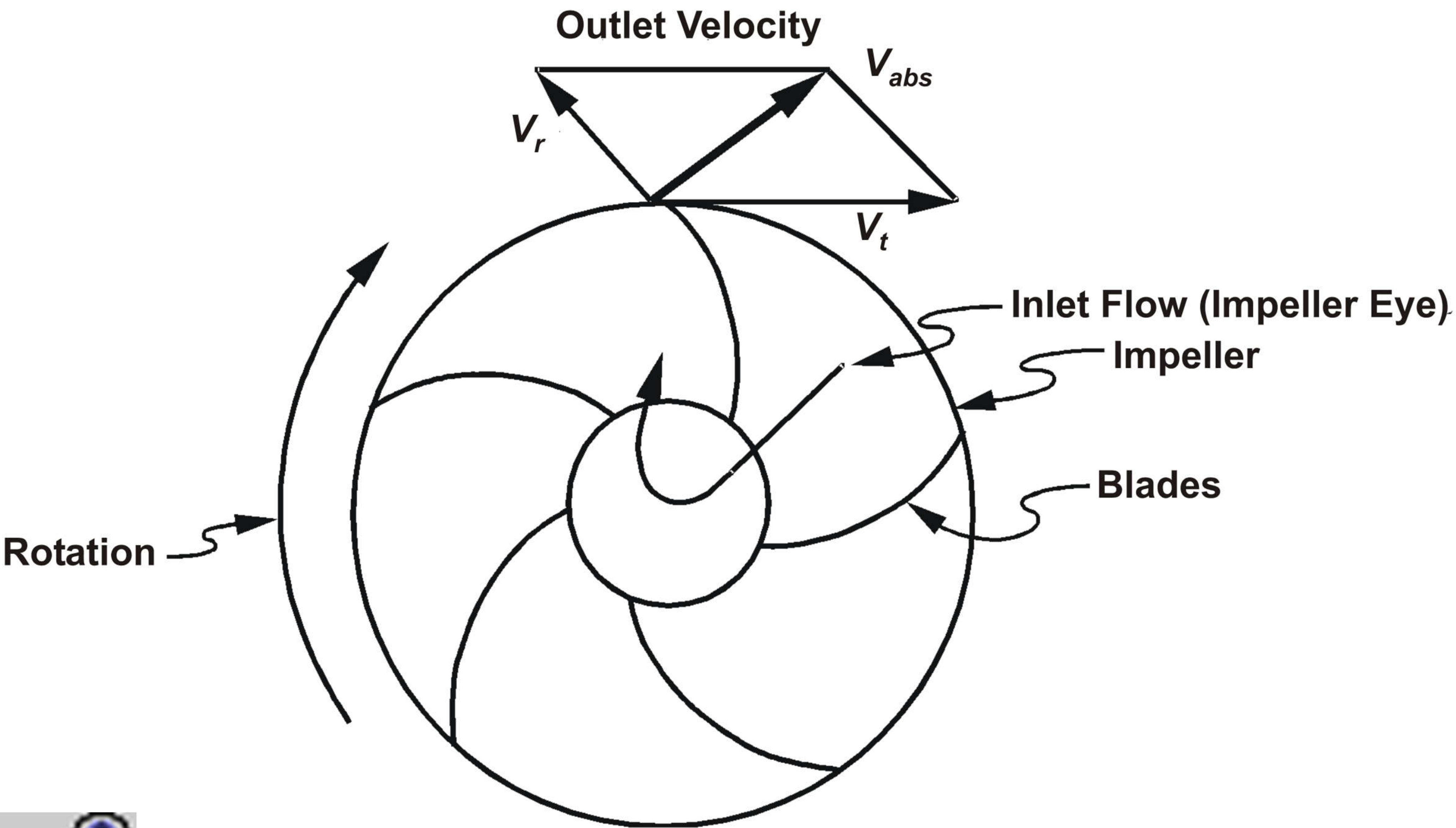
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2012*)

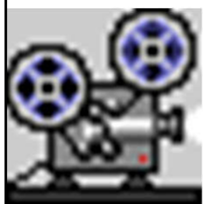
Centrifugal pump, impeller and volute



(Source: *Fundamentals of Water System Design*)

Impeller action on fluid

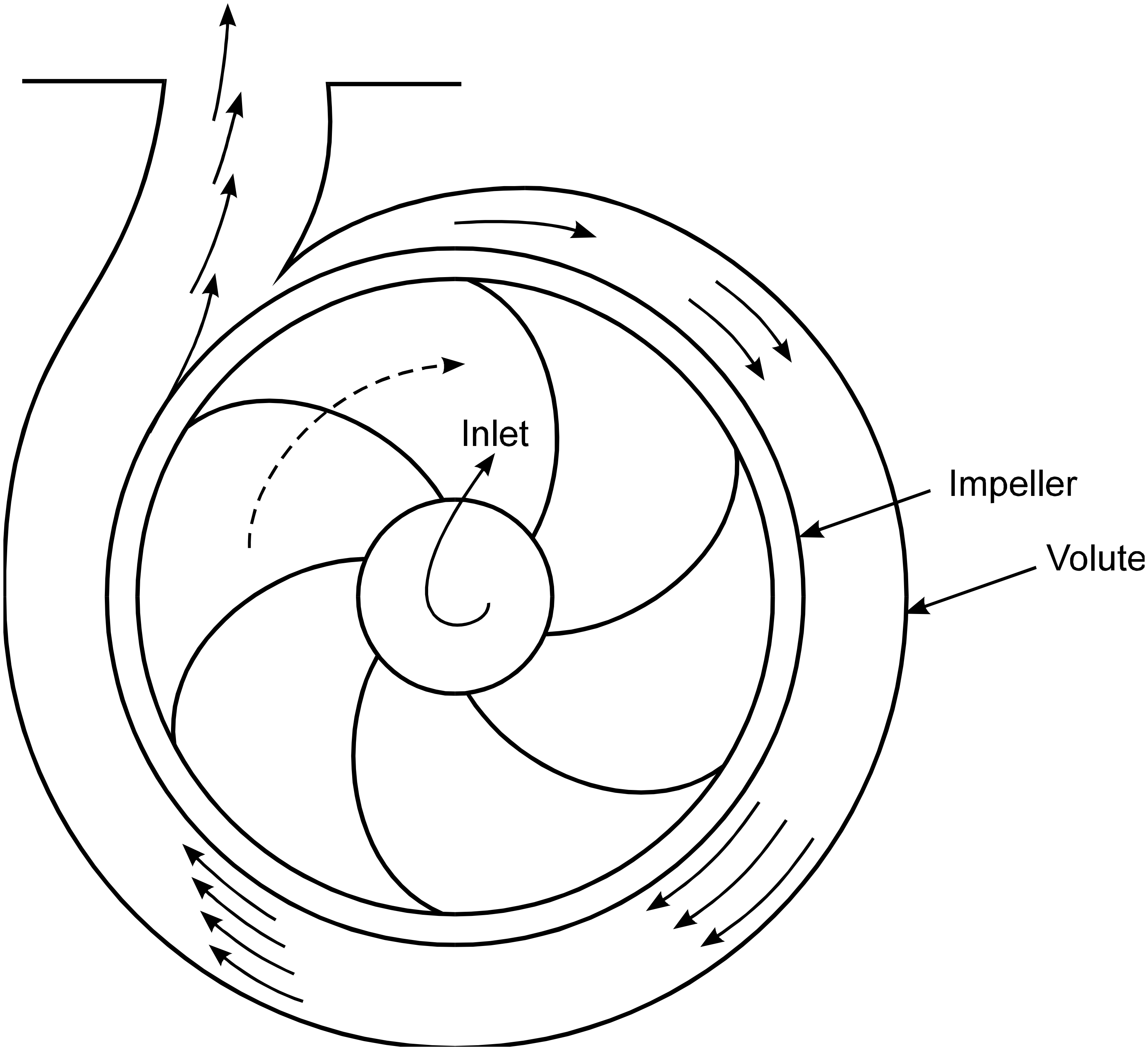




* Video: Centrifugal Pump Working (5:54) https://youtu.be/IiE8skW8btE

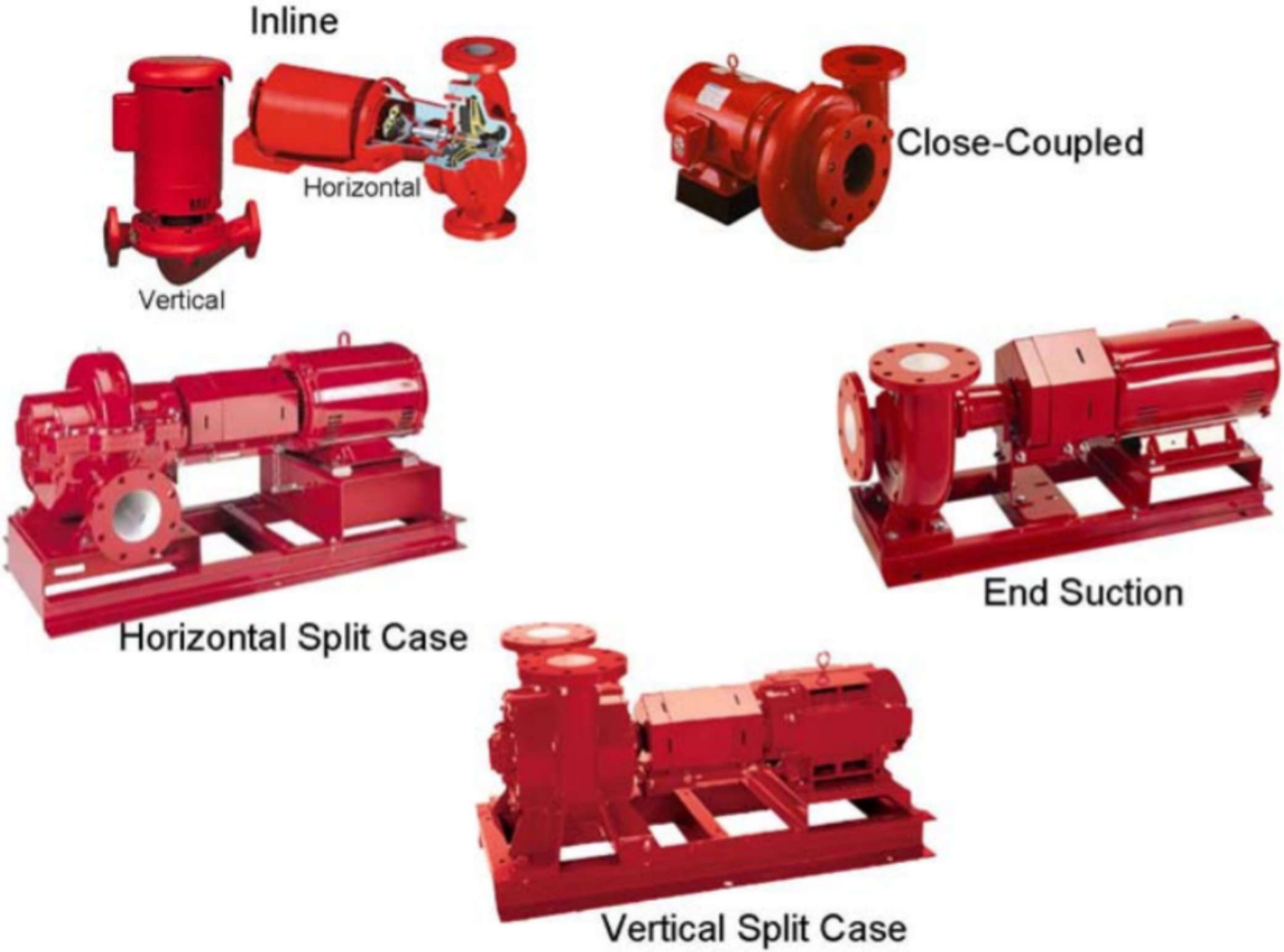
(Source: *Fundamentals of Water System Design*)

Flow pattern of impeller/volute action



(Source: *Fundamentals of Water System Design*)

Types of centrifugal pumps

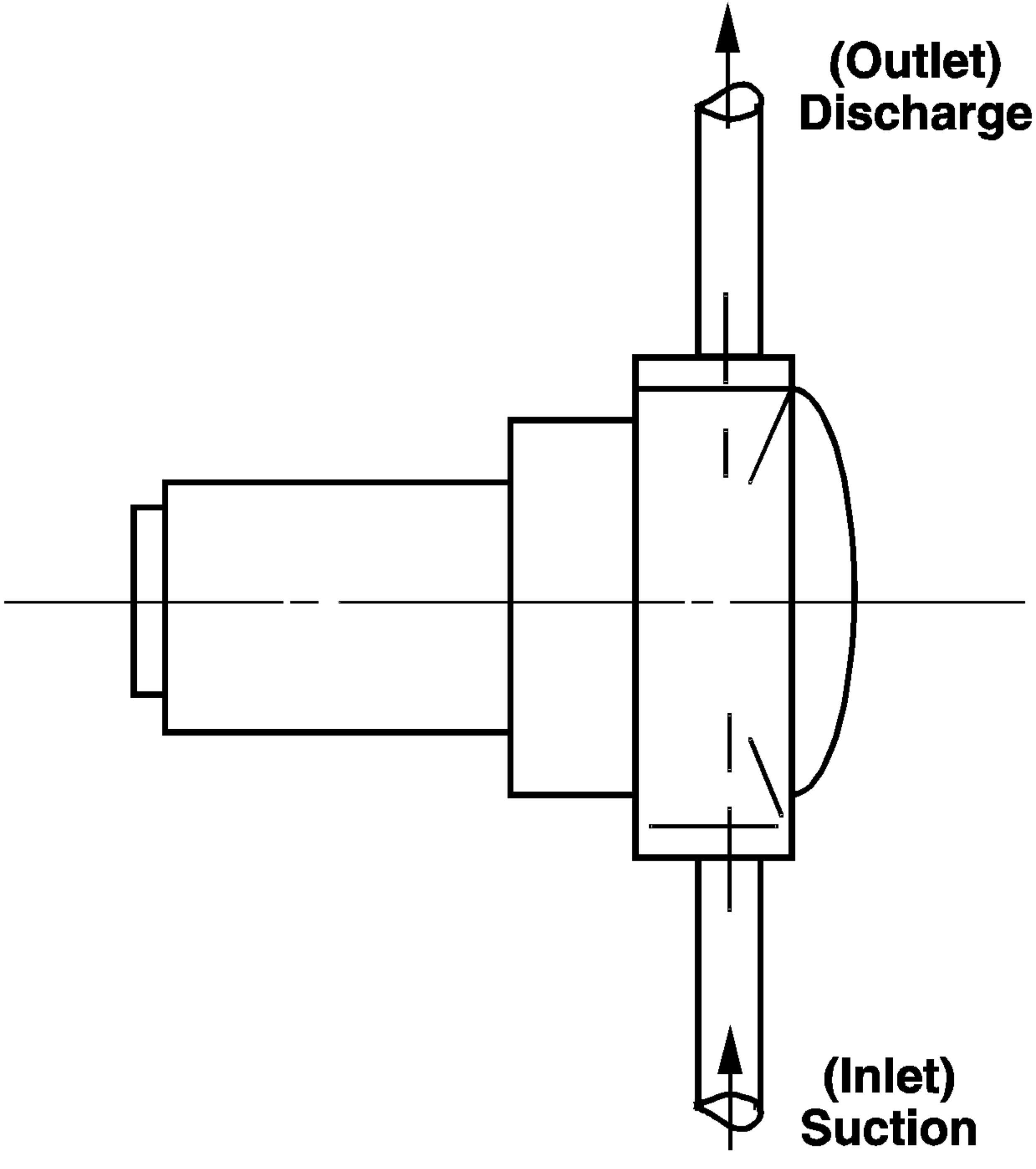


(Source: Carrier Corporation, 2005. *Distribution Systems: Water Piping and Pumps*, Technical Development Program.)

Centrifugal Pumps

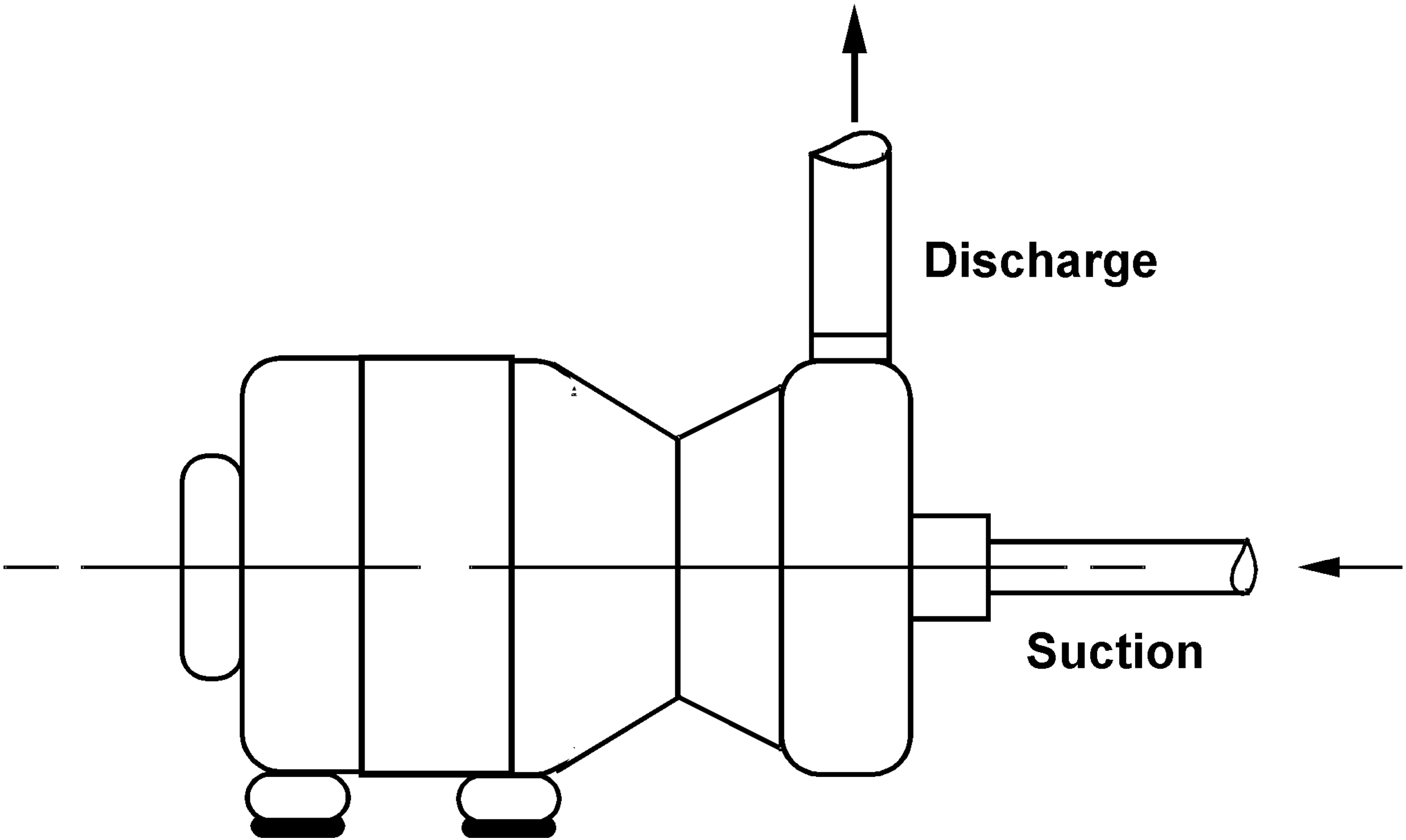
- Types of centrifugal pumps
  - Circulator pump
  - Closed-couple end suction pump
  - Frame-mounted end suction pump
  - Base-mounted horizontal split case pump
  - Vertical inline pump
  - Vertical turbine single or multistage pump

Circulation pump



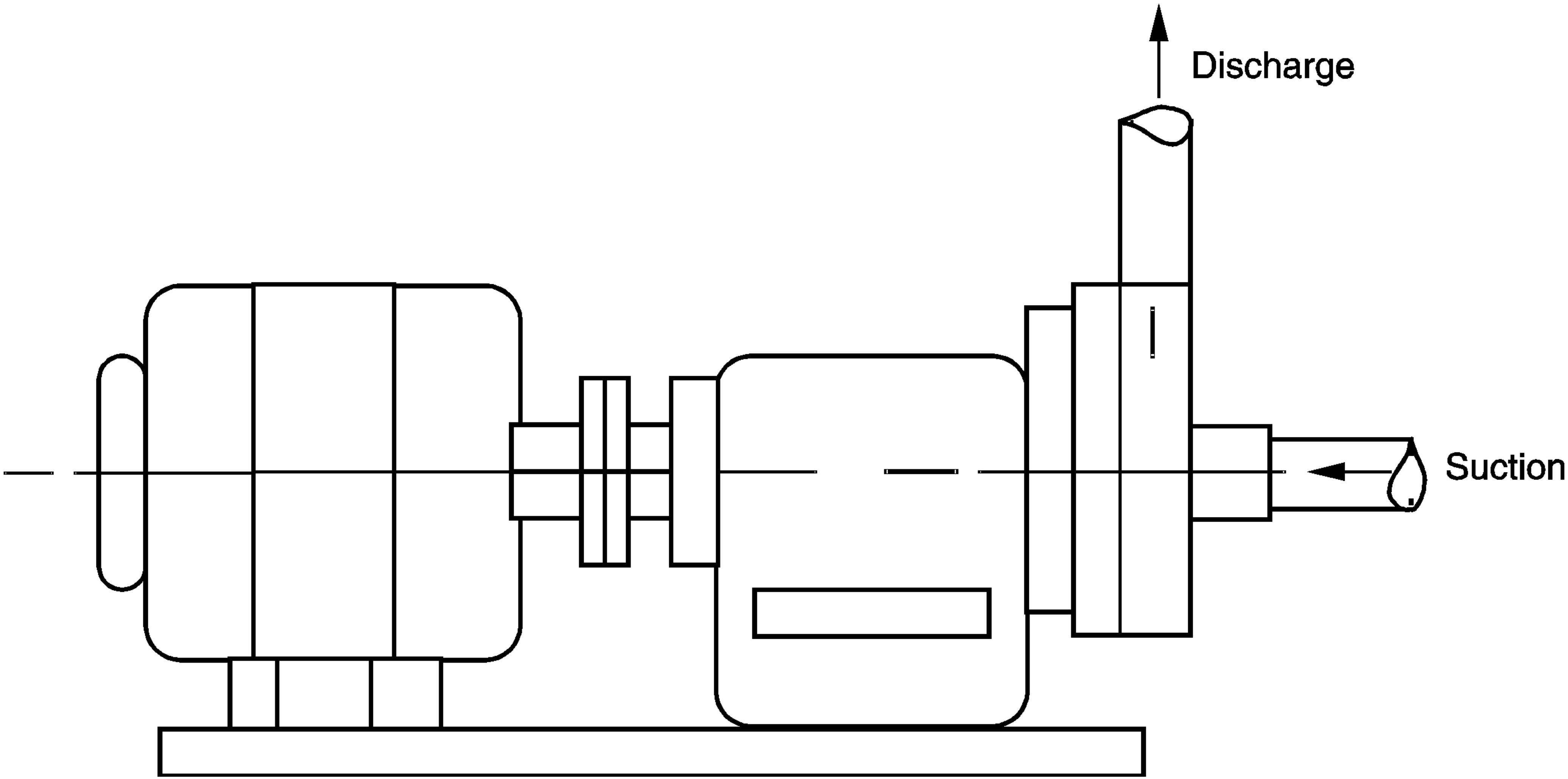
(Source: *Fundamentals of Water System Design*)

Close-coupled end suction pump



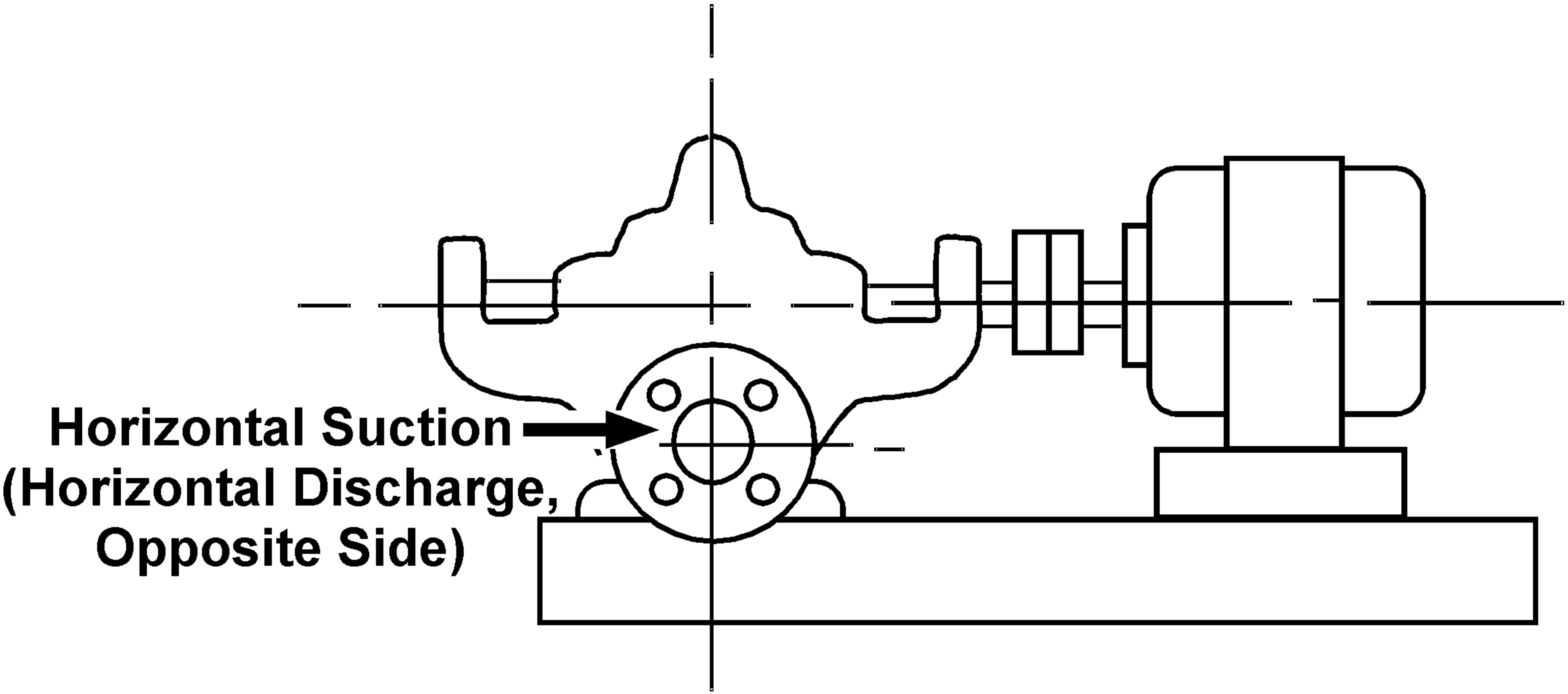
(Source: *Fundamentals of Water System Design*)

Frame-mounted end suction pump



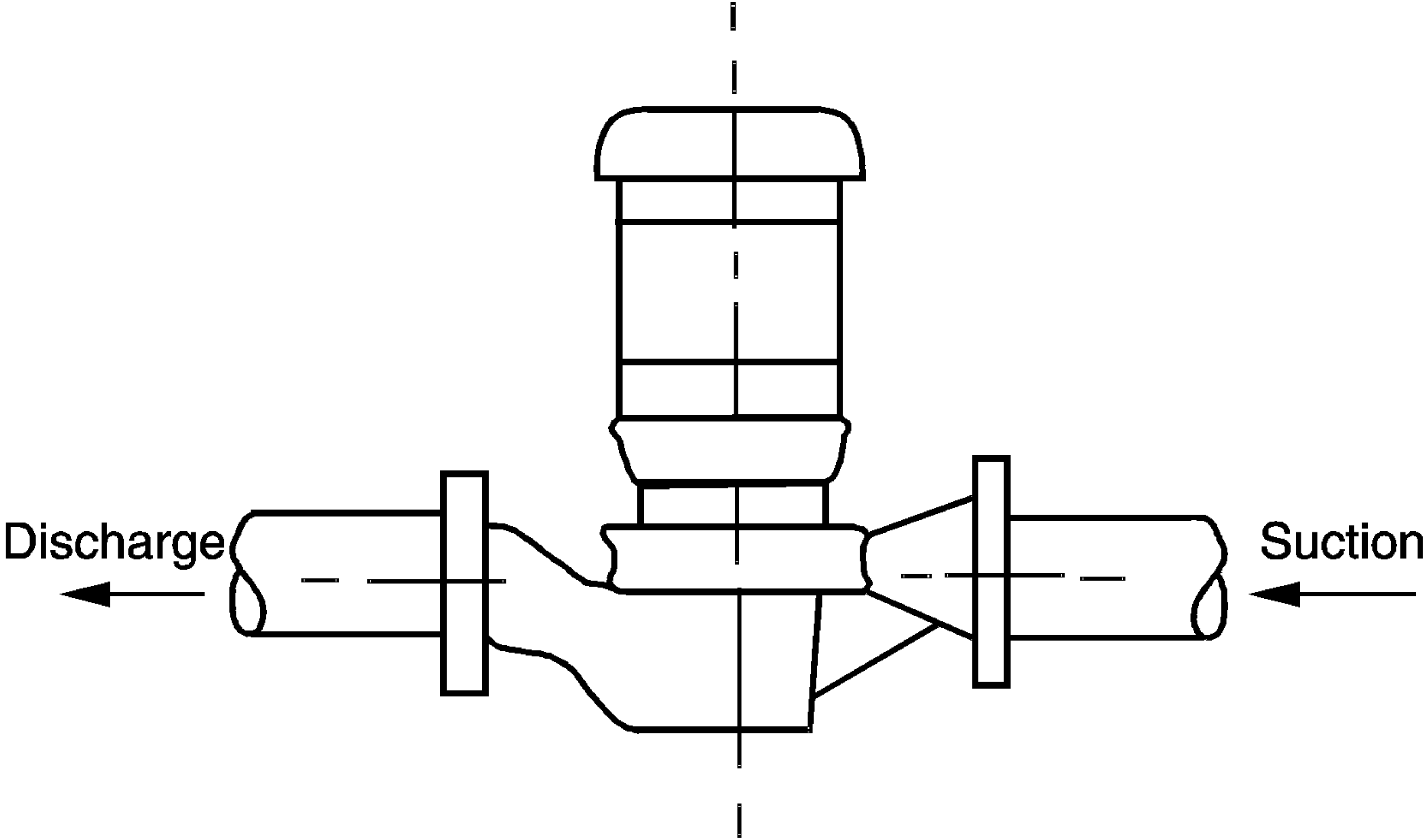
(Source: *Fundamentals of Water System Design*)

Base-mounted horizontal split case pump



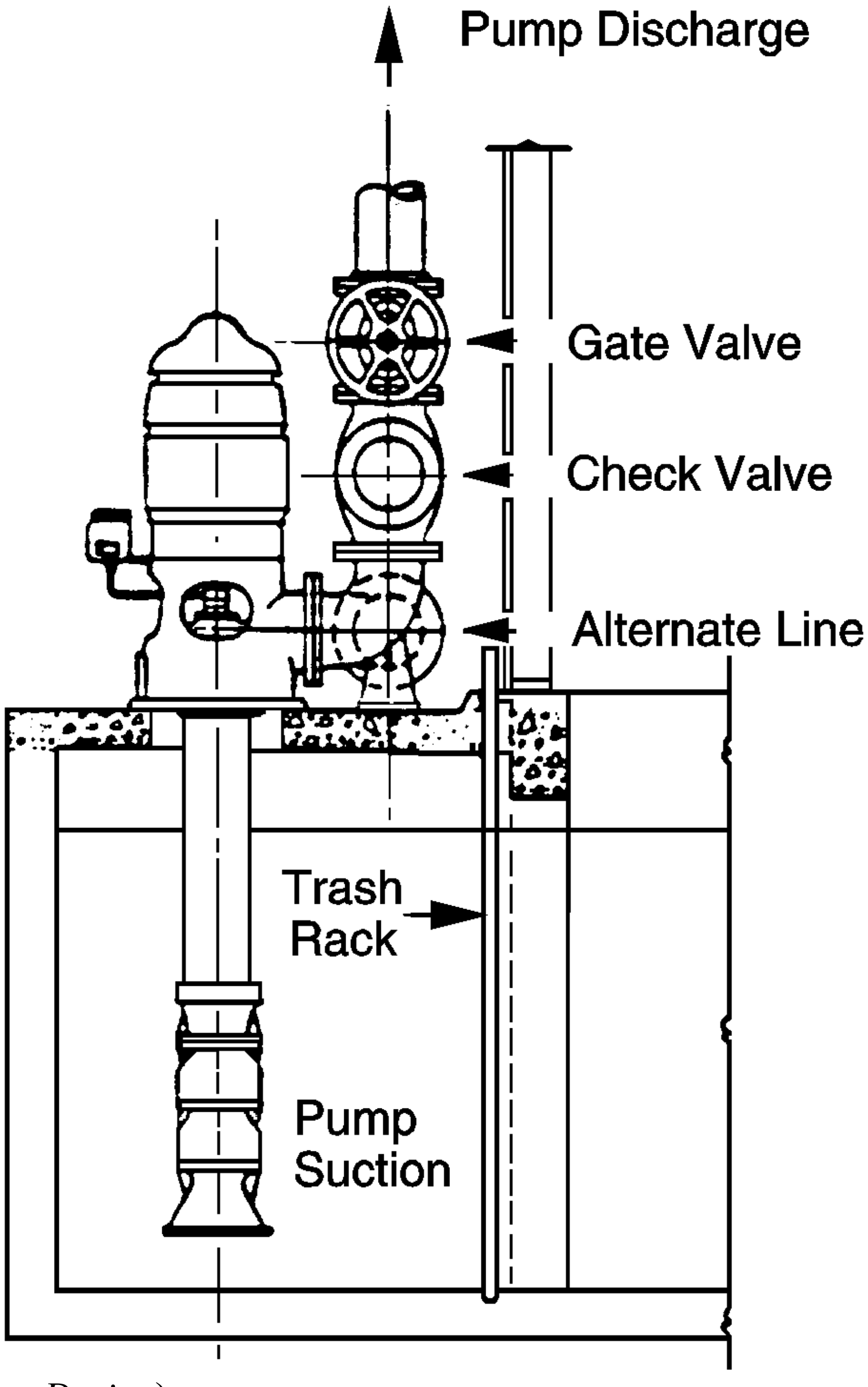
(Source: *Fundamentals of Water System Design*)

Vertical inline pump



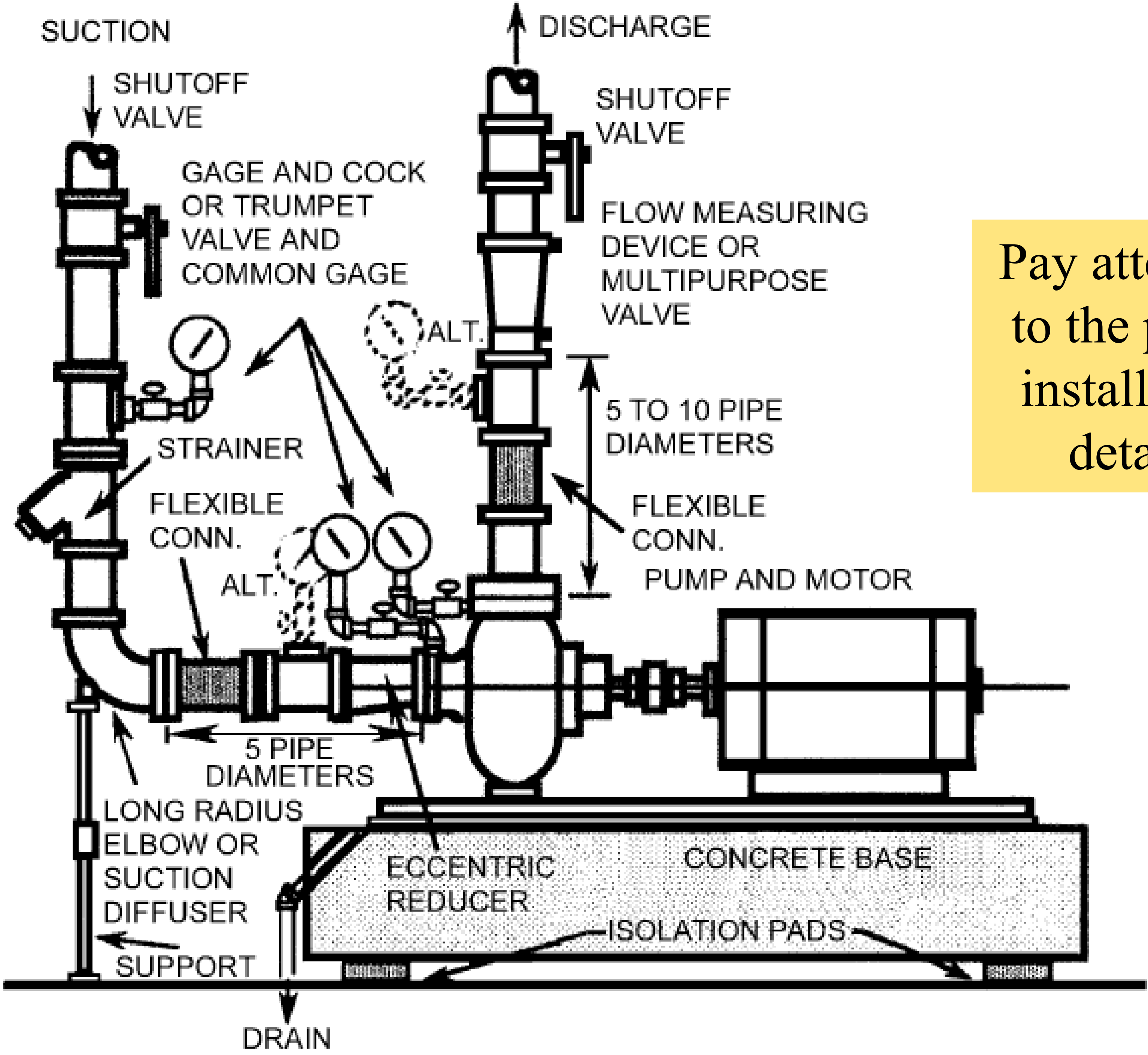
(Source: *Fundamentals of Water System Design*)

Vertical turbine pump, wet sump arrangement



(Source: *Fundamentals of Water System Design*)

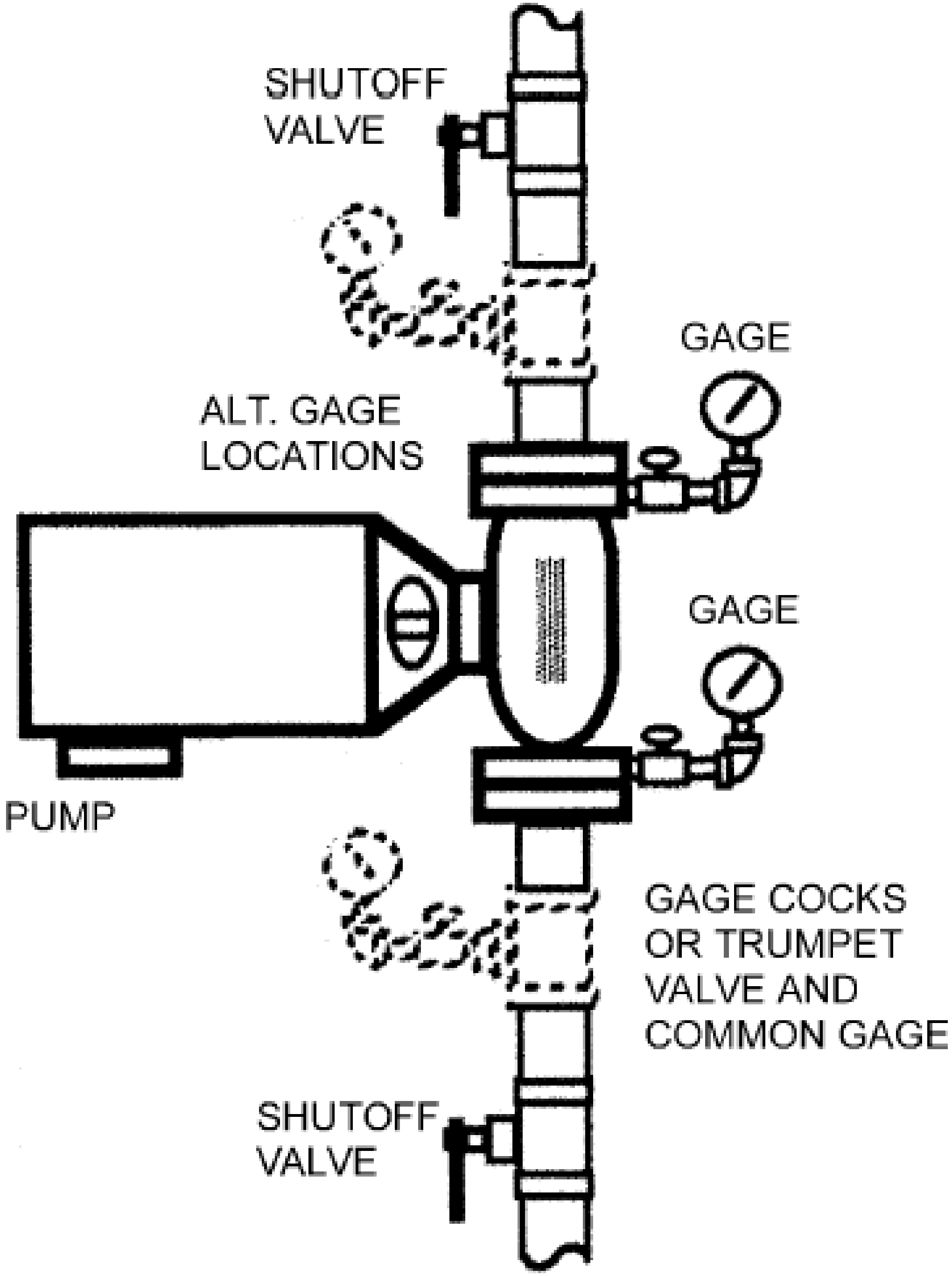
Base plate-mounted centrifugal pump installation



Pay attention to the pump installation details

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

In-line pump installation



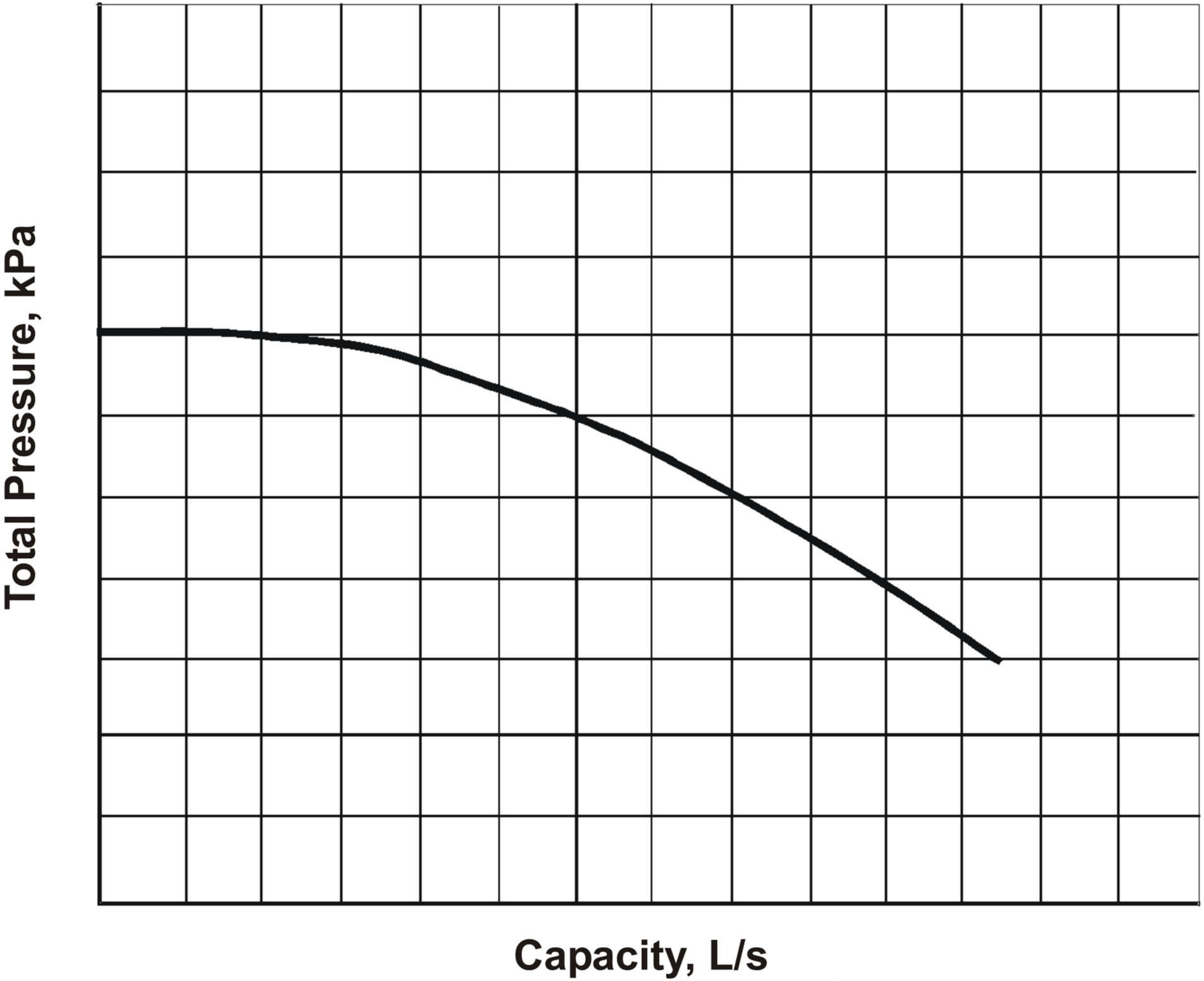
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

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

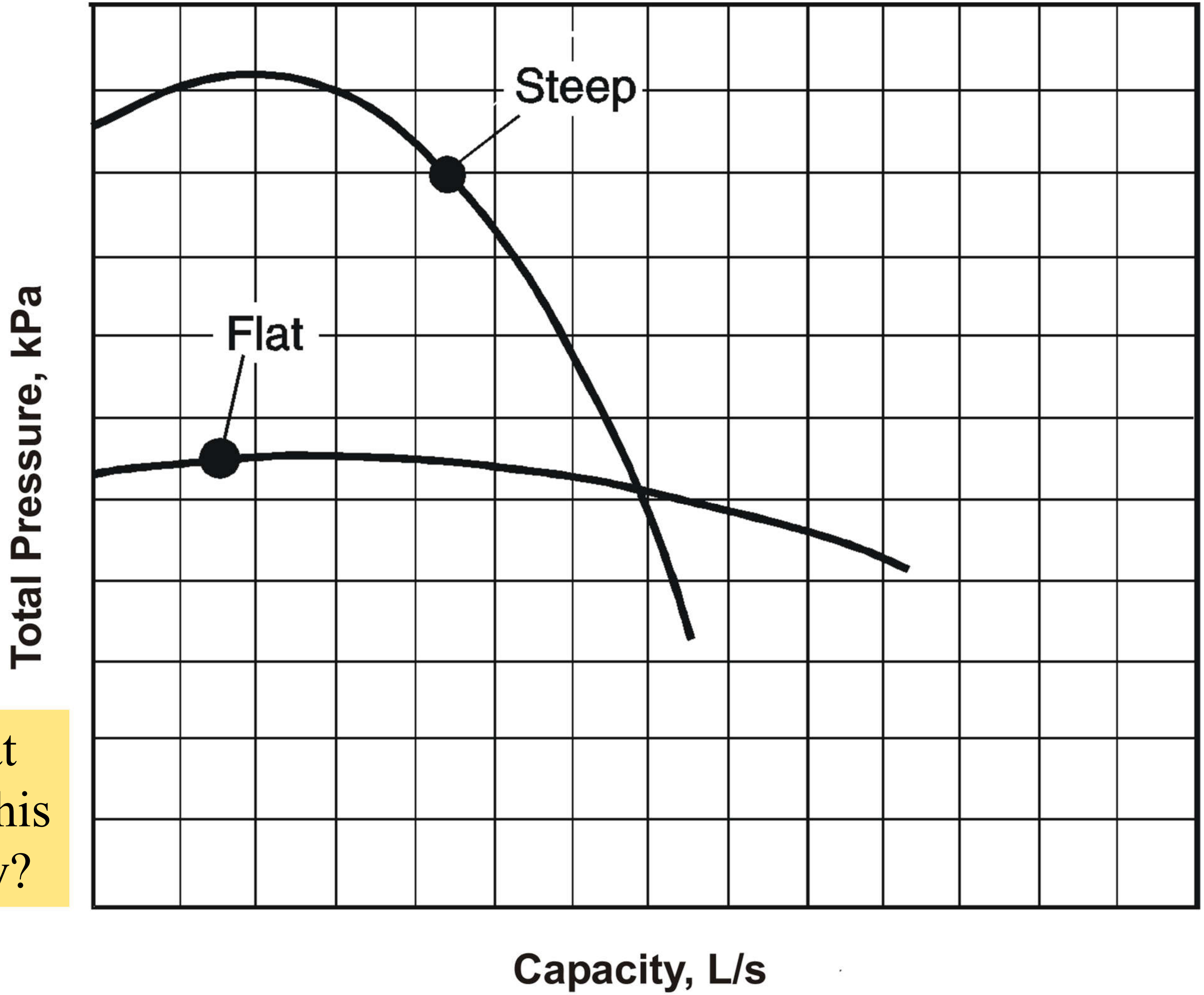
* Video: Centrifugal Pumps | Design Aspects (5:32) https://youtu.be/pWSyrxFJmt4

Total pressure-capacity curve



(Source: *Fundamentals of Water System Design*)

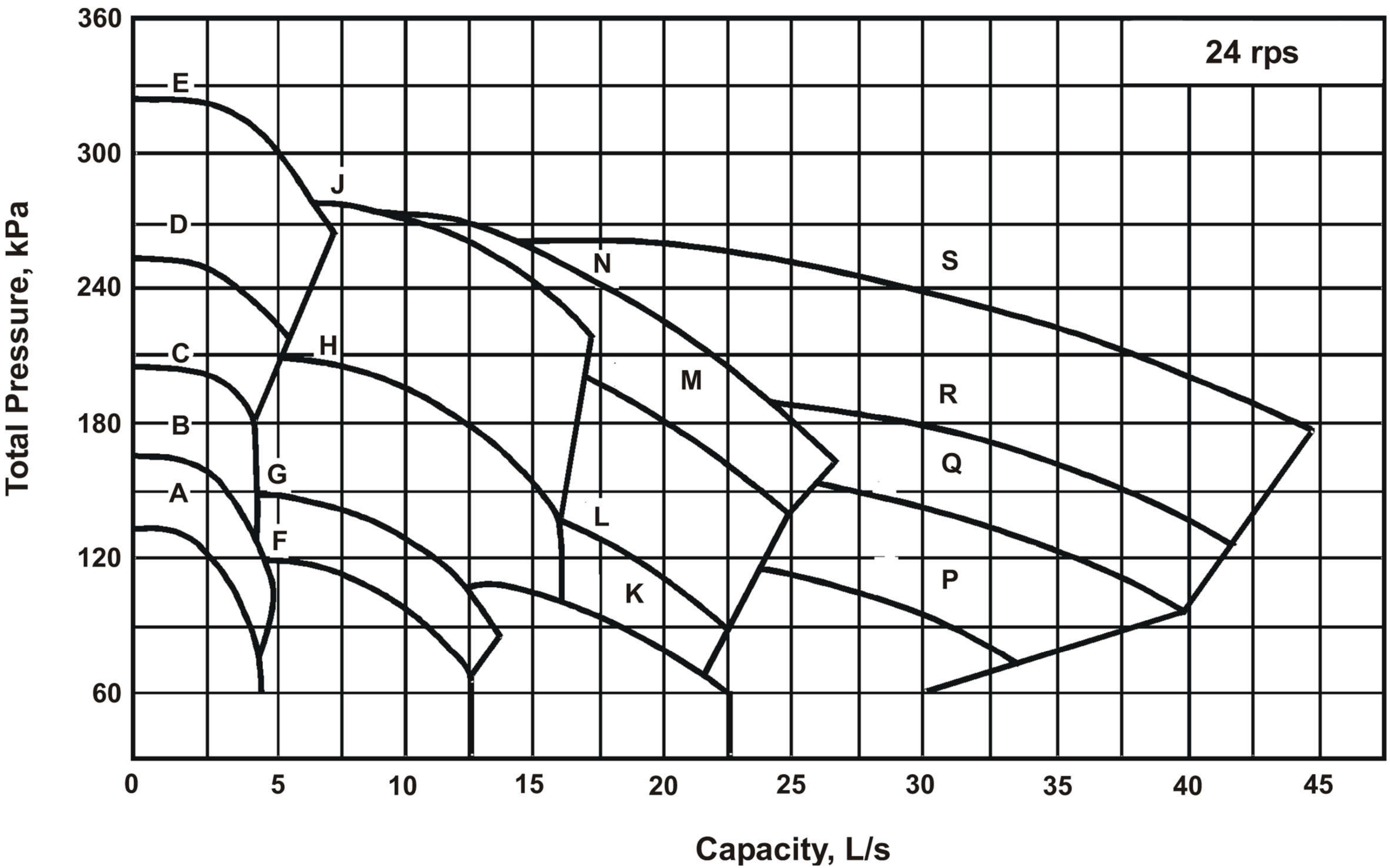
Flat versus steep pump curves



What does this imply?

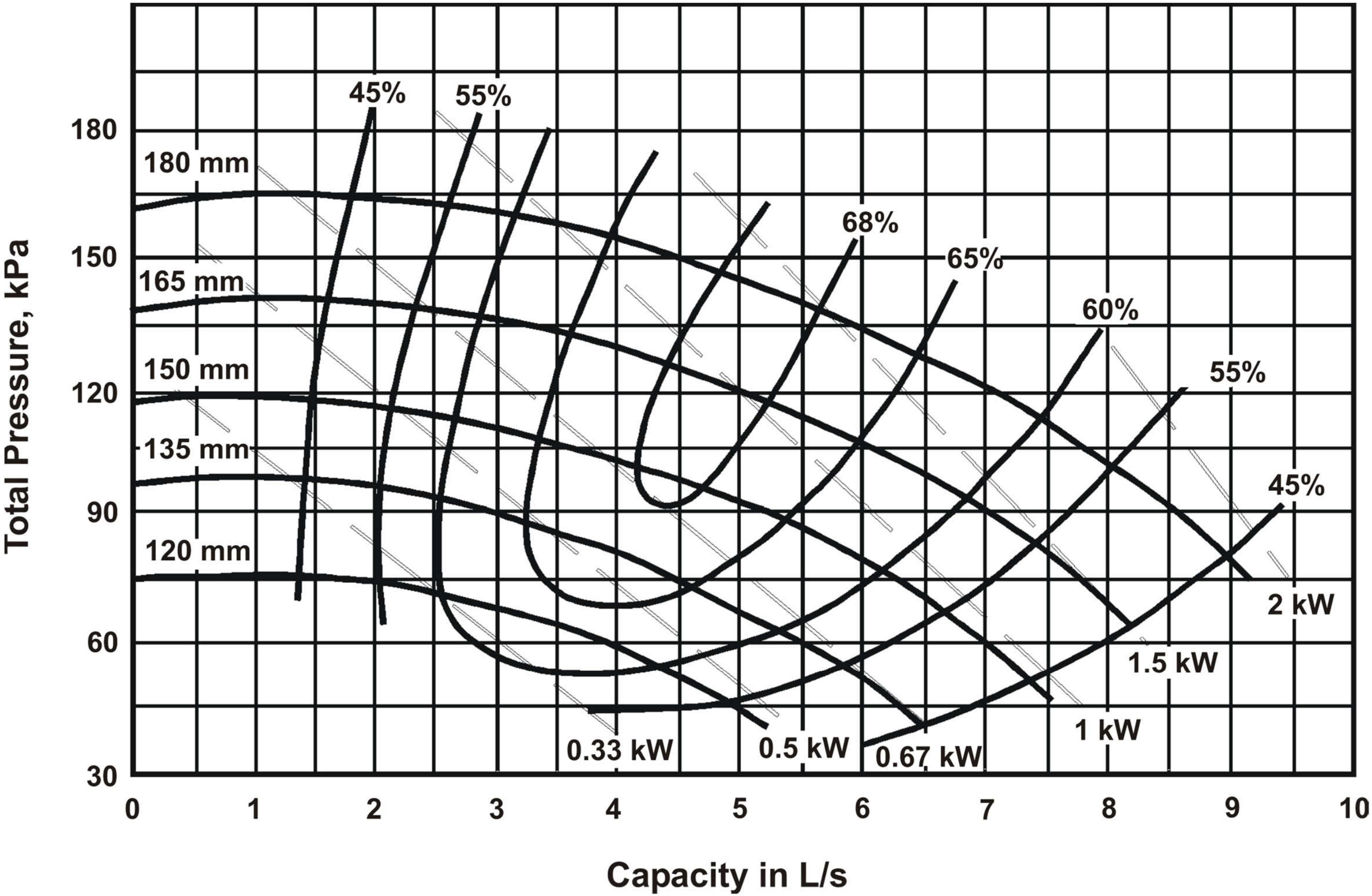
(Source: *Fundamentals of Water System Design*)

Characteristic curves or regions for pump models



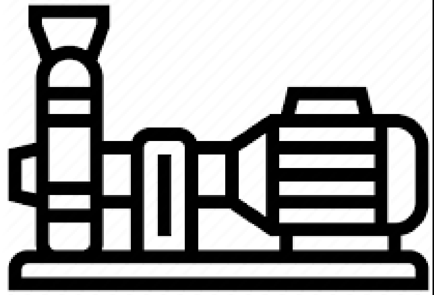
(Source: *Fundamentals of Water System Design*)

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



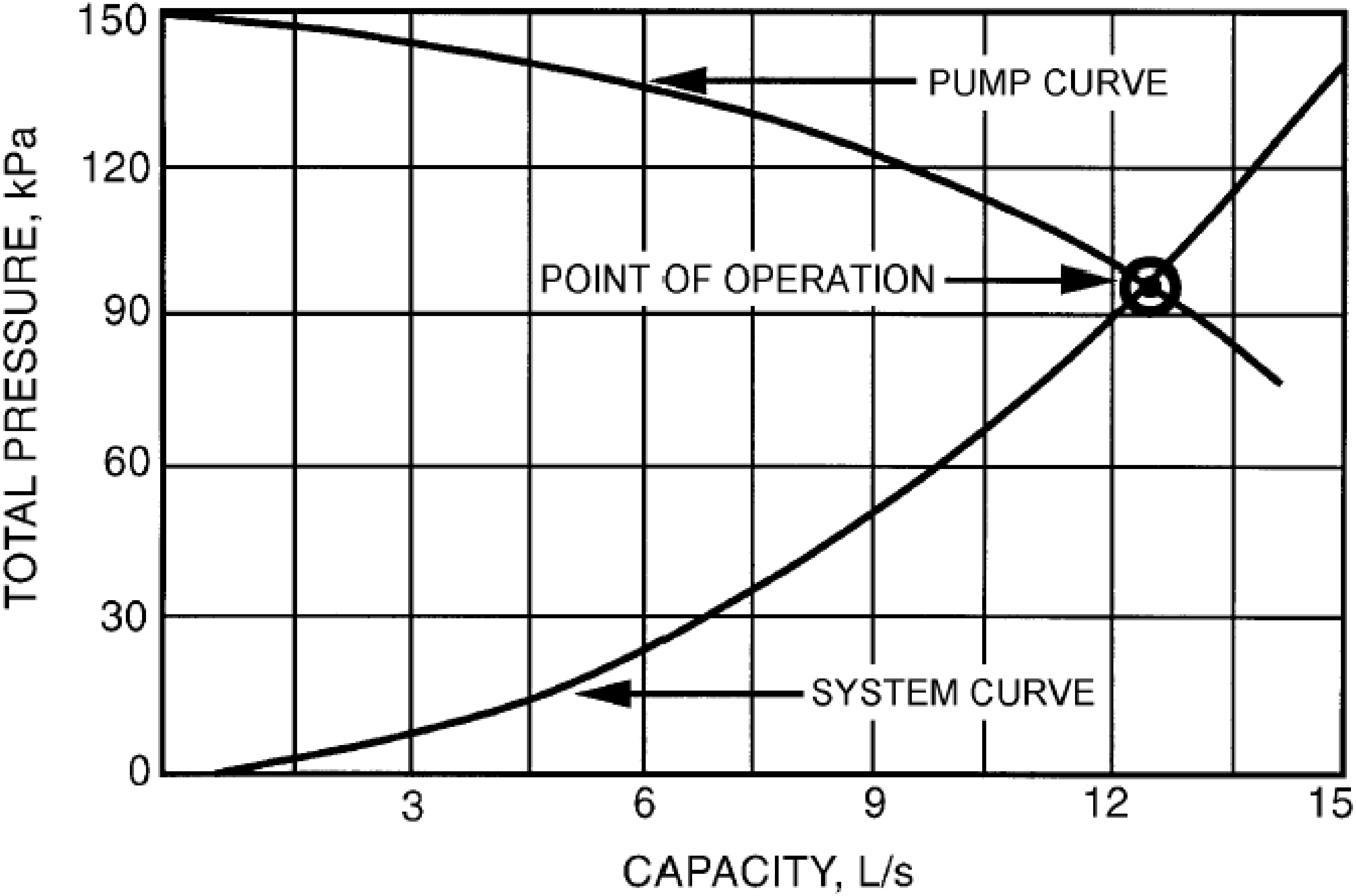
(Source: *Fundamentals of Water System Design*)

Pump Characteristics



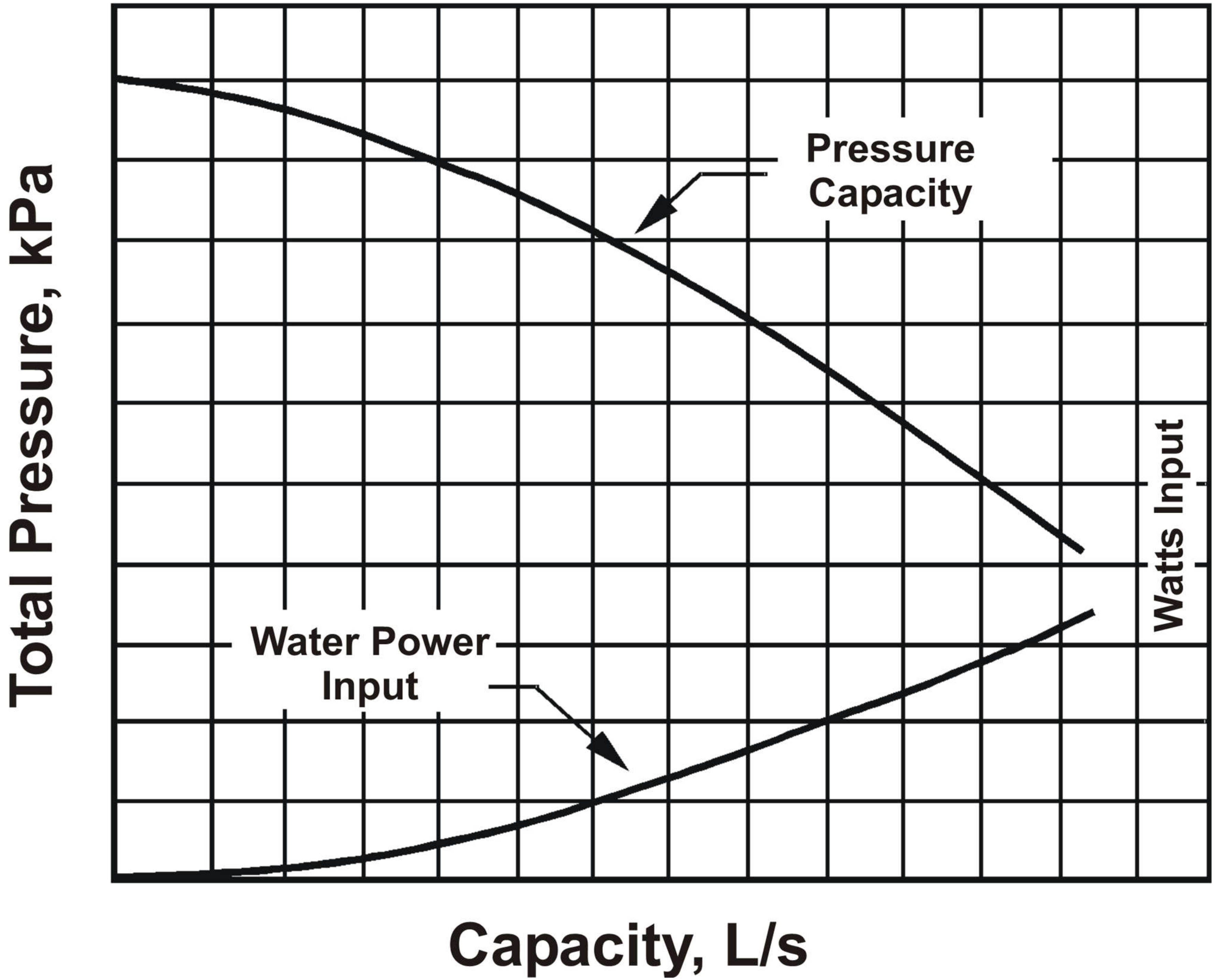
- System pressure characteristic curve
  - Compared w/: fan-duct system characteristics
  - System operating point: intersection of fan curve & system curve
- Pump power (W) = flow (L/s) x pressure (kPa)
  - Pump input power
  - Pump efficiency
    - Matching pump to system curve
    - Best efficiency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

Pump curve, system curve and point of operation



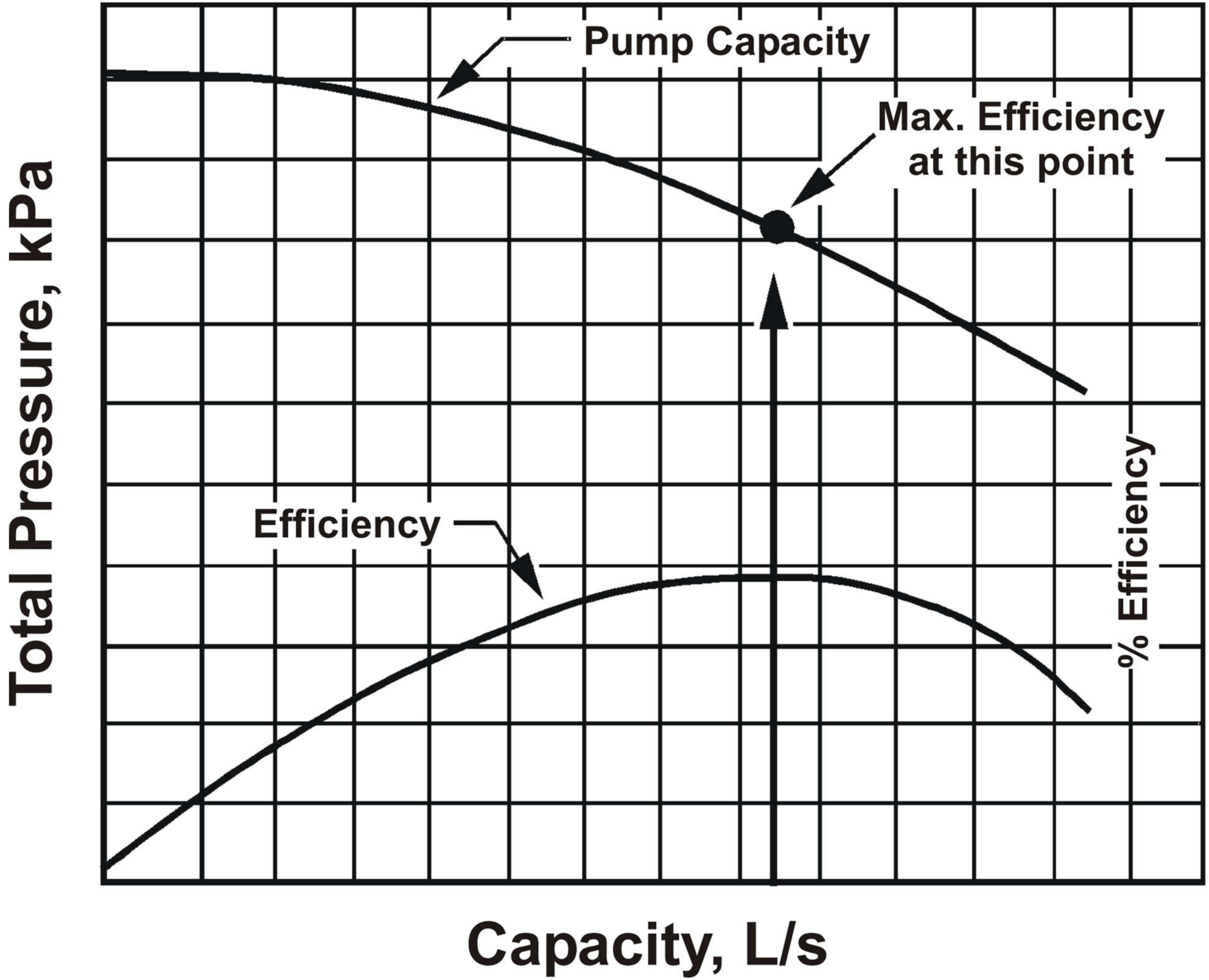
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Increase of pumping power required with pump flow



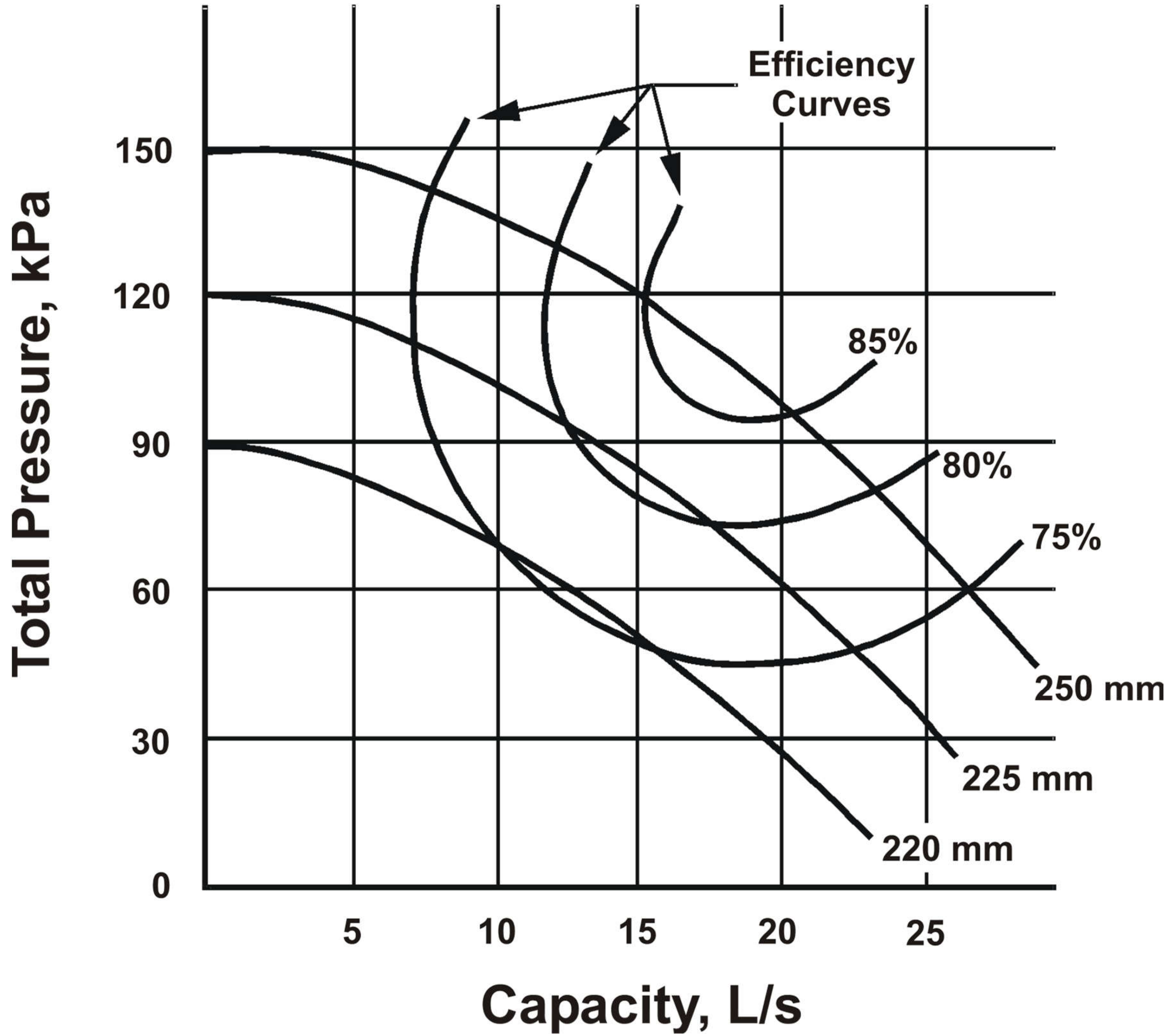
(Source: *Fundamentals of Water System Design*)

Pump efficiency



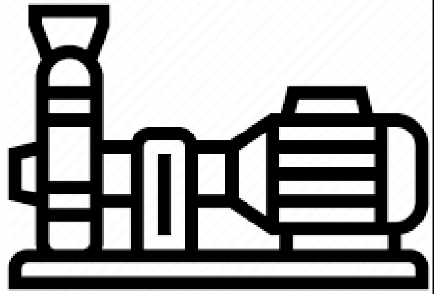
(Source: *Fundamentals of Water System Design*)

Pump efficiency curves



(Source: *Fundamentals of Water System Design*)

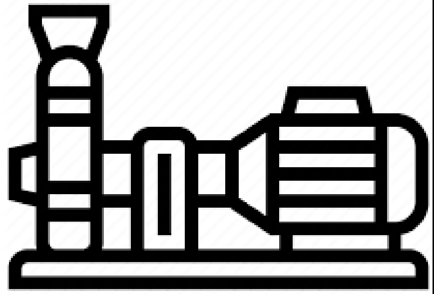
Pump Characteristics



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

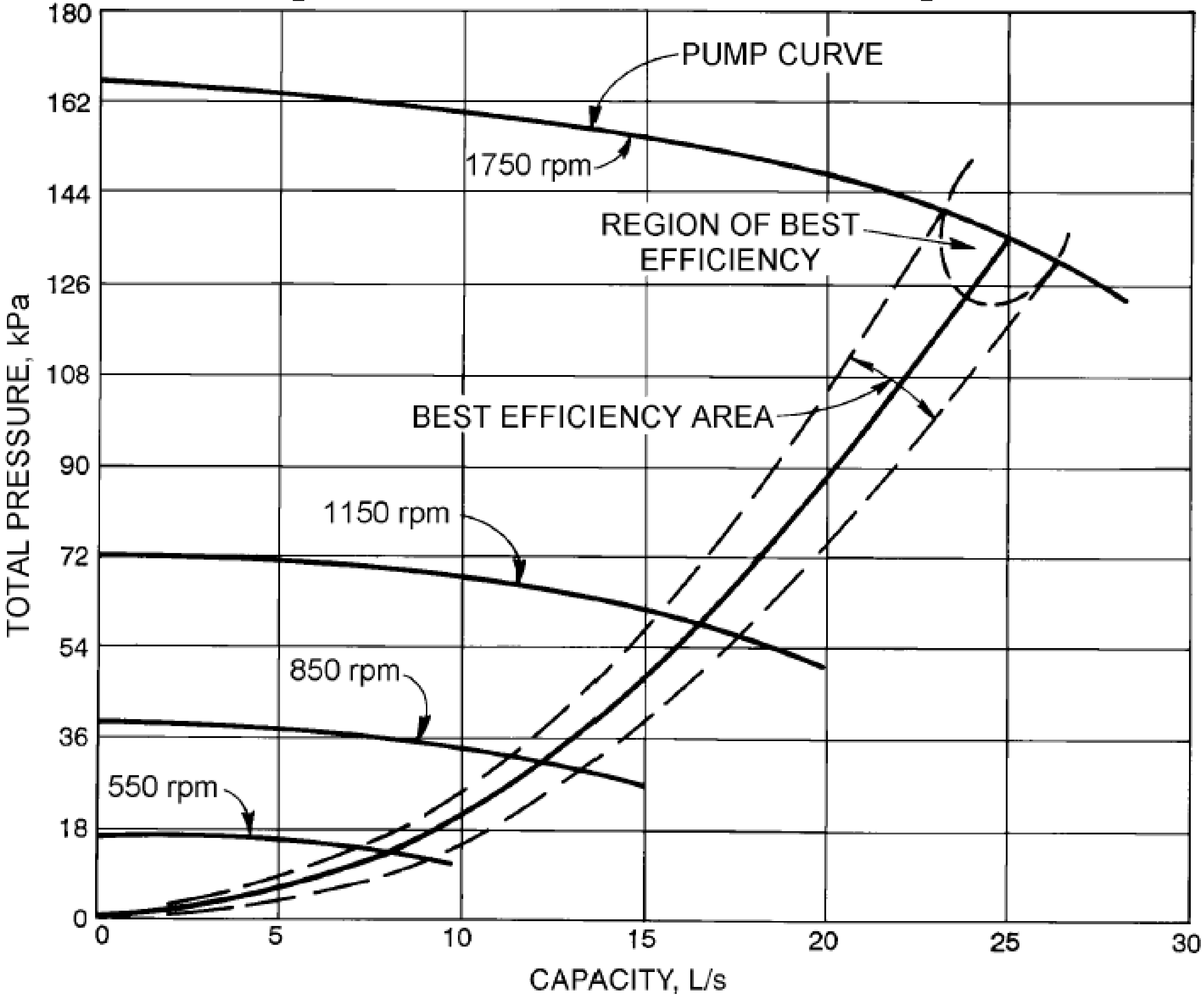
Function	Speed change	Impeller diameter change
Flow	$Q_2 = Q_1\,(N_2/N_1)$	$Q_2 = Q_1\,(D_2/D_1)$
Pressure	$p_2 = p_1\,(N_2/N_1)^2$	$p_2 = p_1\,(D_2/D_1)^2$
Power	$P_2 = P_1\,(N_2/N_1)^3$	$P_2 = P_1\,(D_2/D_1)^3$

Pump Characteristics



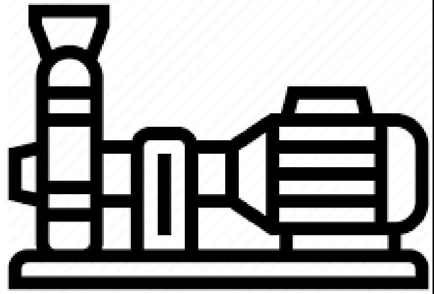
- Pump affinity laws (example)
  - A pump is rated at 15 L/s at 200 kPa with a 24 rpm electric motor. What is the flow and pressure if used with a 16 rps motor? Assume no system static pressure.
  - Solution:
    - Flow: $Q_2 = Q_1\ (N_2/N_1) = 15\ (16/24) = \underline{10\ \text{L/s}}$
    - Pressure: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

Pump curve variation with rotation speed

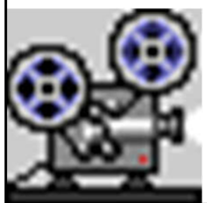


(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Pump Characteristics

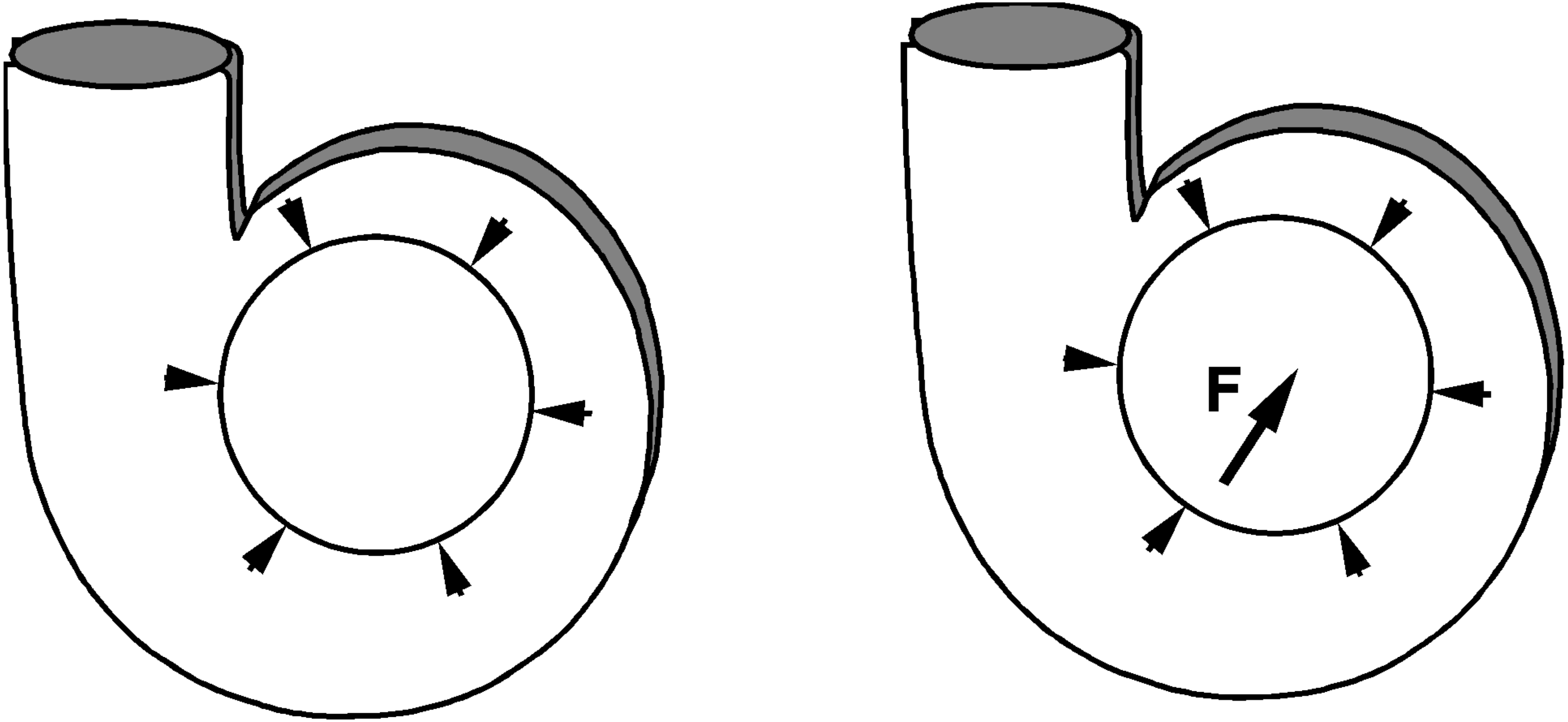


- Radial thrust
  - Non-uniform pressure around impeller
  - Greatest at shutoff
  - Decreases from shutoff to design capacity
  - Increase with overcapacity
- Net positive suction (NPS)
  - Cavitation: vapour pockets form in impeller passages & may cause damages*
  - Net positive suction required (NPSR)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



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

Pressures on impeller causing radial thrust

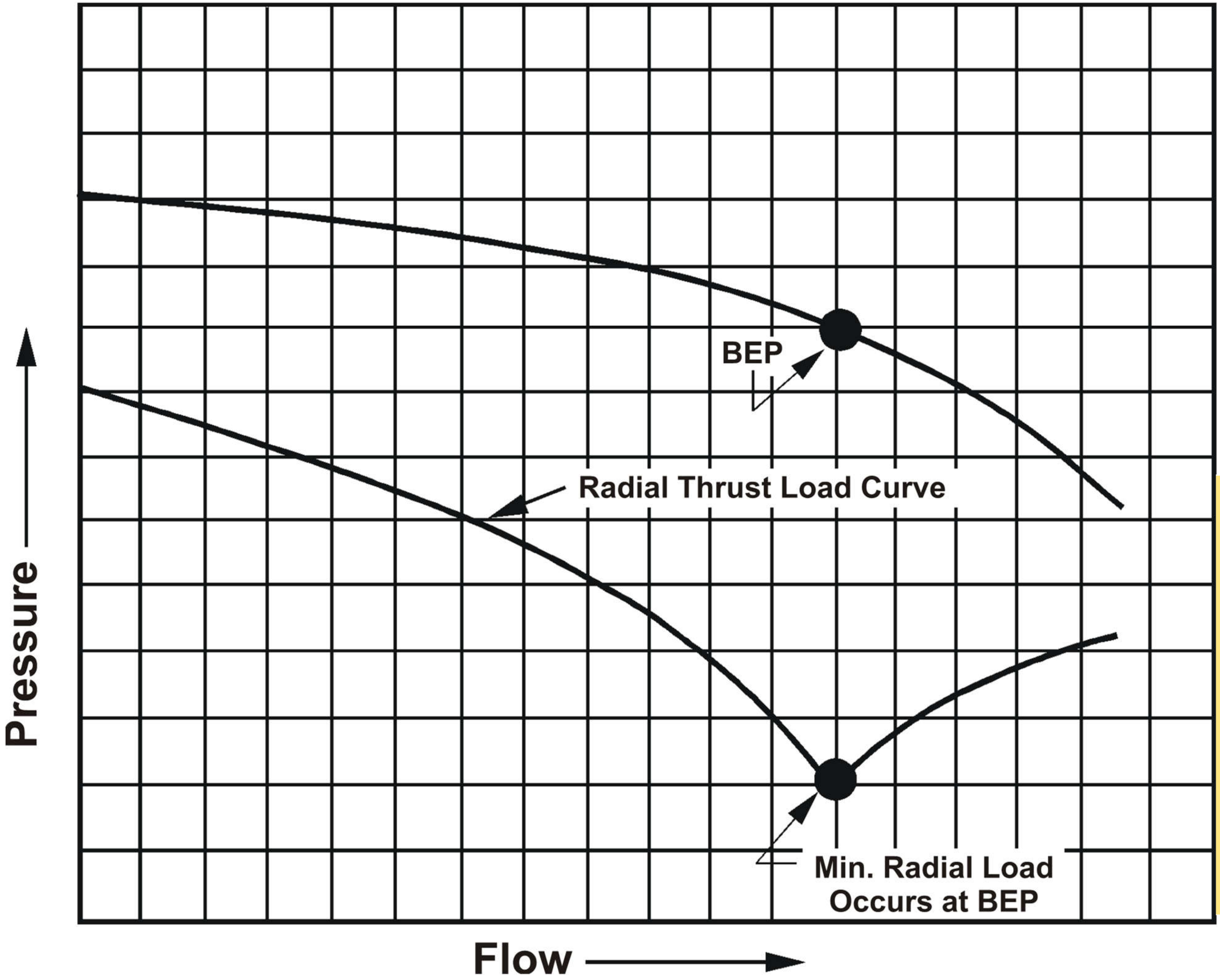


Uniform Pressures Exist at Design Capacity

Non-Uniform Pressures Exist at Reduced Capacities

(Source: *Fundamentals of Water System Design*)

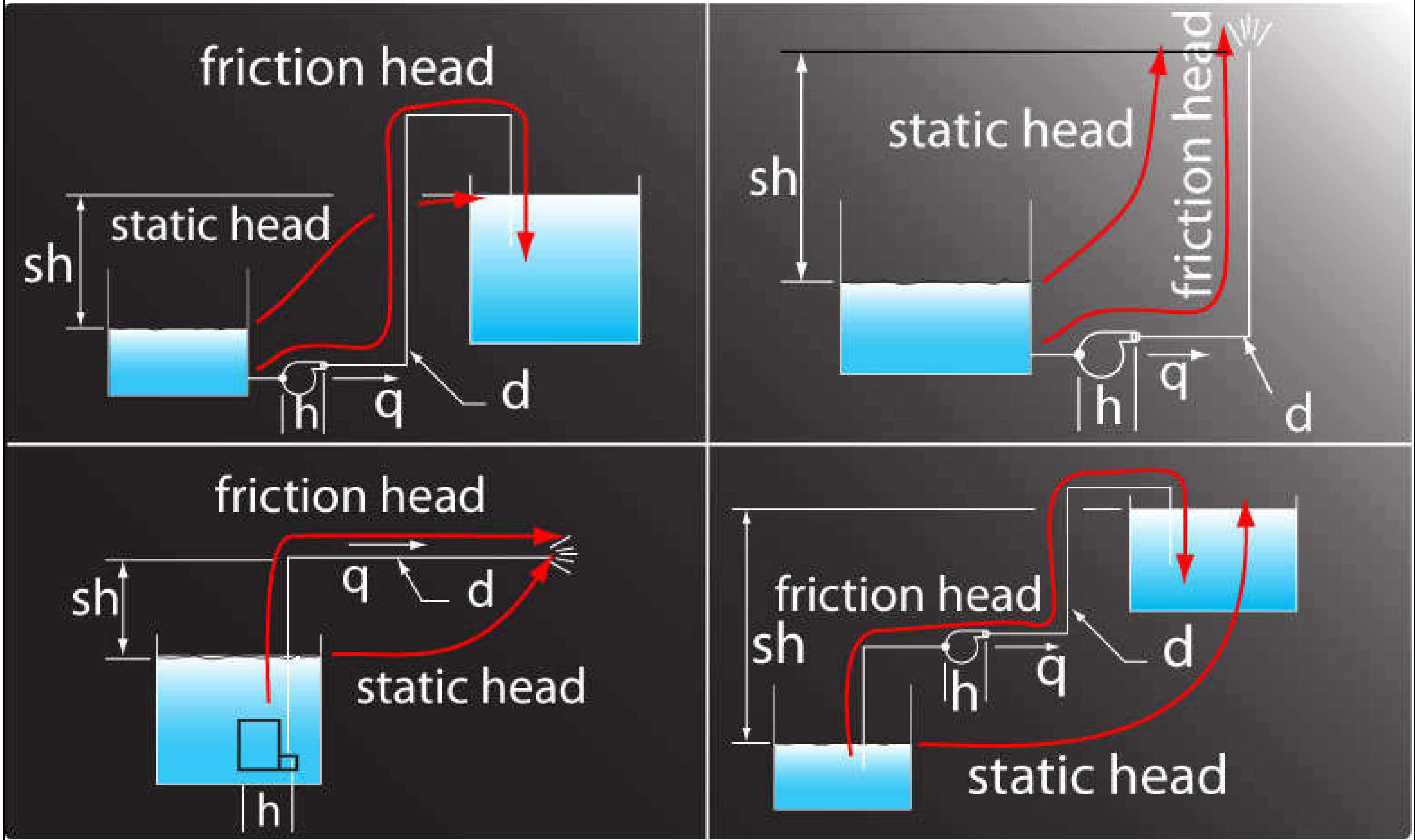
Change in radial thrust versus pumping rate



How radial thrust affects pump efficiency ?

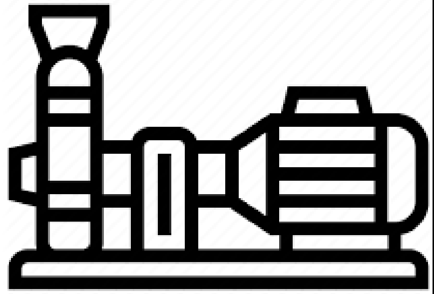
(Source: *Fundamentals of Water System Design*)

Pump head calculation



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

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

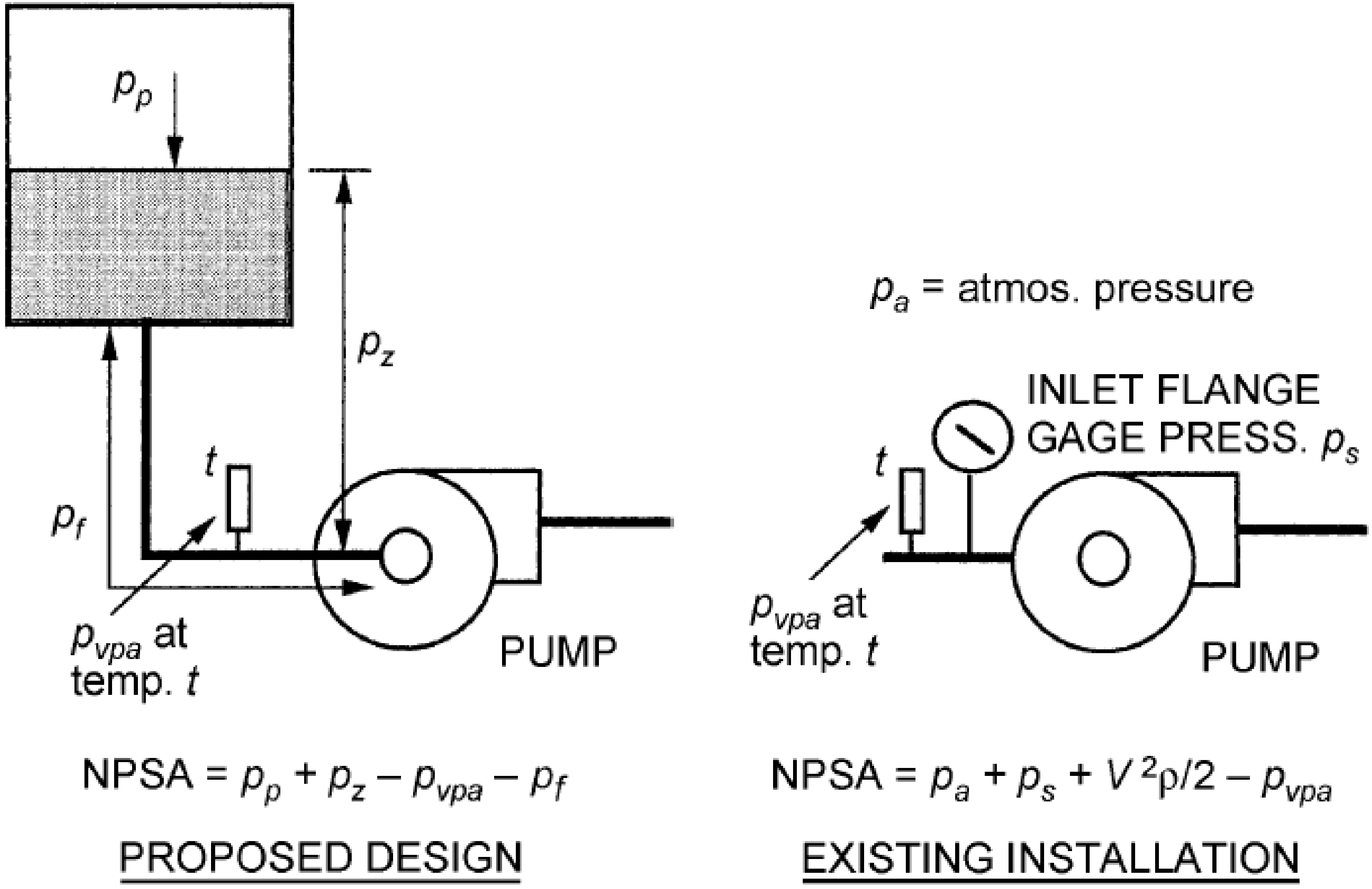
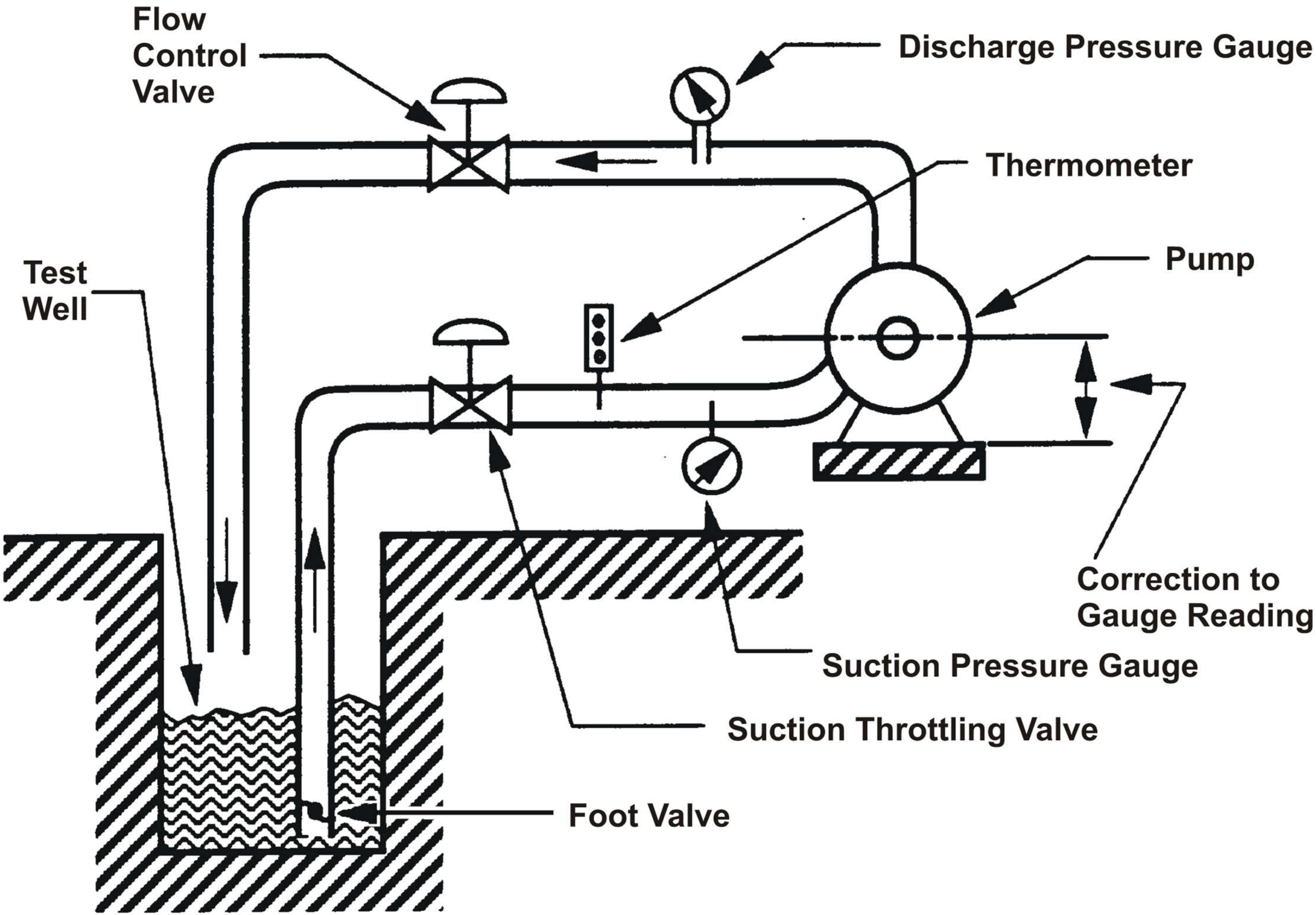


Fig. 29 Net Positive Suction Pressure Available

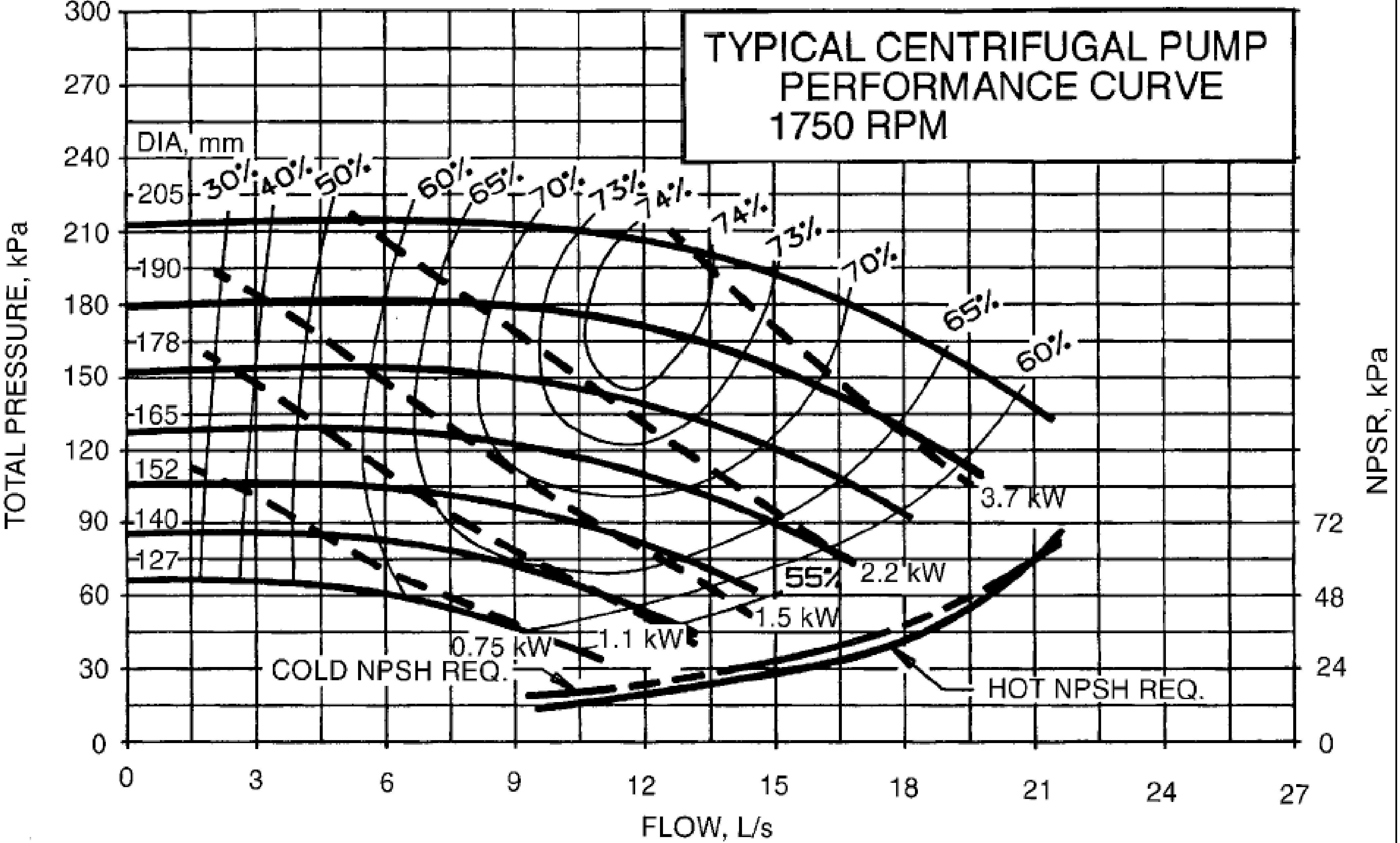
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Test setup to determine pump's NPSR



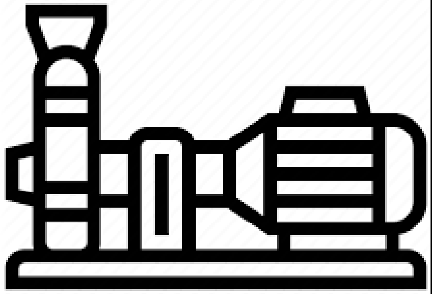
(Source: *Fundamentals of Water System Design*)

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



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

Pump Characteristics

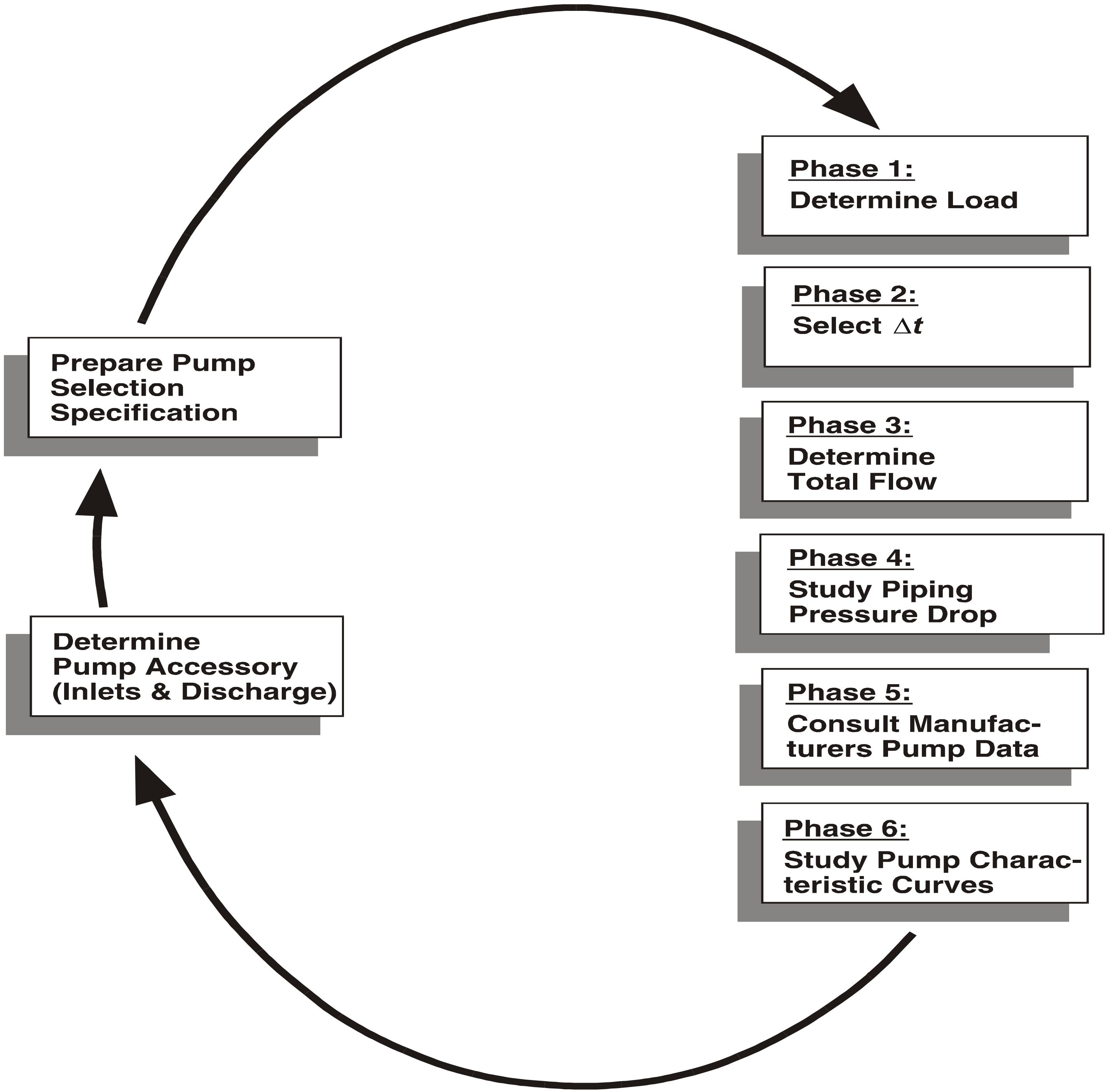


- Videos for illustration & learning:
  - Centrifugal Pump Basics - How centrifugal pumps work working principle hvacr (10:35) https://youtu.be/XpcCUtYzwy0
  - Pump Chart Basics Explained - Pump curve HVACR (13:04) https://youtu.be/U8iWNaDuUek
  - Critical Pump Selection - Three Major Issues (20:25)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

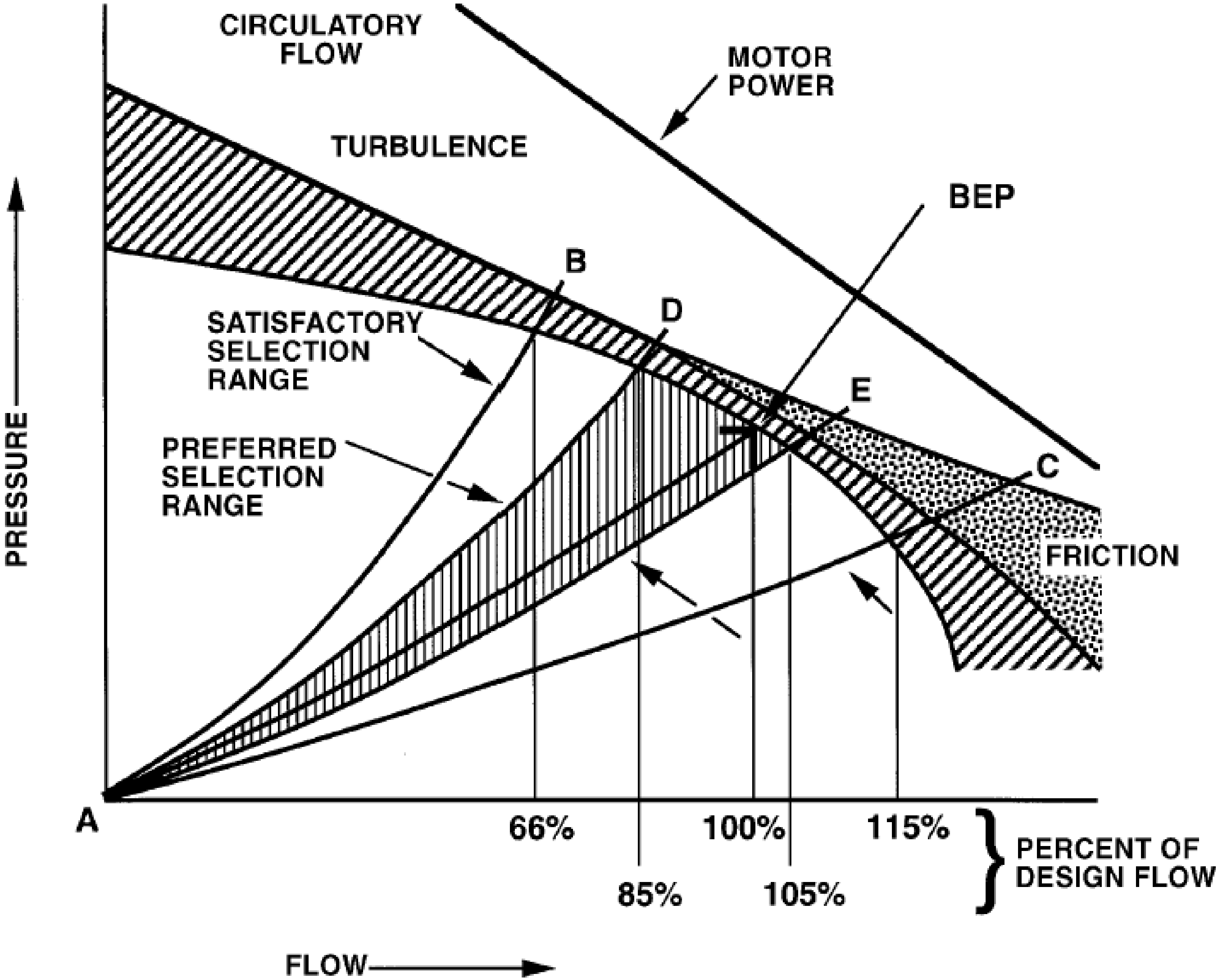


(Source: *Fundamentals of Water System Design*)

Pump Arrangements

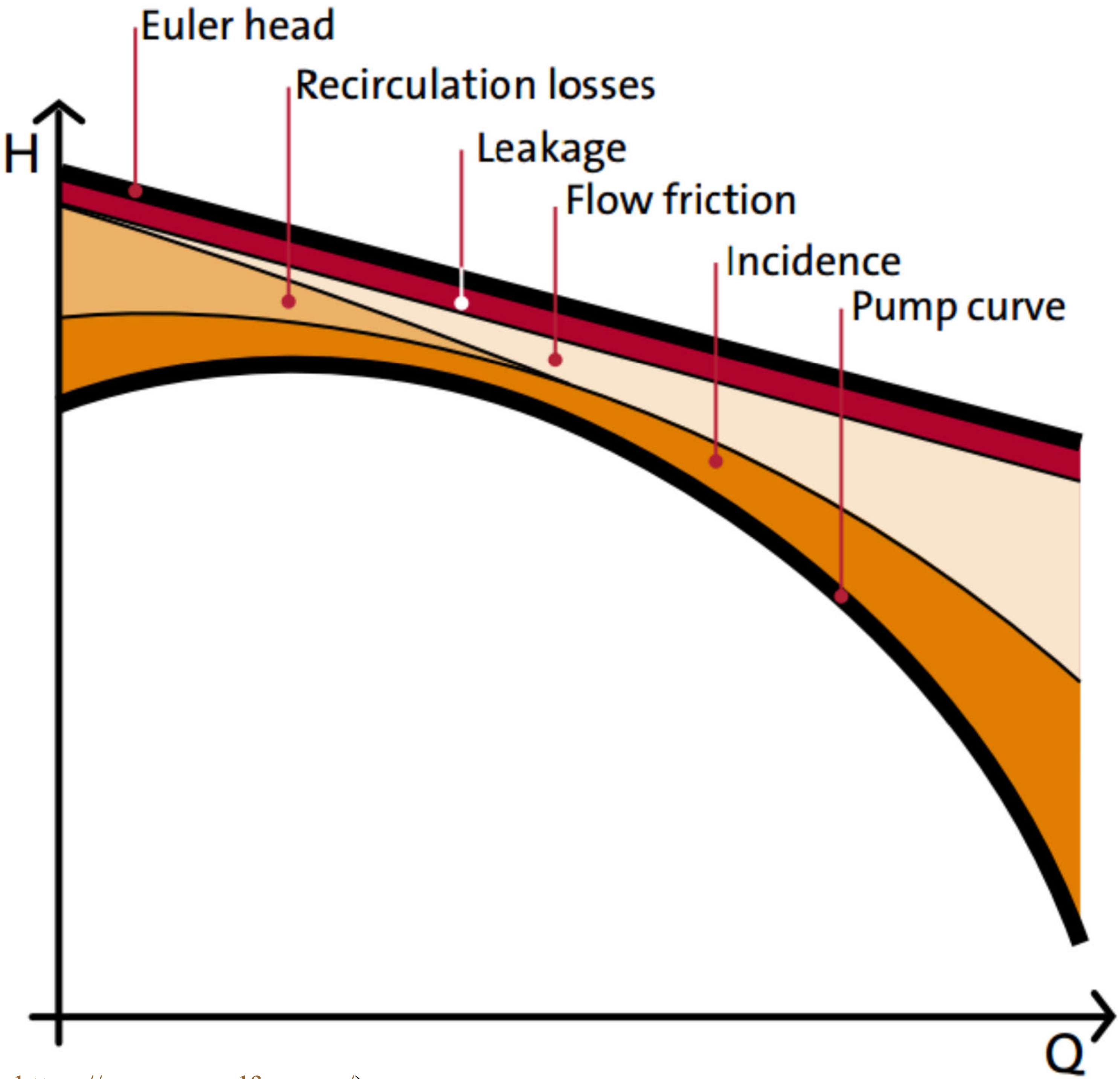
- Pump selection process
  - Determine the load to be pumped
  - Determine design Δt & calculate required flow
  - Sum up the load flows to determine total flow
  - Determine the “critical path” (most resistant)
  - Determine mounting method & support
  - Select a pump from manufacturer
    - Flat curve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

Pump selection factors and regions



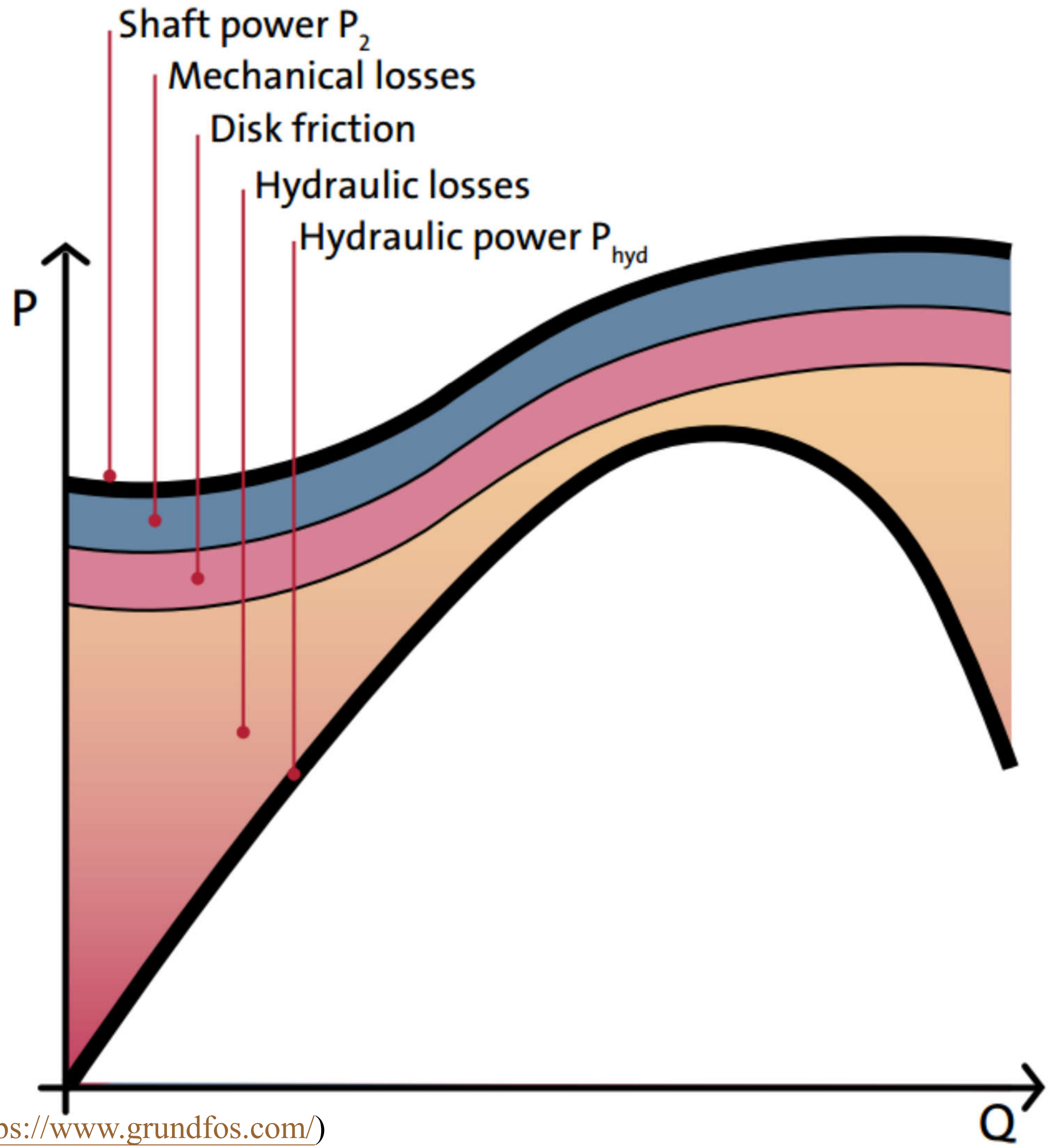
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Reduction of theoretical Euler head due to losses



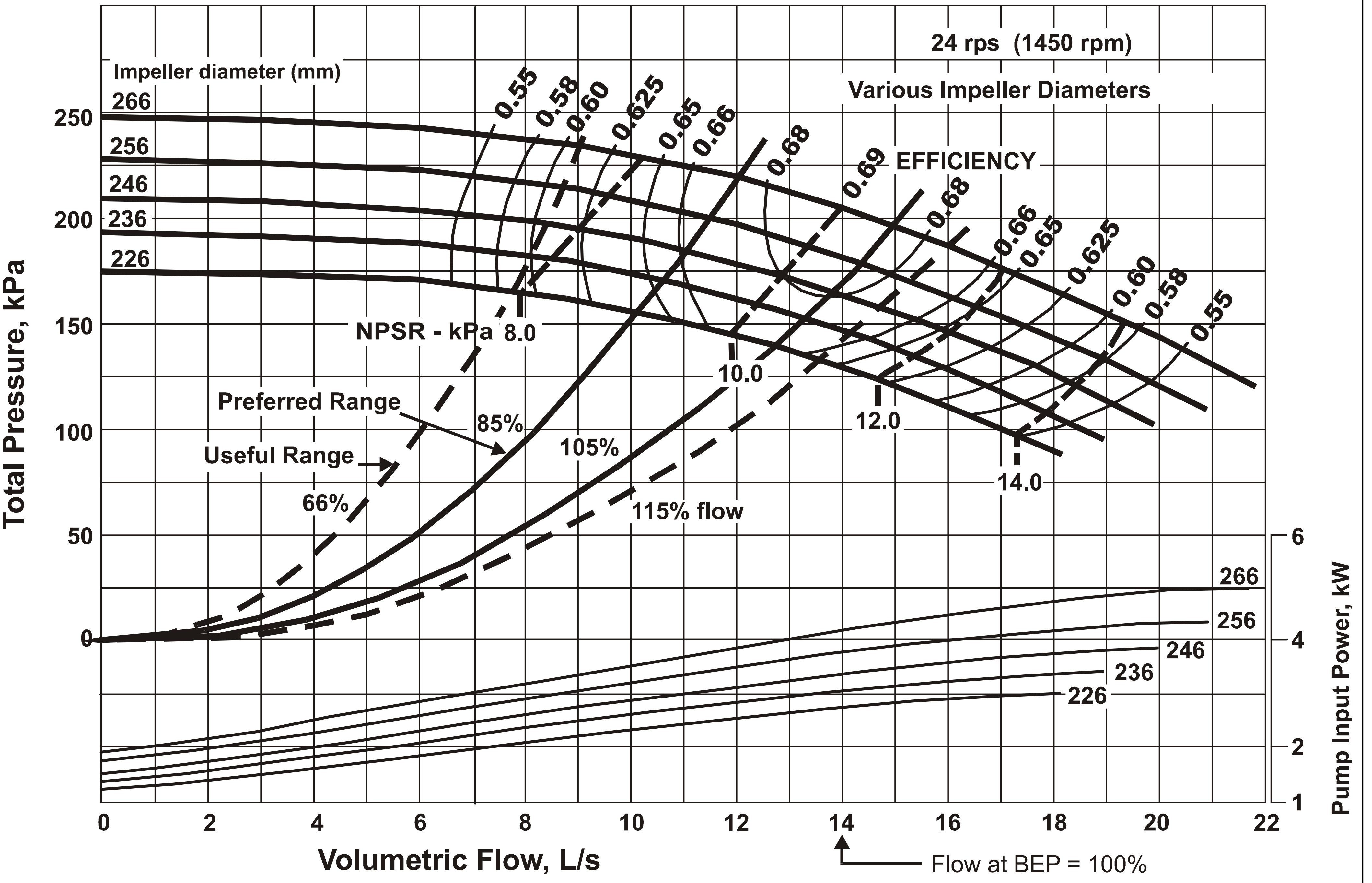
(Source: Grundfos https://www.grundfos.com/)

Increase in power consumption due to losses



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

Pump performance data

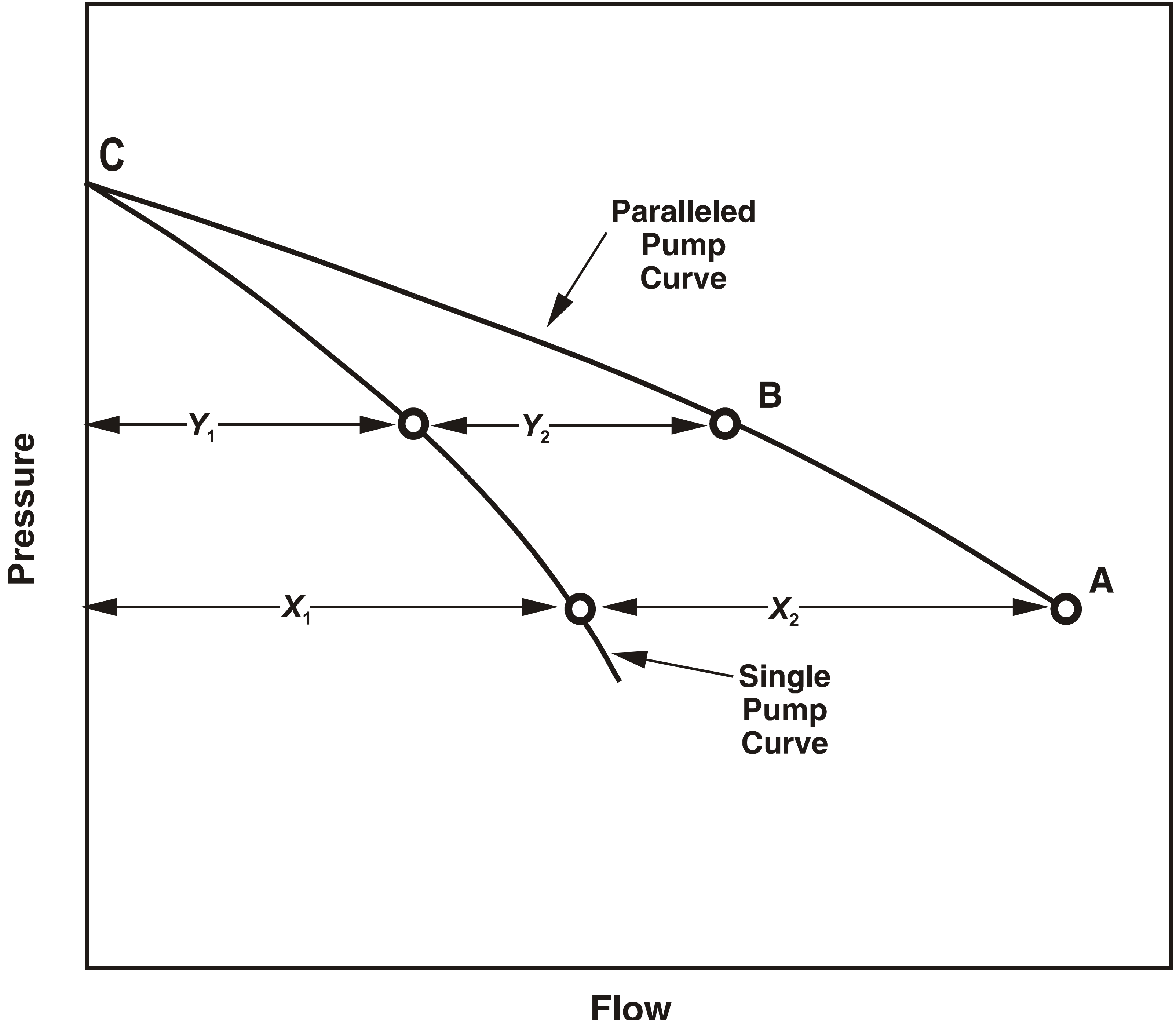


(Source: *Fundamentals of Water System Design*)

Pump Arrangements

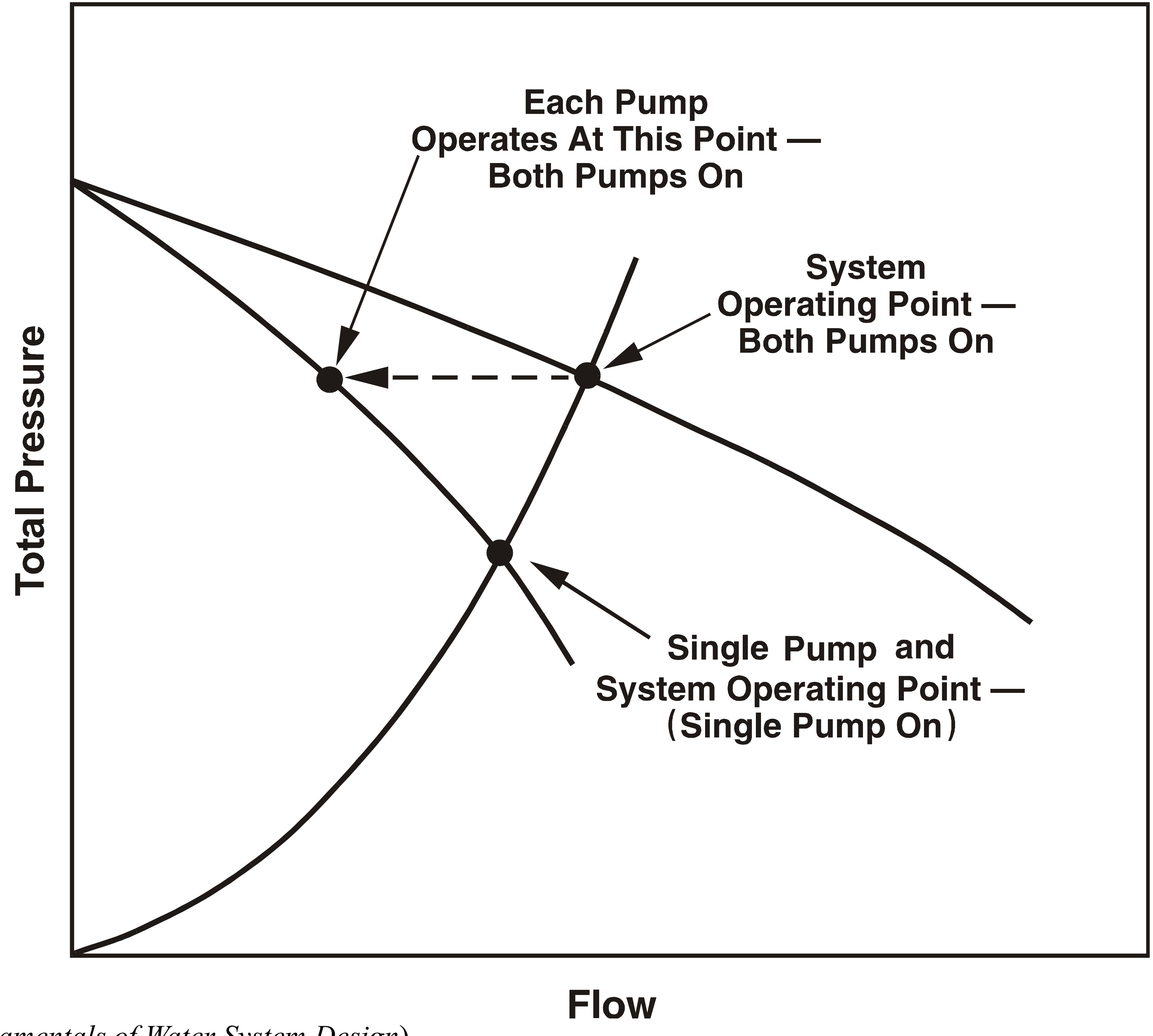
- Pumping arrangements & control scenarios
  - Multiple pumps in parallel or series
  - Standby pump
  - Pumps with two-speed motors
  - Primary-secondary pumping
  - Variable-speed pumping
  - Distributed pumping

Pump curve for parallel operation



(Source: *Fundamentals of Water System Design*)

Operating conditions for parallel pump installation



(Source: *Fundamentals of Water System Design*)

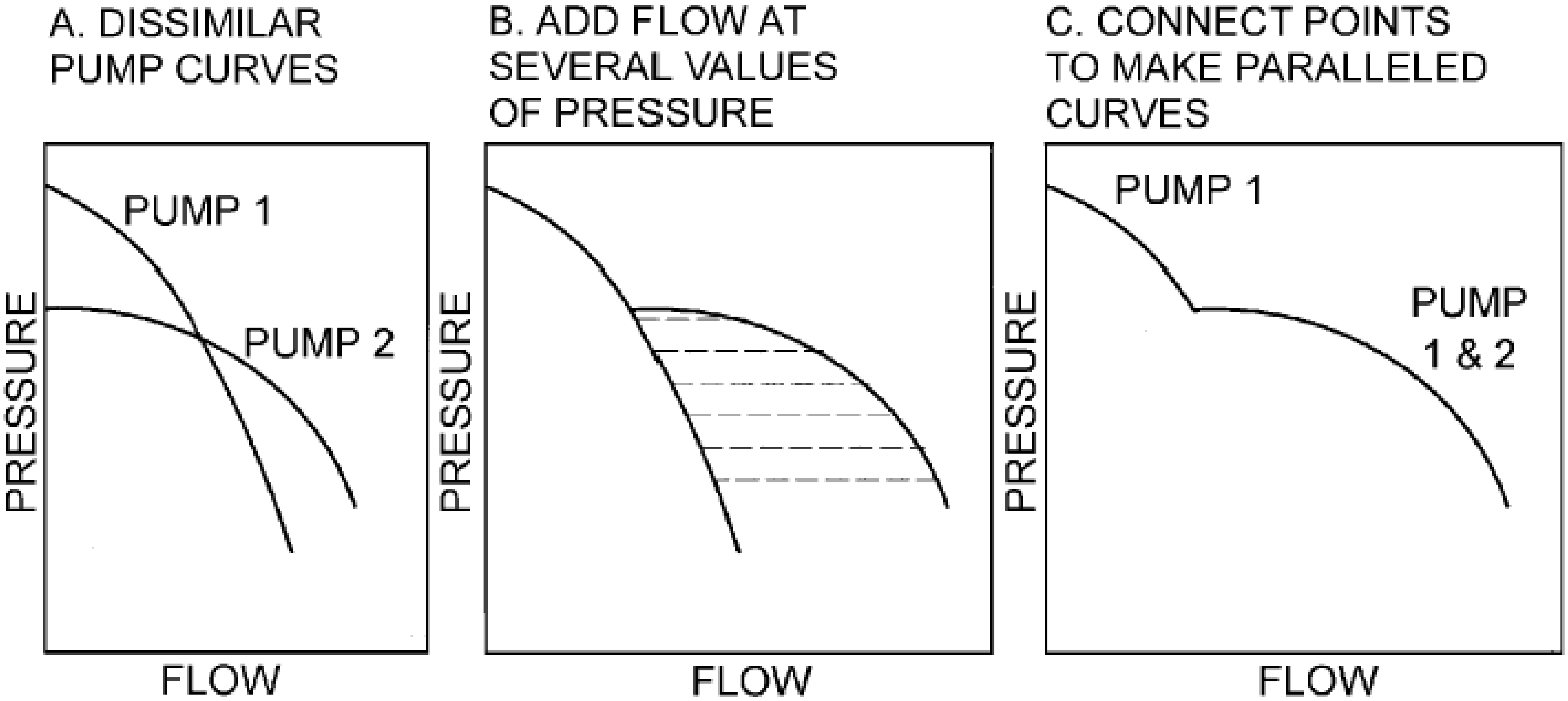


Fig. 34 Construction of Curve for Dissimilar Parallel Pumps

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

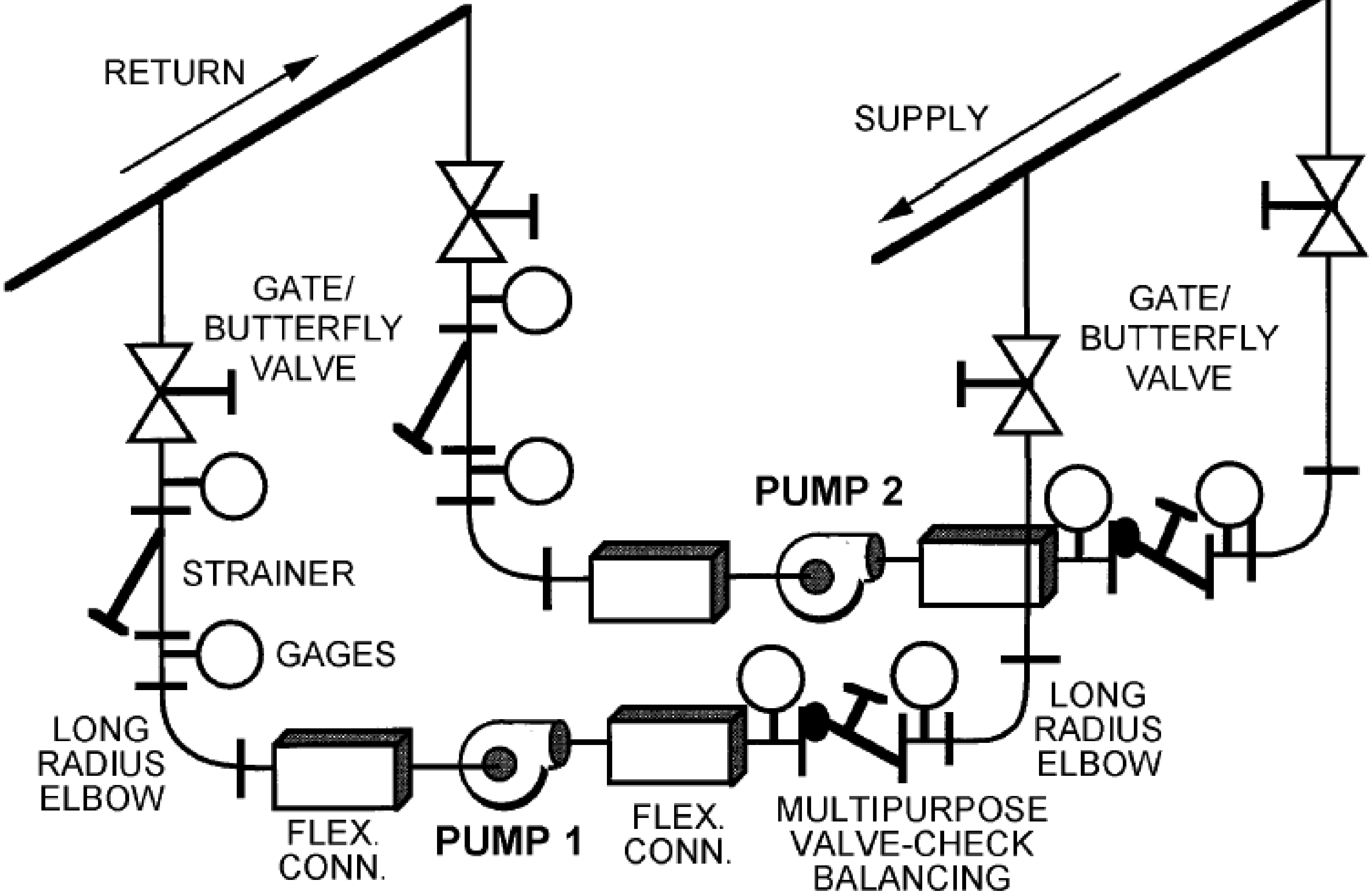
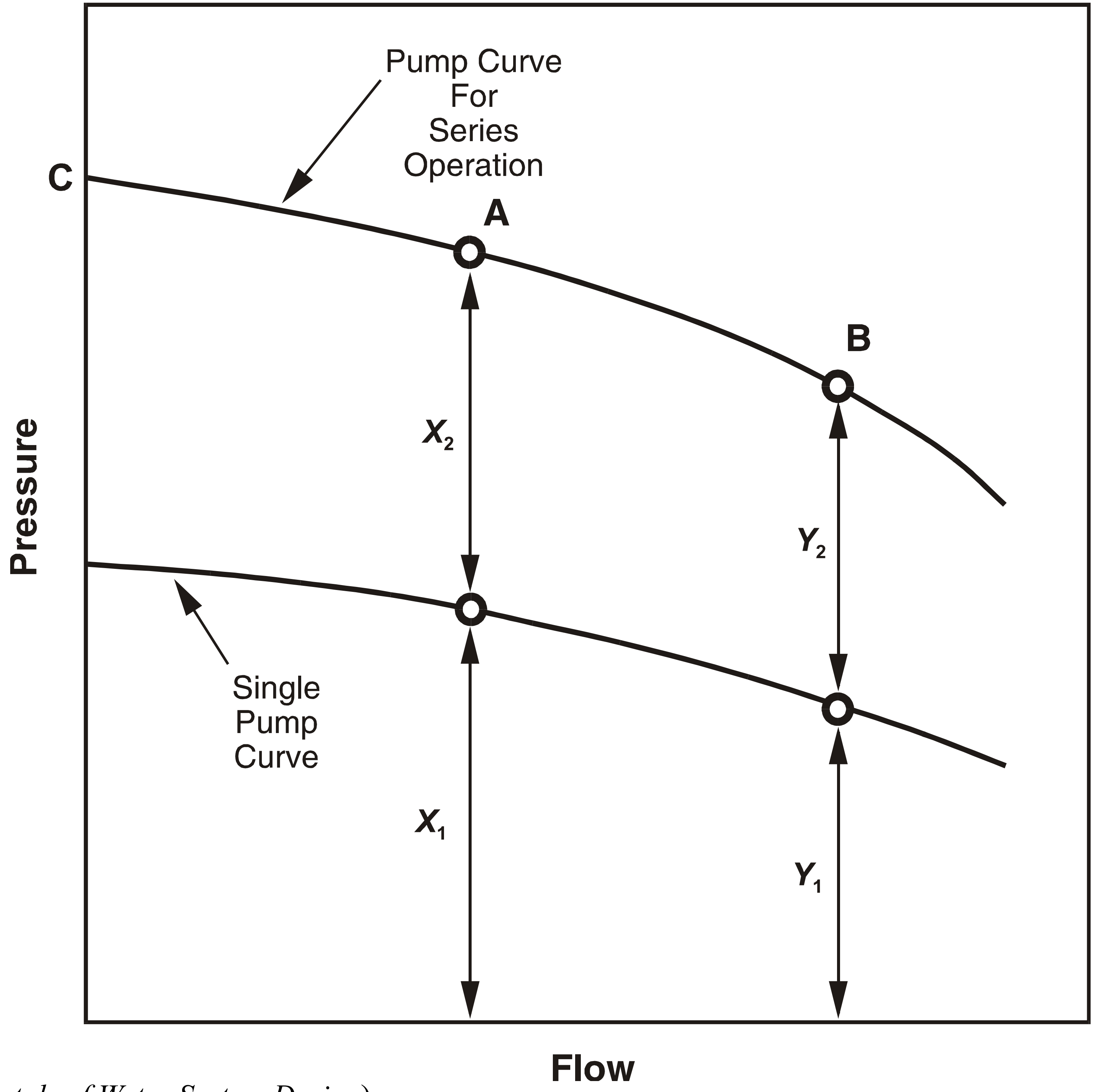


Fig. 35 Typical Piping for Parallel Pumps

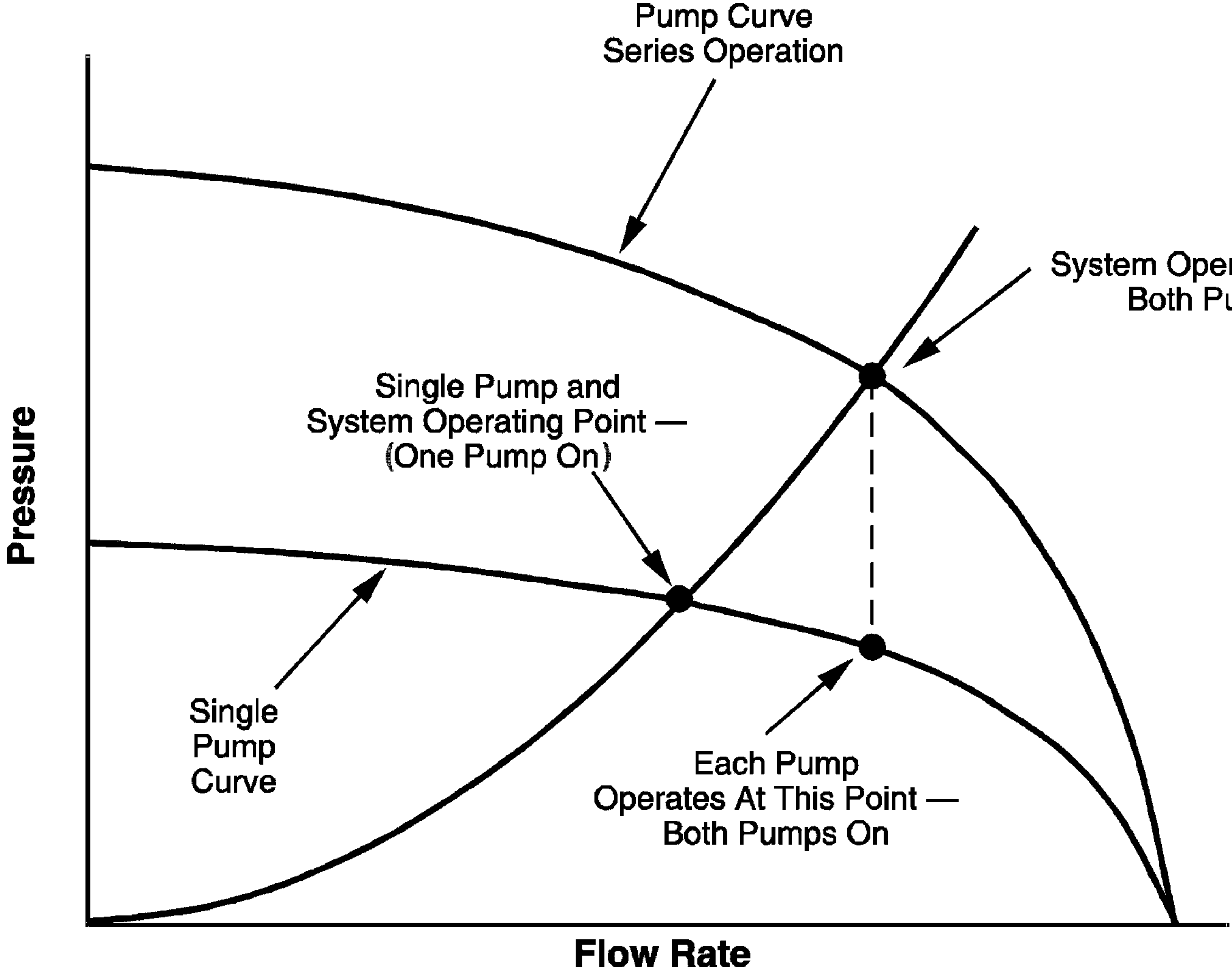
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Pump curve for series operation



(Source: *Fundamentals of Water System Design*)

Operating conditions for series pump



(Source: *Fundamentals of Water System Design*)

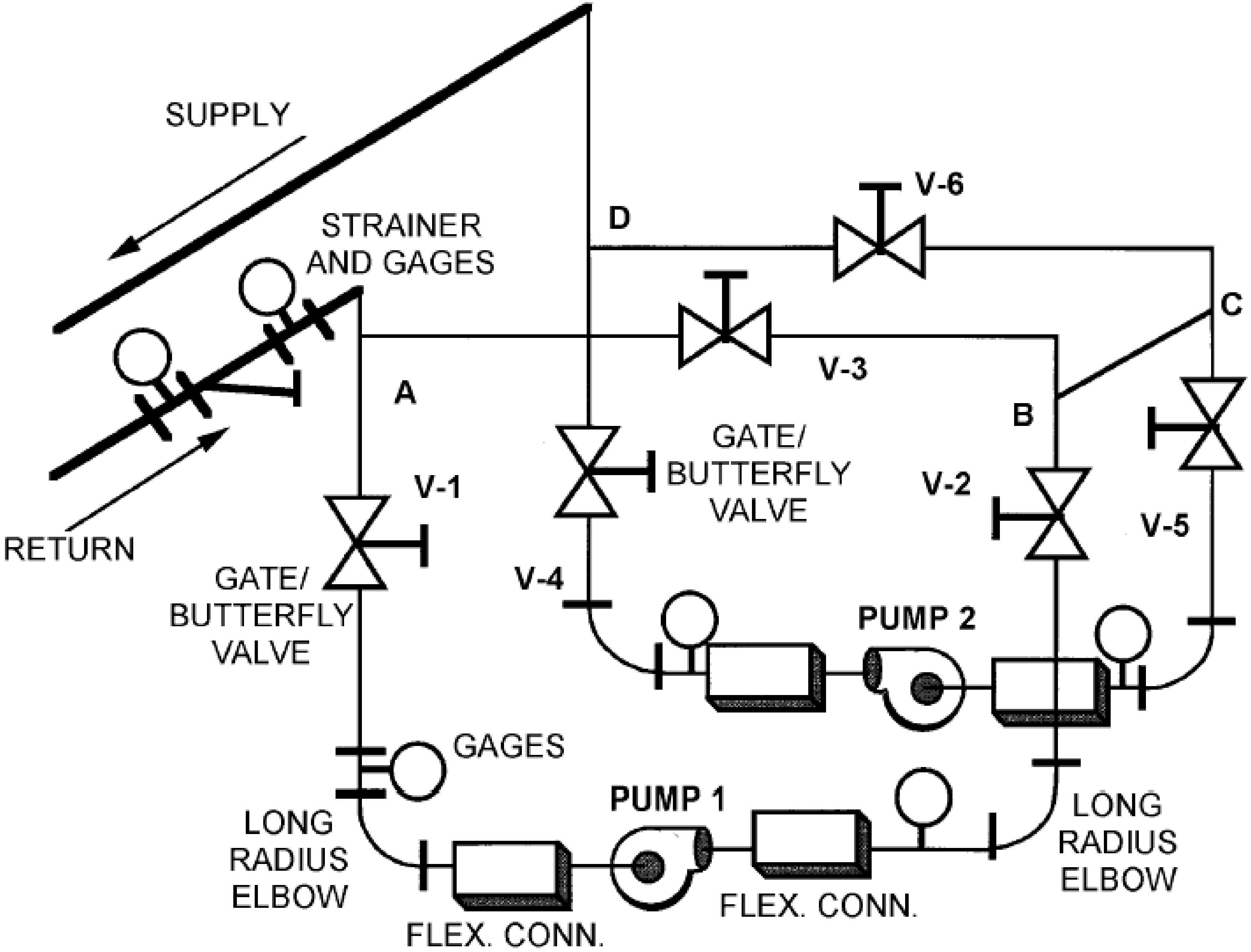


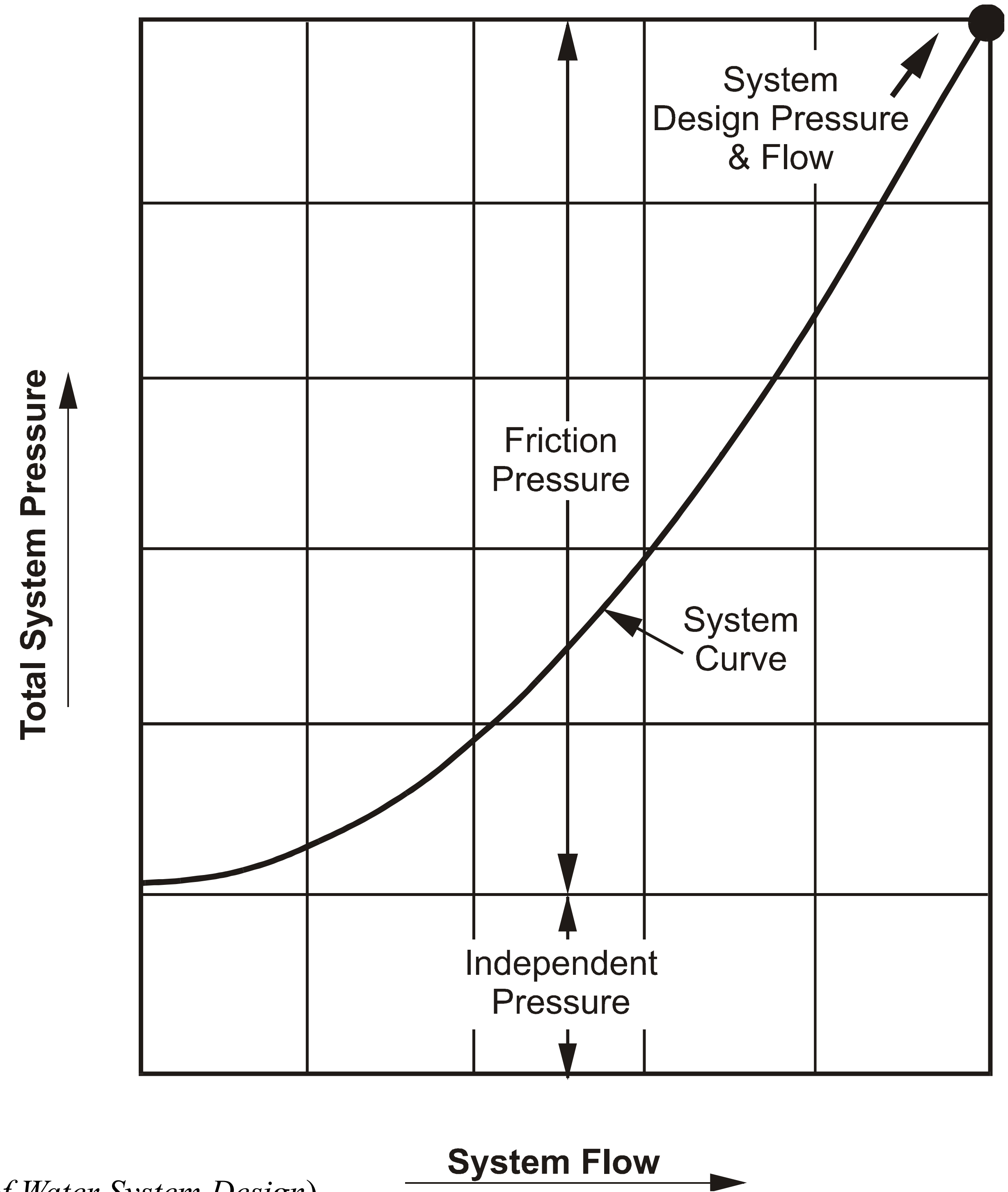
Fig. 38 Typical Piping for Series Pumps

(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

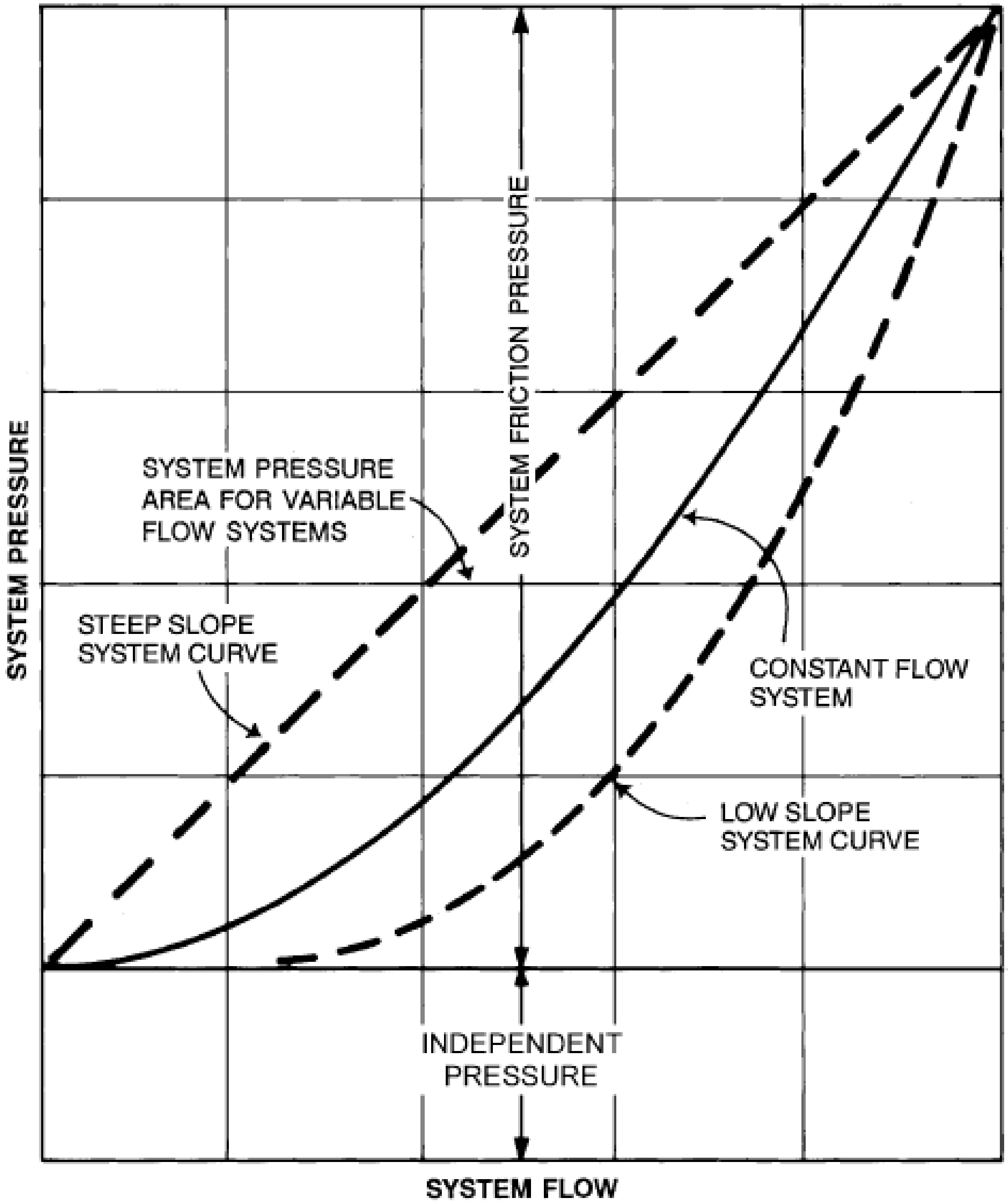
Typical system curve



(Source: *Fundamentals of Water System Design*)

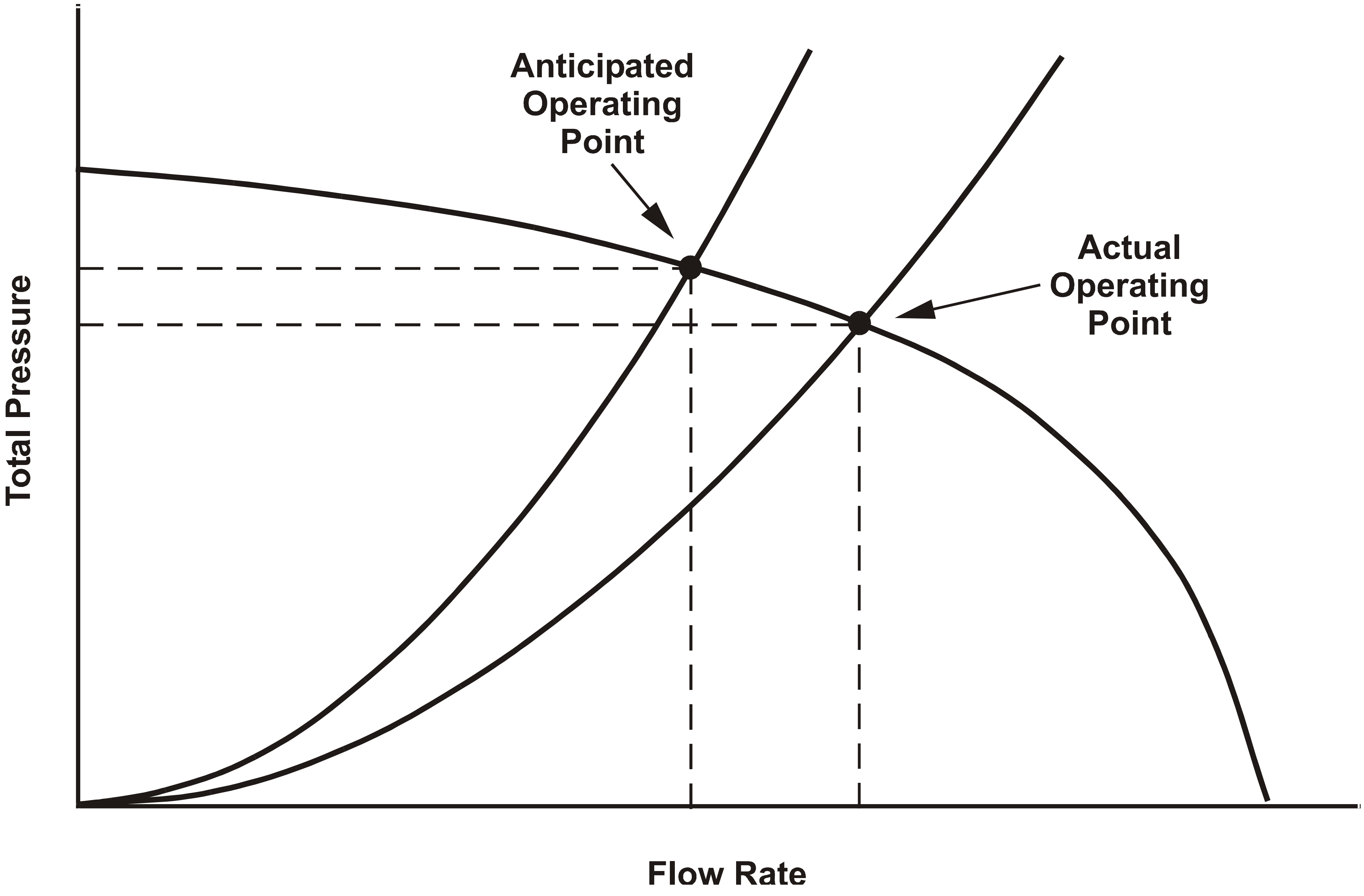
Different types of system curves

How to match the pumps to system curve?



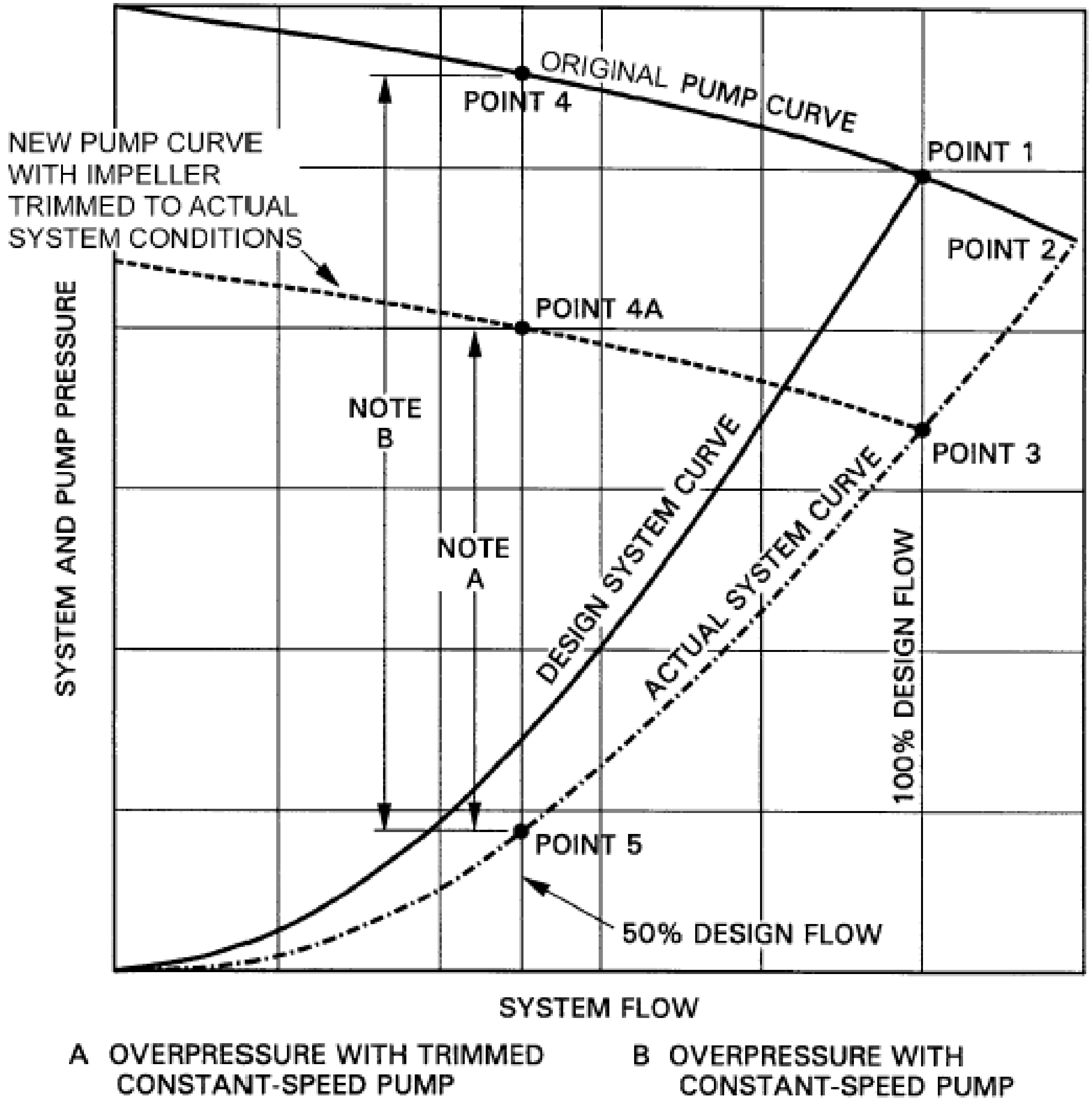
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Shift of system curves

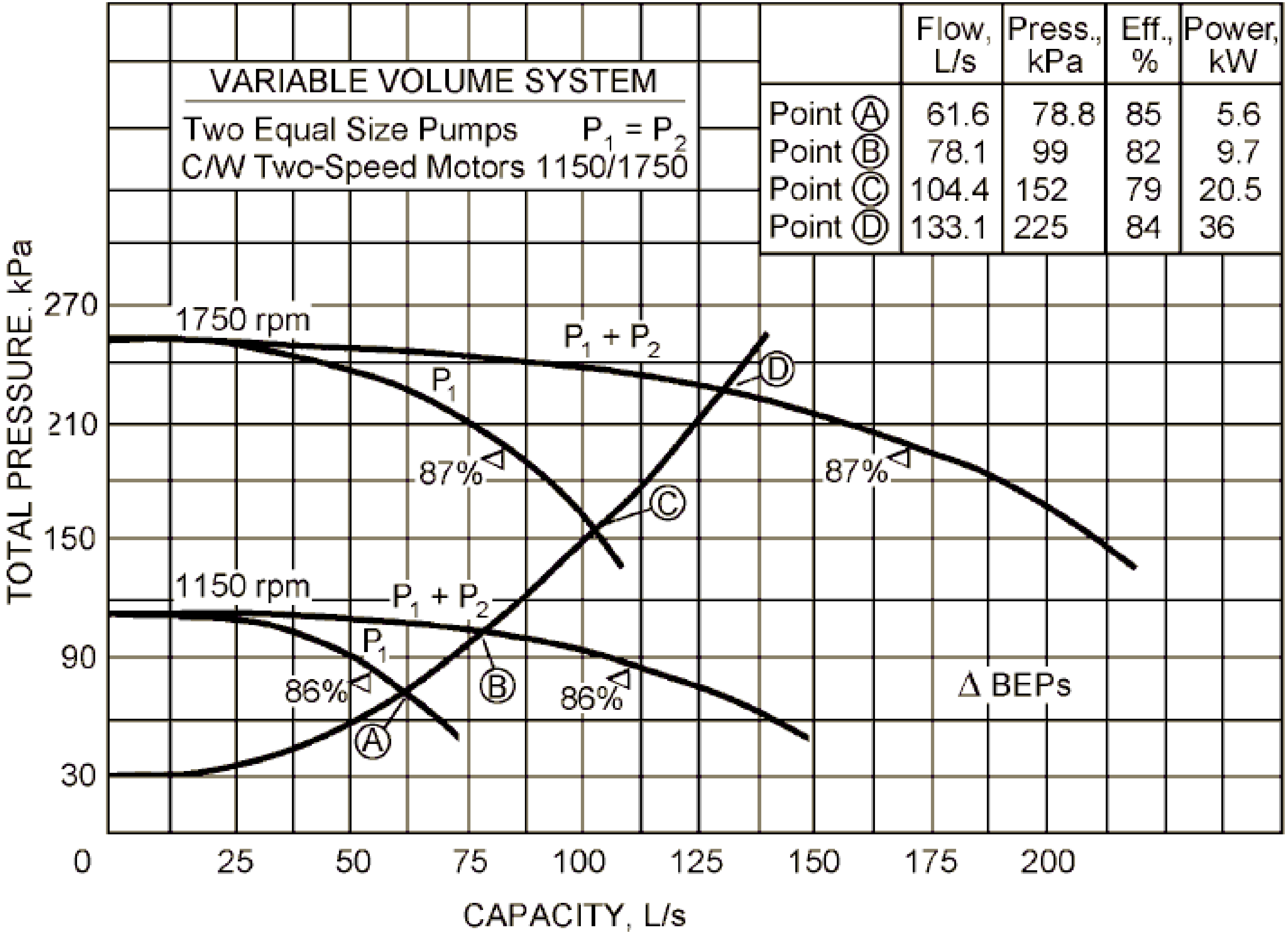


(Source: *Fundamentals of Water System Design*)

Characteristics of pump curve and system curve



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



	Flow, L/s	Press., kPa	Eff., %	Power, kW
Point Ⓐ	61.6	78.8	85	5.6
Point Ⓑ	78.1	99	82	9.7
Point Ⓒ	104.4	152	79	20.5
Point Ⓓ	133.1	225	84	36

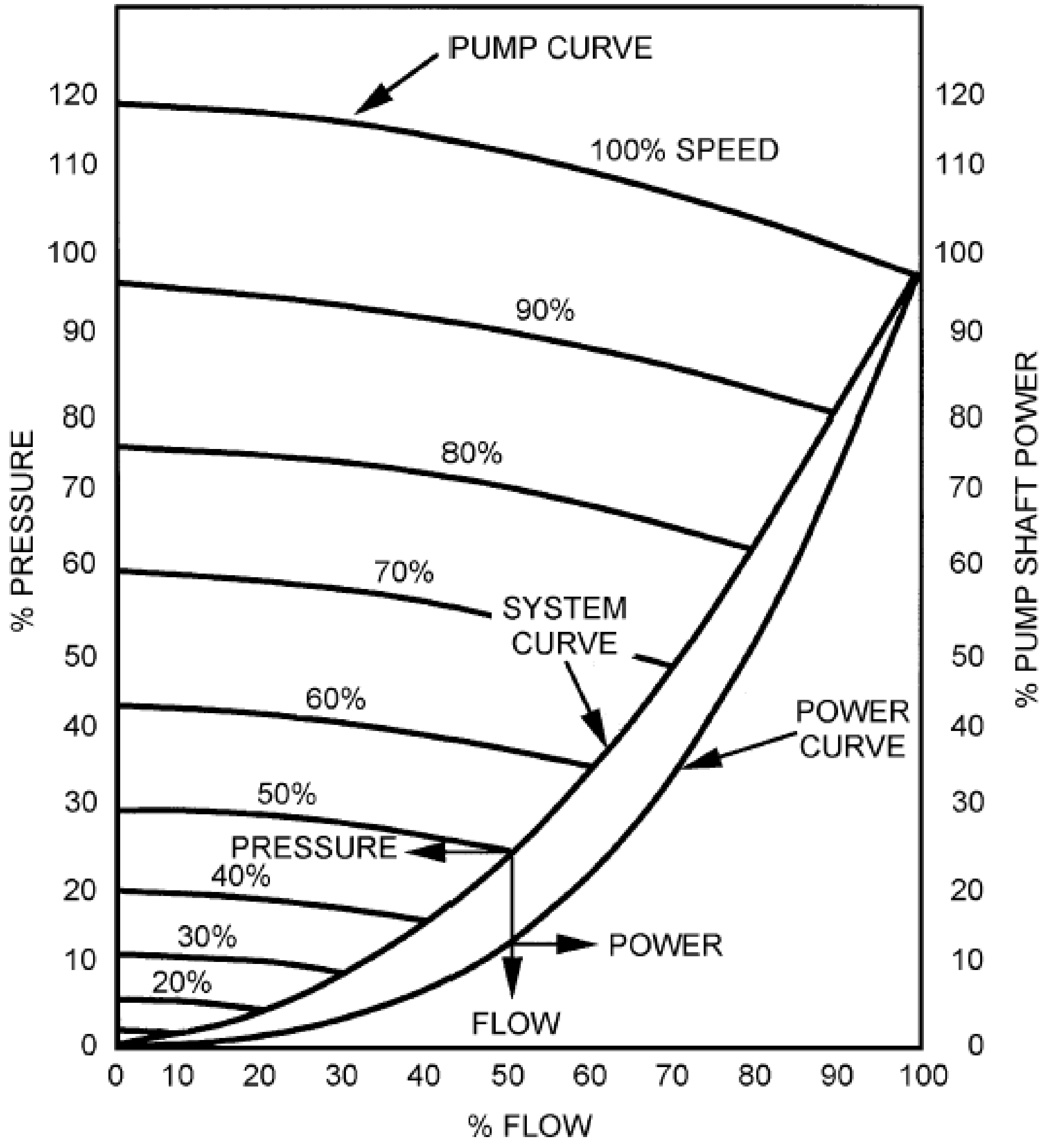
Fig. 39 Example of Two Parallel Pumps with Two-Speed Motors

(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

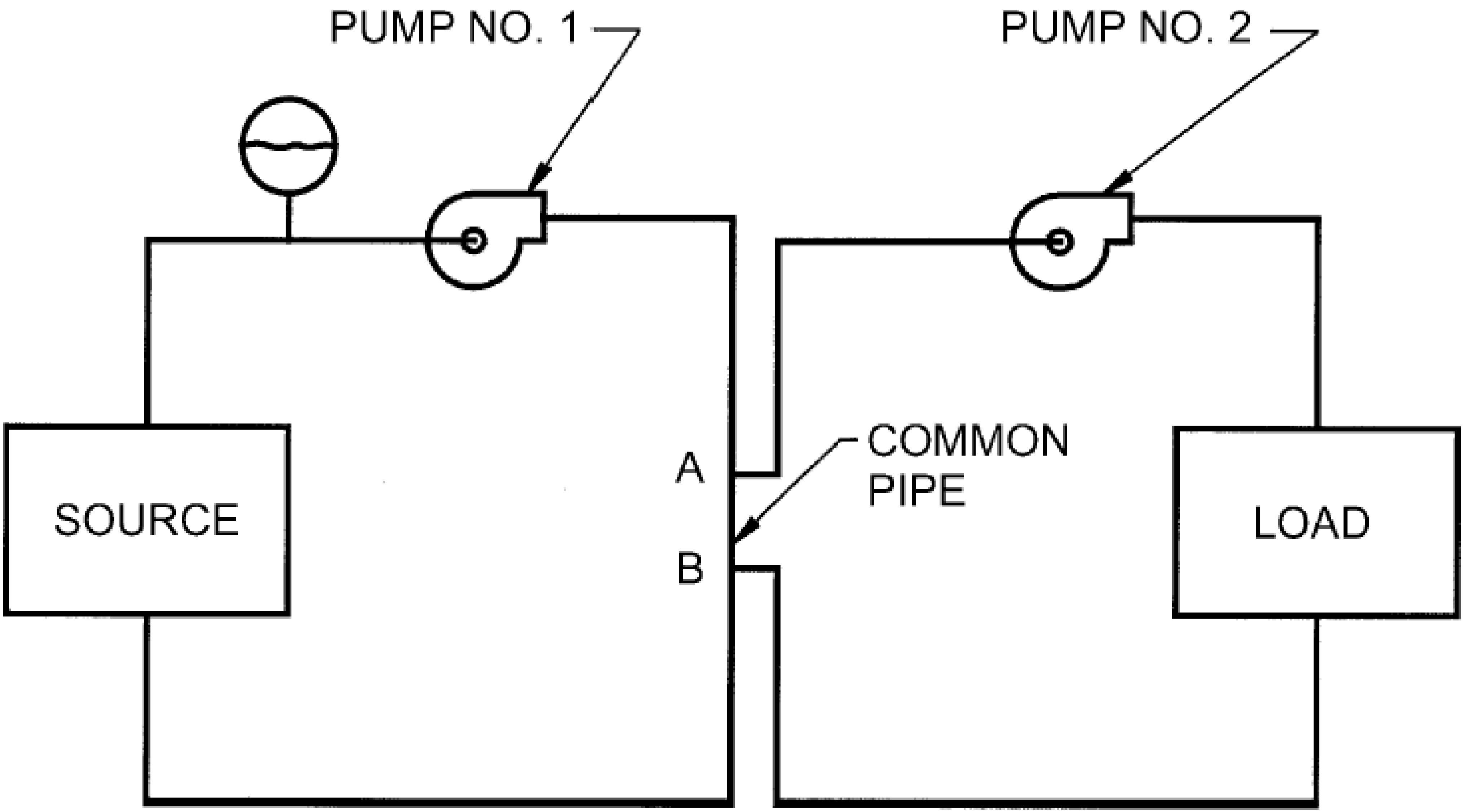


(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

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*)

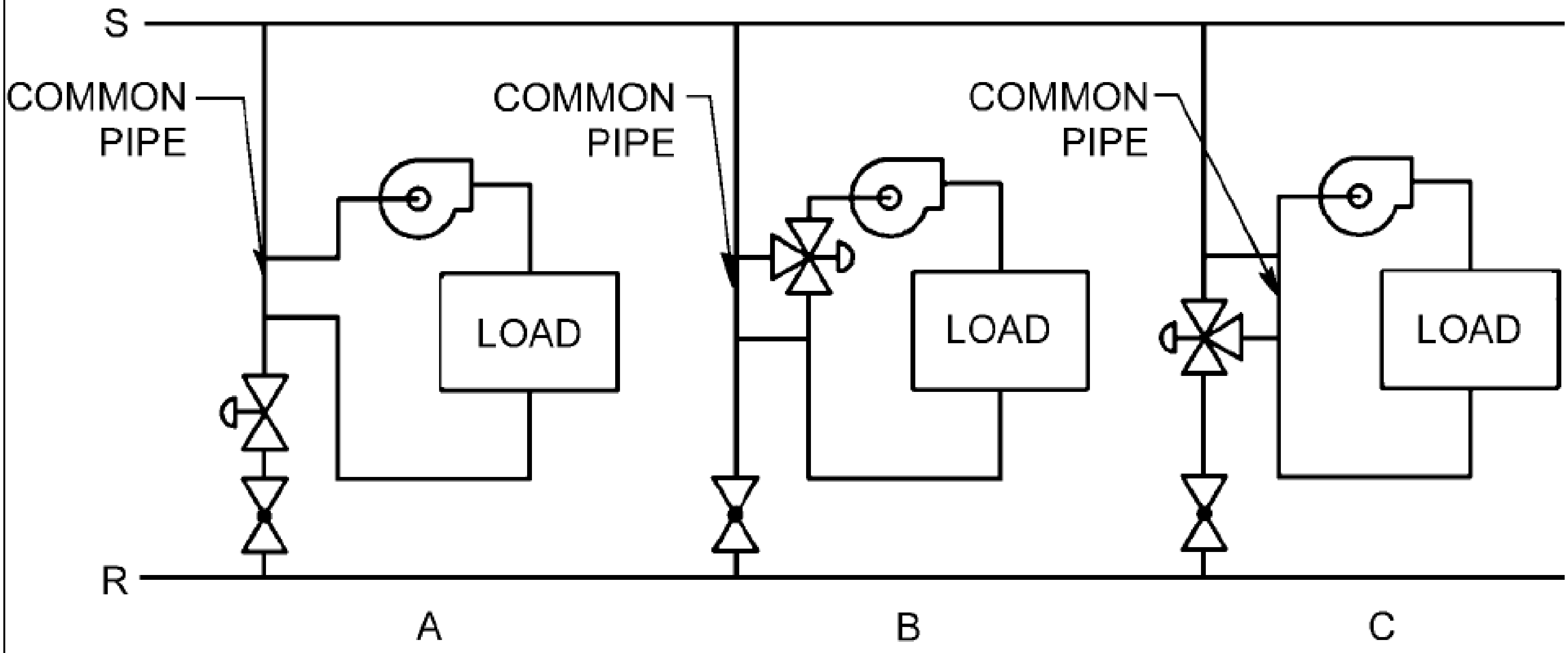
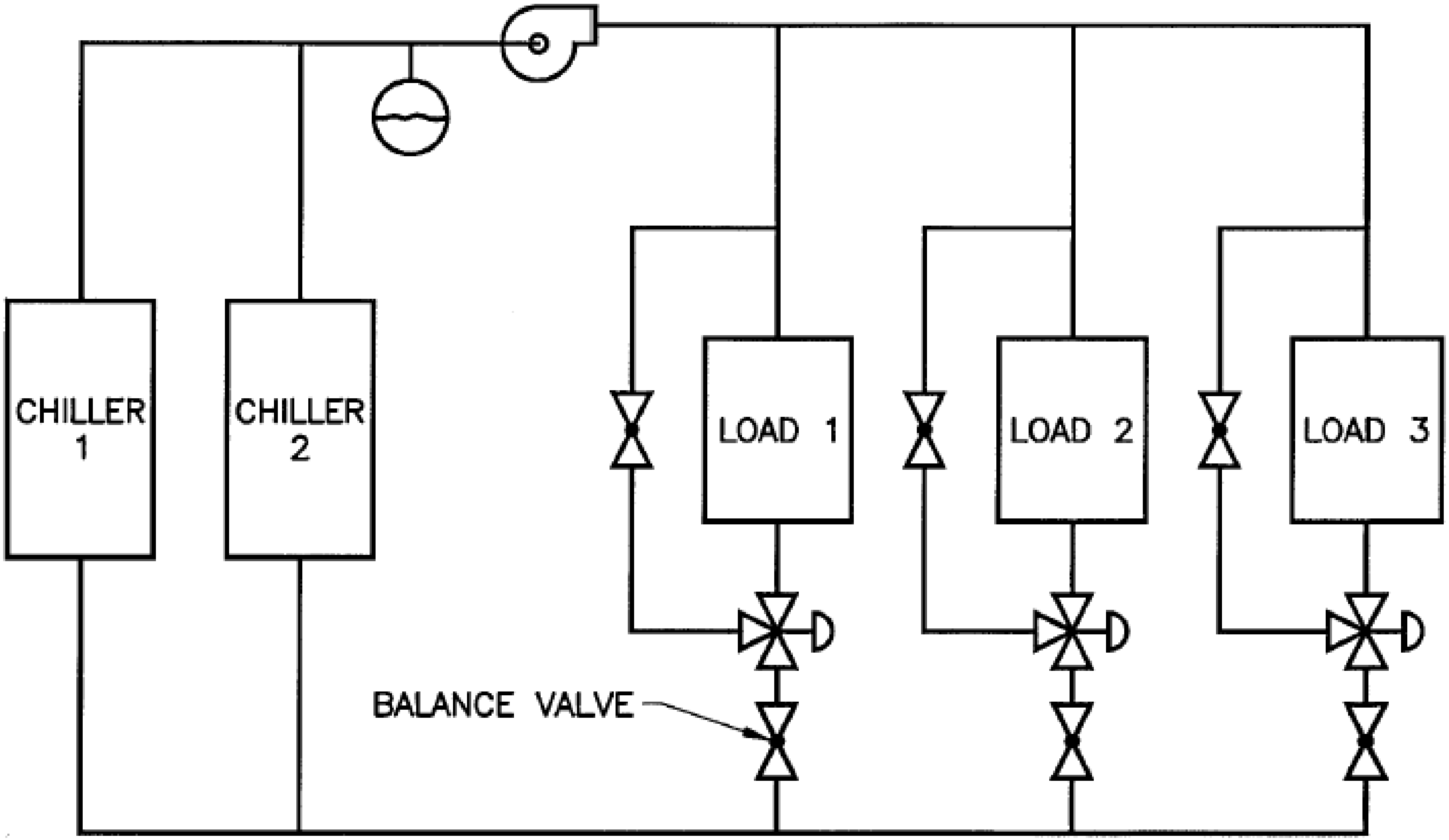


Fig. 40 Primary-Secondary Pumping

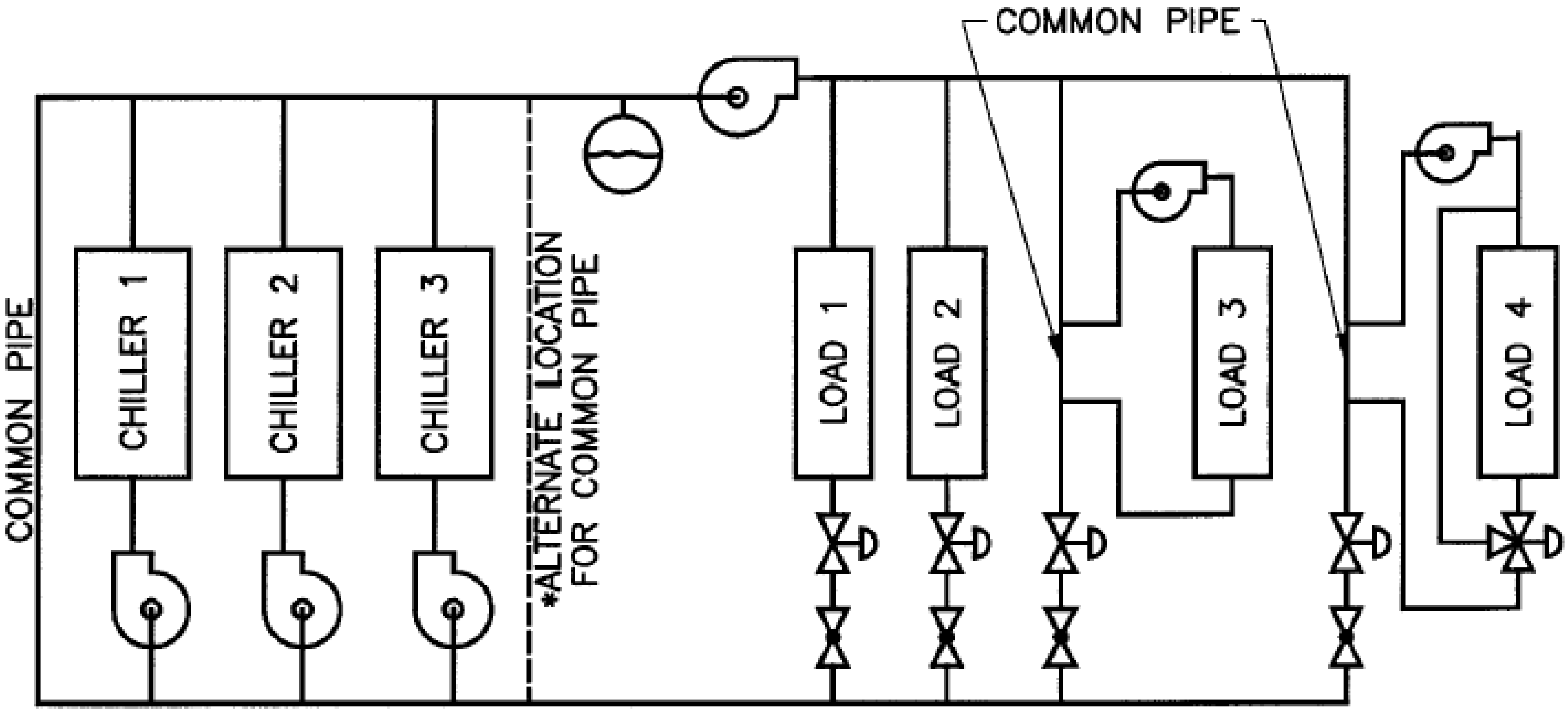
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Constant flow chilled water system



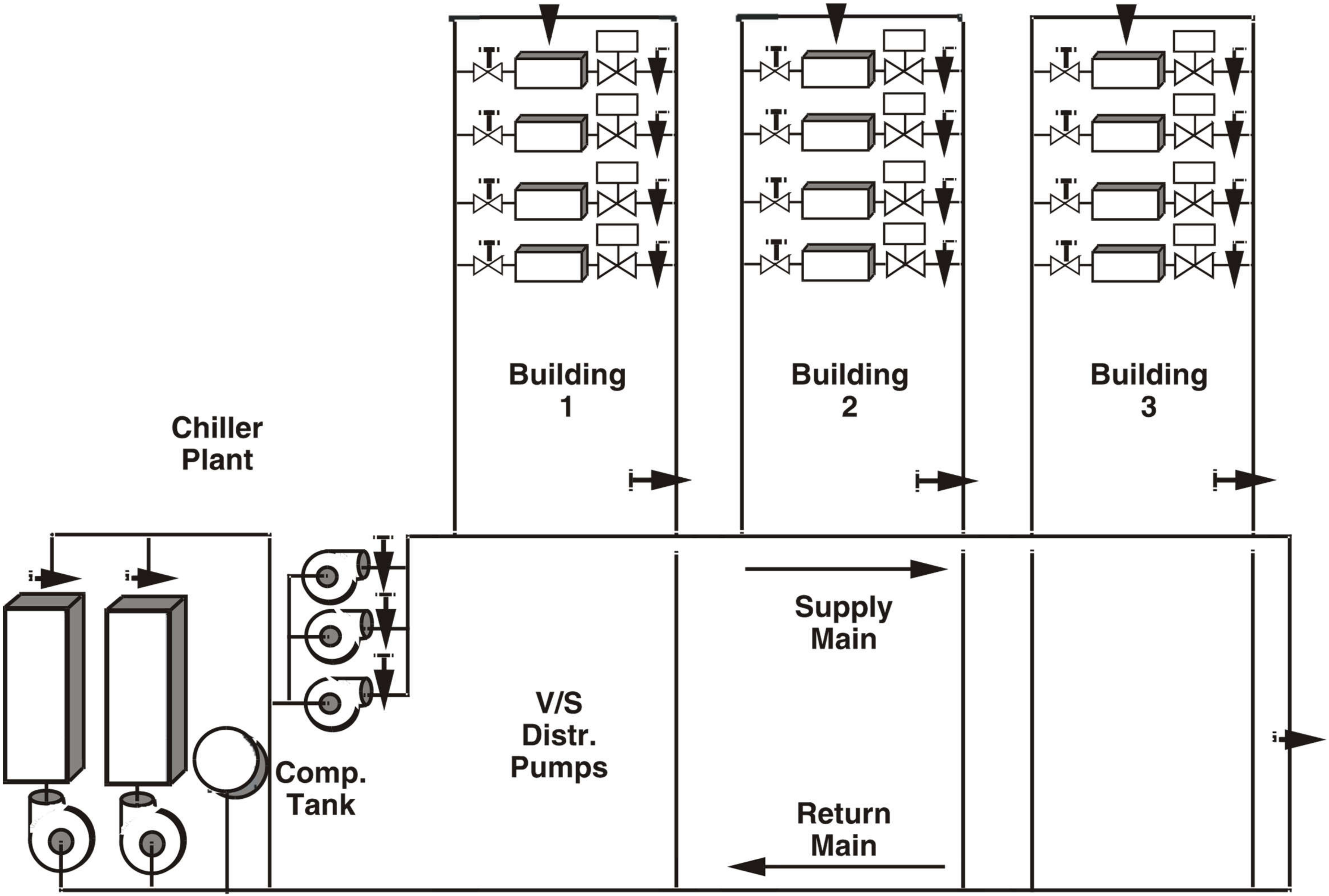
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Variable flow chilled water system (plant-building loop)



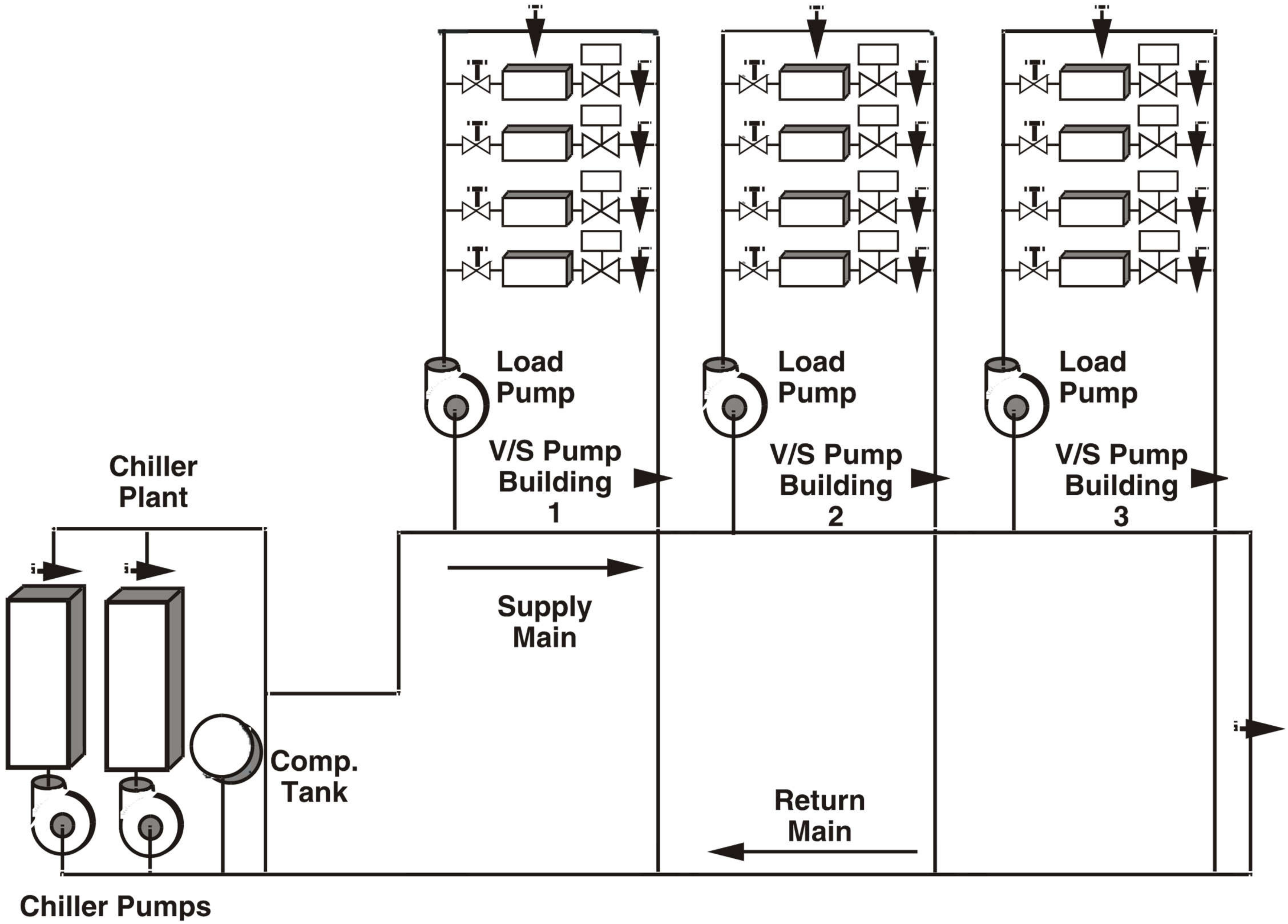
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Primary-secondary variable speed central pumping



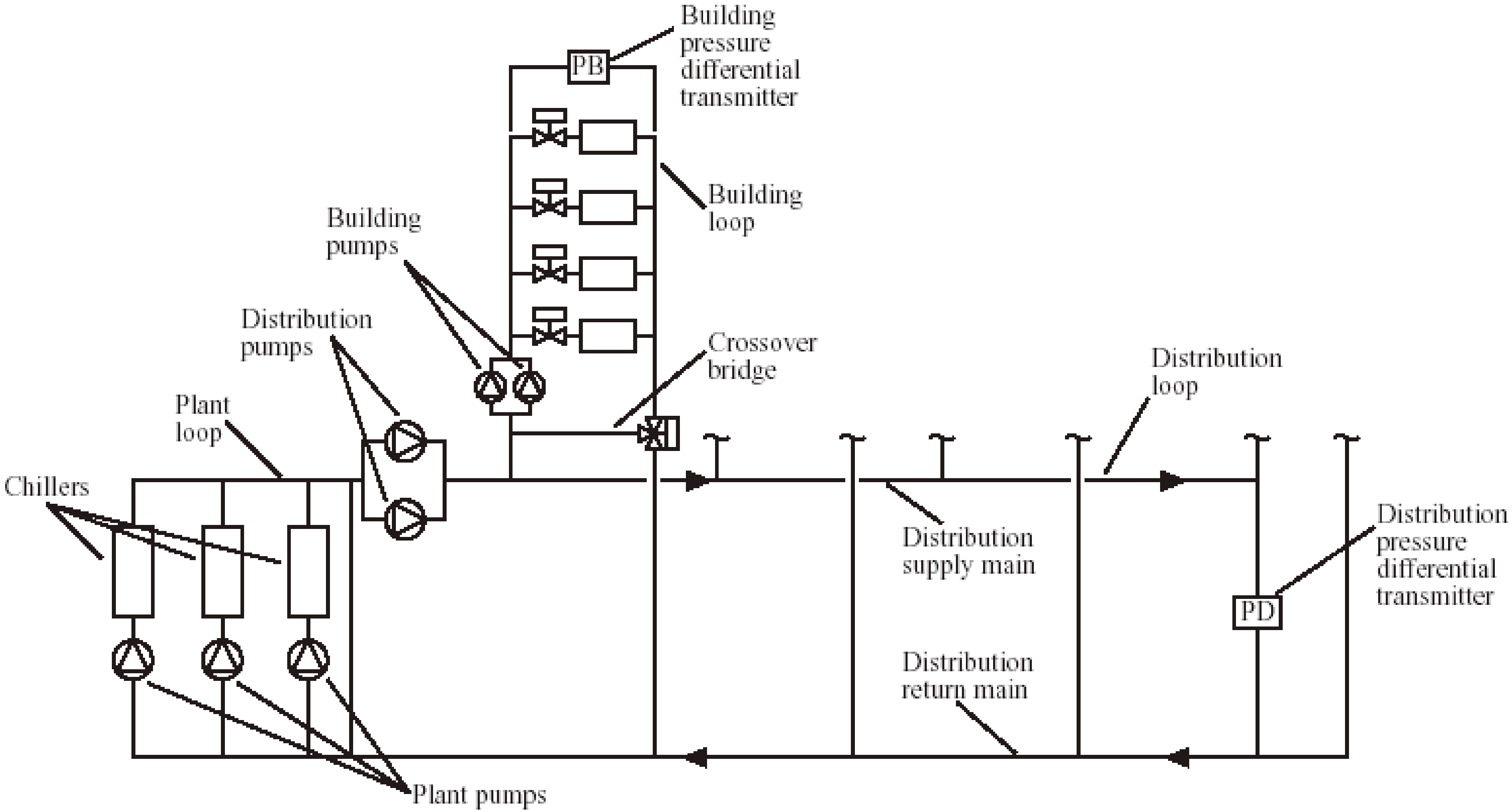
(Source: *Fundamentals of Water System Design*)

Variable speed distributed pumping

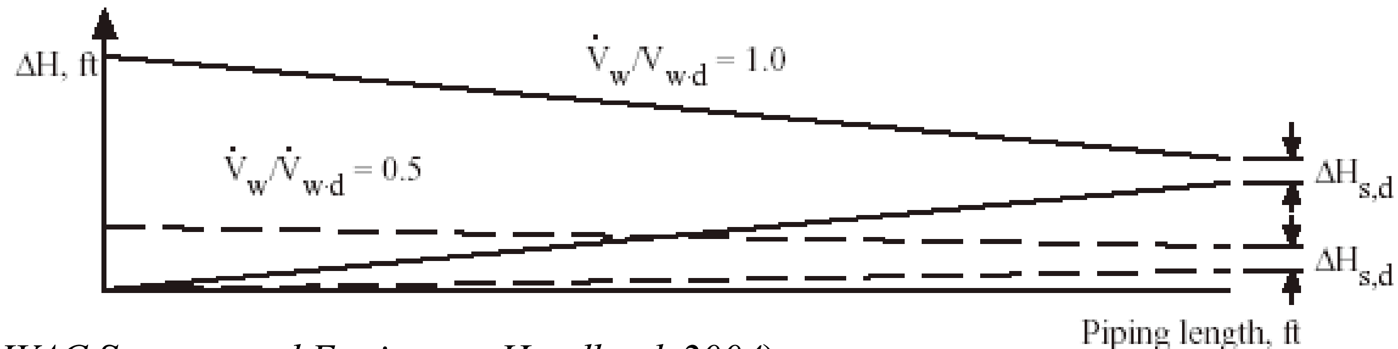


(Source: *Fundamentals of Water System Design*)

Chilled water system using a plant-distribution-building loop

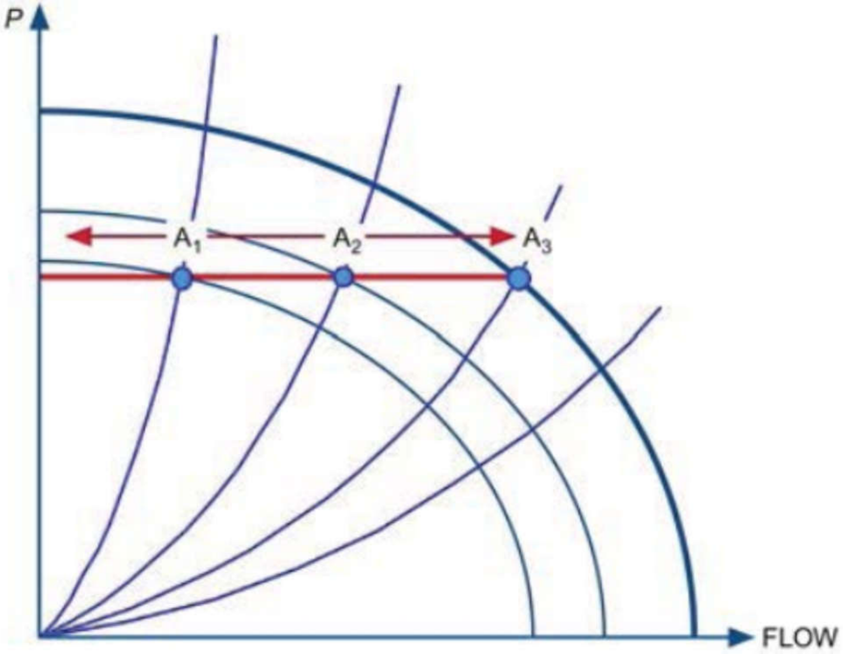


(a)

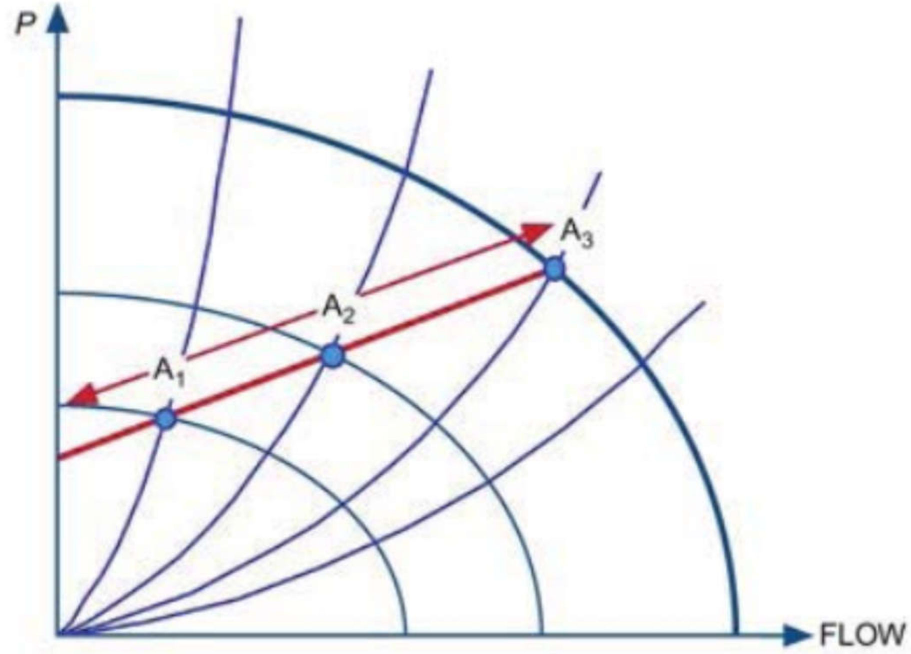


(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

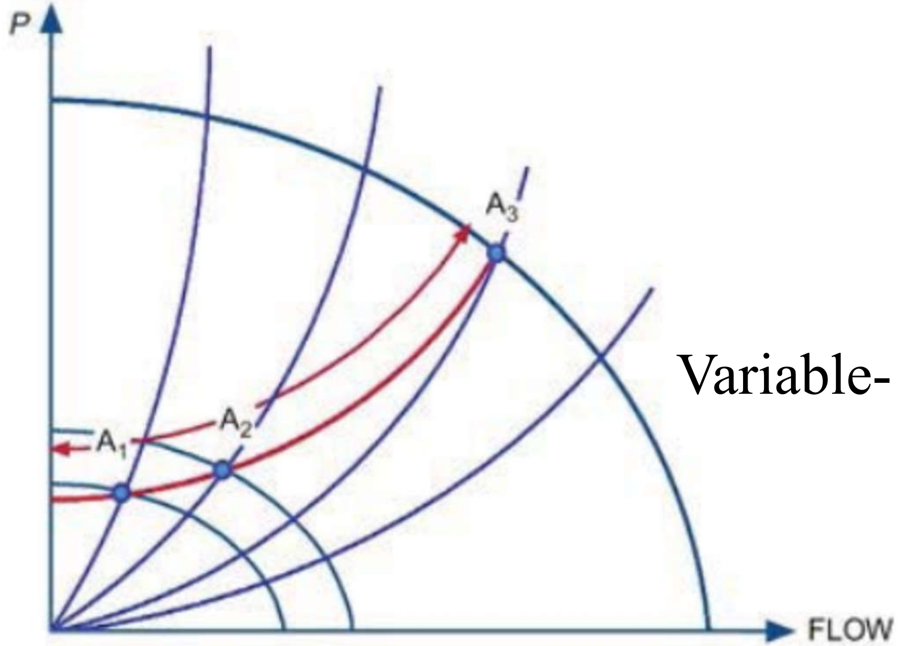
Differential pressure control with predefined control curves



Constant-pressure control



Variable- (Proportional-) pressure control



Variable- (Quadratic-) pressure control

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

Further Reading

- How does a Centrifugal pump work ? https://learnengineering.org/how-does-a-centrifugal-pump-work.html
- ASHRAE, 2016. *ASHRAE Systems and Equipment Handbook 2016*, SI edition, Chp. 44 - Centrifugal Pumps, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Atlanta, GA.
- Energy Impacts of Chilled-Water-Piping Configuration (HPAC Engineering, Nov 2011, pp. 20-26) http://ibse.hk/MEBS7014/BE_YD_Res_VariablePrimaryFlow.pdf

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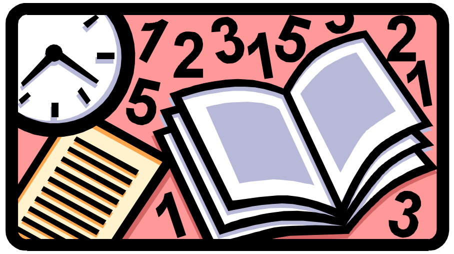

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- Pennycook, K., Churcher, D. and Bleicher, D., 2007. *A Guide to HVAC Building Services Calculations*, 2nd ed., Building Services Research and Information Association, Bracknell, Berkshire, England.
- Trane Company, 2001. *Chilled-water Systems*, 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]