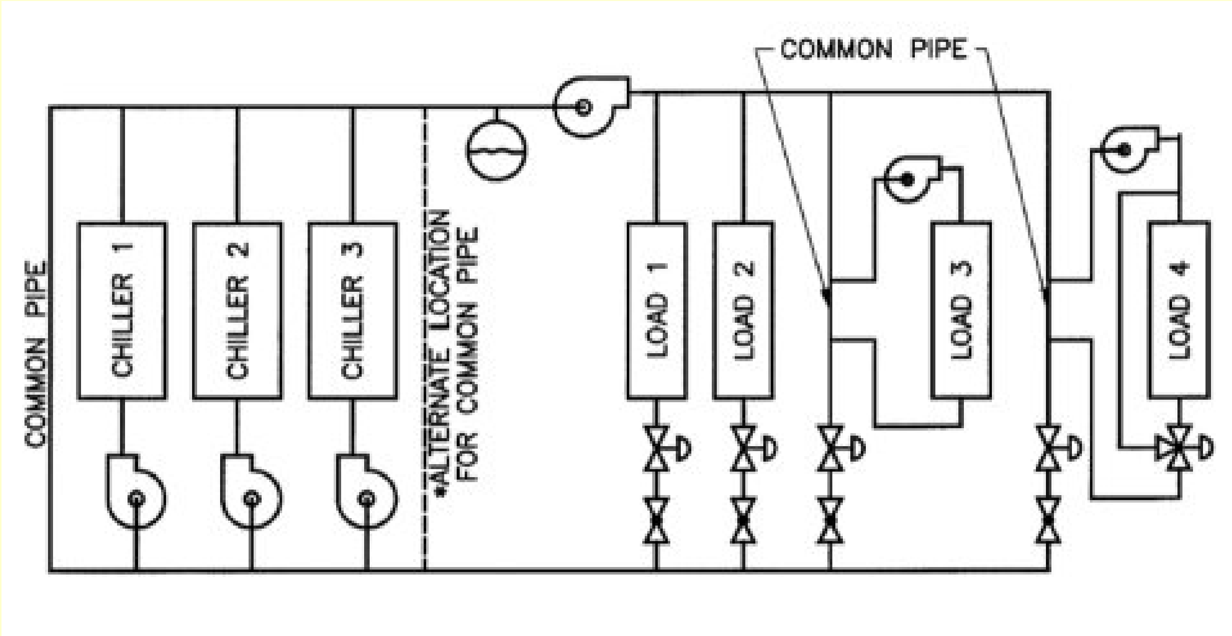

HVAC Water-side Systems

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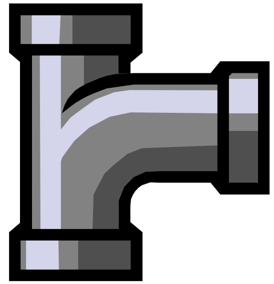
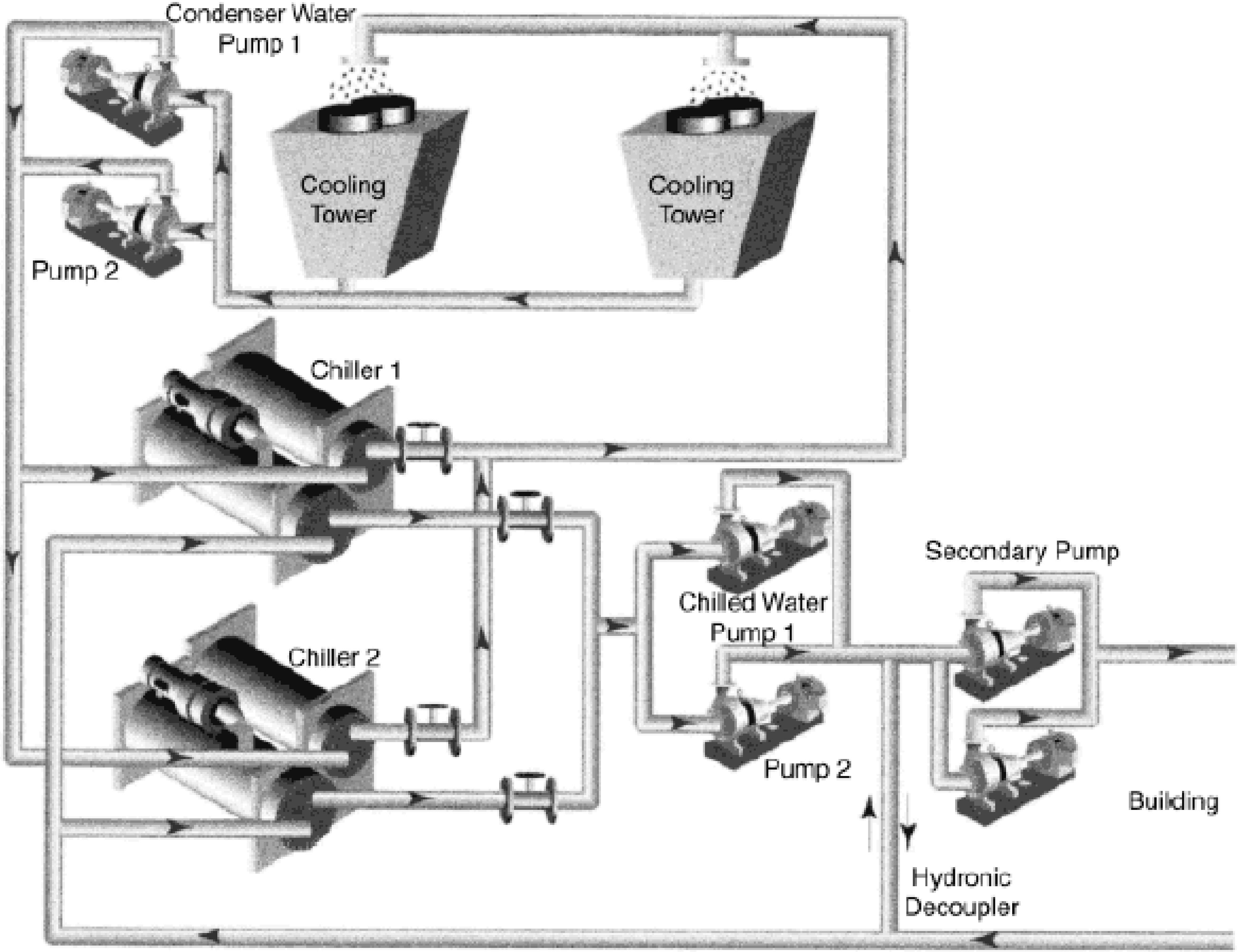
Contents

- Pipe Systems and Design
- Water Systems in HVAC
- Centrifugal Pumps
- Pump Arrangements

Pipe Systems and Design

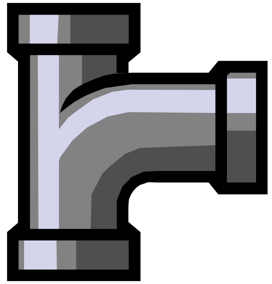


- Common types of HVAC piping systems
  - Chilled water (CHW) system
  - Condenser water (CW) system
  - Sea water system
  - Hot water supply system
  - Steam pipes, gas pipes
- Similar systems in other building services
  - Water supply & distribution (plumbing)



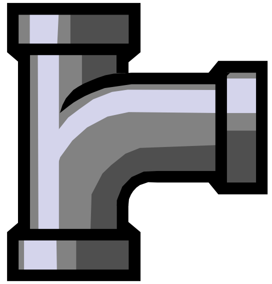
[Source: Kreider, K. F. (ed.), 2001. *Handbook of Heating, Ventilation, and Air Conditioning*, CRC Press, Boca Raton, FL.]

Pipe Systems and Design



- Two major concerns:
  - Size the pipe (e.g. from charts & tables)
  - Determine the flow-pressure relationship
    - To analyse the system, e.g. to find out pump pressure
    - By using manual or computer-based methods
- Calculations for pipelines or pipe networks
  - Can be very complicated for branches & loops
  - Basic parameters: pipe diameter, length, friction factor, roughness, velocity, pressure drop

Pipe Systems and Design



- Basic equations
  - Darcy-Weisbach Equation (for fully developed flows of all Newtonian fluids)

$$\Delta p = f\left(\frac{L}{D}\right)\left(\frac{\rho V^2}{2g}\right) \quad \text{or} \quad \Delta h = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

  - Colebrook-White Equation (for transition region):

$$\frac{1}{\sqrt{f}} = 1.14 + 2\log(D/\varepsilon) - 2\log\left[1 + \frac{9.3}{\mathrm{Re}(\varepsilon/D)\sqrt{f}}\right]$$

    - * The equation is implicit in *f* (appears on both sides), so iterations are required to solve for *f*.

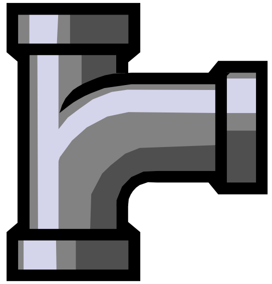
Pipe Systems and Design

- Basic equations (cont'd)
  - Hazen-Williams Equation (alternative to Darcy-Weisbach formula; empirical)

$$\Delta p = 6.819 L \left(\frac{V}{C} \right)^{1.852} \left(\frac{1}{D} \right)^{1.167} (\rho g)$$

    - C = roughness factor (typically, C = 150 for plastic or copper pipe, C = 140 for new steel pipe, C < 100 for badly corroded or very rough pipe)

Pipe Systems and Design



- Valve and fitting losses
  - May be greater than pipe friction alone

$$\Delta p = K_L \rho \left(\frac{V^2}{2} \right) \quad \text{or} \quad \Delta h = K_L \left(\frac{V^2}{2g} \right)$$

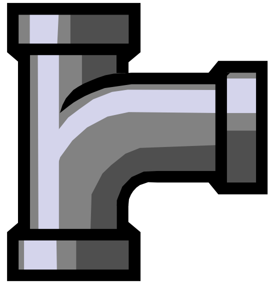
  - K_L = loss coefficient (K factor) of pipe fittings
    - Geometry and size dependent
    - May be expressed as equivalent lengths of straight pipe
  - Valve coefficient (A_v):
    - Volume flow rate $Q = A_v \sqrt{\Delta p / \rho}$

Table 2.5 Loss Coefficients for Fittings

Fitting	K_L
Globe valve, fully open	10.0
Angle valve, fully open	5.0
Butterfly valve, fully open	0.4
Gate valve, fully open	0.2
3/4 open	1.0
1/2 open	5.6
1/4 open	17.0
Check valve, swing type, fully open	2.3
Check valve, lift type, fully open	12.0
Check valve, ball type, fully open	70.0
Foot valve, fully open	15.0
Elbow, 45°	0.4
Long radius elbow, 90°	0.6
Medium radius elbow, 90°	0.8
Short radius (standard) elbow , 90°	0.9
Close return bend, 180°	2.2
Pipe entrance, rounded, r/D < 0.16	0.1
Pipe entrance, square-edged	0.5
Pipe entrance, re-entrant	0.8

(Source: Larock, Jeppson and Watters, 2000: *Hydraulics of Pipeline Systems*)

Pipe Systems and Design



- Practical design issues
  - Select a pipe size for desired total flow rate and available or allowable pressure drop, e.g.
    - Often assume 2.5 m / 100 m pipe length
    - Velocity limit 1.2 m/s for pipe $<$ 50 mm dia., pressure drop limit 400 Pa/m for pipe $>$ 50 mm dia.
  - Rule of thumb for practical design:
    - Assume design pipe length is 1.5 to 2.0 times actual to account for fitting losses; after pipe diameter is selected, then evaluate the influence of each fitting
  - Other considerations: e.g. noise & water hammer

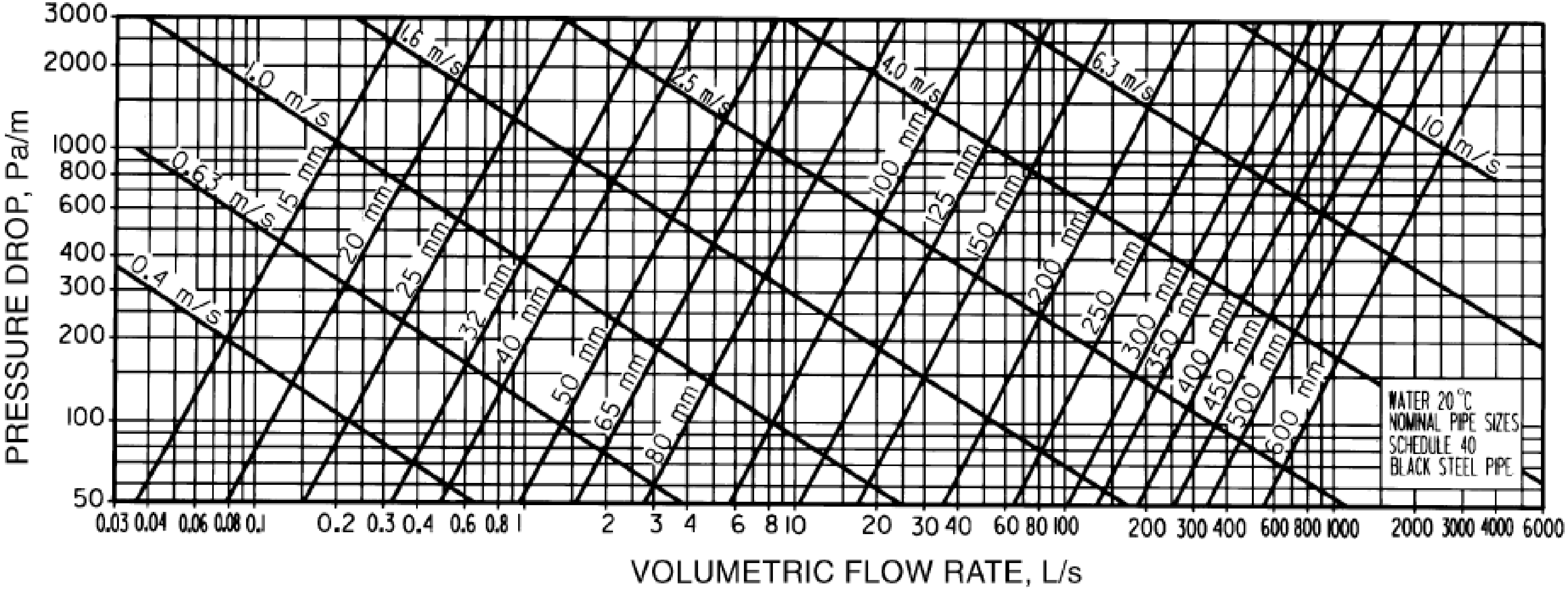


Fig. 4 Friction Loss for Water in Commercial Steel Pipe (Schedule 40)

(Source: ASHRAE Handbook Fundamentals 2005, Chp. 36)

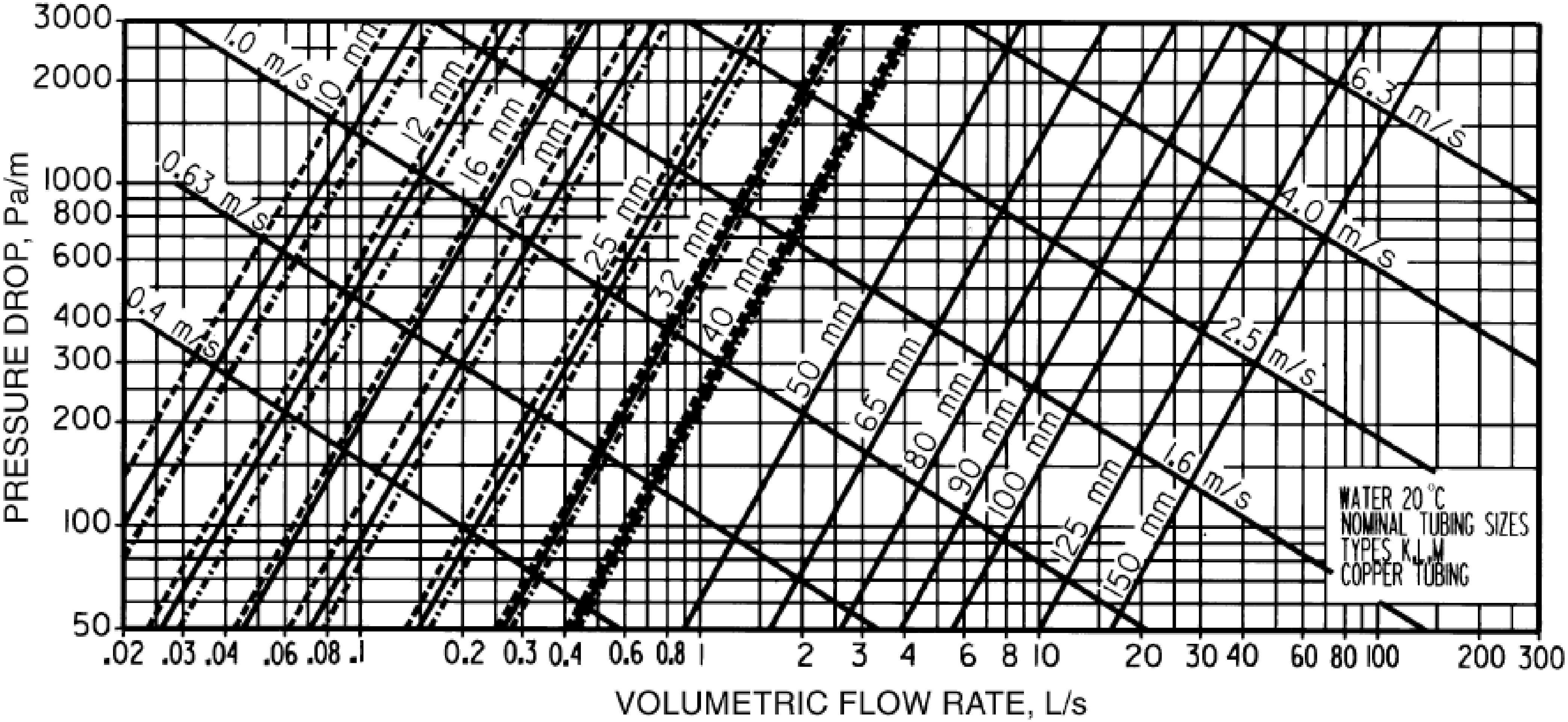
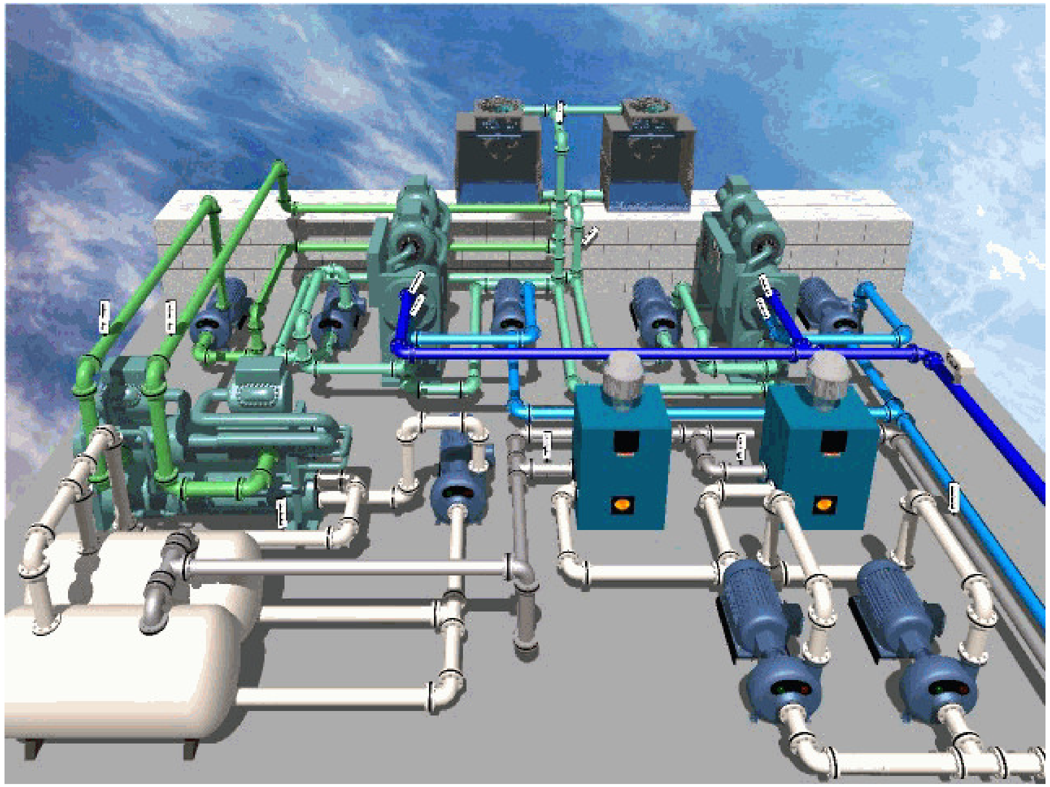


Fig. 5 Friction Loss for Water in Copper Tubing (Types K, L, M)

(Source: ASHRAE Handbook Fundamentals 2005, Chp. 36)

Water Systems in HVAC

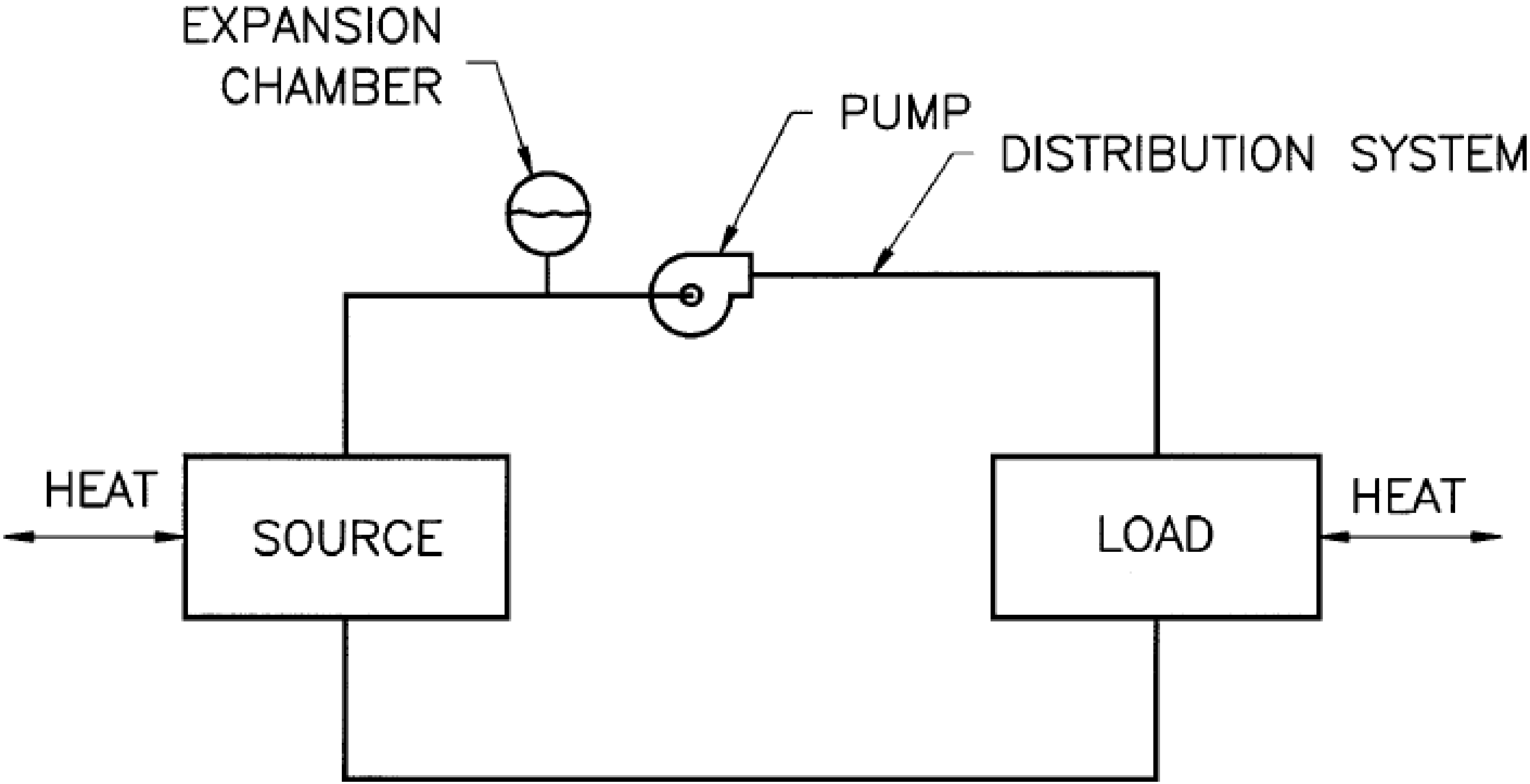
- HVAC water systems can be classified by
  - Operating temperature
  - Flow generation
  - Pressurization
  - Piping arrangement
  - Pumping arrangement



Water Systems in HVAC

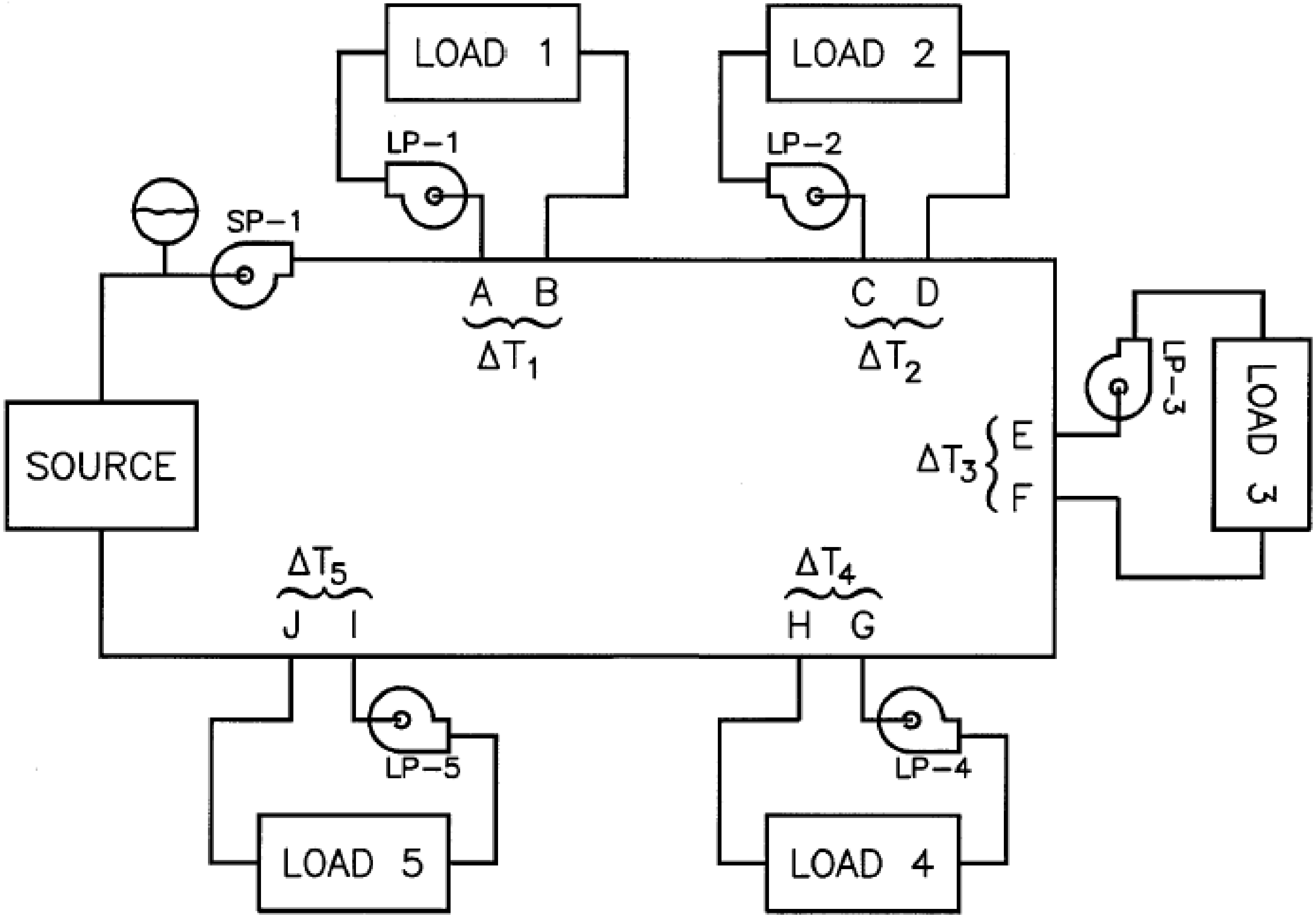
- Open water systems, e.g. using cooling tower
- Closed water systems
  - Chilled water (CHW) system [4-13 ^{o}C, 825 kPa]
  - Condenser water (CW) system
  - Dual temperature water system
  - Low temp. water (LTW) system [Max. 120 ^{o}C, $<$ 1100 kPa]
  - Medium temp. water (MTW) system [120-125 ^{o}C, $<$ 1100 kPa]
  - High temp. water (HTW) system [$>$ 175 ^{o}C, $>$ 2070 kPa]
- Once-through system, e.g. sea water system

Basic components of water (hydronic) system



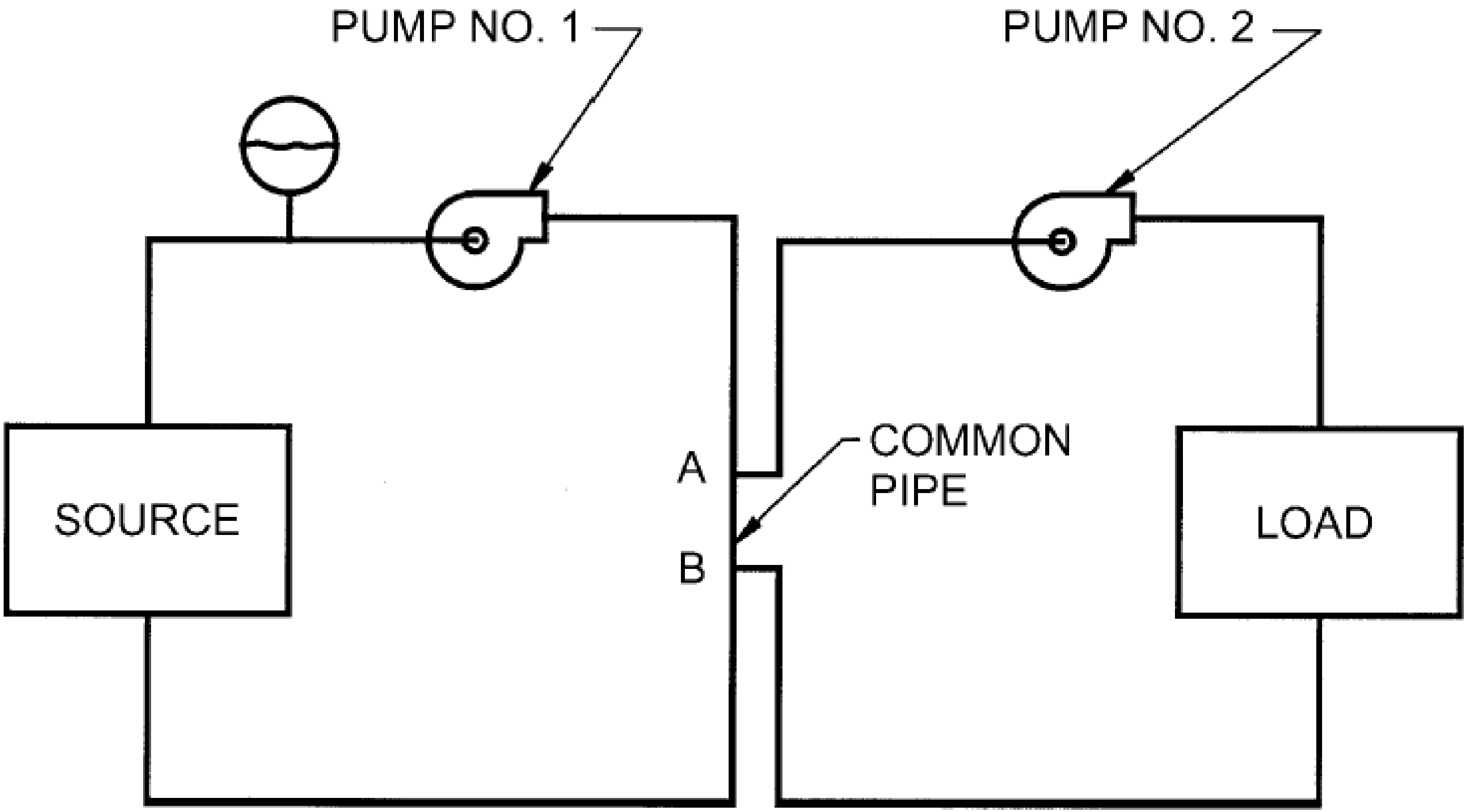
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Series circuit with load pumps



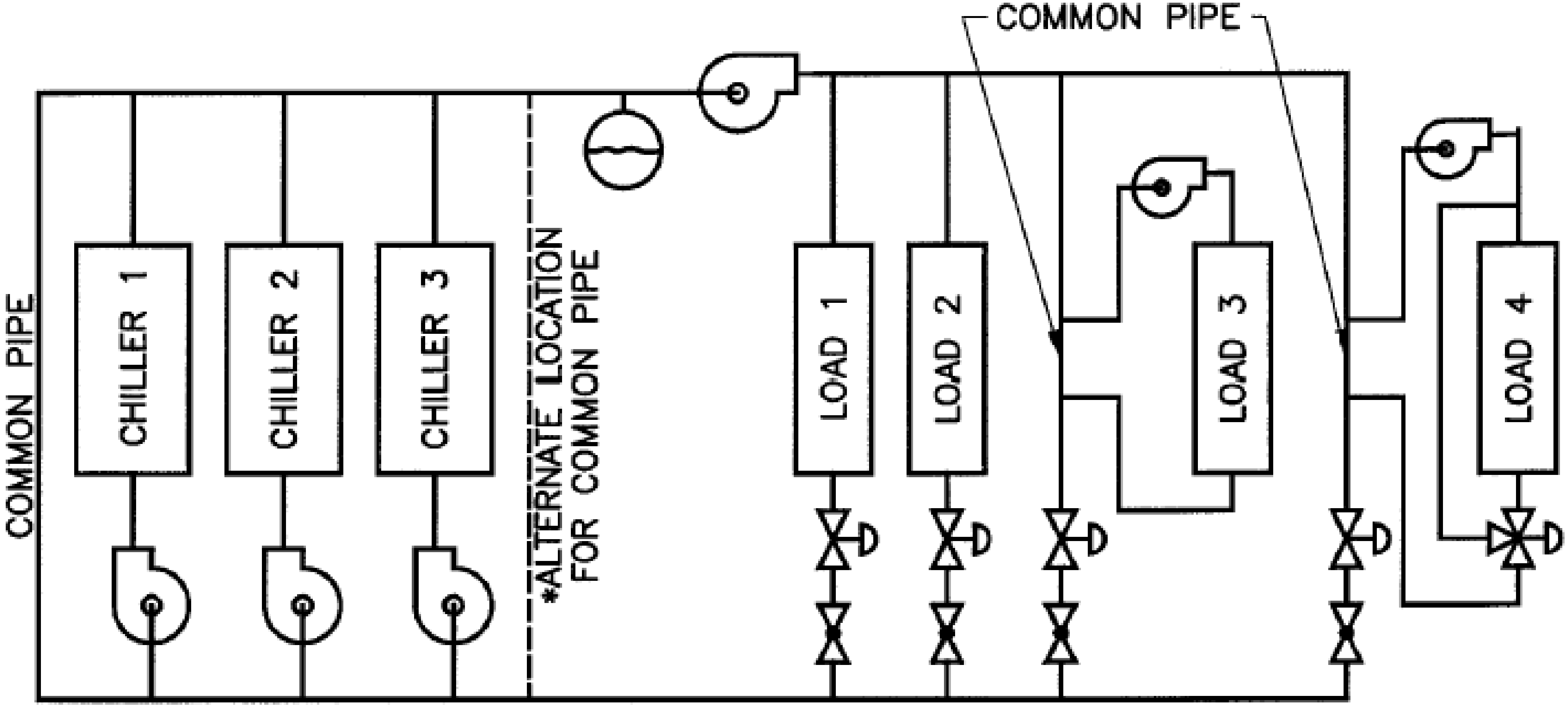
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Primary-secondary loop and pumping

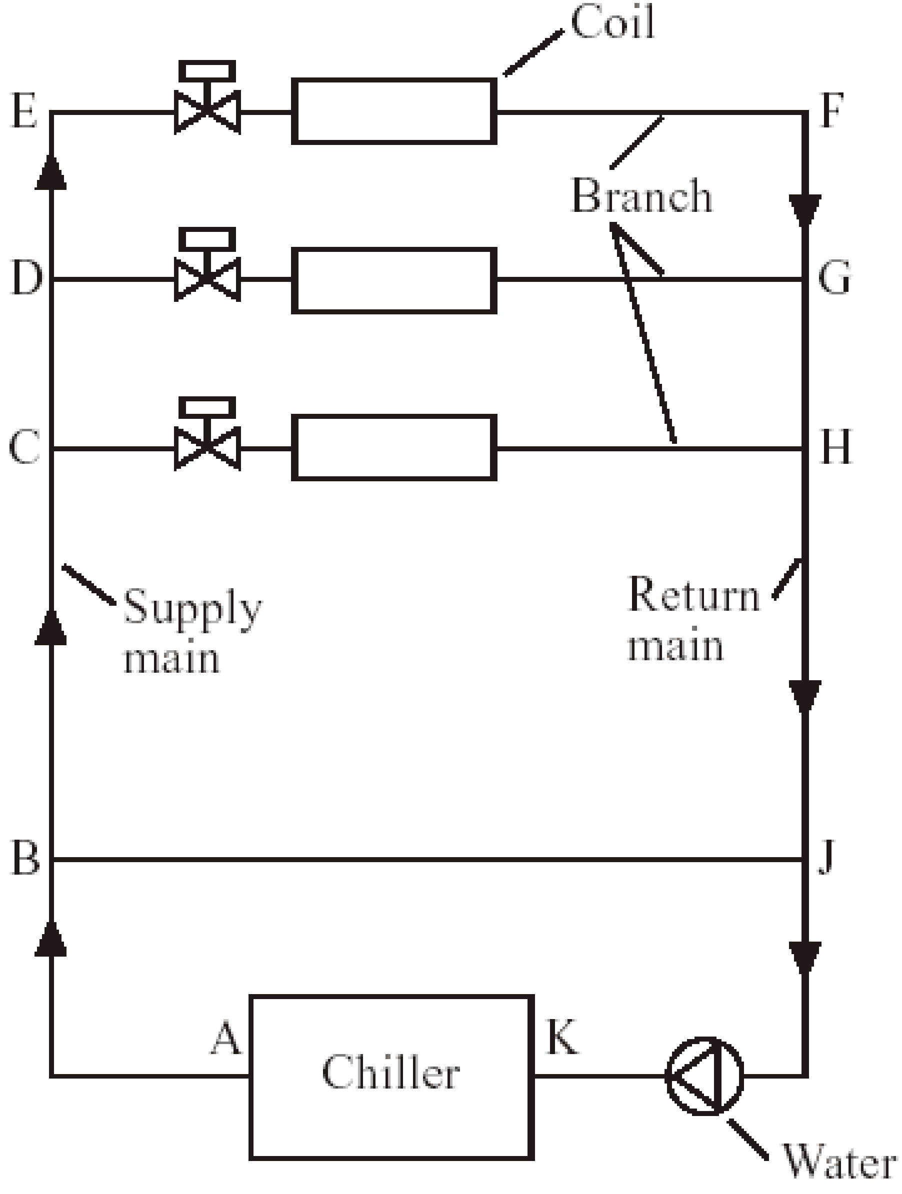


(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Multiple chiller variable flow chilled water system

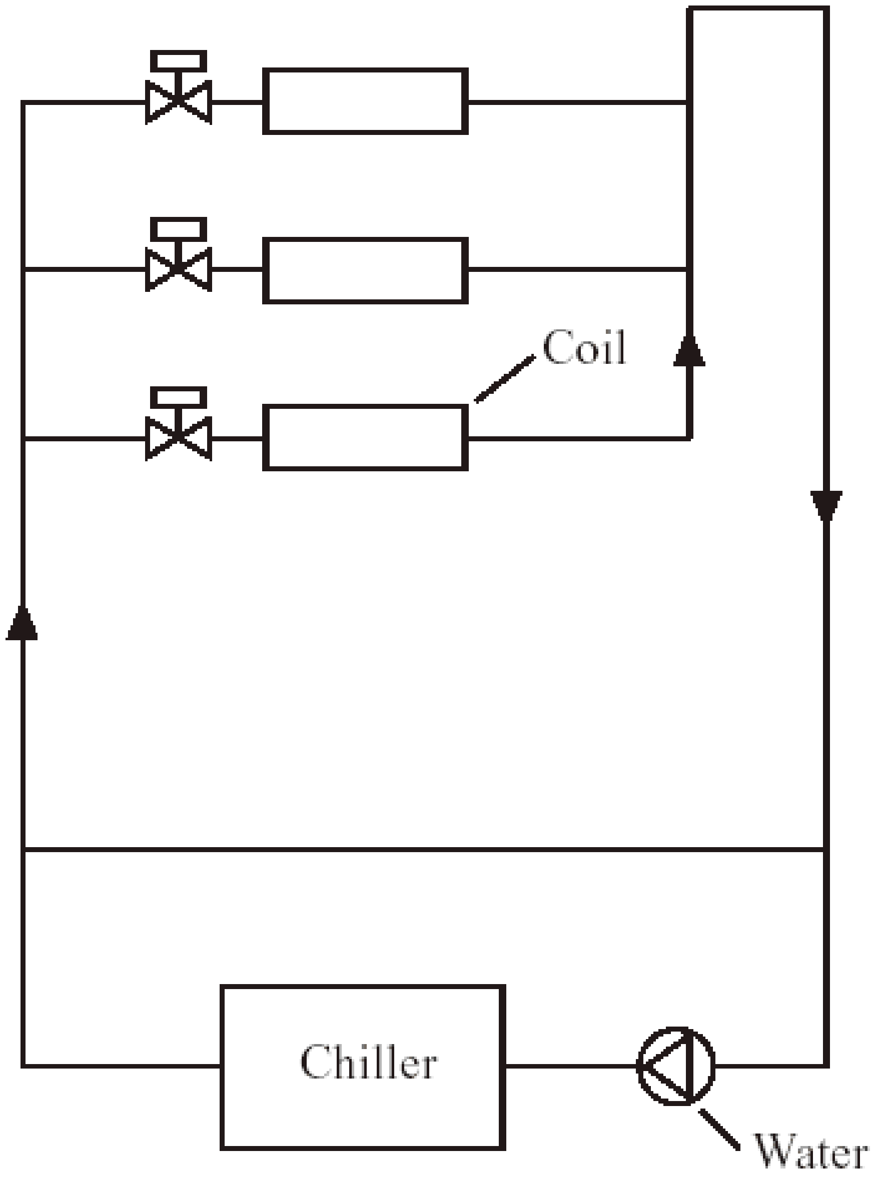


(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)



(a)

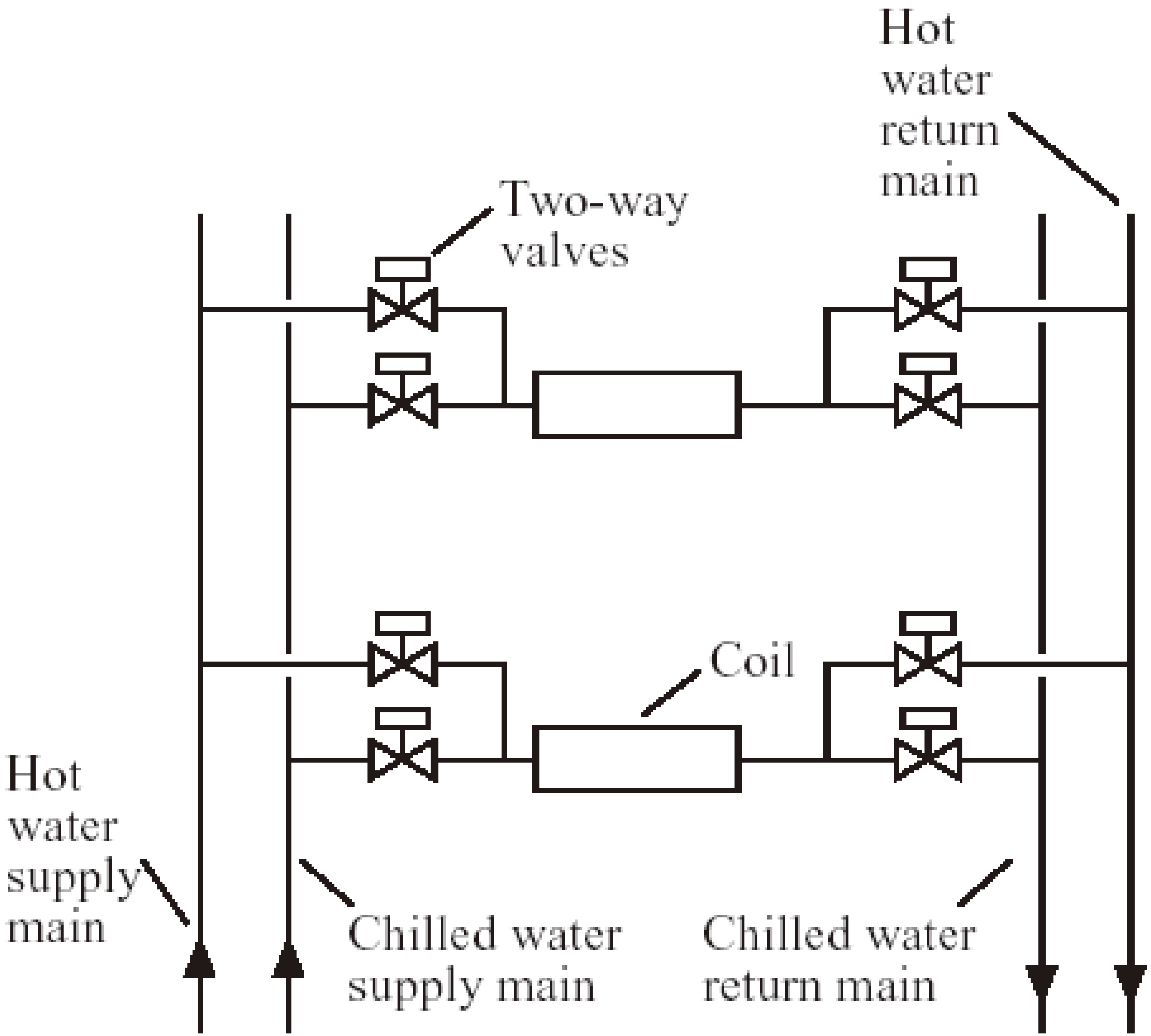
2-pipe direct return



(b)

2-pipe reverse return

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



4-pipe system (dual temperature)

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

Water Systems in HVAC

- Heat transfer in water systems
  - Terminal units/devices that convey heat from/to water for heating/cooling
  - Common heat exchangers
    - Water-to-air finned coil
    - Water-to-water
  - Heating load devices, e.g. radiators
  - Cooling load devices, e.g. fan coil units (FCU)

Calculate Heat Transferred to or from Water:

$$q_w = 1000\dot{m}c_p\Delta t$$

where

q_w = heat transfer rate to or from water, W
$\dot{m}$ = mass flow rate of water, kg/s
c_p = specific heat of water, kJ/(kg·K)
Δt = water temperature increase or decrease across unit, K
1000 = constant to change kJ in c_p to J

$$q_w = \rho_w c_p Q_w \Delta t$$

where

Q_w = water flow rate, L/s
ρ_w = density of water, kg/m^3

Water Systems in HVAC

- Design issues
  - Design water temperature
  - Flow rate
  - Piping layout
  - Pump selection
  - Terminal unit selection
  - Control method

Water Systems in HVAC

- Design principles
  - Constant flow? Variable flow? Intermittent flow?
  - Direct return piping or reverse return piping
  - Direct return riser & reverse zone piping
- Design factors
  - Pump speed controls
  - Pressure distribution
  - System balancing
  - Thermal expansion & joints (or loops)

Water Systems in HVAC

- Piping materials
  - Chilled water: black & galvanized steel
  - Hot water: black steel, hard copper
  - Condenser water: black steel, galvanized ductile iron, PVC
- Flow rate measurements
  - Venturi, nozzle & orifice flowmeters
  - Variable area flowmeters (rotameters)
  - Turbine flowmeters

Water Systems in HVAC

- Other design considerations
  - Makeup water (from city water or wells)
  - Safety relief valves (for pressurised systems)
  - Air elimination (e.g. by air separator/vent)
  - Drain (at low points) & shutoff (for isolation)
  - Balance fittings (allow balancing of sub-circuits)
  - Strainers (remove dirt)
  - Insulation (reduce heat loss & condensation)
  - Condensate drains (to drainage system or recover)

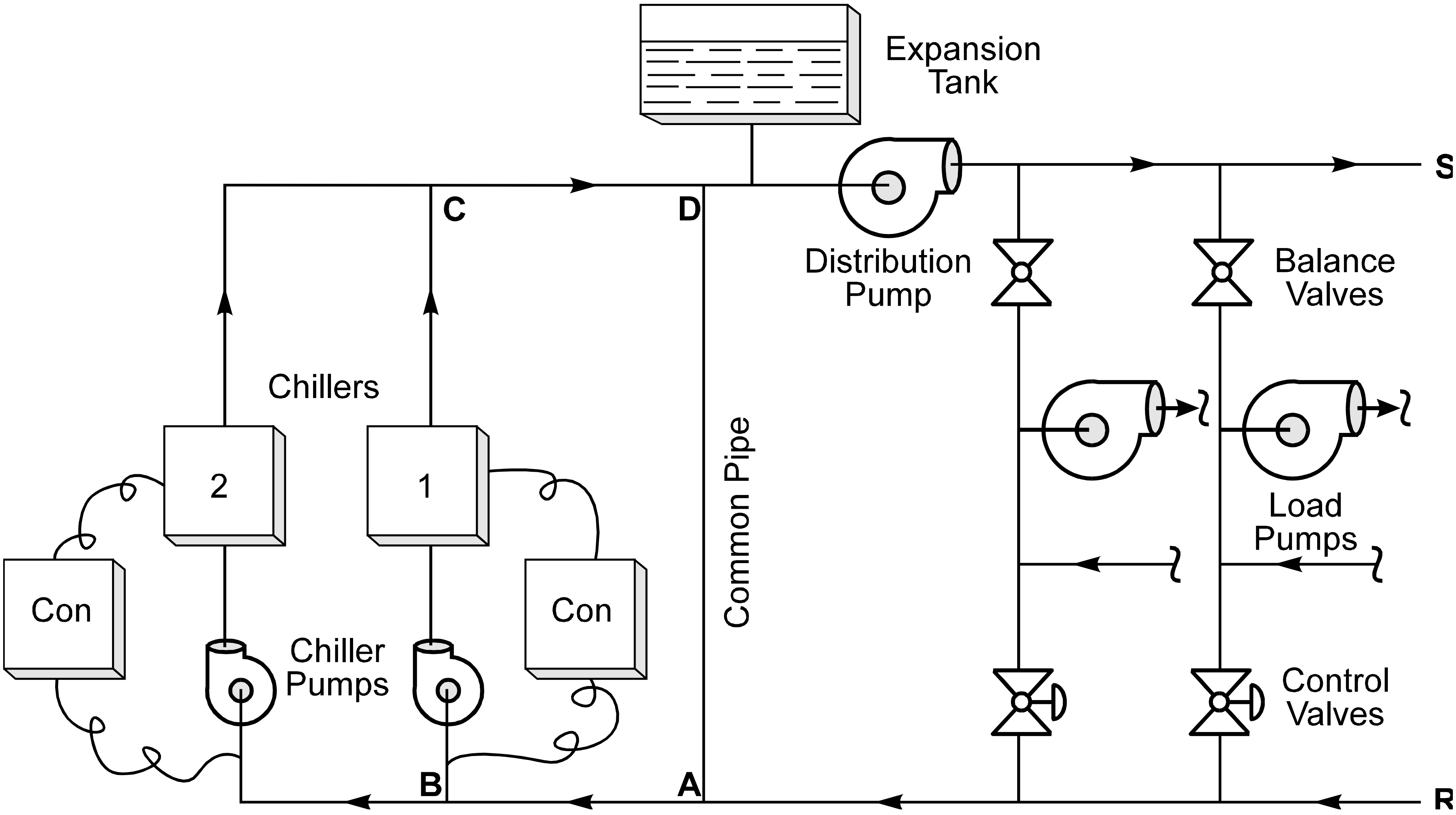
Water Systems in HVAC

- Practical design process (see reference)
  - See "*Practical Guide to HVAC Building Services Calculations*" - water flow distribution systems: overview of system design process
    - W1 Pipe sizing – general
    - W2 Pipe sizing – straight length
    - W3 Pipe sizing – pressure drop across fittings
    - W4 System resistance for pipework – index run
    - W5 Pump sizing
    - W6 Water system pressurisation

Centrifugal Pumps

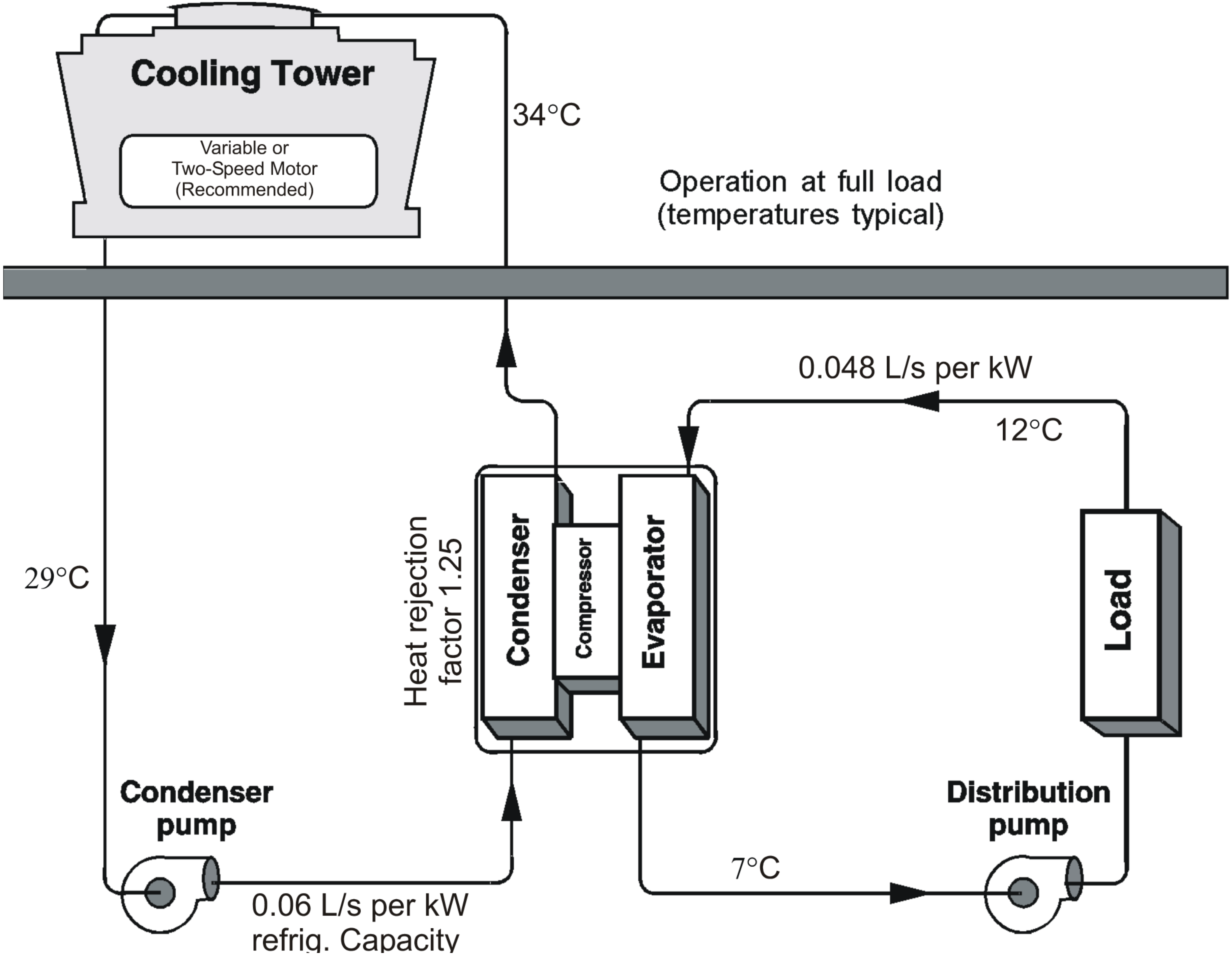
- Centrifugal pump
  - Most widely used in HVAC applications, e .g.
    - Hot water systems
    - Chilled water systems
    - Condenser water systems
    - Boiler feed and condensate return pumps
  - Operation
    - Electric motor's output torque => impeller's rotation
    - Coupling to the pump shaft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

Chilled water pumping system



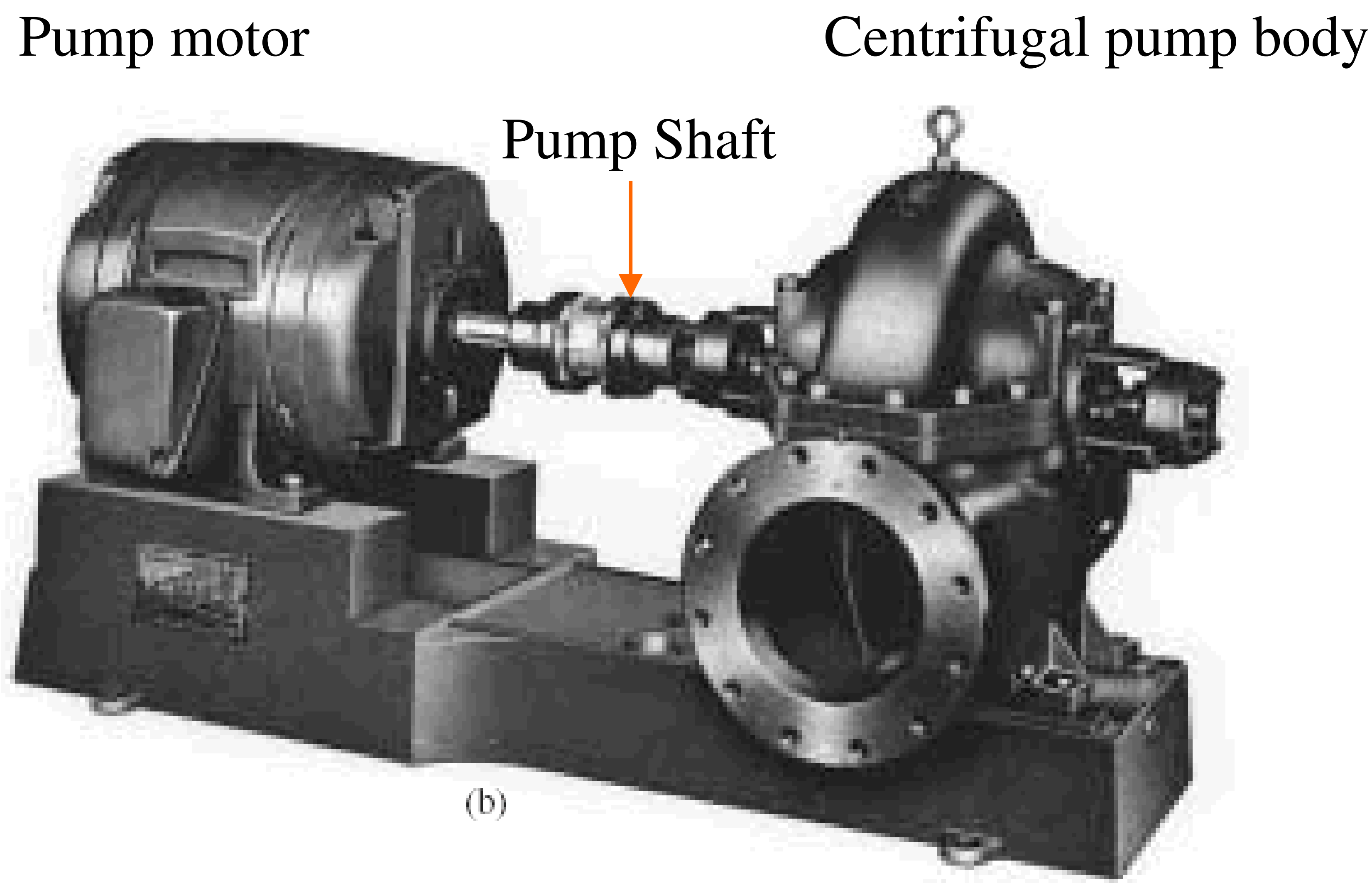
(Source: *Fundamentals of Water System Design*)

Cooling tower pumping system



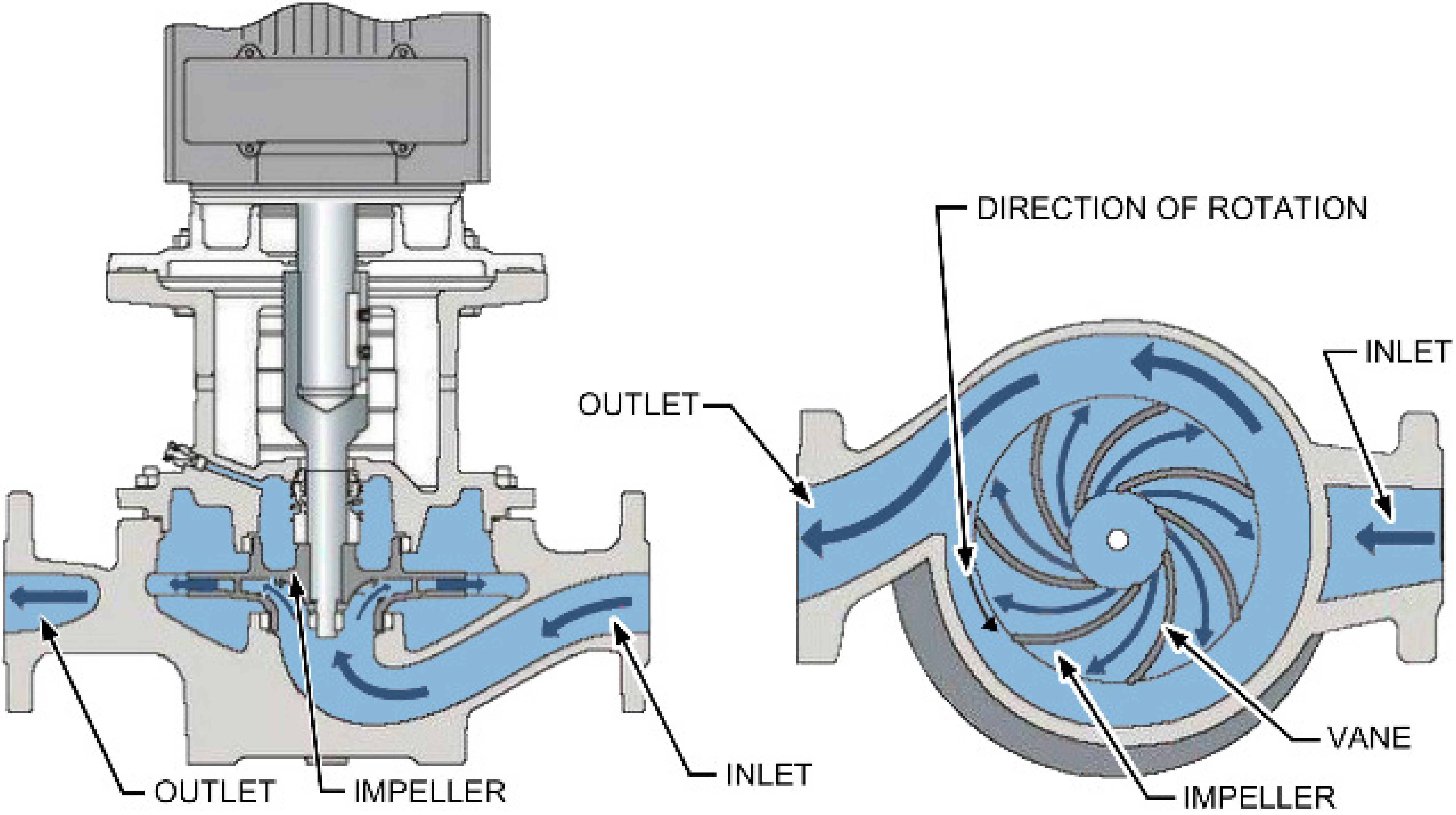
(Source: *Fundamentals of Water System Design*)

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



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

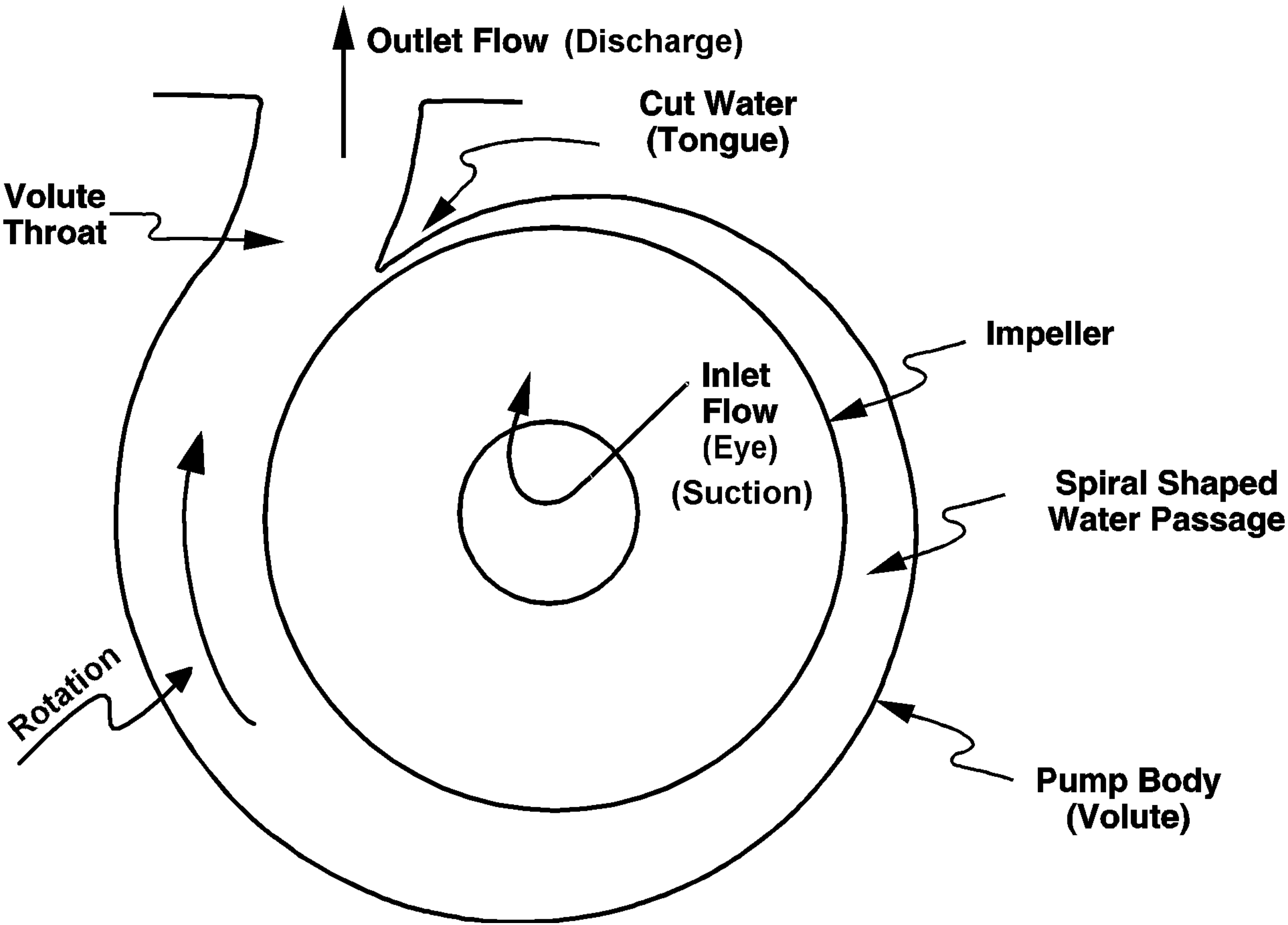
Centrifugal pump



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

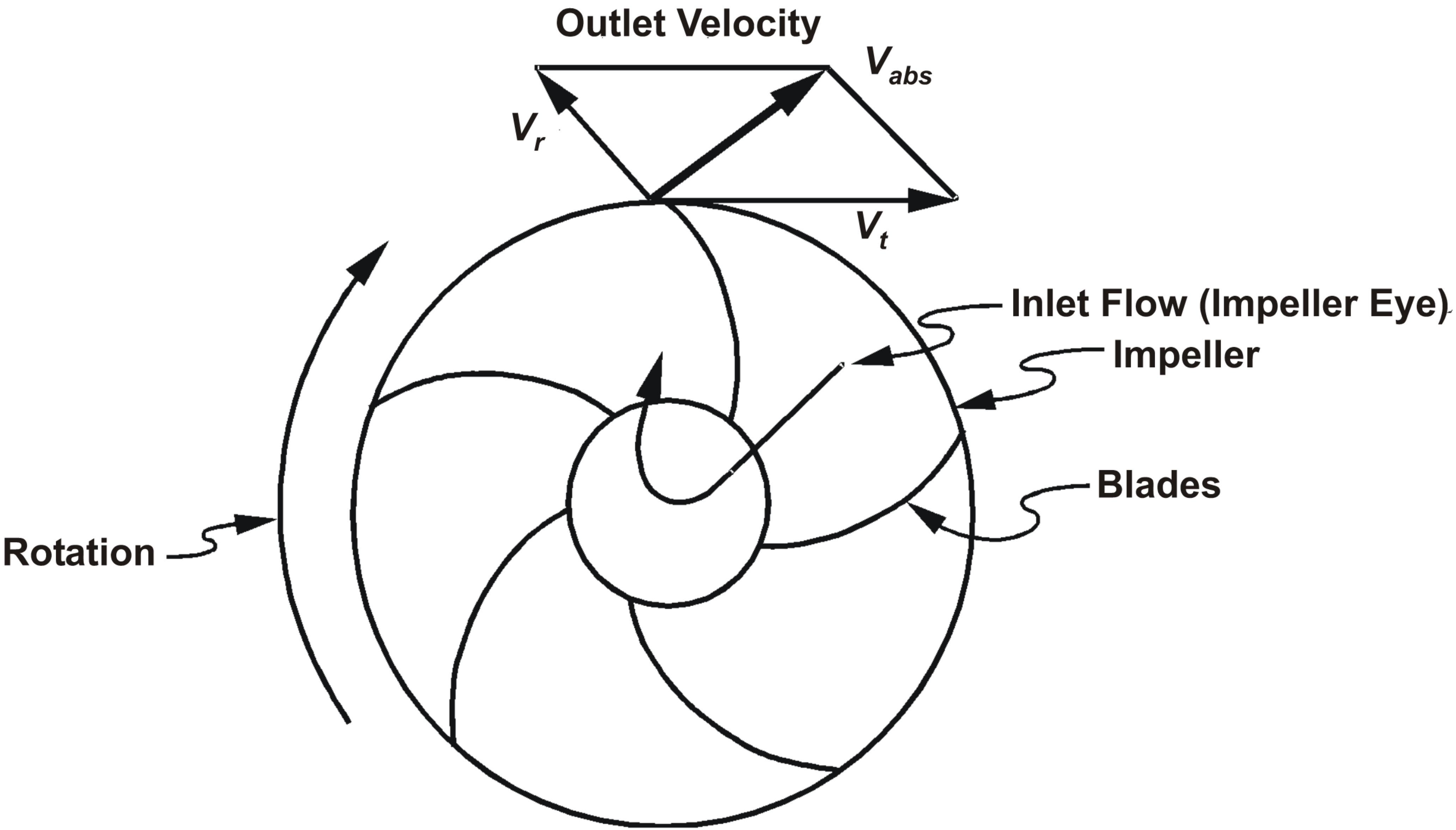
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2012*)

Centrifugal pump, impeller and volute



(Source: *Fundamentals of Water System Design*)

Impeller action on fluid



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

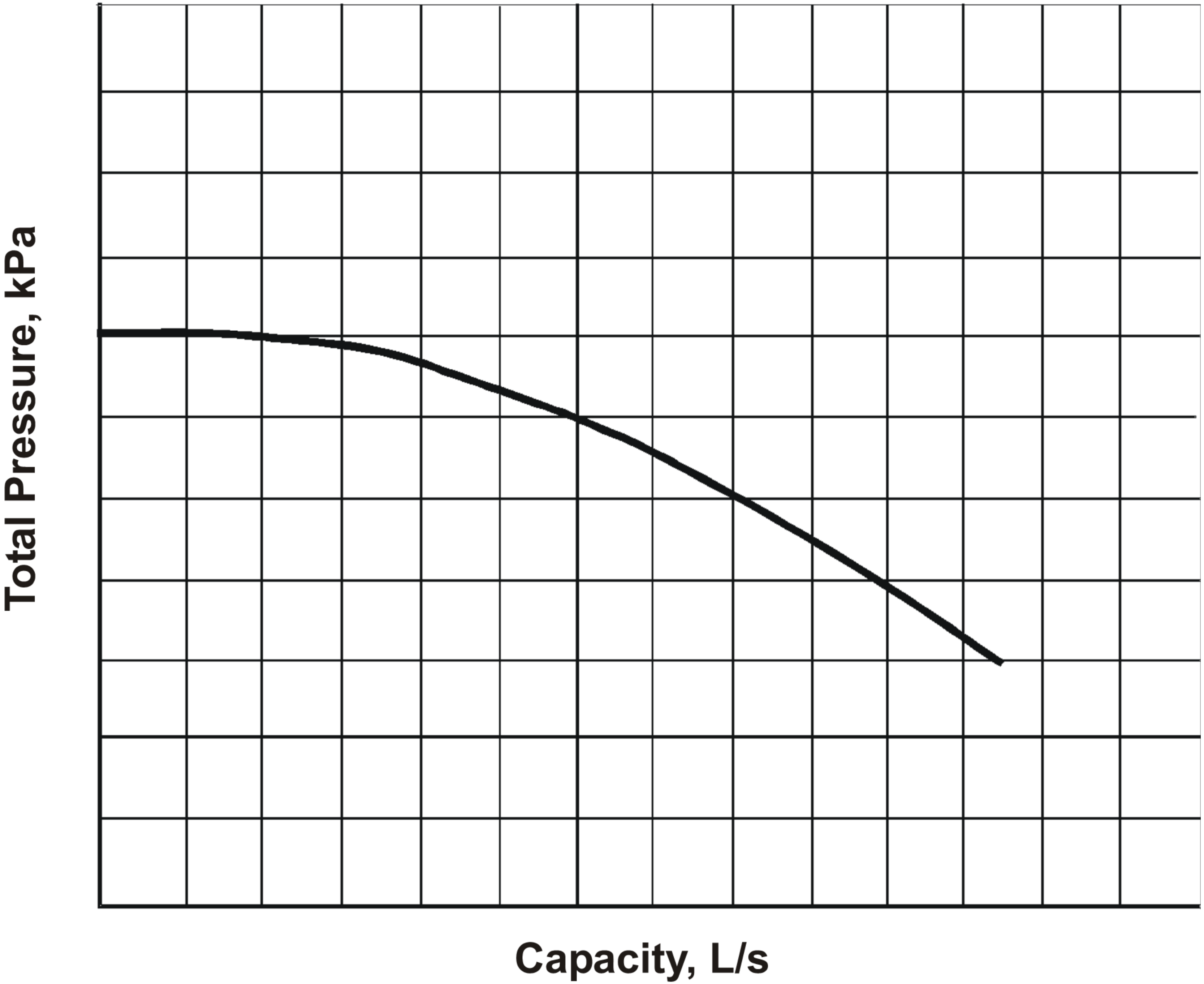
(Source: *Fundamentals of Water System Design*)

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

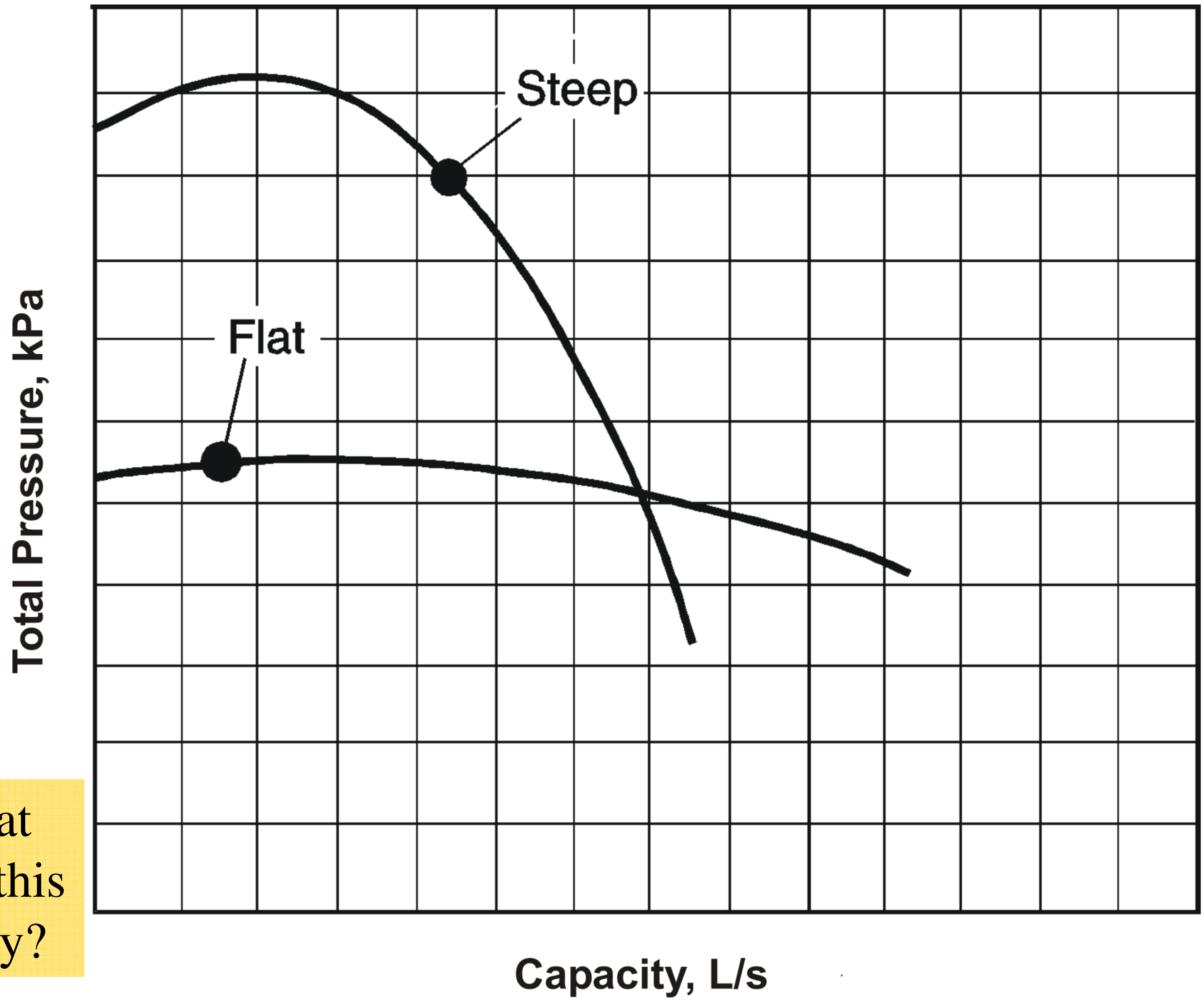
* Video: Centrifugal Pumps | Design Aspects (5:32) http://www.youtube.com/watch?v=pWSyrxFJmt4
http://www.learnengineering.org/2013/03/centrifugal-pumps-design-aspects.html

Total pressure-capacity curve



(Source: *Fundamentals of Water System Design*)

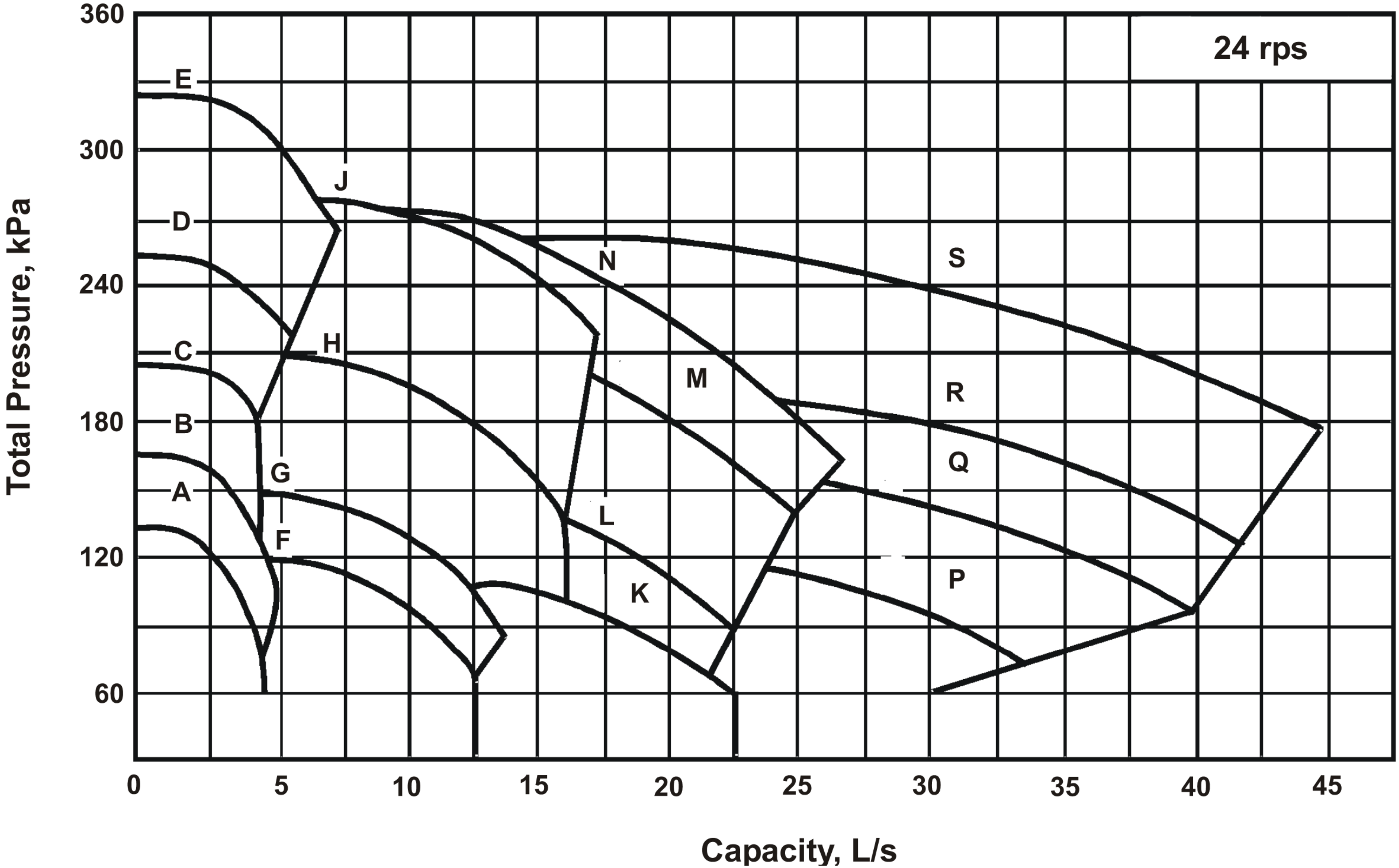
Flat versus steep pump curves



What does this imply?

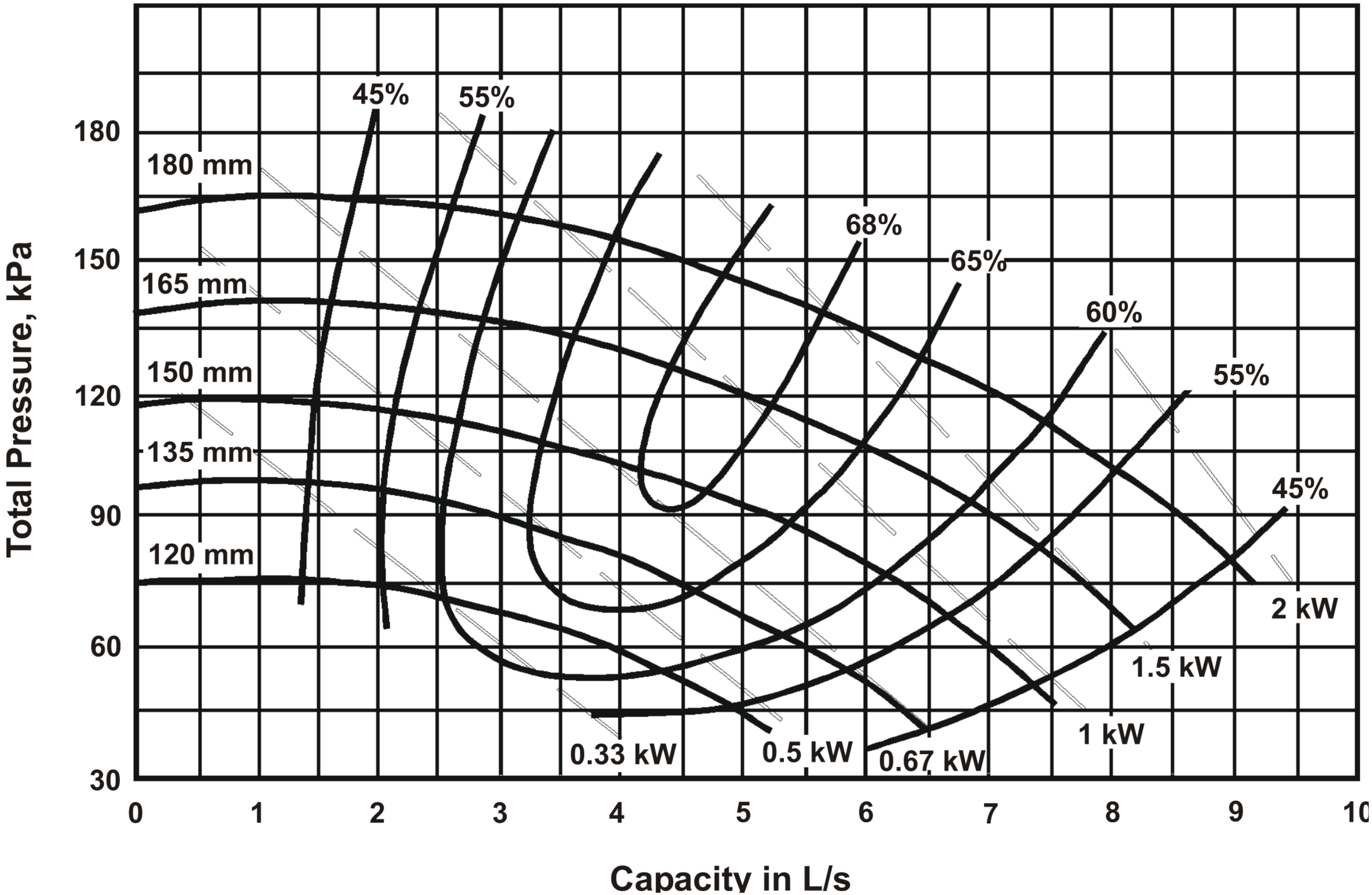
(Source: *Fundamentals of Water System Design*)

Characteristic curves for pump models



(Source: *Fundamentals of Water System Design*)

Selected pump pressure-capacity curve

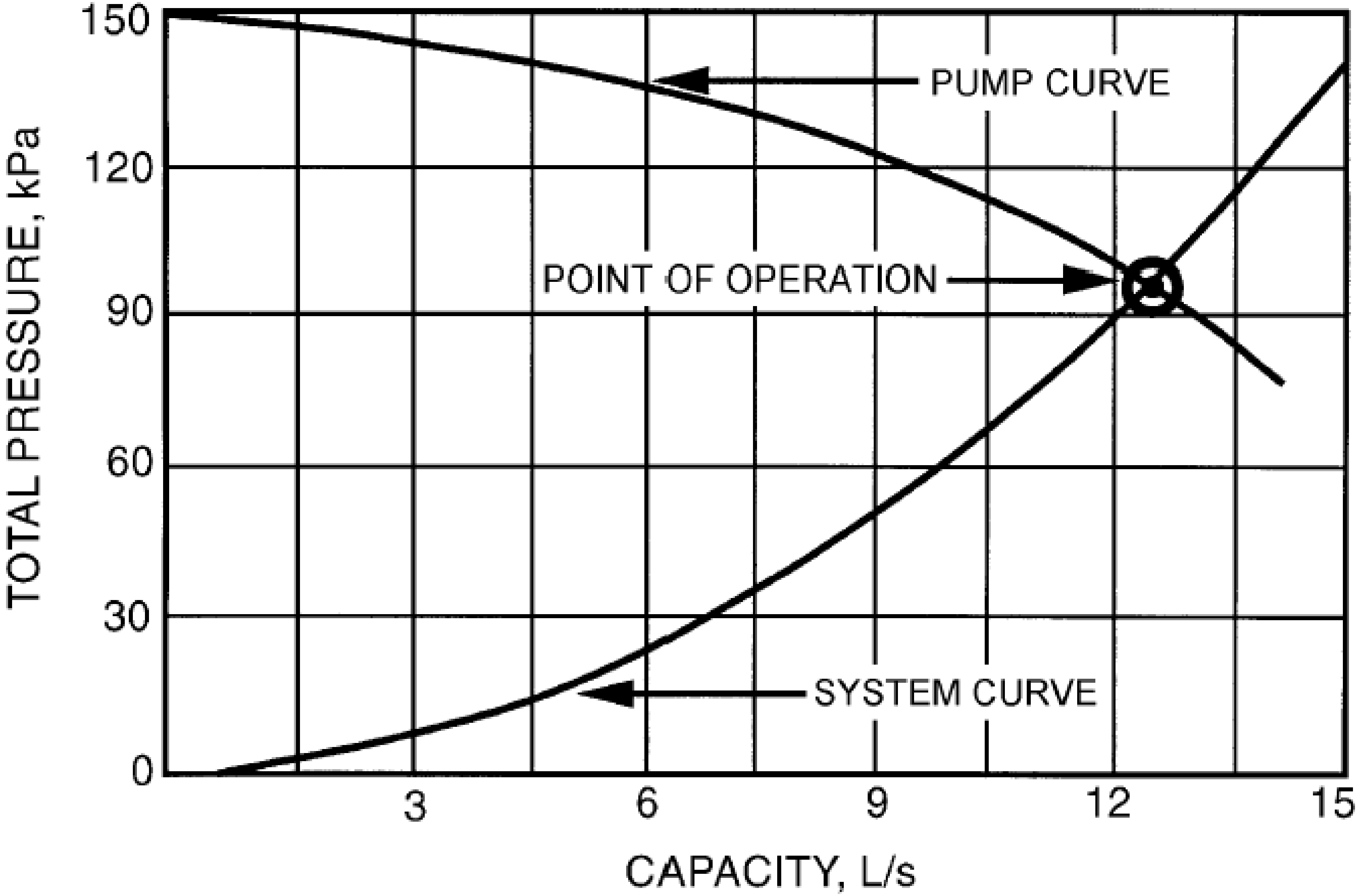


(Source: *Fundamentals of Water System Design*)

Centrifugal Pumps

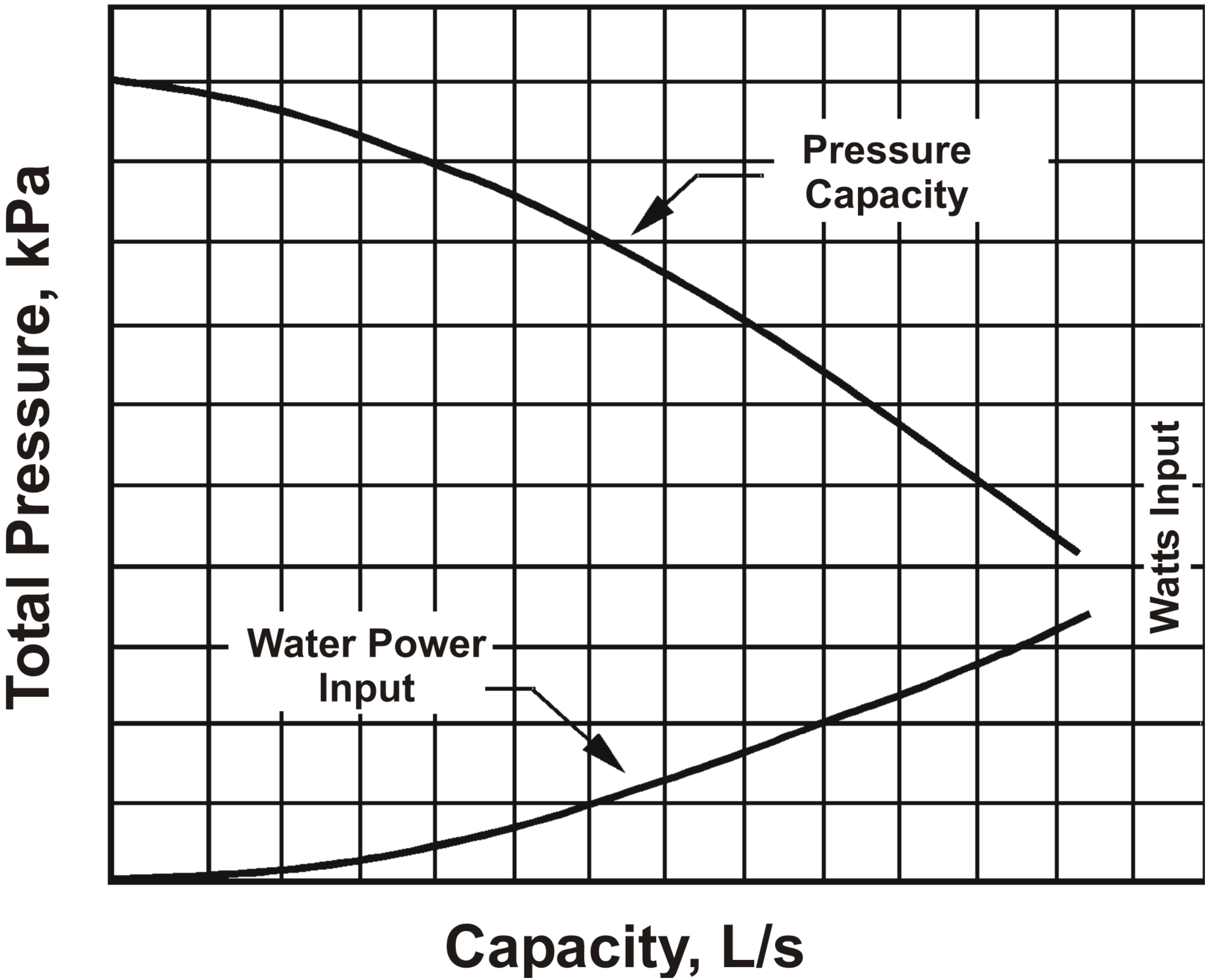
- System pressure characteristic curve
  - Compared w/: fan-duct system characteristics
  - System operating point: intersection of fan curve & system curve
- Pump power (W) = flow (L/s) x pressure (kPa)
  - Pump input power
  - Pump efficiency
    - Matching pump to system curve
    - Best efficiency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

Pump curve and system curve



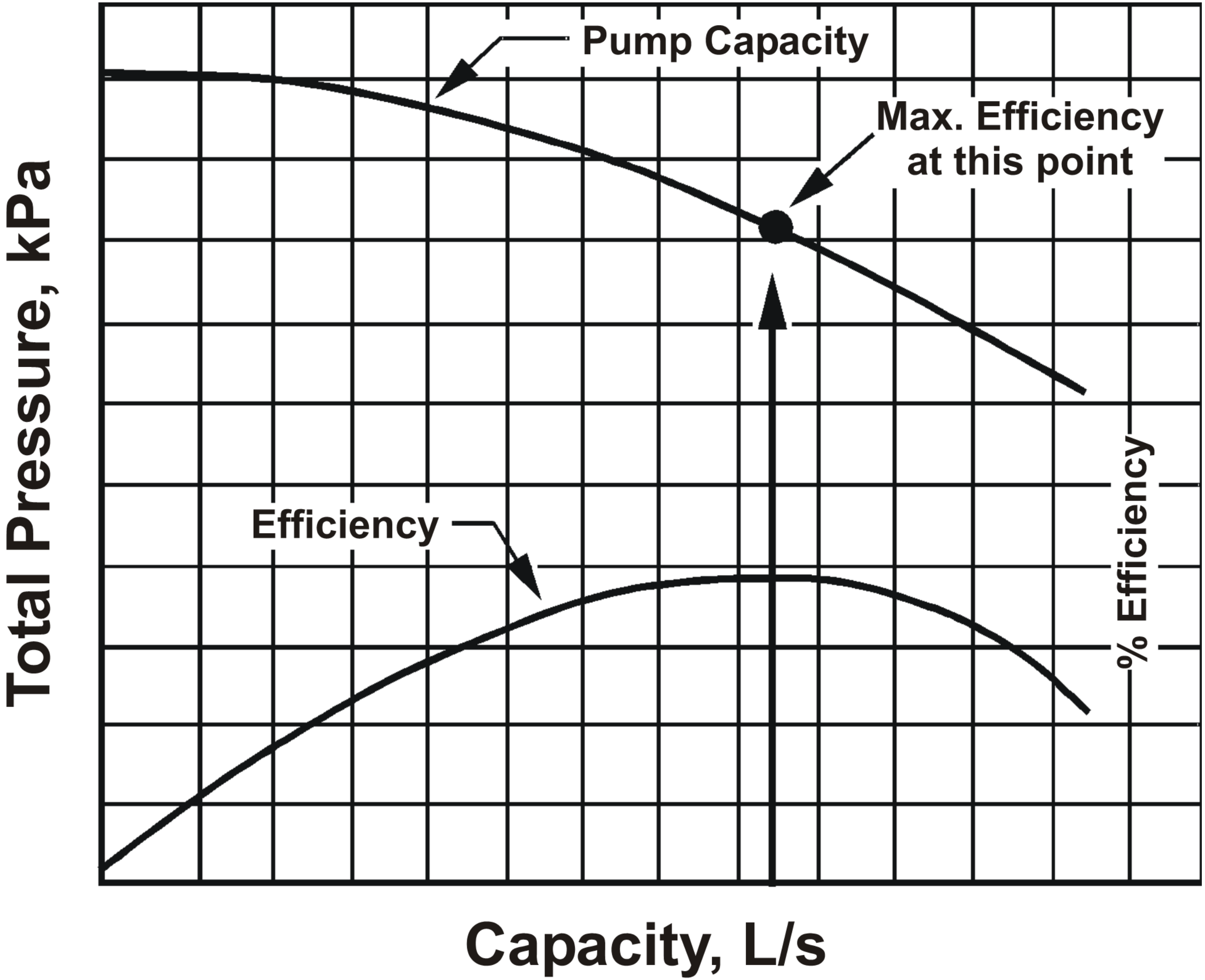
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Increase of pumping power required with pump flow



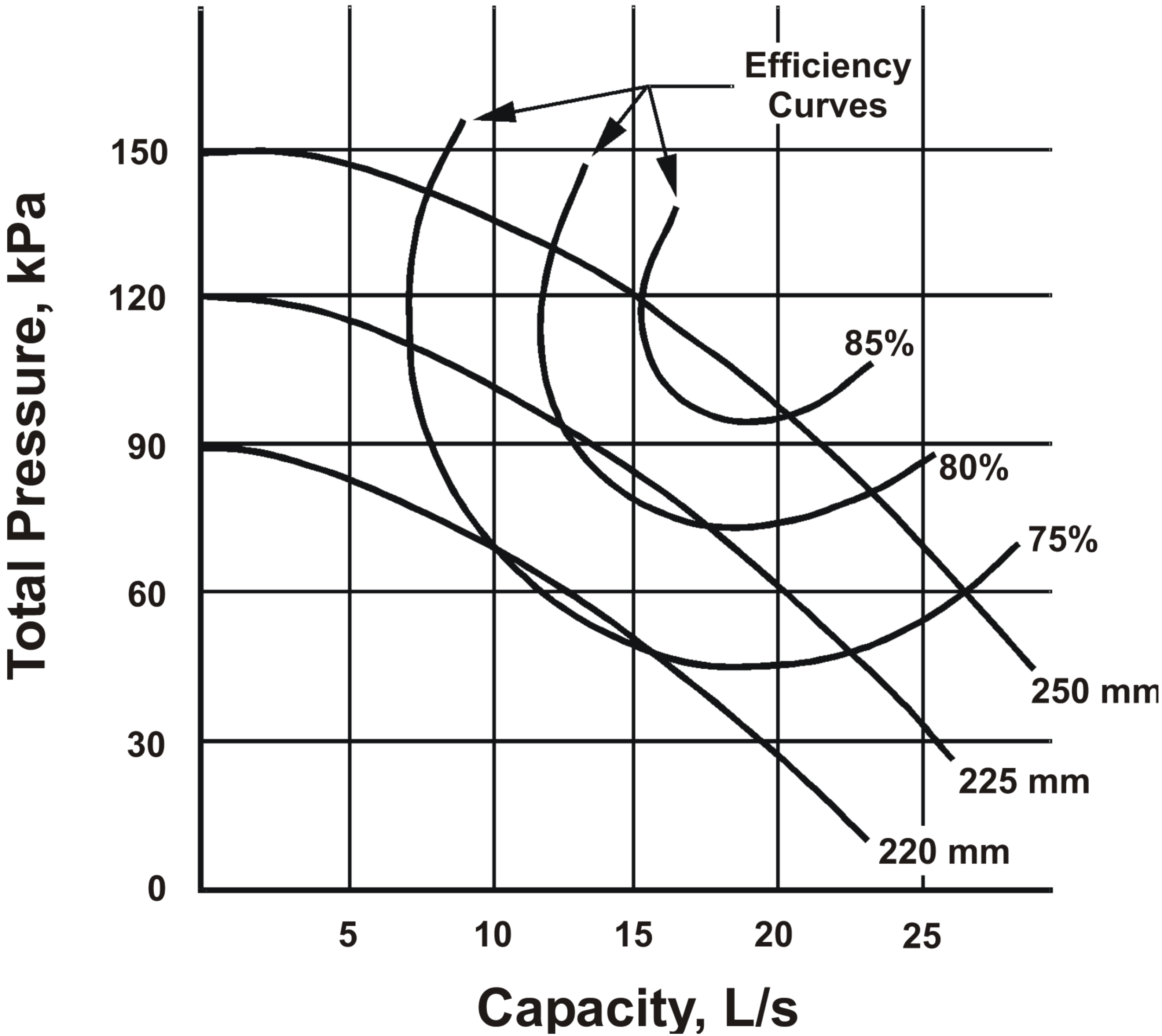
(Source: *Fundamentals of Water System Design*)

Pump efficiency



(Source: *Fundamentals of Water System Design*)

Pump efficiency curves



(Source: *Fundamentals of Water System Design*)

Centrifugal Pumps

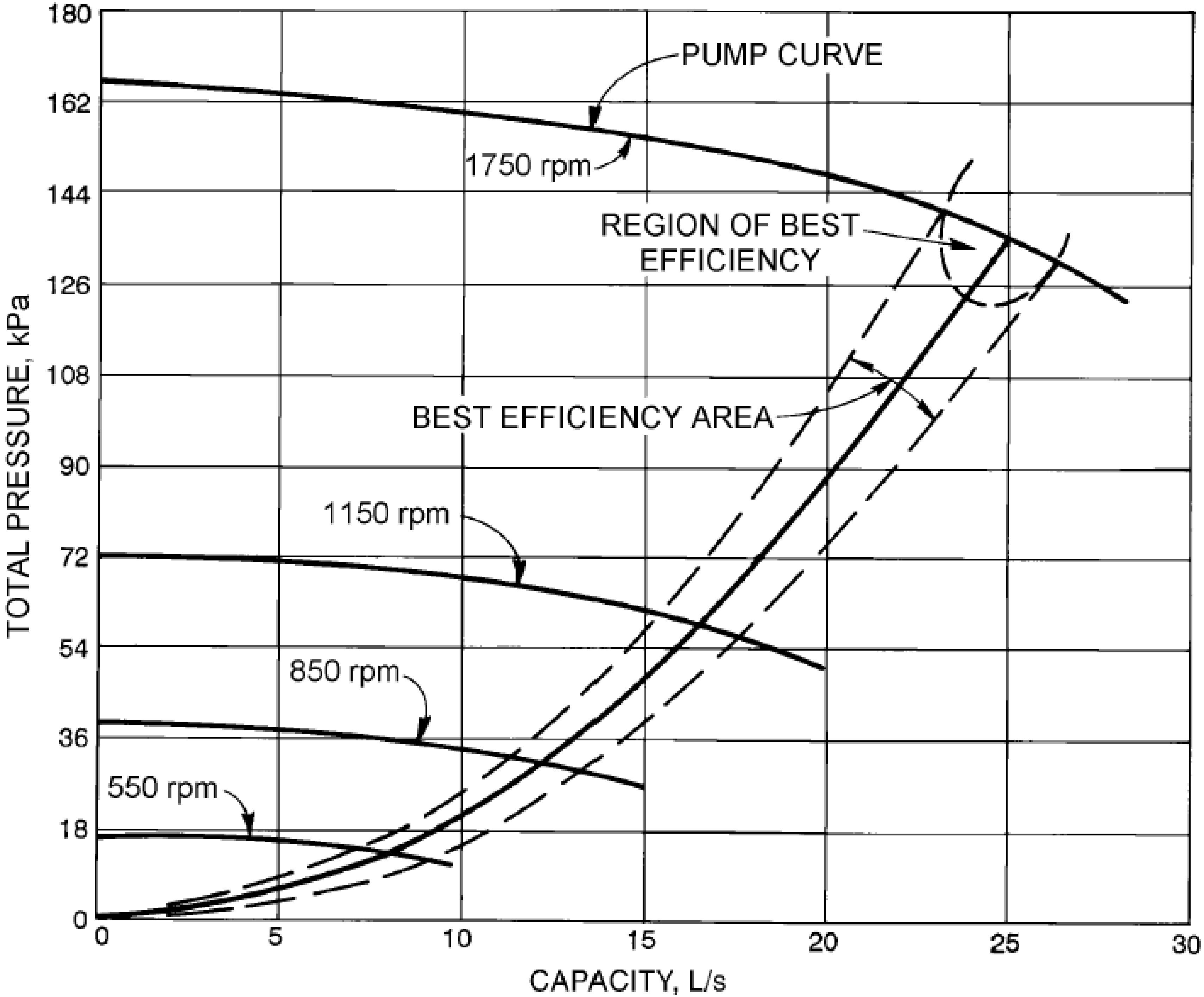
- Similarity relationships
  - Pump affinity laws (c.f. fan laws)

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

Region of best efficiency and best efficiency area

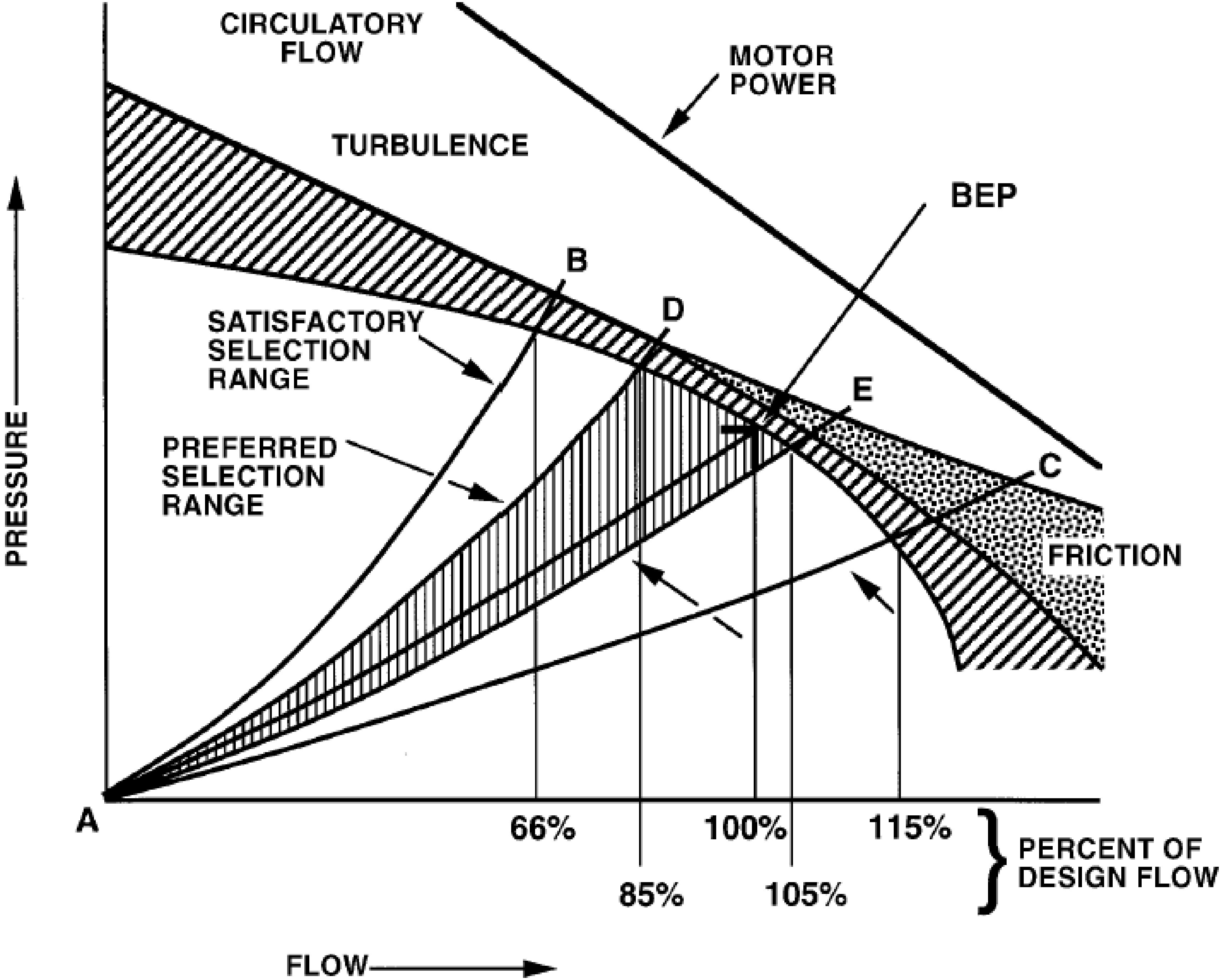


(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Pump Arrangements

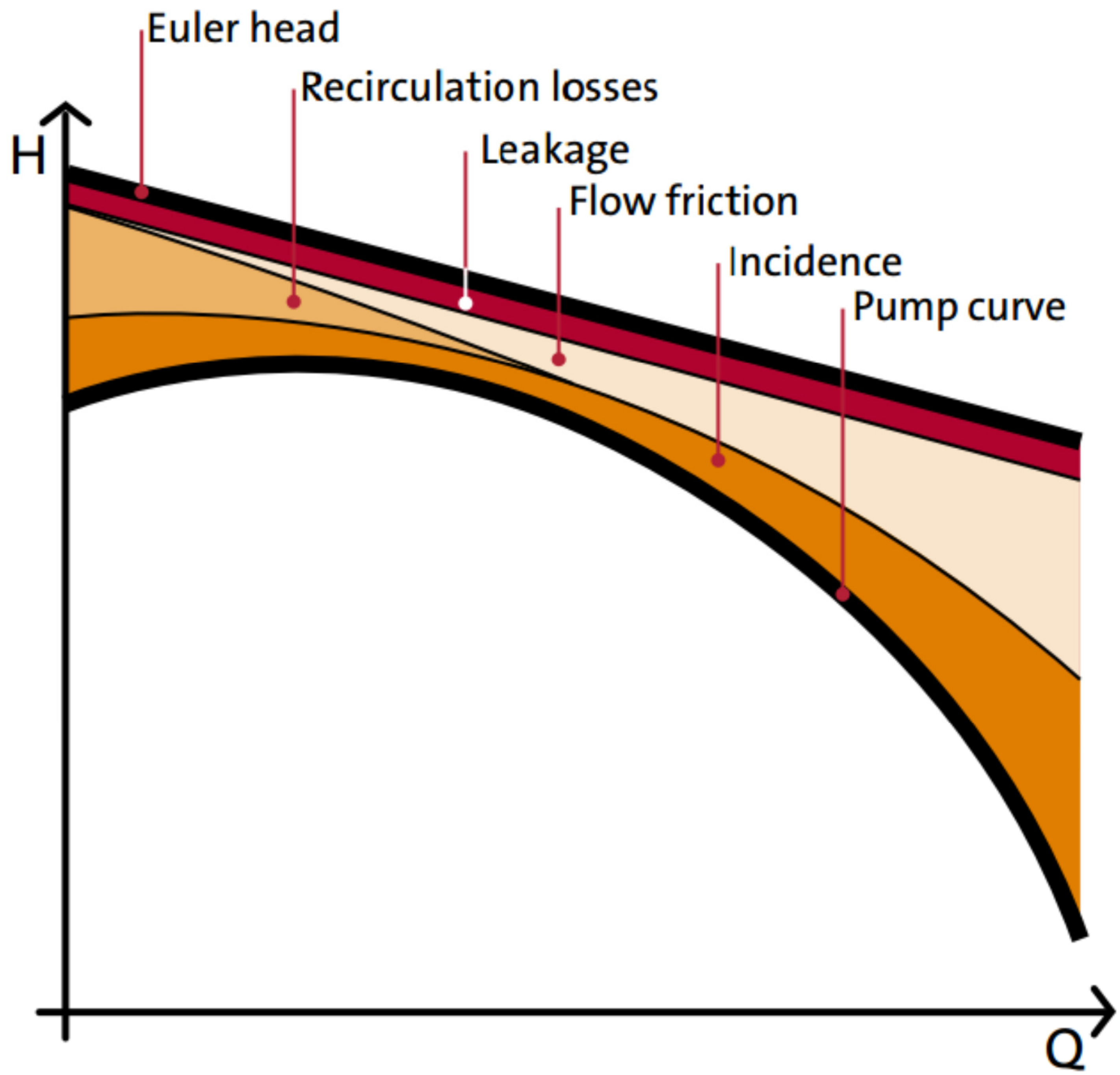
- Pump selection process
  - Determine the load to be pumped
  - Determine design Δt & calculate required flow
  - Sum up the load flows to determine total flow
  - Determine the "critical path" (most resistant)
  - Determine mounting method & support
  - Select a pump from manufacturer
    - Flat curve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

Pump selection regions



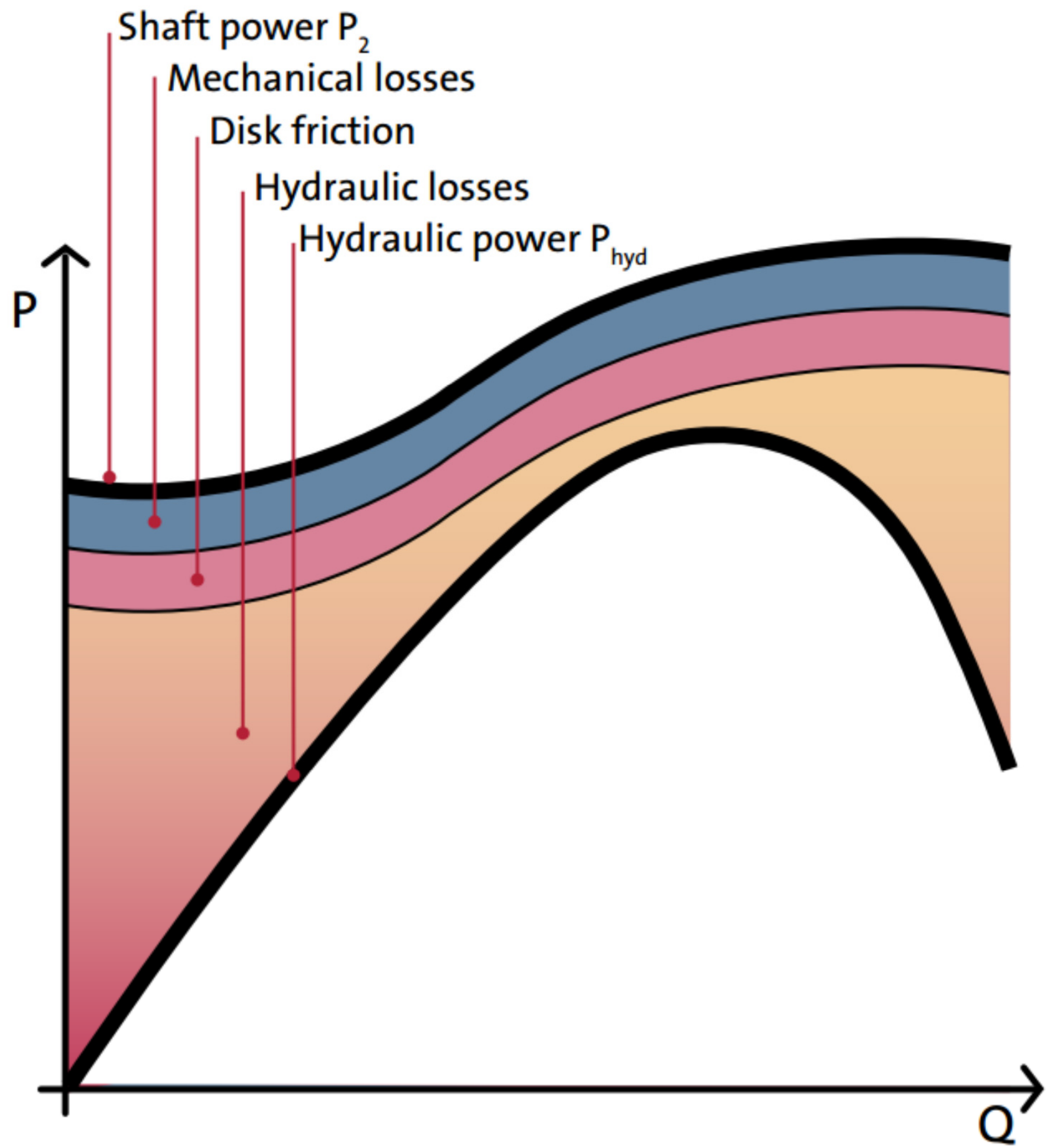
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Reduction of theoretical Euler head due to losses



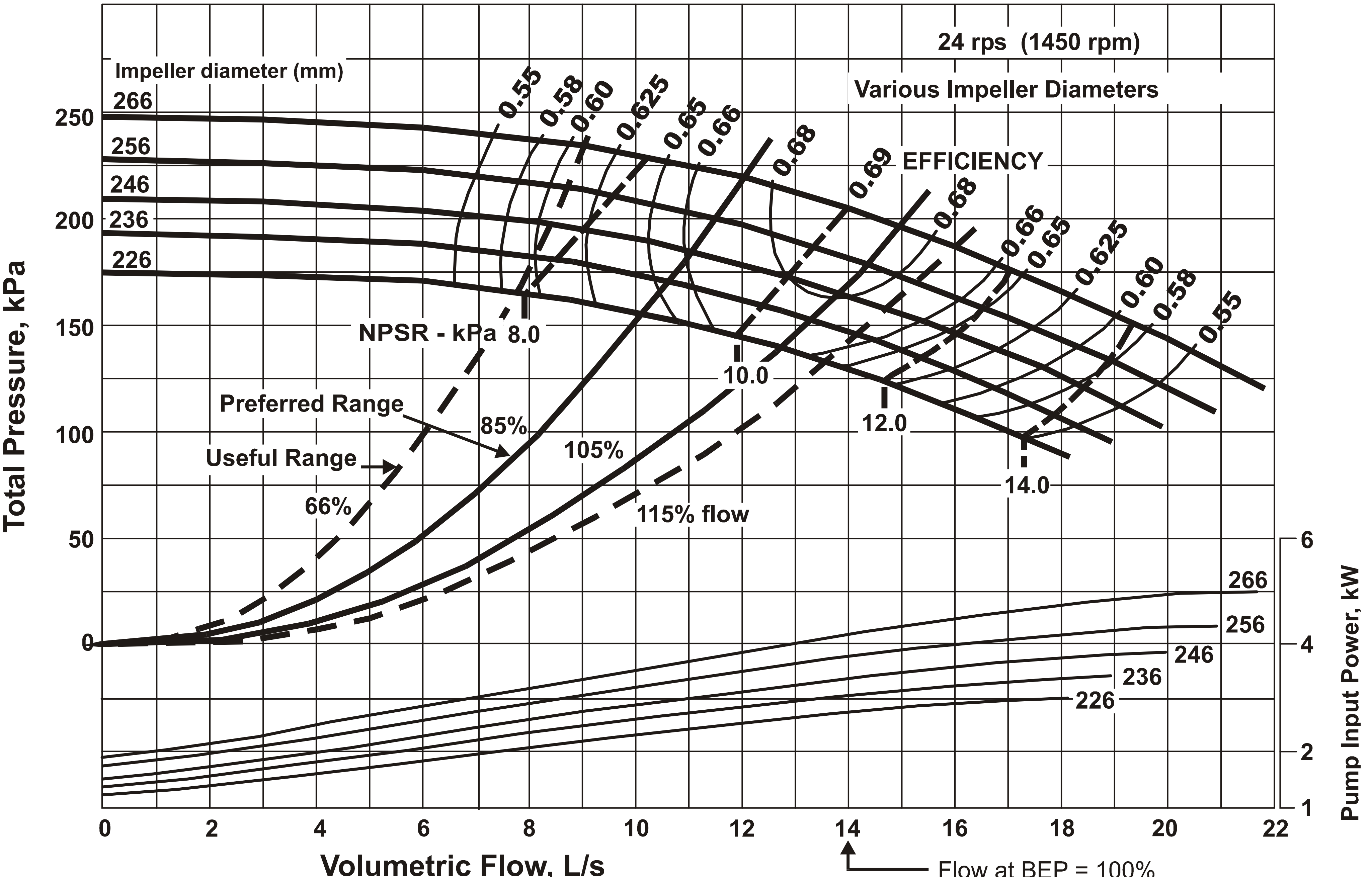
(Source: Grundfos)

Increase in power consumption due to losses



(Source: Grundfos)

Pump performance data

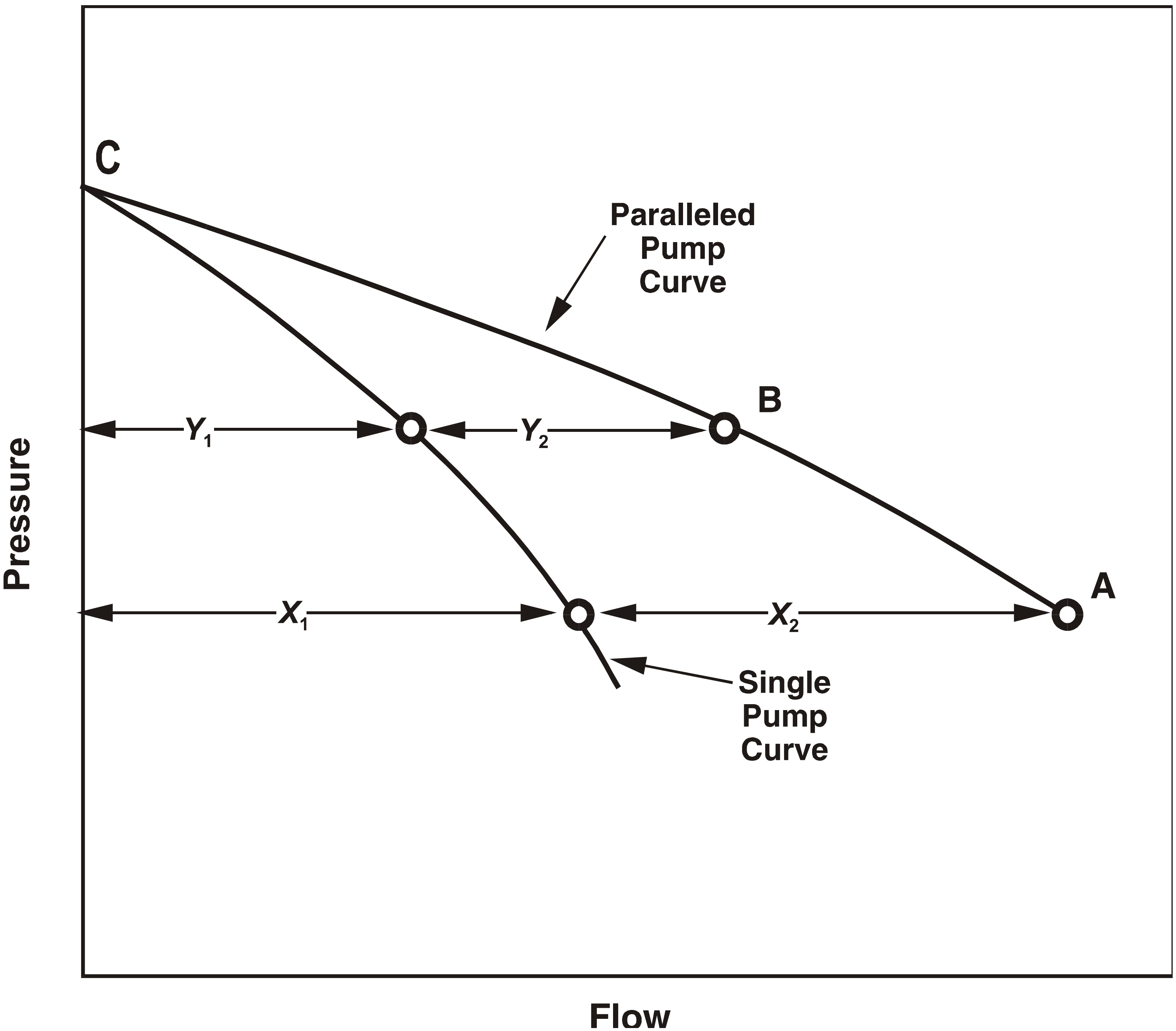


(Source: *Fundamentals of Water System Design*)

Pump Arrangements

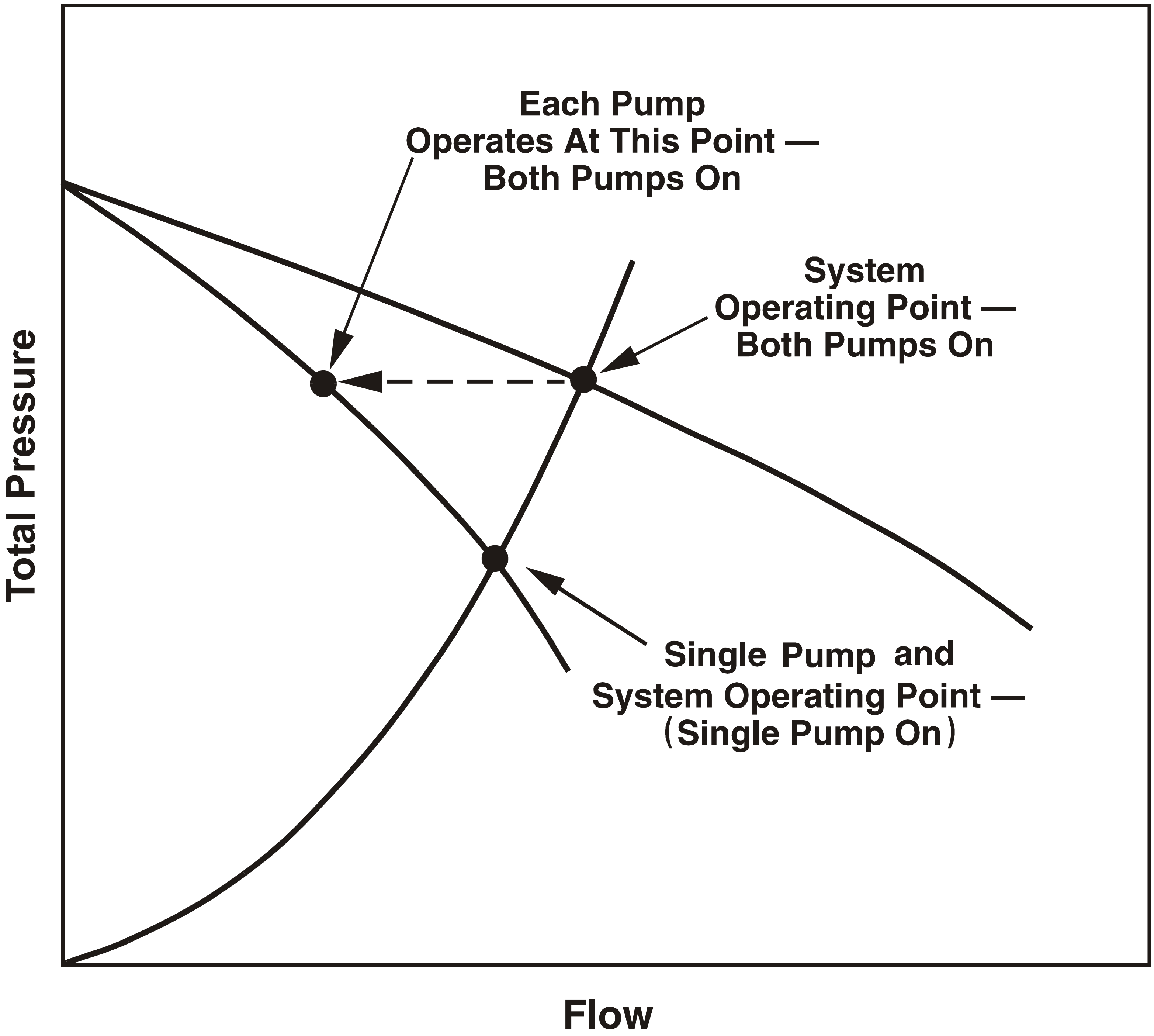
- Pumping arrangements & control scenarios
  - Multiple pumps in parallel or series
  - Standby pump
  - Pumps with two-speed motors
  - Primary-secondary pumping
  - Variable-speed pumping
  - Distributed pumping

Pump curve for parallel operation



(Source: *Fundamentals of Water System Design*)

Operating conditions for parallel pump installation



(Source: *Fundamentals of Water System Design*)

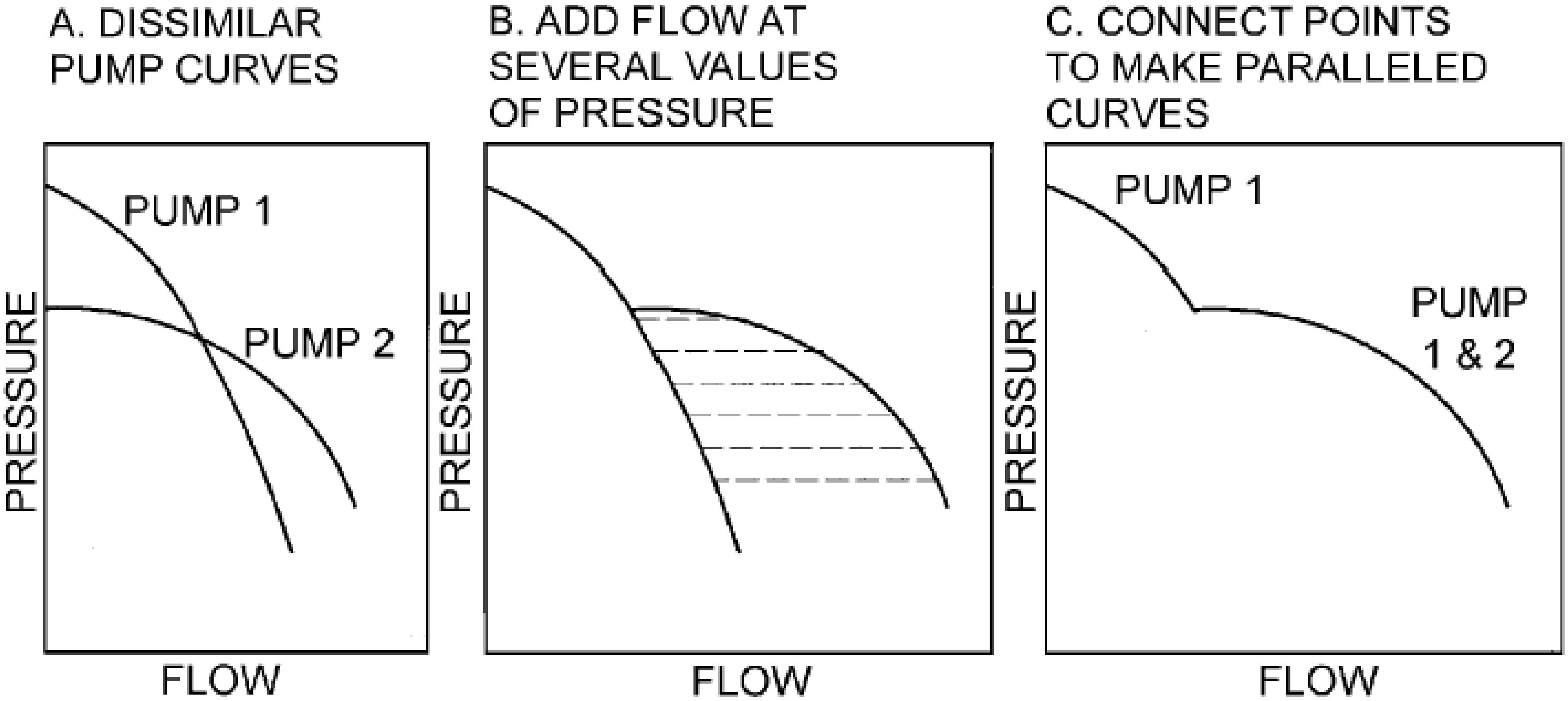


Fig. 34 Construction of Curve for Dissimilar Parallel Pumps

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

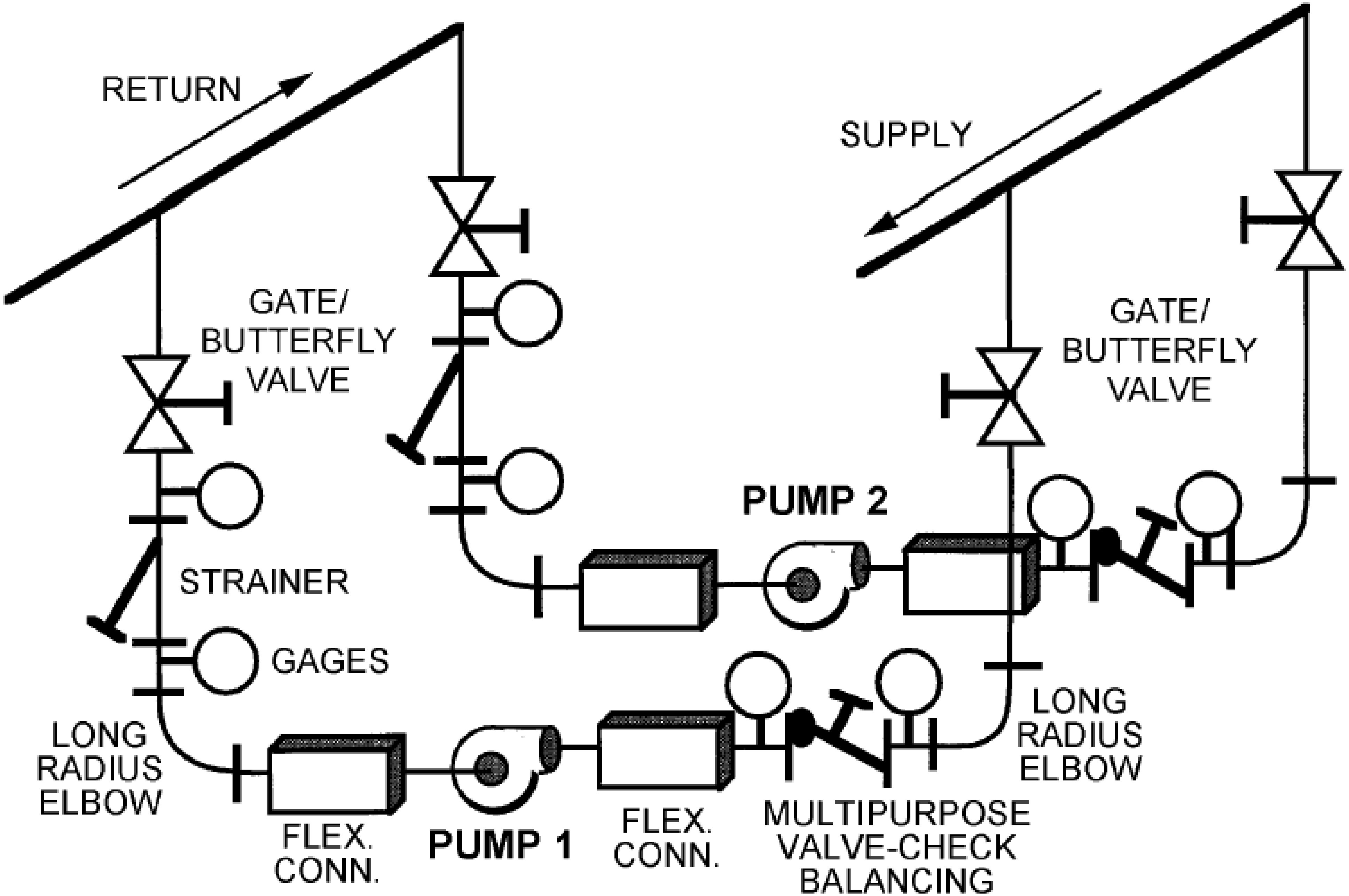
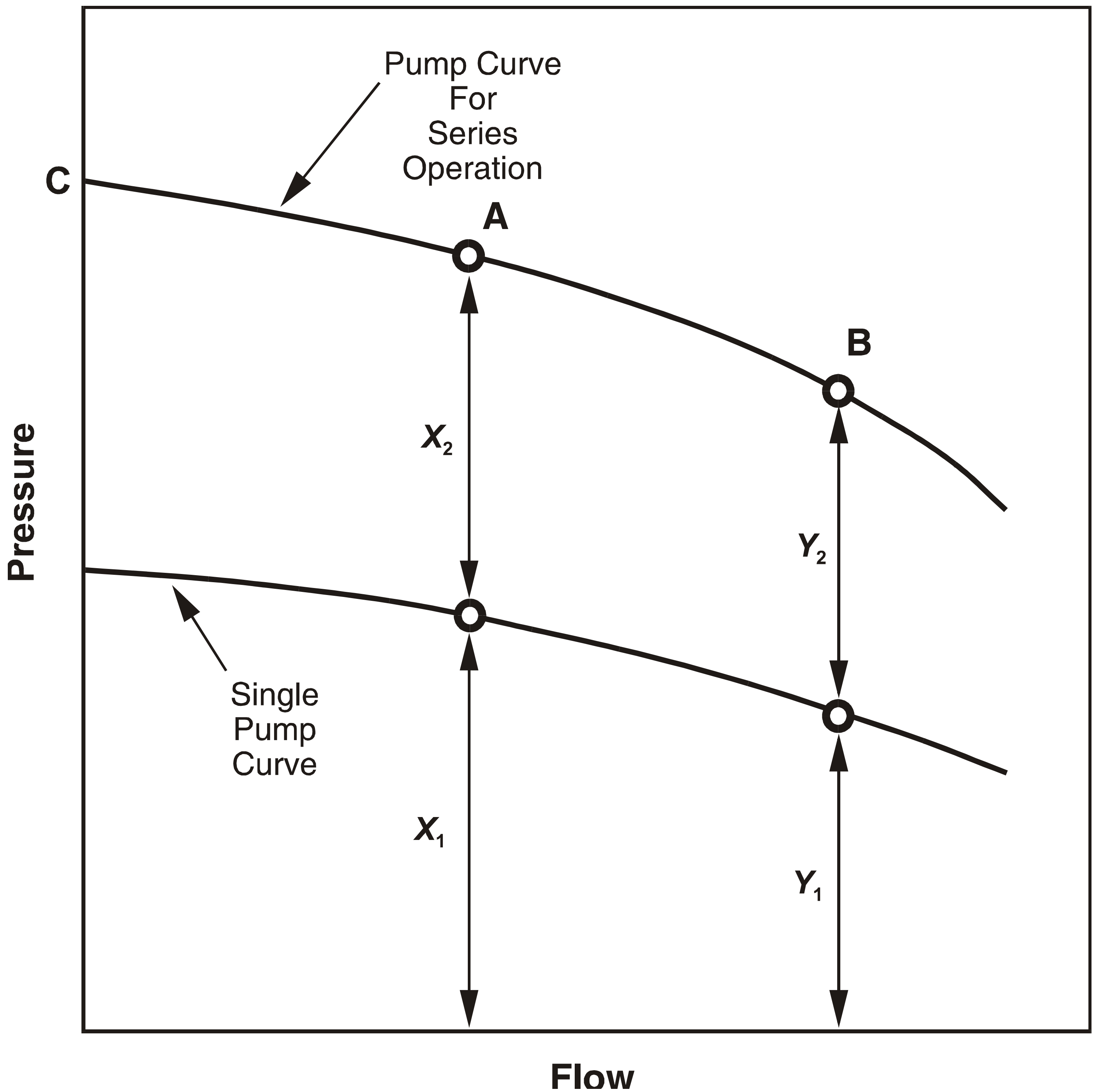


Fig. 35 Typical Piping for Parallel Pumps

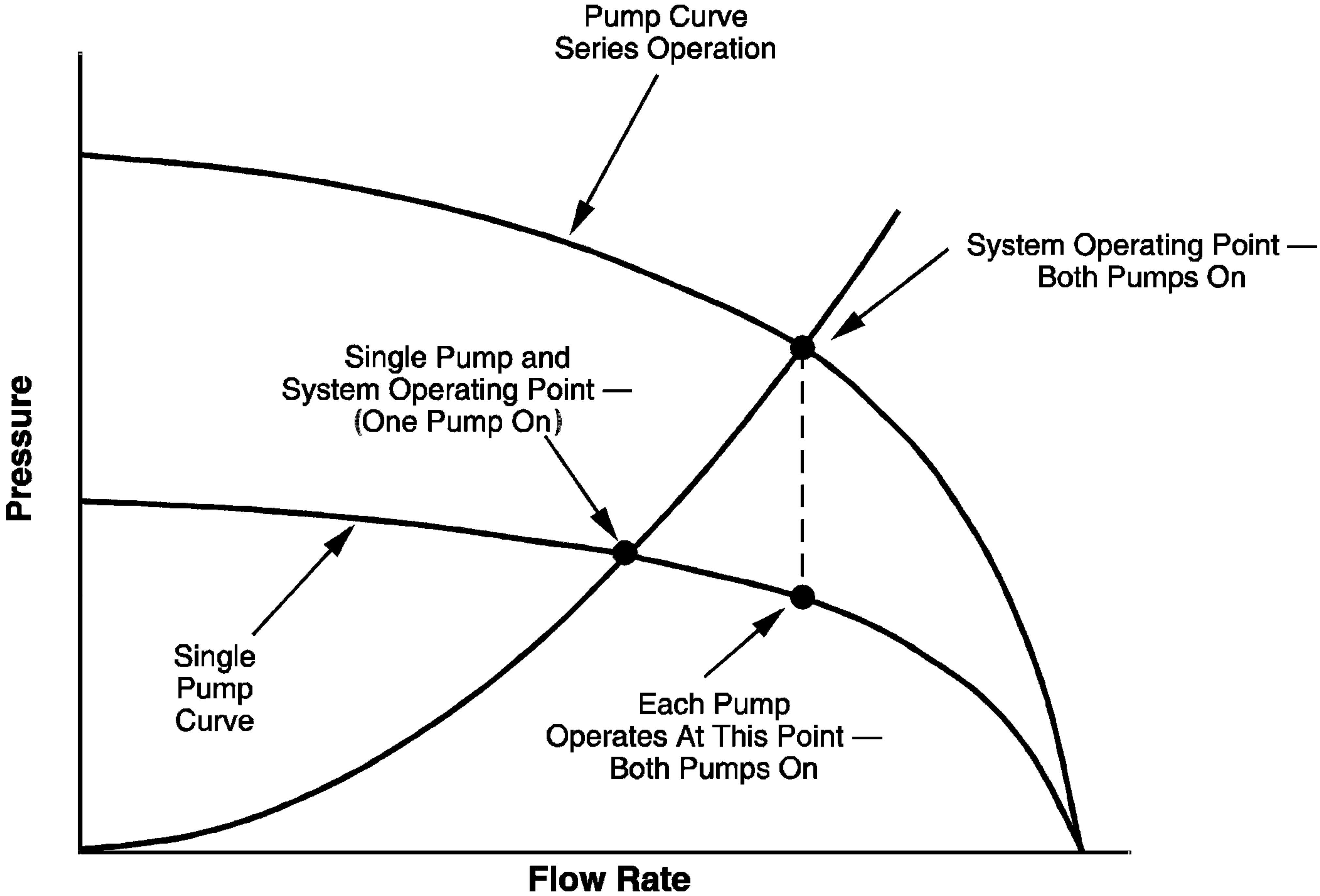
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Pump curve for series operation



(Source: *Fundamentals of Water System Design*)

Operating conditions for series pump



(Source: *Fundamentals of Water System Design*)

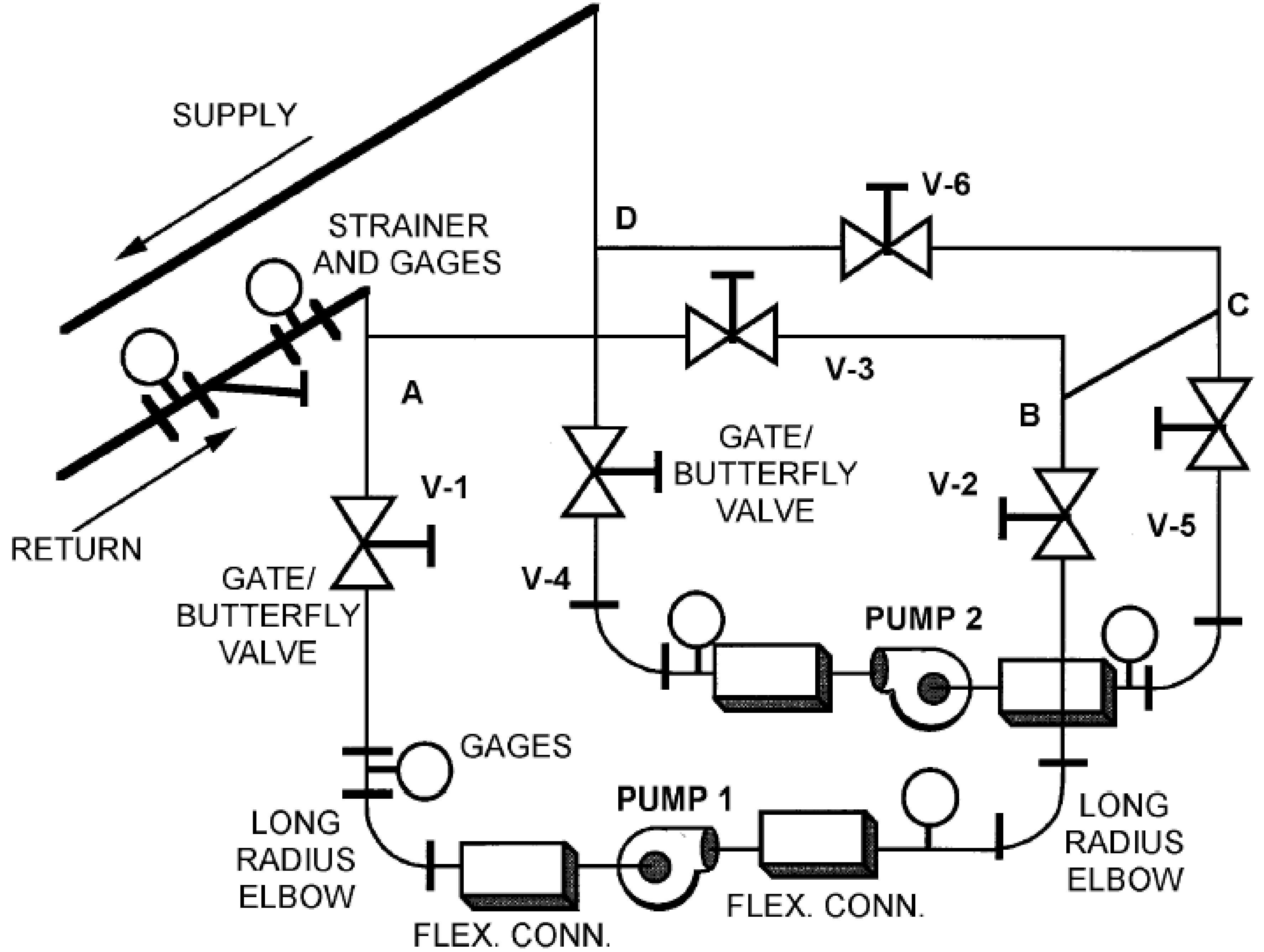


Fig. 38 Typical Piping for Series Pumps

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