FLUID DYNAMICS

Ch.E-204

Umair Aslam

Lecturer

Department of Chemical Engineering

- **Fluid Mechanics** is the branch of physics that studies fluids (liquids, gases, and plasmas) and the forces on them.

- Fluid mechanics can be divided into
  - **Fluid statics**, the study of fluids at rest
  - **Fluid kinematics**, the study of fluids in motion
  - **Fluid dynamics**, the study of the effect of forces on fluid motion

Objective

- The objective of this course in Chemical Engineering is to provide an understanding to undergraduates that enlighten the importance of
    - **Fluid handling devices**
    - **Behavior of fluid**
    - **Behavior fluid motive machineries**

for the sustainability of the chemical industries.

Pre-Requisite

- The basic requisite for **<u>Fluid Dynamics</u>** is to have firm grip on fundamentals of;
  - Fluid Mechanics
  - Material and Energy Balance
  - Basic Sciences (Especially general Mathematics)

Course Outline

- Introduction to Fluid Dynamics
- Transportation of Fluids
- Selection, Design, Procedures and Cost for storage tanks
- Pipes, Fittings and Valves
- Selection of Pipes, Pumps, Compressors, Blowers, Fans, Turbines and Expanders; Design Procedures and costs
- Metering of fluids

Course Outline

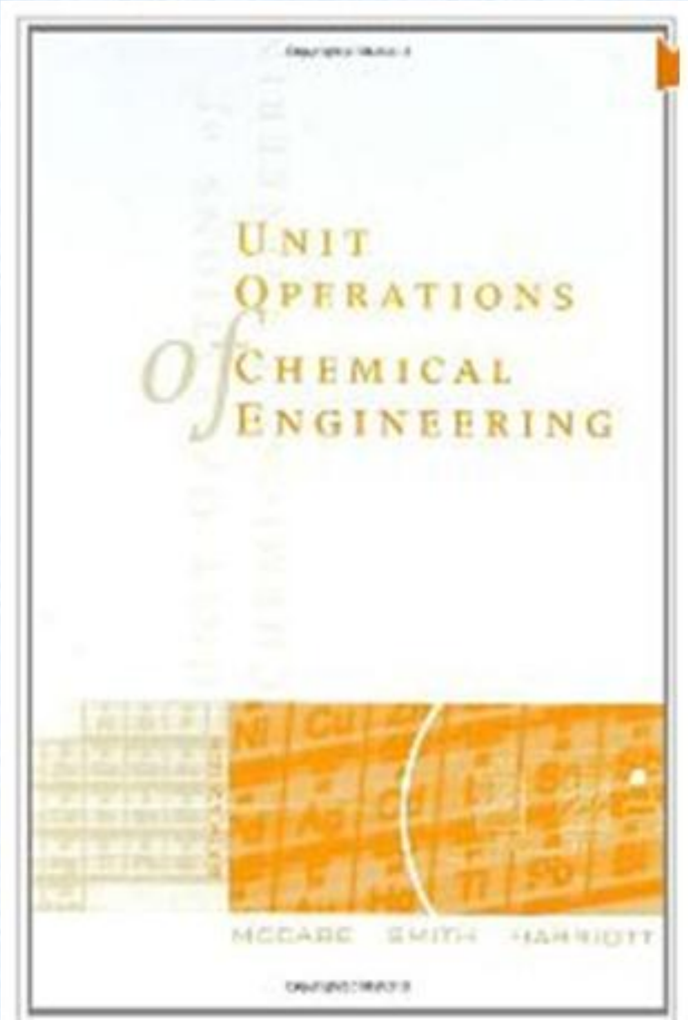
- Agitation and mixing of fluids
- Static fluid Phenomena in Static Mixers
- Dynamic Mixers
- Flow passed immersed bodies
- Fluidization
- Chemical Engineering Computational Fluid Dynamics (CFD)
- Cavitation Prevention of Pump
- Chocking Prevention of Pipes

Course Outline

- Corrosion Prevention
- Surging in Compressors

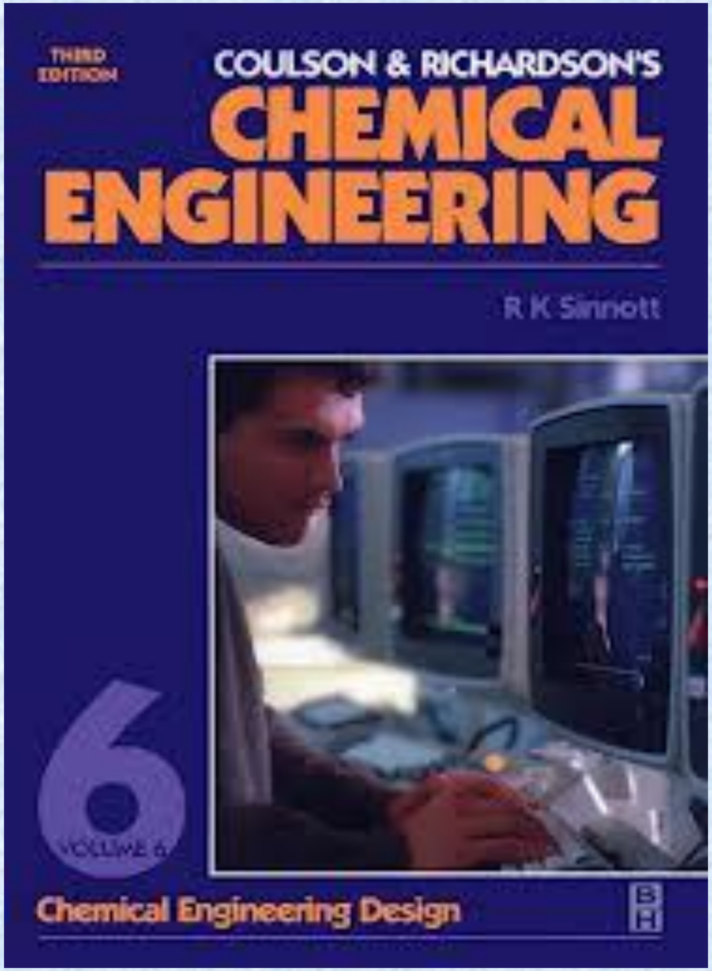
Recommended Books

- **McCabe Warren L., Smith Julian C., Harriott peter "Unit Operations of chemical Engineering" 6th Ed. , McGraw Hill Inc.,2001.**



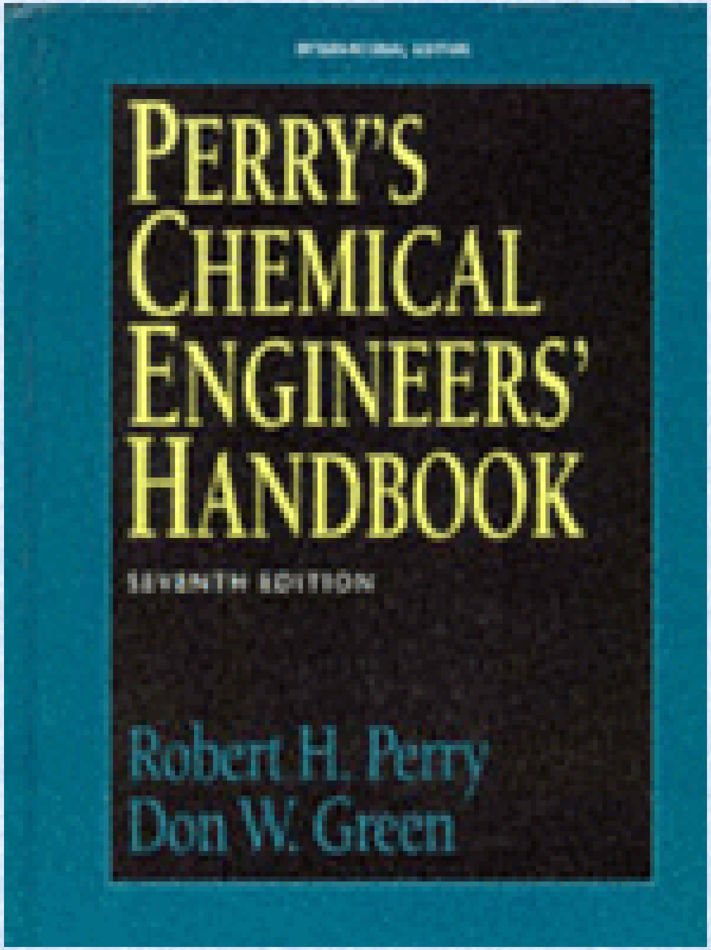
Recommended Books

Coulson J.M., Richardson J.F. "Chemical Engineering" Vol-I, The English Book Society and Pergamon Press,1985.



Recommended Books

- **Perry Robert H., Green Don W. “Perry’s Chemical Engineering Handbook” 7th Ed., McGraw Hill Inc., 1997**



Appendix 5

Nominal pipe size, in.	Outside diameter, in.	Schedule no.	Wall thickness, in.	Inside diameter, in.	Cross-sectional area of metal, in.^{2}	Inside sectional area, ft^2	Circumference, ft or surface, ft^2/ft of length: Outside	Circumference, ft or surface, ft^2/ft of length: Inside	Capacity at 1 ft/s velocity: U.S. gal/min	Capacity at 1 ft/s velocity: Water, lb/h	Pipe weight lb/ft
$\frac{1}{8}$	0.405	40	0.068	0.269	0.072	0.00040	0.106	0.0705	0.179	89.5	0.24
		80	0.095	0.215	0.093	0.00025	0.106	0.0563	0.113	56.5	0.31
$\frac{1}{4}$	0.540	40	0.088	0.364	0.125	0.00072	0.141	0.095	0.323	161.5	0.42
		80	0.119	0.302	0.157	0.00050	0.141	0.079	0.224	112.0	0.54
$\frac{3}{8}$	0.675	40	0.091	0.493	0.167	0.00133	0.177	0.129	0.596	298.0	0.57
		80	0.126	0.423	0.217	0.00098	0.177	0.111	0.440	220.0	0.74
$\frac{1}{2}$	0.840	40	0.109	0.622	0.250	0.00211	0.220	0.163	0.945	472.0	0.85
		80	0.147	0.546	0.320	0.00163	0.220	0.143	0.730	365.0	1.09
$\frac{3}{4}$	1.050	40	0.113	0.824	0.333	0.00371	0.275	0.216	1.665	832.5	1.13
		80	0.154	0.742	0.433	0.00300	0.275	0.194	1.345	672.5	1.47
1	1.315	40	0.133	1.049	0.494	0.00600	0.344	0.275	2.690	1,345	1.68
		80	0.179	0.957	0.639	0.00499	0.344	0.250	2.240	1,120	2.17
$1\frac{1}{4}$	1.660	40	0.140	1.380	0.668	0.01040	0.435	0.361	4.57	2,285	2.27
		80	0.191	1.278	0.881	0.00891	0.435	0.335	3.99	1,995	3.00
$1\frac{1}{2}$	1.900	40	0.145	1.610	0.800	0.01414	0.497	0.421	6.34	3,170	2.72
		80	0.200	1.500	1.069	0.01225	0.497	0.393	5.49	2,745	3.63

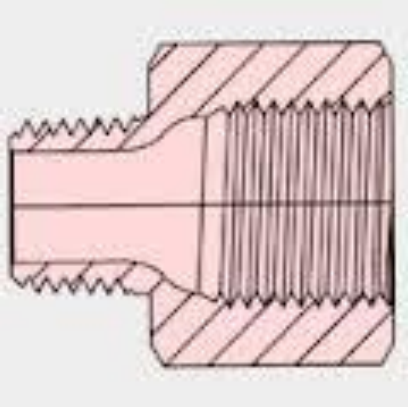
Nominal pipe size, in.	Outside diameter, in.	Schedule no.	Wall thickness, in.	Inside diameter, in.	Cross-sectional area of metal, in.^{2}	Inside sectional area, ft^2	Circumference, ft or surface, ft^2/ft of length		Capacity at 1 ft/s velocity		Pipe weight lb/ft
							Outside	Inside	U.S. gal/min	Water, lb/h	
2	2.375	40	0.154	2.067	1.075	0.02330	0.622	0.541	10.45	5,225	3.65
		80	0.218	1.939	1.477	0.02050	0.622	0.508	9.20	4,600	5.02
2½	2.875	40	0.203	2,469	1.704	0.03322	0.753	0.647	14.92	7,460	5.79
		80	0.276	2.323	2.254	0.02942	0.753	0.608	13.20	6,600	7.66
3	3.500	40	0.216	3.068	2.228	0.05130	0.916	0.803	23.00	11,500	7.58
		80	0.300	2.900	3.016	0.04587	0.916	0.759	20.55	10,275	10.25
3½	4.000	40	0.226	3.548	2.680	0.06870	1.047	0.929	30.80	15,400	9.11
		80	0.318	3.364	3.678	0.06170	1.047	0.881	27.70	13,850	12.51
4	4.500	40	0.237	4.026	3.17	0.08840	1.178	1.054	39.6	19,800	10.79
		80	0.337	3.826	4.41	0.07986	1.178	1.002	35.8	17,900	14.98
5	5.563	40	0.258	5.047	4.30	0.1390	1.456	1.321	62.3	31,150	14.62
		80	0.375	4.813	6.11	0.1263	1.456	1.260	57.7	28,850	20.78
6	6.625	40	0.280	6.065	5.58	0.2006	1.734	1.588	90.0	45,000	18.97
		80	0.432	5.761	8.40	0.1810	1.734	1.508	81.1	40,550	28.57
8	8.625	40	0.322	7.981	8.396	0.3474	2.258	2.089	155.7	77,850	28.55
		80	0.500	7.625	12.76	0.3171	2.258	1.996	142.3	71,150	43.39
10	10.75	40	0.365	10.020	11.91	0.5475	2.814	2.620	246.0	123,000	40.48
		80	0.594	9.562	18.95	0.4987	2.814	2.503	223.4	111,700	64.40
12	12.75	40	0.406	11.938	15.74	0.7773	3.338	3.13	349.0	174,500	53.56
		80	0.688	11.374	26.07	0.7056	3.338	2.98	316.7	158,350	88.57

Appendix 6

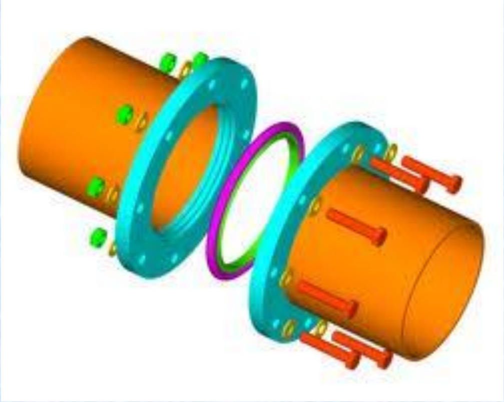
Outside diameter, in.	Wall thickness: BWG no.	Wall thickness: in.	Inside diameter, in.	Cross-sectional area metal, in.^{2}	Inside sectional area, ft^2	Circumference, ft or surface, ft^2/ft of length: Outside	Circumference, ft or surface, ft^2/ft of length: Inside	Velocity, ft/s for 1 U.S. gal/min	Capacity at 1 ft/s velocity: U.S. gal/min	Capacity at 1 ft/s velocity: Water, lb/h	Weight, lb/ft‡
$\frac{5}{8}$	12	0.109	0.407	0.177	0.000903	0.1636	0.1066	2.468	0.4053	202.7	0.602
	14	0.083	0.459	0.141	0.00115	0.1636	0.1202	1.938	0.5161	258.1	0.479
	16	0.065	0.495	0.114	0.00134	0.1636	0.1296	1.663	0.6014	300.7	0.388
	18	0.049	0.527	0.089	0.00151	0.1636	0.1380	1.476	0.6777	338.9	0.303
$\frac{3}{4}$	12	0.109	0.532	0.220	0.00154	0.1963	0.1393	1.447	0.6912	345.6	0.748
	14	0.083	0.584	0.174	0.00186	0.1963	0.1529	1.198	0.8348	417.4	0.592
	16	0.065	0.620	0.140	0.00210	0.1963	0.1623	1.061	0.9425	471.3	0.476
	18	0.049	0.652	0.108	0.00232	0.1963	0.1707	0.962	1.041	520.5	0.367
$\frac{7}{8}$	12	0.109	0.657	0.262	0.00235	0.2291	0.1720	0.948	1.055	527.5	0.891
	14	0.083	0.709	0.207	0.00274	0.2291	0.1856	0.813	1.230	615.0	0.704
	16	0.065	0.745	0.165	0.00303	0.2291	0.1950	0.735	1.350	680.0	0.561
	18	0.049	0.777	0.127	0.00329	0.2291	0.2034	0.678	1.477	738.5	0.432
1	10	0.134	0.732	0.364	0.00292	0.2618	0.1916	0.763	1.310	655.0	1.237
	12	0.109	0.782	0.305	0.00334	0.2618	0.2047	0.667	1.499	750.0	1.037
	14	0.083	0.834	0.239	0.00379	0.2618	0.2183	0.588	1.701	850.5	0.813
	16	0.065	0.870	0.191	0.00413	0.2618	0.2278	0.538	1.854	927.0	0.649

Outside diameter, in.	Wall thickness		Inside diameter, in.	Cross-sectional area metal, in.^{2}	Inside sectional area, ft^2	Circumference, ft or surface, ft^2/ft of length		Velocity, ft/s for 1 U.S. gal/min	Capacity at 1 ft/s velocity		Weight, lb/ft‡
	BWG no.	in.				Outside	Inside		U.S. gal/min	Water, lb/h	
$1\frac{1}{4}$	10	0.134	0.982	0.470	0.00526	0.3272	0.2571	0.424	2.361	1,181	1.598
	12	0.109	1.032	0.391	0.00581	0.3272	0.2702	0.384	2.608	1,304	1.329
	14	0.083	1.084	0.304	0.00641	0.3272	0.2838	0.348	2.877	1,439	1.033
	16	0.065	1.120	0.242	0.00684	0.3272	0.2932	0.326	3.070	1,535	0.823
$1\frac{1}{2}$	10	0.134	1.232	0.575	0.00828	0.3927	0.3225	0.269	3.716	1,858	1.955
	12	0.109	1.282	0.476	0.00896	0.3927	0.3356	0.249	4.021	2,011	1.618
	14	0.083	1.334	0.370	0.00971	0.3927	0.3492	0.229	4.358	2,176	1.258
2	10	0.134	1.732	0.7855	0.0164	0.5236	0.4534	0.136	7.360	3,680	2.68
	12	0.109	1.782	0.6475	0.0173	0.5236	0.4665	0.129	7.764	3,882	2.22

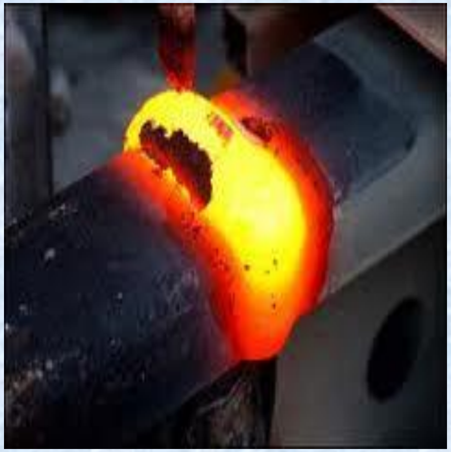
Screwed Fitting



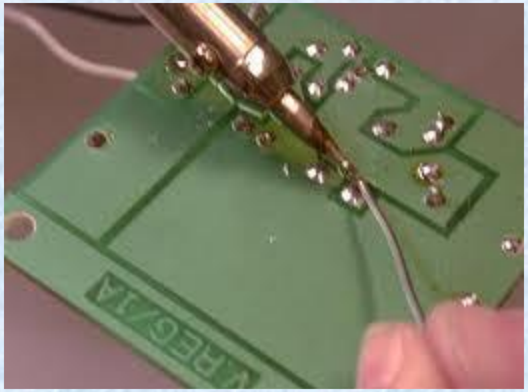
Flanges

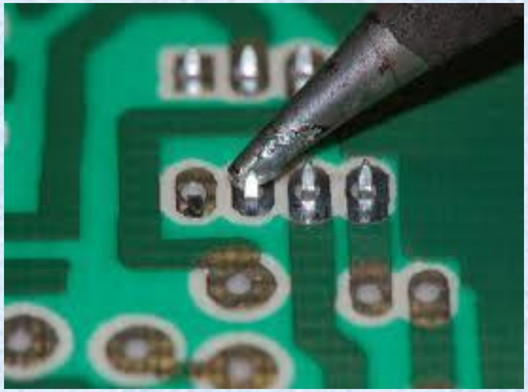


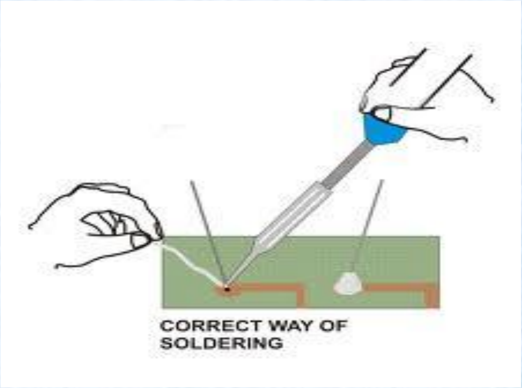
Welded Joint



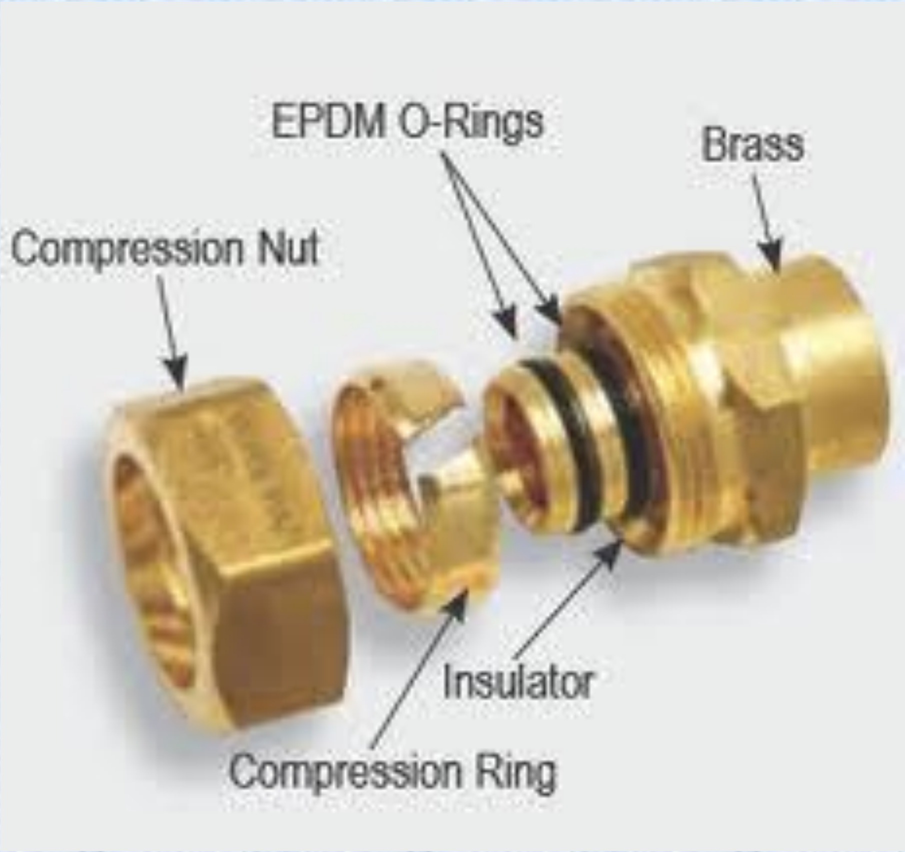
Soldering



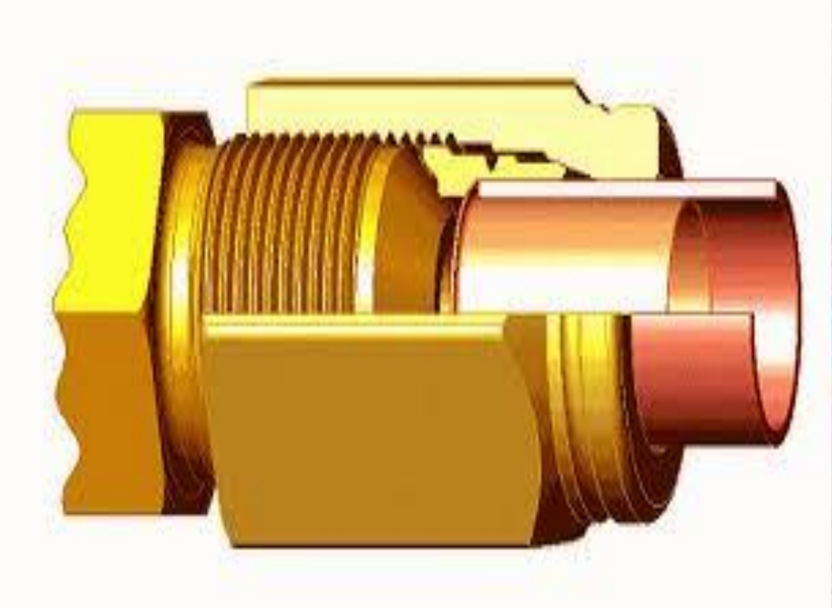




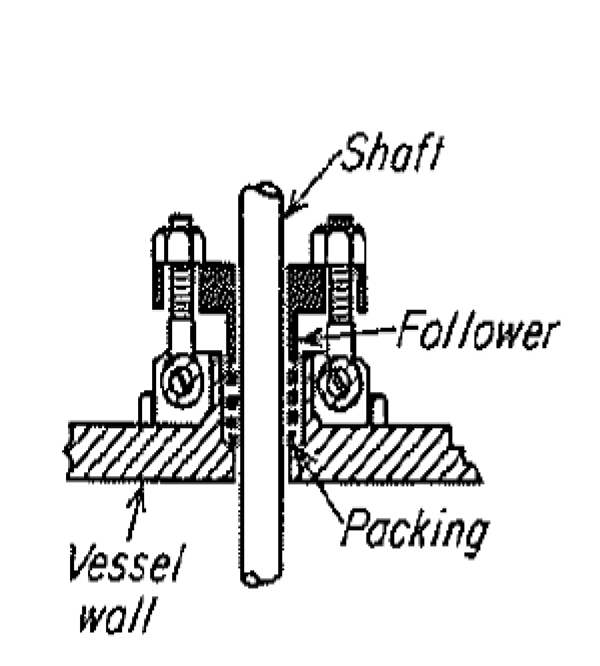
Compression Fitting

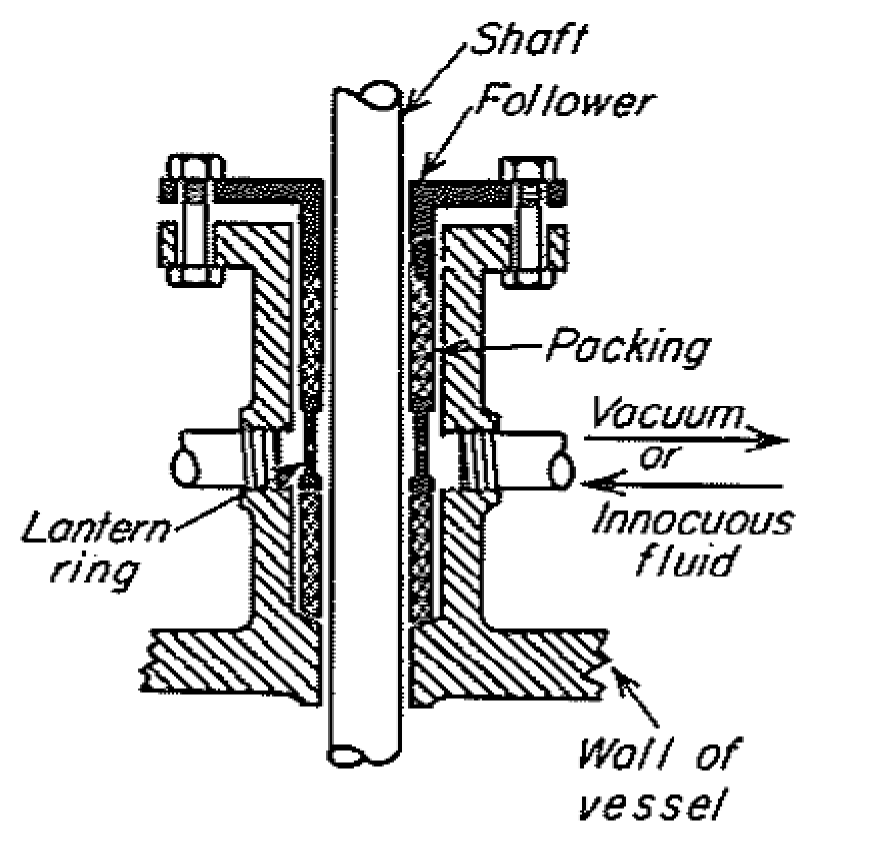


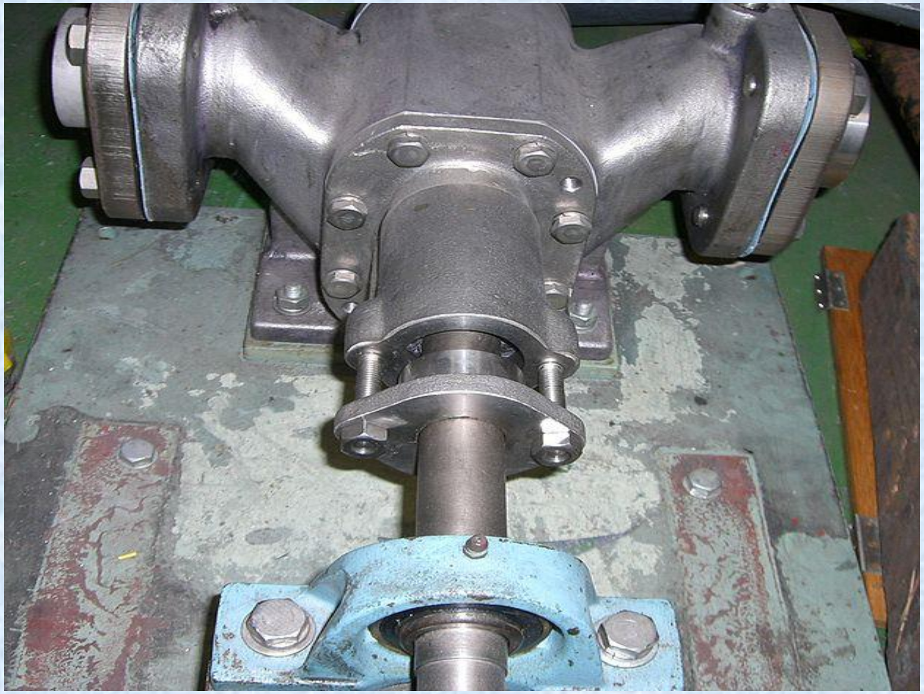
Flare Fitting



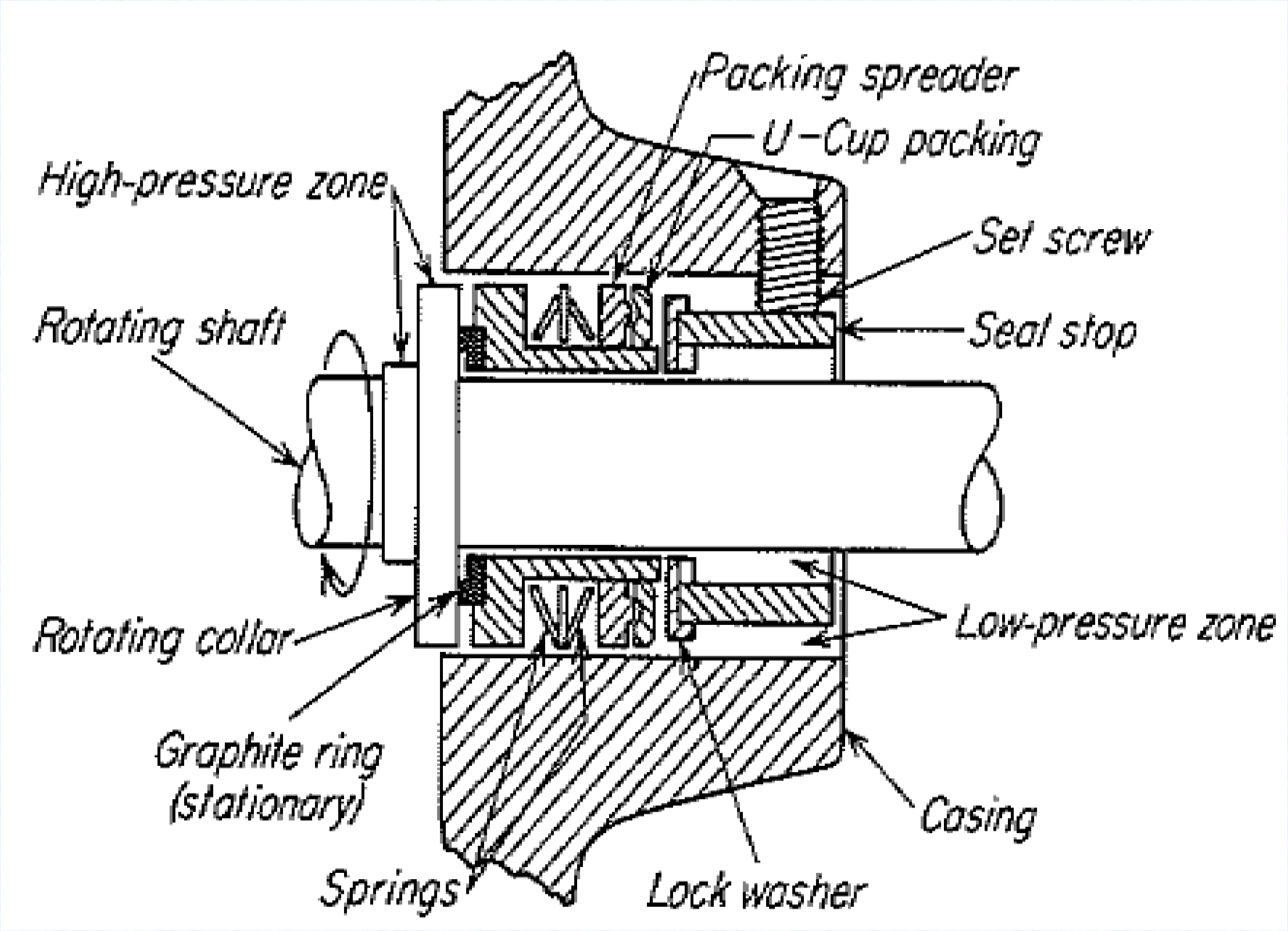
Stuffing Boxes



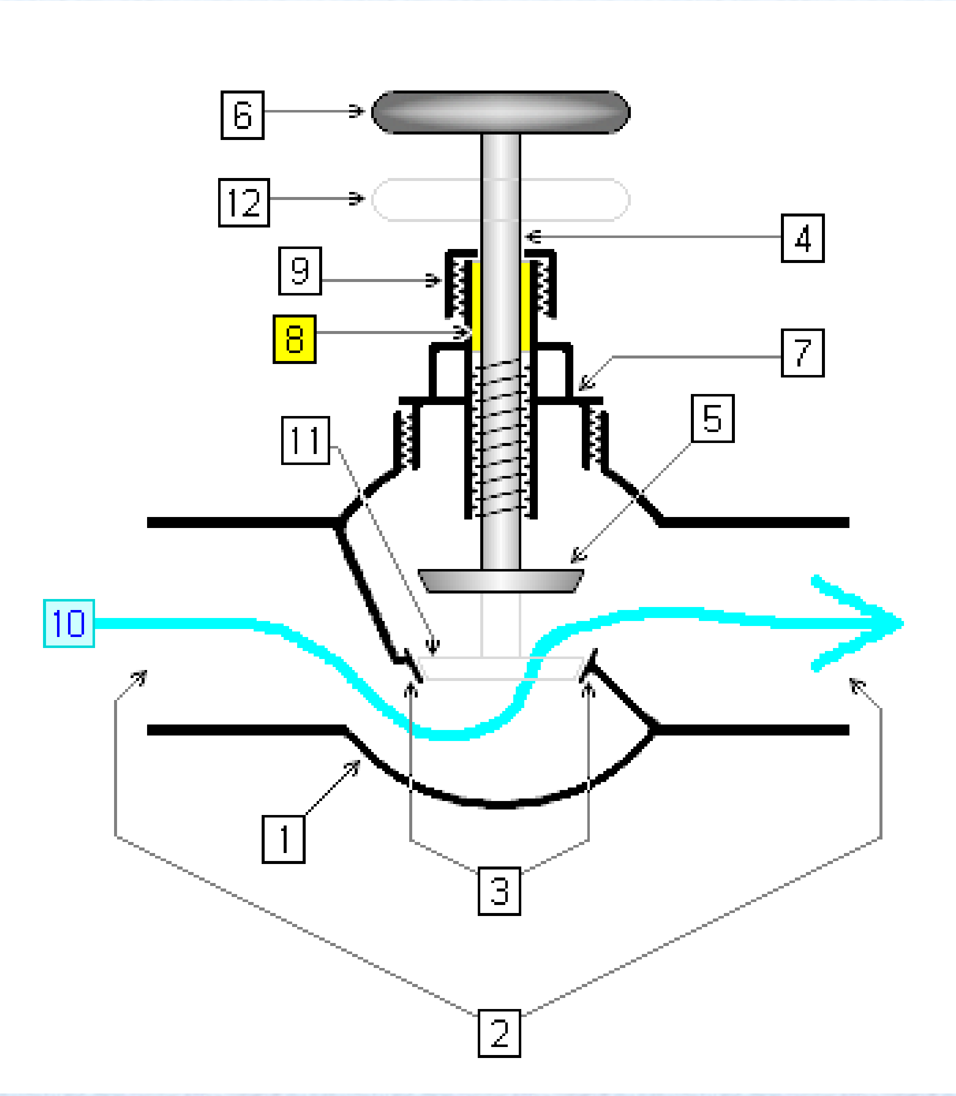




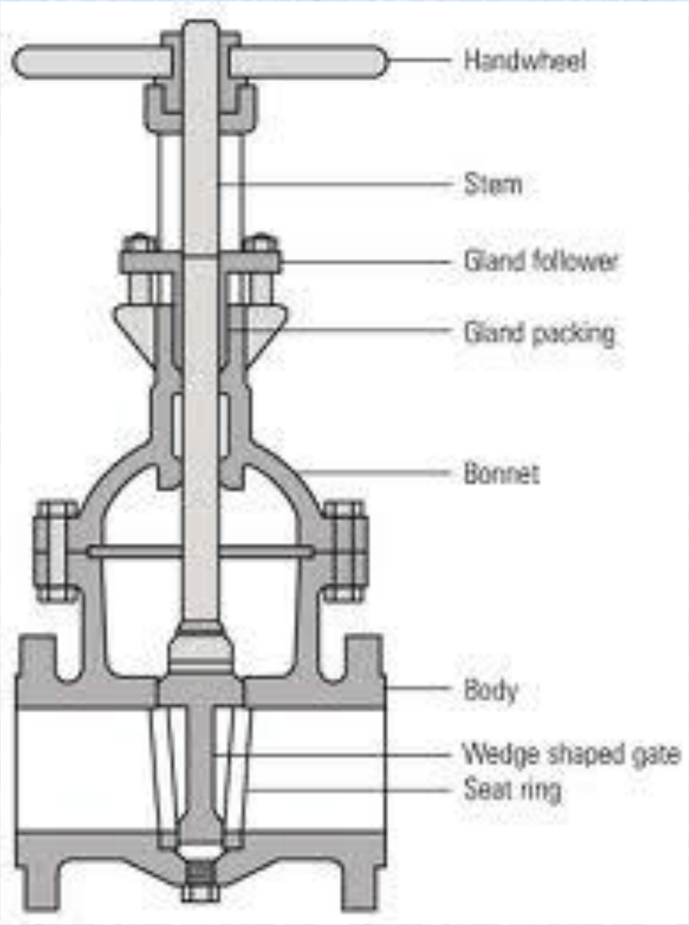
Mechanical Seals

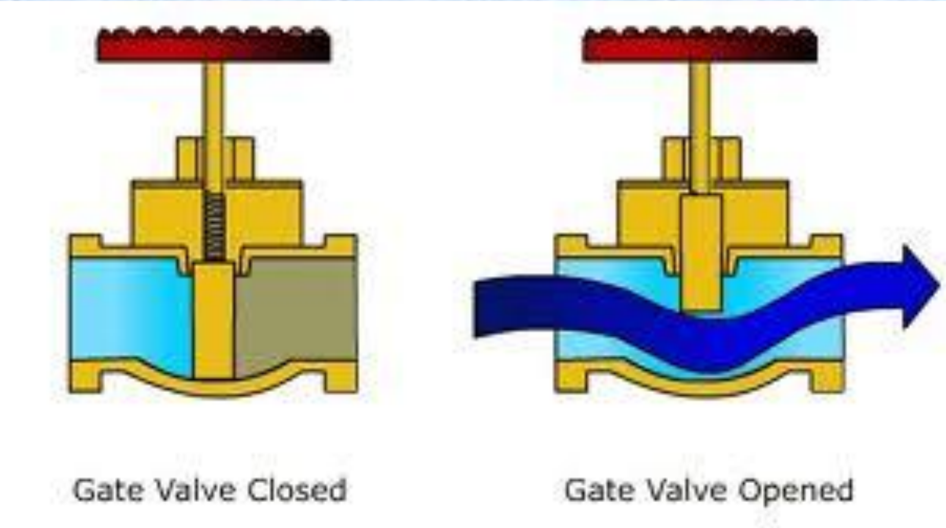


General Parts of A Valve

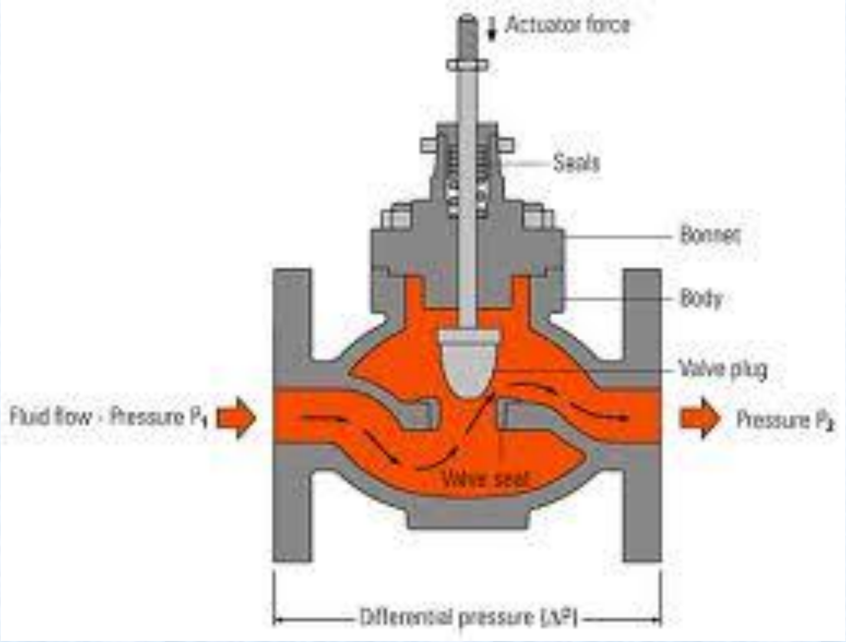


Gate Valve

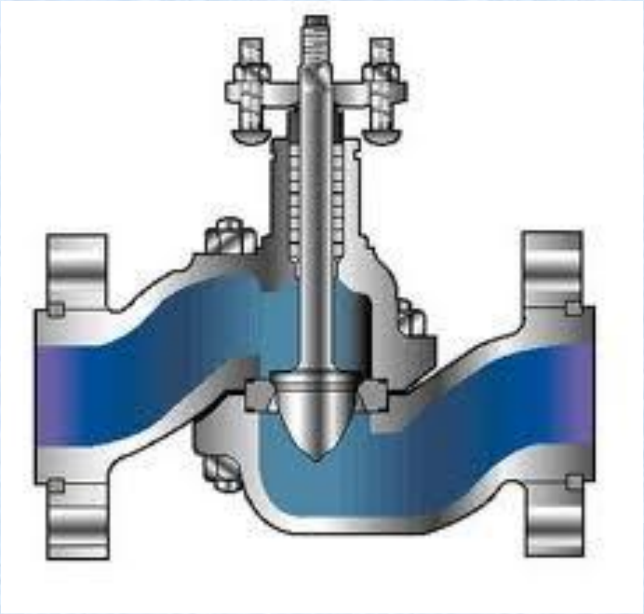

Handwheel
Stem
Gland follower
Gland packing
Bonnet
Body
Wedge shaped gate
Seat ring


Gate Valve Closed
Gate Valve Opened

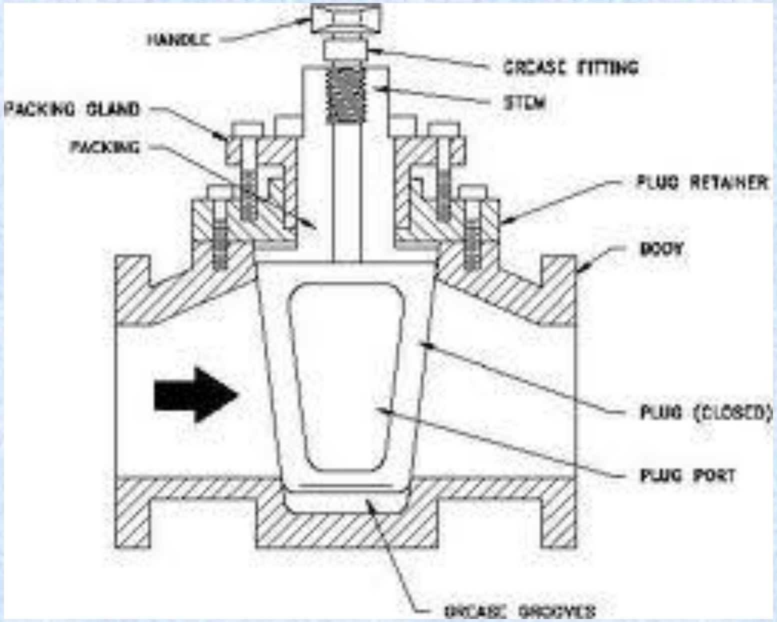
Globe Valve



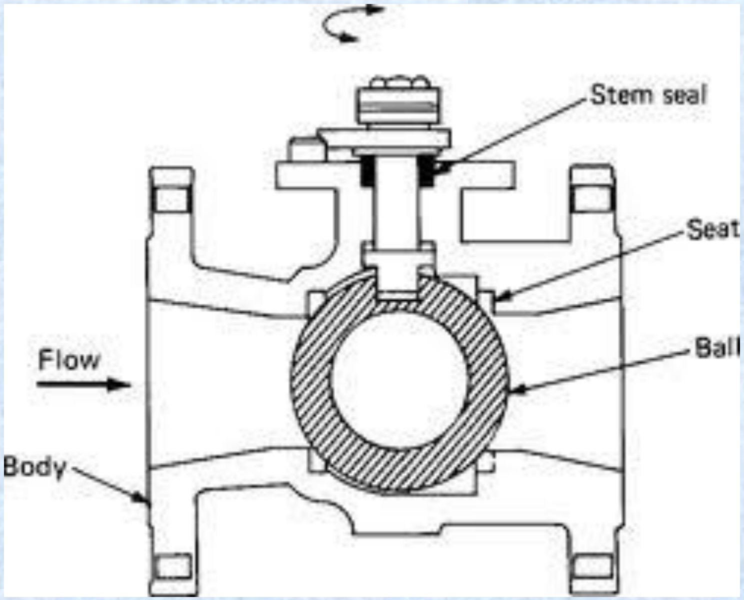
Actuator force
Seals
Bonnet
Body
Valve plug
Fluid flow - Pressure P_1
Pressure P_2
Valve seat
Differential pressure (ΔP)

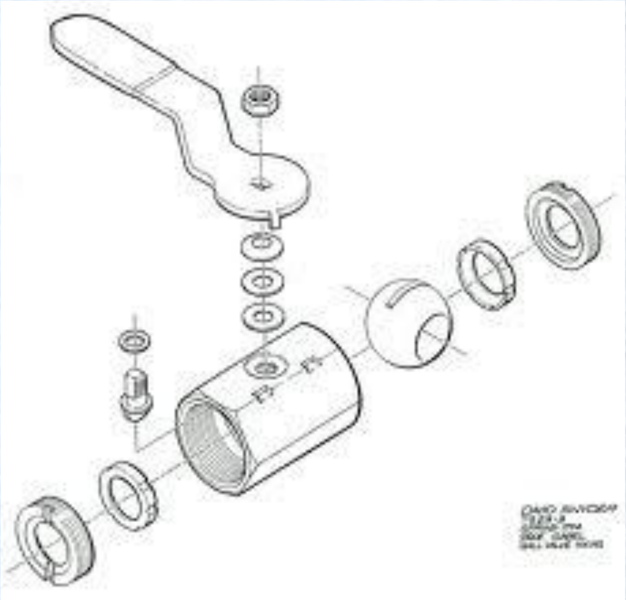


Plug Valve

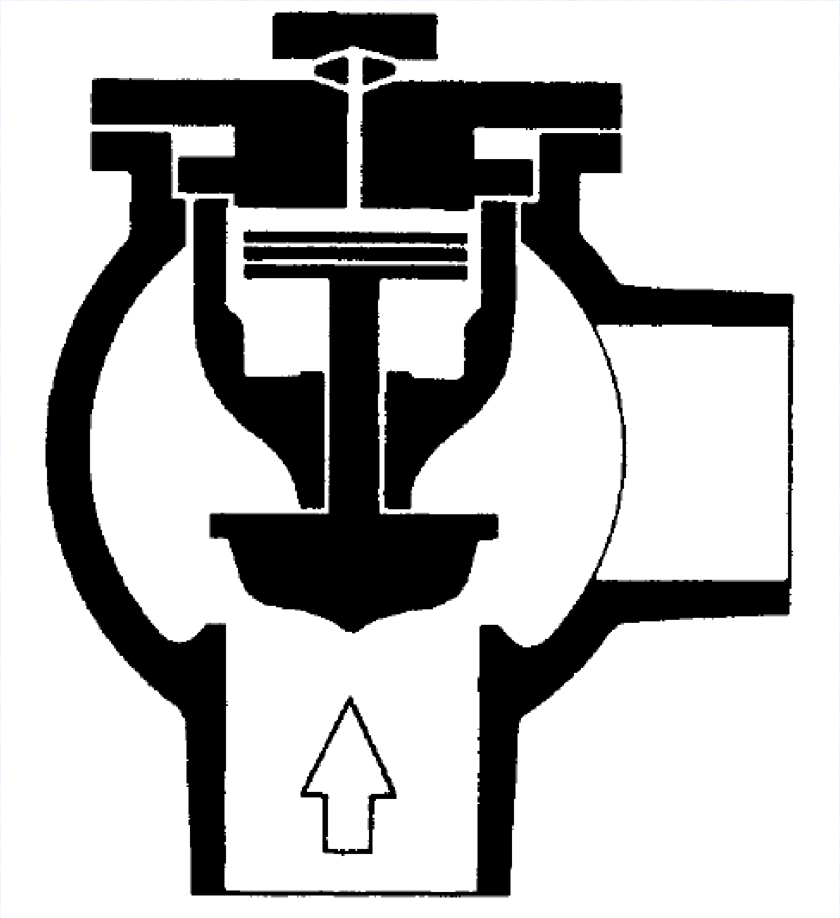

HANDLE
GREASE FITTING
STEM
PACKING GLAND
PACKING
PLUG RETAINER
BODY
PLUG (CLOSED)
PLUG PORT
GREASE GROOVES

Ball Valve

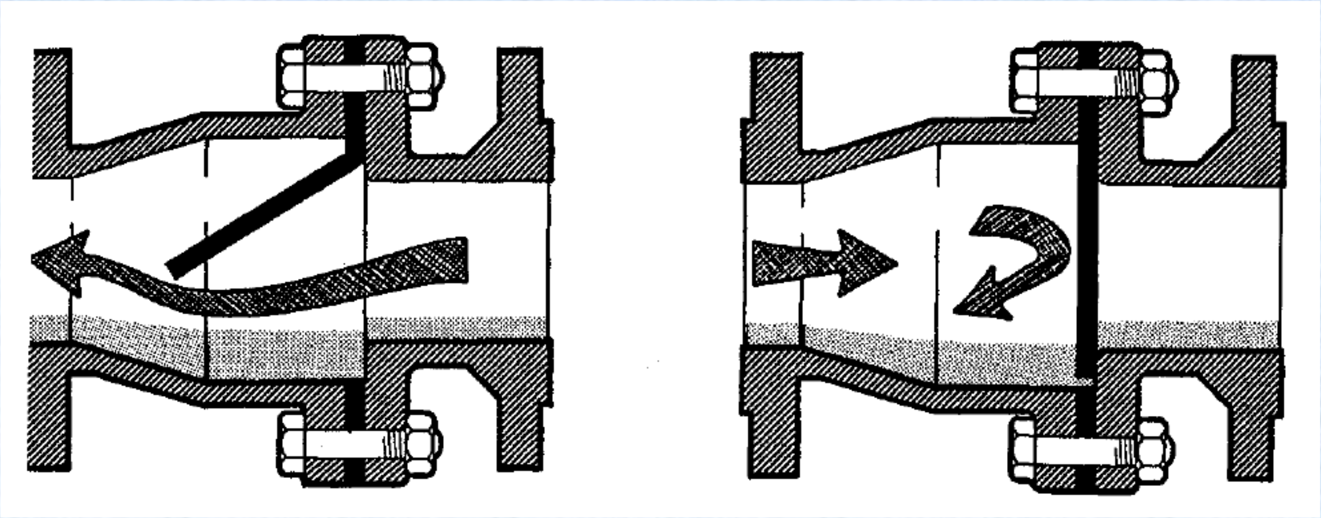




Lift Check Valve

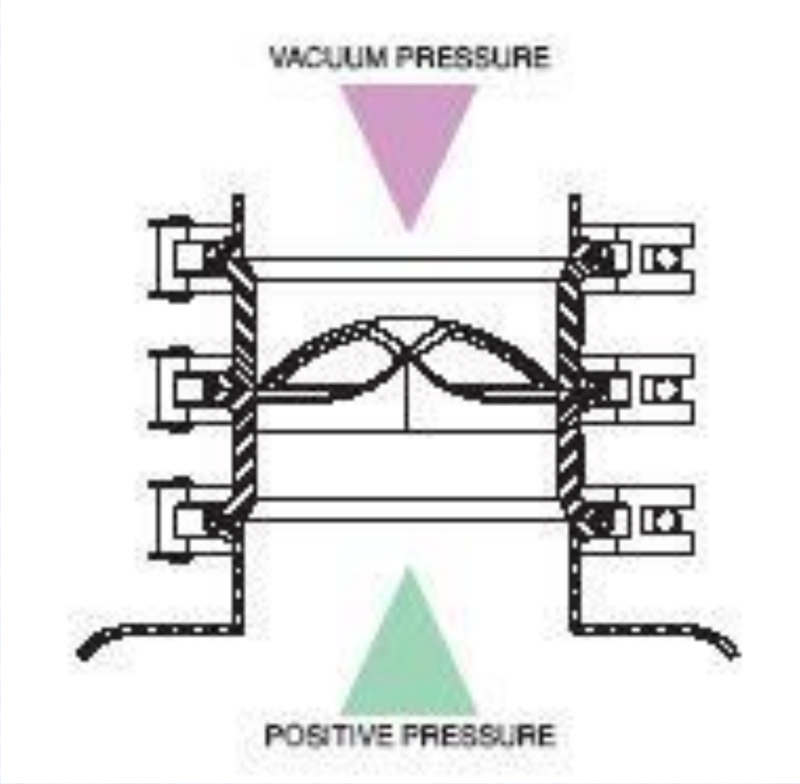


Swing Check Valve



Pressure Relief Valve

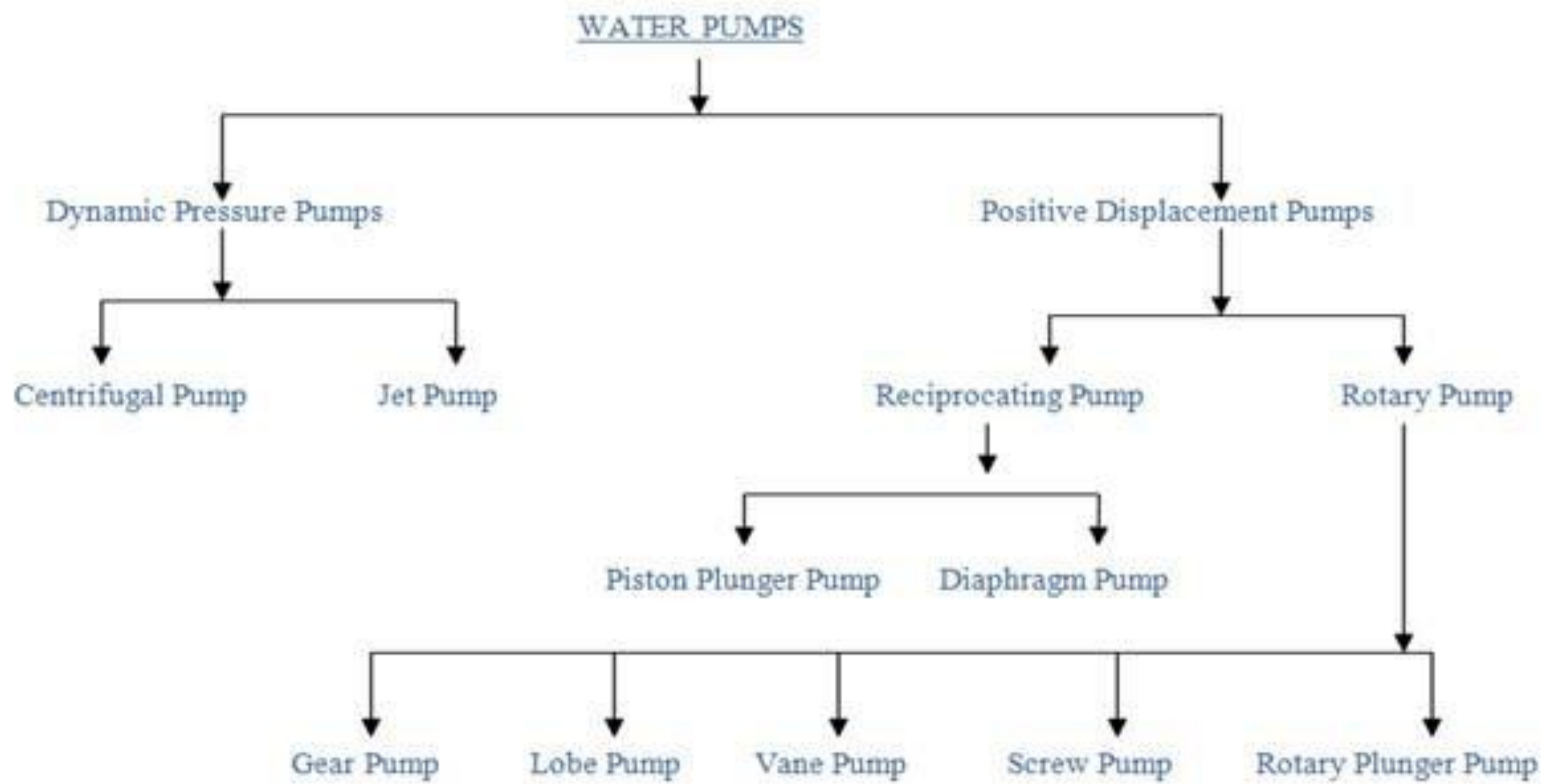
Rupture Discs



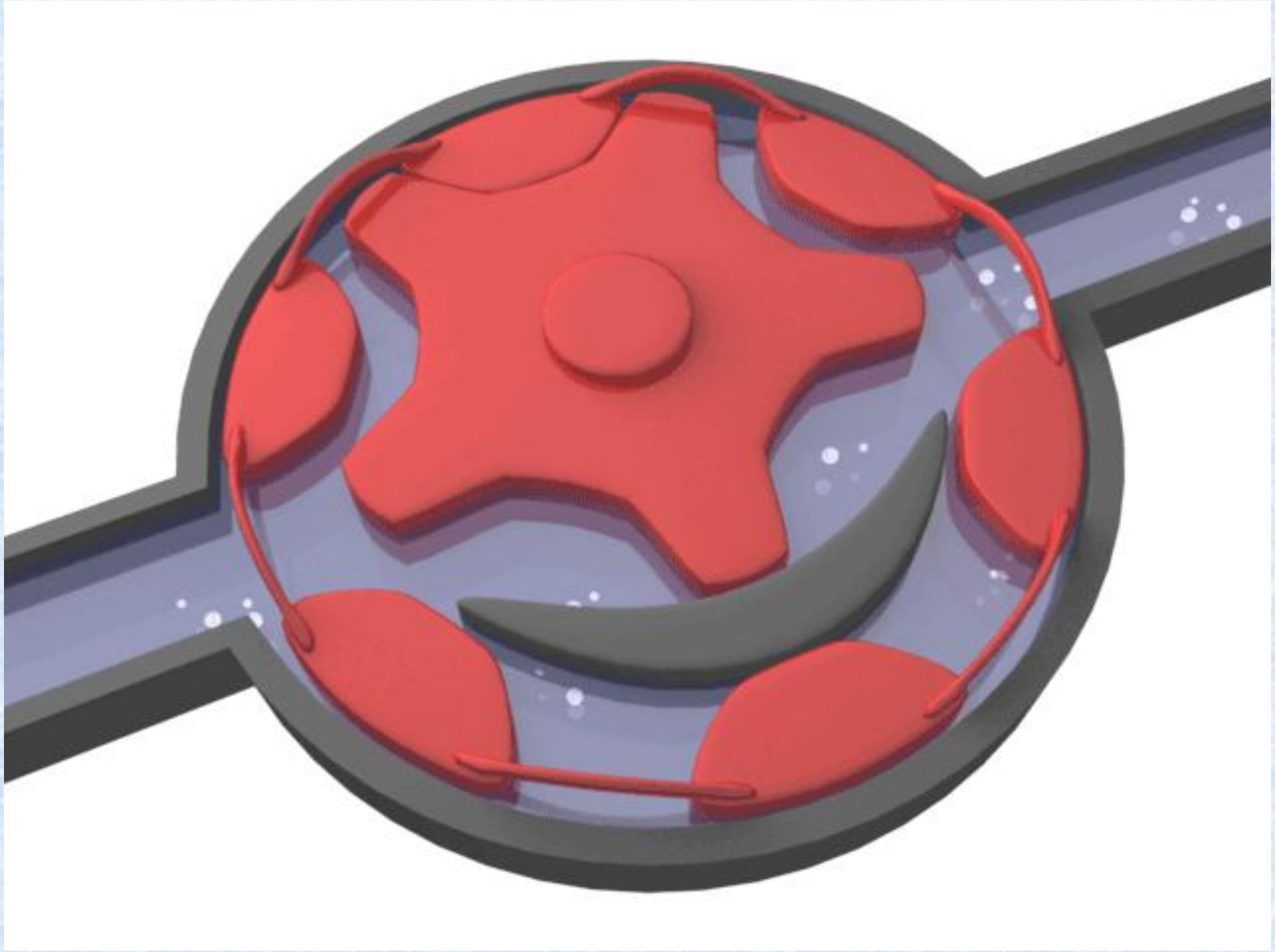
Practices

- Lines should be parallel and contains as many right angles bends as possible.
- In systems where the process lines are likely to become clogged, provision should be made for opening the lines to permit cleaning them out.
- With hazardous materials, especially volatile ones, flanged or screwed fittings should be used sparingly.
- Leakage through valves should also be expected.
- Valves should be mounted vertically with their stems up.
- Thermal expansion allowance for pipes should be provided.

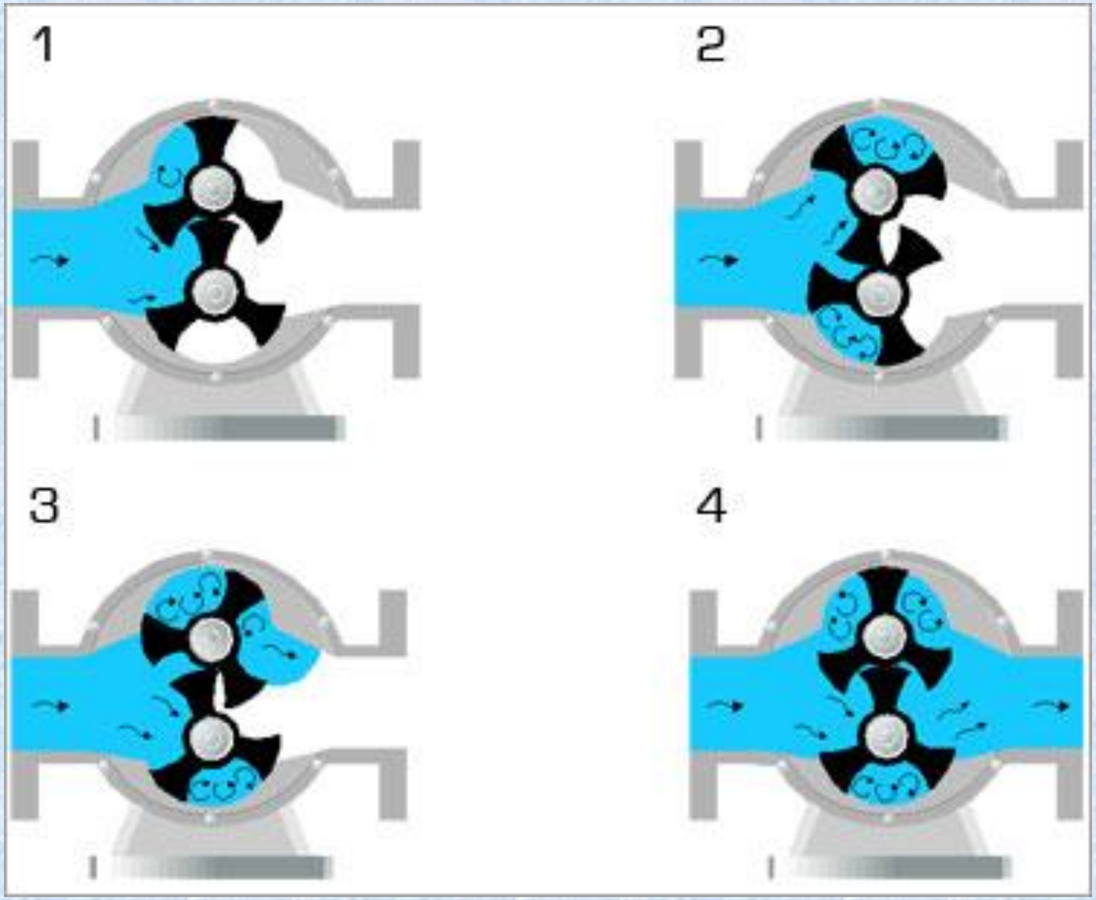
Pump Classification



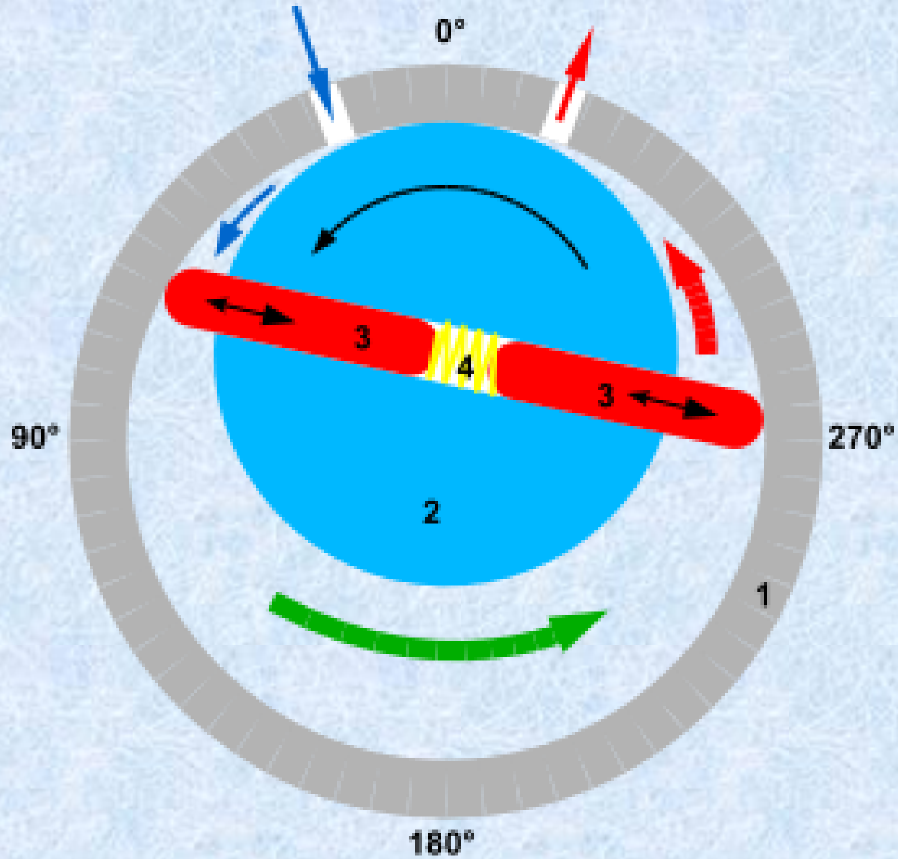
Gear Pump



Lobe Pump

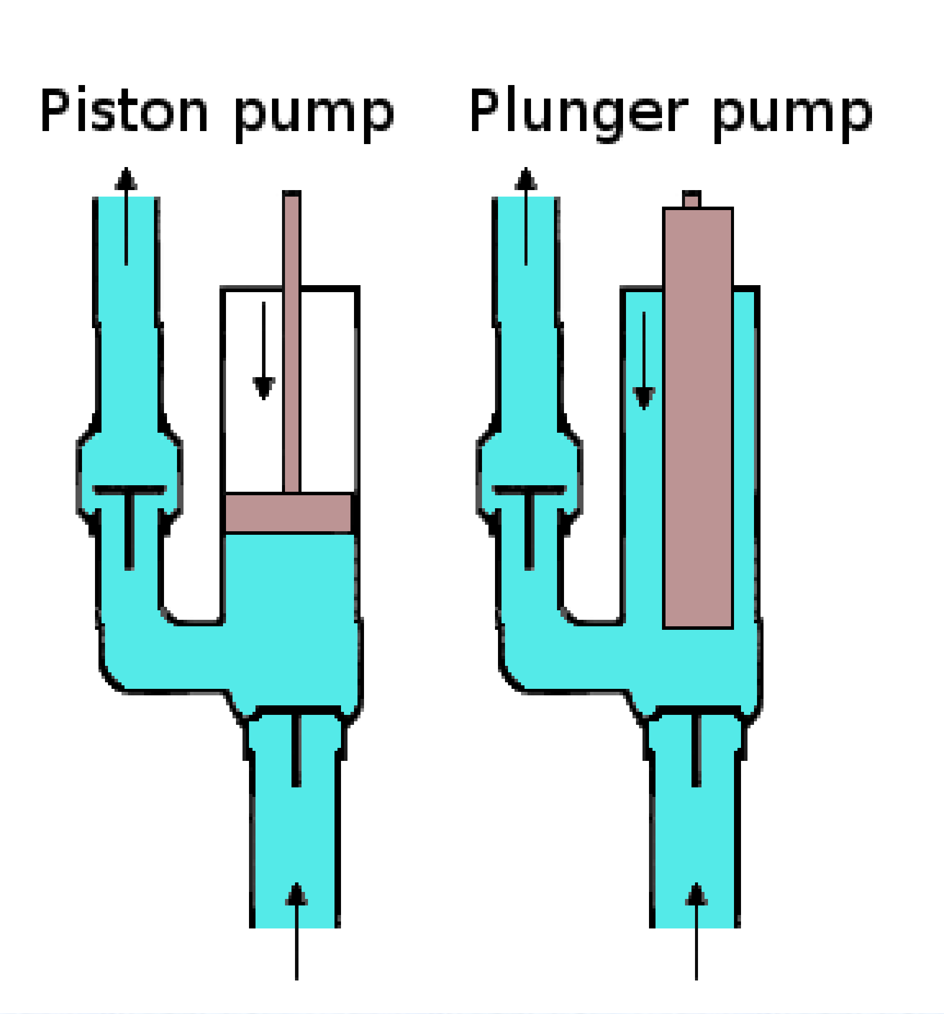


Vane Pump



Screw Pump

Piston and Plunger Pump



Diaphragm Pump

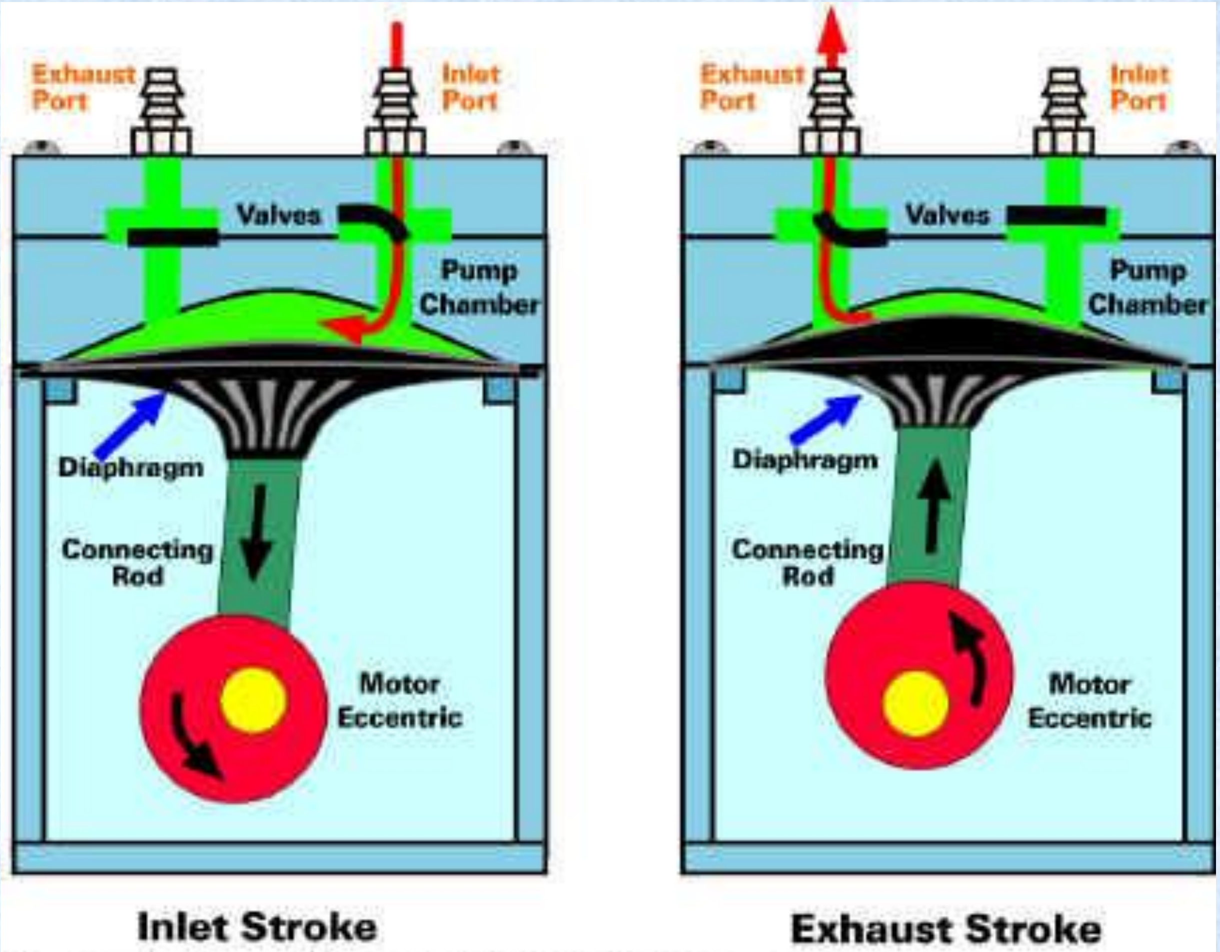
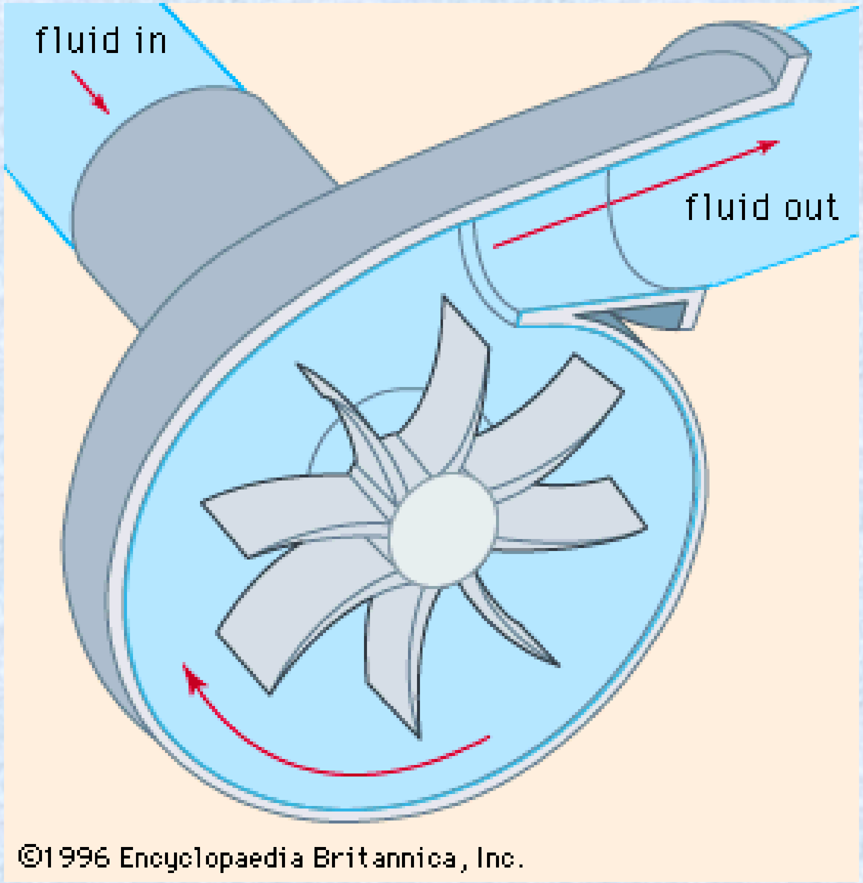
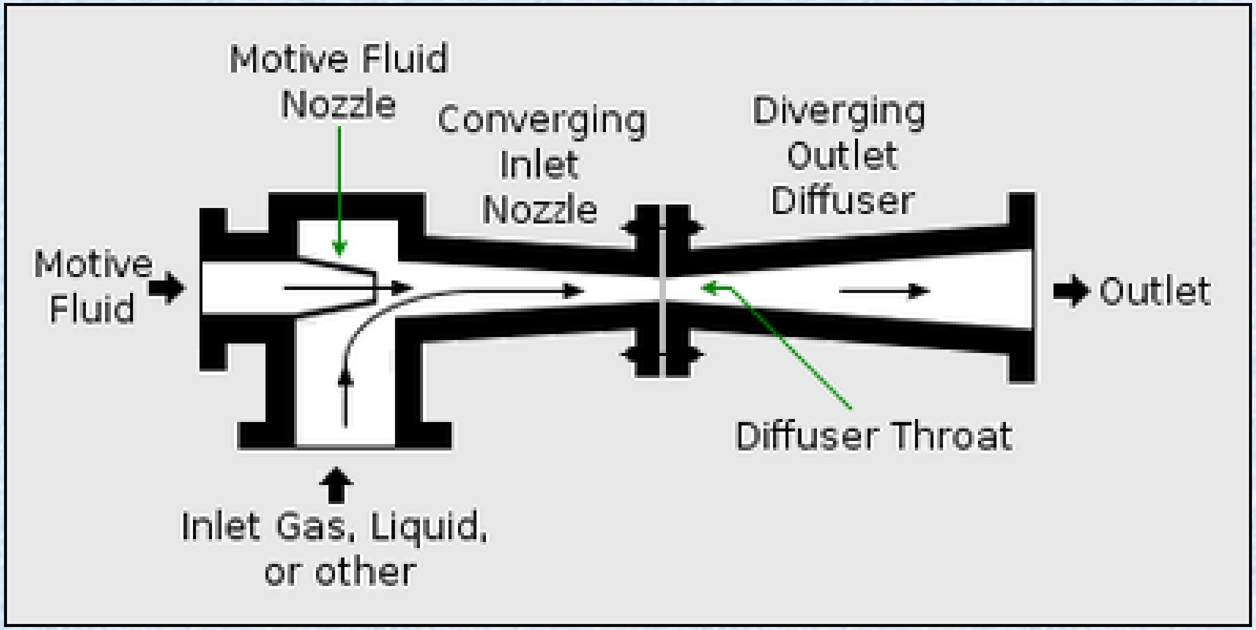


Figure 1 Operation of a liquid diaphragm pump.

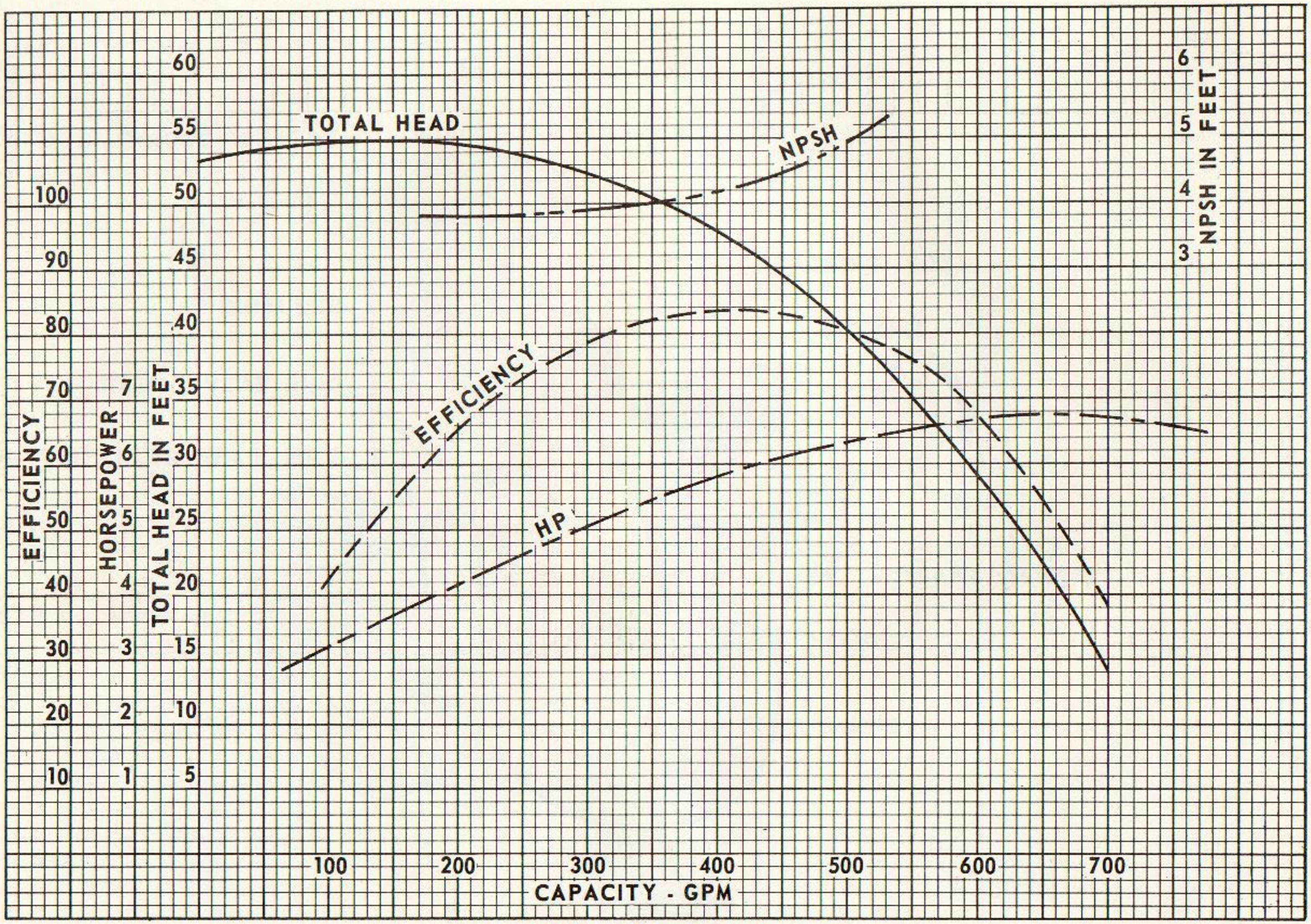
Centrifugal Pump



Jet Pump



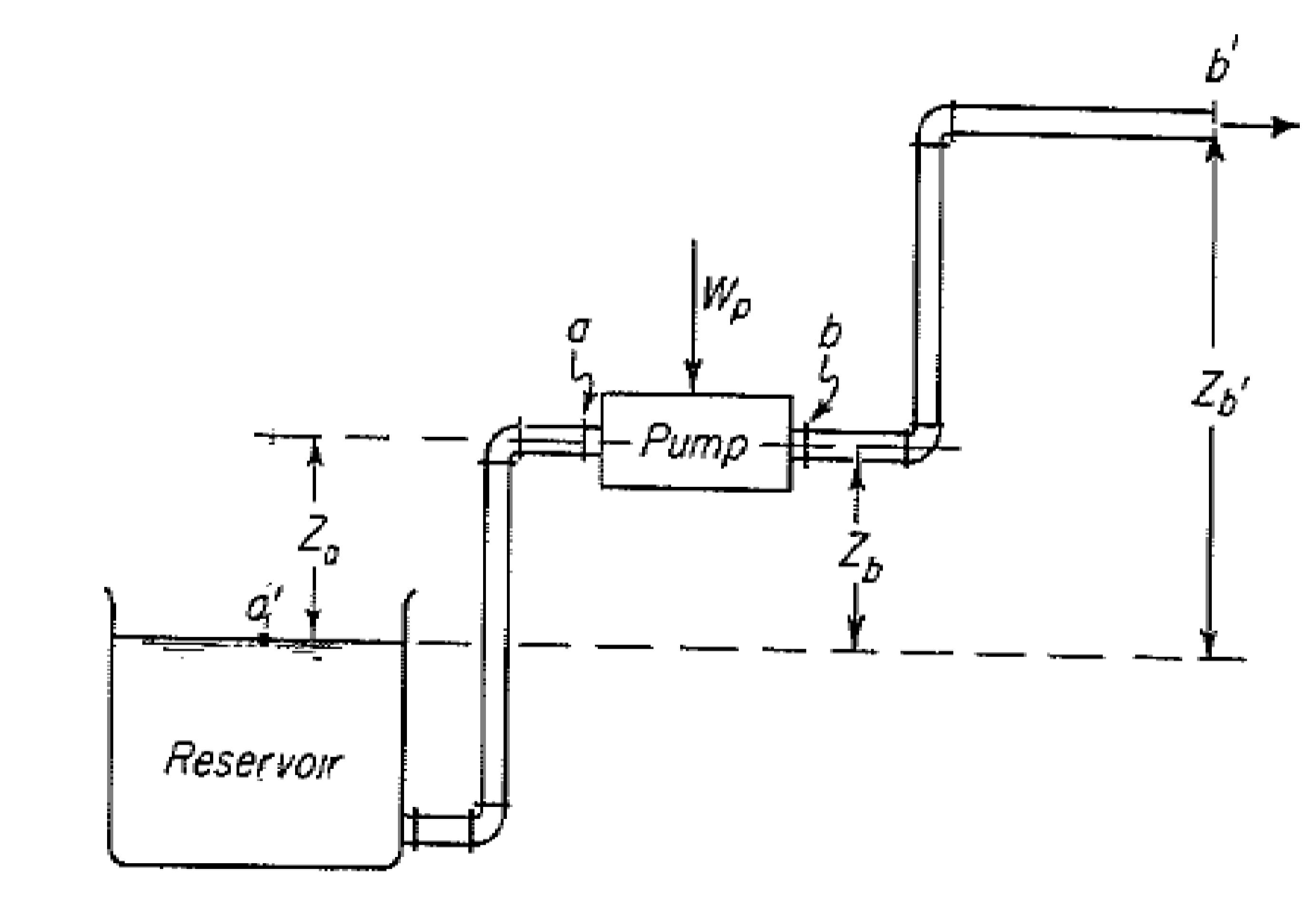
Motive Fluid
Nozzle
Converging
Inlet
Nozzle
Diverging
Outlet
Diffuser
Motive
Fluid
Outlet
Diffuser Throat
Inlet Gas, Liquid,
or other



PERFORMANCE CURVES

EXHIBIT 3

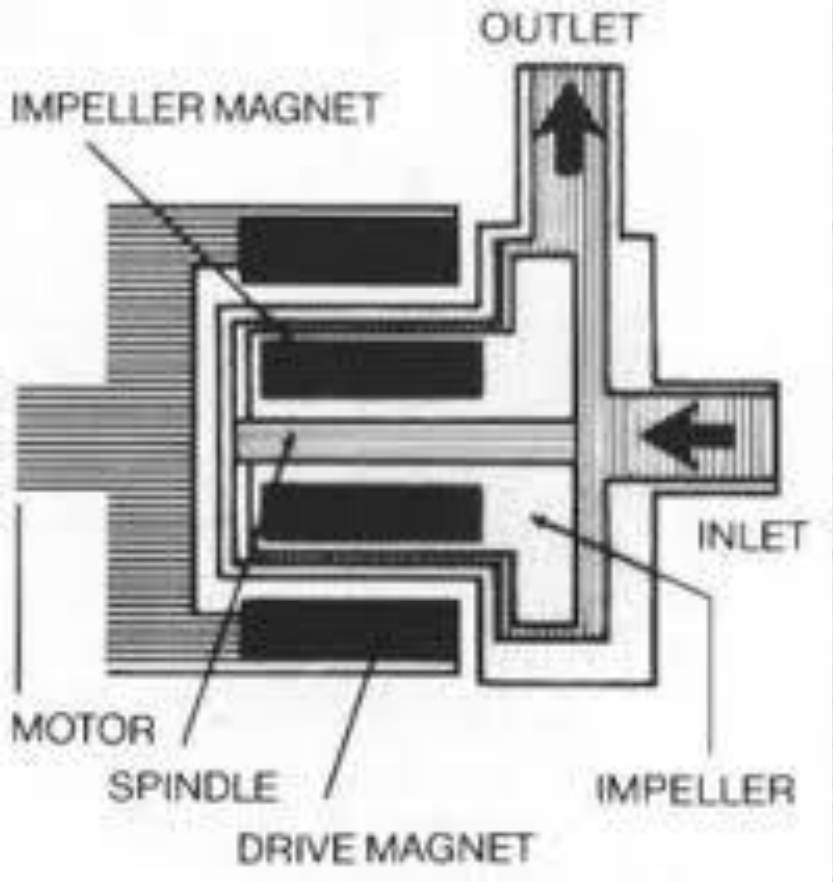
- Benzene at 100^oF is pumped through the system of figure at the rate of 40 gal/min. The reservoir is at atmospheric pressure. The gauge pressure at the end of the discharge line is 50 lb_f/in^2. The discharge is 10 ft and the pump suction 4 ft above the level in the reservoir. The discharge line is 1.5 in. Schedule 40 pipe. The friction in the suction line is known to be 0.5 lb_f/in^2 and that in the discharge line is 5.5 lb_f/in^2. The mechanical efficiency of the pump is 0.60. The density of benzene is 54 lb/ft^3 and its vapor pressure at 100^oF is 3.8 lb_f/in^2. Calculate;
  - Developed head of the pump
  - Total power input
  - If the pump manufacturer specifies a required NPSHR of 10 ft, will the pump be suitable for this service.


b'
W_p
a
b
Pump
Z_a
Z_b
$Z_{b'}$
a'
Reservoir

It is proposed to pump 10,000 kg/h of toluene at 114°C and 1.1 atm abs pressure from the reboiler of a distillation tower to a second distillation unit without cooling the toluene before it enters the pump. If the friction loss in the line between the reboiler and pump is 7 kN/m^2 and the density of toluene is 866 kg/m^3, how far above the pump must the liquid level in the reboiler be maintained to give a net positive suction head of 2.5 m?

Calculate the power required to drive the pump in Prob. 8.2 if the pump is to elevate the toluene 10 m, the pressure in the second unit is atmospheric, and the friction loss in the discharge line is 35 kN/m^2. The velocity in the pump discharge line is 2 m/s.

Magnetic Drive Pump



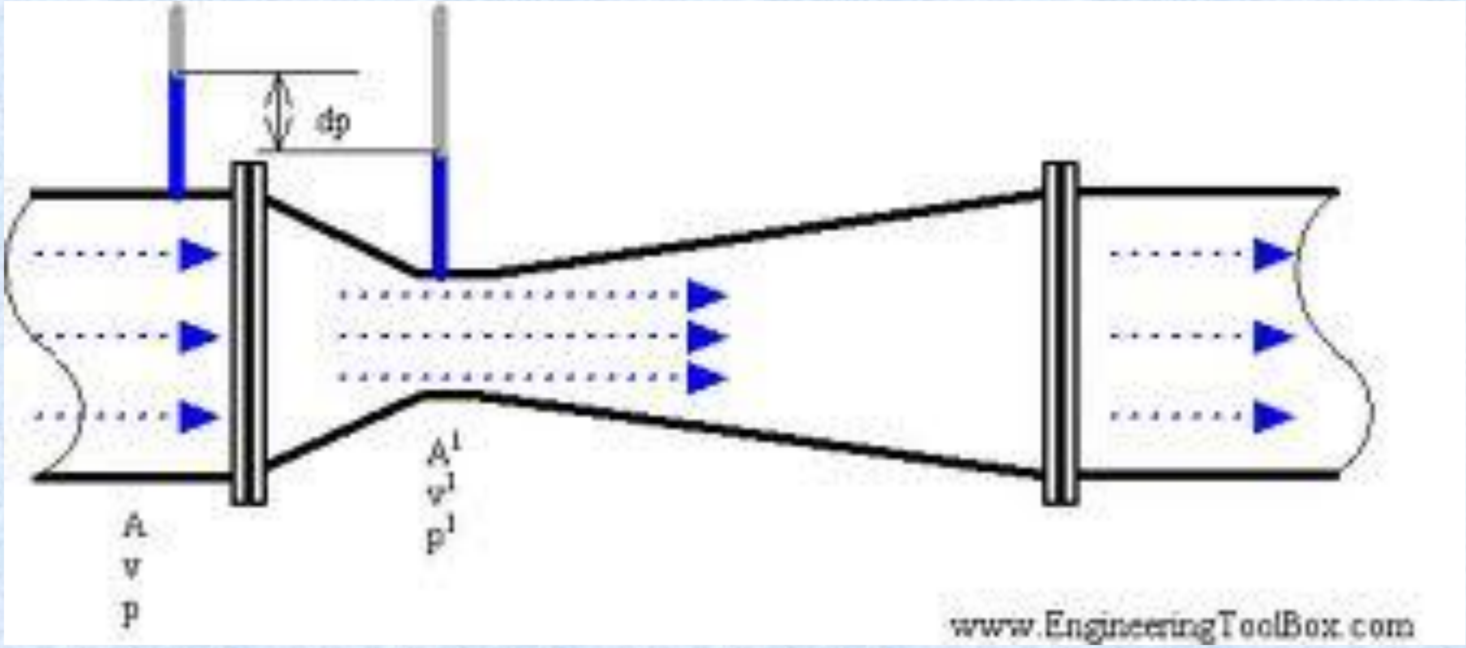
- A centrifugal fan is used to take flue gas at rest and at a pressure of 29 in.Hg and a temperature of 200^{o}F and discharge it at a pressure of 30.1 in.Hg and a velocity of 150 ft/s. Calculate the power needed to move 10000 std ft^3/min of gas. The efficiency of the fan is 65% and the molecular weight of the gas is 31.3.

- A three stage reciprocating compressor is to compress 180 std ft^3/min of methane from 14 to 900 lb_f/in^2 abs. The inlet temperature is 80°F. For the expected temperature range the average properties of methane are

$$C_p = 9.3 \text{ Btu/lb mol-°F } (38.9 \text{ J/g mol-°C}) \qquad \gamma = 1.31$$

  - What is the horse power if the mechanical efficiency is 80%?
  - What is the discharge temperature from the first stage?
  - If the temperature of the cooling water is to rise 20°F, how much water is needed in the intercoolers and after cooler for the compressed gas to leave each cooler at 80°F? Assume that the jacket cooling is sufficient to absorb frictional heat.

Venturi Meter

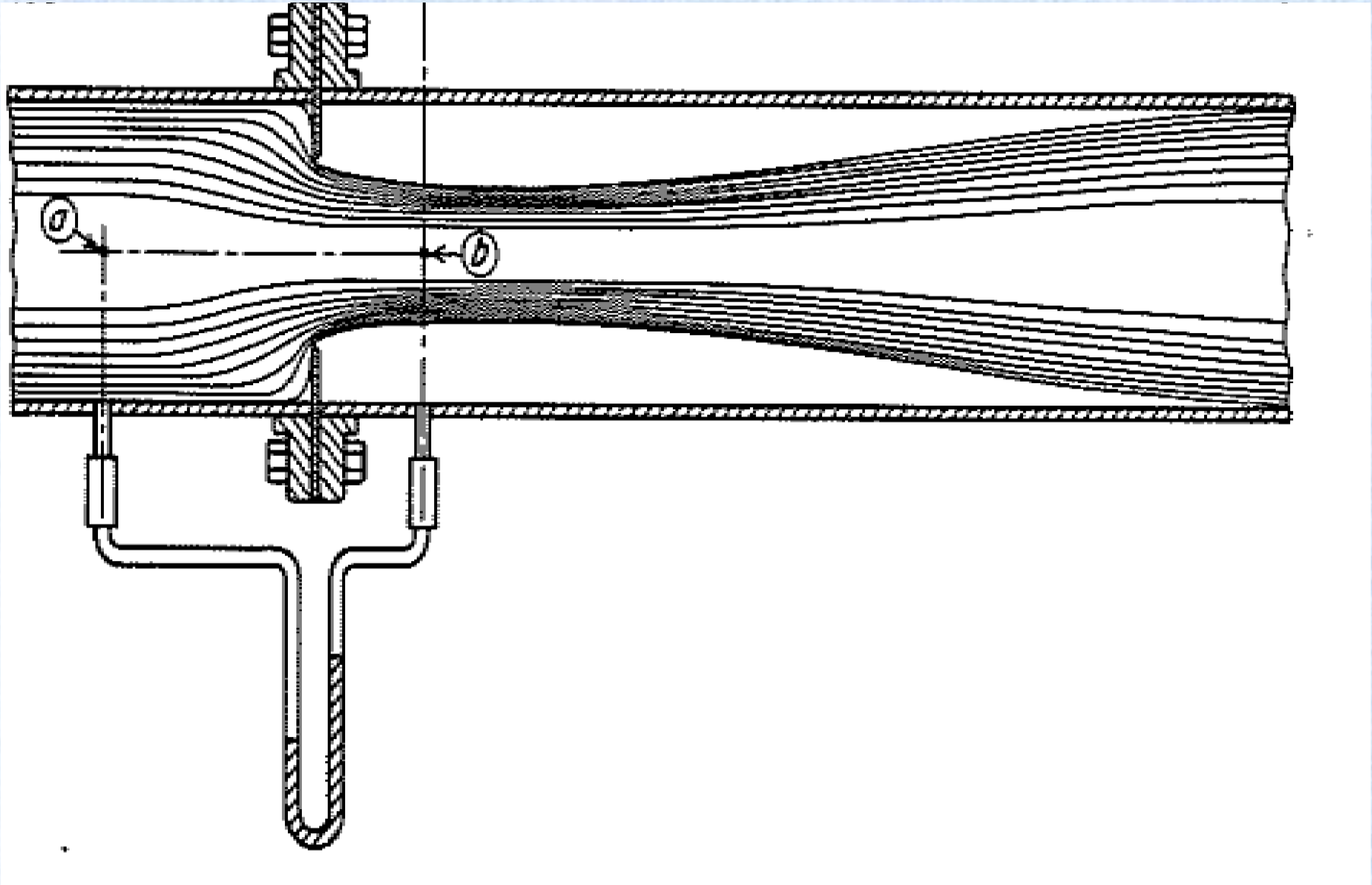


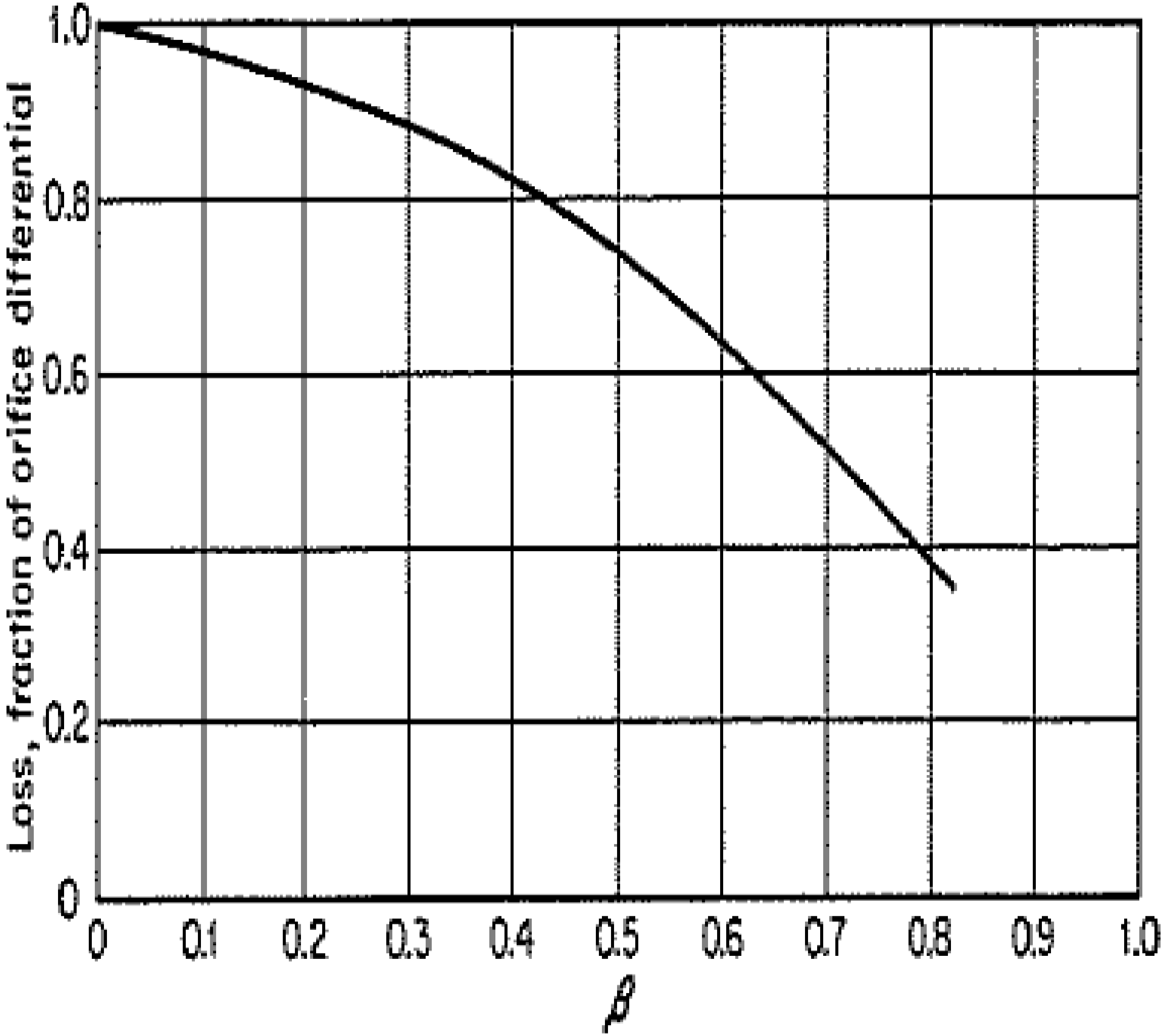
A venturi meter is to be installed in a 100-mm line to measure the flow of water. The maximum flow rate is expected to be 75 m^3/h at 15°C. The manometer used to measure the differential pressure is to be filled with mercury, and water is to fill the leads above the surfaces of the mercury. The water temperature will be 15°C throughout. (*a*) If the maximum manometer reading is to be 1.25 m and the venturi coefficient is 0.98, what throat diameter, to the nearest millimeter, should be specified for the venturi? (*b*) What will be the power to operate the meter at full load if the pressure recovery is 90 percent of the differential pressure?

Air entering at 70°F and atmospheric pressure is to be compressed to 4000 $lb_f/in.^2$ gauge in a reciprocating compressor at the rate of 125 std ft^3/min. How many stages should be used? What is the theoretical shaft work per standard cubic foot for frictionless adiabatic compression? What is the brake horsepower if the efficiency of each stage is 85 percent? For air $\gamma = 1.40$.

What is the discharge temperature of the air from the first stage

Orifice Meter

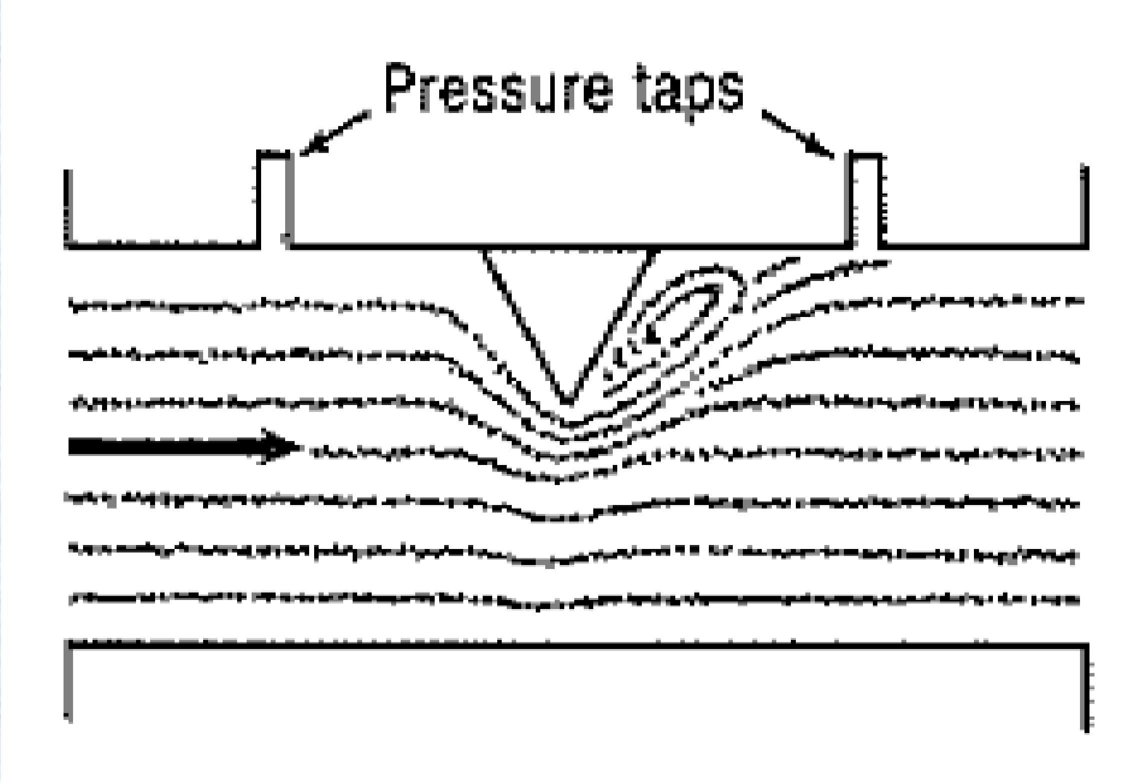




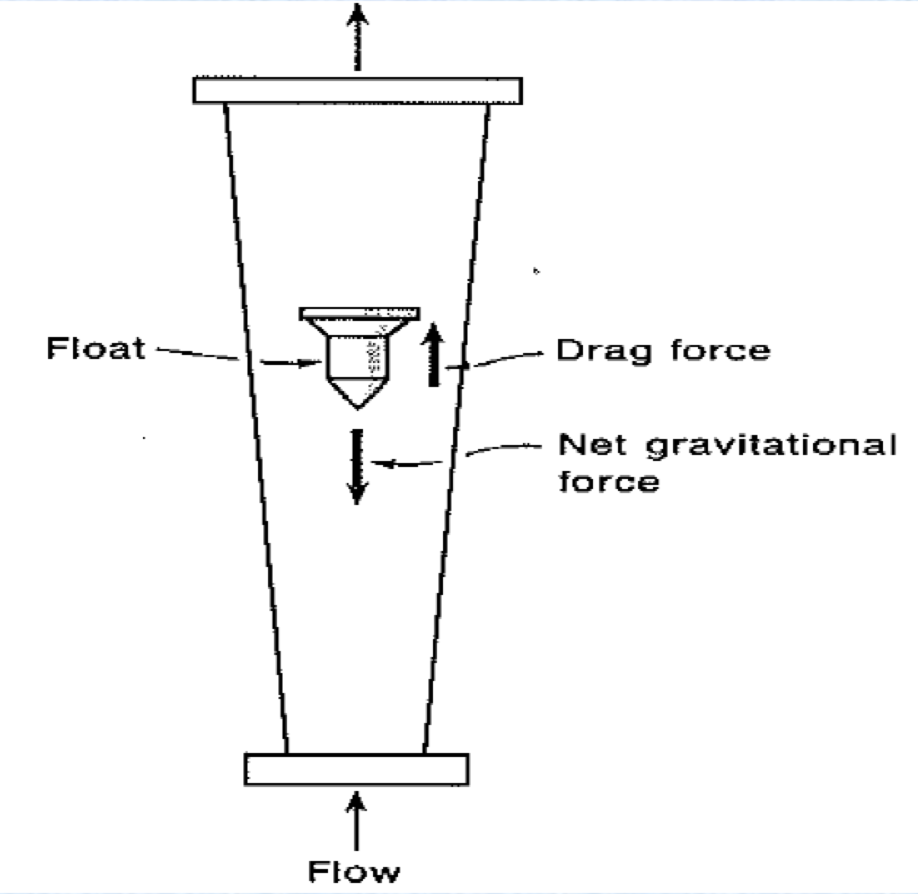
Loss, fraction of orifice differential
1.0
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
β

An orifice meter equipped with flange taps is to be installed to measure the flow rate of topped crude to a cracking unit. The oil is flowing at 100°F (37.8°C) through a 4-in. (100-mm) Schedule 40 pipe. An adequate run of straight horizontal pipe is available for the installation. The expected maximum flow rate is 12,000 bbl/d (1 bbl = 42 U.S. gal) (79.5 m^3/h), measured at 60°F (15.6°C). Mercury is to be used as a manometer fluid, and glycol (specific gravity 1.11) is to be used in the leads as sealing liquid. The maximum reading of the meter is to be 30 in. (762 mm). The viscosity of the oil at 100°F (37.8°C) is 5.45 cP. The specific gravity (60°F/60°F) of the oil is 0.8927. The ratio of the density of the oil at 100°F (37.8°C) to that at 60°F (15.6°C) is 0.984. Calculate (*a*) the diameter of the orifice and (*b*) the power loss.

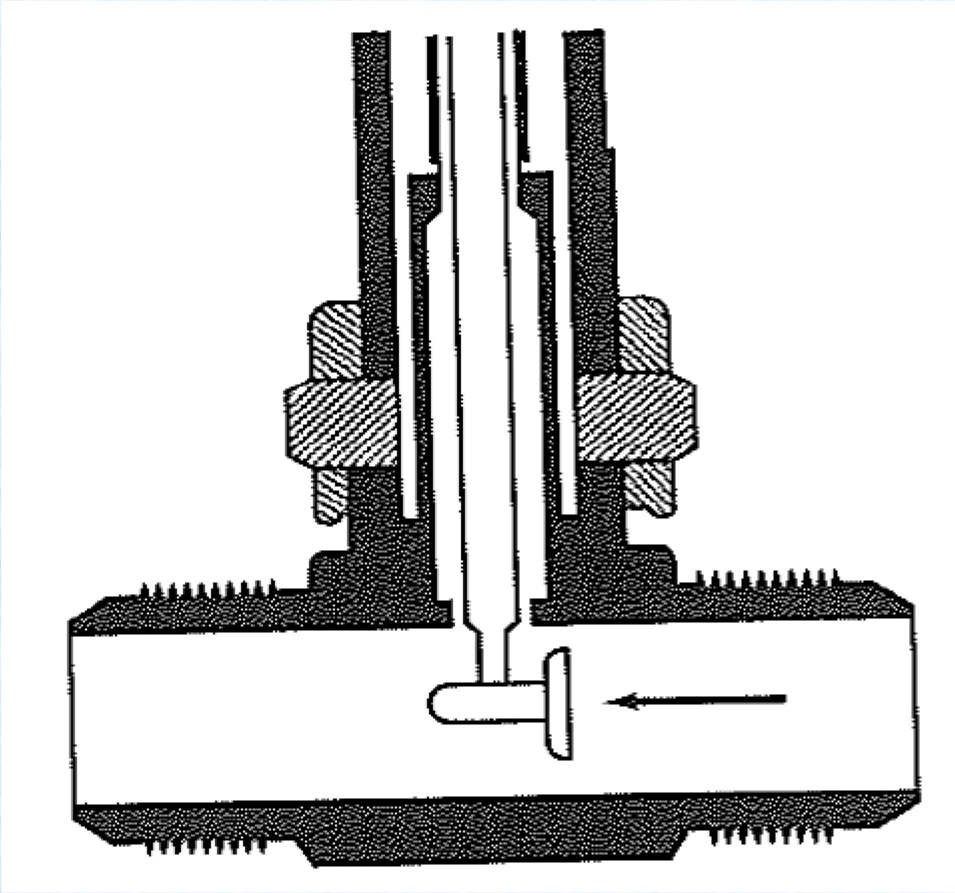
V-Elements Meter



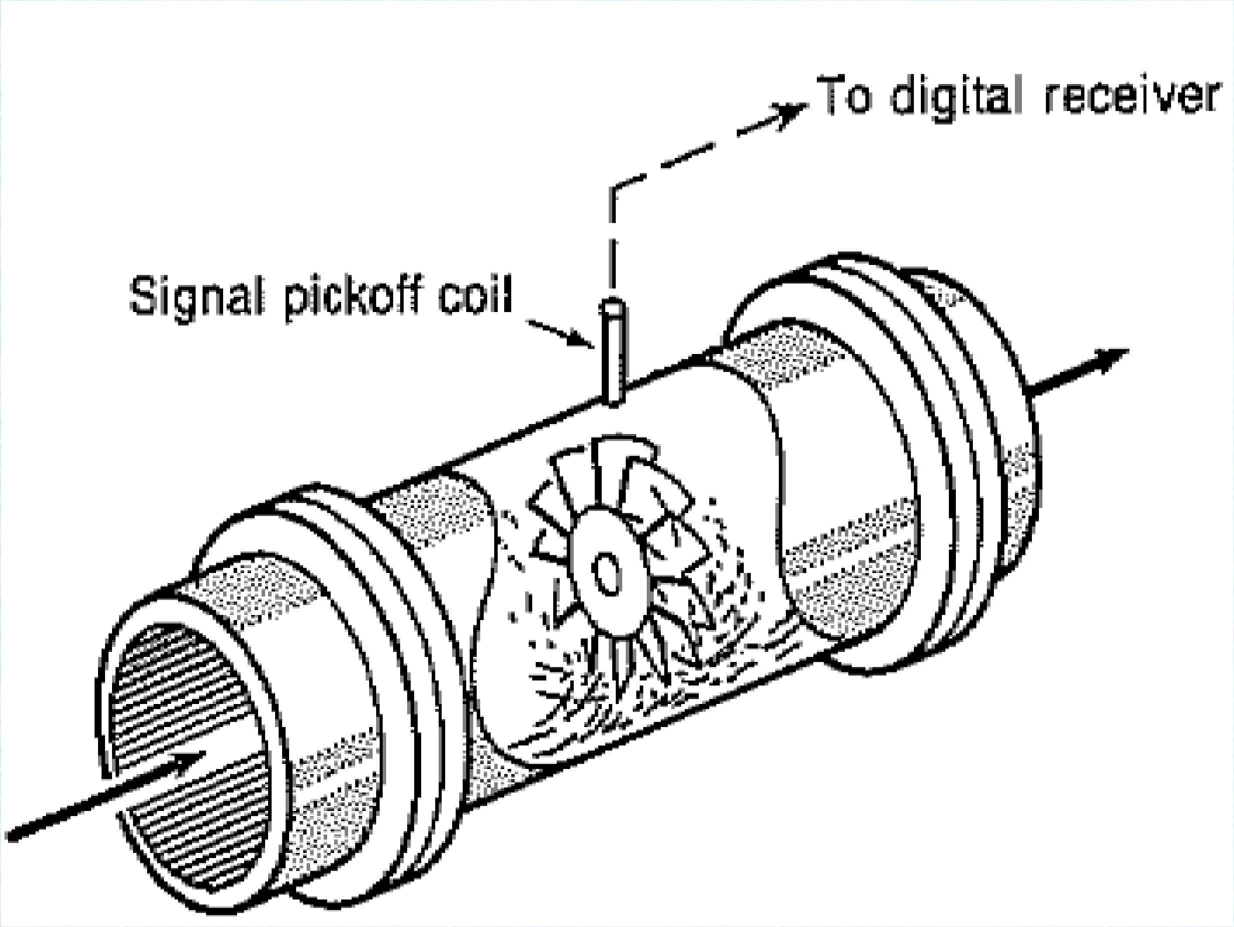
Rota Meter (Variable Area Meter)



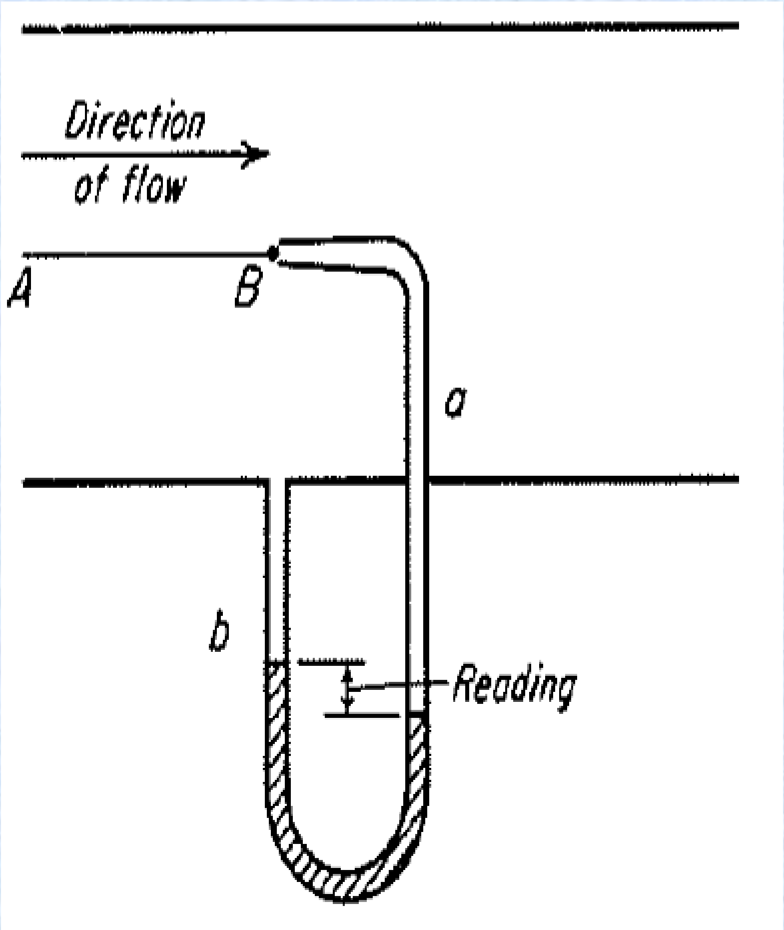
Target Meter



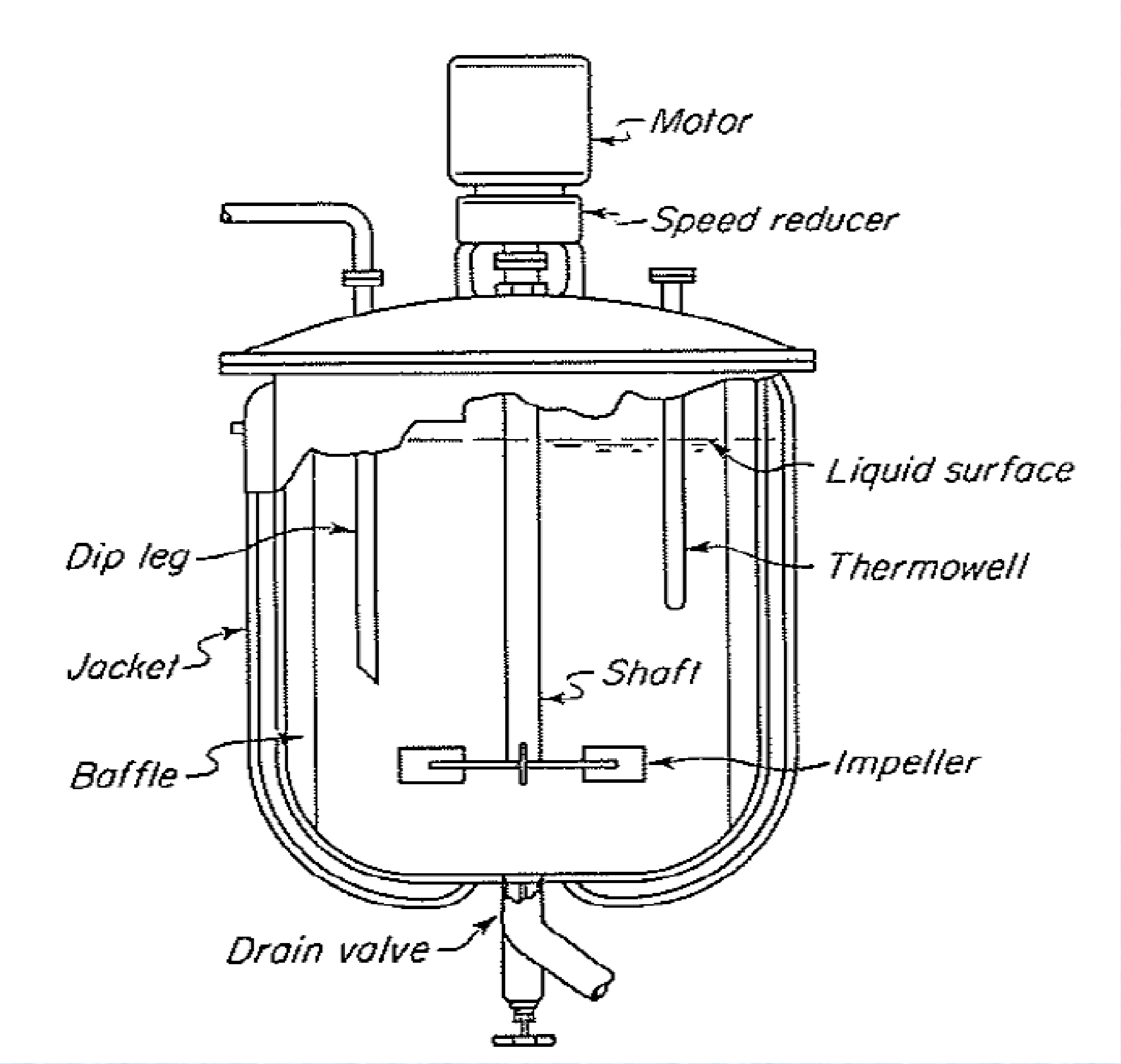
Turbine Meter

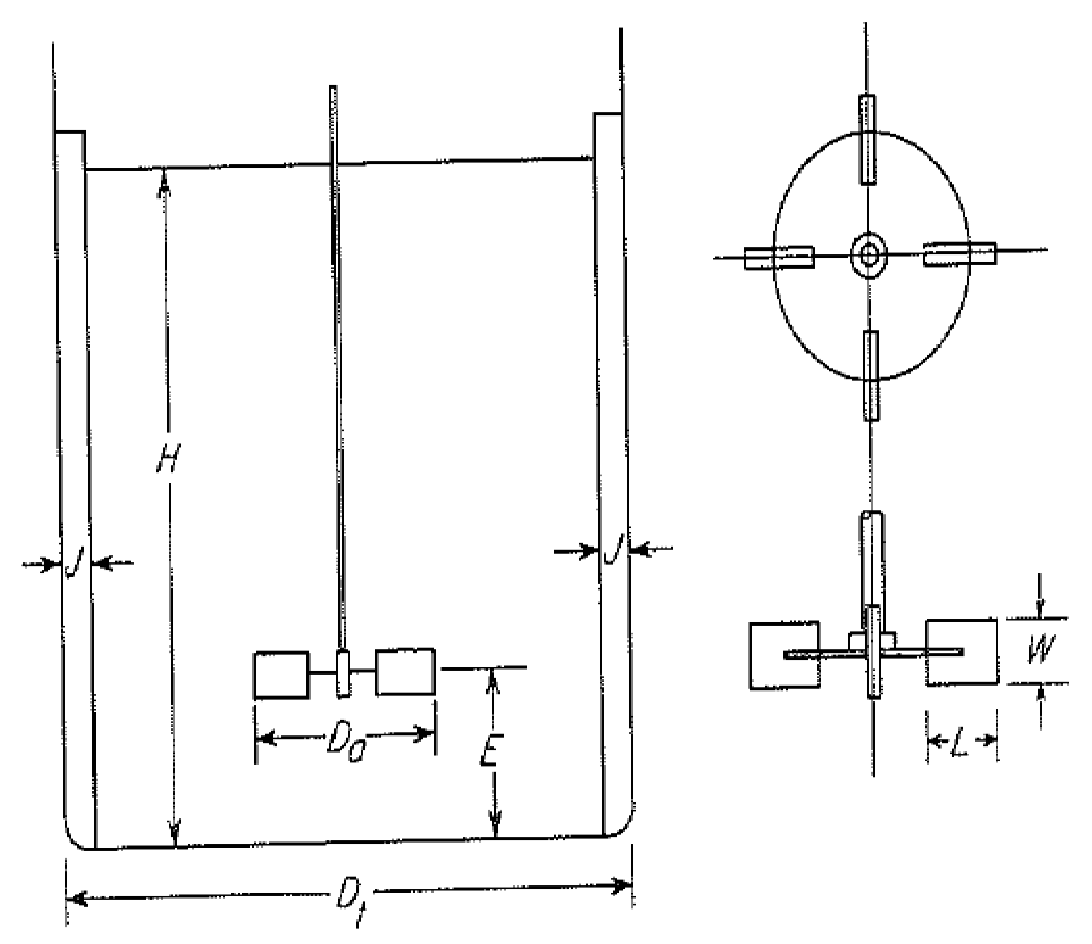


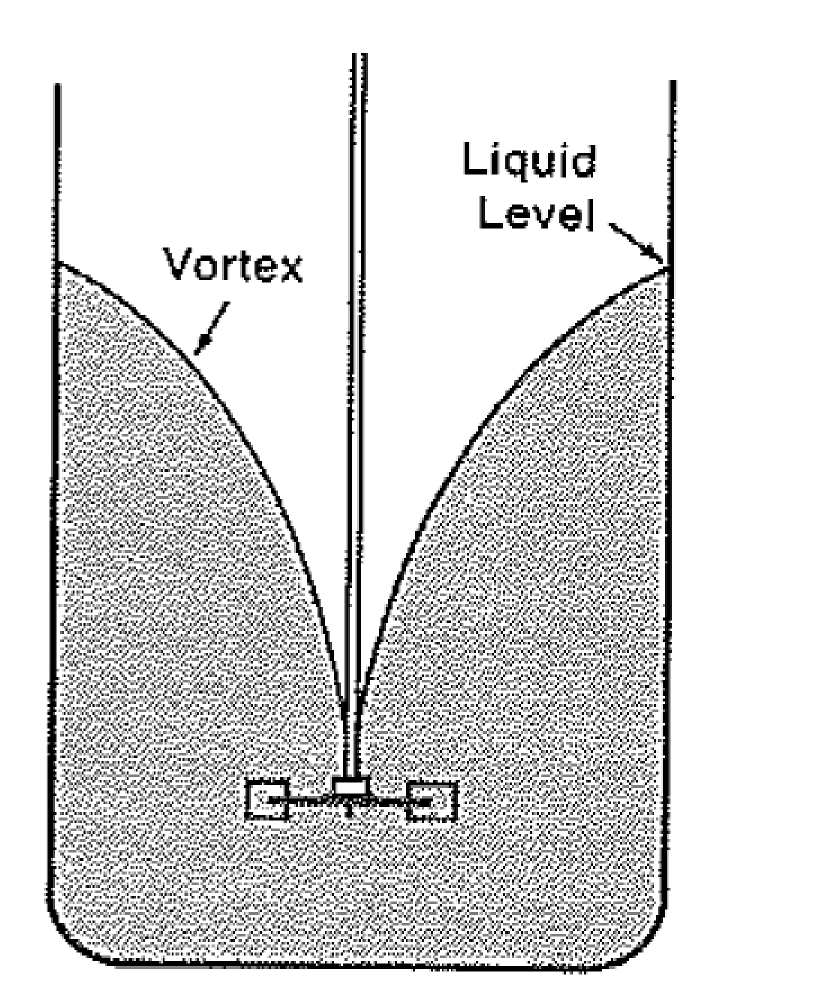
Pitot Tube



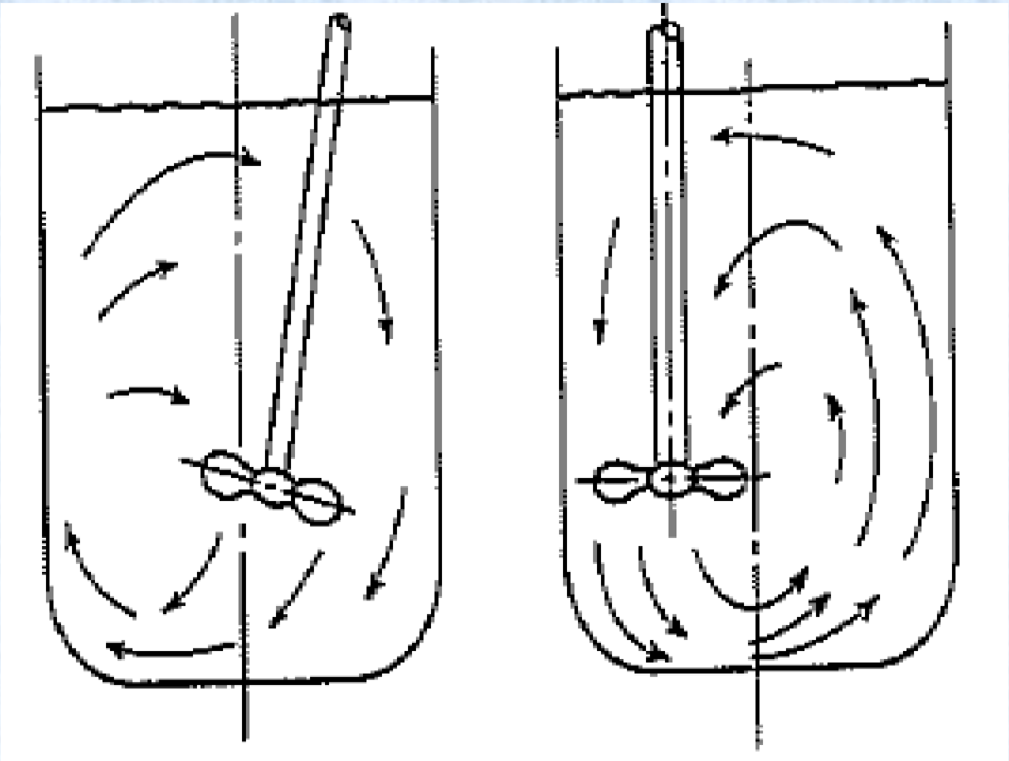
A horizontal venturi meter having a throat diameter of 20 mm is set in a 75-mm-ID pipeline. Water at 15°C is flowing through the line. A manometer containing mercury under water measures the pressure differential over the instrument. When the manometer reading is 500 mm, what is the flow rate in gallons per minute? If 12 percent of the differential is permanently lost, what is the power consumption of the meter?

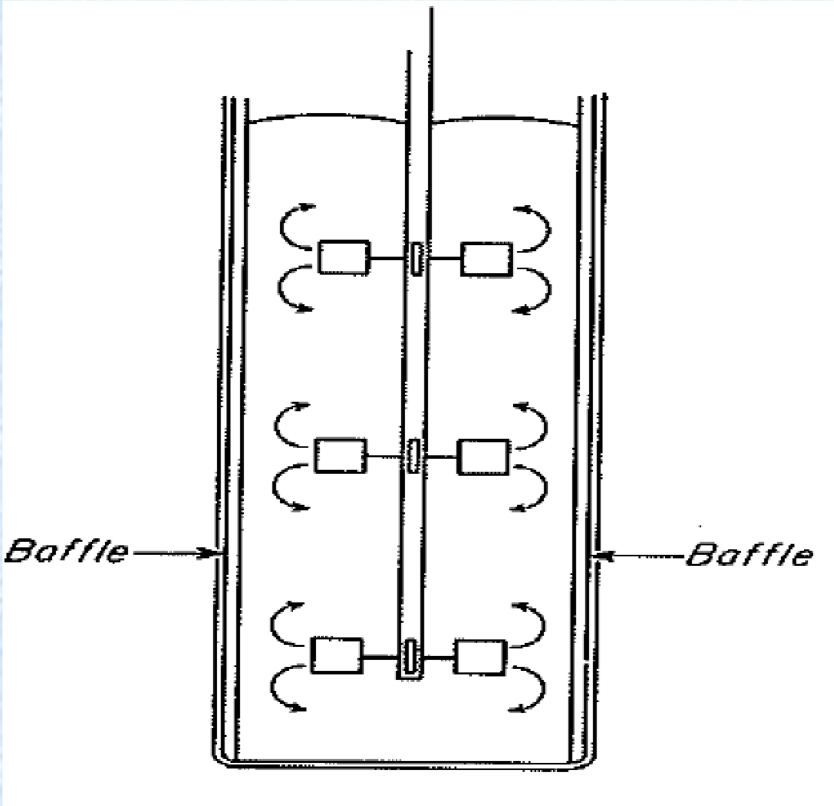

Motor
Speed reducer
Liquid surface
Dip leg
Thermowell
Jacket
Shaft
Baffle
Impeller
Drain valve


H
J
J
D_a
E
D_t
W
L


Liquid
Level
Vortex

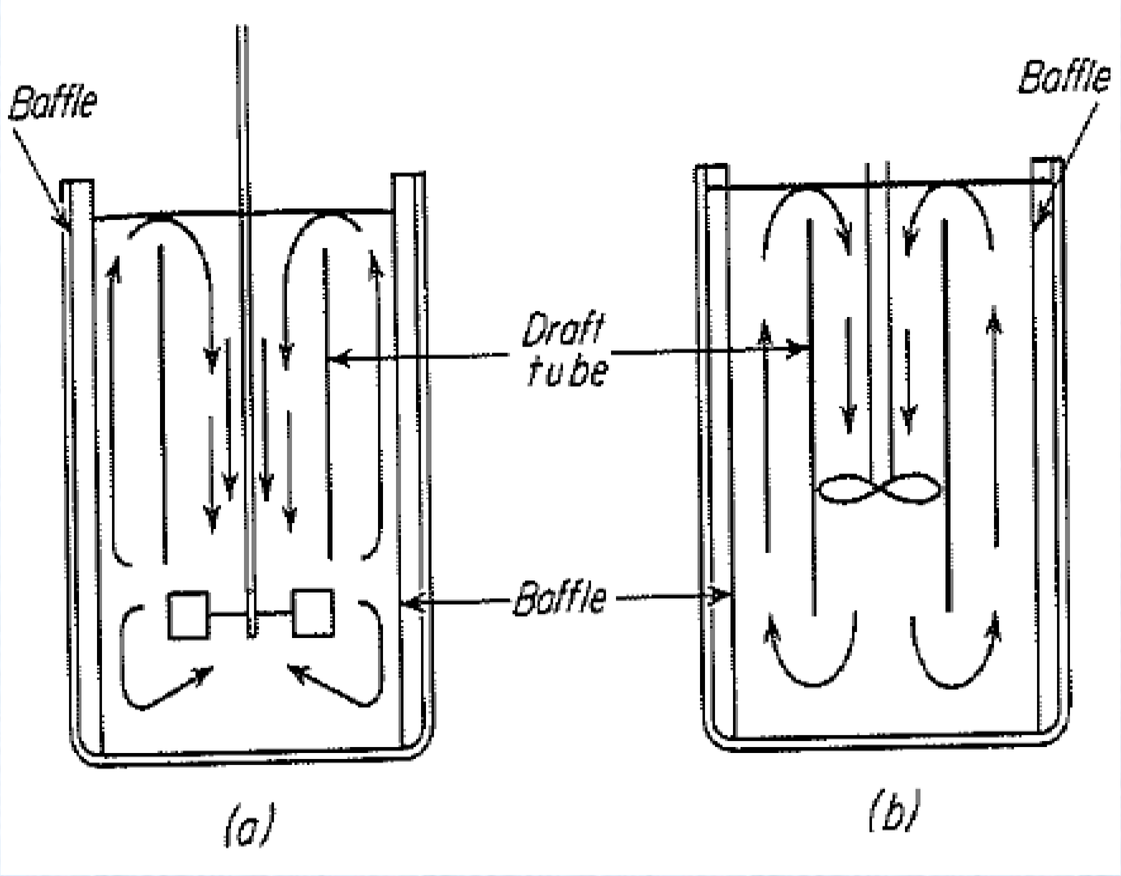
Prevention of Swirling

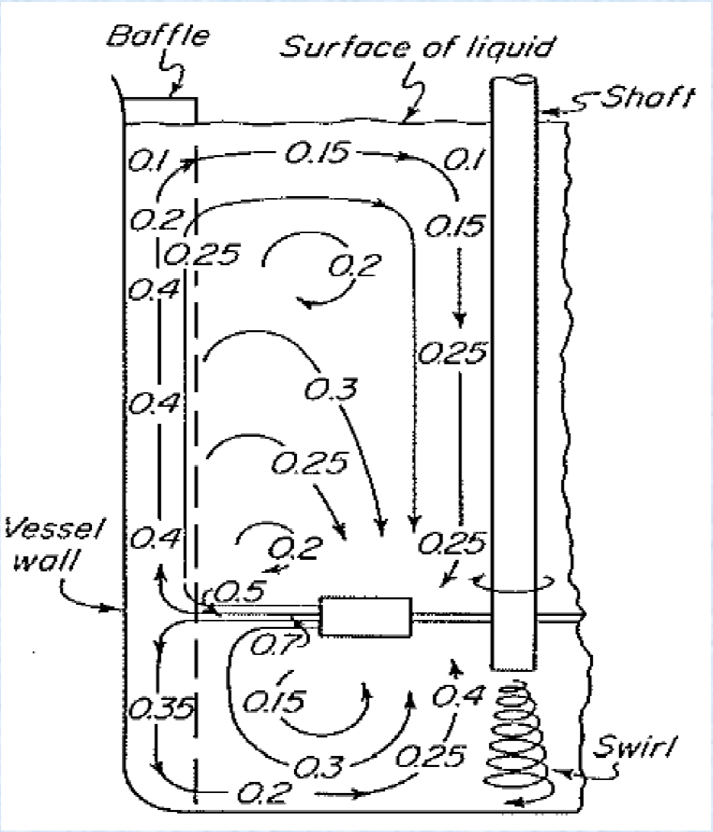




Baffle
Baffle

Draft Tubes




Baffle
Surface of liquid
Shaft
0.1
0.15
0.1
0.2
0.15
0.25
0.2
0.4
0.25
0.3
0.4
0.25
Vessel wall
0.4
0.2
0.25
0.5
0.7
0.15
0.4
0.35
0.3
0.25
Swirl
0.2

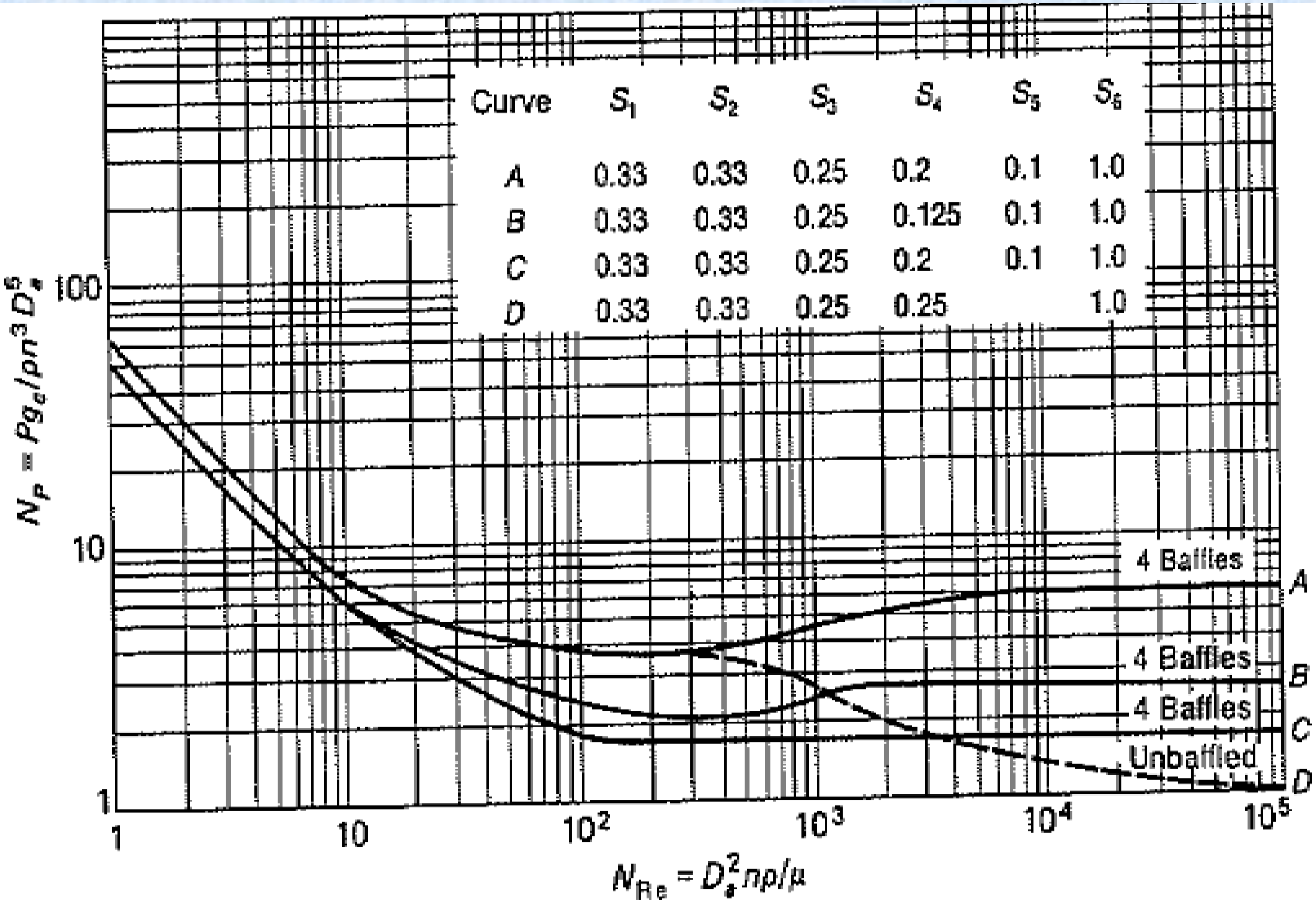


FIGURE 9.12
Power number N_p versus N_{Re} for six-blade turbines. (*After Chudacek*[11]; *Oldshue.*[35]) With the dashed portion of curve D, the value of N_p read from the figure must be multiplied by N_{Fr}^m.

A flat-blade turbine with six blades is installed centrally in a vertical tank. The tank is 6 ft (1.83 m) in diameter; the turbine is 2 ft (0.61 m) in diameter and is positioned 2 ft (0.61 m) from the bottom of the tank. The turbine blades are 5 in. (127 mm) wide. The tank is filled to a depth of 6 ft (1.83 m) with a solution of 50 percent caustic soda, at 150°F (65.6°C), which has a viscosity of 12 cP and a density of 93.5 lb/ft^3 (1498 kg/m^3). The turbine is operated at 90 r/min. The tank is baffled. What power will be required to operate the mixer?

The mixer is to be used to mix a rubber-latex compound having a viscosity of 1200 P and a density of 70 lb/ft^3 (1120 kg/m^3). What power will be required?