CHBE 344: Course Overview

Unit 1: Characterization and Creation of Particles

Unit 2: Mechanical Separations

Unit 3: Thermal Separations and Other Unit Operations

Unit 3: Thermal Separations and Other Unit Operations

Topics:

- Evaporation
  - energy balance (review), overall heat transfer coefficient, single effect vs. multiple effect
  - boiling point elevation, enthalpy of mixing, steam economy
- Pumping
  - Bernoulli equation, frictional losses, efficiency, cavitation
  - pump selection, pump types, pump curves
- Fluidized Beds
  - fluidization types, minimum fluidization velocity

Unit 3: Thermal Separations and Other Unit Operations

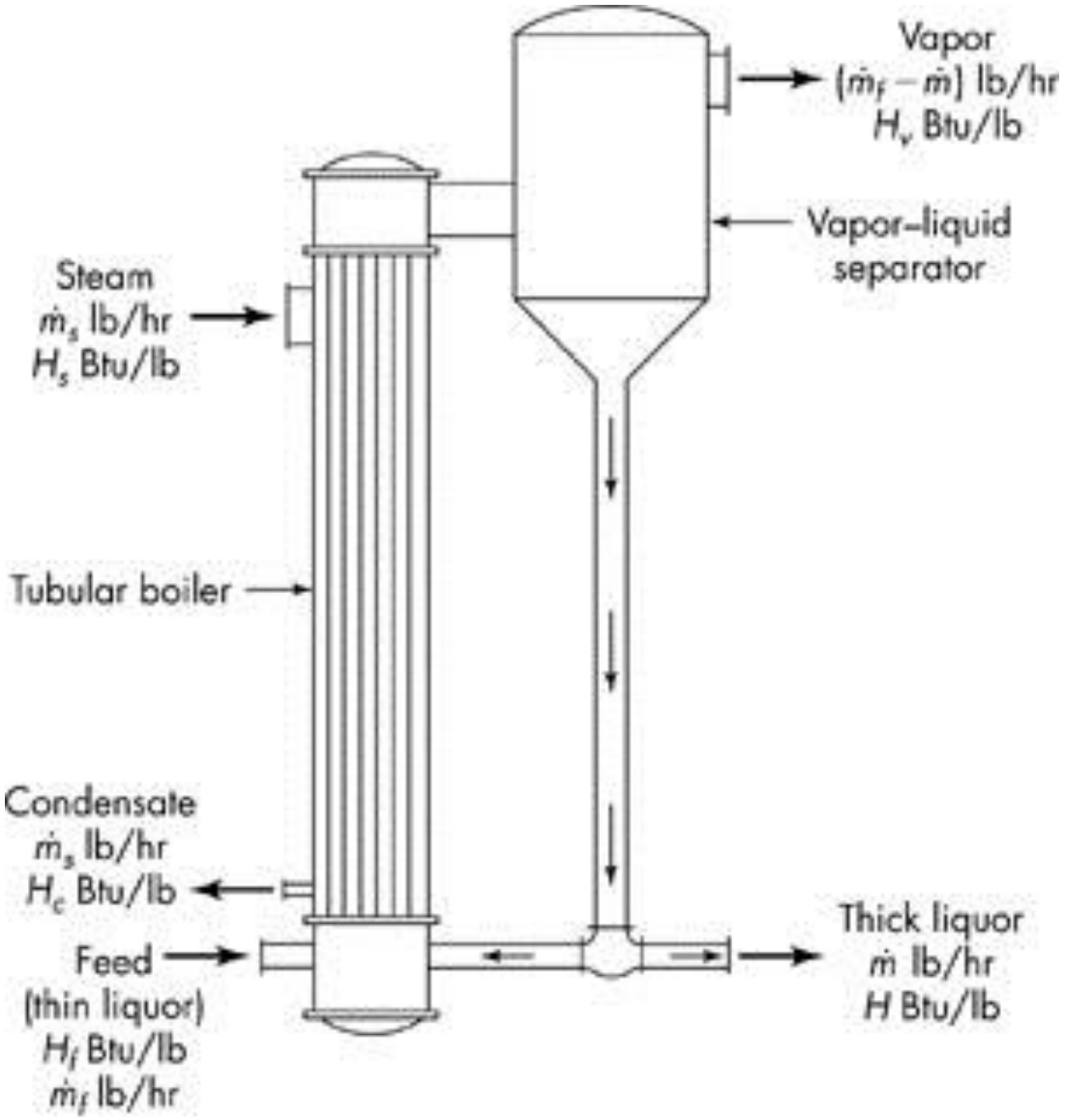
Objectives:

- **Describe** the fundamental physics underlying the following unit operations
  - single-effect evaporator, multiple-effect evaporator, pump, fluidized bed
- **Apply** basic process design equations for the unit operations listed above to **calculate** some process parameters such as
  - heat exchanger area, energy requirements, steam economy, temperature difference, boiling point elevation
  - pump head, frictional losses, flow rate, net positive suction head
  - minimum fluidization velocity
- **Apply** computing programming to carry out processing calculations using the following techniques in Matlab or Python
  - functions, plotting, root finding, lookup tables and data interpolation

Evaporation

- Maple Syrup
- Wiped film evaporator
- Steam Trap
  - Venturi steam trap

Evaporator

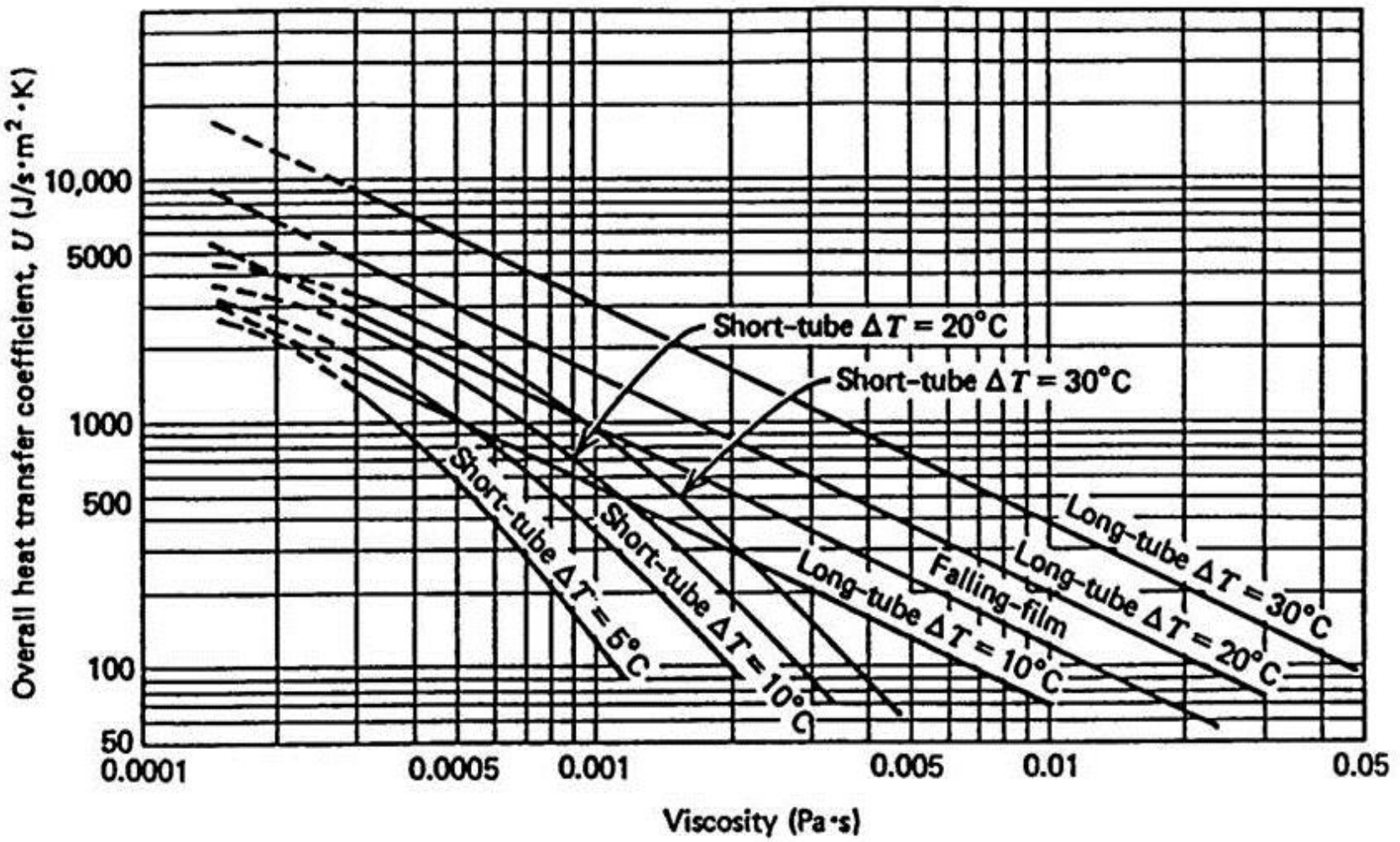

Vapor
$(\dot{m}_f - \dot{m})$ lb/hr
H_v Btu/lb
Vapor–liquid separator
Steam
$\dot{m}_s$ lb/hr
H_s Btu/lb
Tubular boiler
Condensate
$\dot{m}_s$ lb/hr
H_c Btu/lb
Feed
(thin liquor)
H_f Btu/lb
$\dot{m}_f$ lb/hr
Thick liquor
$\dot{m}$ lb/hr
H Btu/lb

Overall Heat Transfer Coefficient

Table 10.1
Typical overall coefficients in evaporators

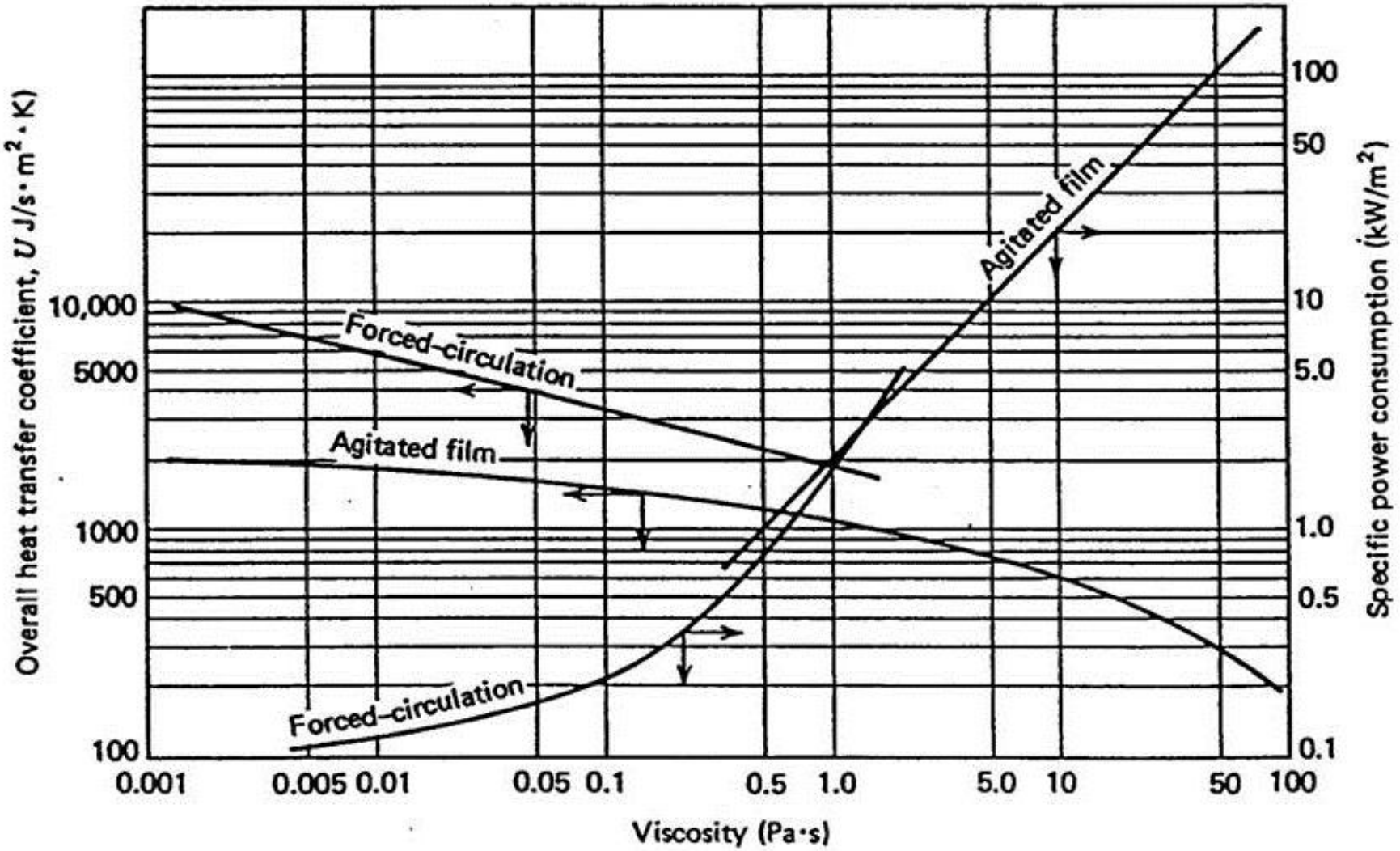
	Overall Coefficient, U	
Type	**W/m^2-°C**	**Btu/ft^2-h-°F**
Long-tube vertical evaporators	1000-2500	200-500
Natural circulation	2000-5000	400-1000
Forced circulation		
Agitated-film evaporator, Newtonian liquid		
1 cP	2000	400
1 P	1500	300
100 P	600	120

Overall Heat Transfer Coefficient



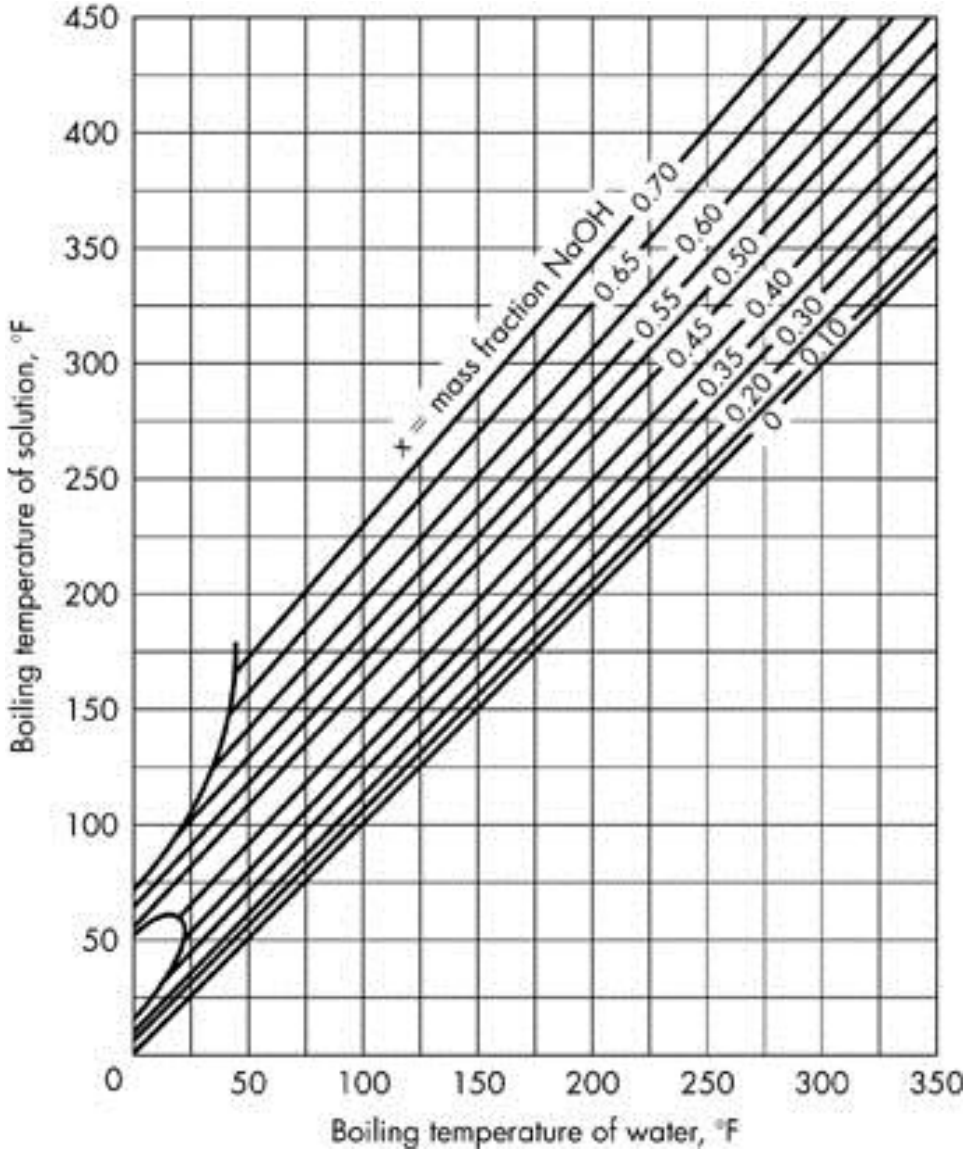
Overall heat transfer coefficients for preliminary design of natural convection evaporators (water-based systems).

Overall Heat Transfer Coefficient



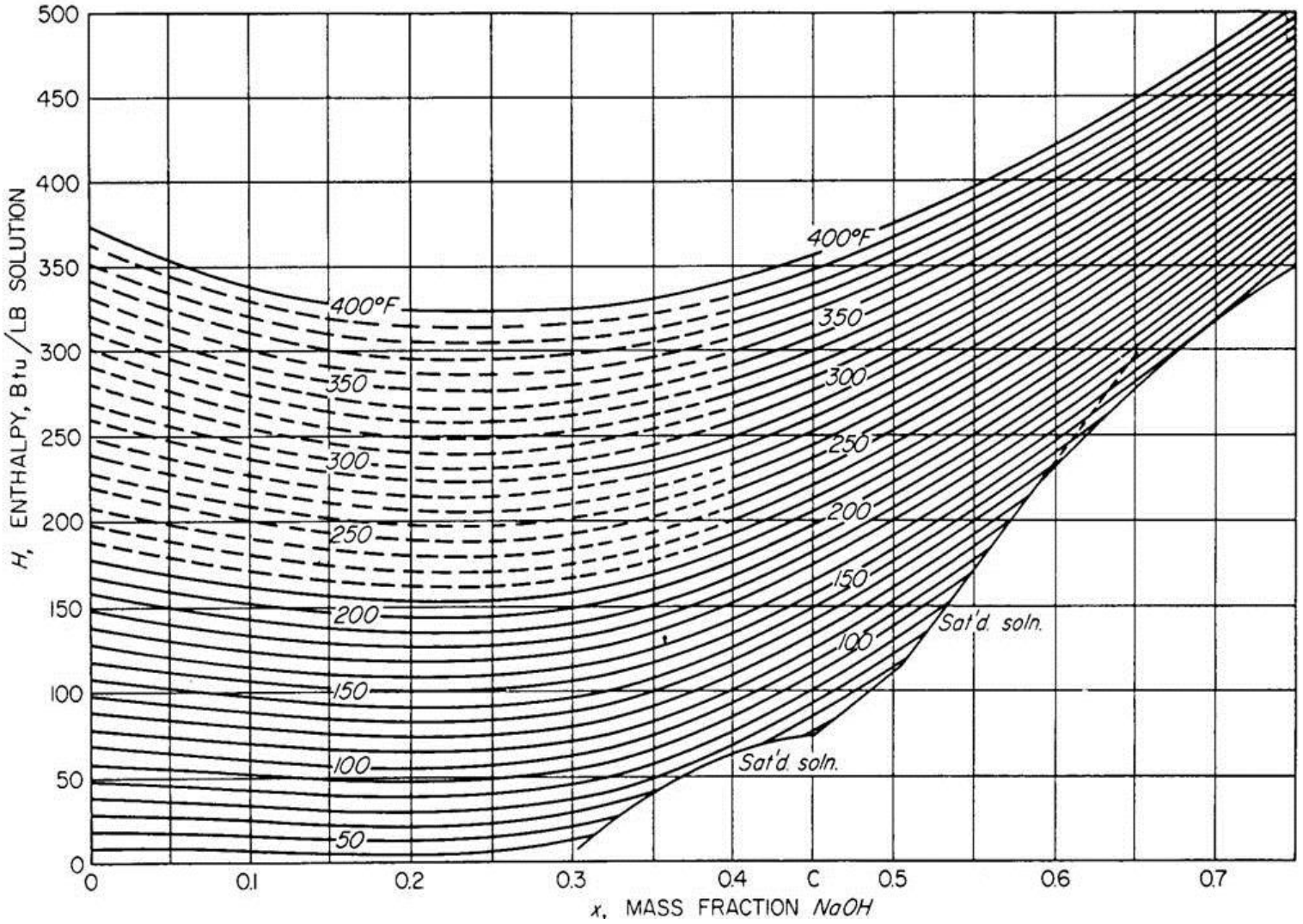
Overall heat transfer coefficients and specific power consumption for preliminary design of forced-circulation evaporators (water-based systems).

Boiling Point Elevation: Duhring's Diagram

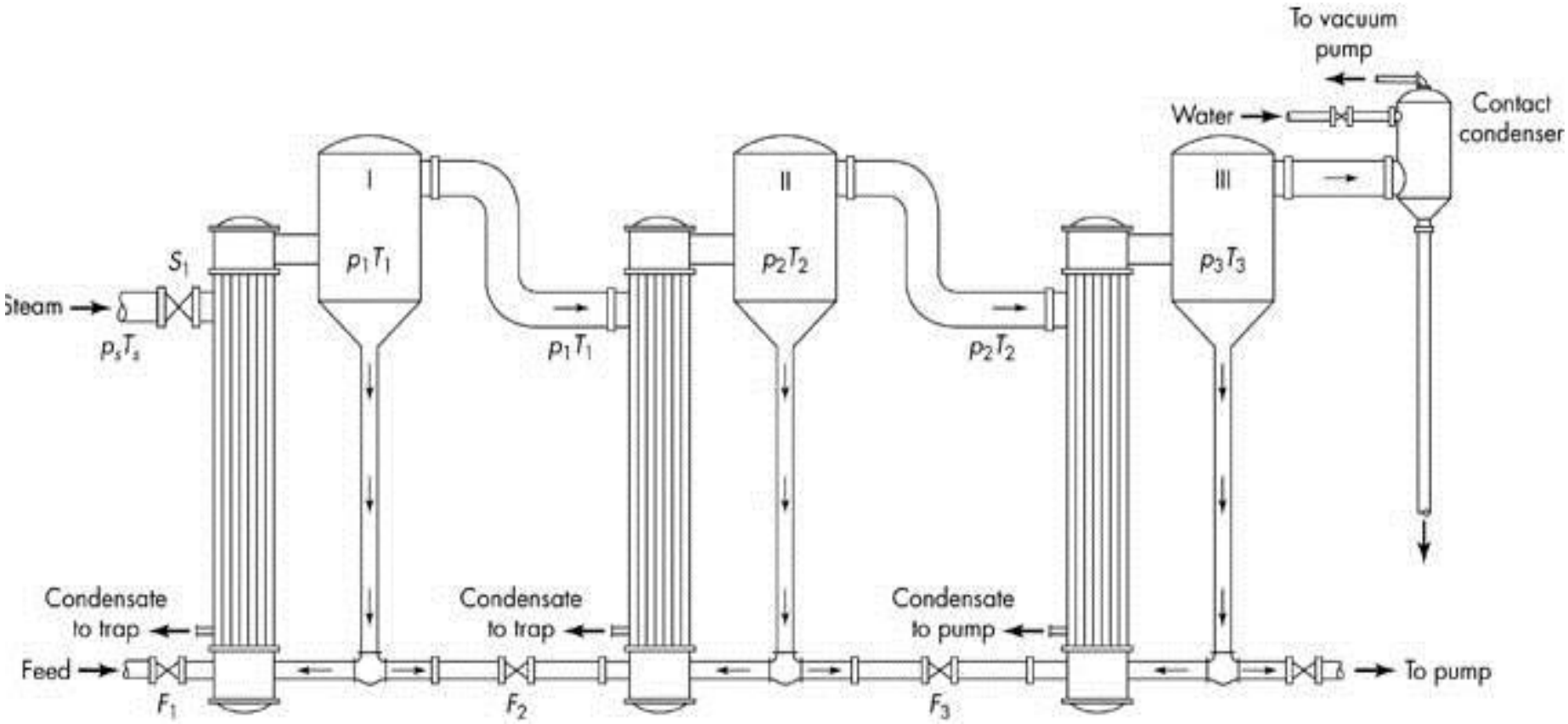


Heat of Mixing (Dilution)

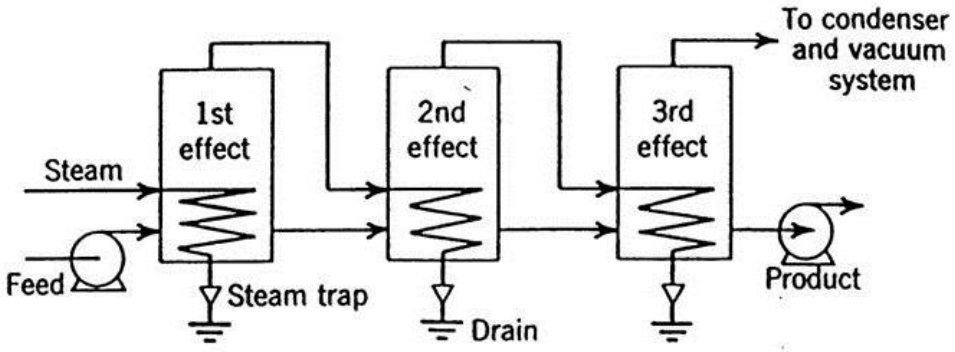
Sodium Hydroxide



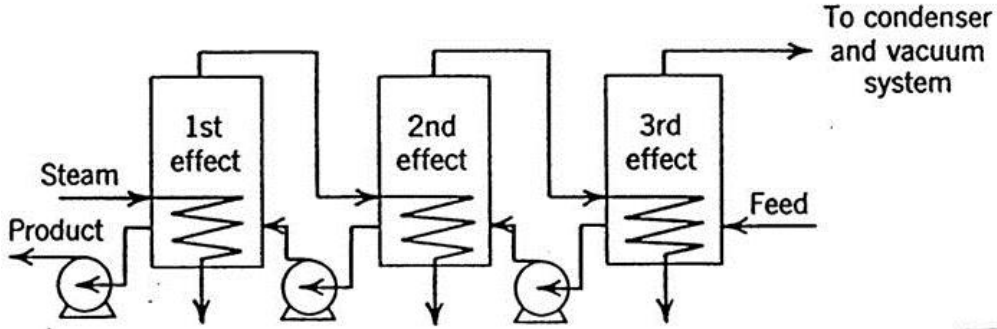
Multiple-Effect Evaporators



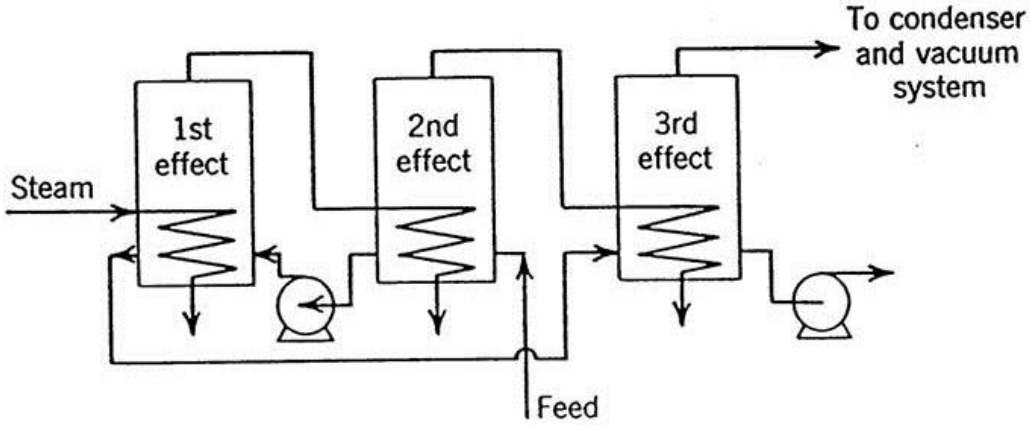
Alternate Configurations



(*a*) Forward feed.



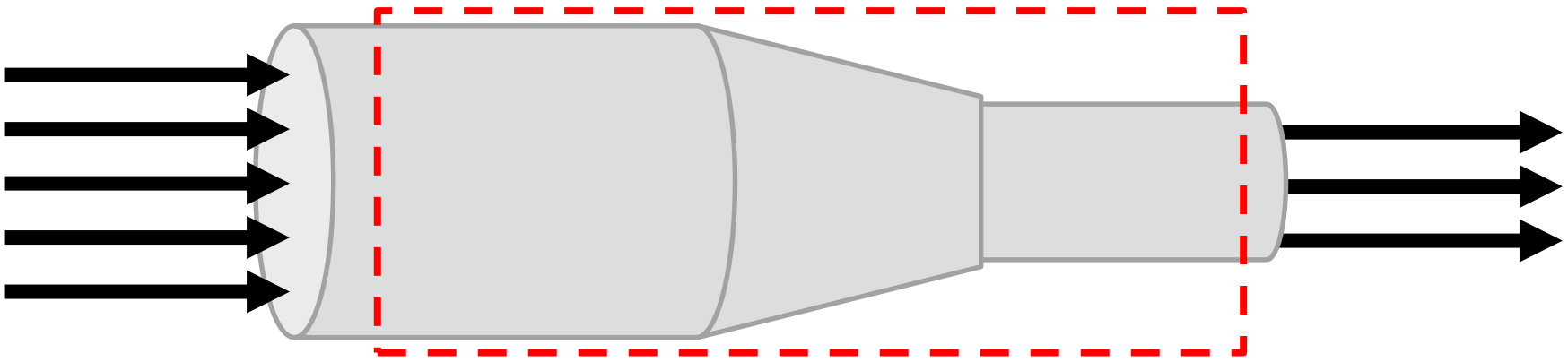
(*b*) Backward feed.



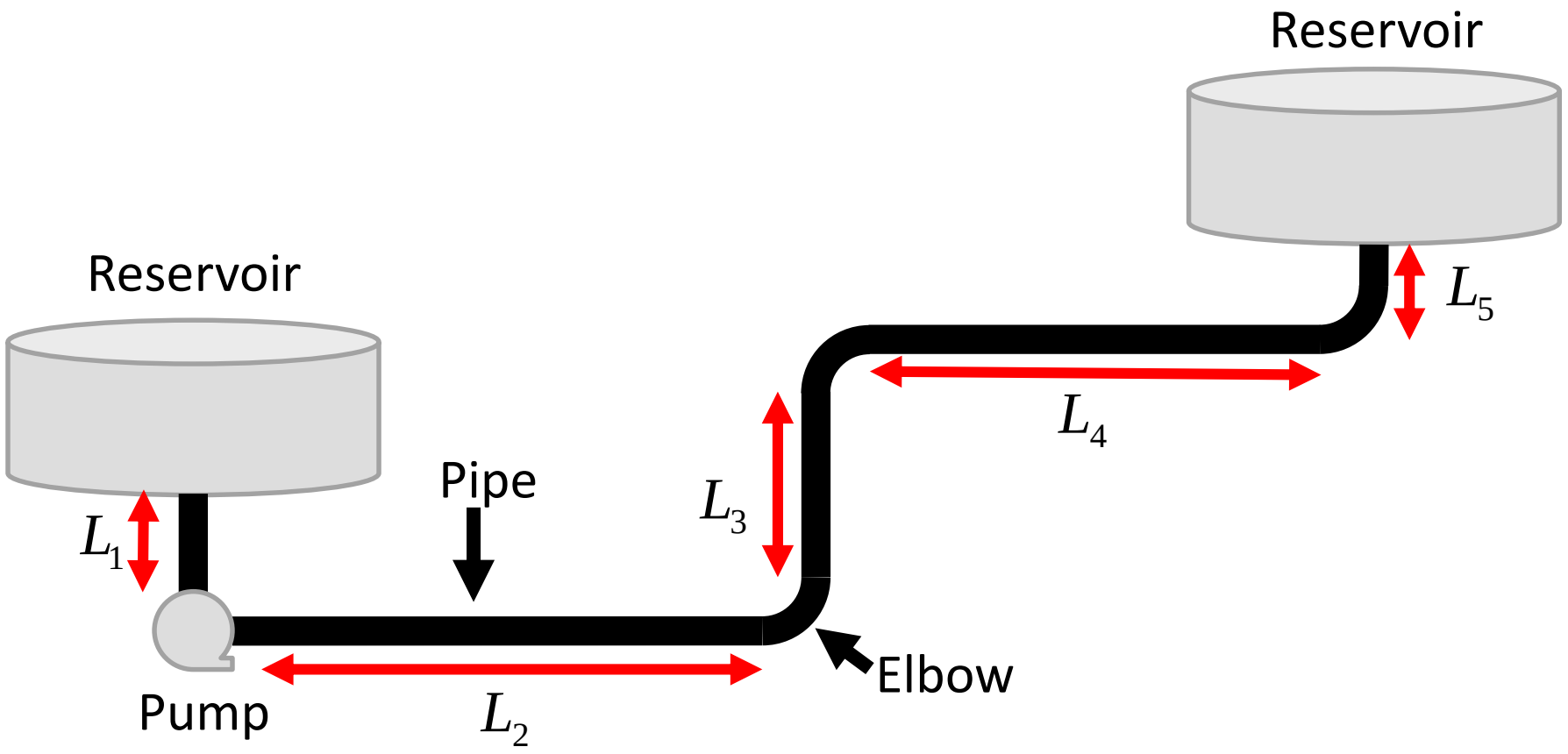
(*c*) Mixed feed.

Vapor recompression

Mass Balance in Fluid Flow

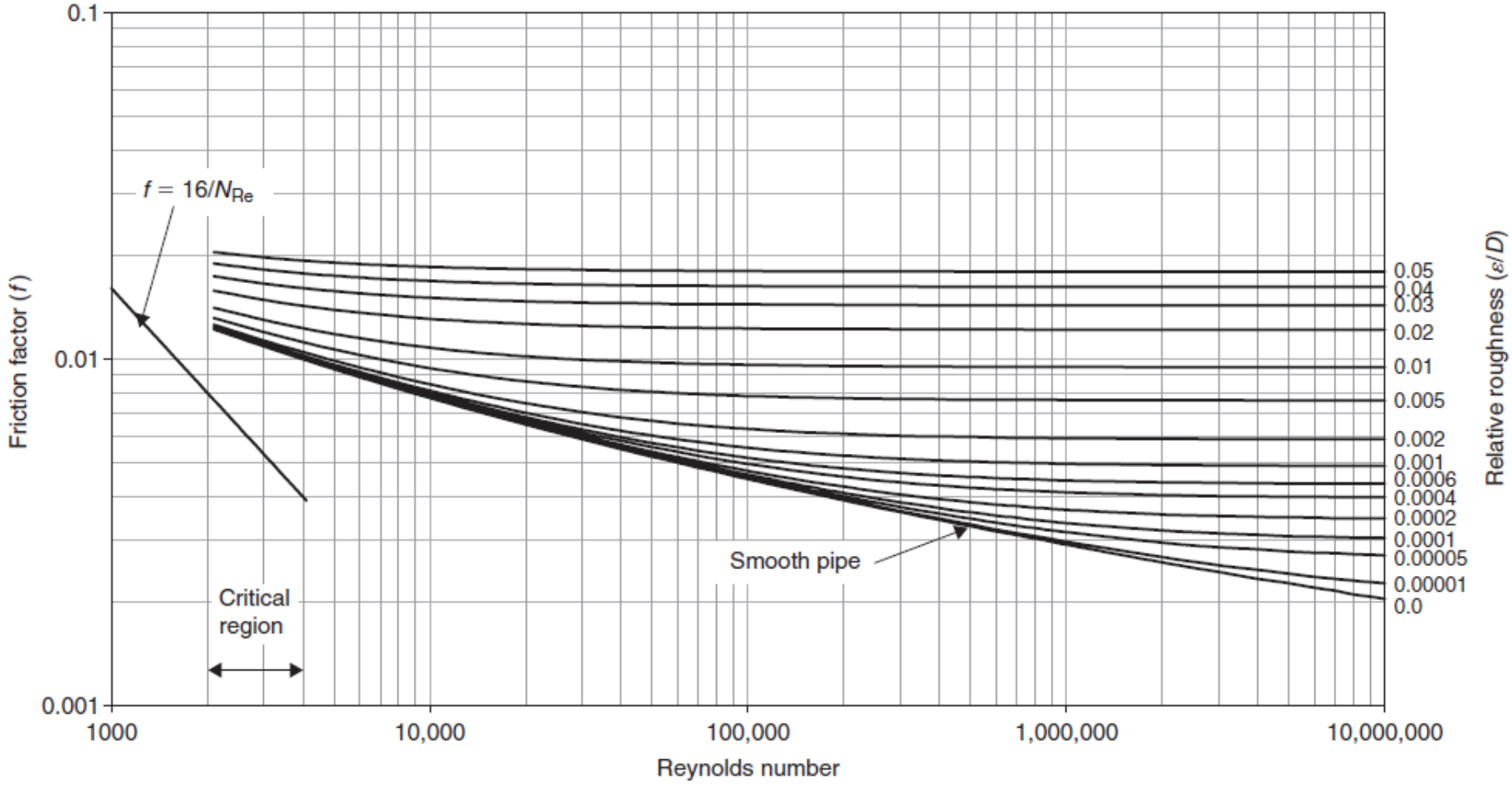


Energy Balance in Fluid Flow



Friction Factor

$$E_{friction} = E_{f,major} + E_{f,expansion} + E_{f,contraction} + E_{f,fittings}$$



Frictional Losses

Table 2.2 Friction Losses for Standard Fittings

Type of Fitting	C_{ff}
Elbows	
Long radius 45°, flanged	0.2
Long radius 90°, threaded	0.7
Long radius 90°, flanged	0.2
Regular 45°, threaded	0.4
Regular 90°, flanged	0.3
Regular 90°, threaded	1.5
180° Return bends	
180° return bend, flanged	0.2
180° return bend, threaded	1.5
Tees	
Branch flow, flanged	1.0
Branch flow, threaded	2.0
Line flow, flanged	0.2
Line flow, threaded	0.9
Union threaded	0.8
Valves	
Angle, fully open	2
Ball valve, ⅓ closed	5.5
Ball valve, ⅔ closed	210
Ball valve, fully open	0.05
Diaphragm valve, open	2.3
Diaphragm valve, ¼ closed	2.6
Diaphragm valve, ½ closed	4.3
Gate, ¾ closed	17
Gate, ¼ closed	0.26
Gate, ½ closed	2.1
Gate, fully open	0.15
Globe, fully open	10
Swing check, backward flow	∞
Swing check, forward flow	2

$$E_{f,i} = C_{f,i}\frac{\bar{u}^2}{2} = \frac{\Delta P_{f,i}}{\rho}$$

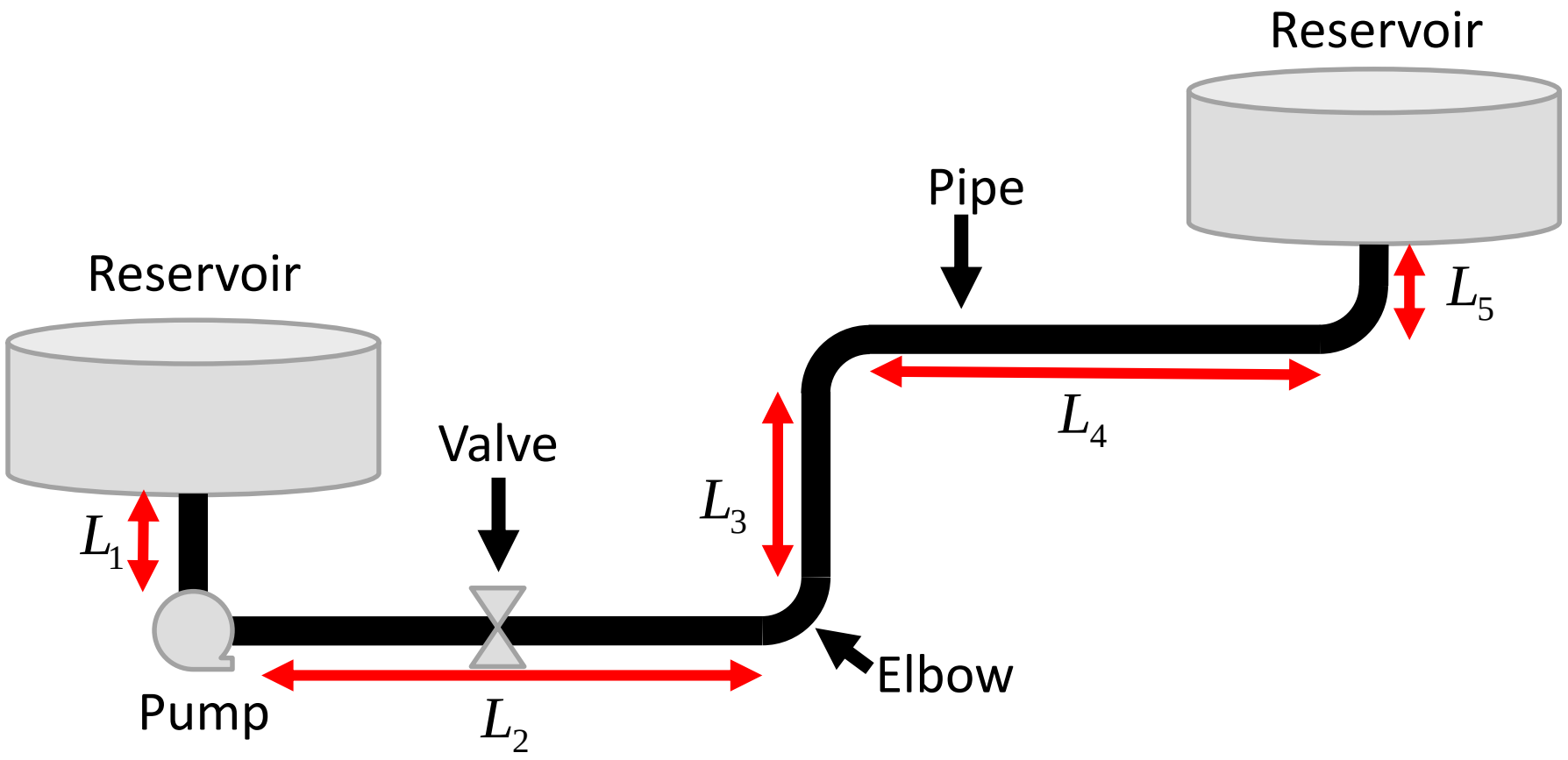
$$C_{f,contraction} = \frac{2}{5}\left[\frac{5}{4} - \frac{A_2}{A_1}\right] \rightarrow \frac{A_2}{A_1} < 0.715$$

$$C_{f,contraction} = \frac{3}{4}\left[1 - \frac{A_2}{A_1}\right] \rightarrow \frac{A_2}{A_1} > 0.715$$

$$C_{f,expansion} = \left[1 - \frac{A_1}{A_2}\right]^2$$

Types of Valves

Valves



Moving Liquids

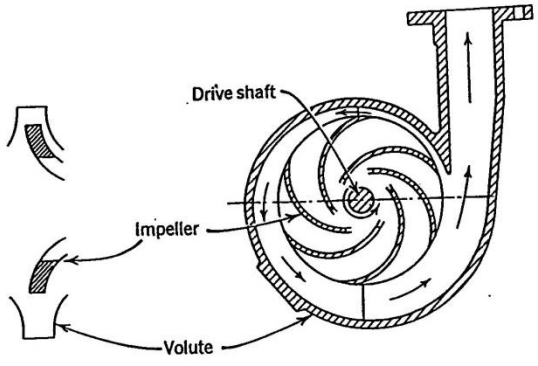
Centrifugal pump (0:00 – 3:00)

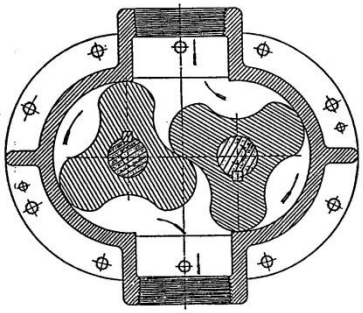
Positive Displacement Pumps

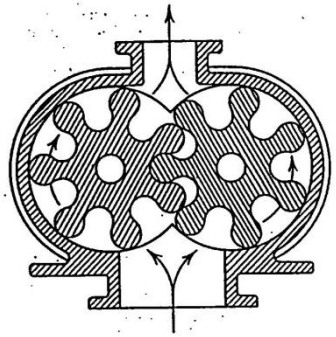
- Rotary pump
- Reciprocating pump

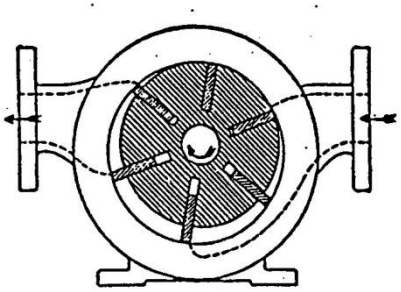
Pump selector tools

- Pump selector
- Pump info









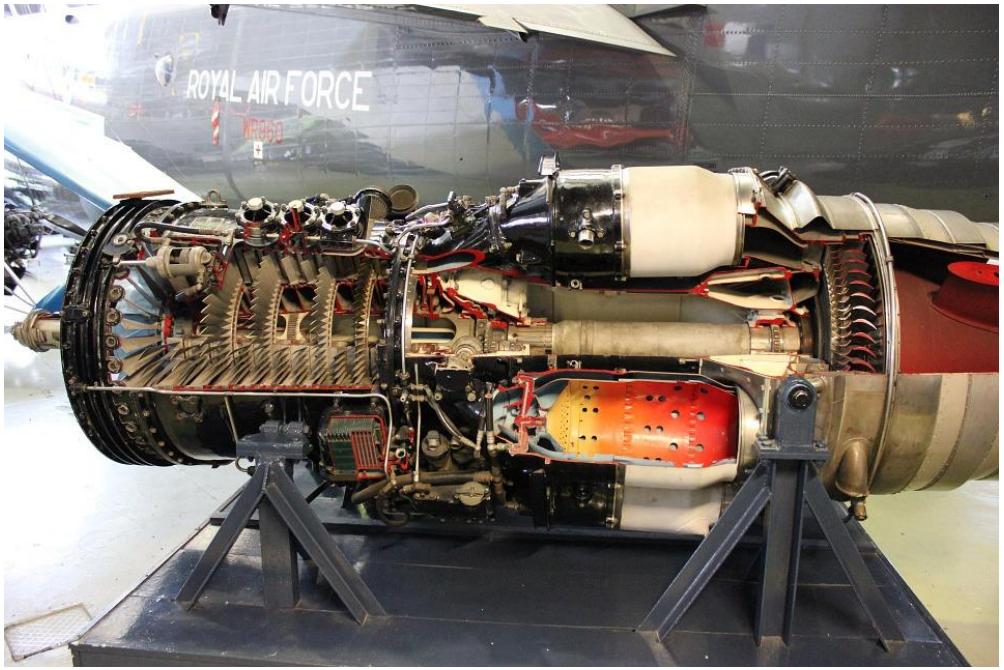
Moving Gases

Fan (Propeller)

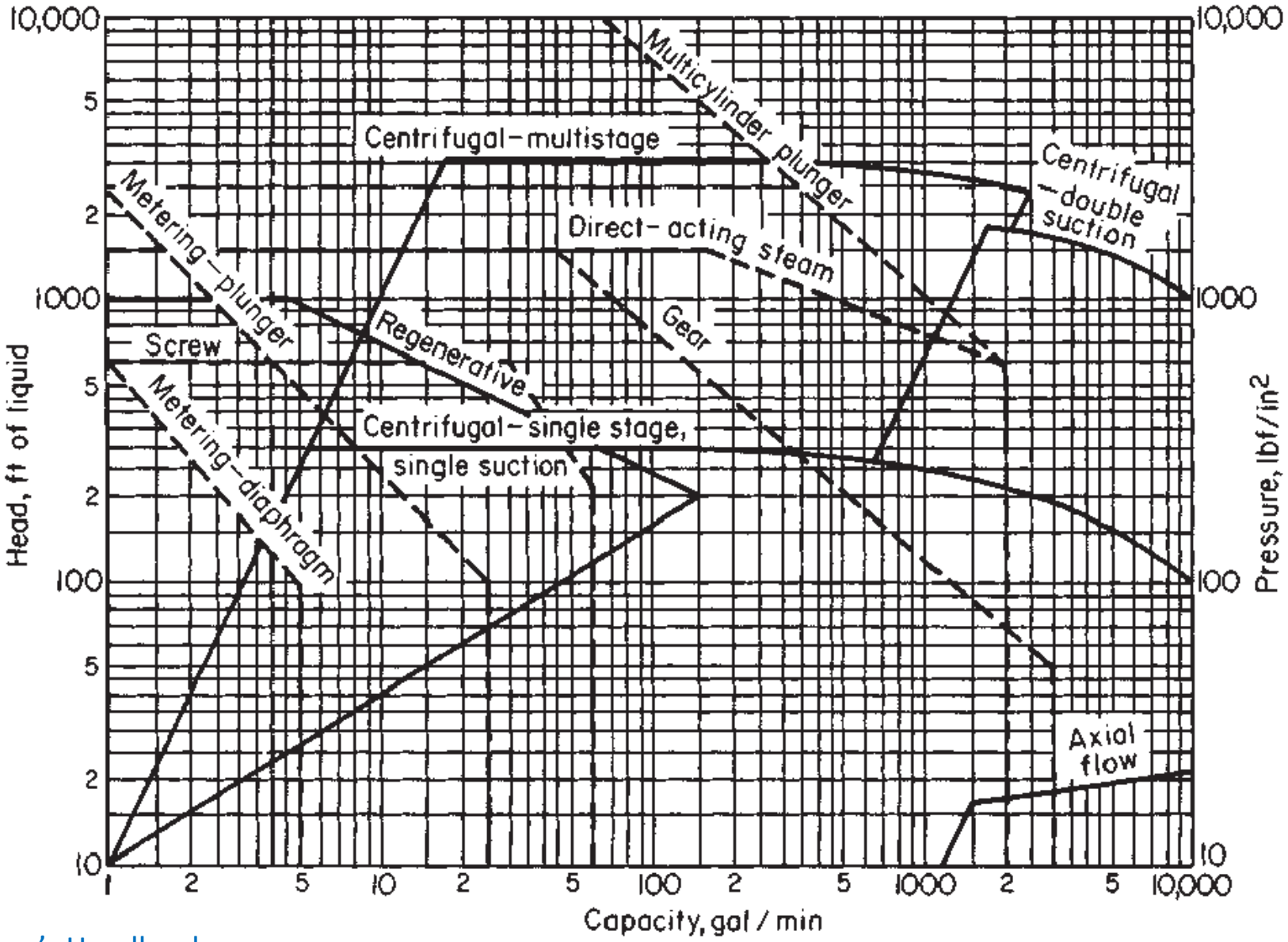
Blower (Impeller)

https://www.mcmaster.com/#squirrel-cage-blowers/=19vc0wl

Jet Engine (Compressor and Turbine)

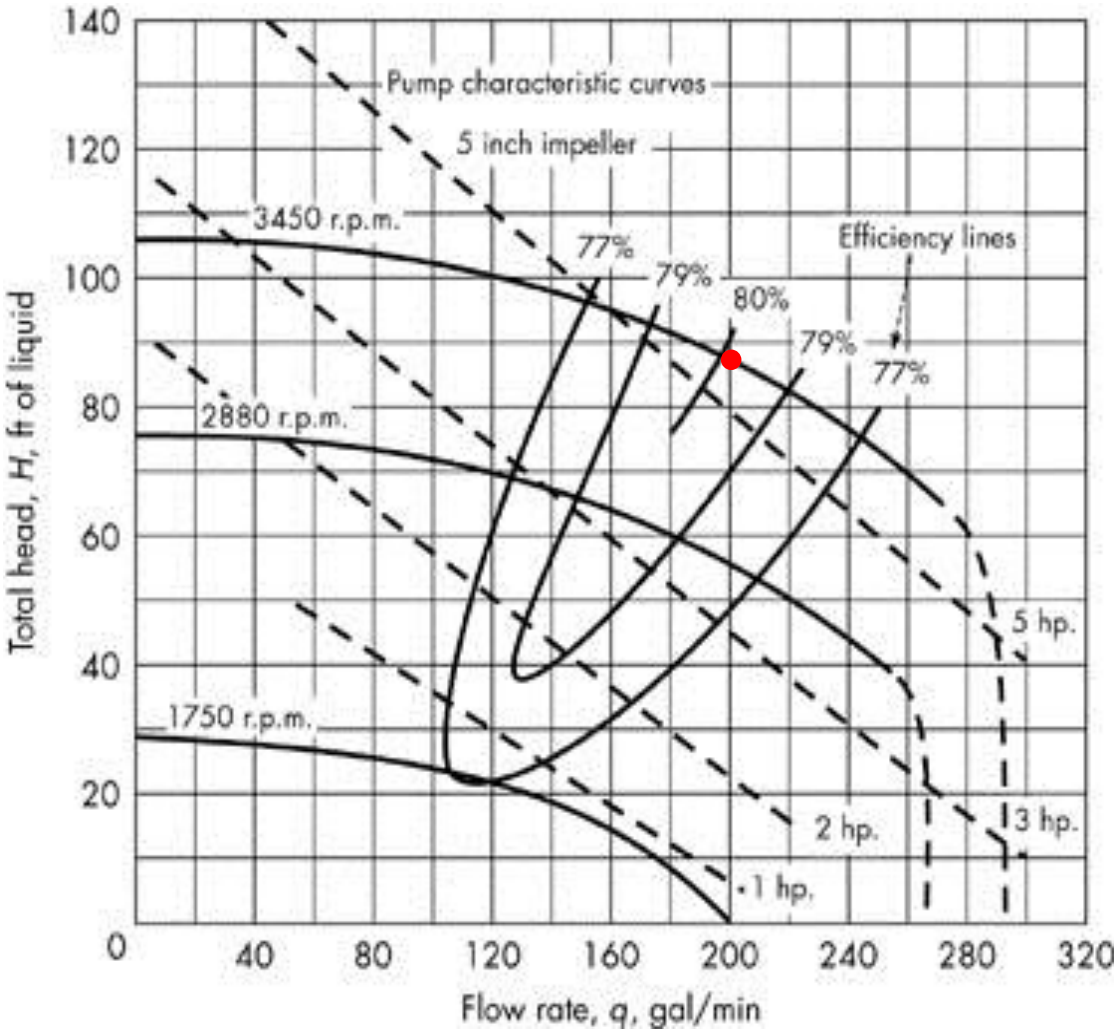


Starting Point for Pump Selection



See Perry's Handbook

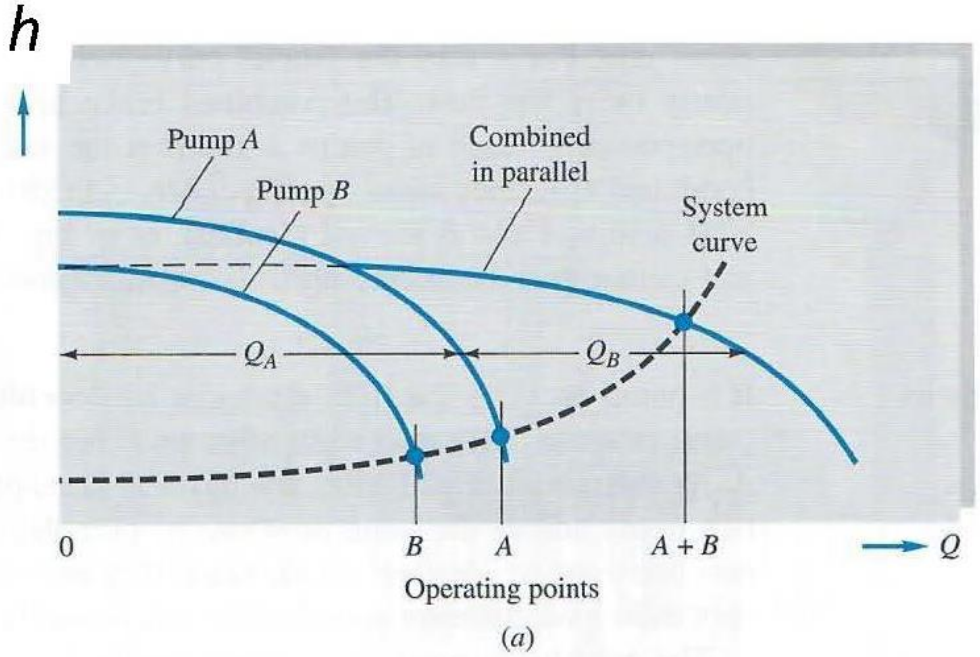
Characteristic Curves of Centrifugal Pump



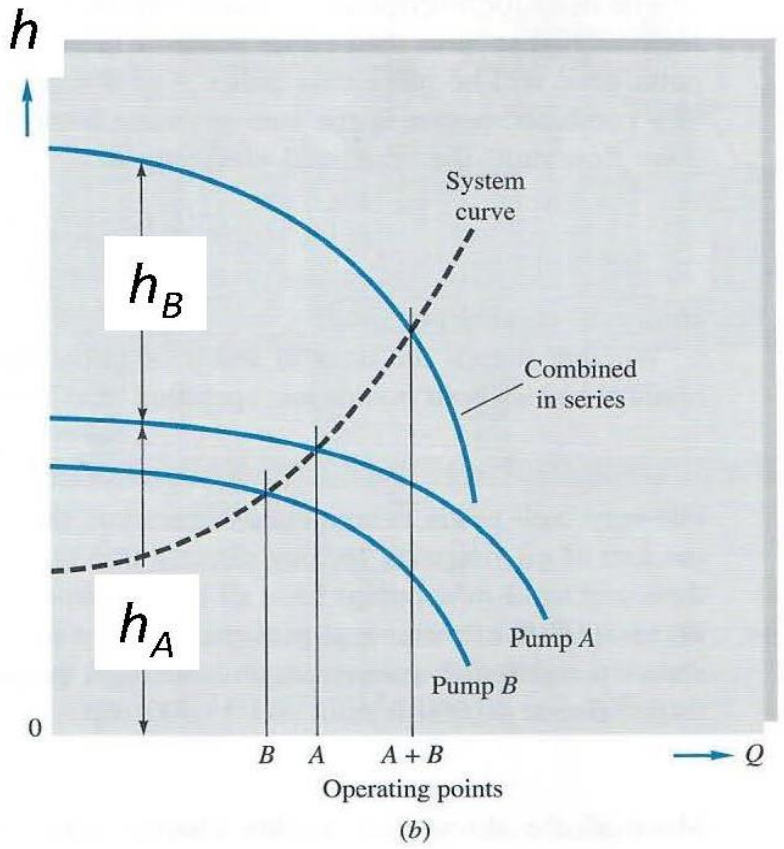
Example: At 3,450 RPM and a flow rate of 200 gal/min:
The total head will be 88 ft, the power required is ~5.5 hp and the efficiency is 80%.

Combinations of Pumps

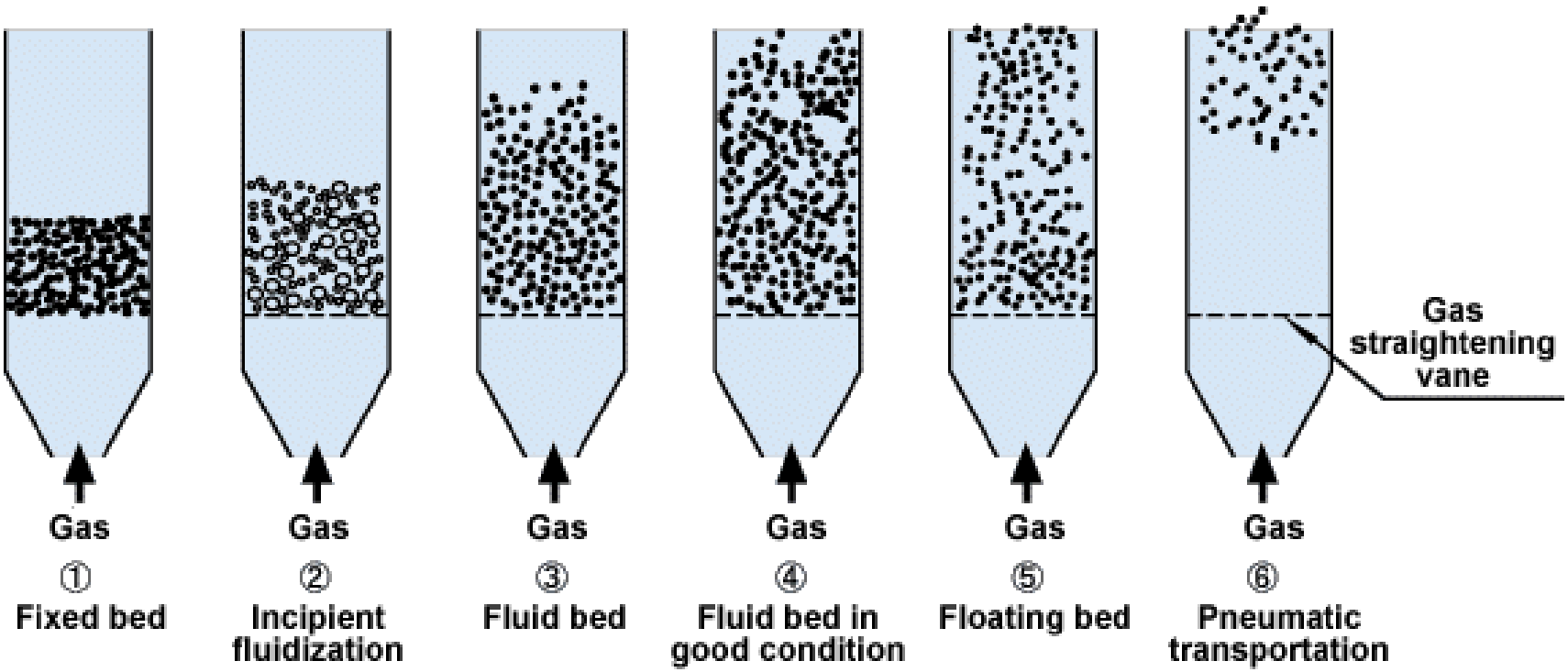
Pumps in Parallel



Pumps in Series



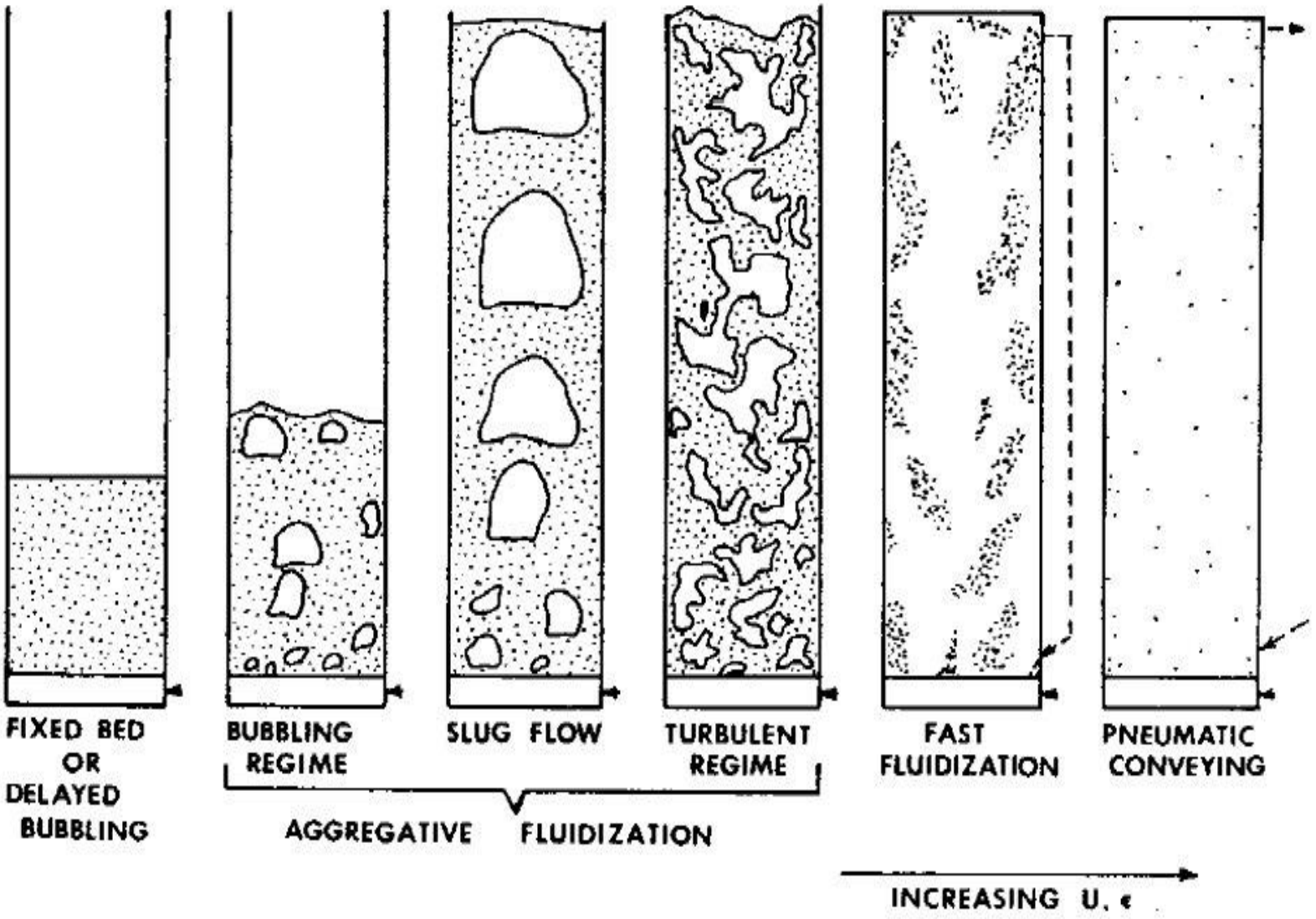
Fluidization



Scientific fluidization video (0 – 1:30)

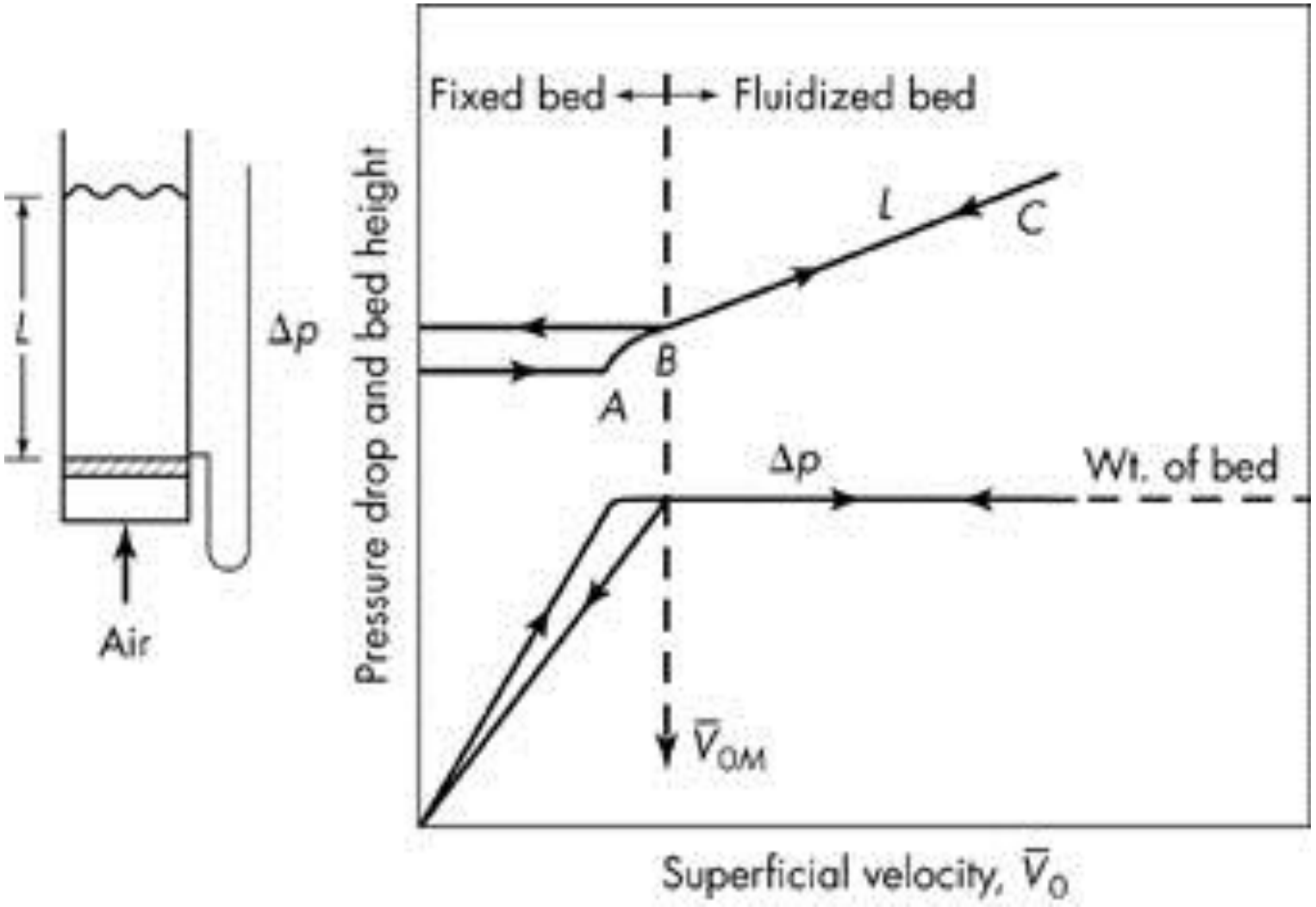
Fun fluidization video (0 – 0:30)

Types of Fluidization

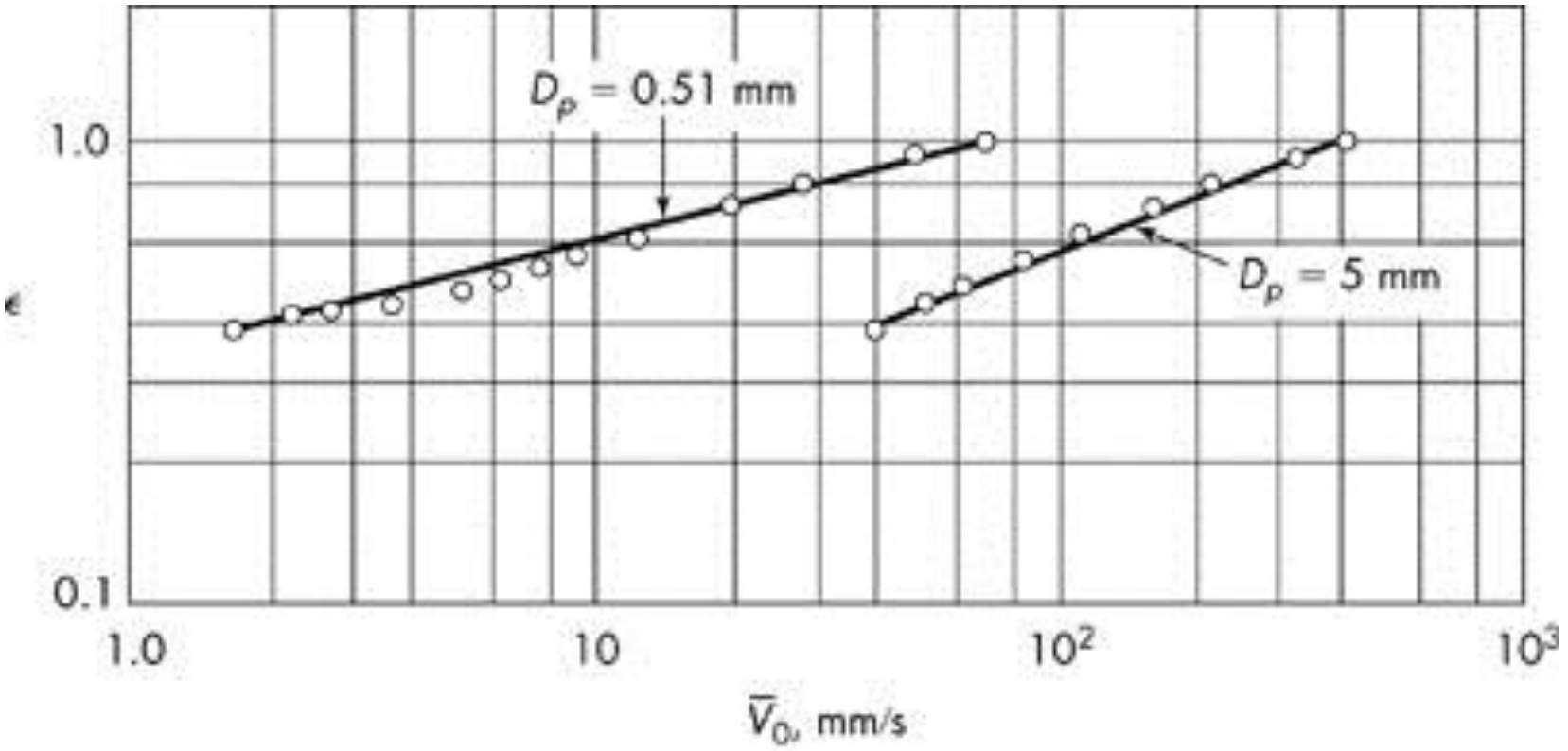


Bubbling flow video

Minimum Fluidization Velocity

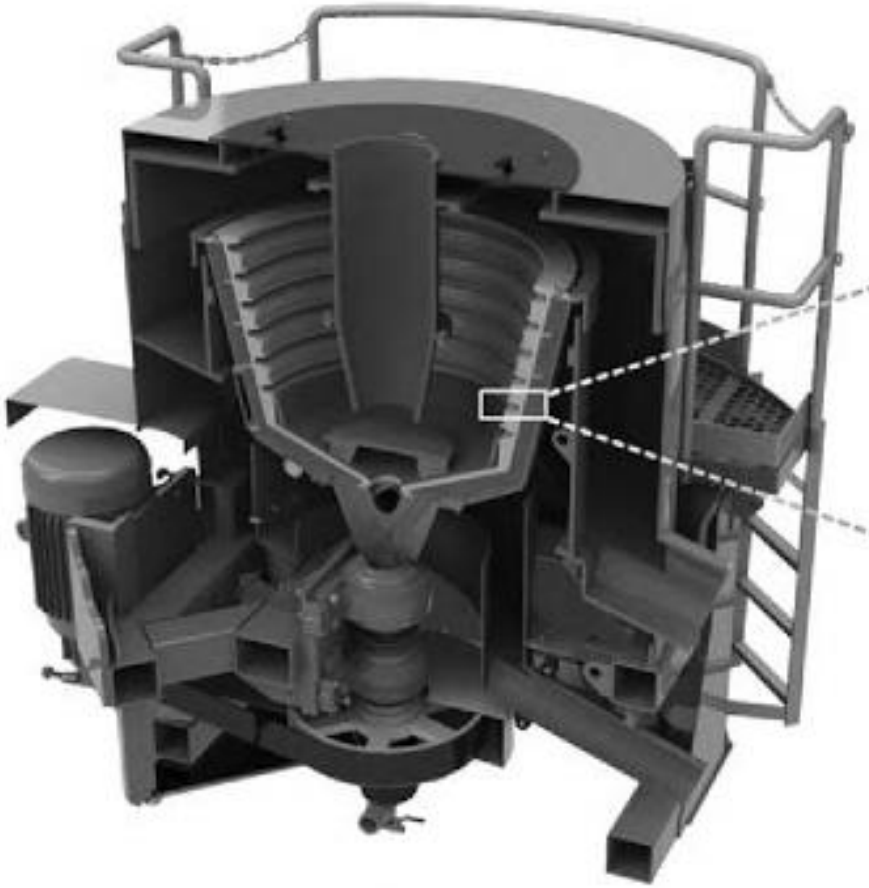


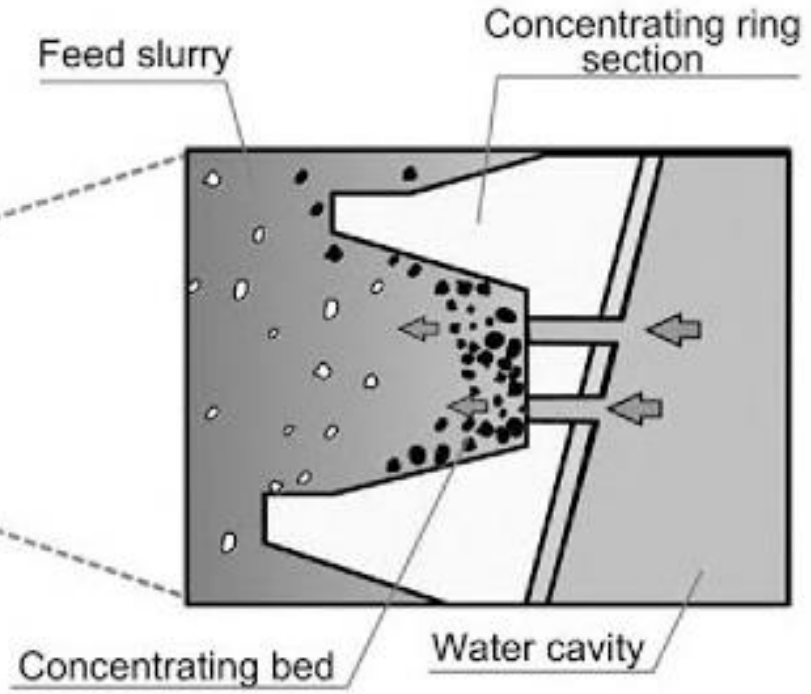
Bed Expansion



Porosity versus fluid velocity in a fluidized bed (McCabe, Smith and Harriott, 1993).

Fluidized Cengtrifugation





Knelson Concentrator