MEBS6008 Environmental Services II

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Fans and Pumps I

Dr. Sam C. M. Hui

Department of Mechanical Engineering

The University of Hong Kong

E-mail: cmhui@hku.hk

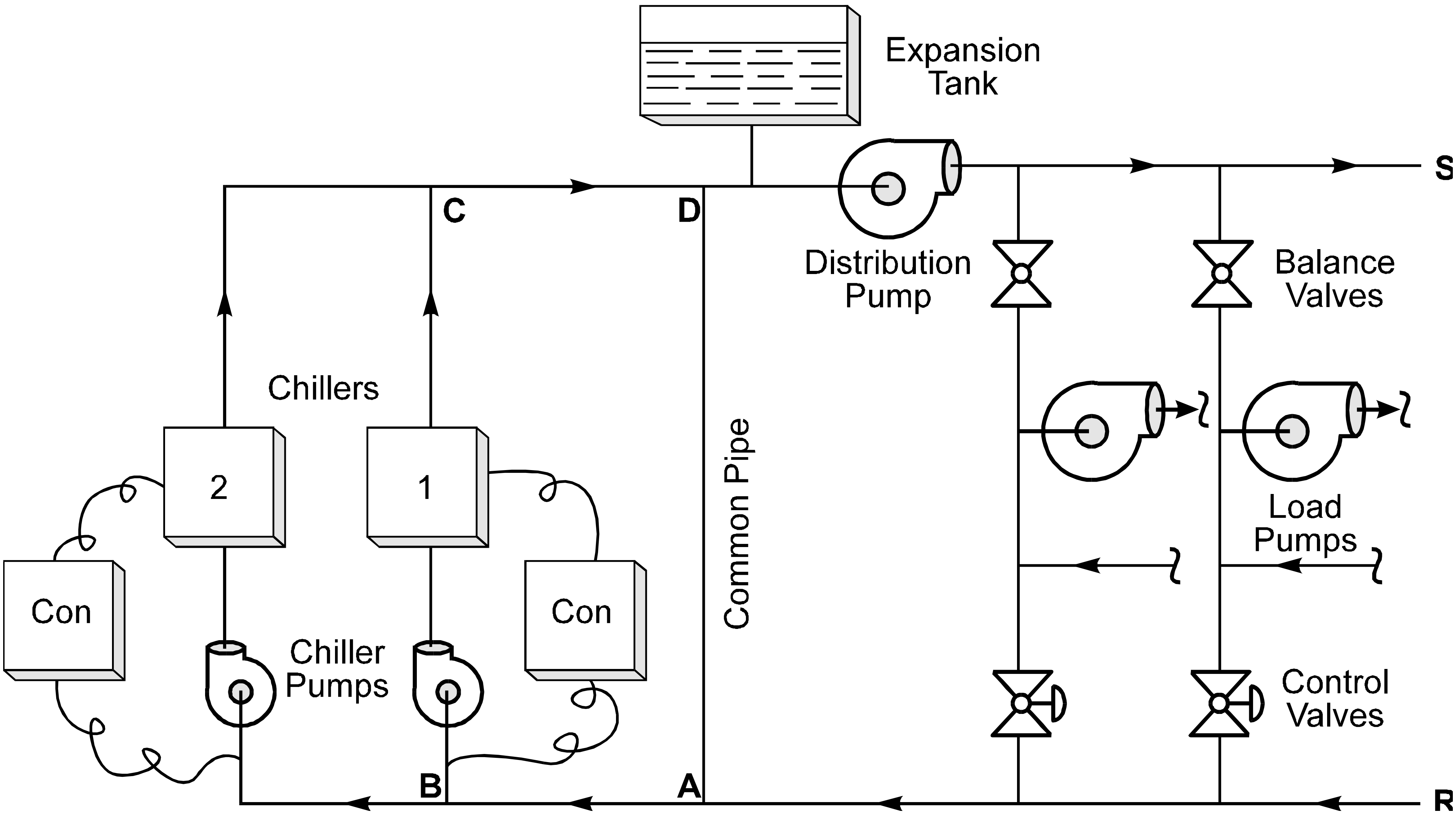
Jan 2015

Contents

- Centrifugal Pumps
- Pump Arrangements
- Matching Pumps to Systems

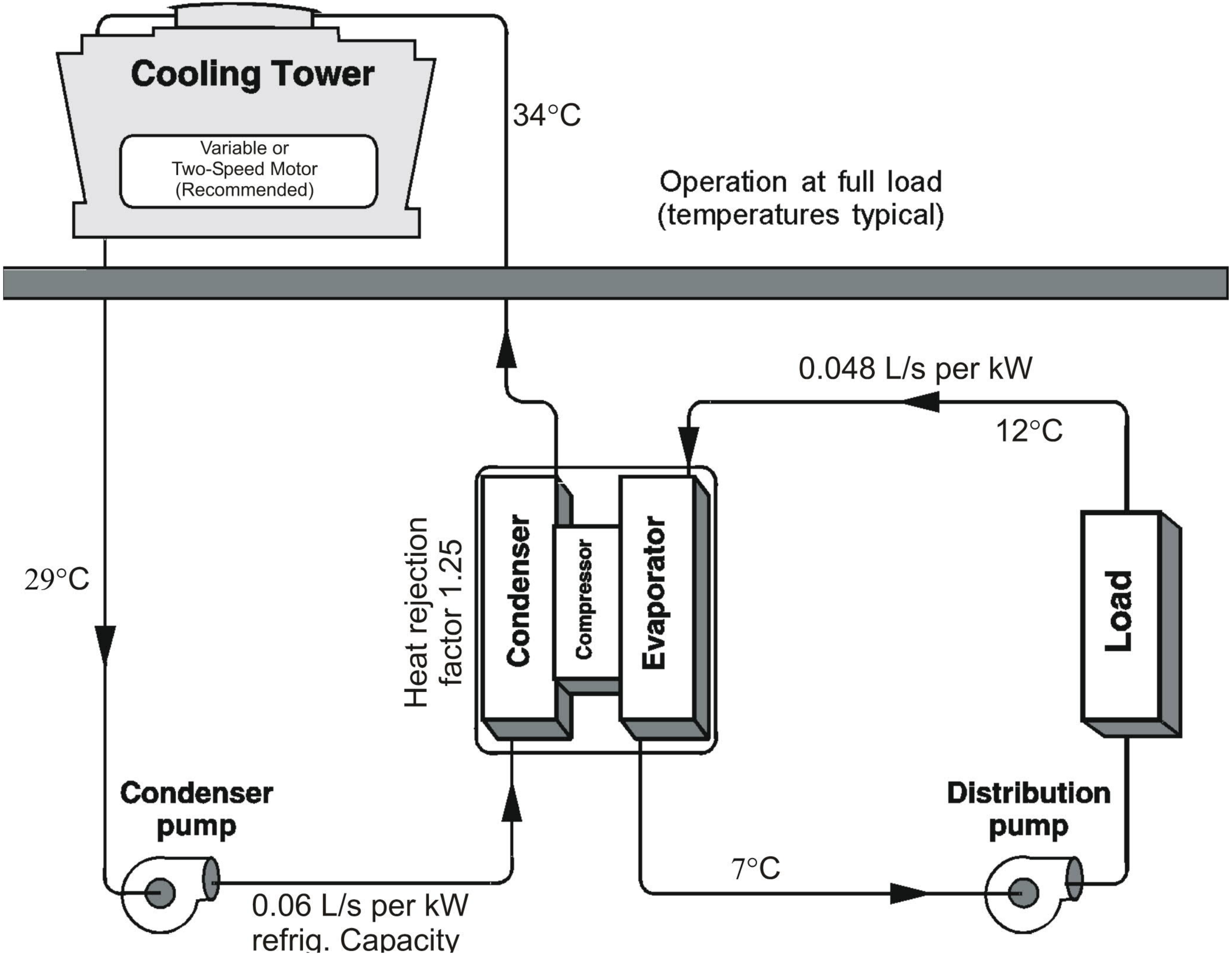
Centrifugal Pumps

- Centrifugal pump
  - 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



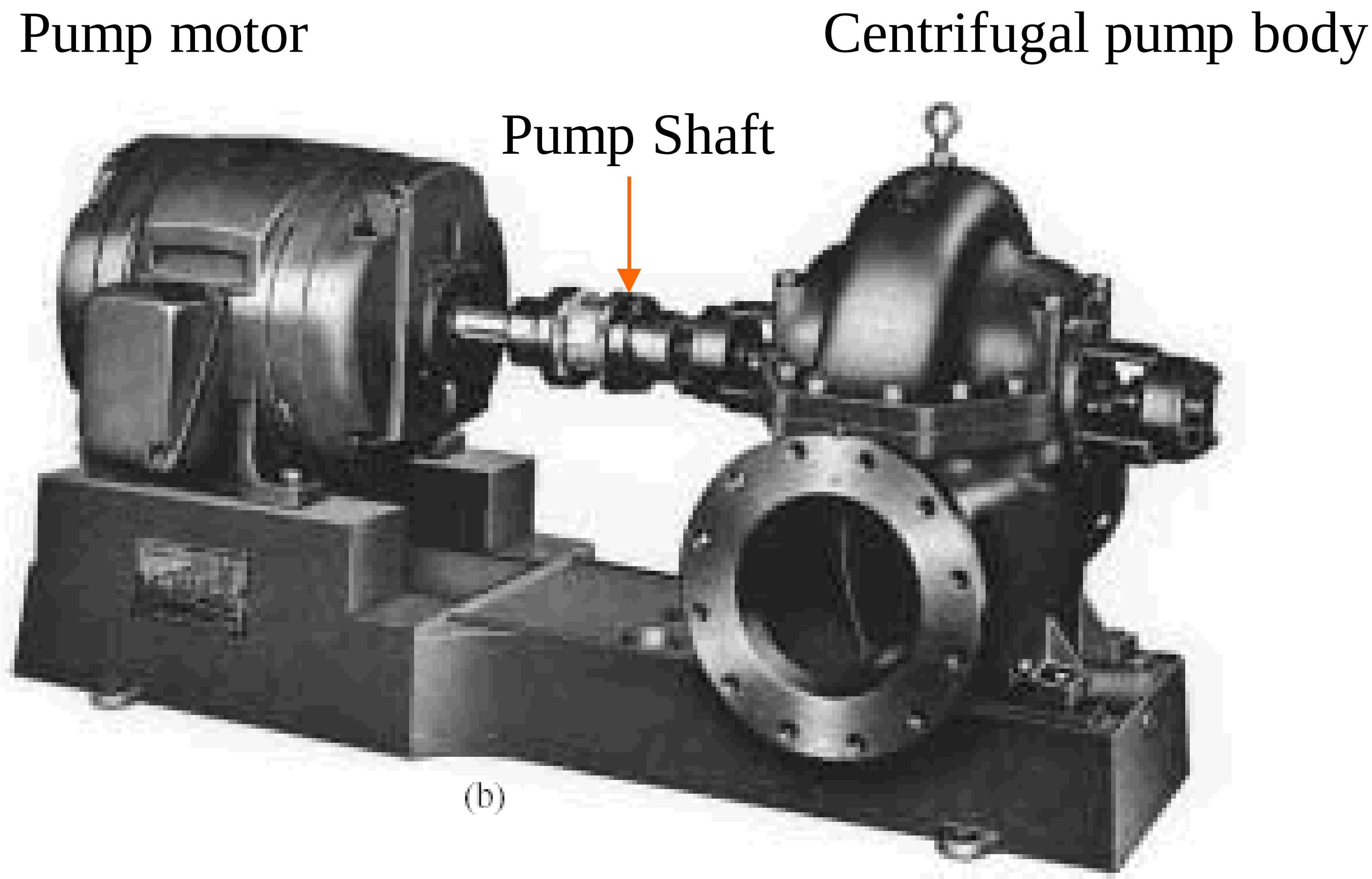
Chilled water pumping system

(Source: *Fundamentals of Water System Design*)



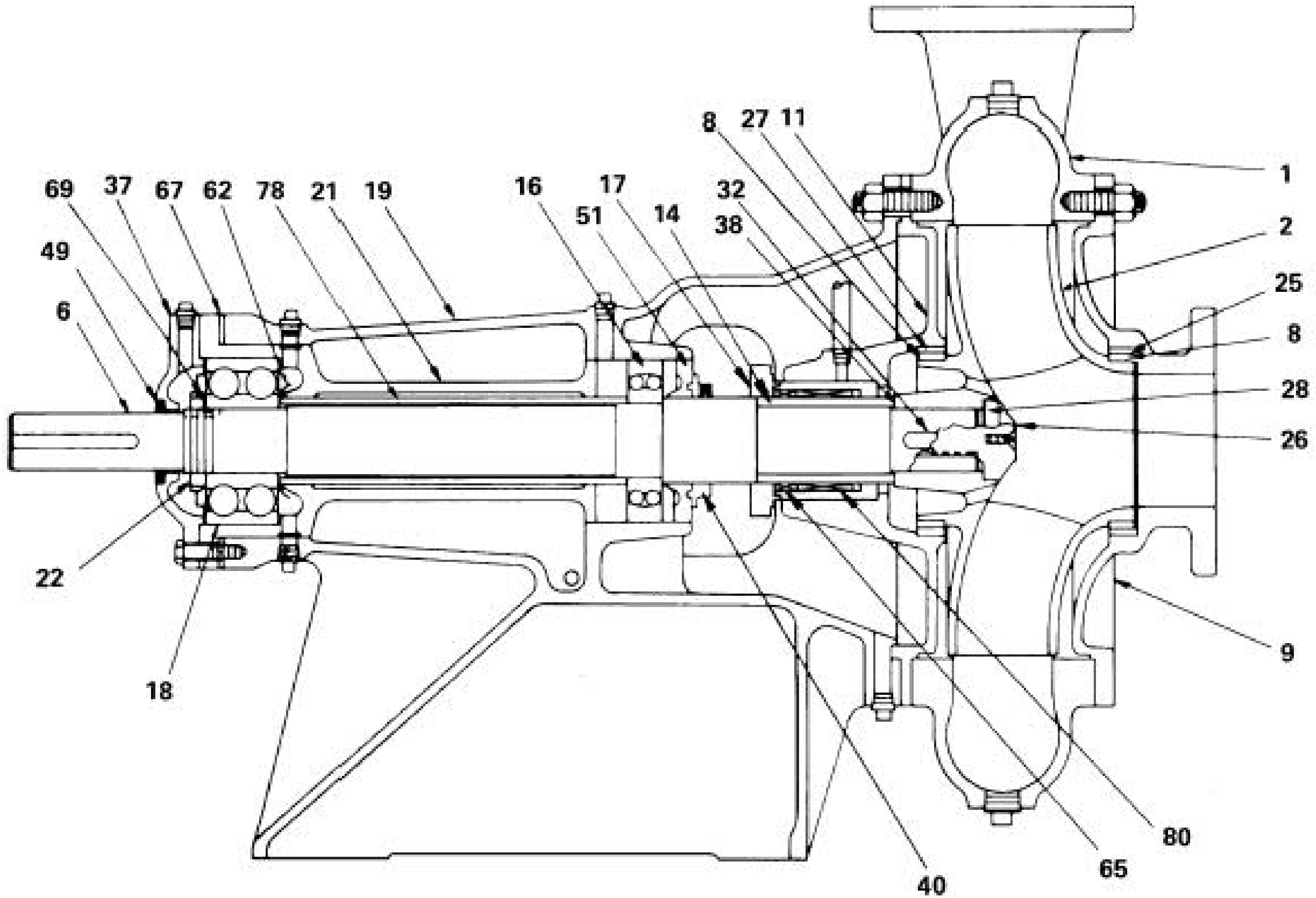
Cooling tower pumping system

(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*)

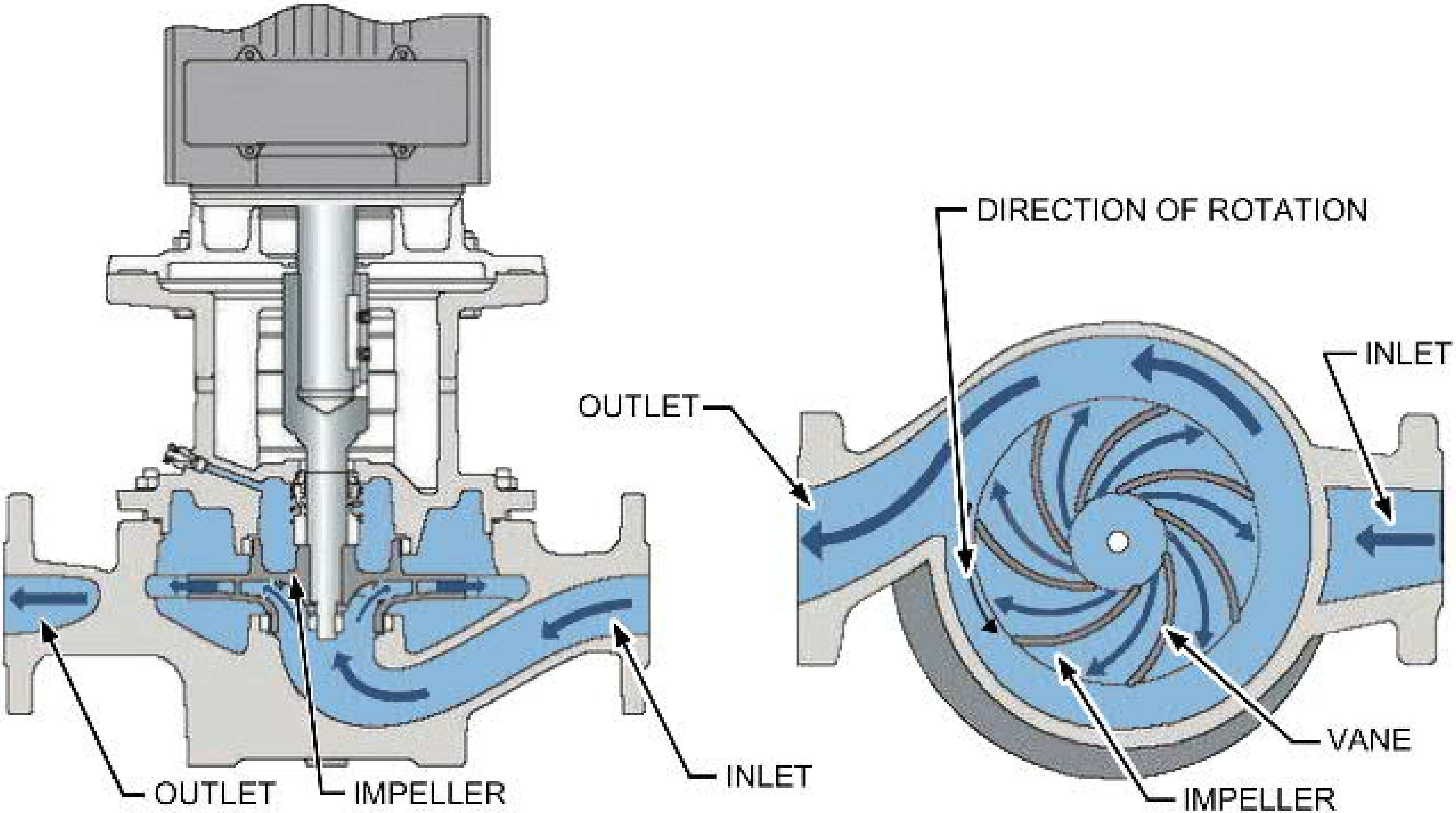


1 Casing
2 Impeller
6 Shaft, pump
8 Ring, impeller
9 Cover, suction
11 Cover, stuffing box
14 Sleeve, shaft
16 Bearing, inboard
17 Gland
18 Bearing, outboard
19 Frame
21 Liner, frame
22 Locknut, bearing
25 Ring, suction cover
26 Screw, impeller
27 Ring, stuffing box cover
28 Gasket, impeller screw
32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

Typical overhung-impeller end-suction pump

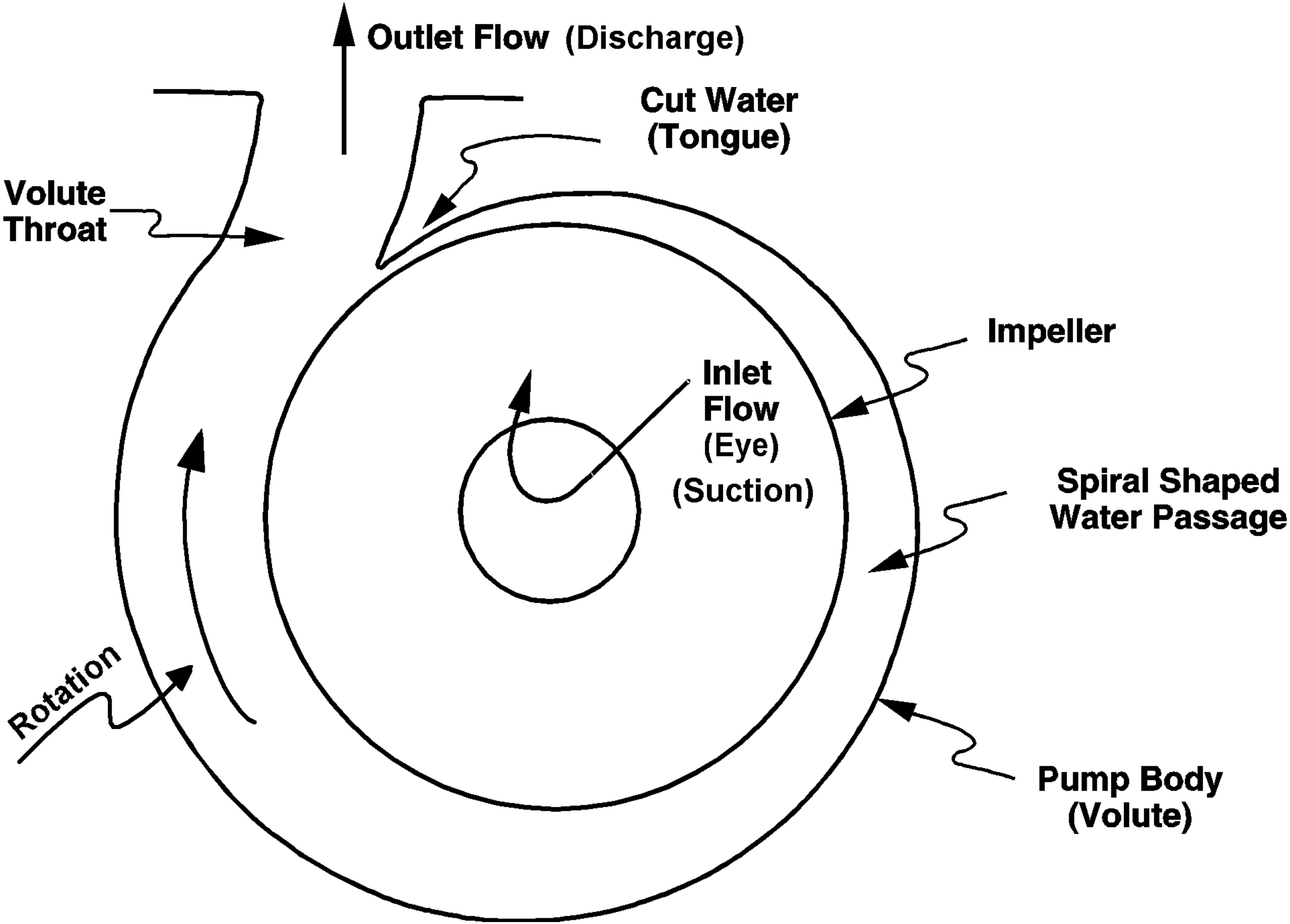
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

* Video: How does a Centrifugal pump work ? (4:37) https://www.youtube.com/watch?v=BaEHVpKc-1Q
http://www.learnengineering.org/2014/01/centrifugal-hydraulic-pumps.html



Centrifugal pump

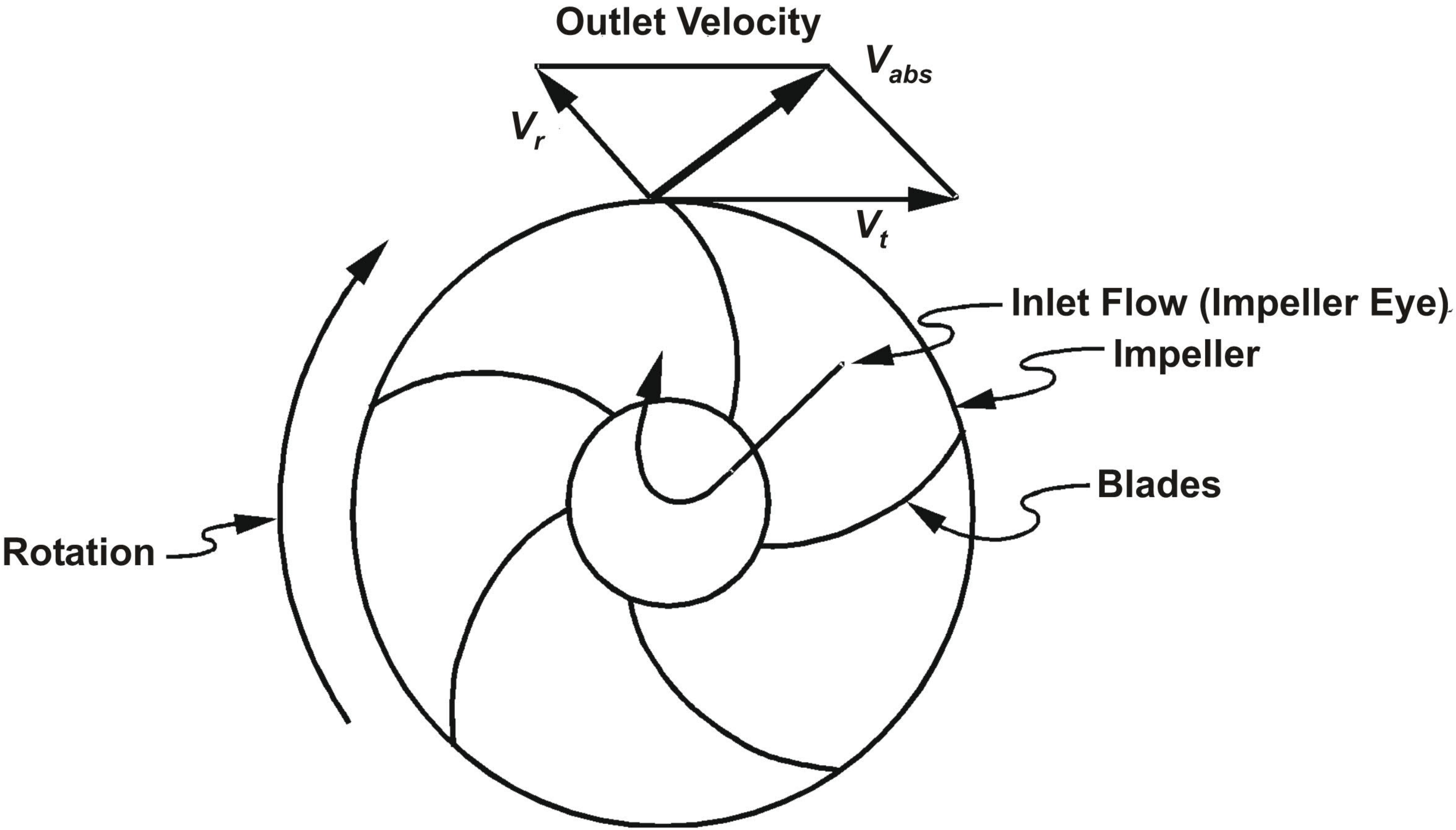
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2012*)



Centrifugal pump, impeller and volute

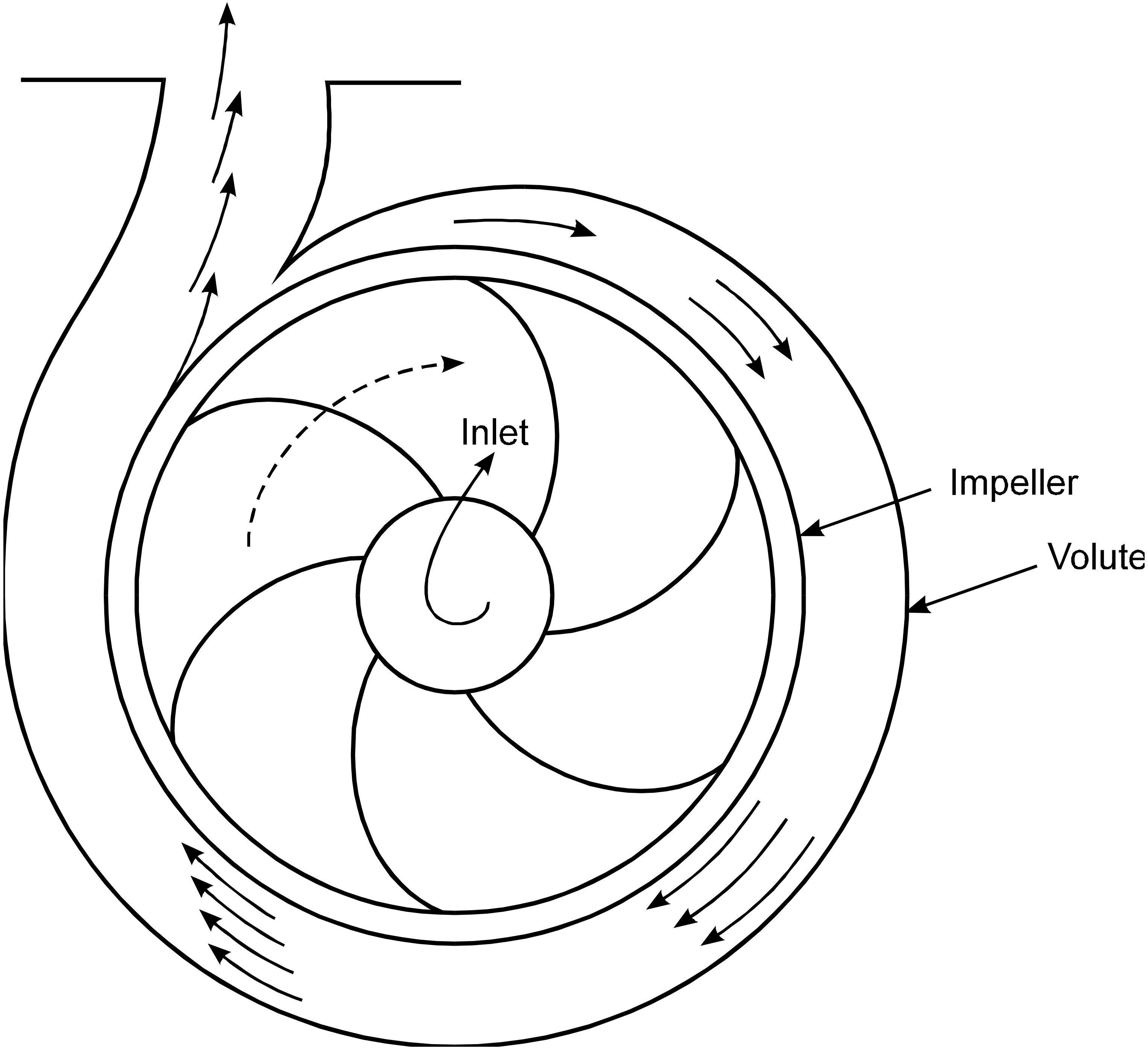
(Source: *Fundamentals of Water System Design*)

* Video: Centrifugal Pump Working (5:54) https://www.youtube.com/watch?v=IiE8skW8btE
http://www.learnengineering.org/2013/03/centrifugal-pump.html



Impeller action on fluid

(Source: *Fundamentals of Water System Design*)

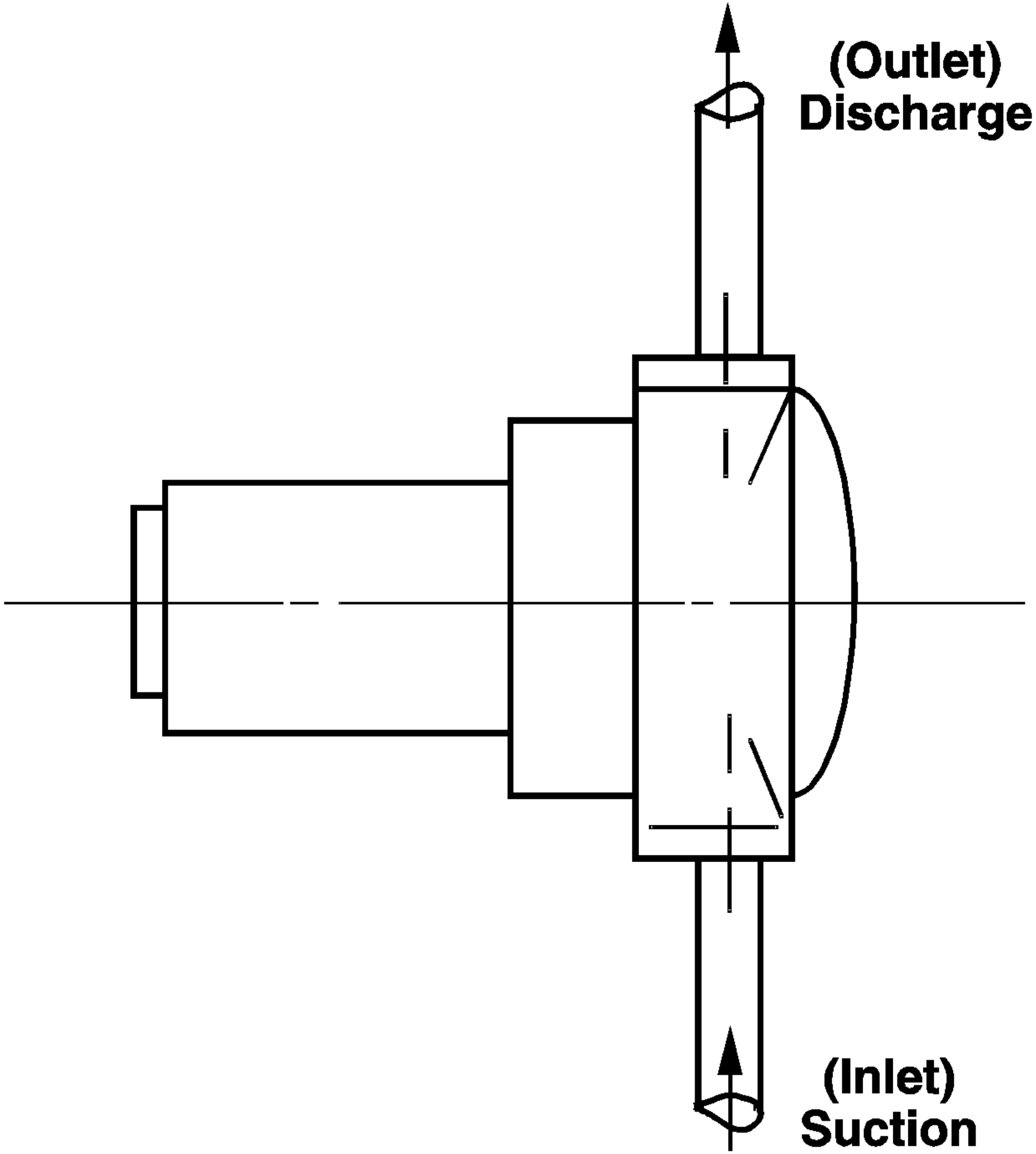


Flow pattern of impeller/volute action

(Source: *Fundamentals of Water System Design*)

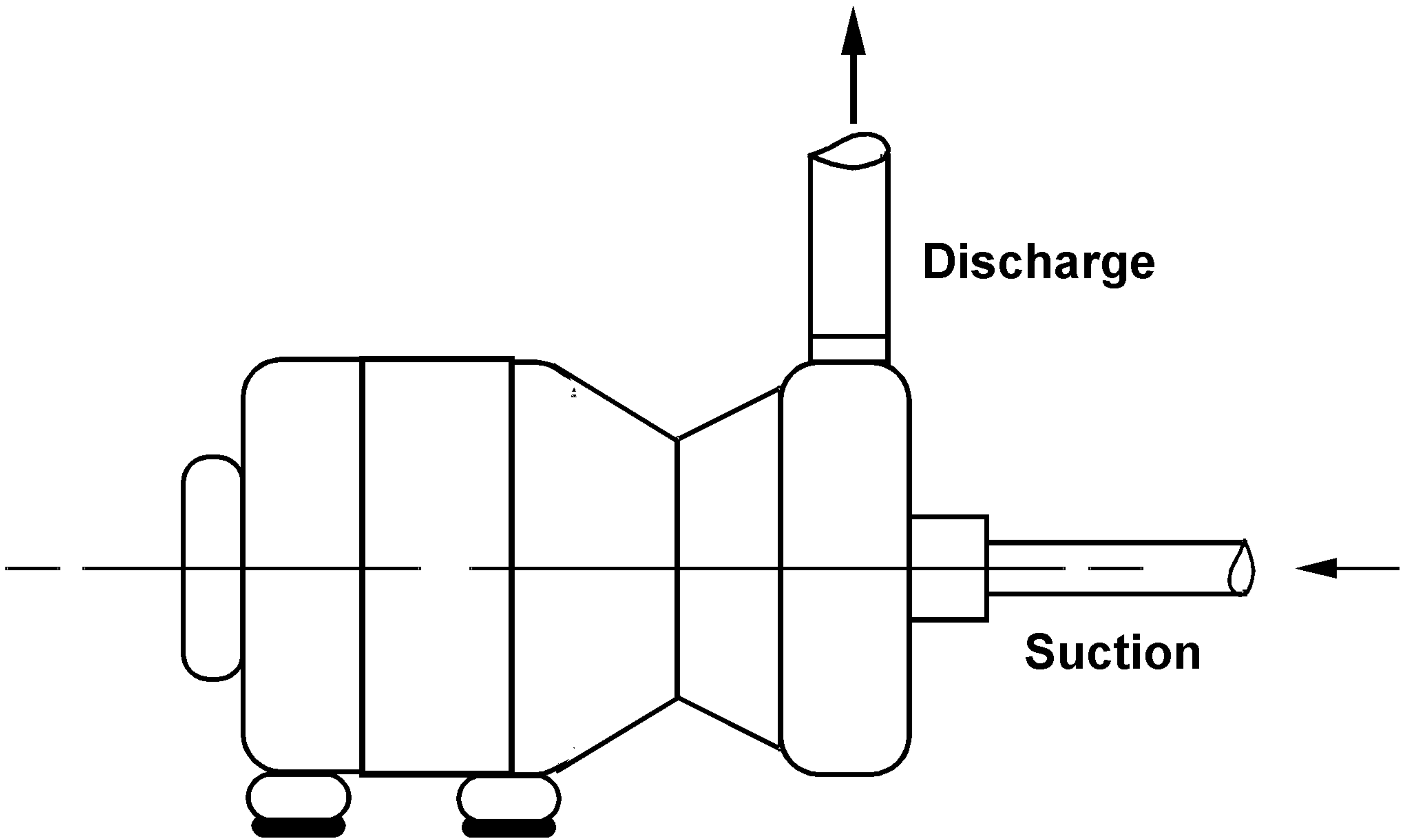
Centrifugal Pumps

- 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



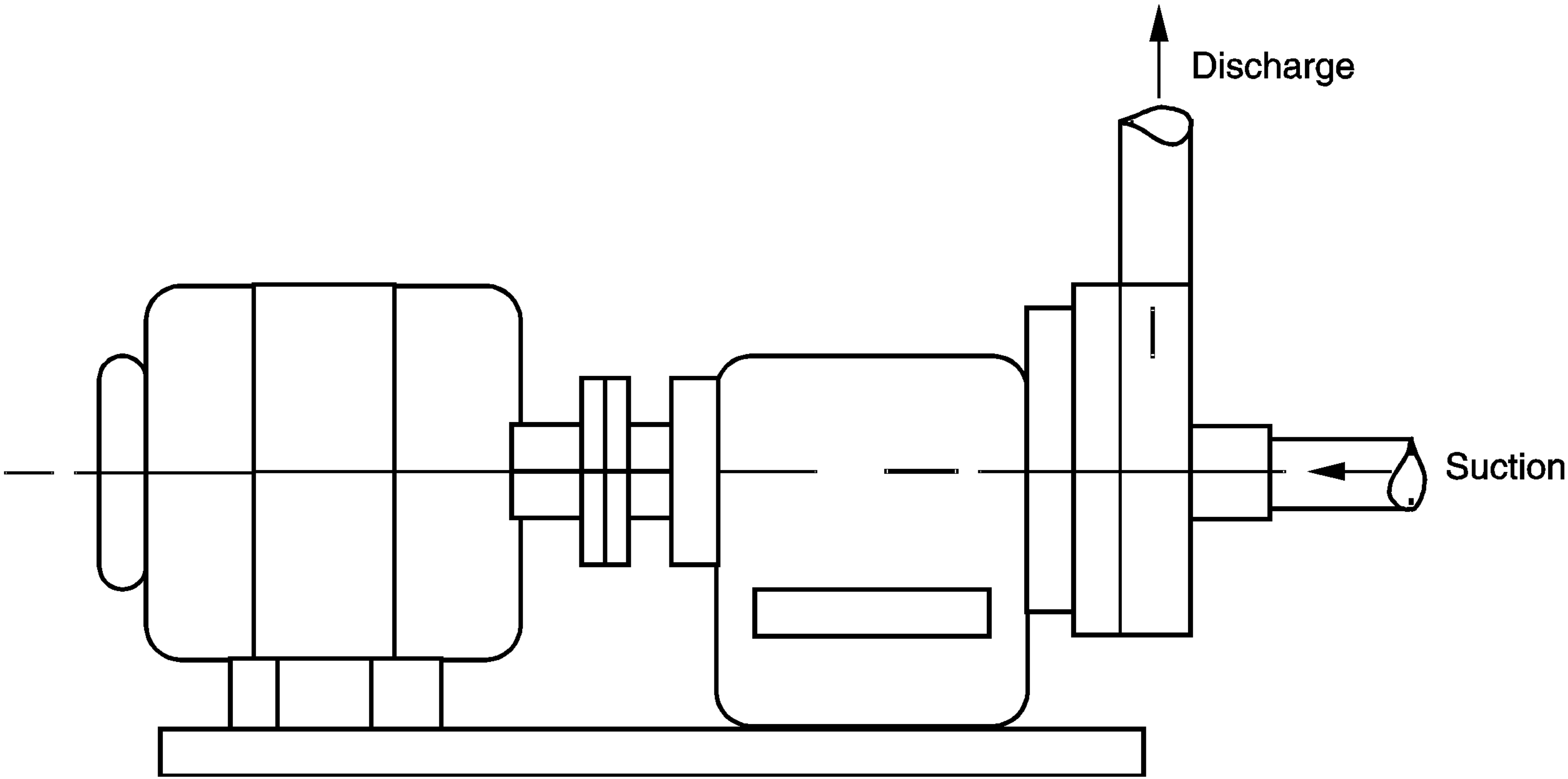
Circulation pump

(Source: *Fundamentals of Water System Design*)



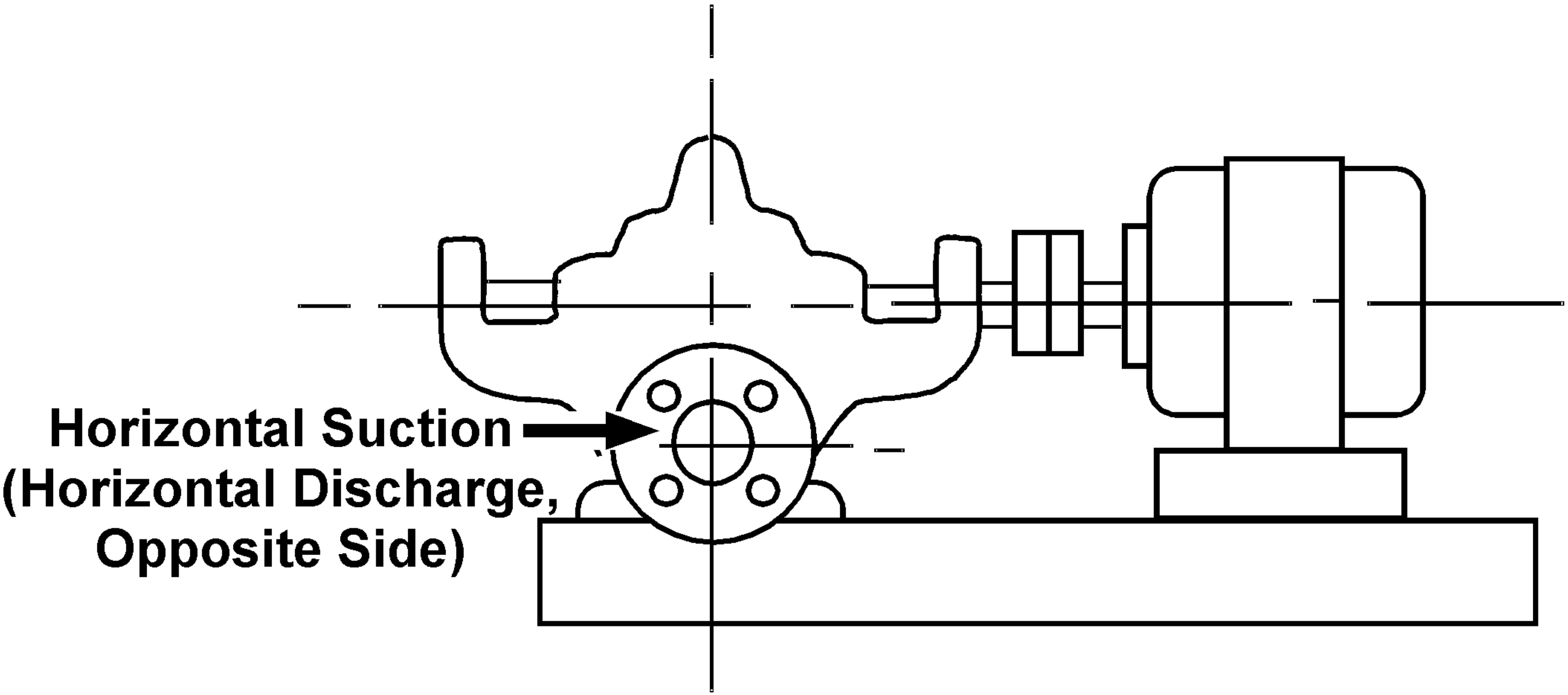
Close-coupled end suction pump

(Source: *Fundamentals of Water System Design*)



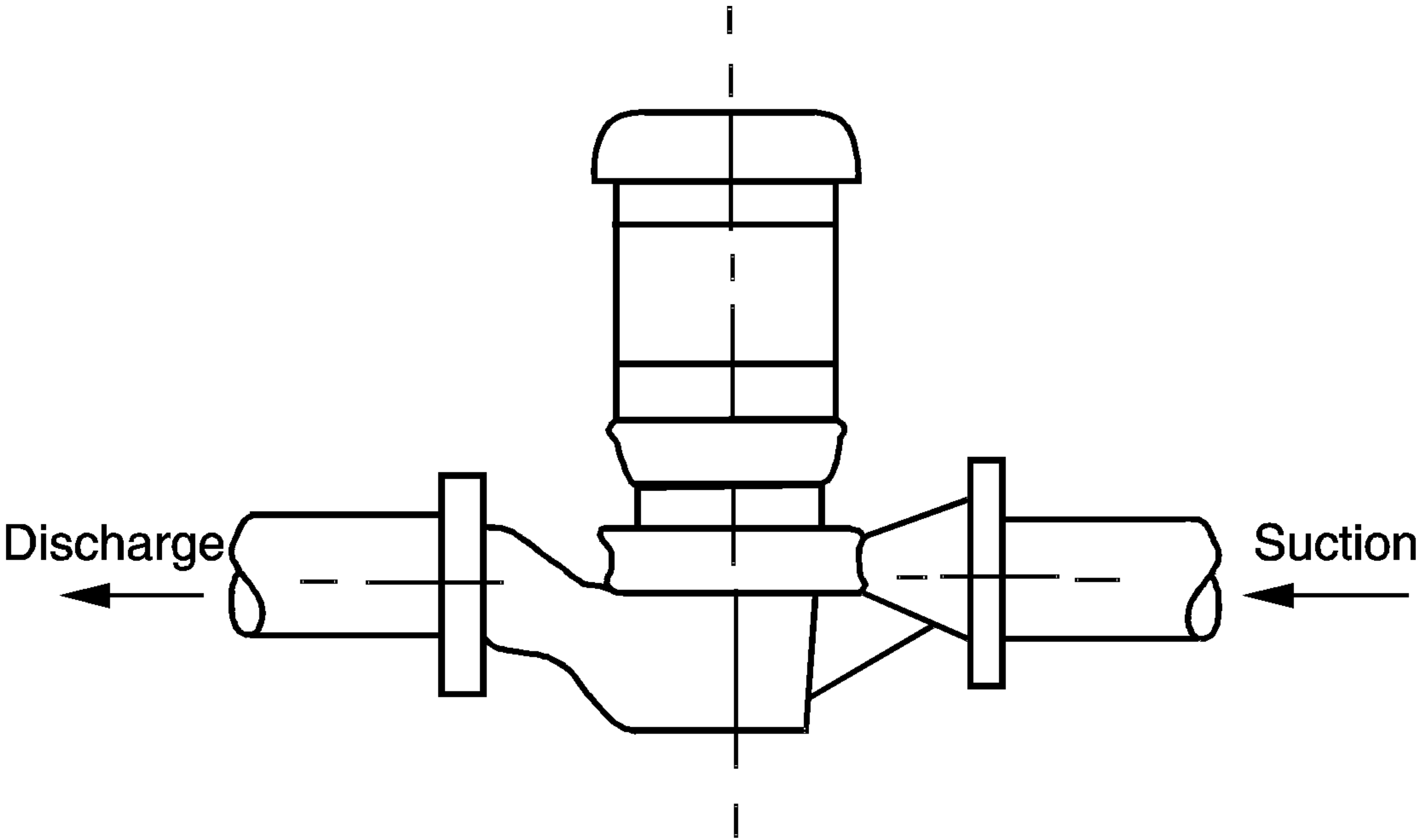
Frame-mounted end suction pump

(Source: *Fundamentals of Water System Design*)



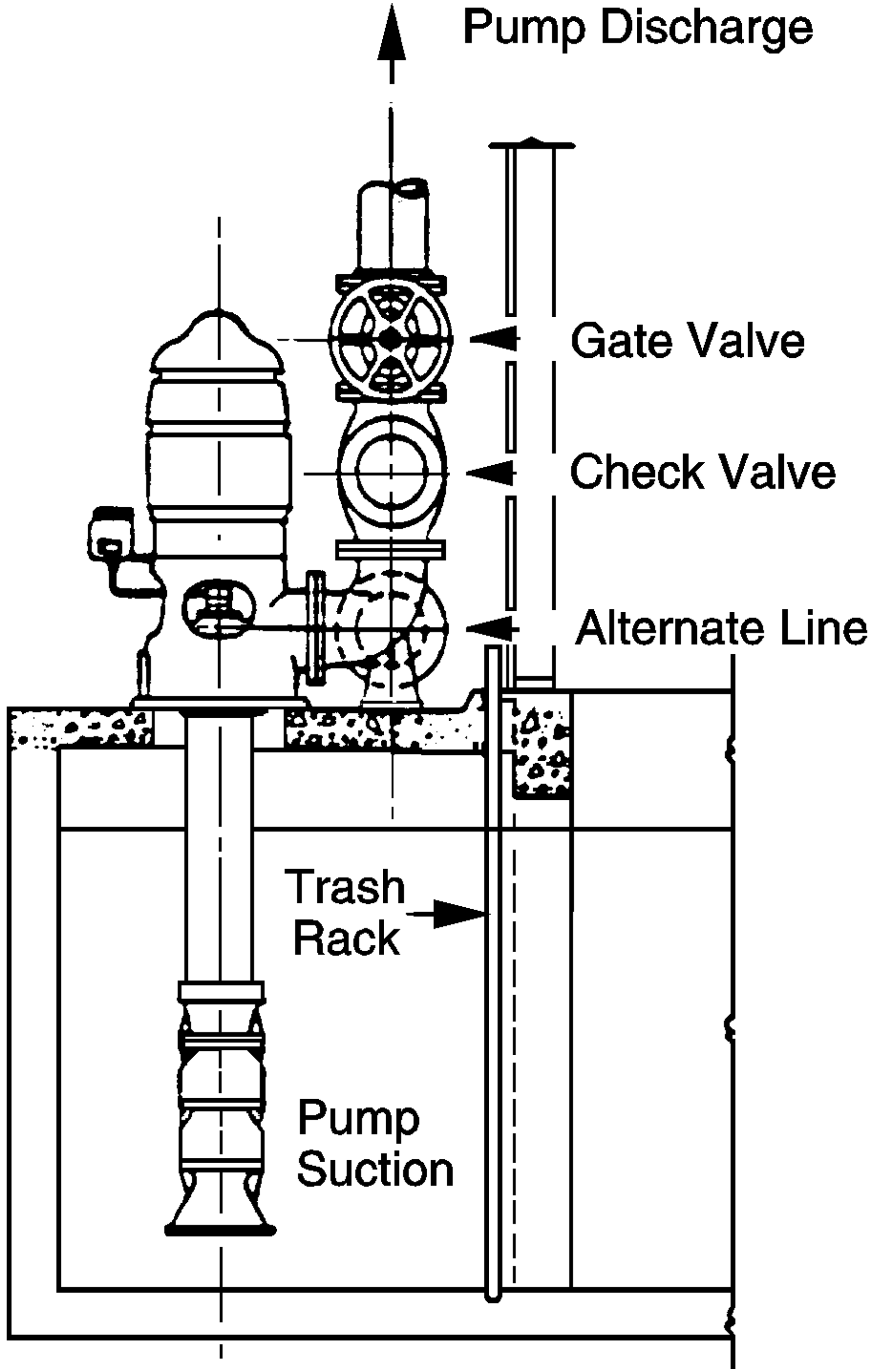
Base-mounted horizontal split case pump

(Source: *Fundamentals of Water System Design*)



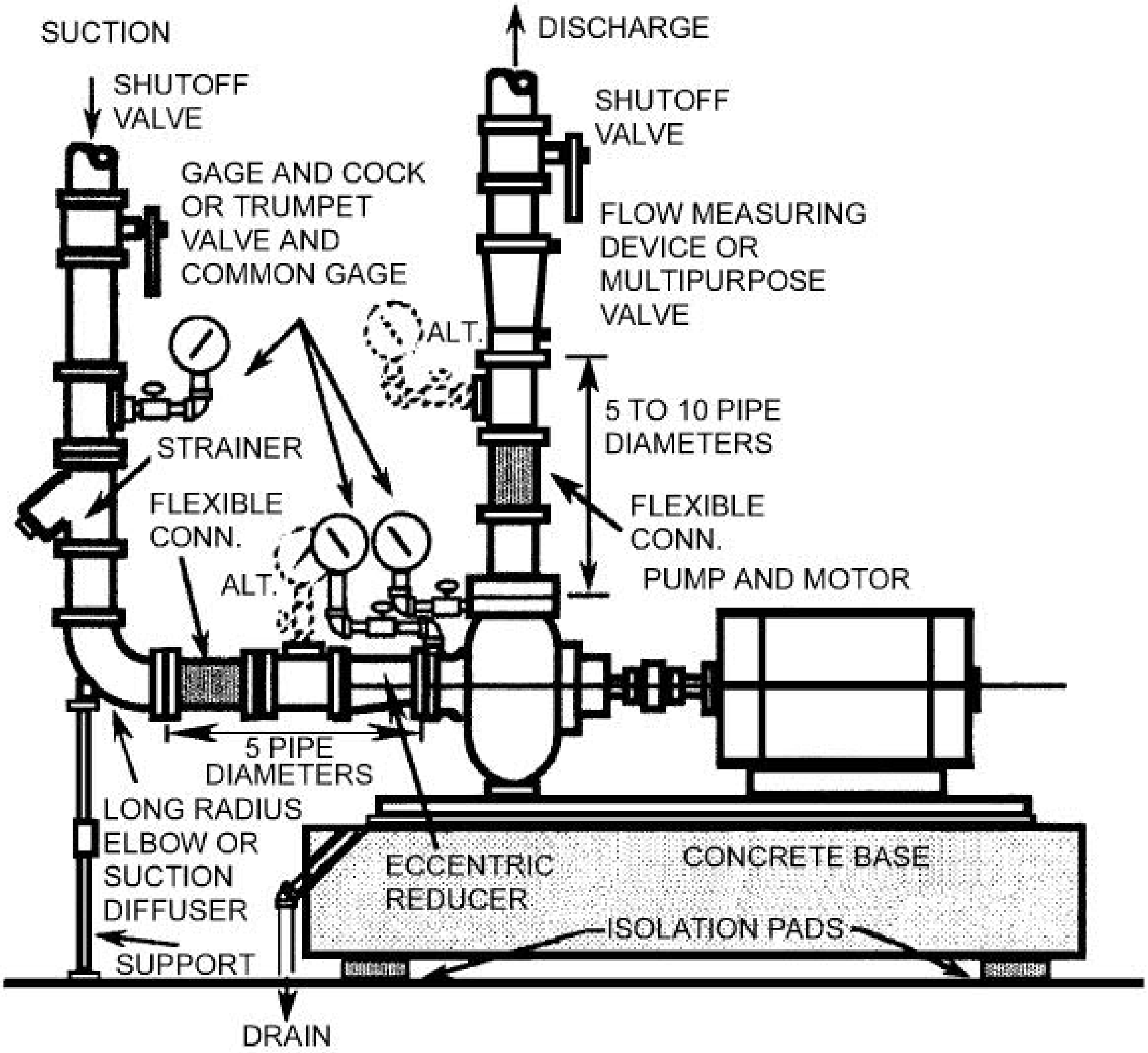
Vertical inline pump

(Source: *Fundamentals of Water System Design*)



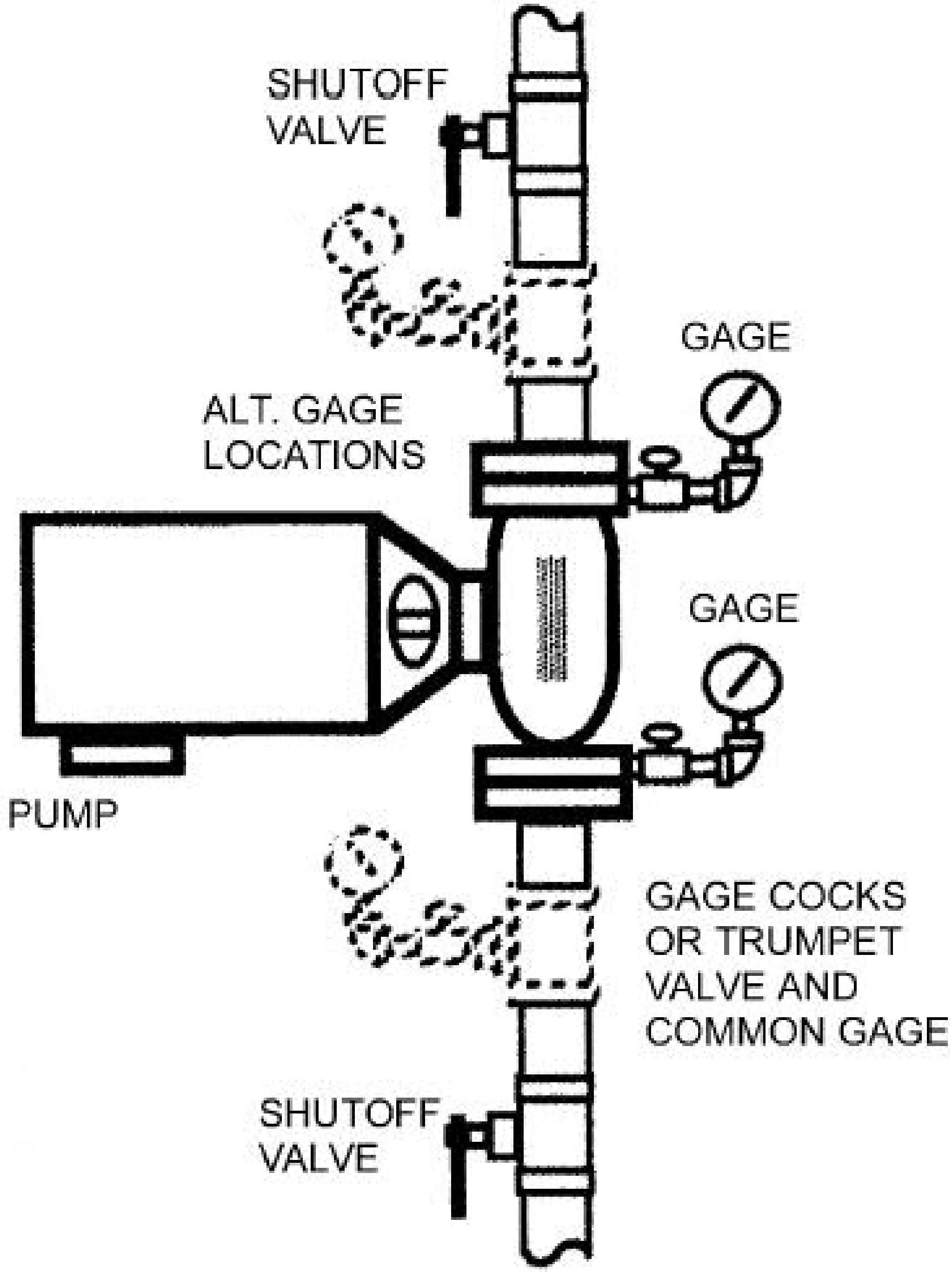
Vertical turbine pump, wet sump arrangement

(Source: *Fundamentals of Water System Design*)



Base plate-mounted centrifugal pump installation

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



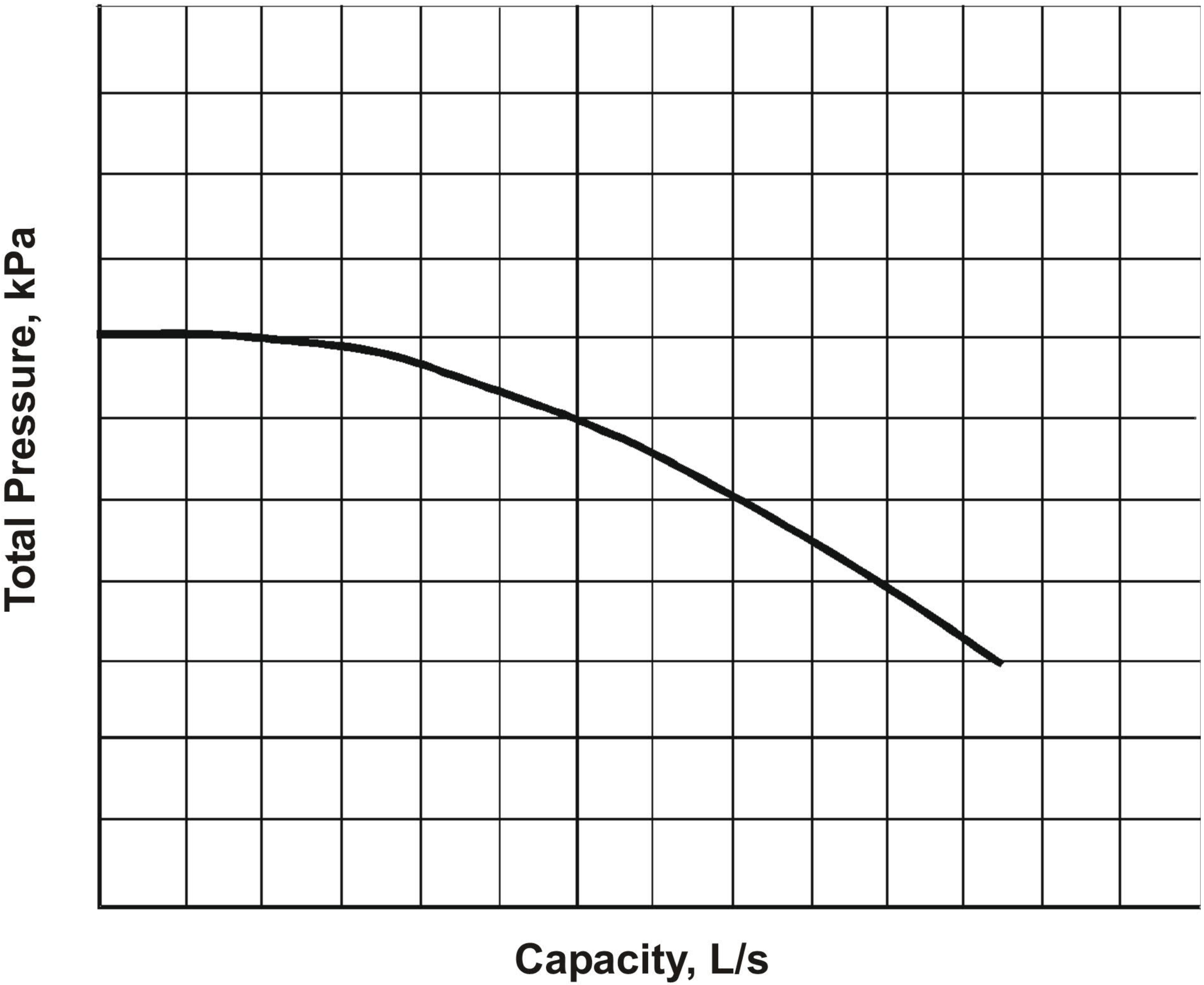
In-line pump installation

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

Centrifugal Pumps

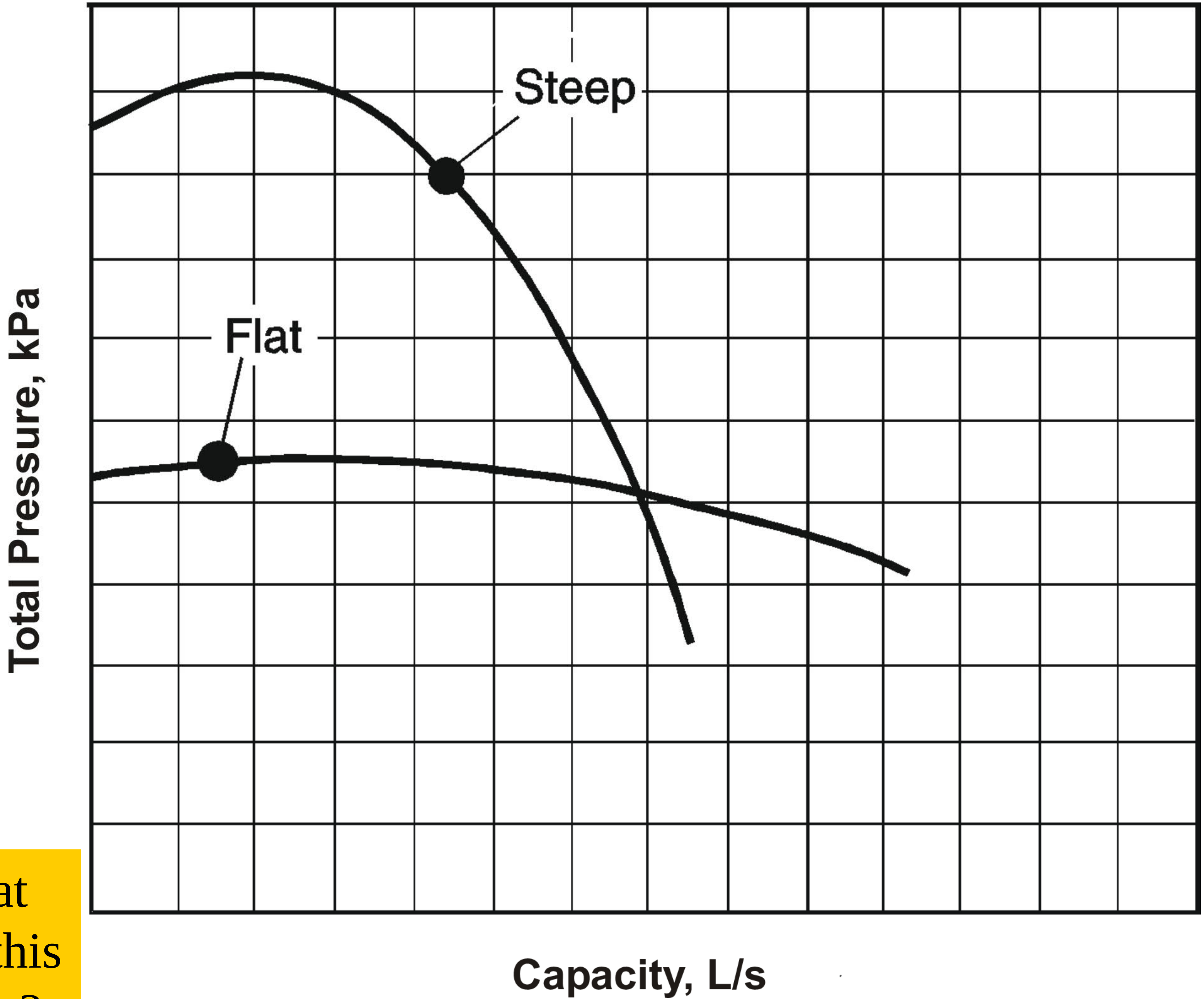
- Variable speed pumps
  - Less expensive nowadays
- Centrifugal pump characteristics*
  - Total pressure-capacity curve
    - Flat curve: applied on closed piping systems with modulating valves
    - Steep curve: usually for open piping systems (cooling towers), w/ high pressure, constant flow
  - Family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

* Video: Centrifugal Pumps | Design Aspects (5:32) https://www.youtube.com/watch?v=pWSyrxFJmt4
http://www.learnengineering.org/2013/03/centrifugal-pumps-design-aspects.html



Total pressure-capacity curve

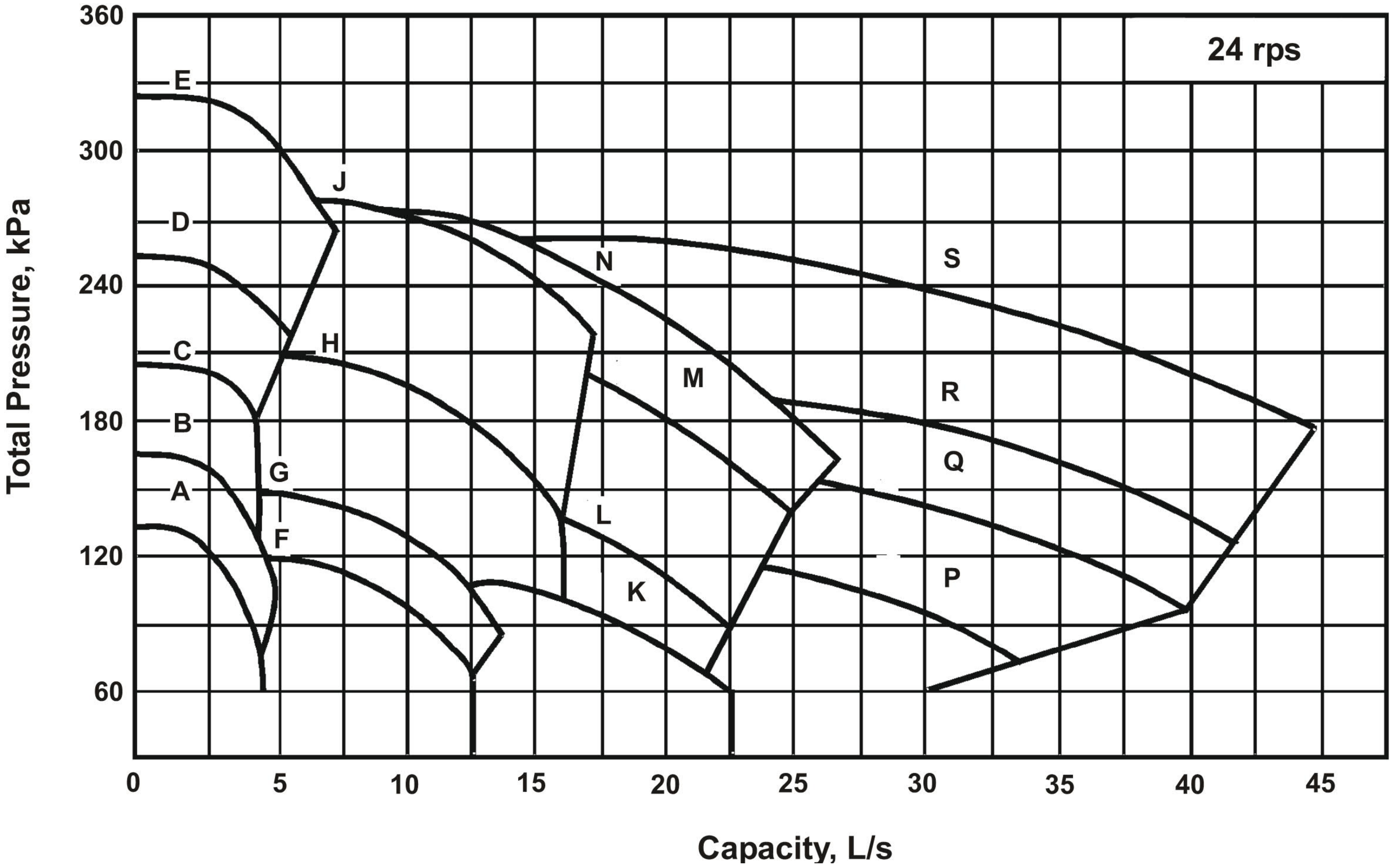
(Source: *Fundamentals of Water System Design*)



What does this imply?

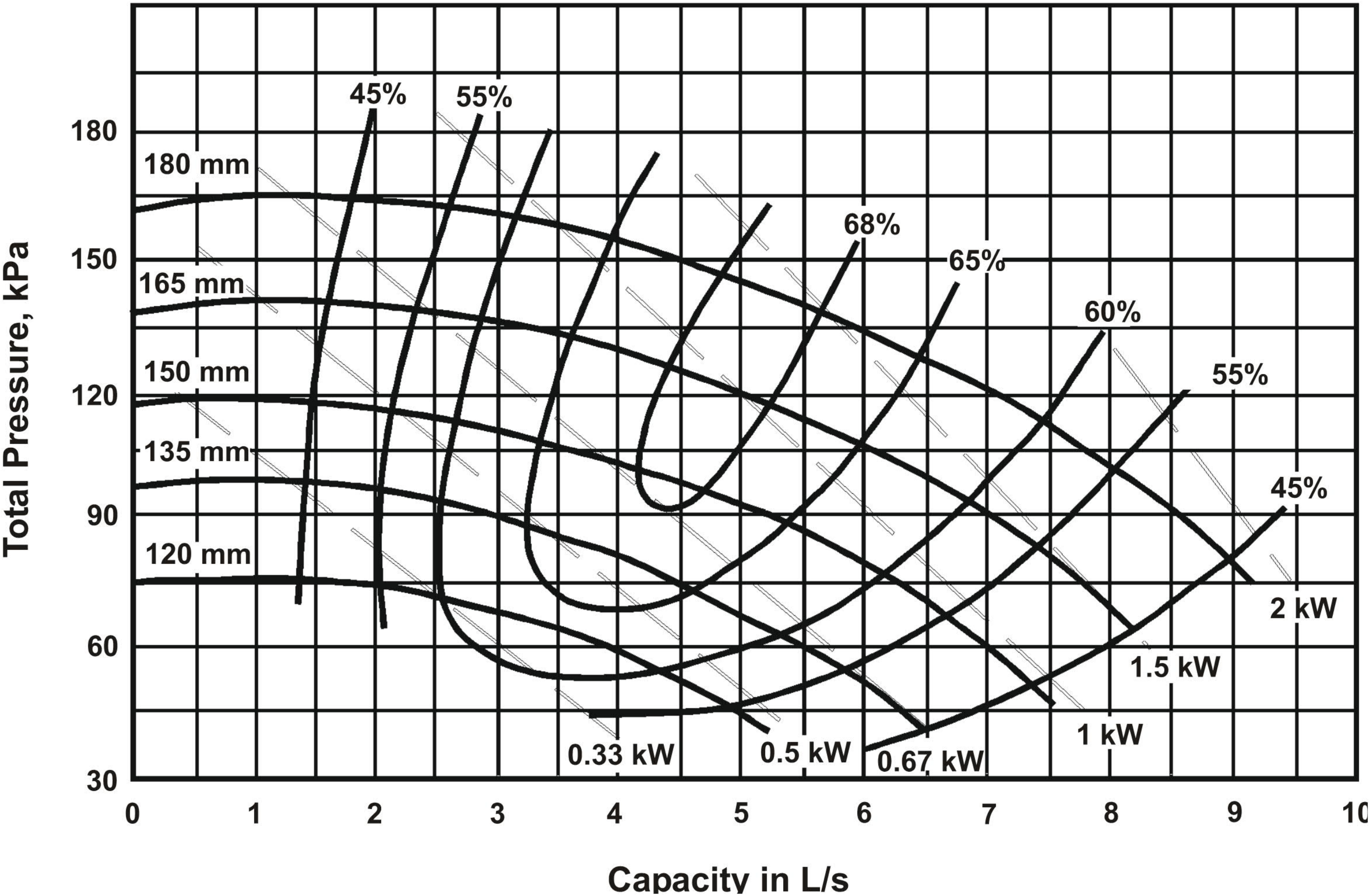
Flat versus steep pump curves

(Source: *Fundamentals of Water System Design*)



Characteristic curves for pump models

(Source: *Fundamentals of Water System Design*)

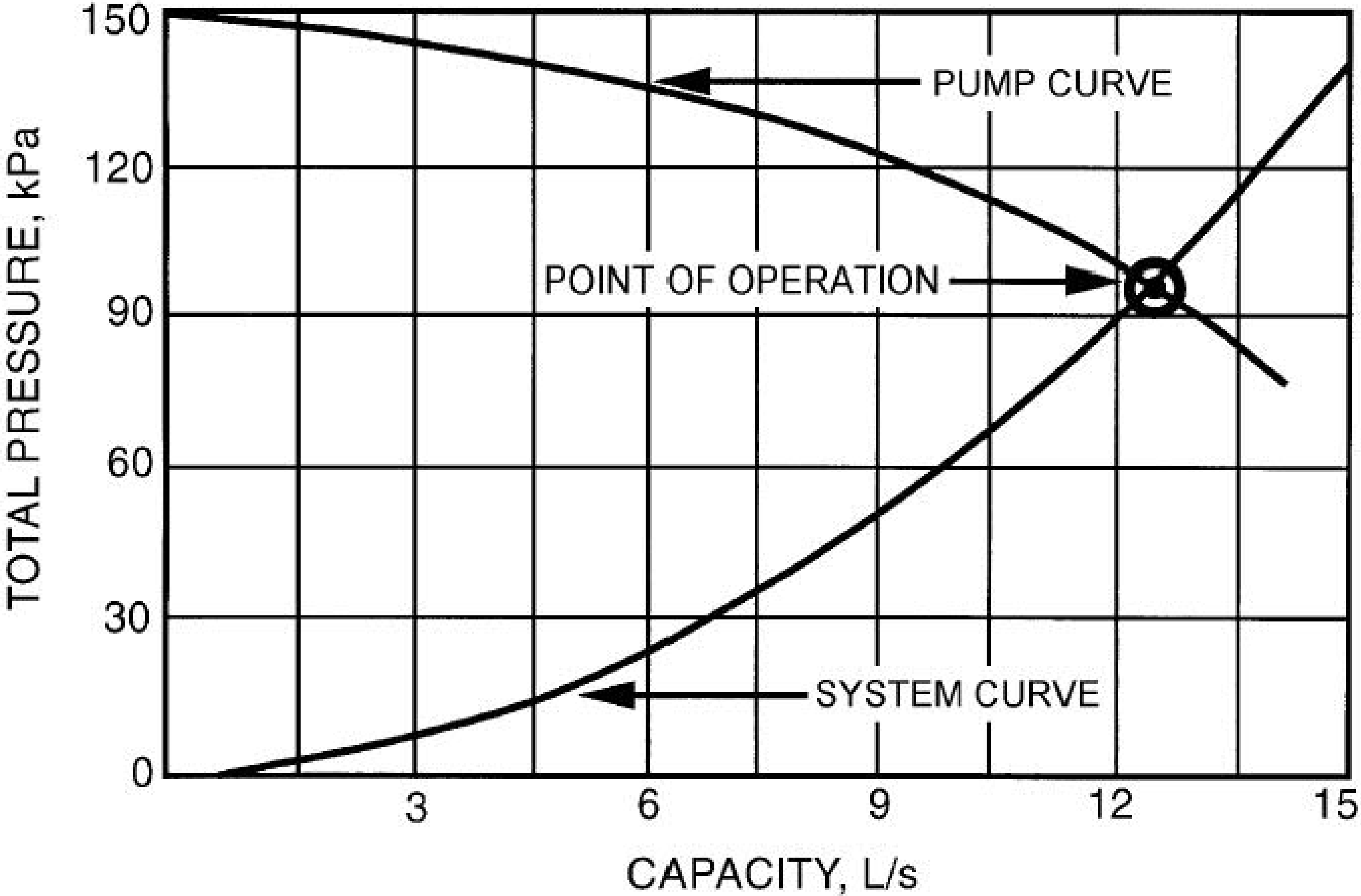


Selected pump pressure-capacity curve

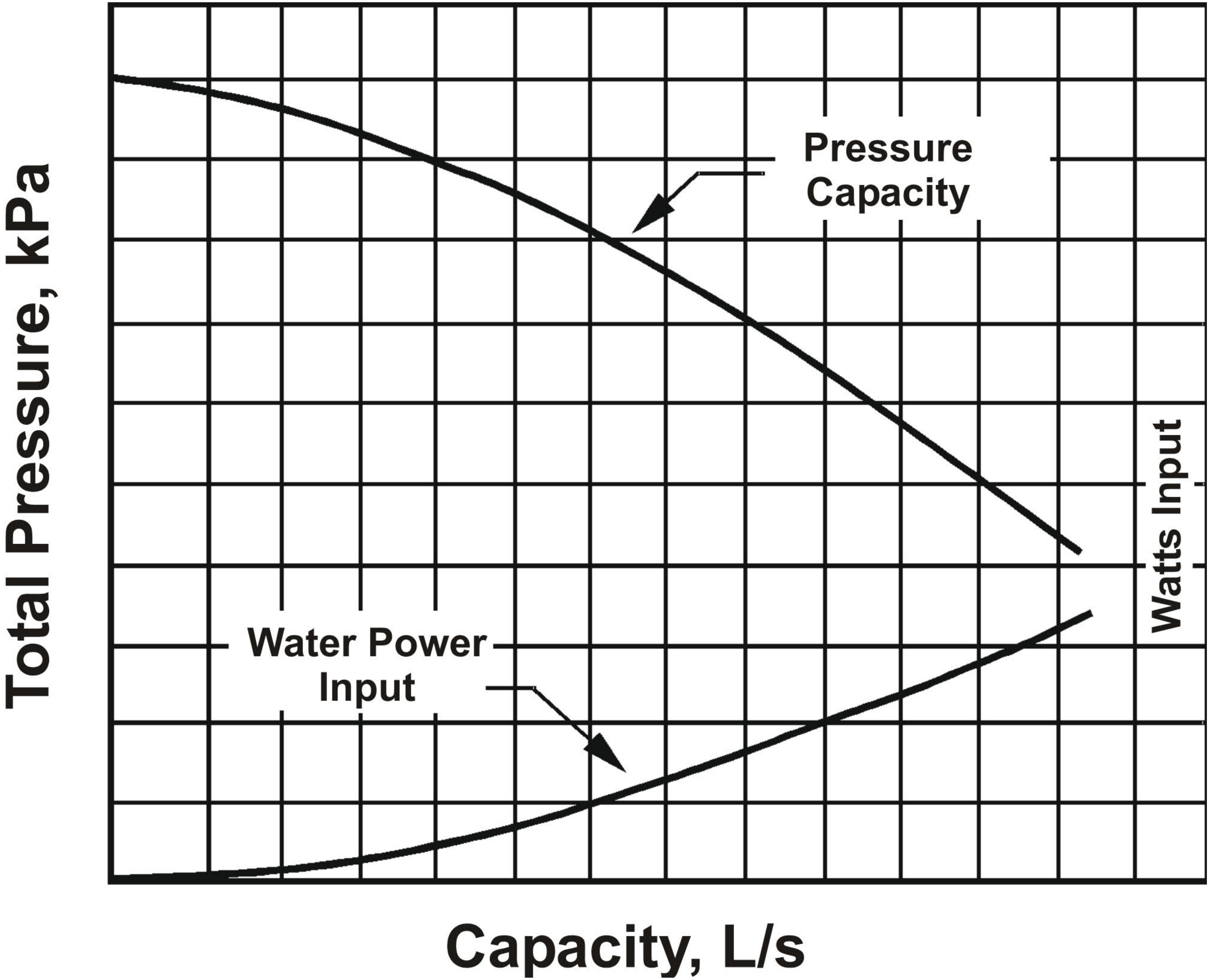
(Source: *Fundamentals of Water System Design*)

Centrifugal Pumps

- 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

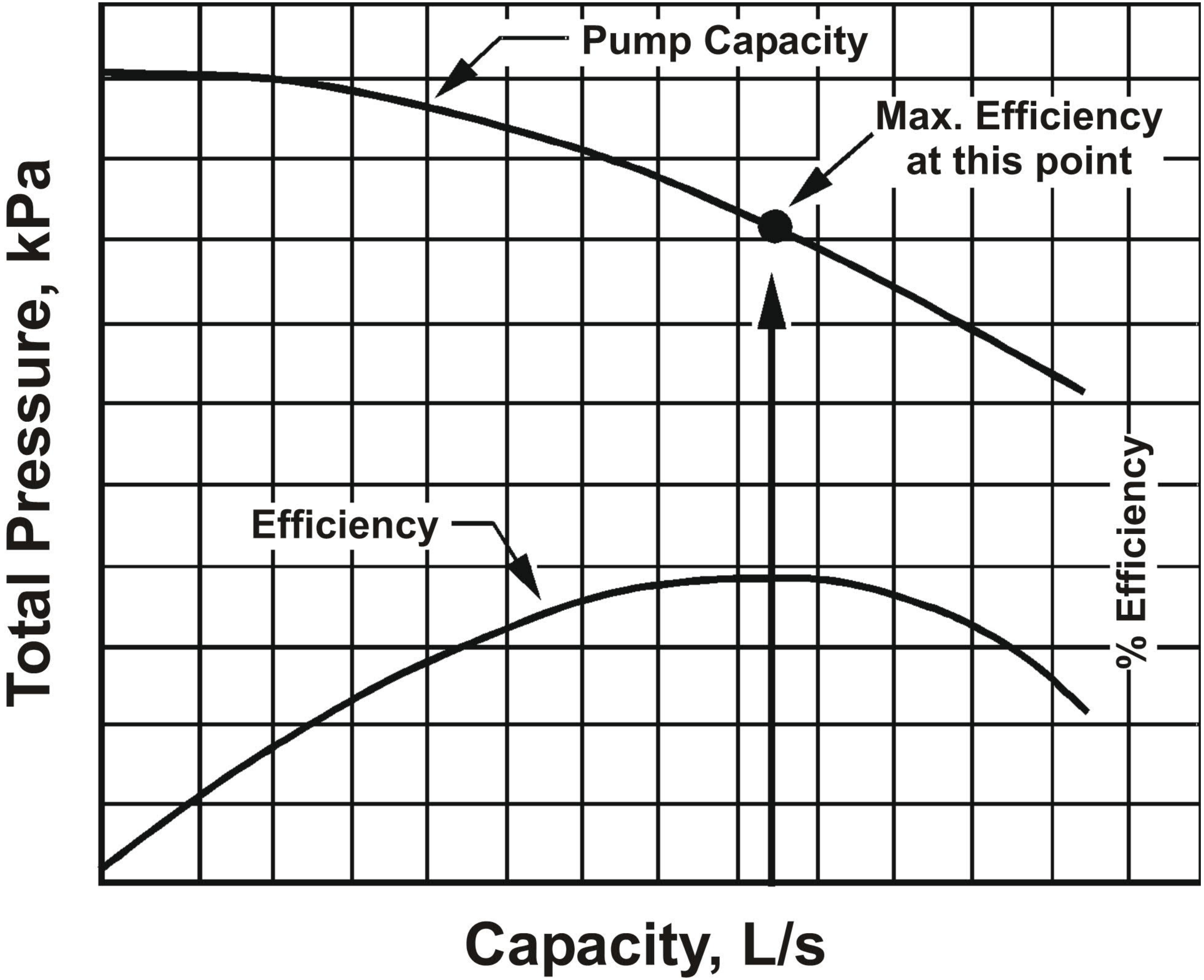


(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)



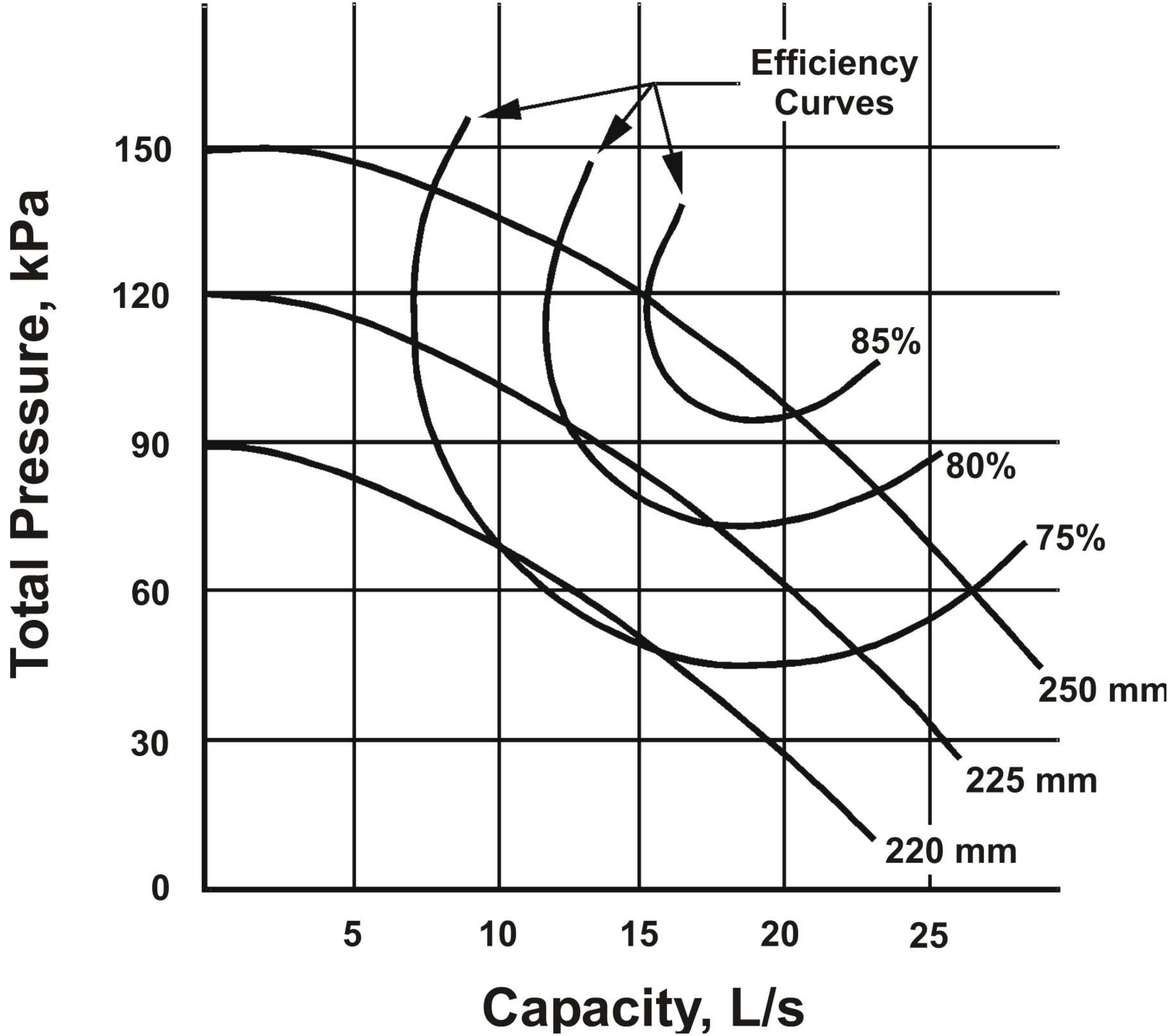
Increase of pumping power required with pump flow

(Source: *Fundamentals of Water System Design*)



Pump efficiency

(Source: *Fundamentals of Water System Design*)



Pump efficiency curve

(Source: *Fundamentals of Water System Design*)

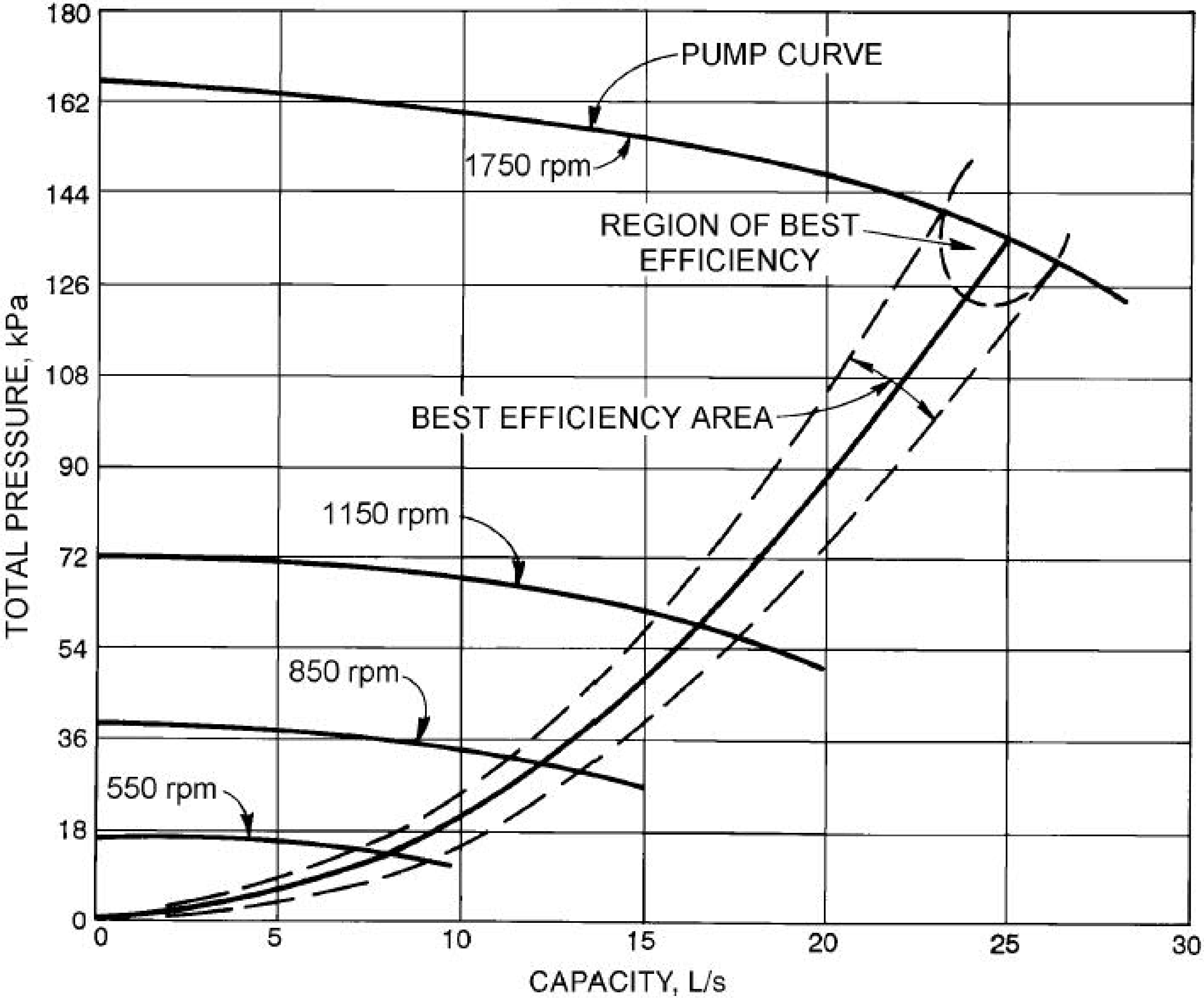
Centrifugal Pumps

- 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	$P_2 = P_1\ (N_2/N_1)^3$	$P_2 = P_1\ (D_2/D_1)^3$

Centrifugal Pumps

- 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.
  - <u>Solution</u>:
    - Flow: $Q_2 = Q_1\ (N_2/N_1) = 15\ (16/24) = \underline{10\ \text{L/s}}$
    - Pressure: $p_2 = p_1\ (N_2/N_1)^2 = 200\ (16/24)^2 = \underline{88.9\ \text{kPa}}$

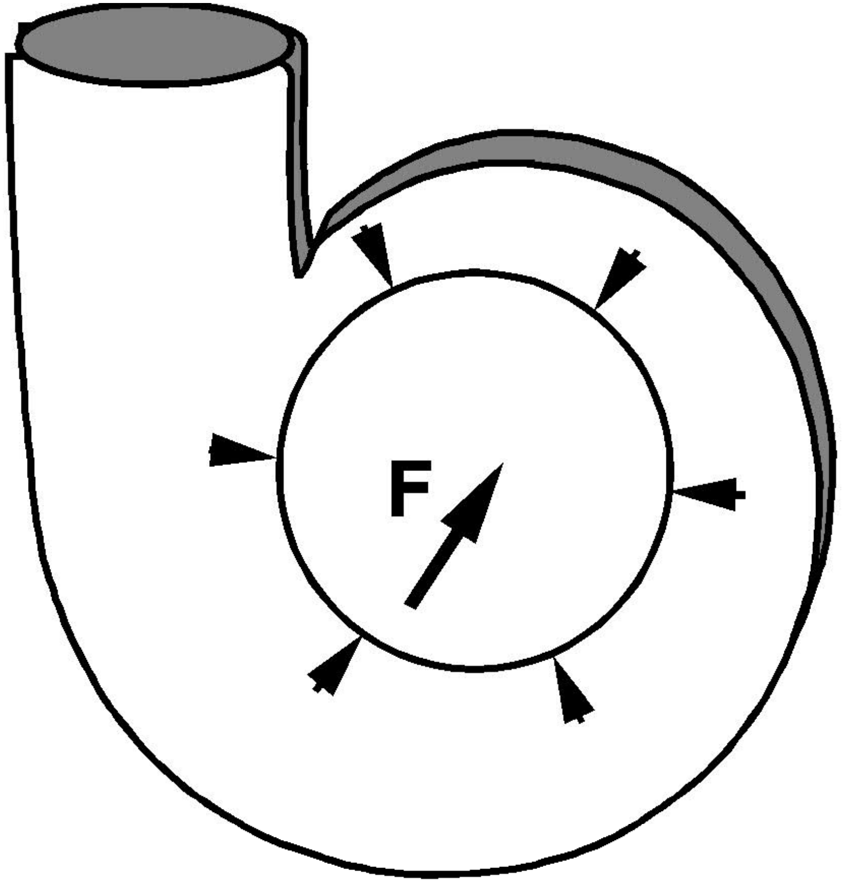


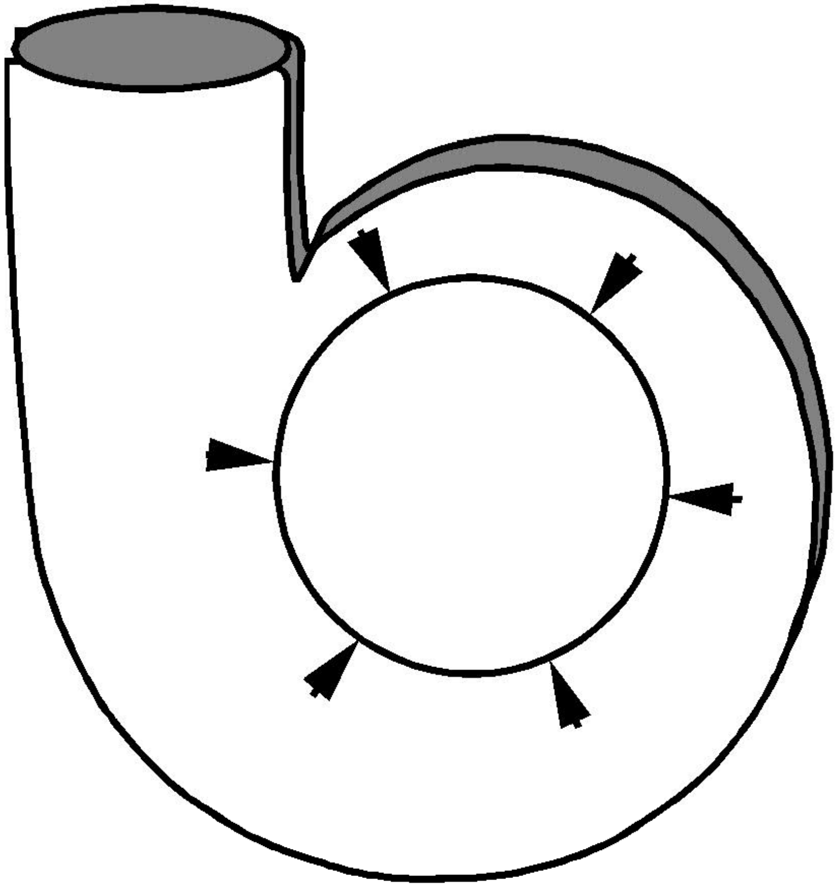
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Centrifugal Pumps

- 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://www.youtube.com/watch?v=oRYYP4F8LTU



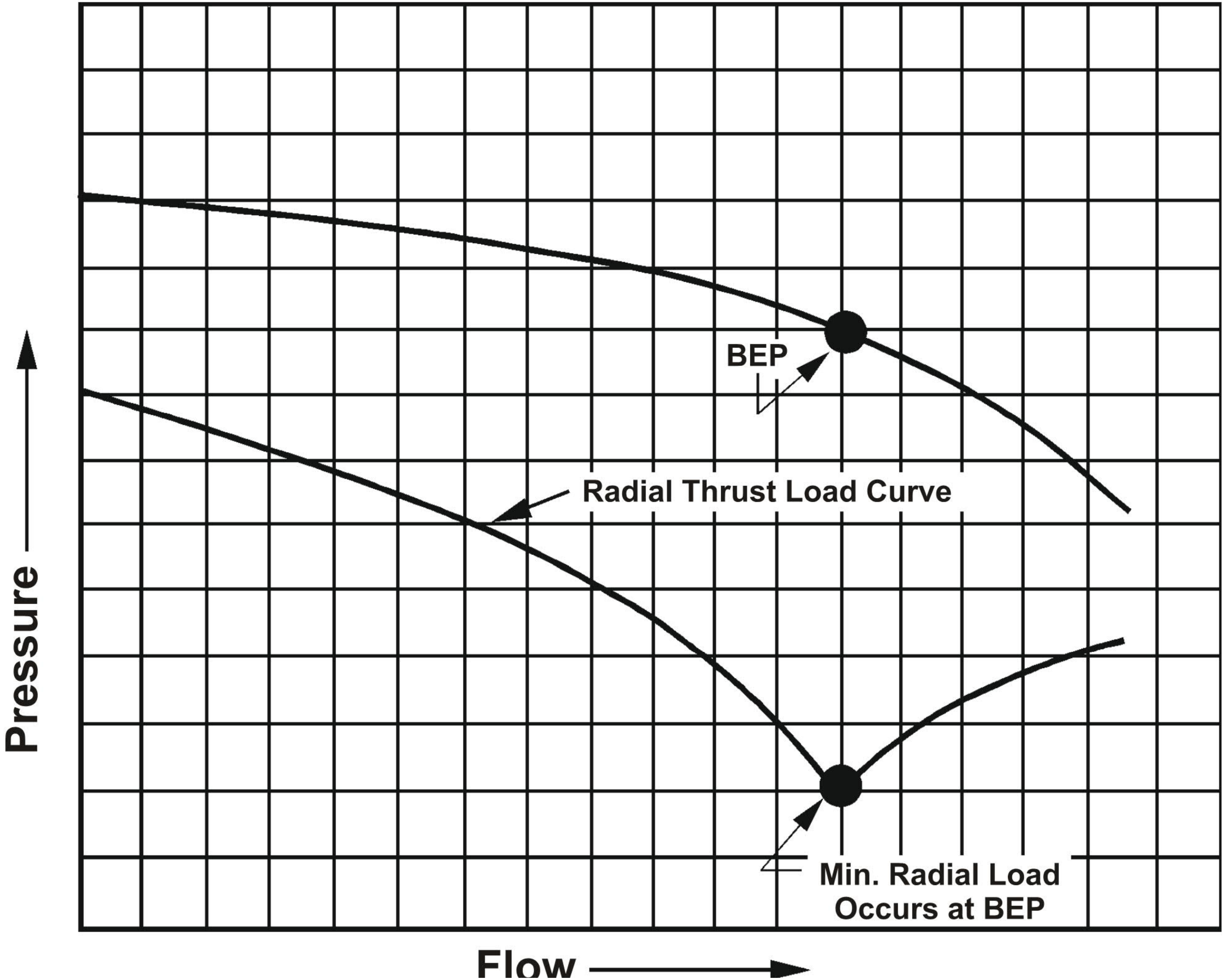


Uniform Pressures Exist at Design Capacity

Non-Uniform Pressures Exist at Reduced Capacities

Pressures on impeller causing radial thrust

(Source: *Fundamentals of Water System Design*)



Change in radial thrust versus pumping rate

(Source: *Fundamentals of Water System Design*)

Centrifugal Pumps

- Net positive suction available (NPSA)
  - 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.
  - Avoid problem, NPSA > NPSR

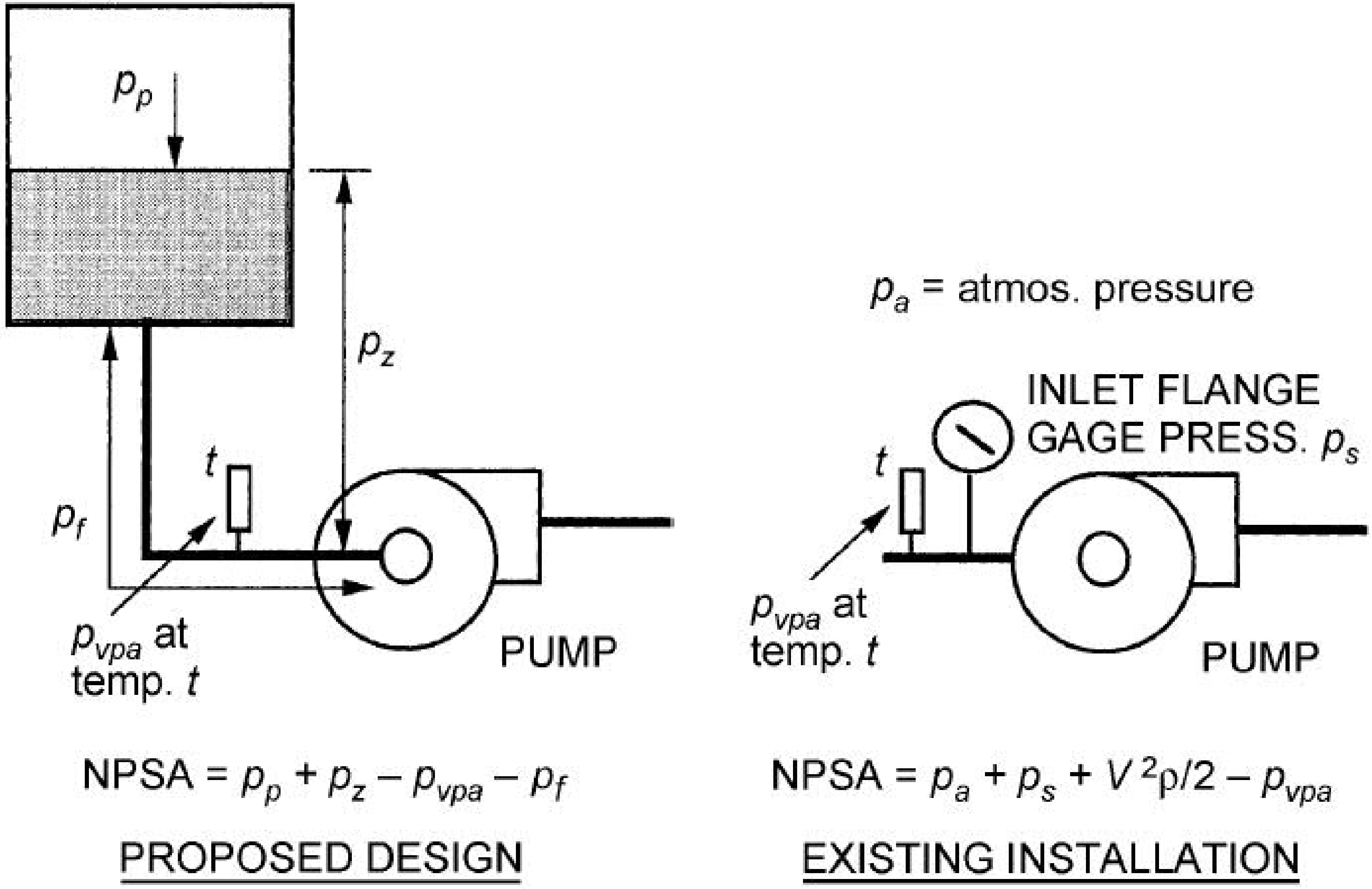
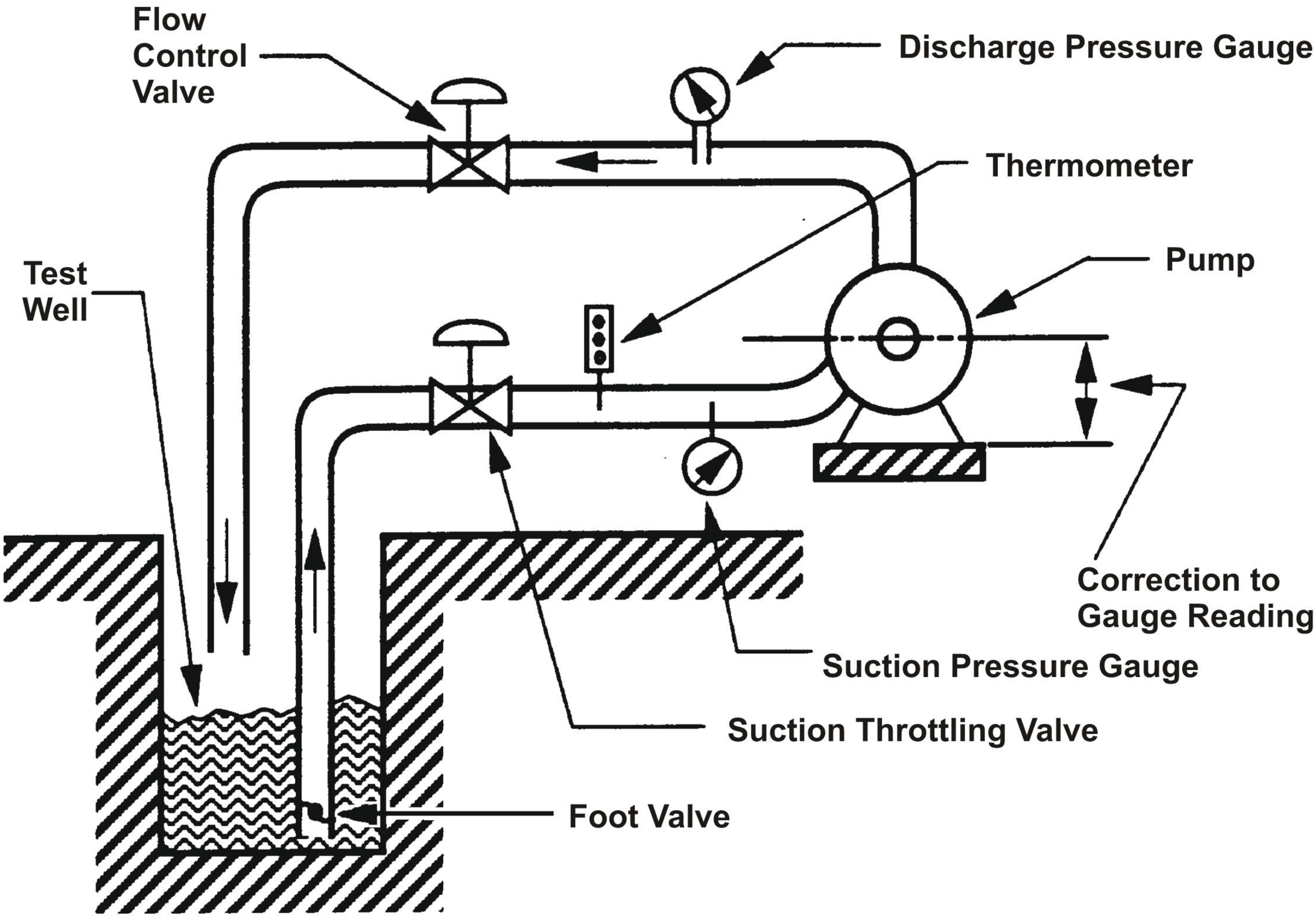


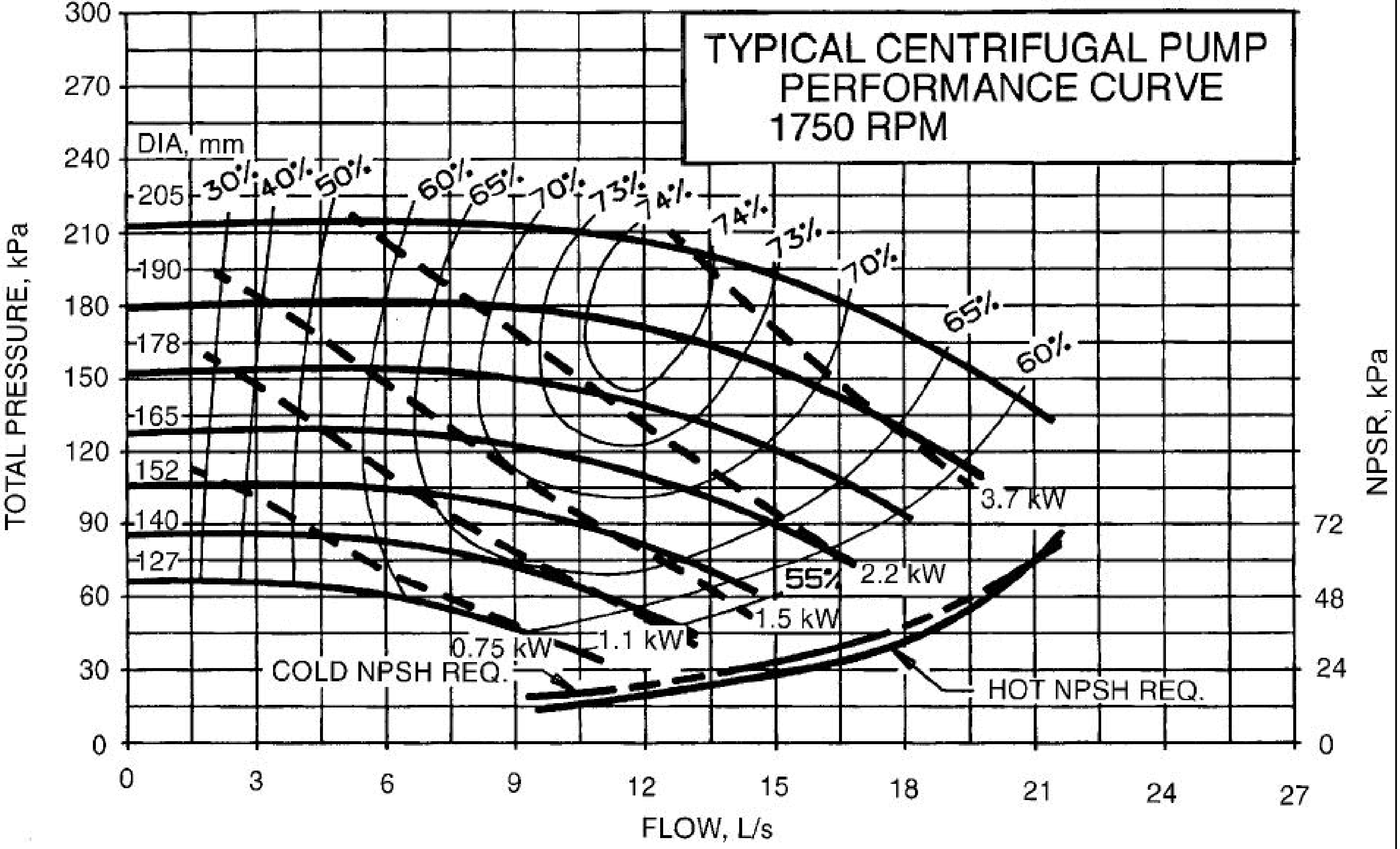
Fig. 29 Net Positive Suction Pressure Available

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



Test setup to determine pump’s NPSR

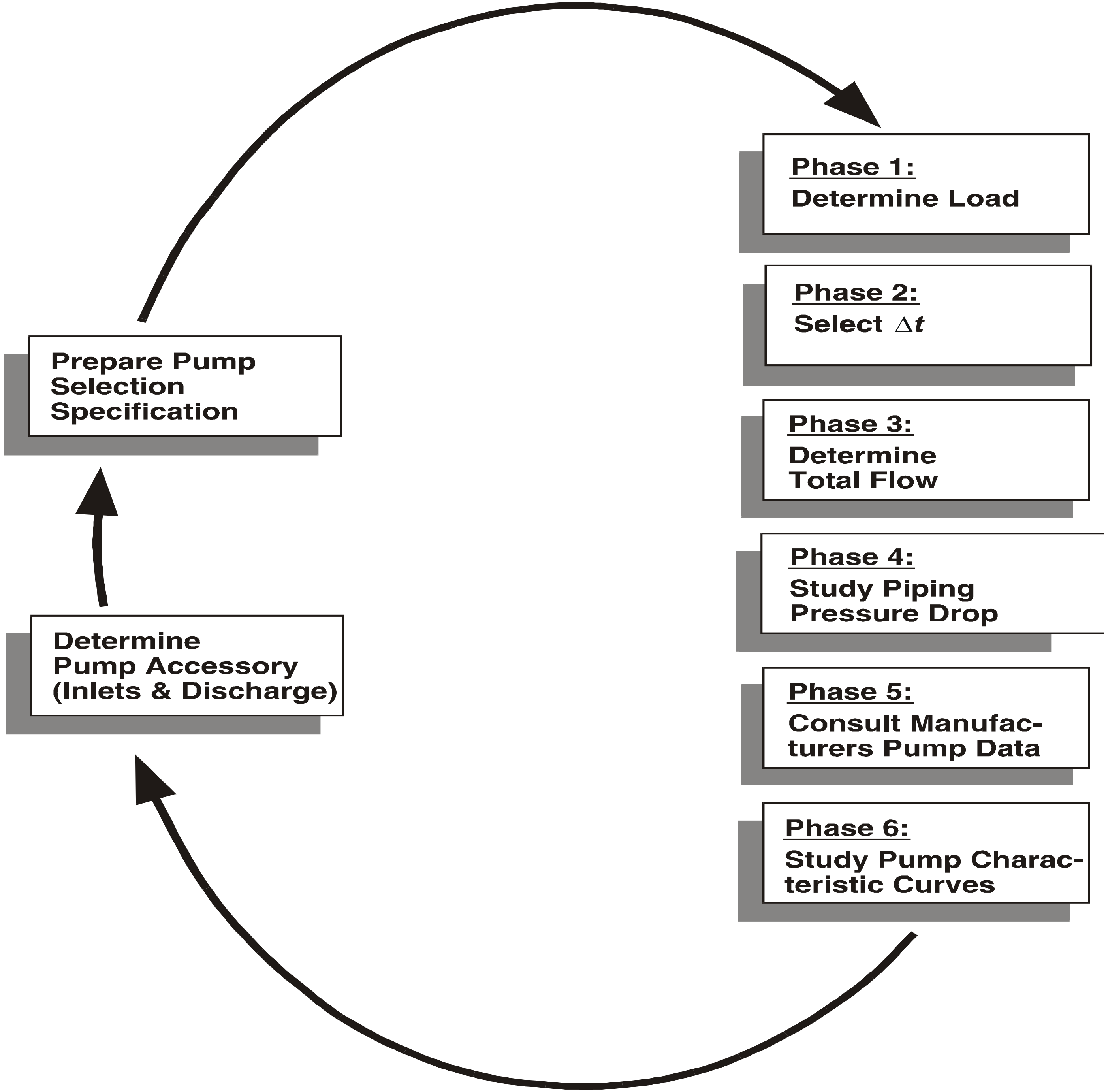
(Source: *Fundamentals of Water System Design*)



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

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



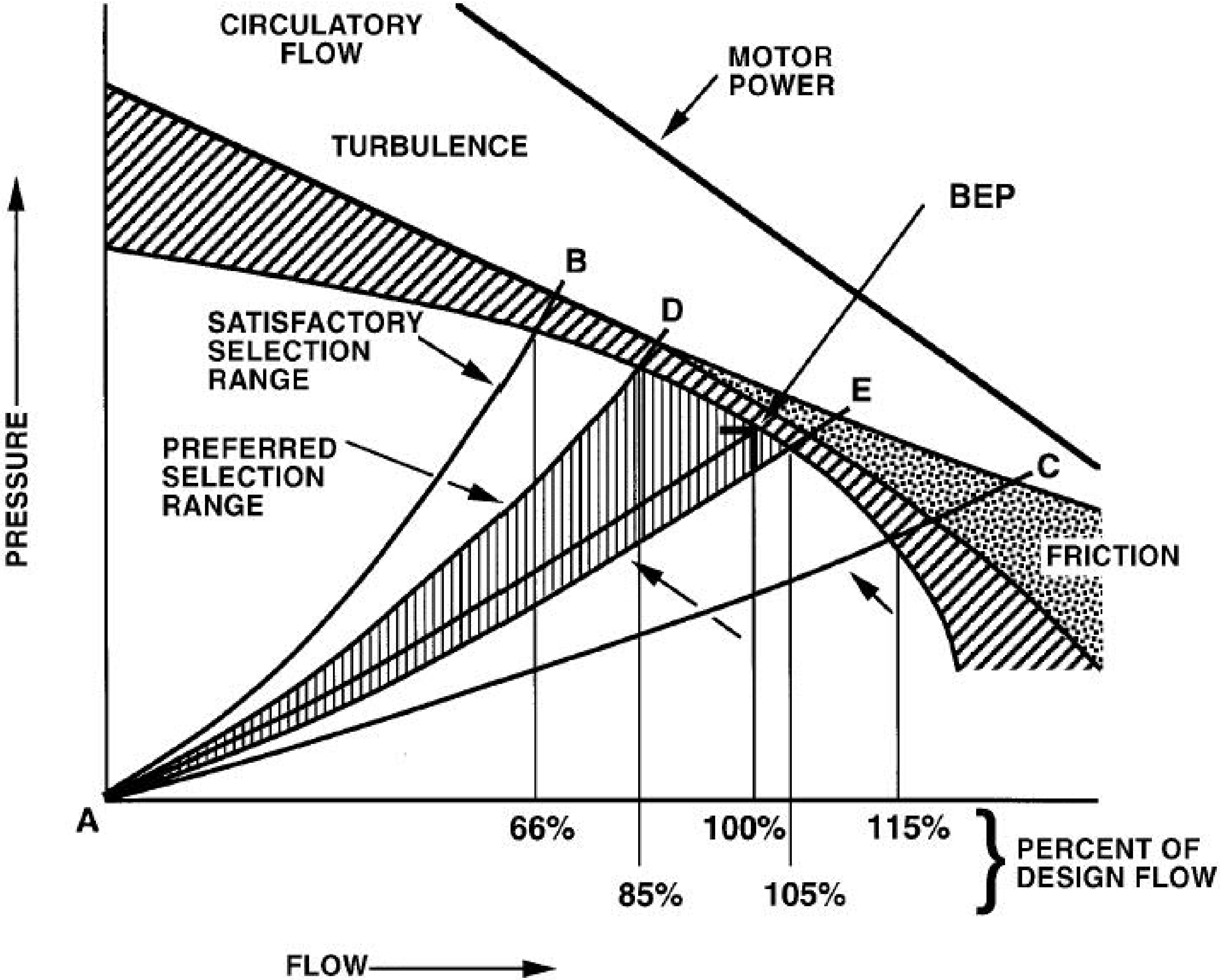
Pump selection process

(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

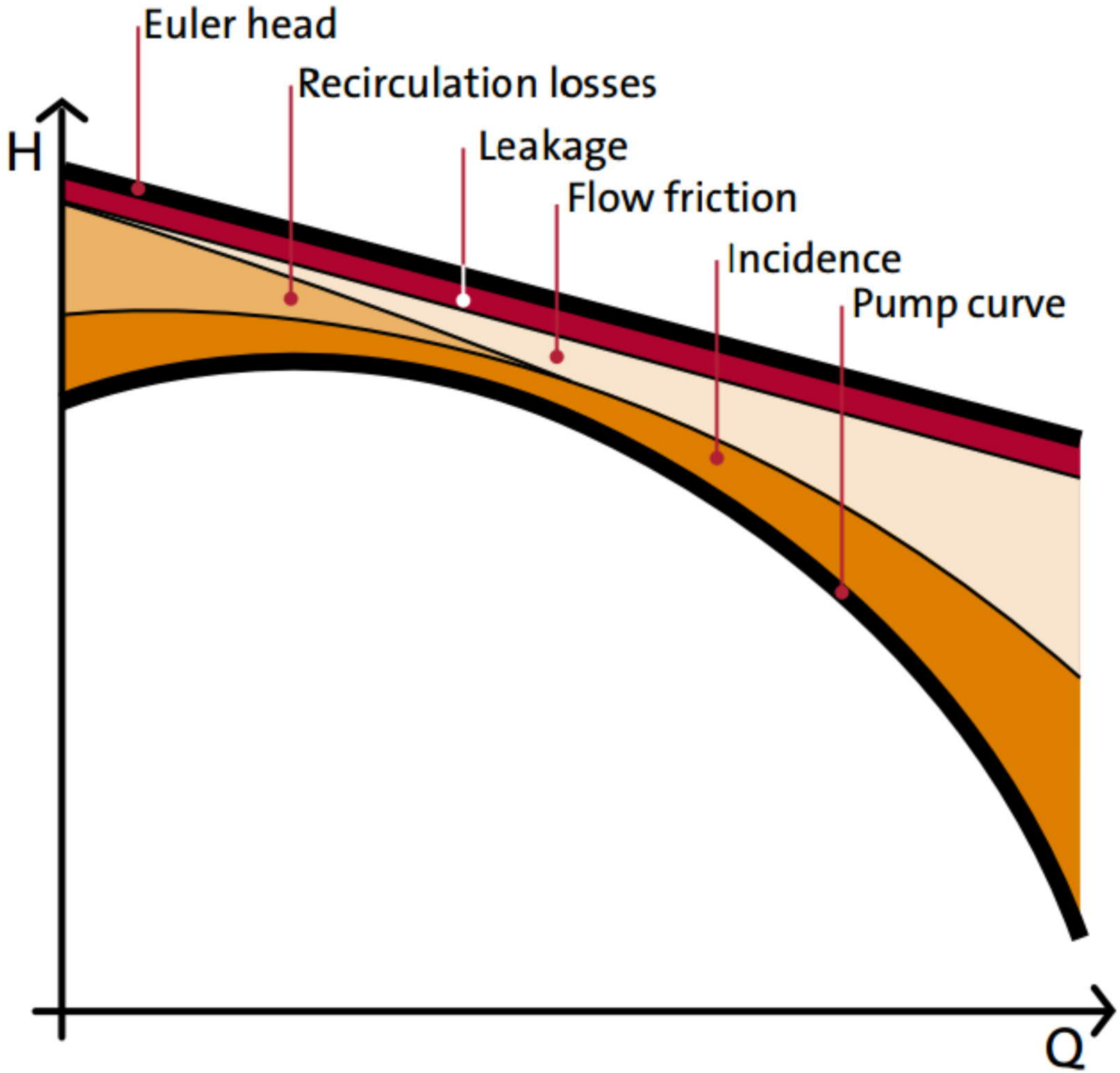
* Critical Pump Selection - Three Major Issues (20:25) https://www.youtube.com/watch?v=qUONRrP-5pc



Pump selection regions

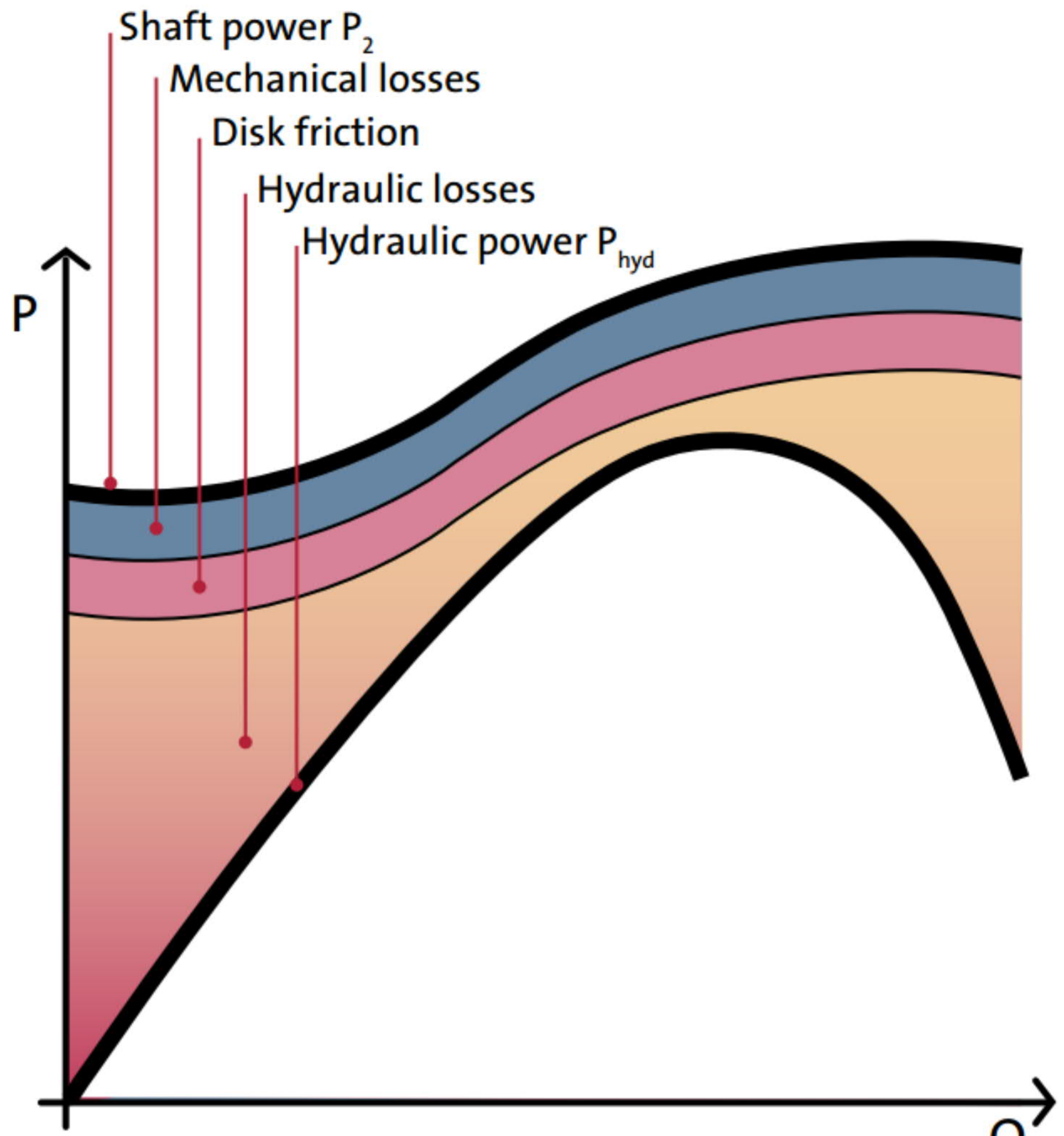
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Reduction of theoretical Euler head due to losses

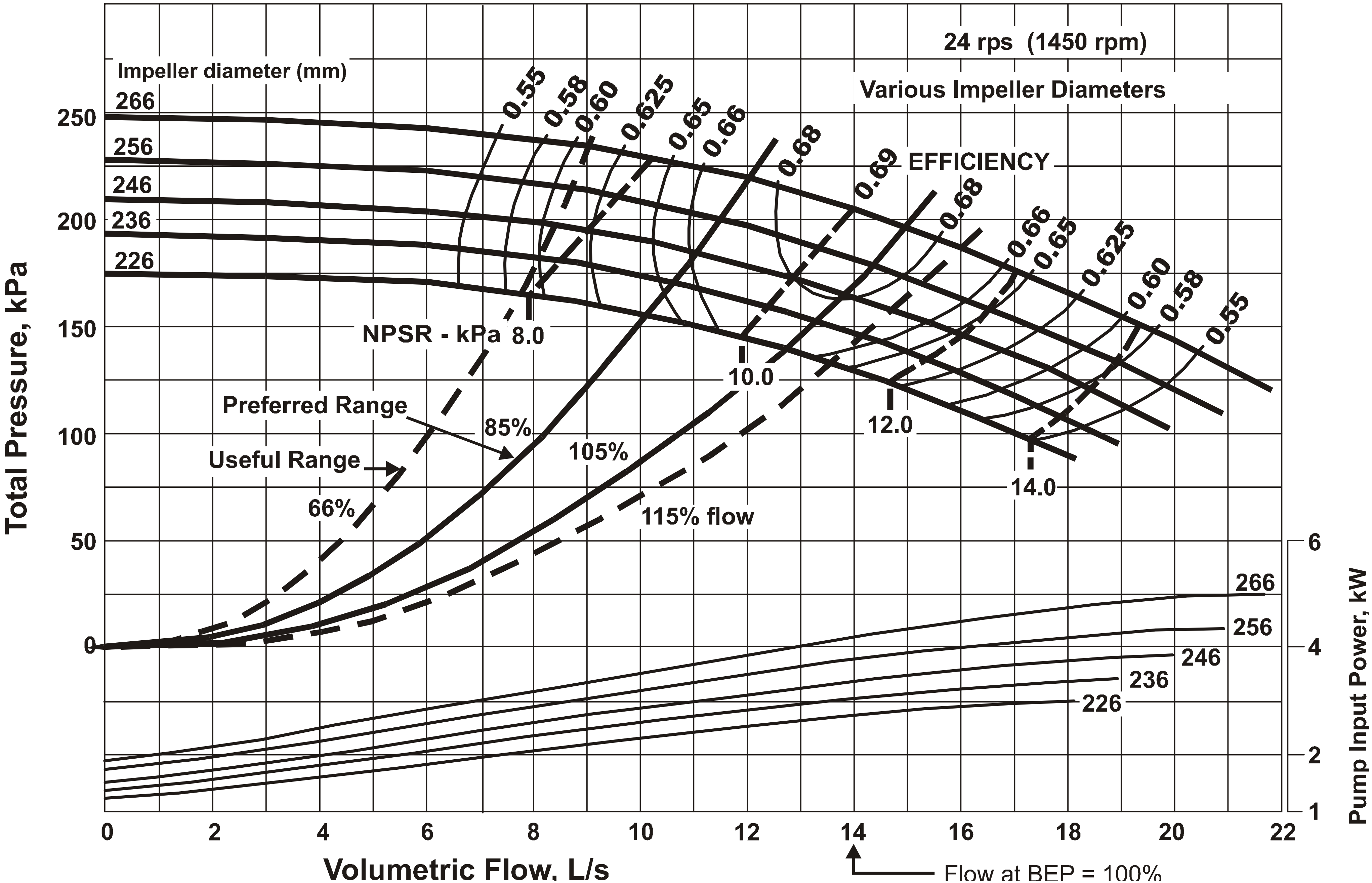


(Source: Grundfos)

Increase in power consumption due to losses



(Source: Grundfos)

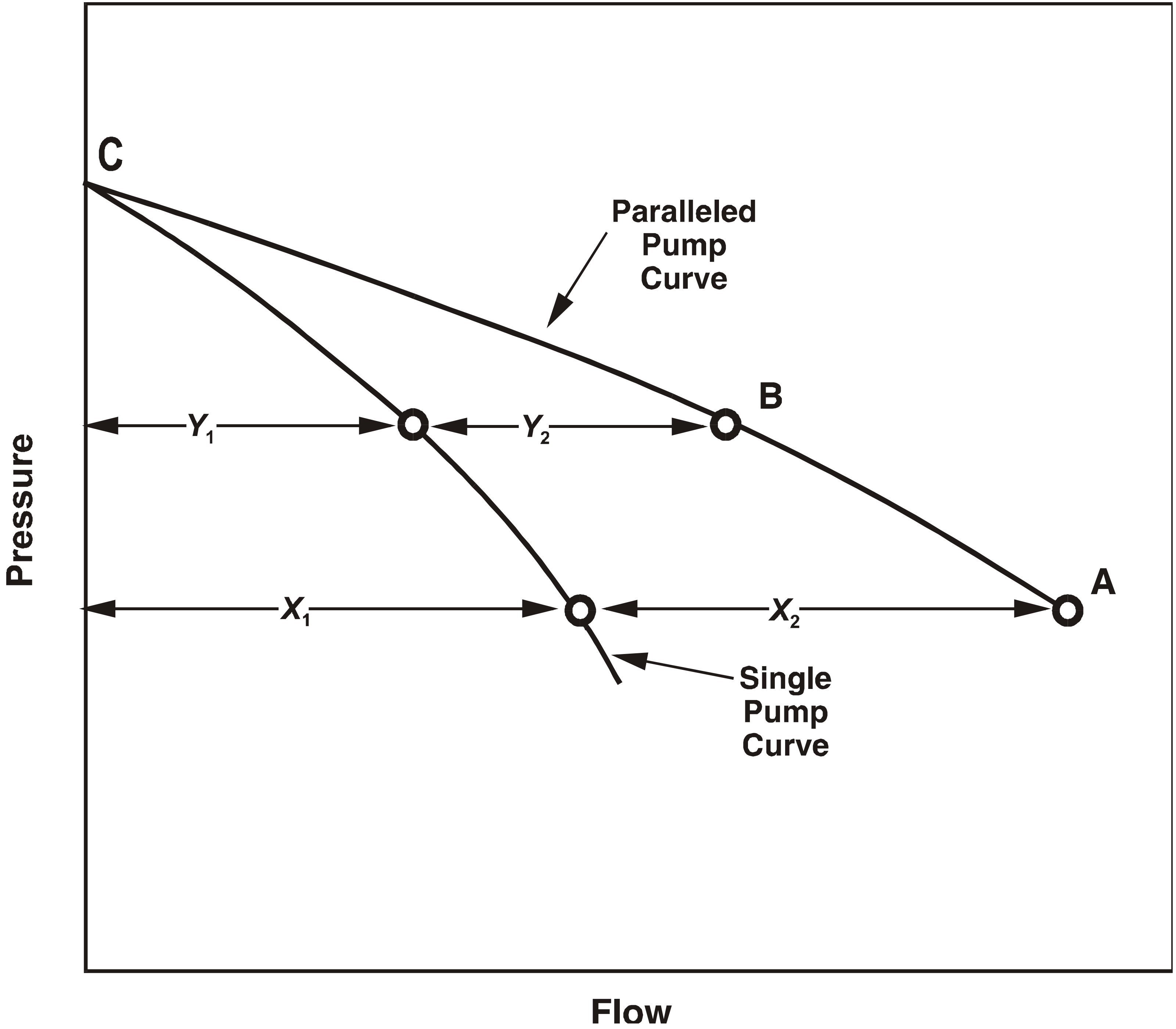


Pump performance data

(Source: *Fundamentals of Water System Design*)

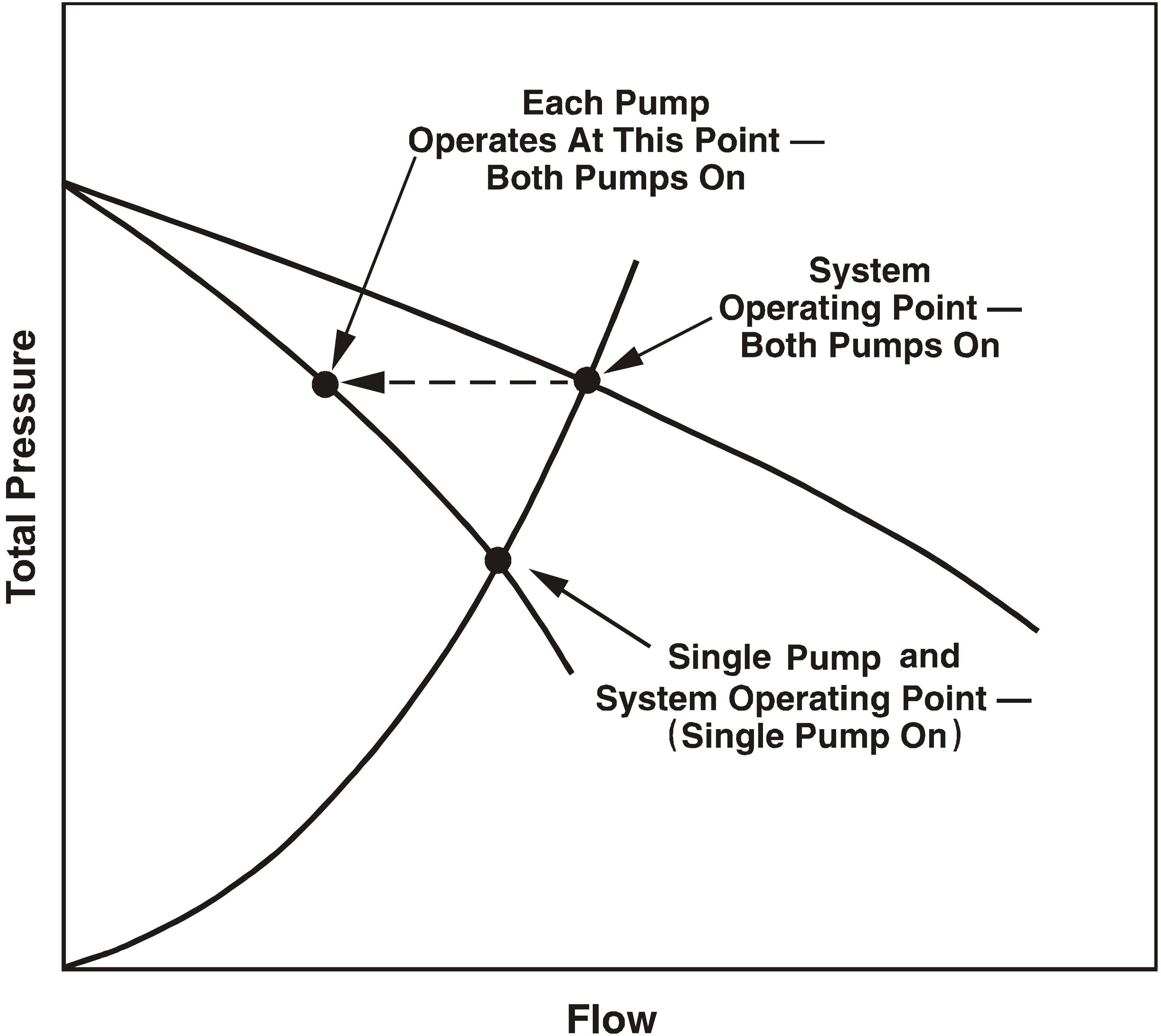
Pump Arrangements

- 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*)

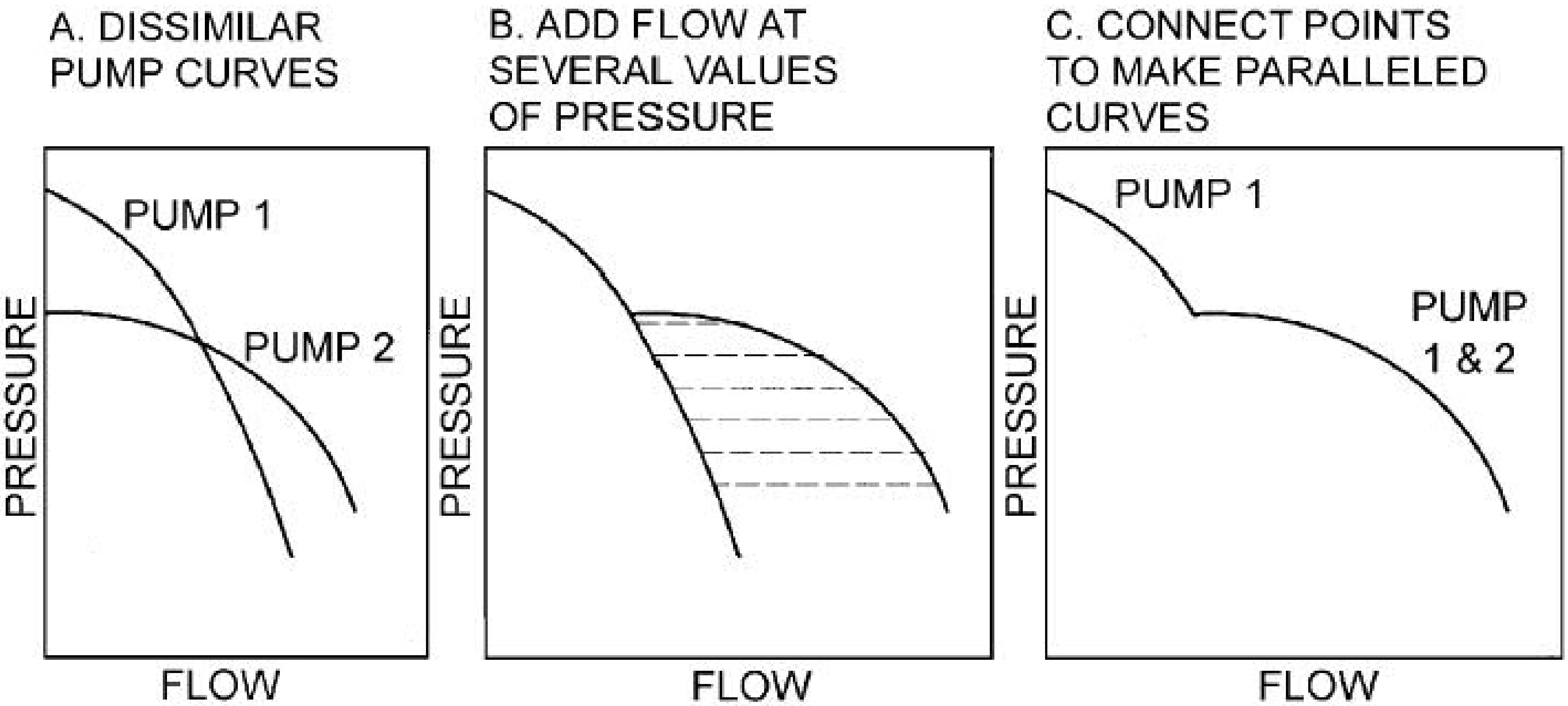


Fig. 34 Construction of Curve for Dissimilar Parallel Pumps

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

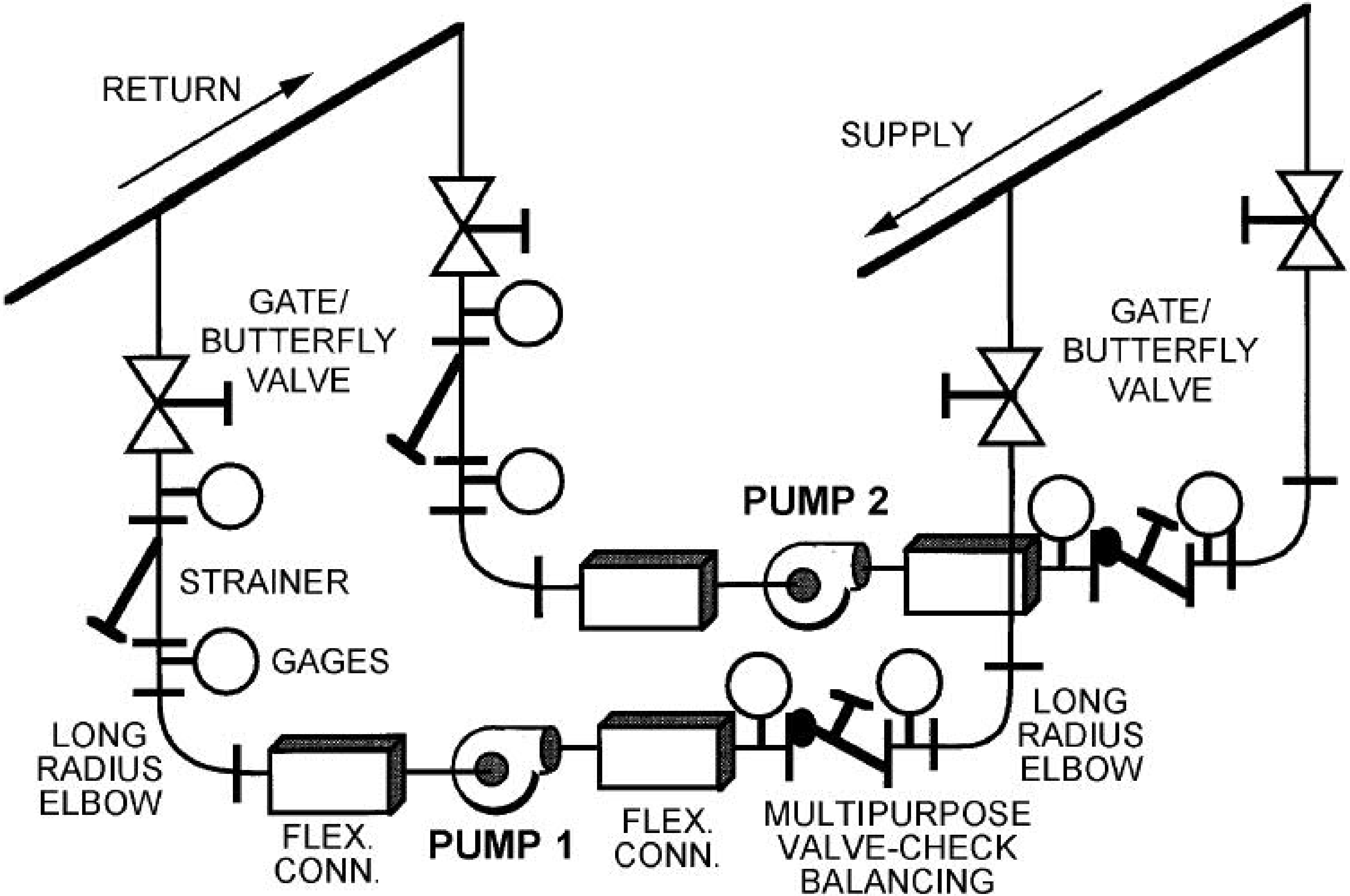
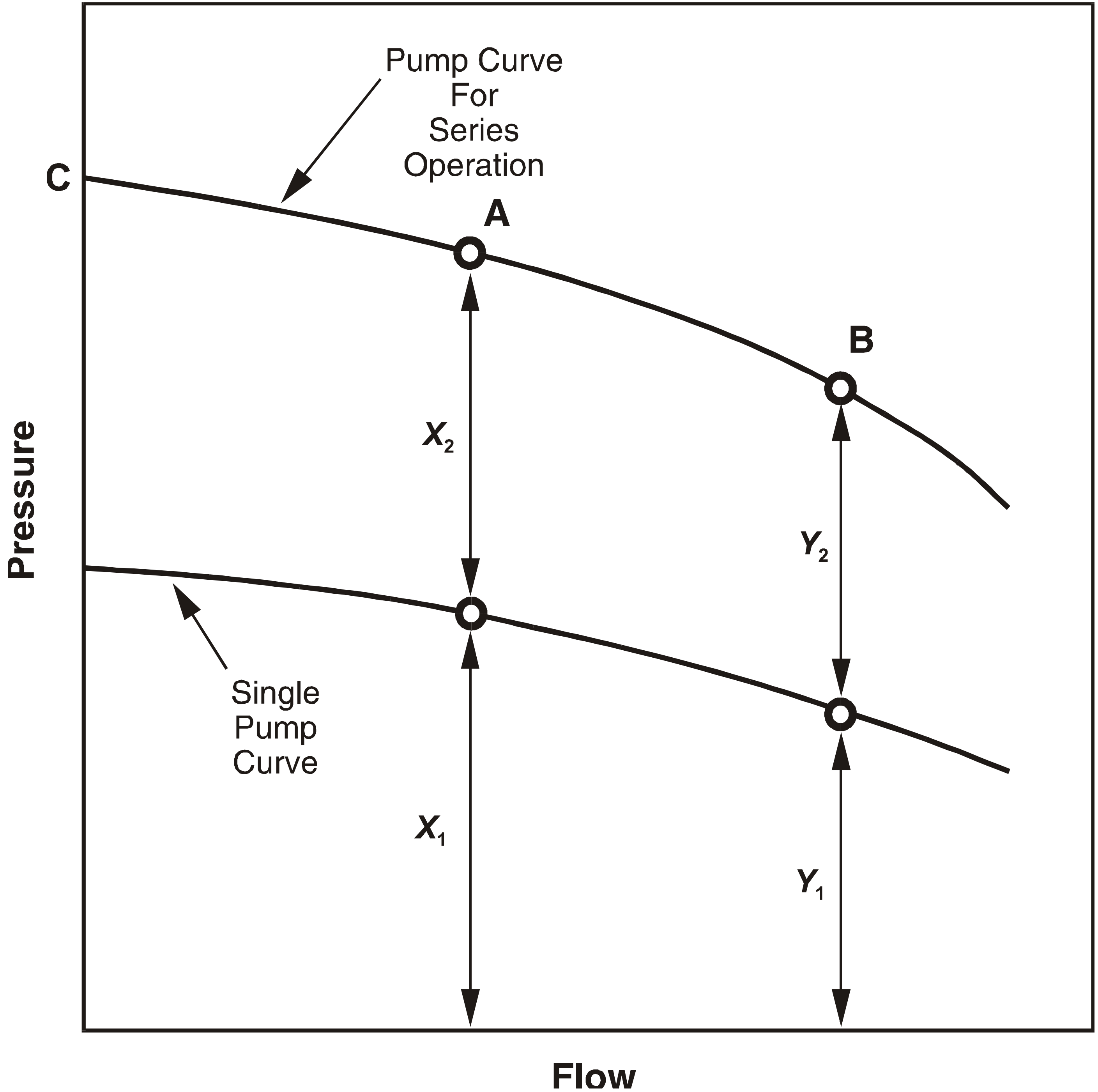


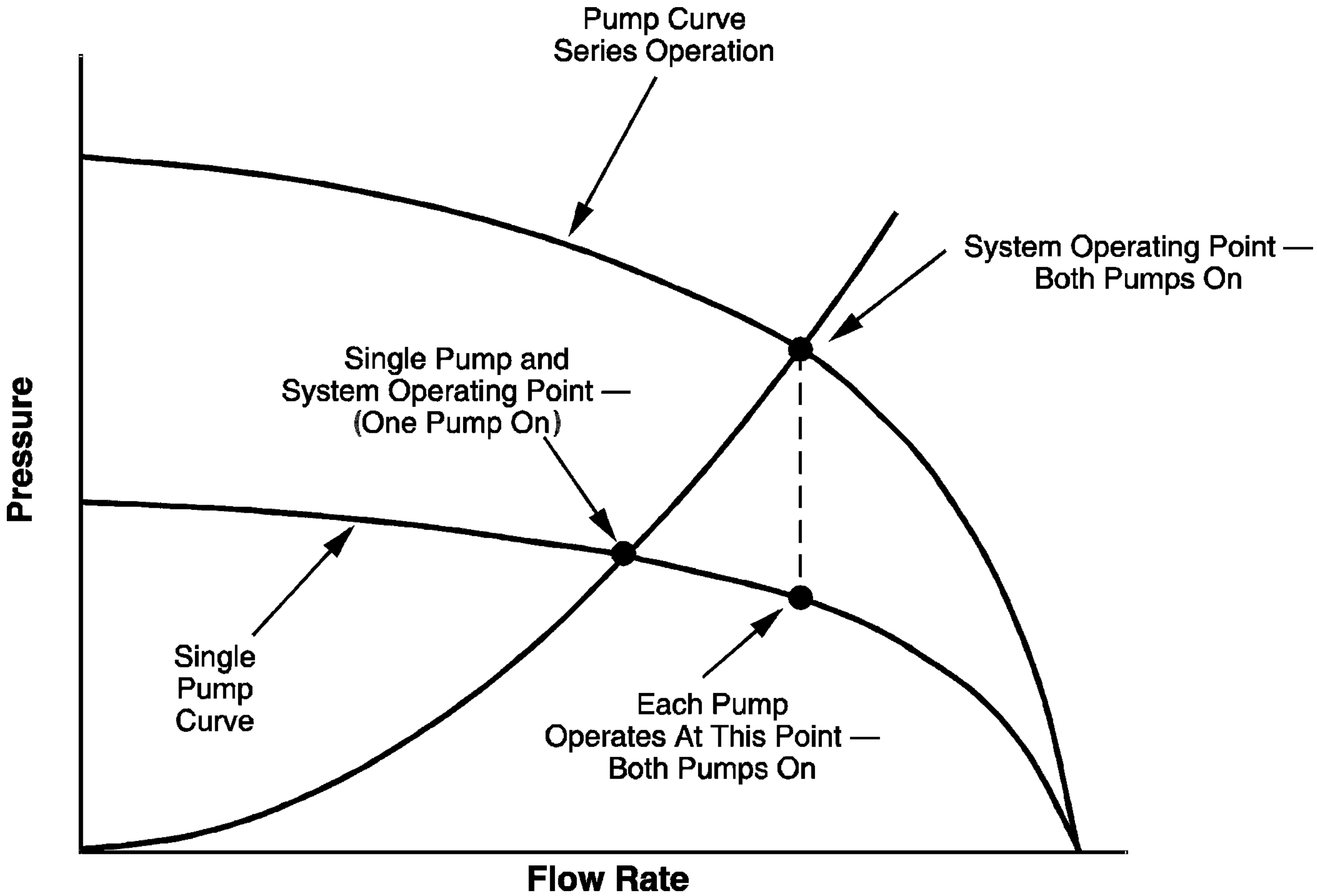
Fig. 35 Typical Piping for Parallel Pumps

(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*)

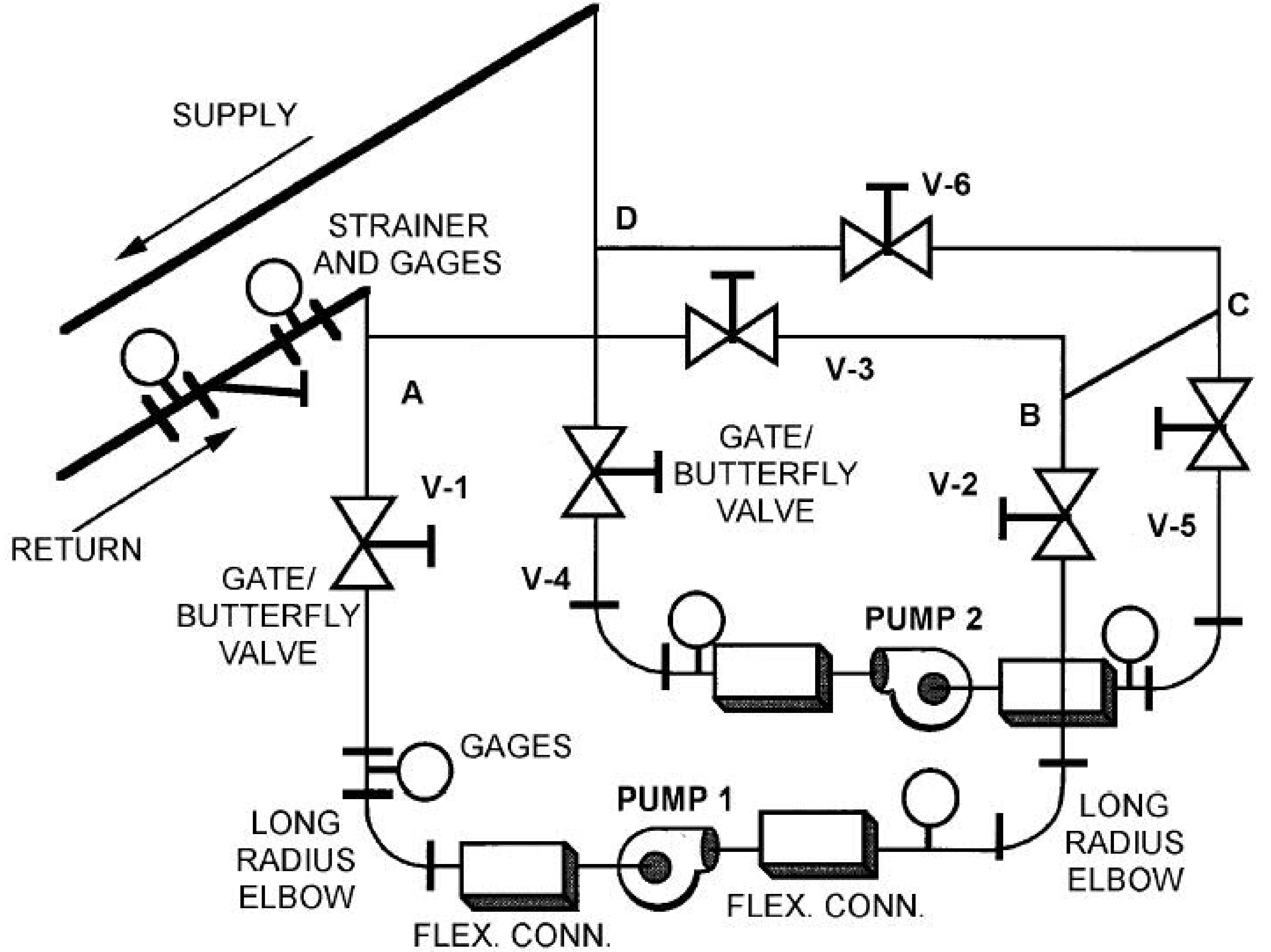
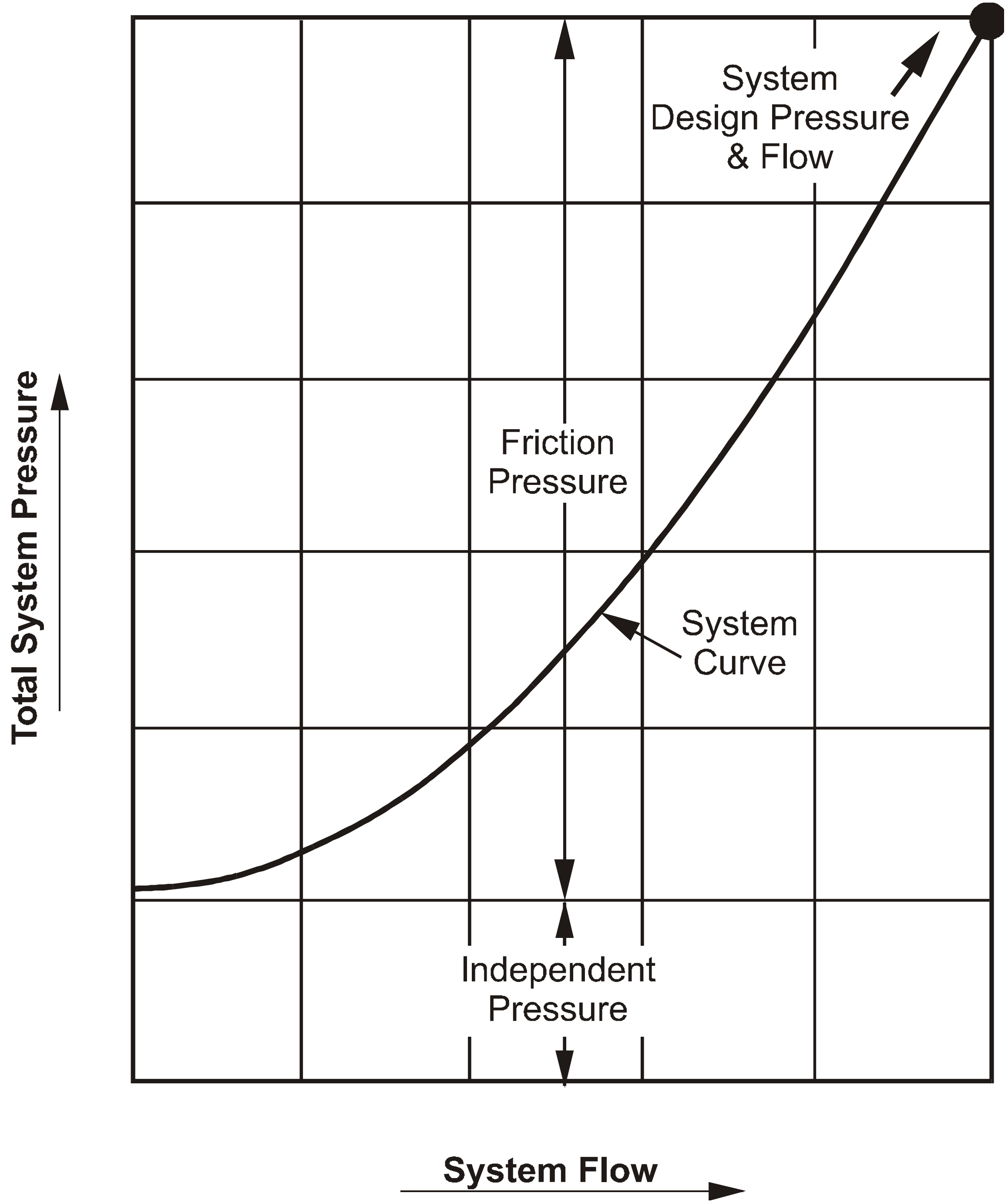


Fig. 38 Typical Piping for Series Pumps

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

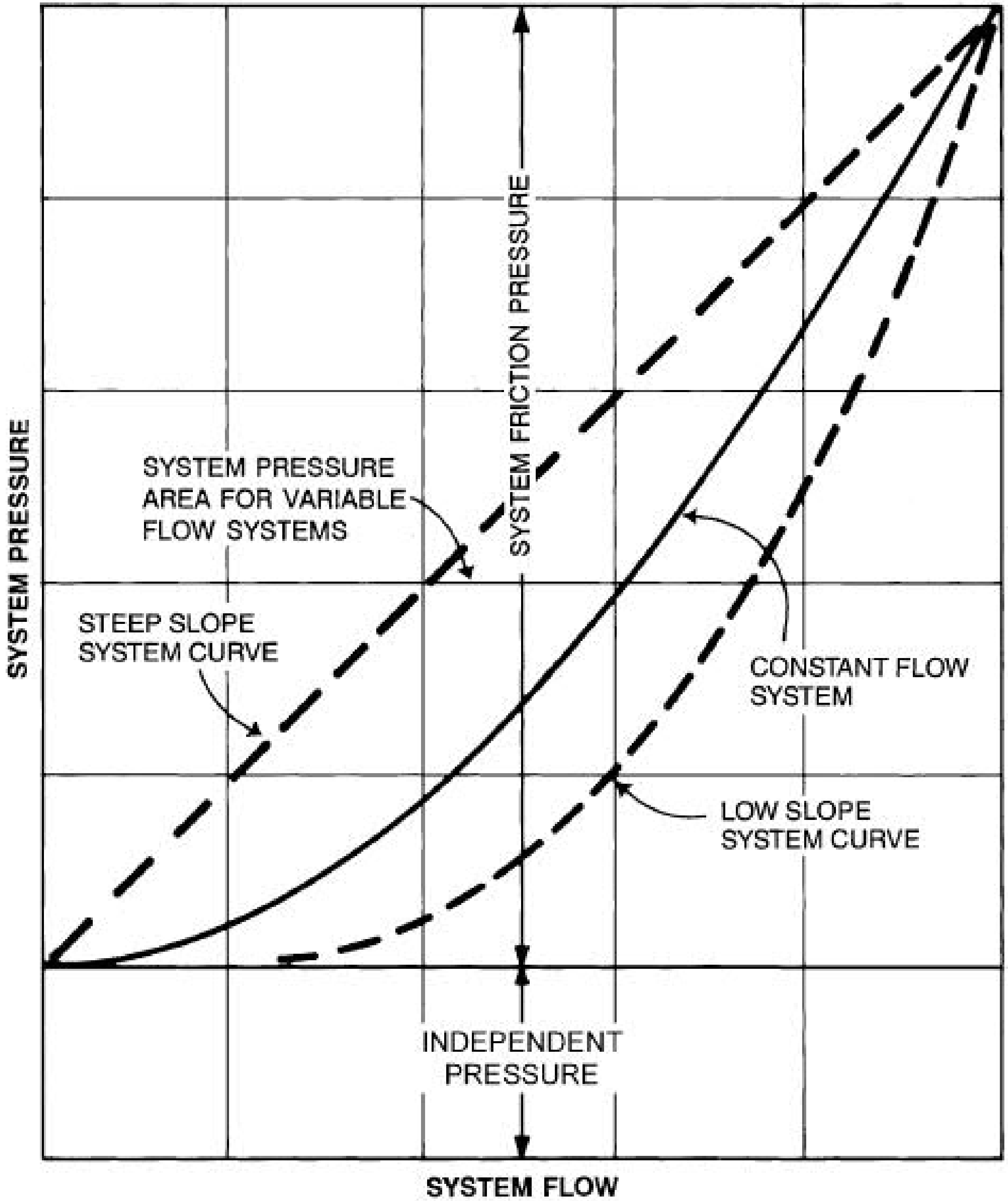
Matching Pumps to Systems

- 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

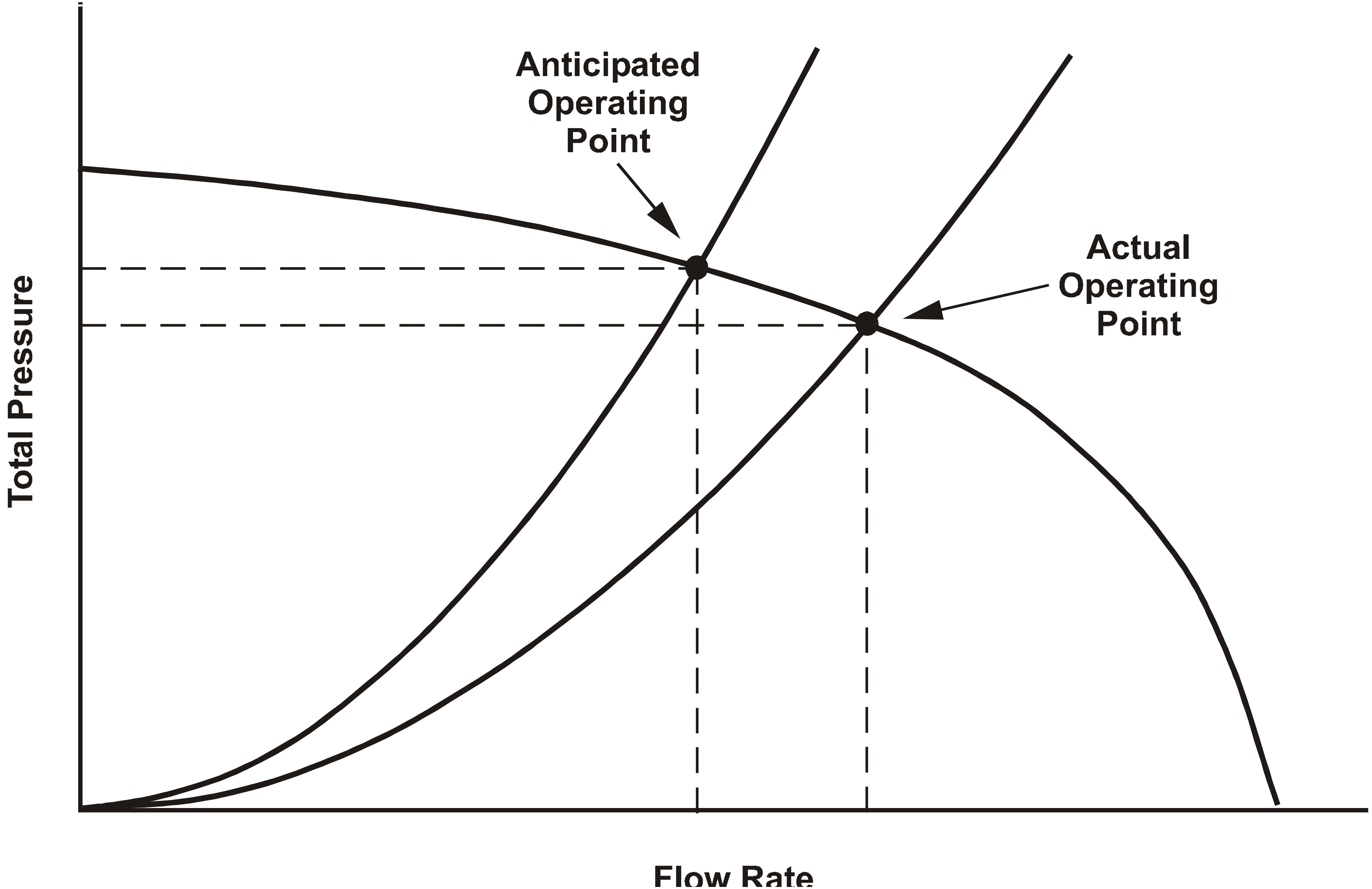


Typical system curve

(Source: *Fundamentals of Water System Design*)

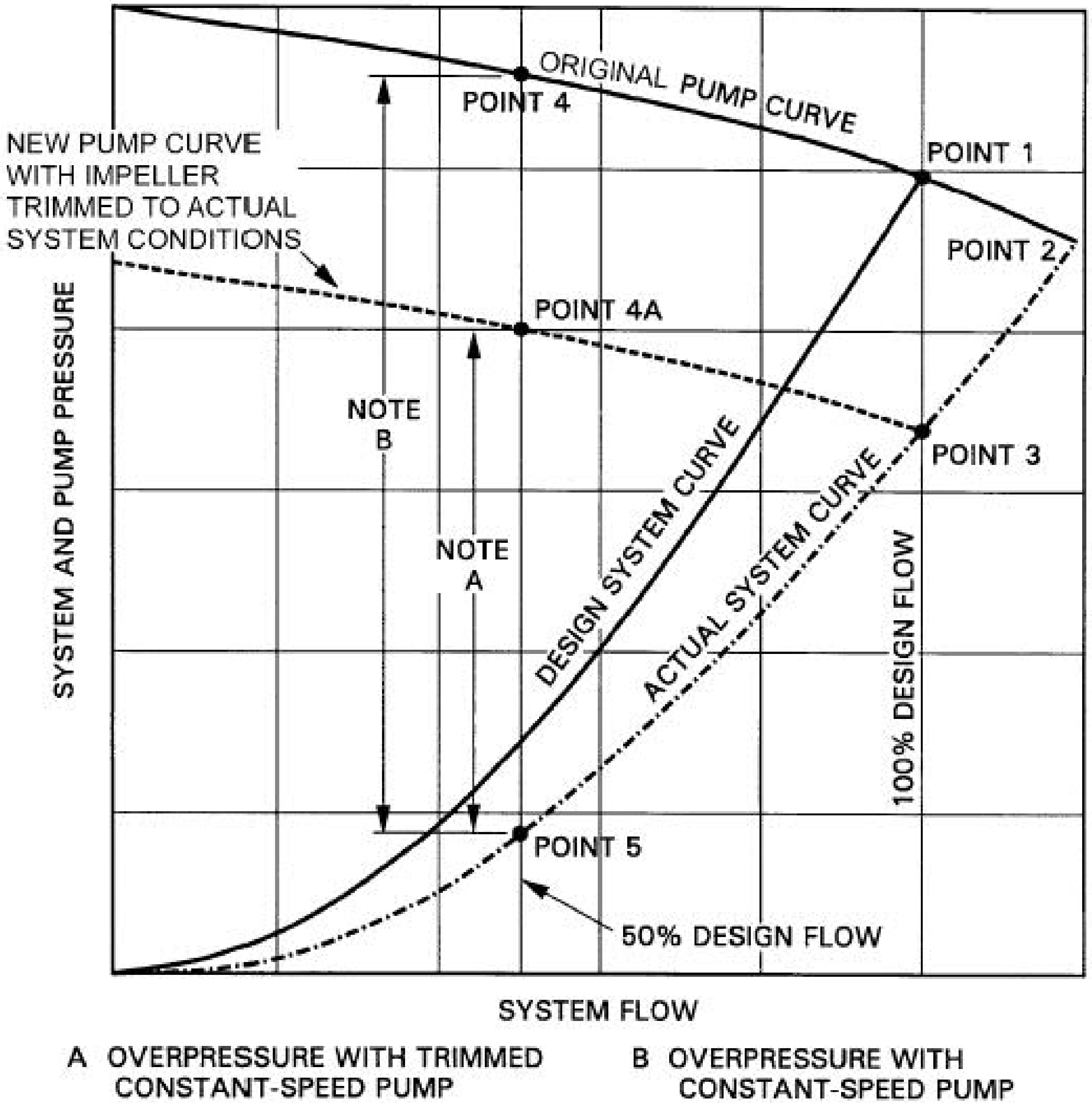


(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

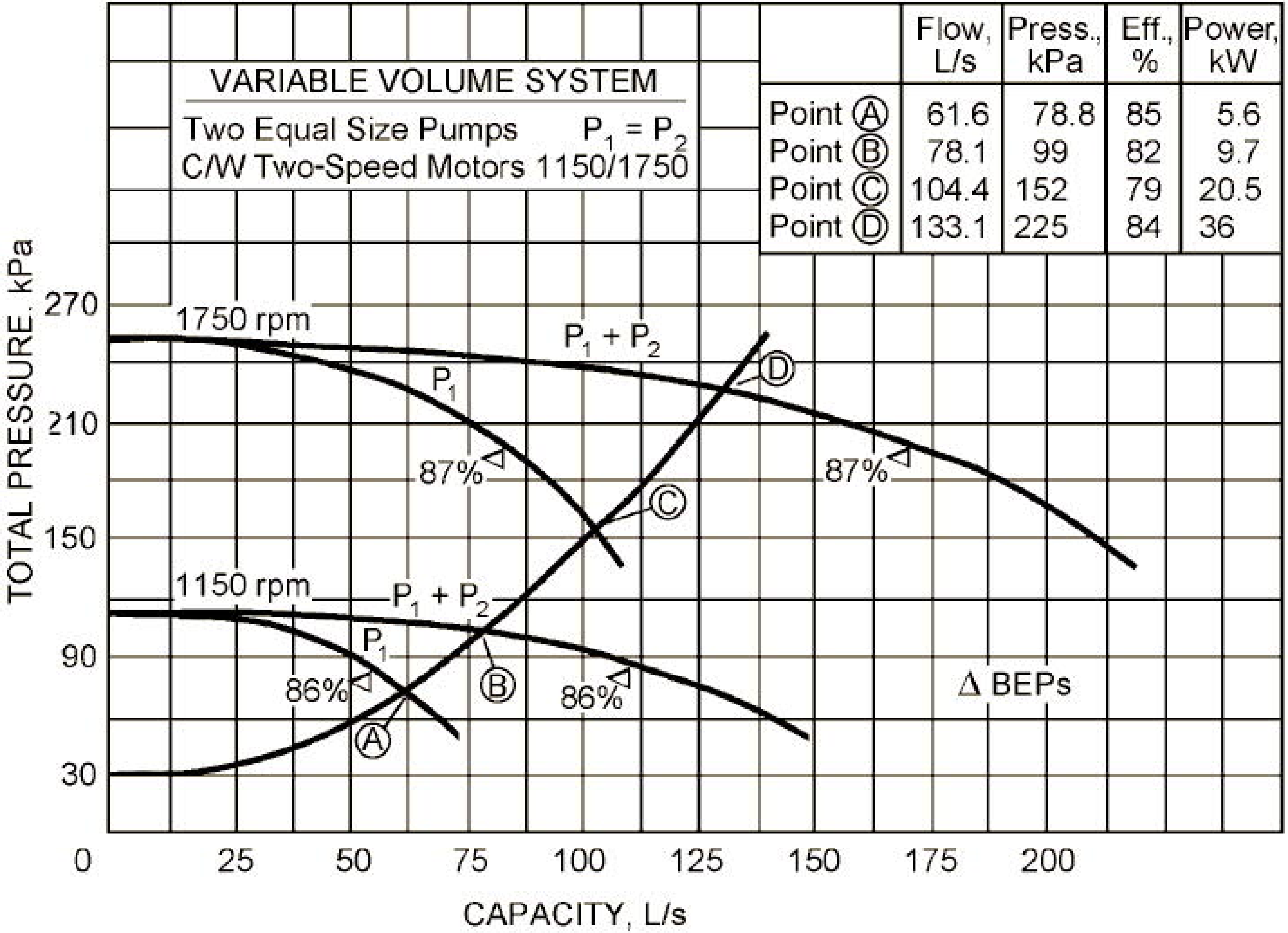


Shift of system curves

(Source: *Fundamentals of Water System Design*)



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



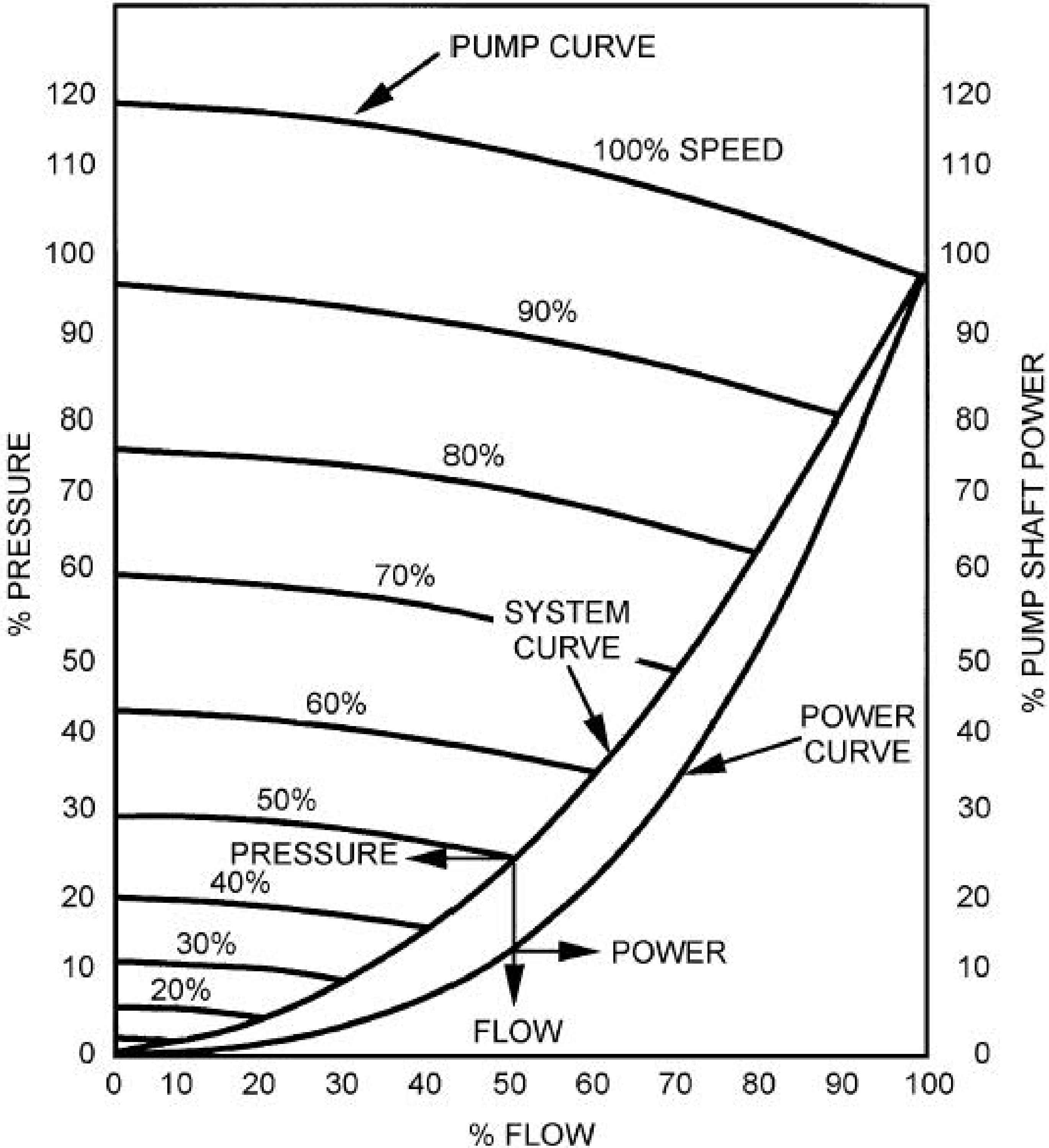
	Flow, L/s	Press., kPa	Eff., %	Power, kW
Point Ⓐ	61.6	78.8	85	5.6
Point Ⓑ	78.1	99	82	9.7
Point Ⓒ	104.4	152	79	20.5
Point Ⓓ	133.1	225	84	36

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

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

Matching Pumps to Systems

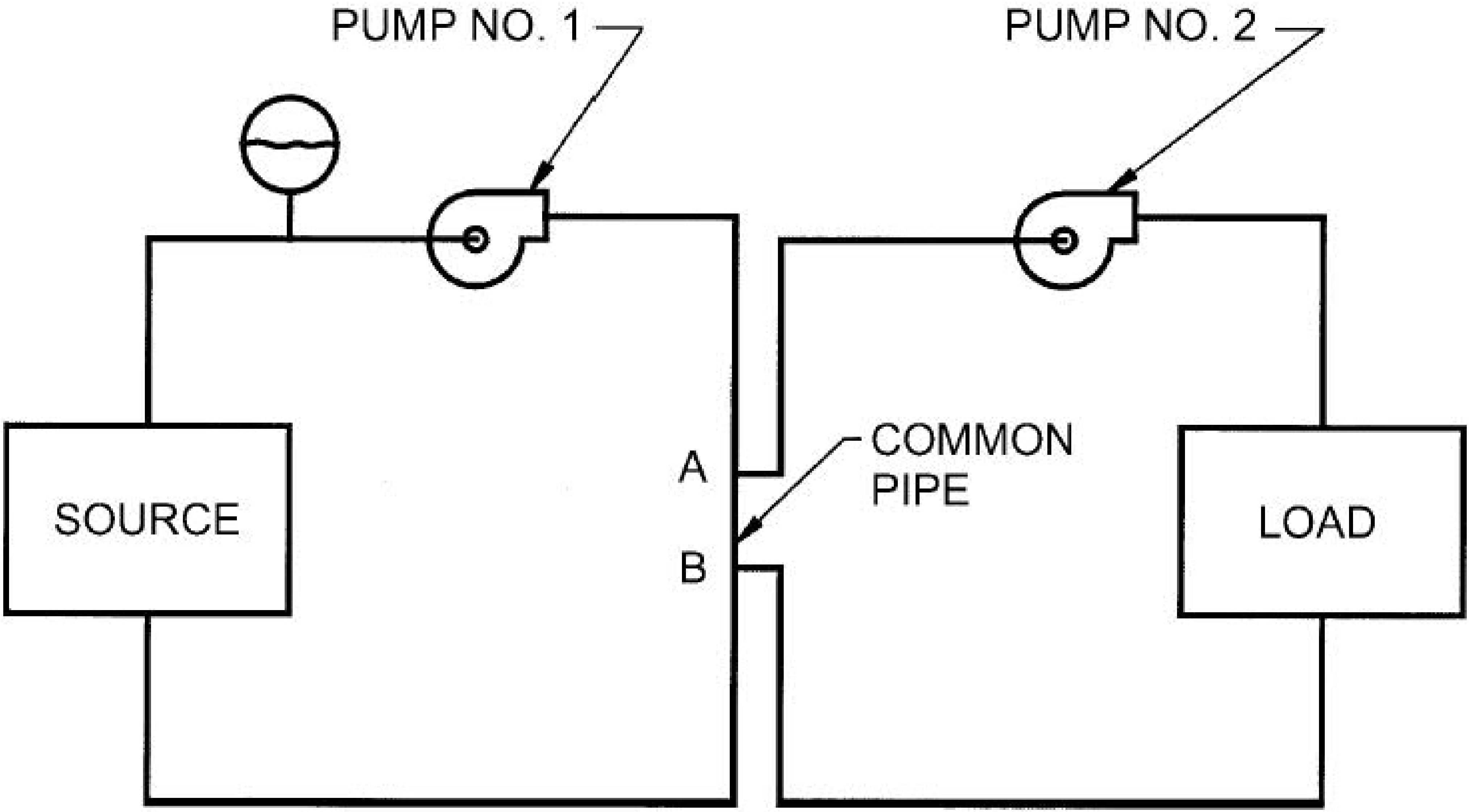
- Modulation of pump-piping systems
  - Throttle volume flow by using a valve
    - Change flow resistance – new system curve
    - Also known as “riding on the curve”
  - Turn water pumps on or off in sequence
    - Sudden increase/drop in flow rate and head
  - Vary the pump speed
    - System operating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



(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*)

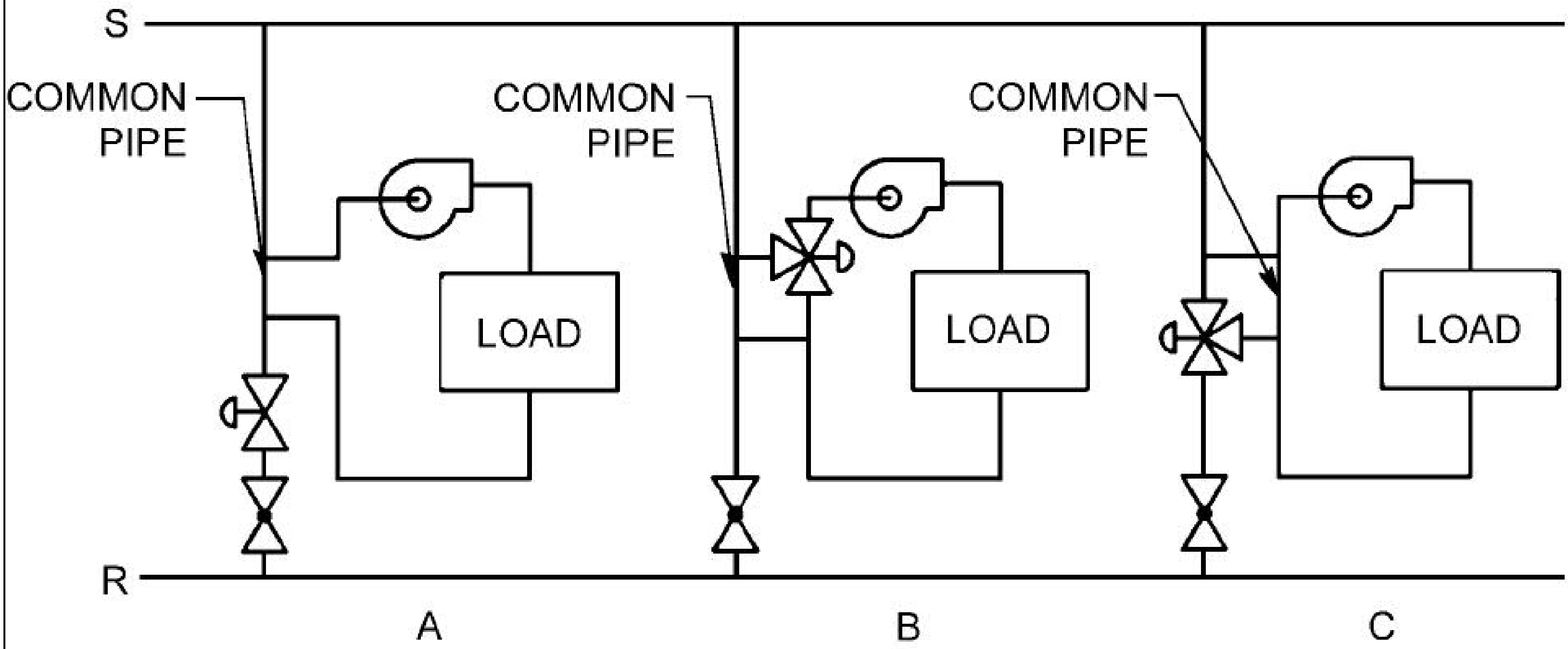
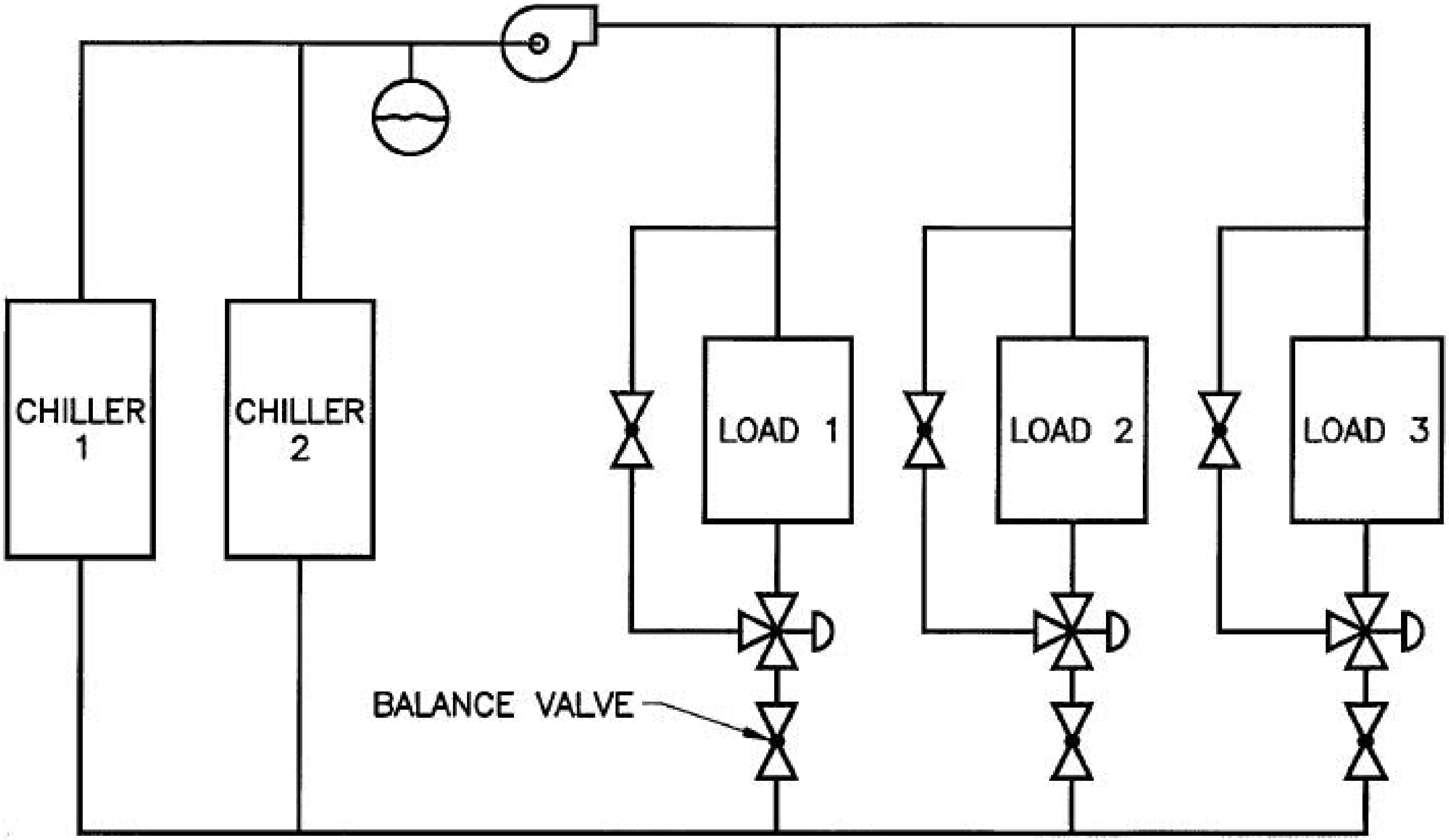


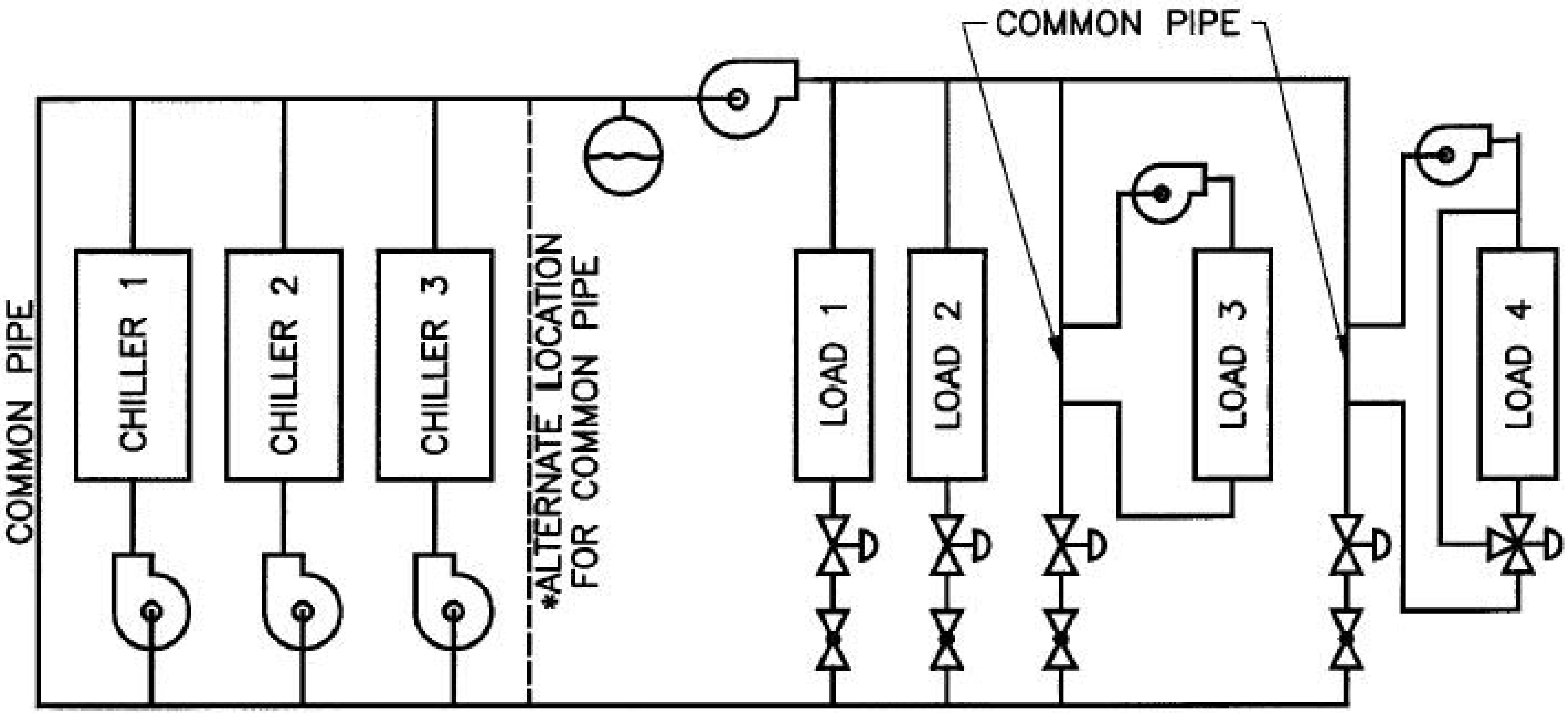
Fig. 40 Primary-Secondary Pumping

(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*)

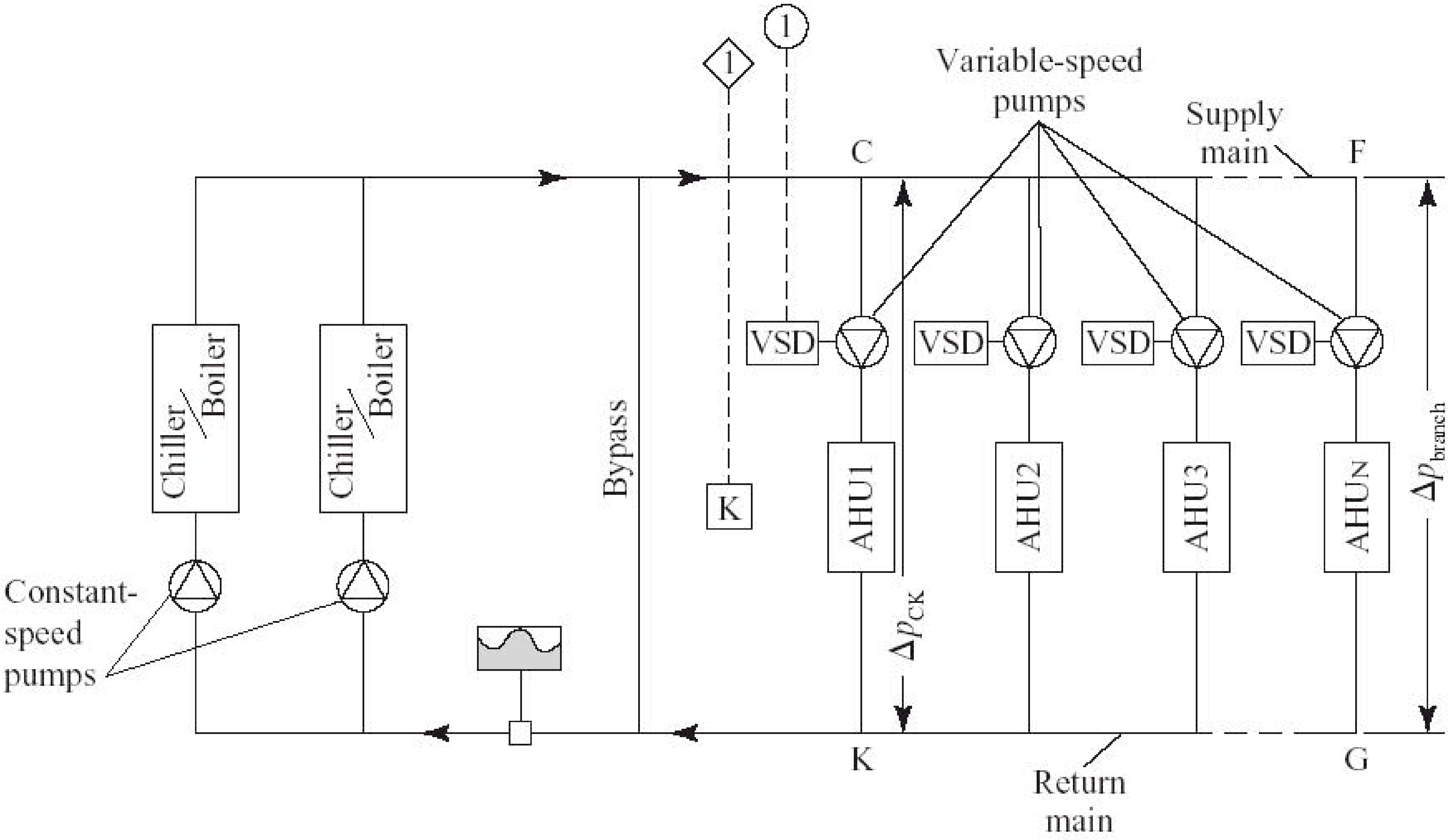
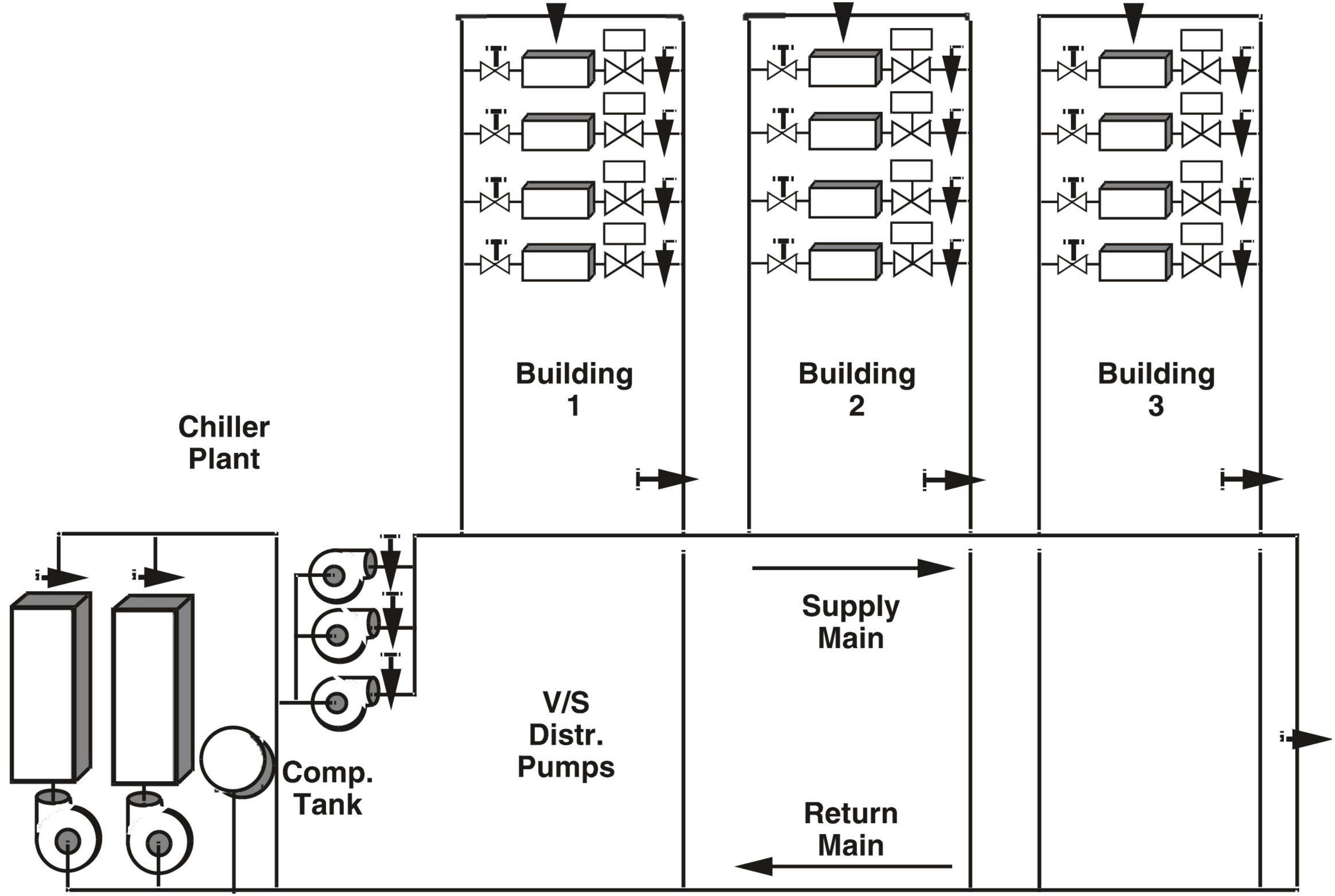


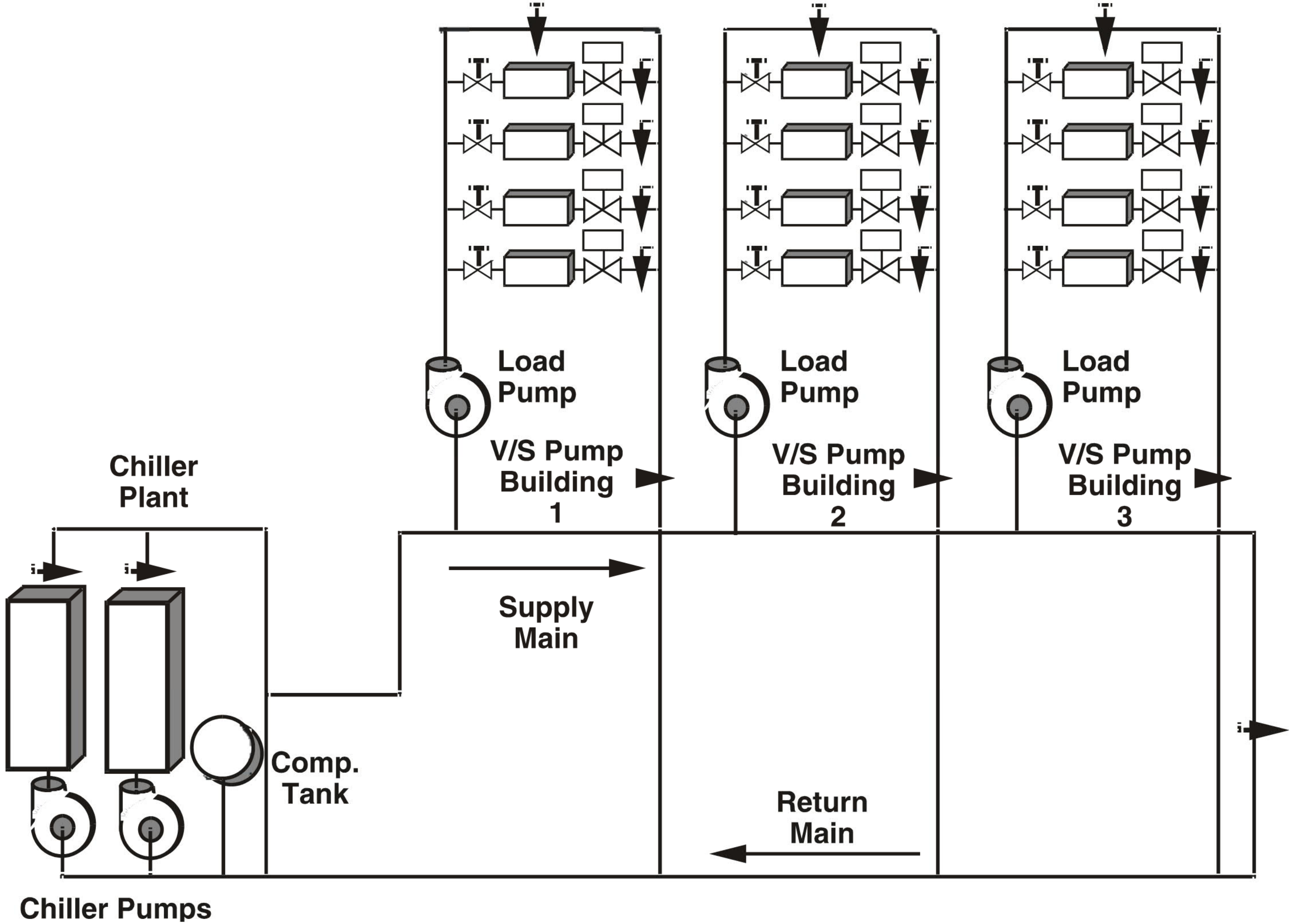
FIGURE 7.21 Schematic diagram of a plant-distributed pumping loop .

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



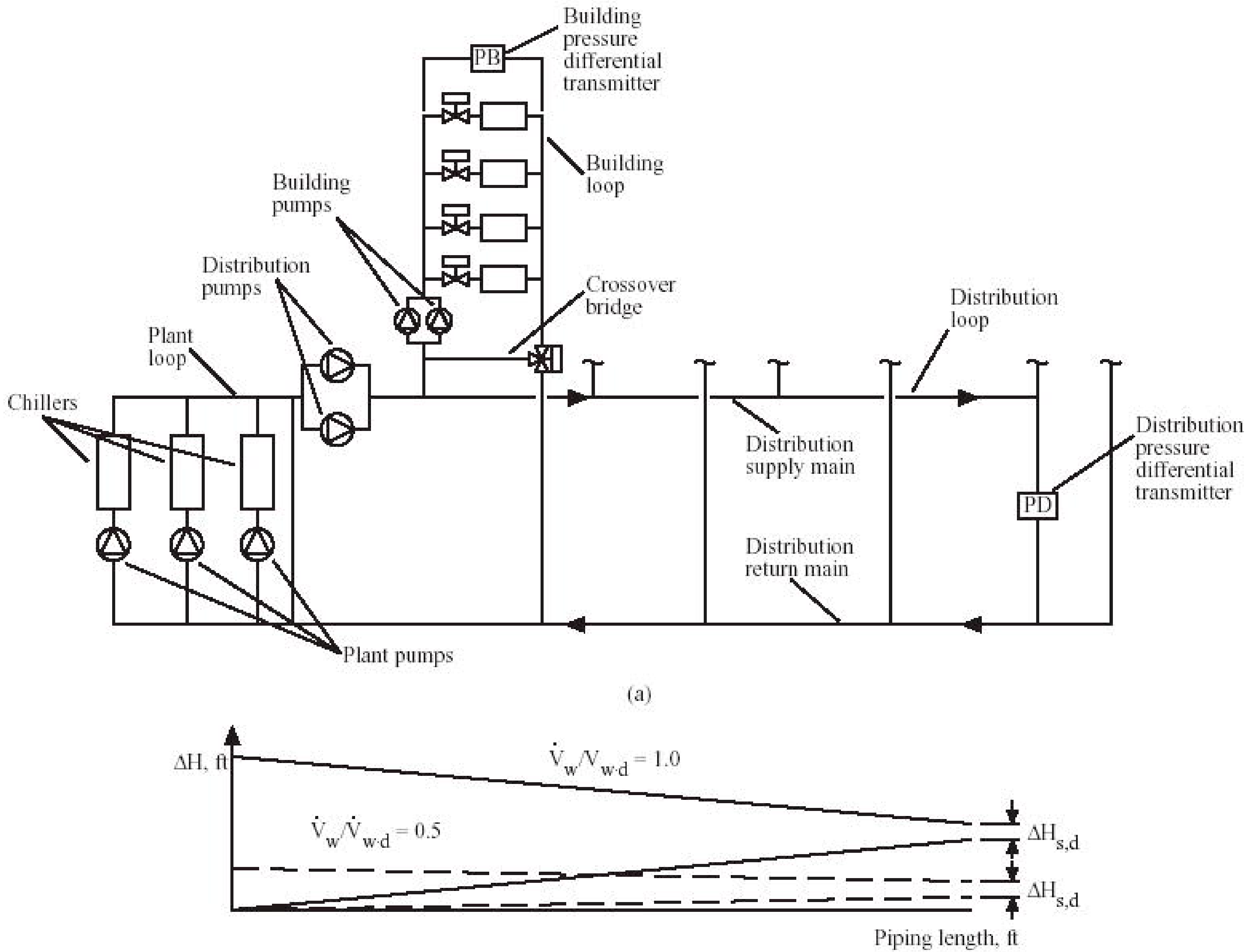
Primary-secondary variable speed pumping

(Source: *Fundamentals of Water System Design*)



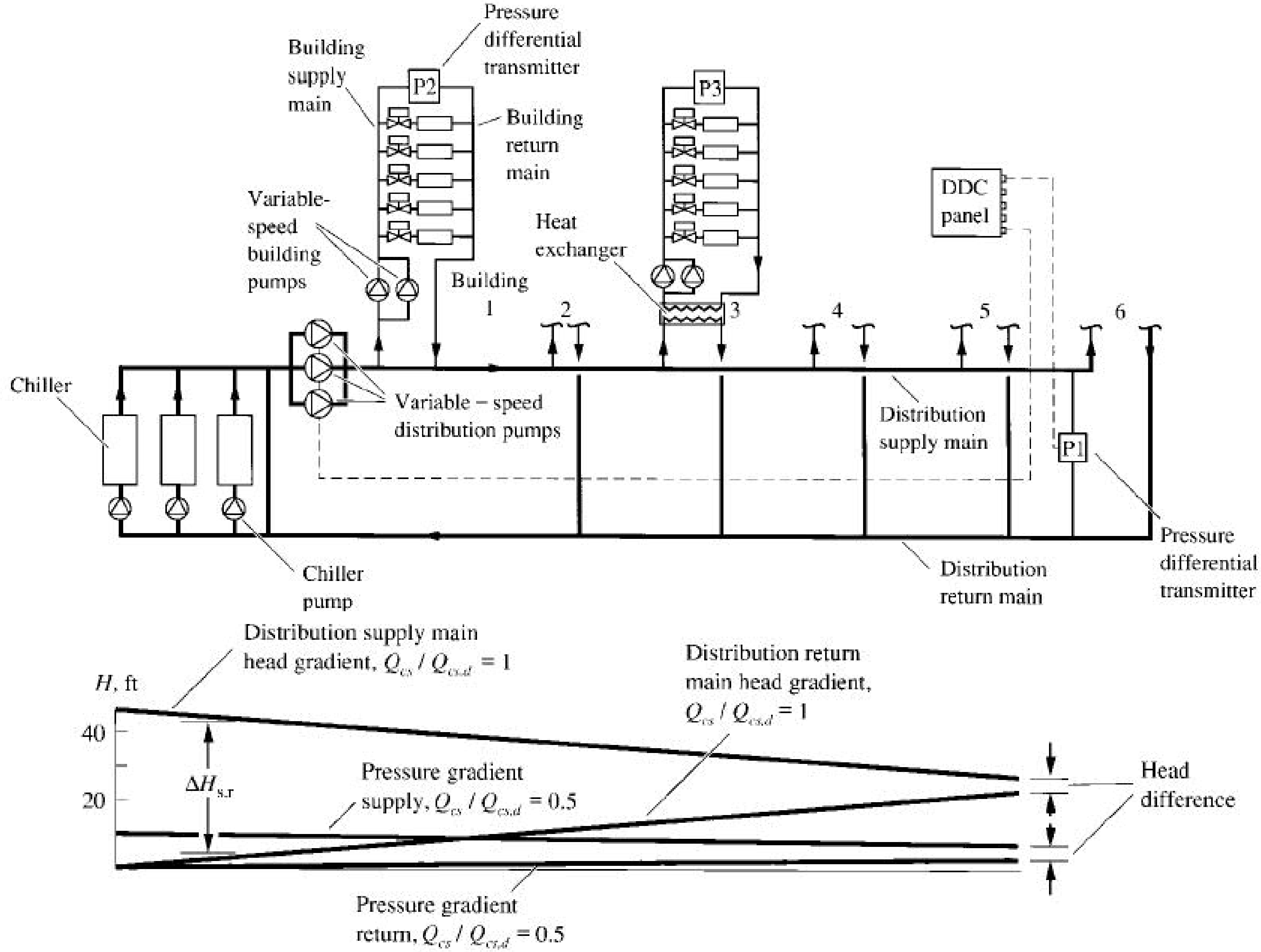
Distributed variable speed pumping

(Source: *Fundamentals of Water System Design*)



Chilled water system using a plant-distribution-building loop

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



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

Matching Pumps to Systems

- Chiller plant operation/performance management
  - Parallel chiller arrangement
  - Series chiller arrangement
  - Decoupled chiller arrangement
  - Chiller plant control
  - Tertiary pumping