


Pumps and Motors

Peter Nathanson, PE
DBS&A Independent Contractor
peternathanson@kunm.org

Topics

Centrifugal Pump Types, Anatomy, Configuration

Pump Design and Hydraulics

Pump Systems and TDH

Pumps, Motors and Energy

Pump Curves

System O&M

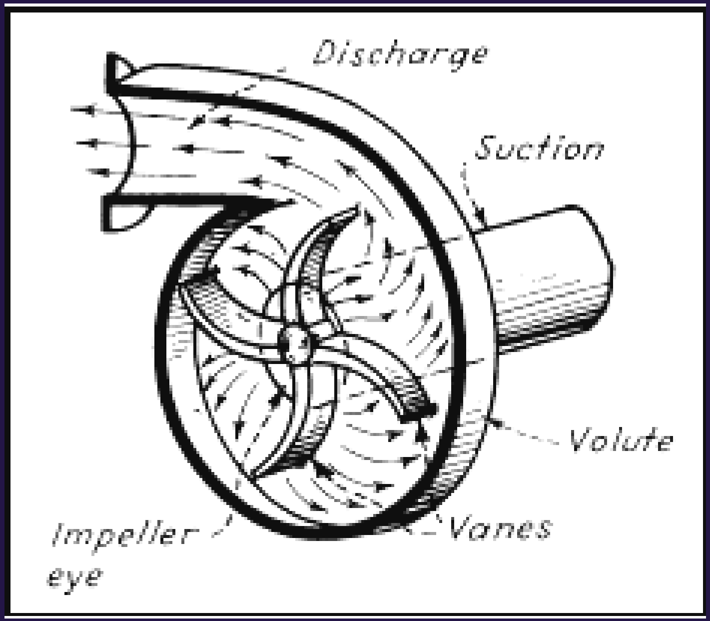
Chemical Feed Pumps

Pump Types, Anatomy & Configurations

Types of Pumps

- Centrifugal (meaning…?)
  - Low pressure
  - High flow
  - Flow changes when pressure changes
- Positive displacement / Peristaltic
  - High pressure
  - Low flow
  - Flow does not change when pressure changes

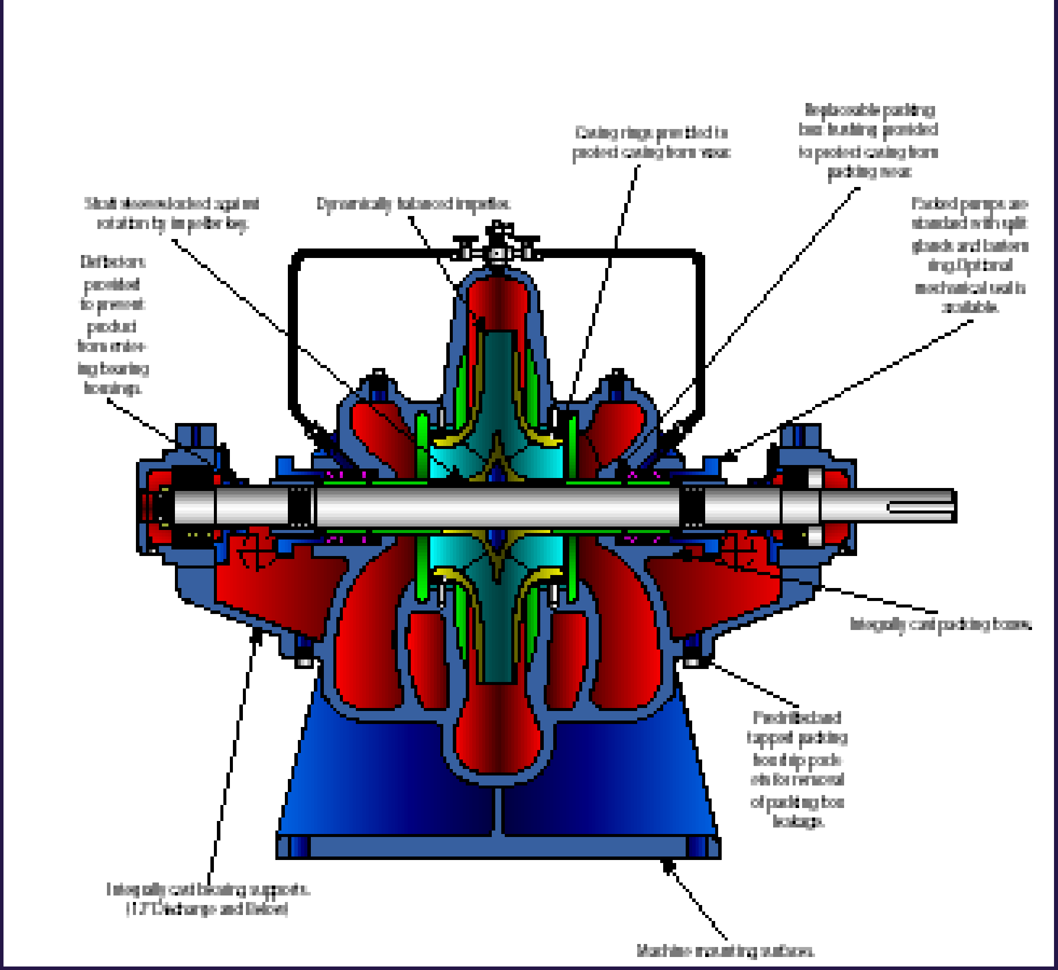
Centrifugal Forces: Impeller Rotation



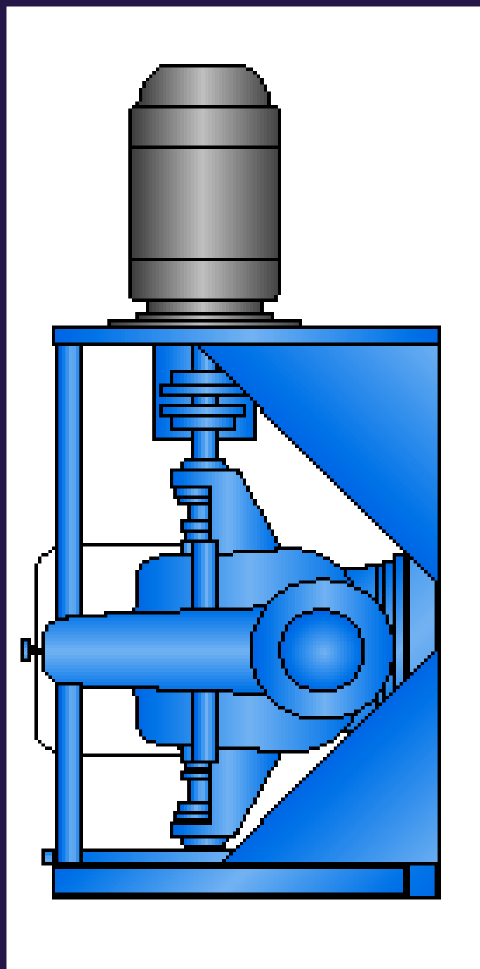
Centrifugal Pump Design

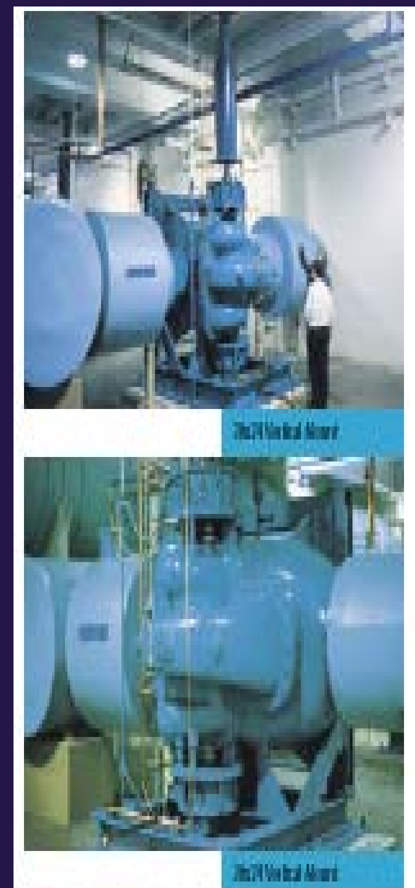
- Split case (clam shell)
  - Initial design
  - Horizontal or vertical shaft
  - Open access for maintenance
  - Large amount of floor space
- End suction
  - Less floor space
  - Suction and discharge at right angles

Split Case Horizontal



Vertical Split Case



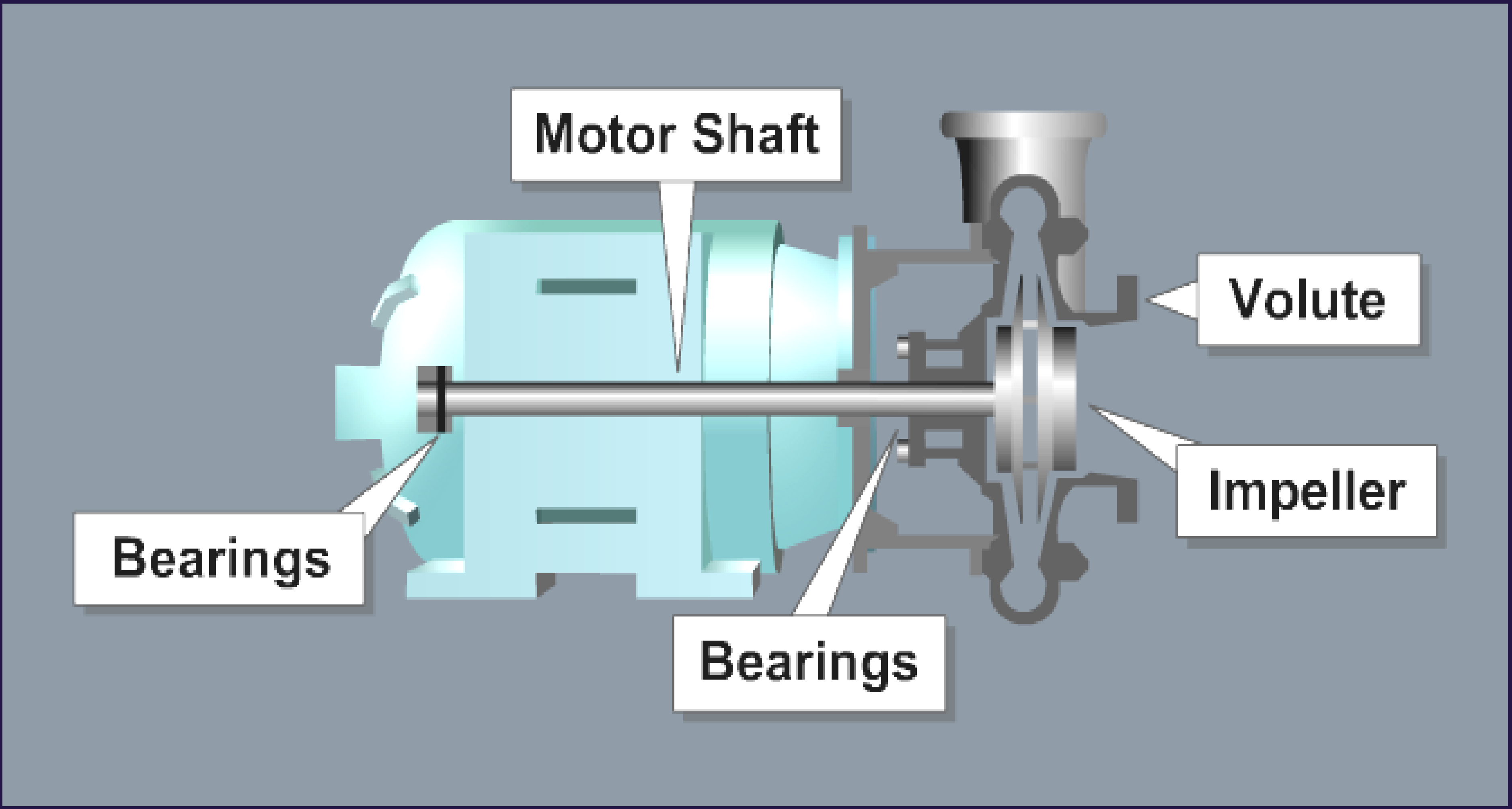


End Suction

- Close-coupled units
  - Pump is assembled on motor shaft
- Frame-mounted units
  - Assembly includes pump, motor, base, coupling, and OSHA coupling guard

Example, Close-Coupled End Suction

Close-Coupled End Suction Anatomy



Shaft Assembly

- Connects pump to motor
- Can be direct-coupled
  - Same shaft for pump and motor
- Frame-mounted
  - Motor shaft and pump shaft mechanically coupled
  - Alignment must be maintained
- Shaft sleeve
  - Fits over shaft
  - Protects shaft where it passes through the pump casing

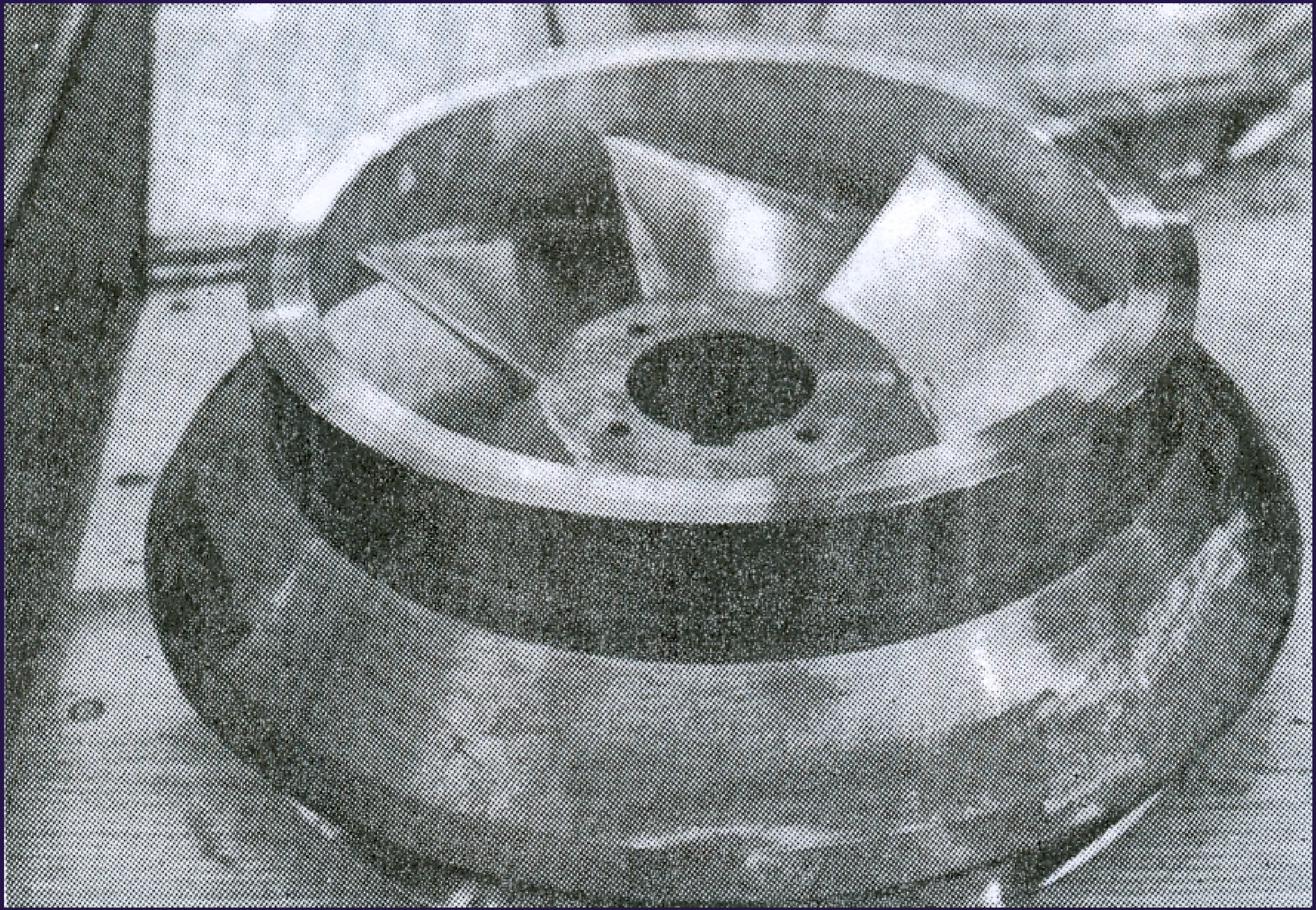
Shaft Assembly (cont.)

- Bearings
  - Supports and holds spinning shaft in place
  - Radial bearings prevent side-to-side movement
  - Thrust bearings prevent up and down movement from water pressure against impeller

Pump Assembly

- Volute
  - Portion of casing that directs water as it enters and leaves the impeller
  - Cross-sectional area increases, velocity decreases, pressure increases
- Piping
  - Diameter suction side > diameter discharge side
  - 4 fps suction side velocity
  - 7 fps discharge side velocity

Wear Ring

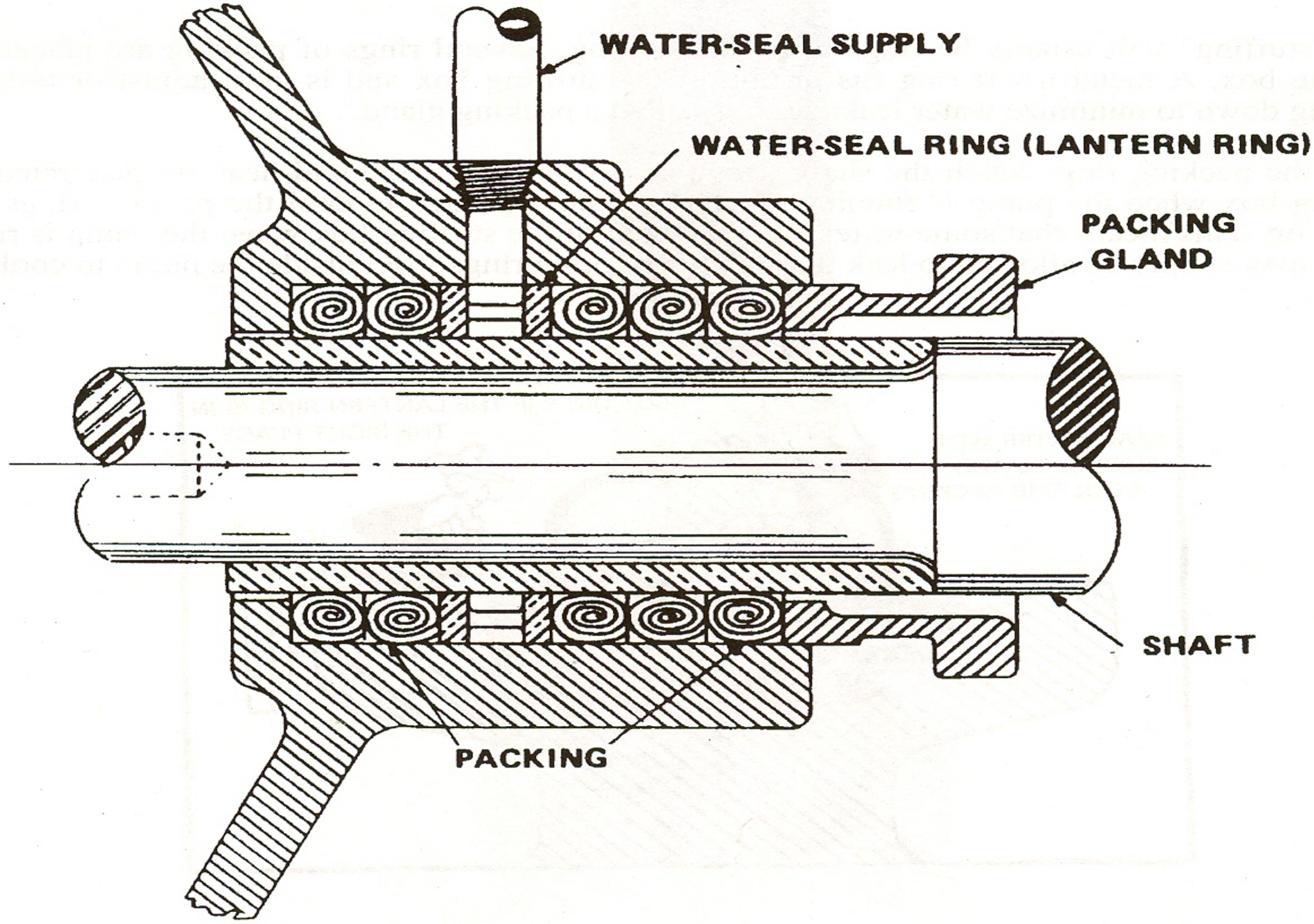


Seals

- Plugs hole where shaft enters pump body
- Keeps water in and air out of pump
- Stuffing box
  - Part of pump casing where shaft passes through
  - Contains several rings of packing
  - Want rings staggered to allow distribution of lubricating/ cooling water
- Packing gland
  - Metal ring on top of stuffing box
  - Used to put pressure on packing to minimize water leakage

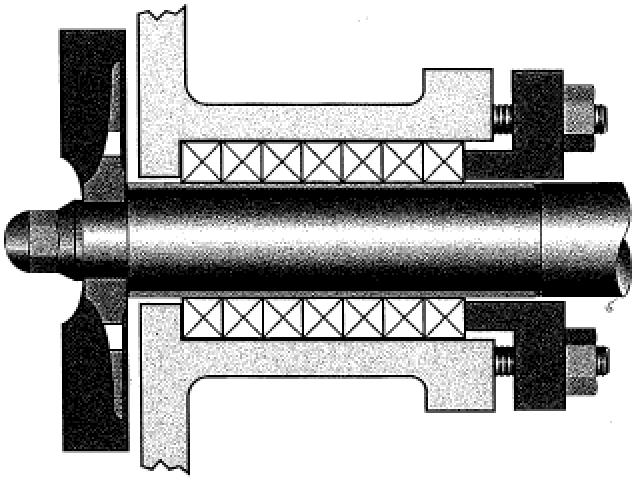
Seals (cont.)

- Seal water
  - Used to cool and lubricate the rings of packing
  - Can come from low pressure side (suction) of pump if sufficient pressure
  - Otherwise, pipe from discharge side (high pressure) of pump
  - Need air gap if mixing potable and nonpotable water
- Lantern ring
  - Used to direct water from seal water piping to inside of stuffing box where rings of packing are located around the shaft sleeve
  - Metal ring with holes
  - Water circulates around outside of ring and passes through the holes to get to packing

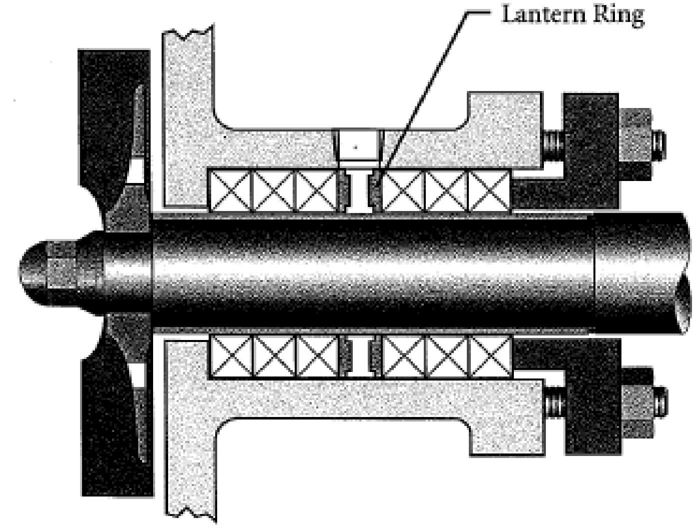


STUFFING BOX WITH LANTERN RING

Packing and Glands



Packing Solid



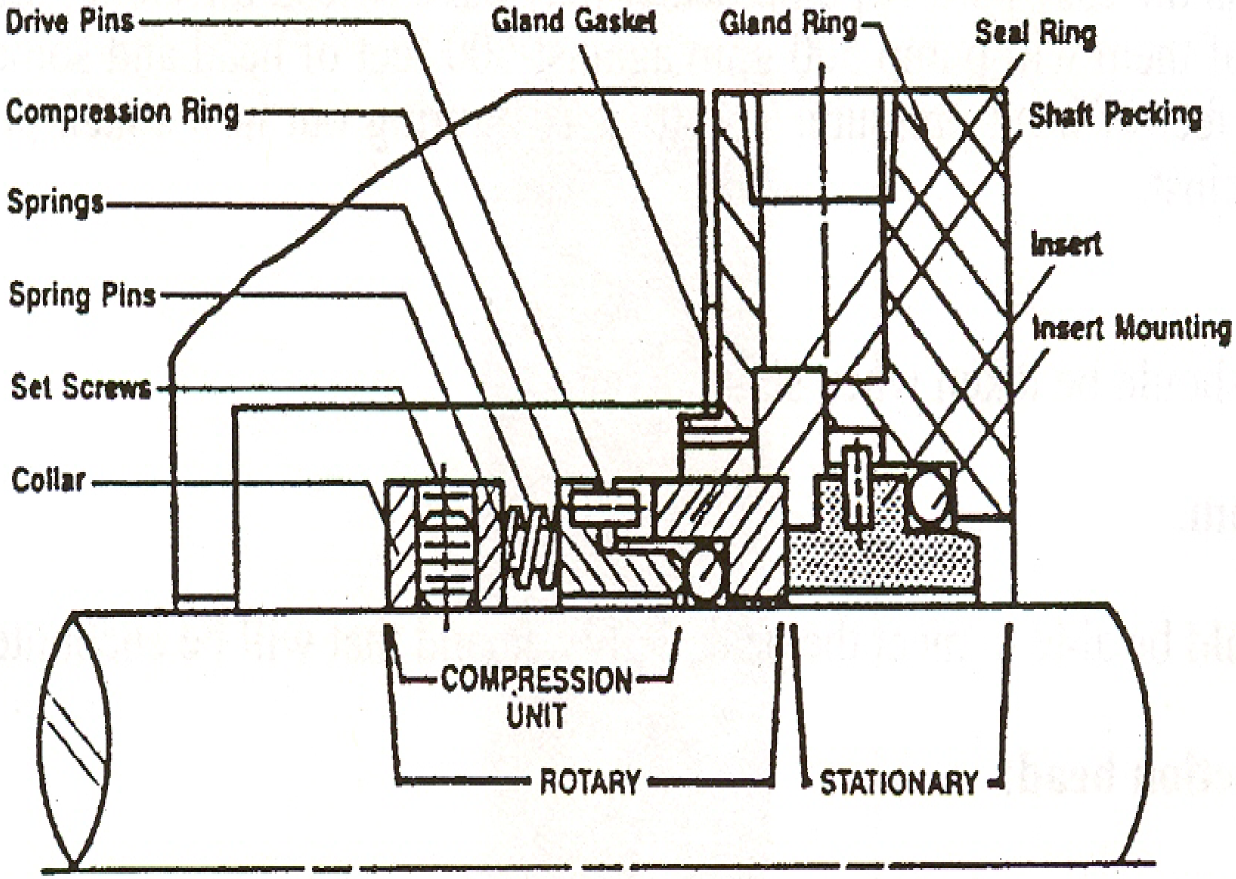
Packing with
Lantern Ring

Mechanical Seals

- Replace packing rings inside stuffing box
- Include two highly polished seal faces
  - One face is inserted in a gland ring
    - Gland ring replaces packing gland
  - Other seal face is attached to rotating shaft
    - Held in place on shaft with a locking collar
    - Collar includes spring-loaded assembly that pushes the two seal faces together when pump not running

Mechanical Seals (cont.)

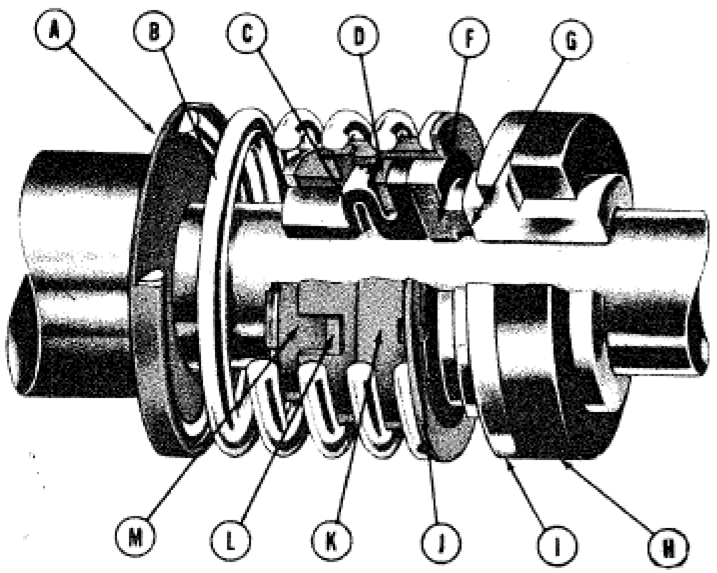
- Seal water (same criteria as for packing seals)
  - When pump running, seal water forces two seal faces apart
  - This closes gap and keeps water in and air out
  - Insufficient seal water pressure or no pressure will result in seal faces rubbing against each other and seal failure



MECHANICAL SEAL COMPONENTS

Mechanical Seal

SEAL PARTS DESCRIPTION

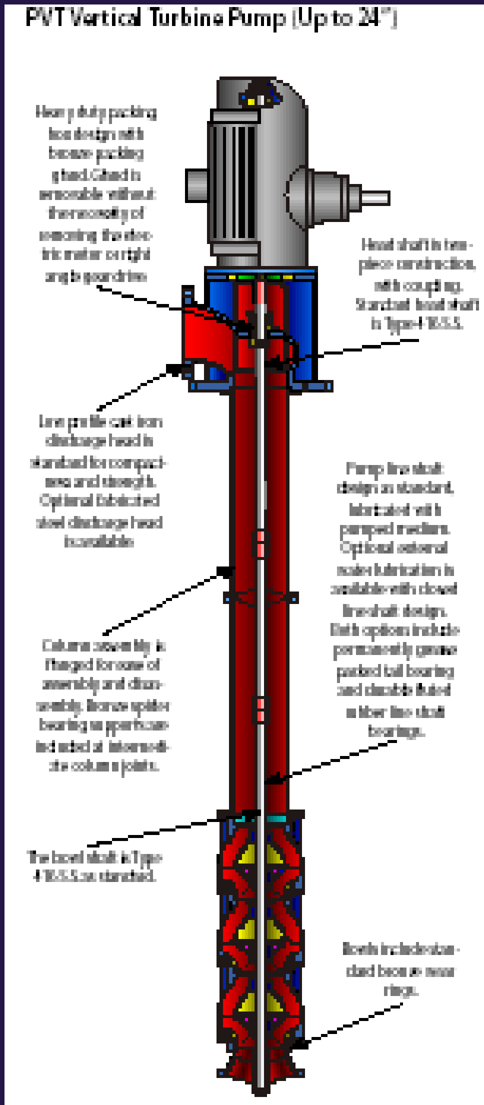


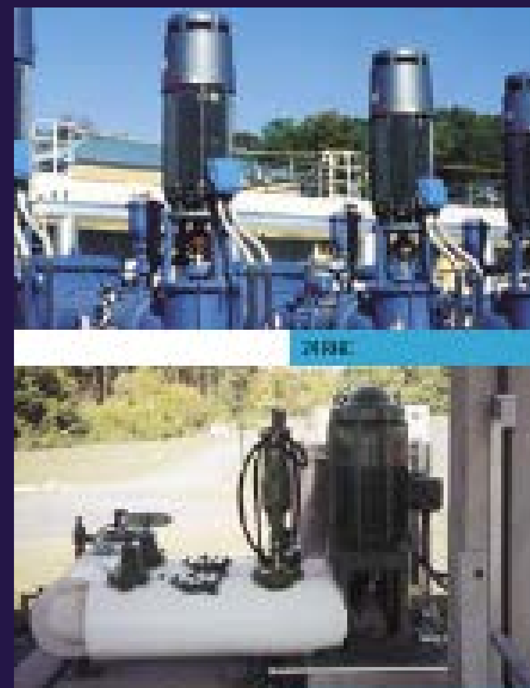
A Spring Holder
B Spring
C Synthetic Rubber Bellows
D Disc
F Sealing Washer
G Lapped Sealing Faces
H Seat Ring
I Stationary Floating Seat
J Washer Driving Notch
K Retainer
L Driving Band

Multi-Stage Pumps

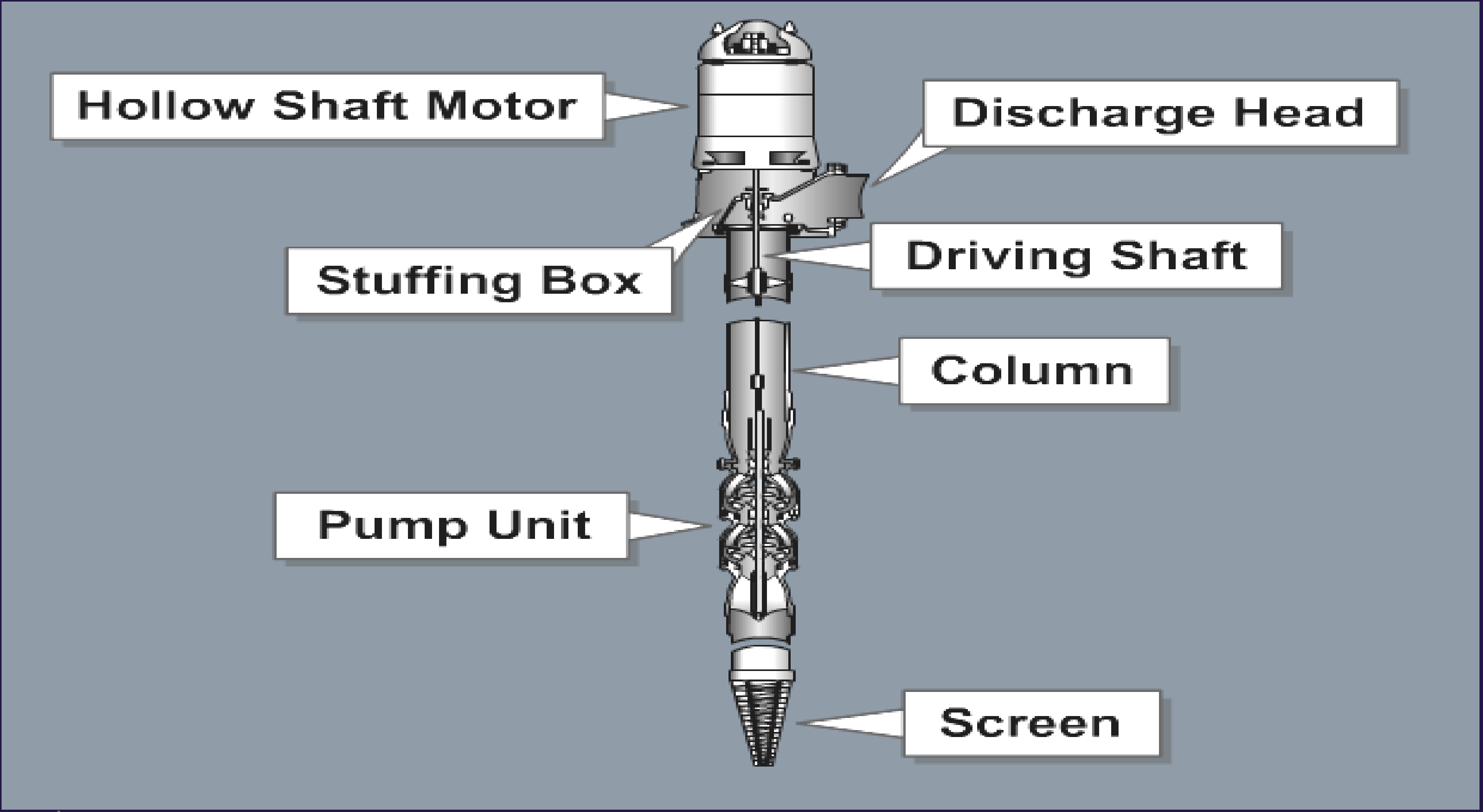
- Multiple impellers on single shaft
- Axial flow, not right angle
- Very high discharge pressure
  - Like putting single-impeller pumps in series
    - Flow does not change
  - Putting pumps in parallel changes flow, not pressure
- Examples
  - Line shaft turbines
  - Submersible turbines

Vertical Turbine



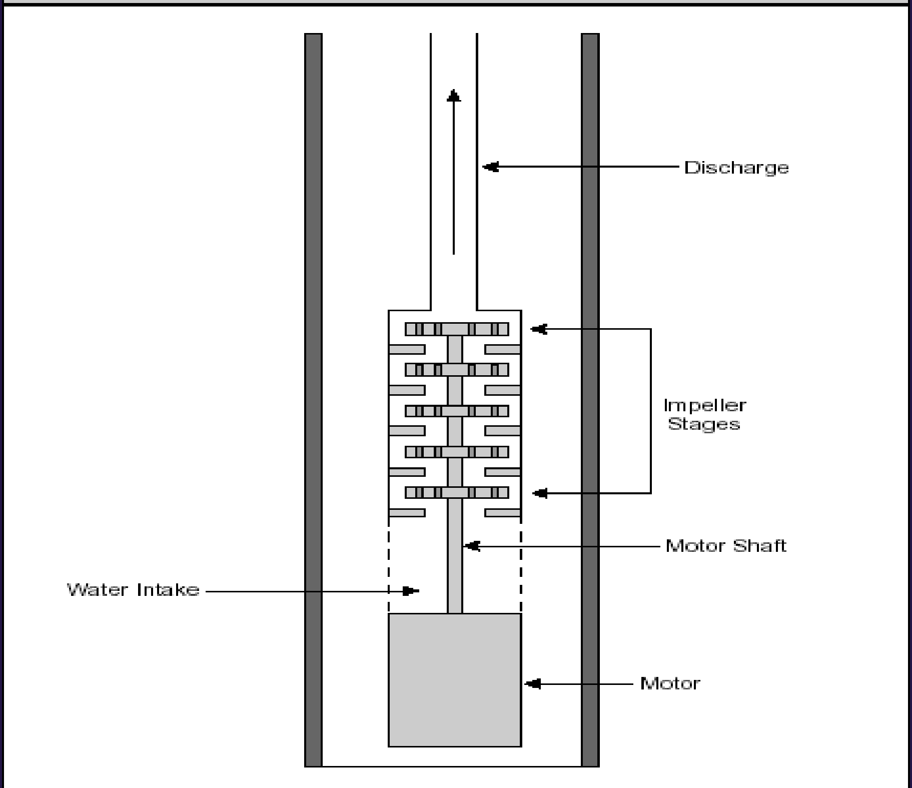


Vertical Turbine Anatomy



Submersible Pump Motor Assembly

Figure 2-3: Submersible Pump Elementary Overview Diagram



Pump Design and Hydraulics

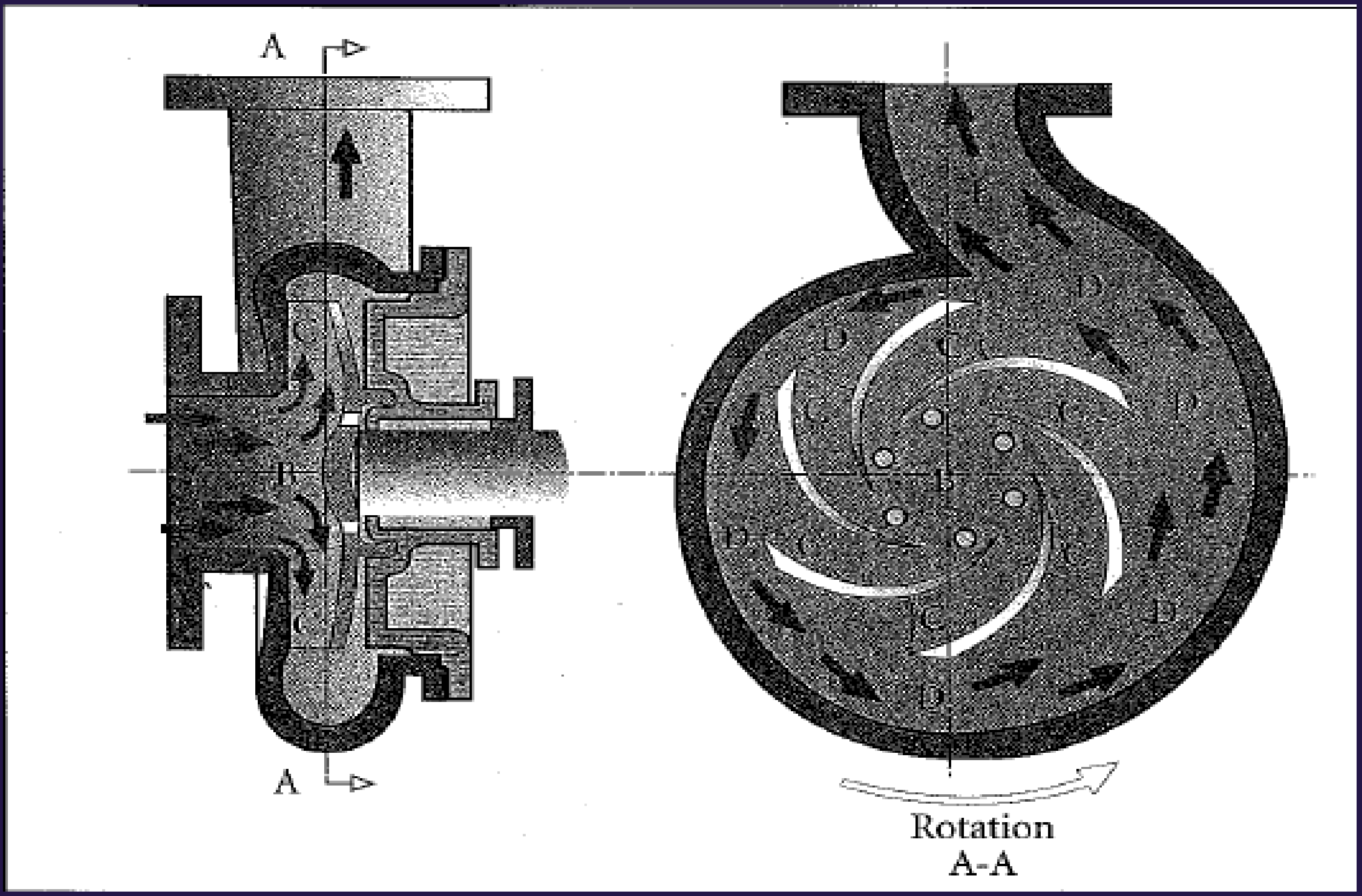
Terminology

- Flow rate
- Head
- Net positive suction head (NPSH)
- Pump efficiency
- Motor rpm
- Horsepower (hp)
- Electrical phases

Flow Rate

- The volume per time of water flow, typically measured in:
  - Gallons per minute (gpm)
  - Gallons per hour (gph)
  - Gallons per day (gpd)

End Suction Units



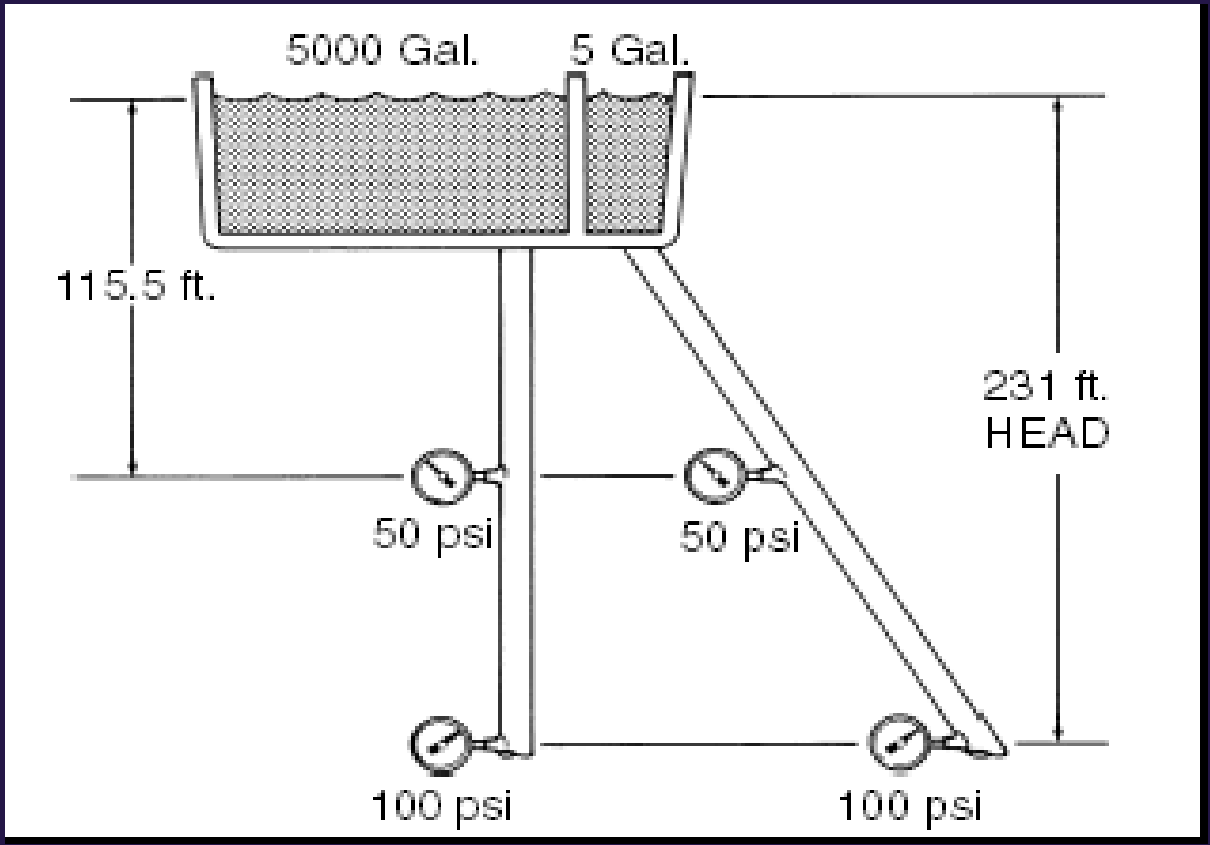
Pressure

- Pressure is a force based on weight per unit area
  – Measured in pounds per square inch (psi) or pounds per square foot (psf)
  – Exerted on the bottom of a container
  – Not related to the volume of the container or the size of the base
  – Only dependent on the height of the fluid in the container

Head

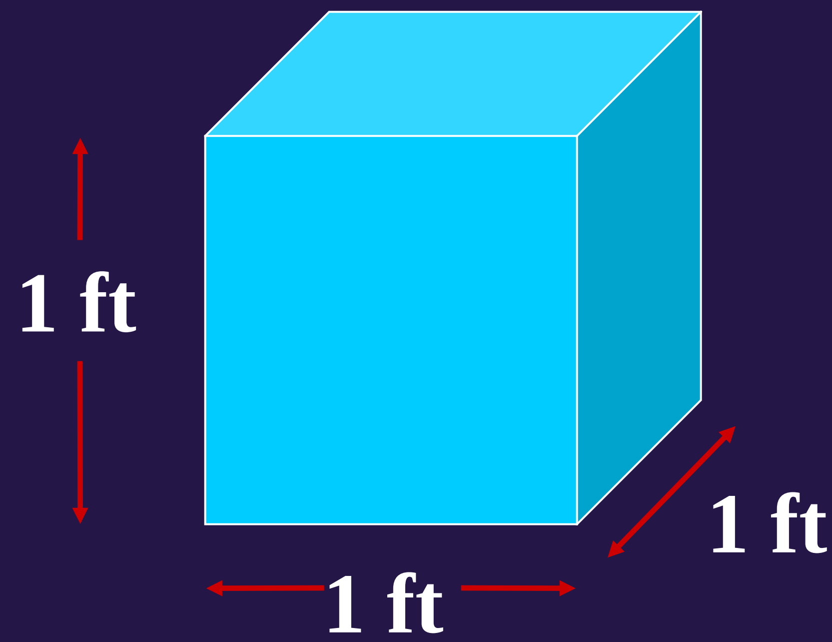
- The height of the fluid in a container
- Direct measurement in feet
- What exerts pressure

Pressure vs. Head



Relationship between Pressure and Head

- Weight of water is 62.4 pounds per cubic foot:
  - $7.48\ gal/ft^3 \times 8.34\ lb/gal = 62.4\ lb/ft^3$

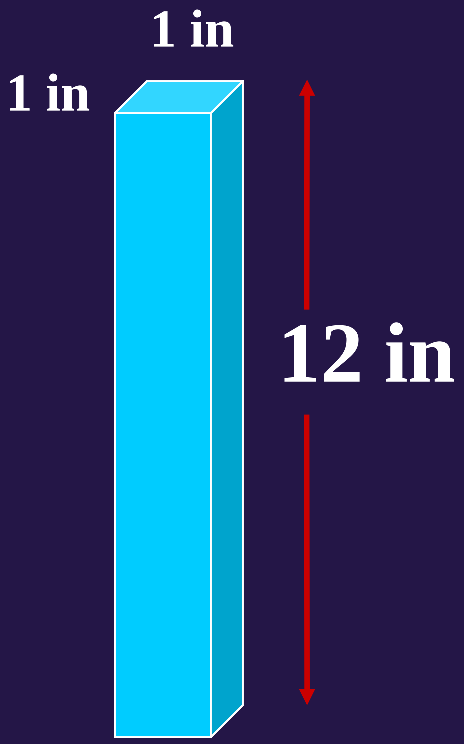


Pressure and Head

- Imagine a cube of water 1 ft x 1 ft x 1 ft. The surface area of any one side of the cube will be 144 in^2 (12 in. x 12 in.). The cube will also contain 144 columns of water 1 ft tall and 1 inch square.
- Weight = 62.4 lb/144 in^2

  = 0.433 psi
- 1 ft of head = 1 ft ÷ 0.433 psi

  = 2.31 ft/psi
- 1 ft = 0.433 psi and 1 psi = 2.31 ft



Remember these Conversion Factors

- psi x 2.31 ft/psi = ft
  - Example: 43.3 psi x 2.31 ft/psi = 100 ft
- ft x 0.433 psi/ft = psi
  - Example: 100 ft x 0.433 psi/ft = 43.3 psi

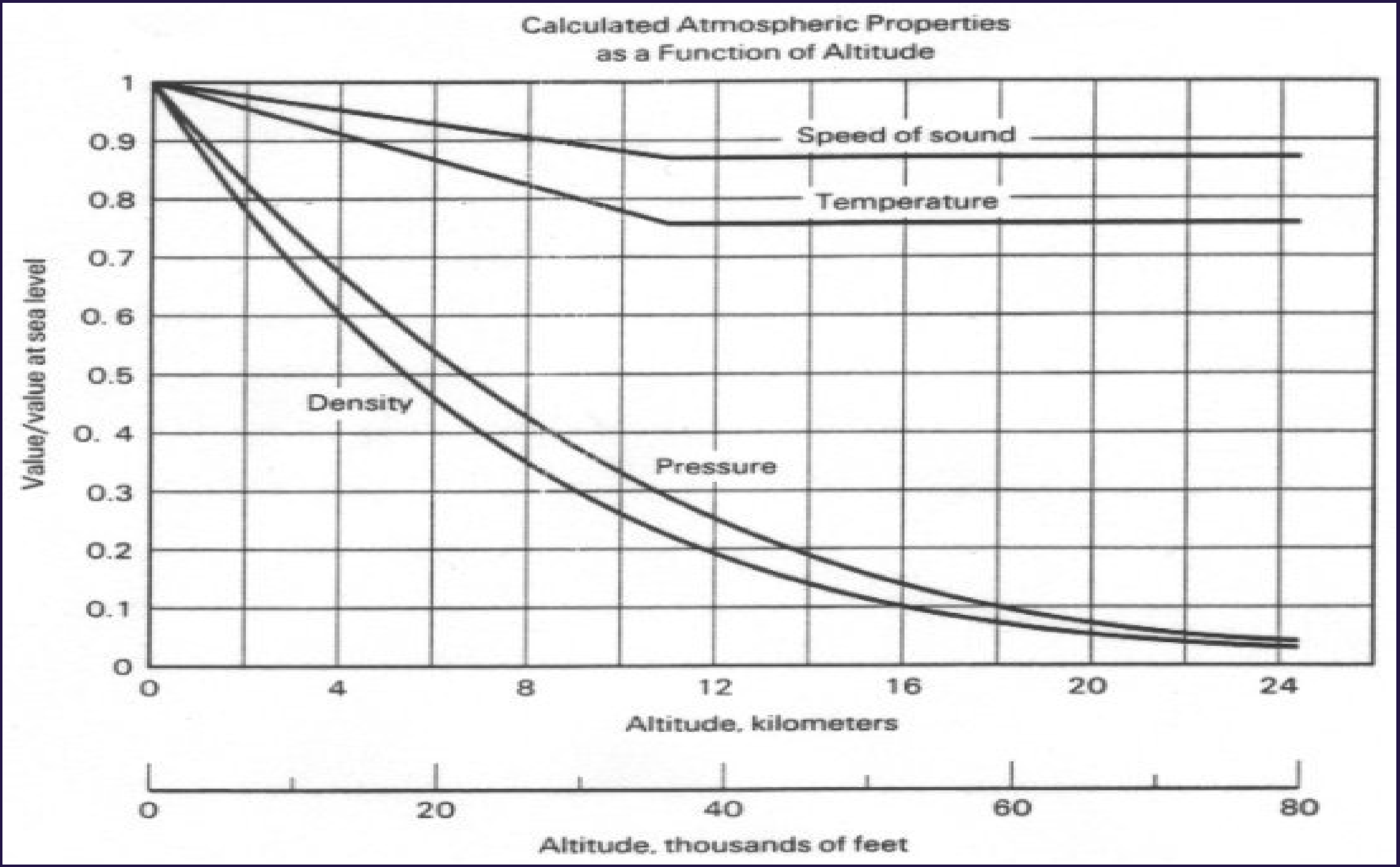
Gauge vs. Absolute Pressure

- psig common type measured within plant environment
  - Does not include effects of atmospheric pressure
    - P_{atm} = 14.7 psi = 33.9 ft = 34 ft (at sea level)
    - Maximum practical lift of a pump at sea level
  - psig = 0 means system is at atmospheric pressure
  - psig < 0 considered a vacuum for the system (still some value below atmospheric pressure)
    - Until psi < -14.7 psi, pressure due to atmosphere

Gauge vs. Absolute Pressure

- psia (absolute)
  - Usually used to describe a vacuum
  - Includes atmospheric pressure
  - psia = 0 means no pressure in system
  - psia < 0 absolute vacuum
- psia = psig + P_{atm}

Changes in Atmospheric Pressure with Height



Energy and Head

- Energy in water has four forms:
  - Elevation head (E_H): measured in feet as height above datum
  - Pressure (P) in psi: Pressure head (P_H) in ft = P x 2.31 ft/psi
  - Velocity (V) in fps
    - Velocity head (V_H) in ft = $V^2/2g$
    - g = gravitational acceleration = 32.2 ft/s^2
  - Head loss (H_L) in ft

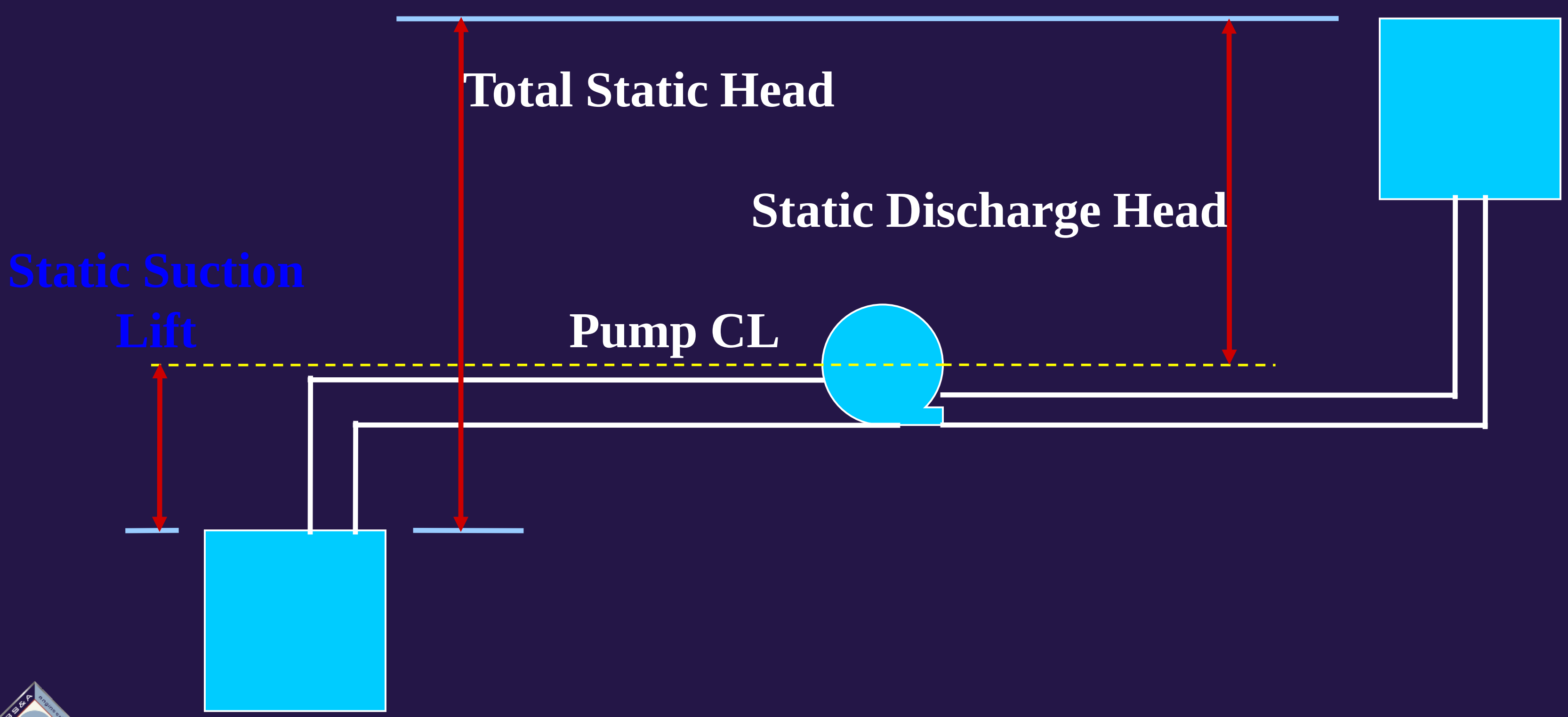
Energy and Head (cont.)

- Head loss (H_L) in ft
  - Caused by turbulence, friction
  - Creates heat energy, which is lost from system
  - Increases with smaller pipe diameter, higher flow, rougher pipe walls

Pump Systems and TDH

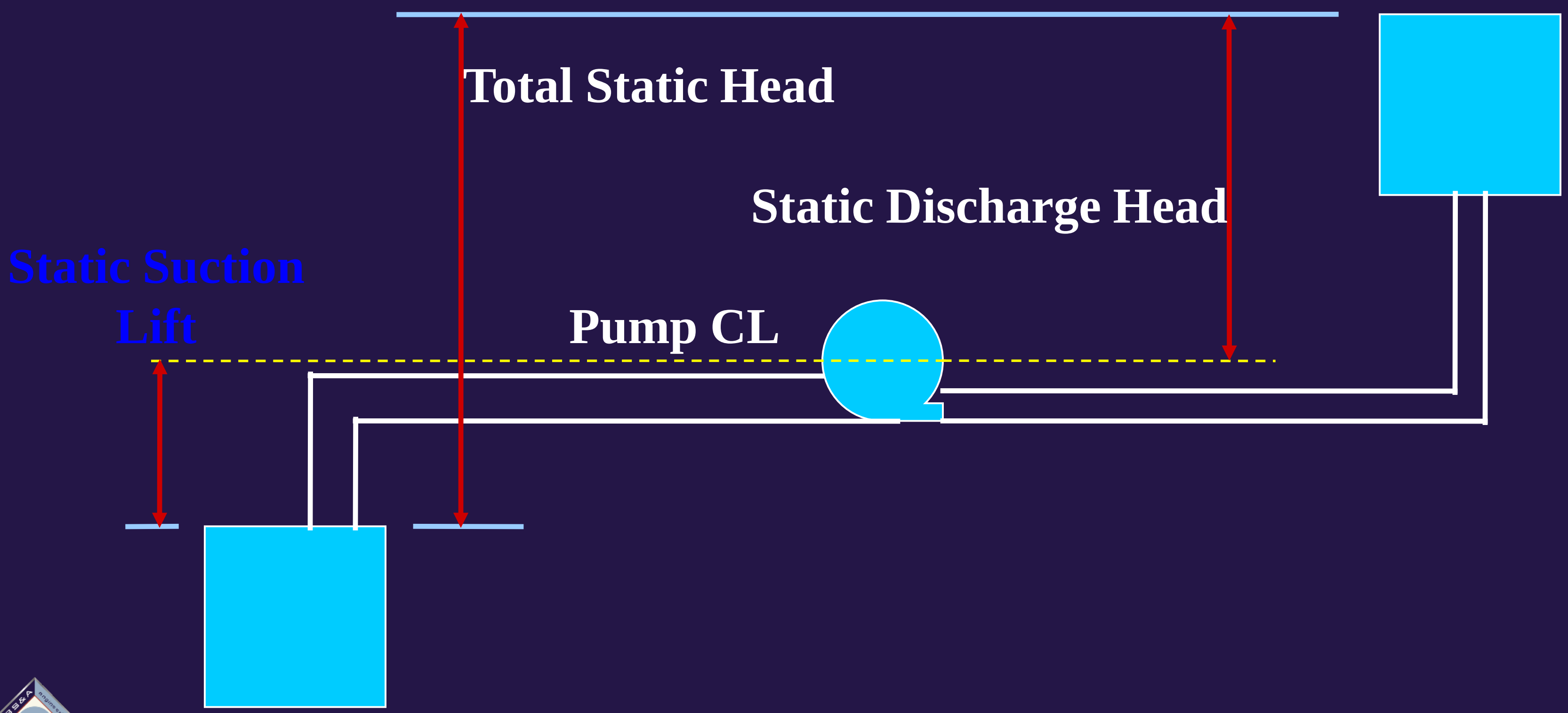
Static Suction Lift TDH

- Fluid level suction side below eye of pump impeller
- TDSL = static suction lift + V_{Hs} + H_{Ls}



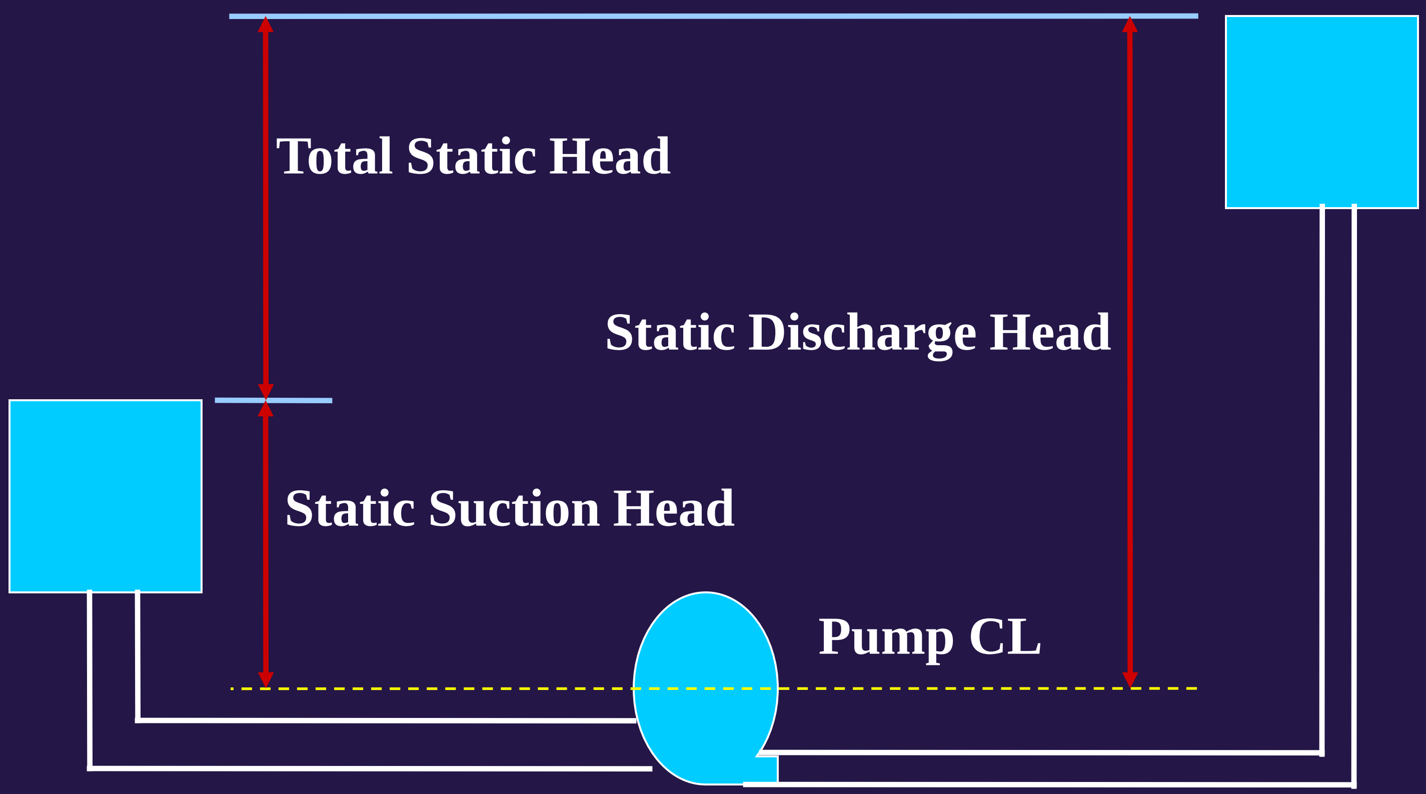
Static Suction Lift TDH (cont.)

- TDDH = static discharge head + V_{Hd} + H_{Ld}
- TDH = SSL + V_{Hs} + H_{Ls} + SDH + V_{Hd} + H_{Ld}



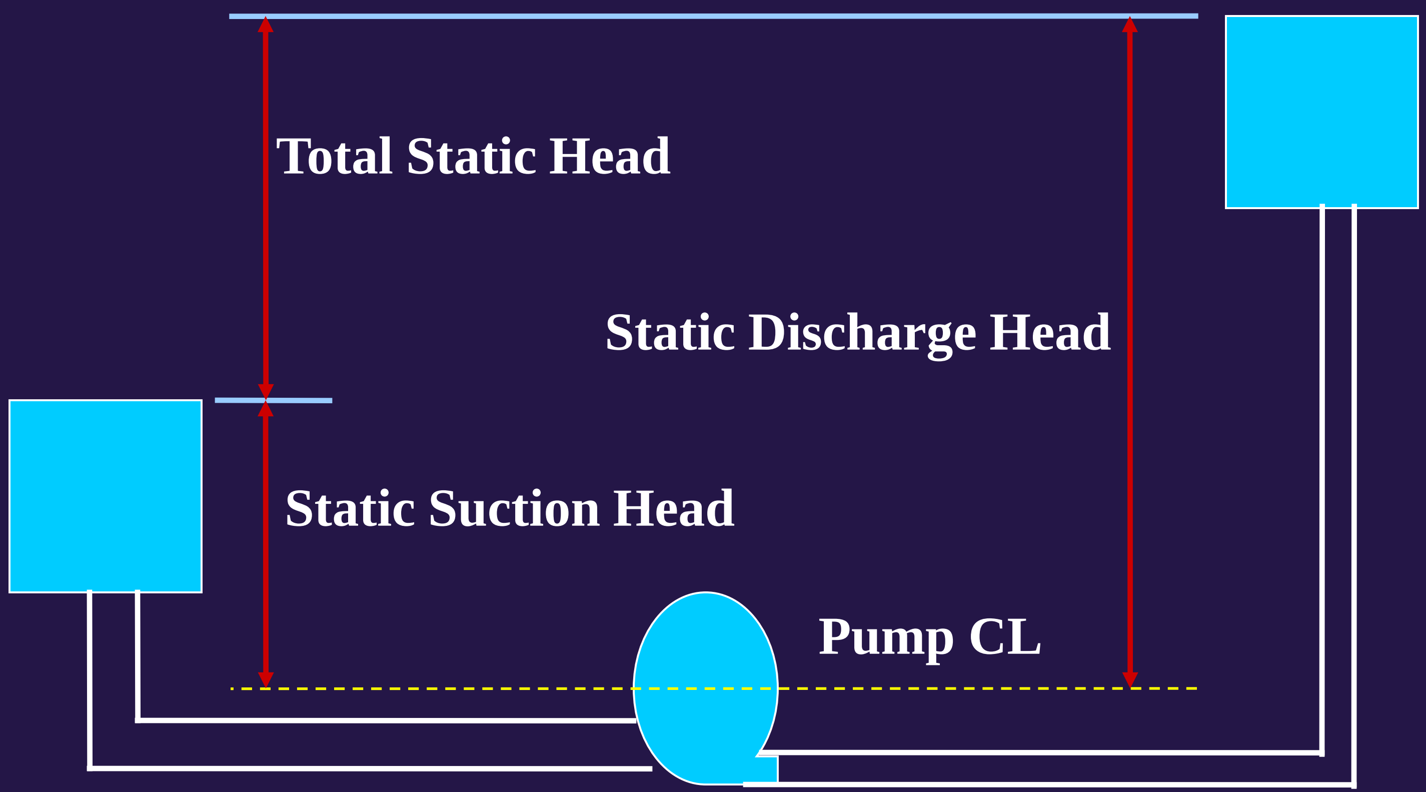
Static Suction Head TDH

- Fluid level suction side above eye of pump impeller
- TDSH = static suction head + P_{atm} - V_H - H_L



Static Suction Head TDH (cont.)

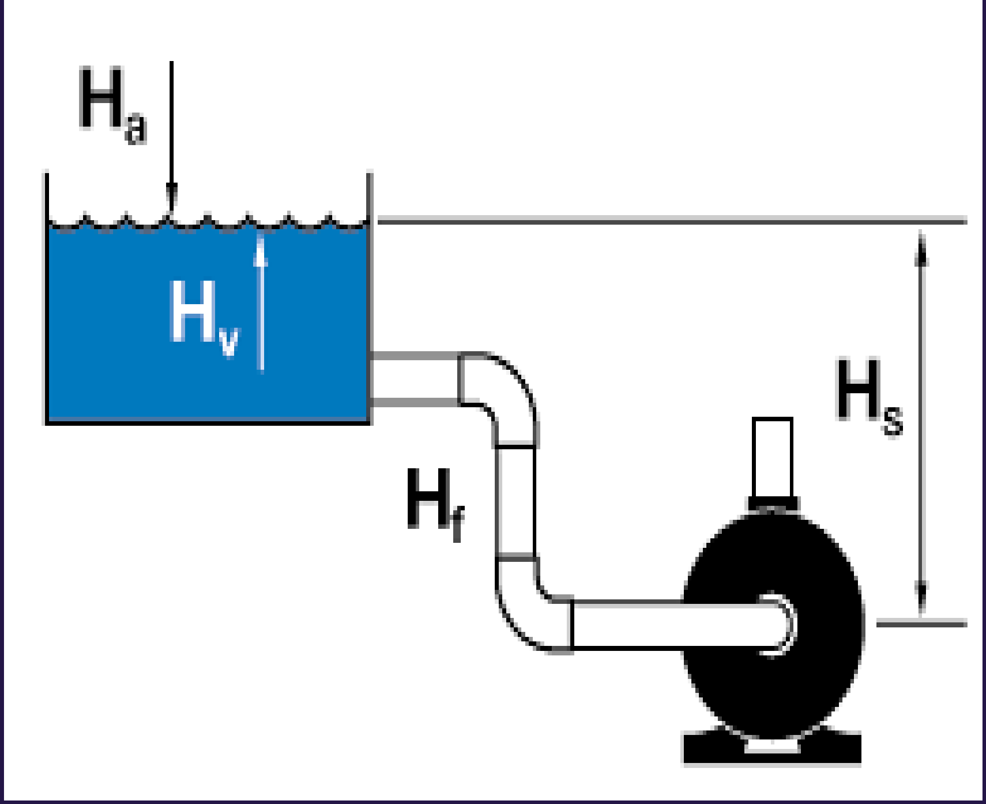
- TDDH = static discharge head + V_{Hd} + H_{Ld}
- TDH = SDH - SSH + V_{Hs} + H_{Ls} + V_{Hd} + H_{Ld}



Net Positive Suction Head - NPSH

NPSH Available:
the amount by which suction head exceeds liquid vapor pressure

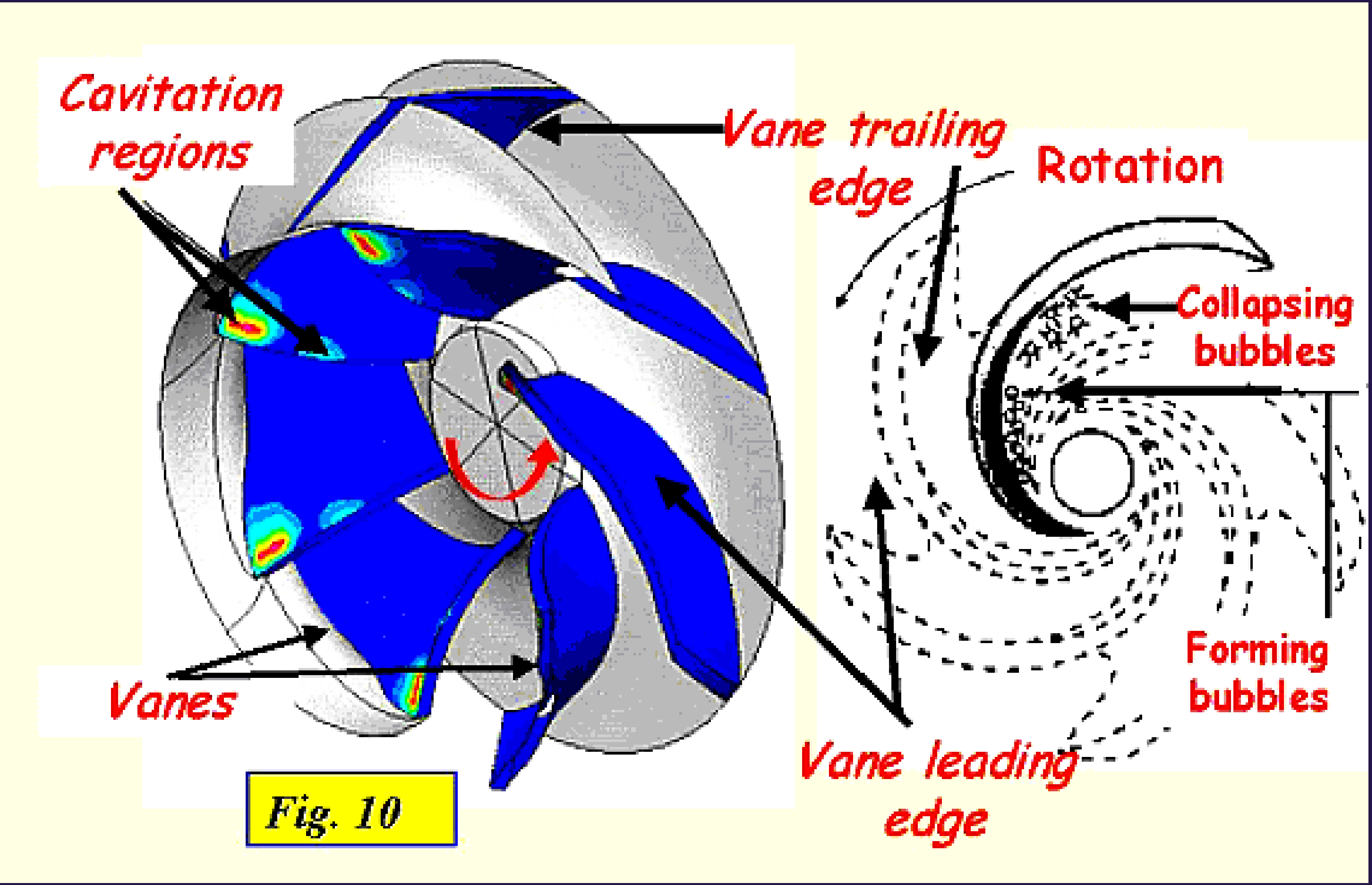
NPSH Required:
suction head needed to avoid ***cavitation***



When NPSH Is Insufficient…

- **Cavitation** or **vaporization** occurs where bubbles form inside pump
- The following problems occur when vapor bubbles collapse:
  - Erosion of vane surfaces
  - Increased noise and vibration
  - Choking of impeller passages

Impeller Cavitation Areas



Cavitation Damage

Net Positive Suction Head (NPSH)

- The total energy available to move water into the volute and the eye of the impeller
- At sea level, NPSH = 1 atm = 14.7 psi = 34 ft
- However, this energy is reduced by:
  - Static suction lift (biggest factor)
  - Velocity head (V_H) to get water moving
  - Head loss (H_L)
  - Vapor pressure (based on temperature)
    - Portion of water evaporates when placed under a vacuum (at the eye of impeller)

Net Positive Suction Head (cont.)

- NPSHR = net positive suction head required
- NPSHA = net positive suction head available
- For suction lift condition:
  - $NPSH = P_{atm} - P_V - \text{static suction lift} - H_L$
- For suction head condition:
  - $NPSH = \text{static suction head} + P_{atm} - P_V - H_L$

Relationship between Temperature, Vapor Pressure and Boiling Point

Temperature (˚F)	Vapor Pressure (ft)
32	0.204
59	0.565
68	0.774
100	2.17
150	8.56
200	26.45
212	????

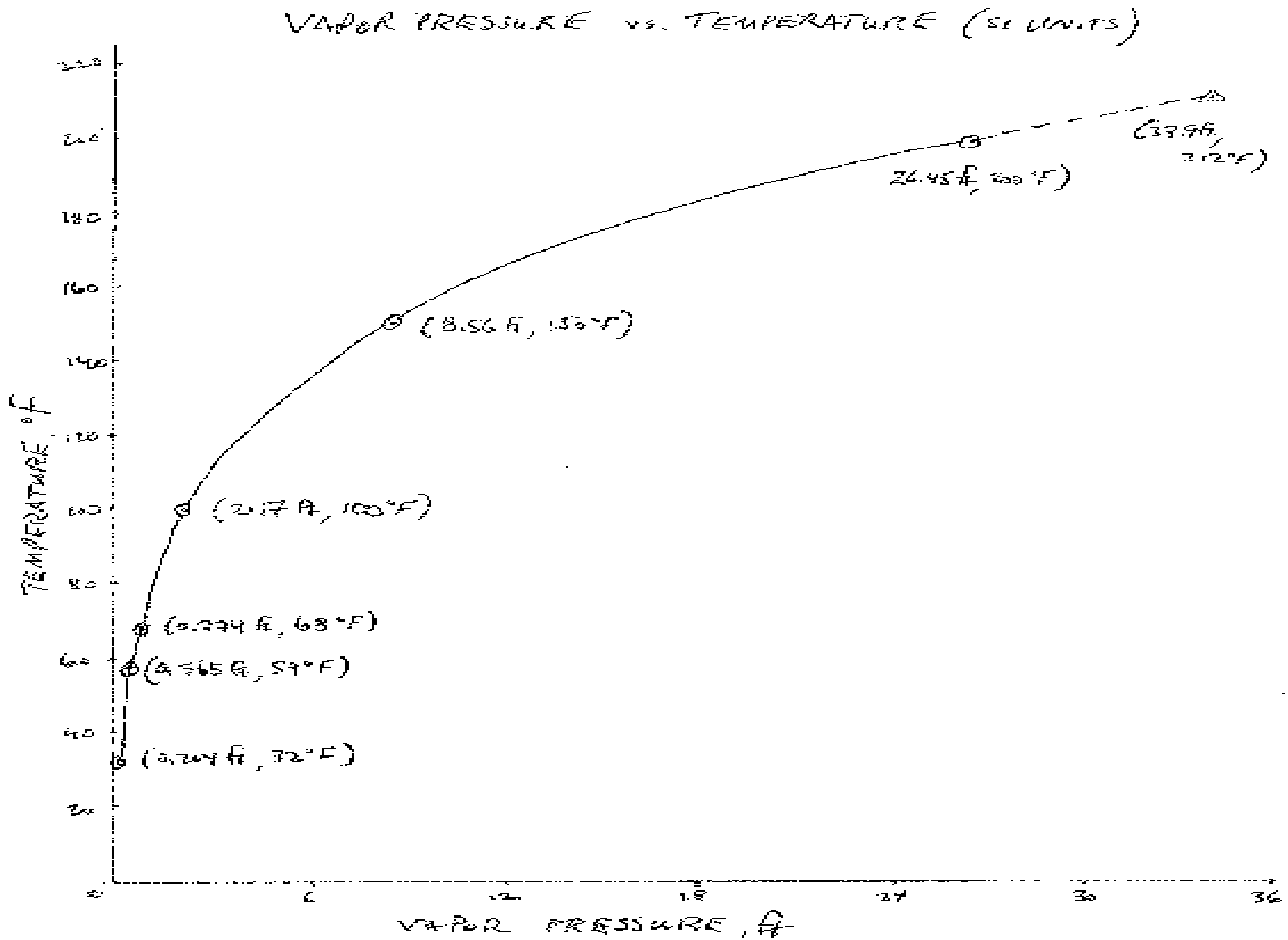

VAPOR PRESSURE vs. TEMPERATURE (SI UNITS)
TEMPERATURE °F
VAPOR PRESSURE, ft
(33.9 ft, 212°F)
(26.45 ft, 200°F)
(8.56 ft, 150°F)
(2.17 ft, 100°F)
(0.774 ft, 68°F)
(0.565 ft, 59°F)
(0.204 ft, 32°F)
0
6
12
18
24
30
36
20
40
60
80
100
120
140
160
180
200

Table 2-15: Altitude vs. Barometric Pressure and Boiling Point of Water

Altitude		Barometer Reading		Atm. Pressure		Boiling Point
Feet (ft.)	Meters (m)	in.-Hg	mm-Hg	psia	ft. Water	°F
0	0.0	29.9	760	14.7	33.9	212.0
+ 500	+ 152.4	29.4	747	14.4	33.3	211.1
1000	304.8	28.9	734	14.2	32.8	210.2
4000	1219.2	25.8	655	12.7	29.2	204.7
4500	1371.6	25.4	645	12.4	28.8	203.8
5000	1524.0	24.9	633	12.2	28.2	202.9
5500	1676.4	24.4	620	12.0	27.6	201.9
6000	1828.8	24.0	610	11.8	27.2	201.0
6500	1981.2	23.5	597	11.5	26.7	200.1
7000	2133.6	23.1	587	11.3	26.2	199.2
7500	2286.0	22.7	577	11.1	25.7	198.3
8000	2438.4	22.2	564	10.9	25.2	197.4
8500	2590.8	21.8	554	10.7	24.7	196.5
9000	2743.2	21.4	544	10.5	24.3	195.5
9500	2895.6	21.0	533	10.3	23.8	194.6
10000	3048.0	20.6	523	10.1	23.4	193.7
15000	4572.0	16.9	429	8.3	19.2	184.0

Total Dynamic Head (TDH)

- Influenced by:
  - Pipe type/material
  - Pipe age and condition
  - Pipe diameter
  - Pipe length
  - Flow rate & velocity
  - Pipe network configuration
    - Number and type of fittings
    - Enlargements and contractions
    - Changes in direction

Total Dynamic Head (TDH)

- Increases with:
  - Pipe roughness
  - Pipe age (typically)
  - Decreasing pipe diameter
  - Pipe length
  - Flow rate & velocity
  - Pipe network configuration
    - Number and type of fittings
    - Enlargements and contractions
    - Changes in direction

Total Dynamic Head (TDH)

- Total energy in ft required to move water from fluid level suction side to fluid level discharge side
  - Combination of E_H, V_H, and H_L of suction and discharge lines
  - V_H discharge side > V_H suction side due to reduced diameter of discharge piping
- Total dynamic suction lift (TDSL)
  - Fluid level suction side below eye of impeller
  - TDSL = static suction lift + V_H + H_L
  - Compare to net positive suction head (NPSH): energy required to move water into volute or impeller eye

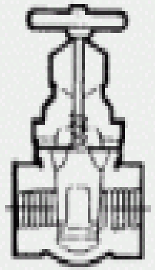
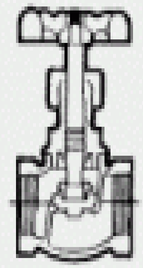
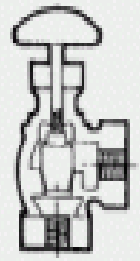
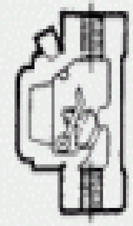
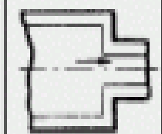
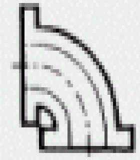
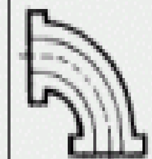
Total Dynamic Head (cont.)

- Net positive suction head
  - Available NPSH = P_{atm} - P_V - static suction lift - H_L
  - Check pump curve to compare available vs. required NPSH
- Total dynamic suction head (TDSH)
  - Fluid level suction side above eye of impeller
  - NPSH = static suction head + P_{atm} - P_V - H_L
  - Pump choice OK if static suction head ≥ NPSH required
  - TDSH = static suction head + P_{atm} - V_H - H_L

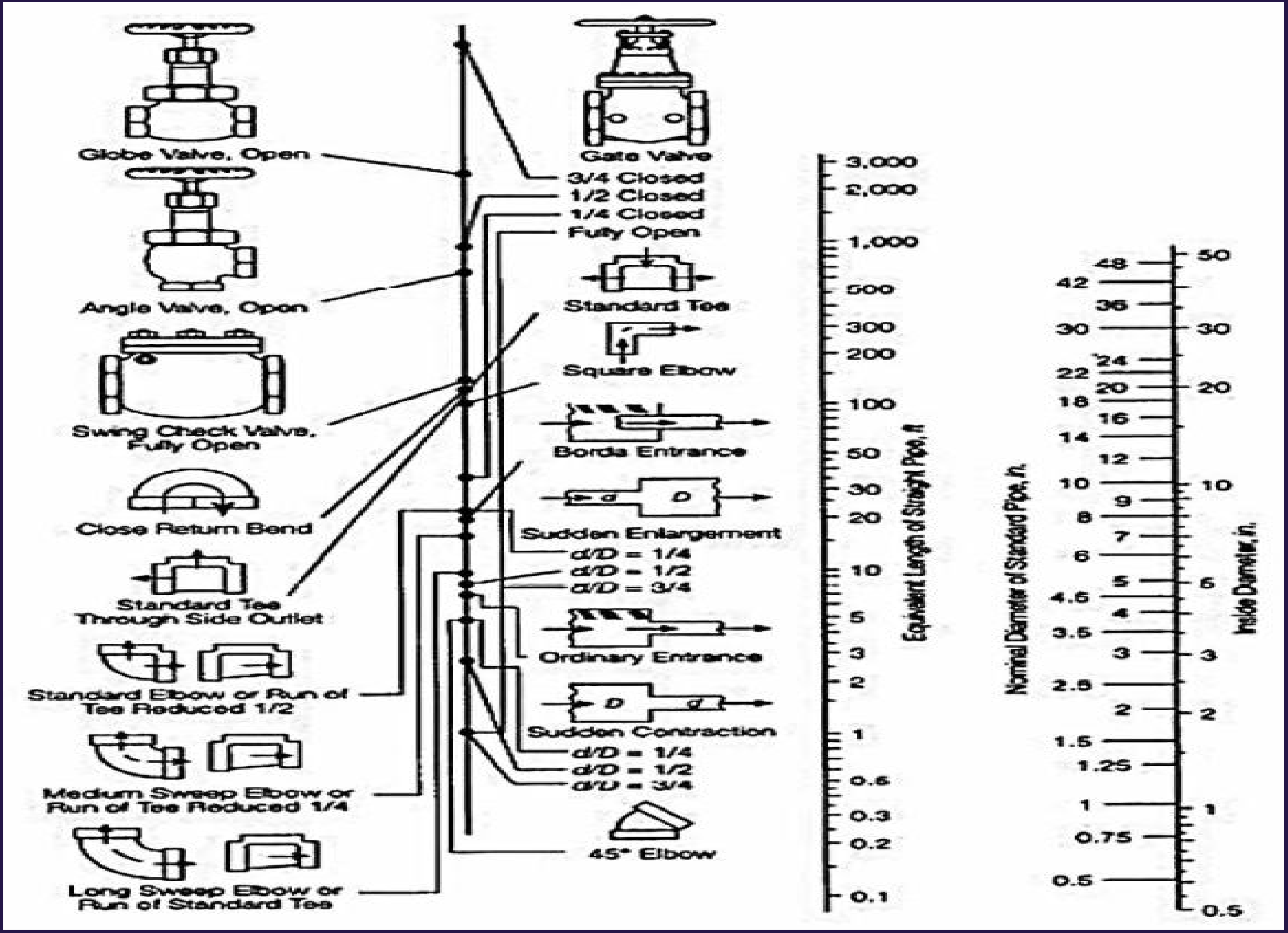
VELOCITY CHART & FRICTION OF WATER

(new steel pipe) at 60° F						
1 INCH						
	STANDARD WEIGHT STEEL - SCH. 40			EXTRA STRONG STEEL - SCH. 80		
	1.049" Inside Diameter			.957" InsideDiameter		
FLOW U.S. GPM	VELOCITY (Ft./Sec.)	VELOCITY (Head Ft.)	**HEAD LOSS (Ft./100 Ft.)**	VELOCITY (Ft./Sec.)	VELOCITY (Head Ft.)	**HEAD LOSS (Ft./100 Ft.)**
2	0.74	.009	**.385**	.89	.01	**.599**
3	1.11	.019	**.787**	1.34	.03	**1.19**
4	1.48	.034	**1.270**	1.79	.05	**1.99**
5	1.86	.054	**1.90**	2.23	.08	**2.99**
6	2.23	.077	**2.65**	2.68	.11	**4.17**
8	2.97	.137	**4.50**	3.57	.20	**7.11**
10	3.71	.214	**6.81**	4.46	.31	**10.80**
12	4.45	.308	**9.58**	5.36	.45	**15.20**
14	5.20	.420	**12.80**	6.25	.61	**20.40**
16	5.94	.548	**16.50**	7.14	.79	**26.30**
18	6.68	.694	**20.60**	8.03	1.00	**32.90**
20	7.42	.857	**25.20**	8.92	1.24	**40.30**
22	8.17	1.036	**30.30**	9.82	1.50	**48.40**
24	8.91	1.23	**35.80**	10.70	1.80	**57.20**
26	9.65	1.45	**41.70**	11.60	2.10	**66.80**
28	10.39	1.68	**48.10**	12.50	2.40	**77.10**
30	11.10	1.93	**55.00**	13.40	2.80	**88.20**
35	13.00	2.62	**74.10**	15.60	3.80	**119.00**
40	14.80	3.43	**96.10**	17.90	5.00	**154.00**
45	16.70	4.33	**121.00**	20.10	6.30	**194.00**

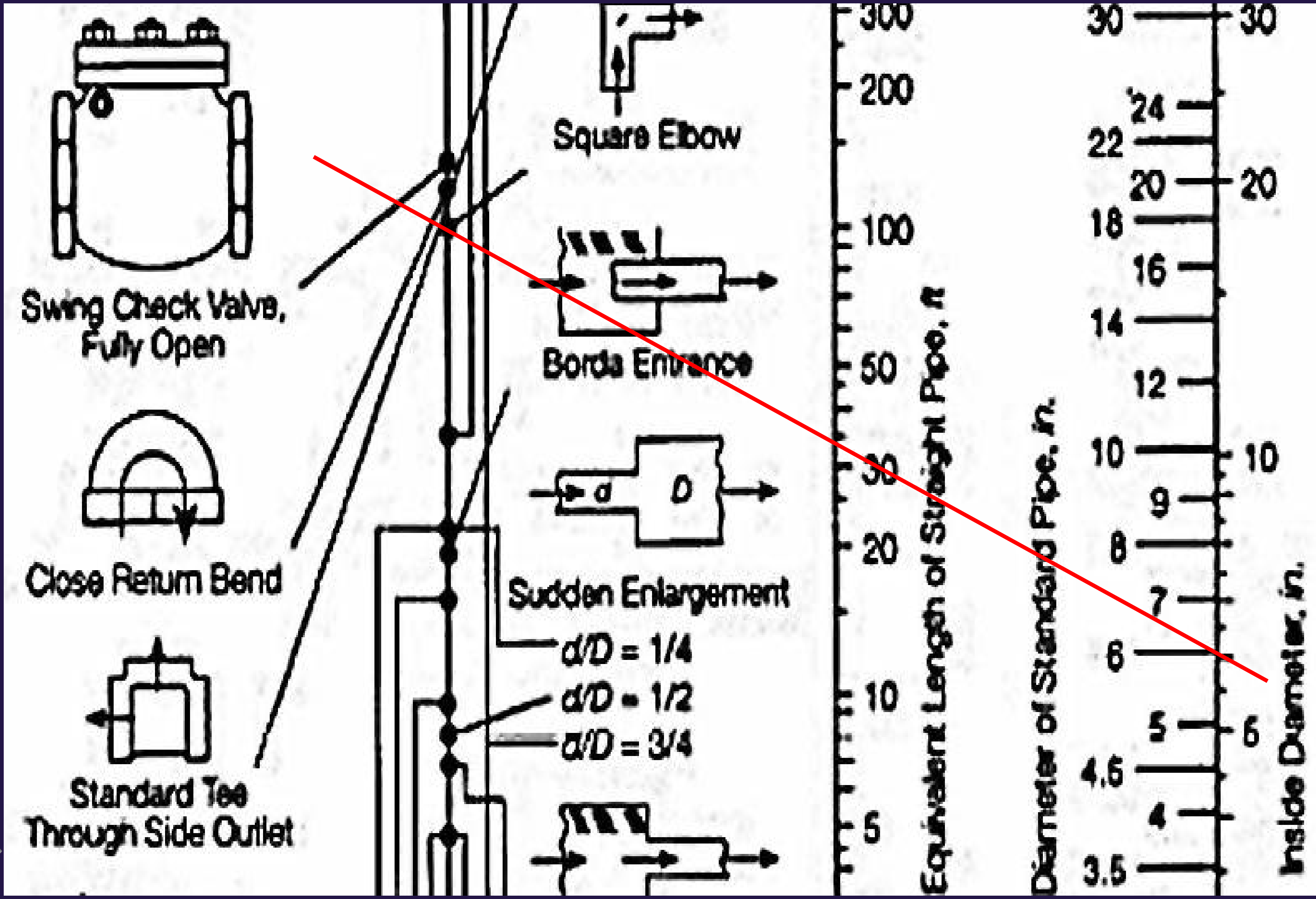
FRICTION LOSSES THROUGH PIPE FITTINGS & VALVES

	 GATE VALVE										
SIZE OF PIPE (Inches)	WIDE OPEN	1/4 CLOSED	1/2 CLOSED	3/4 CLOSED	GLOBE VALVE-WIDE OPEN	ANGLE VALVE-WIDE OPEN	CHECK VALVE-WIDE OPEN	ORDINARY ENTRANCE TO PIPE LINES	STD. 90° ELBOW	MEDIUM SWEEP 90° ELBOW	LONG SWEEP 90° ELBOW
STRAIGHT PIPE IN FEET (EQUIVALENT LENGTH)											
1/8"	.14	.85	5.00	19.00	9.00	5.00	2.00	.46	.74	.65	.50
1/4"	.21	1.25	7.00	26.00	12.00	6.00	3.00	.60	1.00	.86	.70
3/8"	.27	1.80	9.00	36.00	16.00	8.00	4.00	.75	1.40	1.15	.90
1/2"	.41	2.10	12.00	44.00	17.60	7.78	5.18	.90	1.60	1.55	1.10
3/4"	.55	2.90	14.00	59.00	23.30	10.30	6.86	1.40	2.30	2.06	1.50
1"	.70	3.40	18.00	70.00	29.70	13.10	8.74	1.60	2.70	2.62	2.00
1-1/4"	.92	4.80	24.00	96.00	39.10	17.80	11.50	2.50	3.60	3.45	2.50
1-1/2"	1.07	5.60	28.00	116.00	45.60	20.10	13.40	3.00	4.50	4.03	2.90
2"	1.38	7.00	36.00	146.00	58.60	25.80	17.20	3.50	5.40	5.17	3.60
2-1/2"	1.65	8.40	41.00	172.00	70.00	30.90	20.60	4.00	6.50	6.17	4.40
3"	2.04	10.00	52.00	213.00	86.90	38.40	25.50	5.00	8.50	7.67	5.50
3-1/2"	2.10	12.50	60.00	246.00	100.00	52.00	24.00	5.50	10.0	8.50	6.30
4"	2.40	14.00	70.00	285.00	116.00	57.00	27.00	6.50	12.0	9.50	7.20

Hazen-Williams H_L Nomograph



Hazen-Williams H_L Nomograph



Pumps, Motors and Energy

Mechanical Power

- Expressed as horsepower (hp).
- The amount of work required to lift 1 lb to the height of 1 ft is defined as 1 ft-lb.
- 1 hp is the theoretical power required to lift 33,000 lb to a height of 1 ft in 1 minute.
  - 1 hp = 33,000 ft-lb/min
  - 1 hp = 550 ft-lb/s

Electrical Power

- Measured in hp, watts (W) or kilowatts (kW)
- 1,000 W = 1 kW = 1.34 hp
- 1 hp = 746 W = 0.746 kW

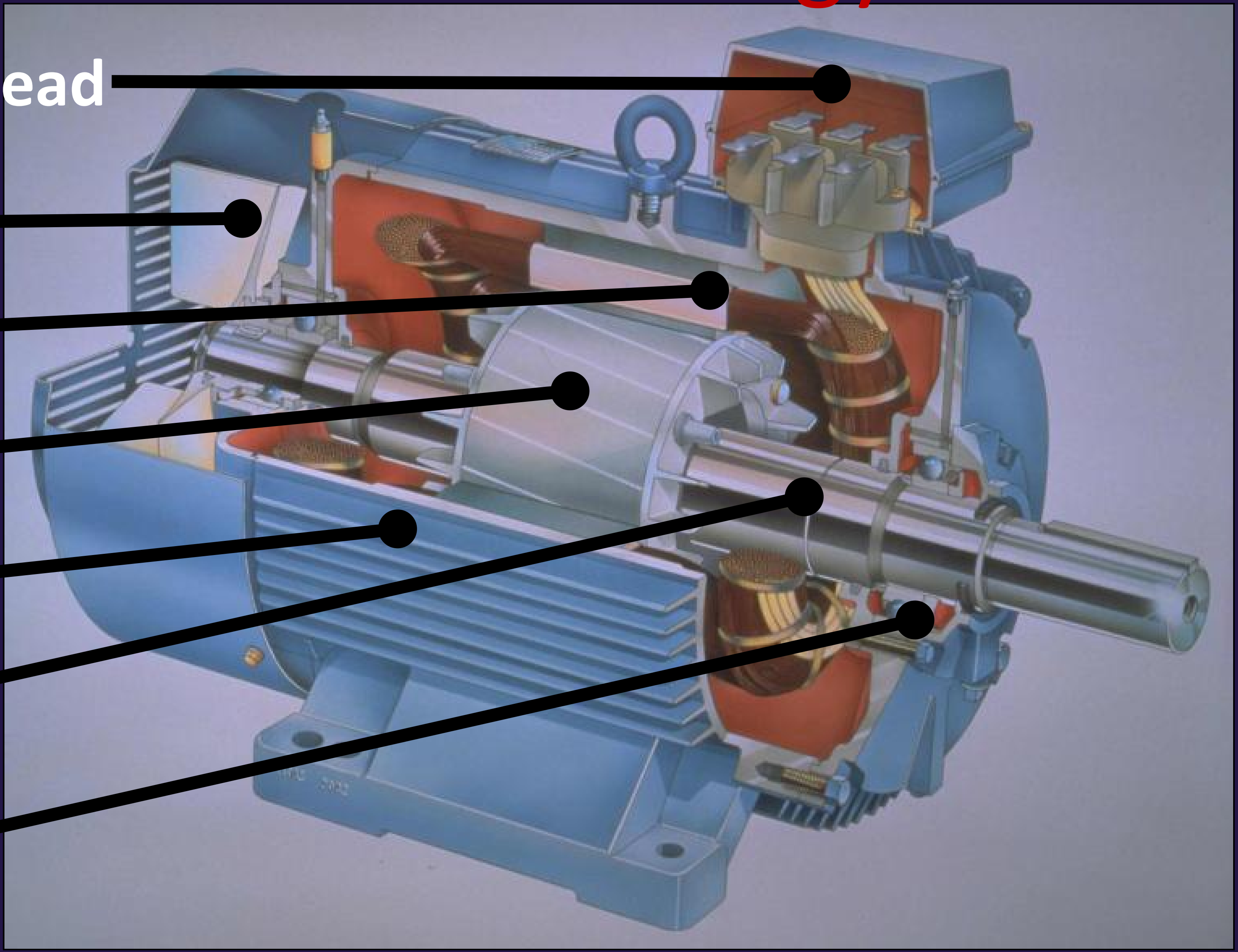
Electrical Power (cont.)

- Single-phase: 115 or 230 volt AC consisting of three legs (hot, neutral, and ground). Normally requires a starting circuit (relays and capacitors).
- Three-phase: 208/230/460 volt AC consisting of three hot legs and a ground. Possible to reverse rotation by changing any two legs. Balancing phase is important to life.

Motor RPM

- rpm = revolutions per minute
- 2-pole motors rated for 3500 rpm
- 4-pole motors rated for 1750 rpm

Motor Terminology



Common Motor Types, NEMA Frame Types

- **TEFC** (Totally Enclosed Fan Cooled)
- **TENV** (Totally Enclosed Non-Ventilated)
- **TEAO** (Totally Enclosed Air Over)
- **TEXP** (Totally Enclosed Explosion-Proof)
- **ODP** (Open Drip-Proof)
- **C-Face**

Motors

General Purpose TEFC

- Single and Three Phase
- 1/12 Hp thru 600 Hp stock, to 800 Hp custom
- Foot and Face Mount
- Enclosures: TEFC and TENV
- Low and medium voltage including 200V and 575V

Single Phase

- Single Phase
- 1/12 thru 15 Hp stock
- Enclosures TEFC, TENV and ODP
- Foot or face mount

Two Speed

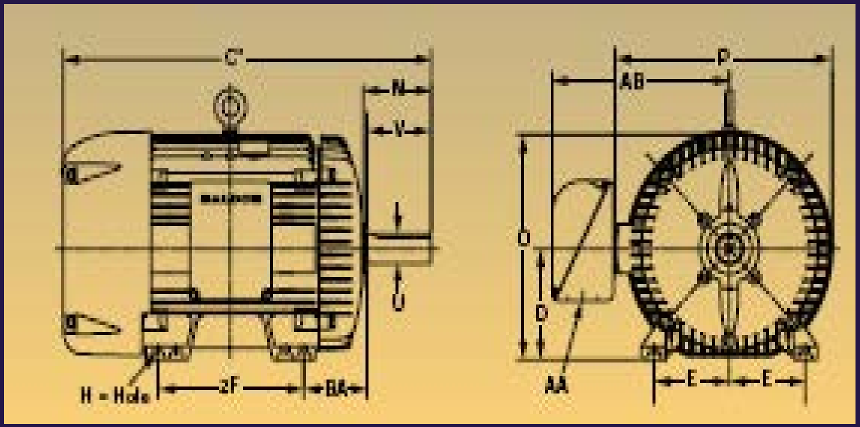
- Three Phase
- 1/12 Hp thru 25 Hp stock, 1000 Hp custom
- Enclosures: TEFC, OPEN and OPSB

General Purpose ODP

- Single and Three Phase
- 1/12 Hp thru 600 Hp stock, to 1500 Hp custom
- Foot and Face Mount
- Enclosures: ODP, WPI, WPII
- Low and medium voltage including 200V and 575V

C-Face and D-Flange

- C-Face motors available from stock in most all configurations and product families
- D-Flange motors are available as custom items or through Mod Express
- NEMA or IEC style



Common AC Motor Types

- Induction
- Synchronous

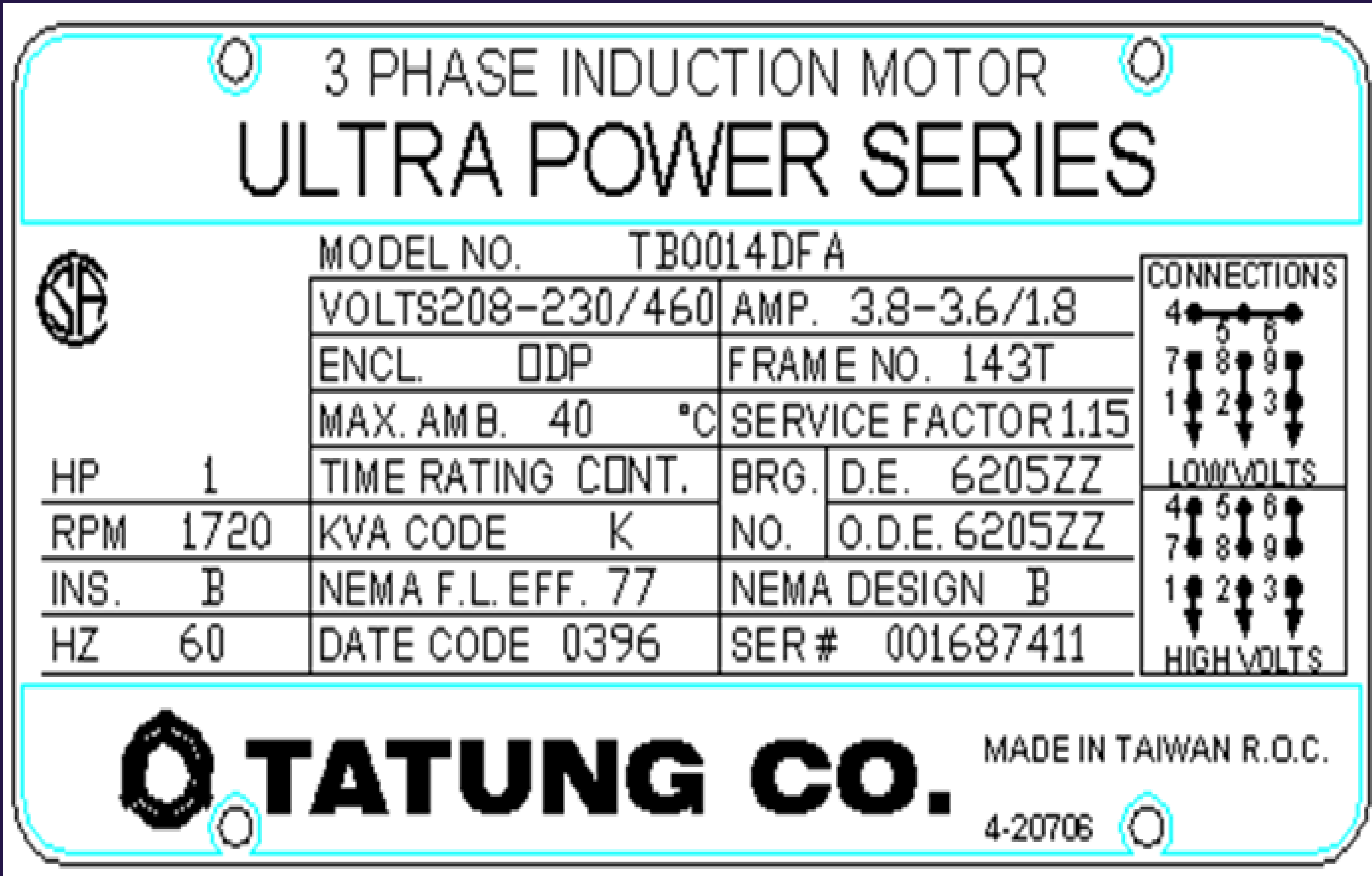
Induction Motors

- Power is applied only to the stator
- Rotational motion is ***induced*** to the rotor by means of a rotating magnetic field
- Less efficient than synchronous motors

Synchronous Motors

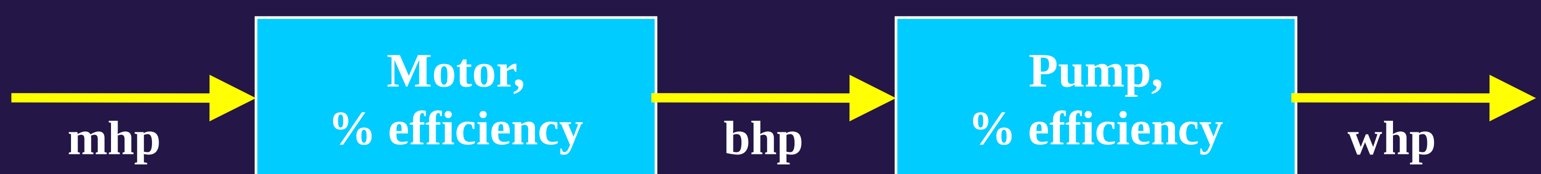
- Power is applied to both rotor and stator
- ***Slip rings*** used to energize rotor windings
- Cannot start by themselves - must be started by induction until reaching synchronous speed (~95%)
- Constant speed until ***pull-out torque*** is reached, at which point motor stops
- More efficient than induction motors

Understanding Motor Nameplates



Pump and Motor Efficiencies

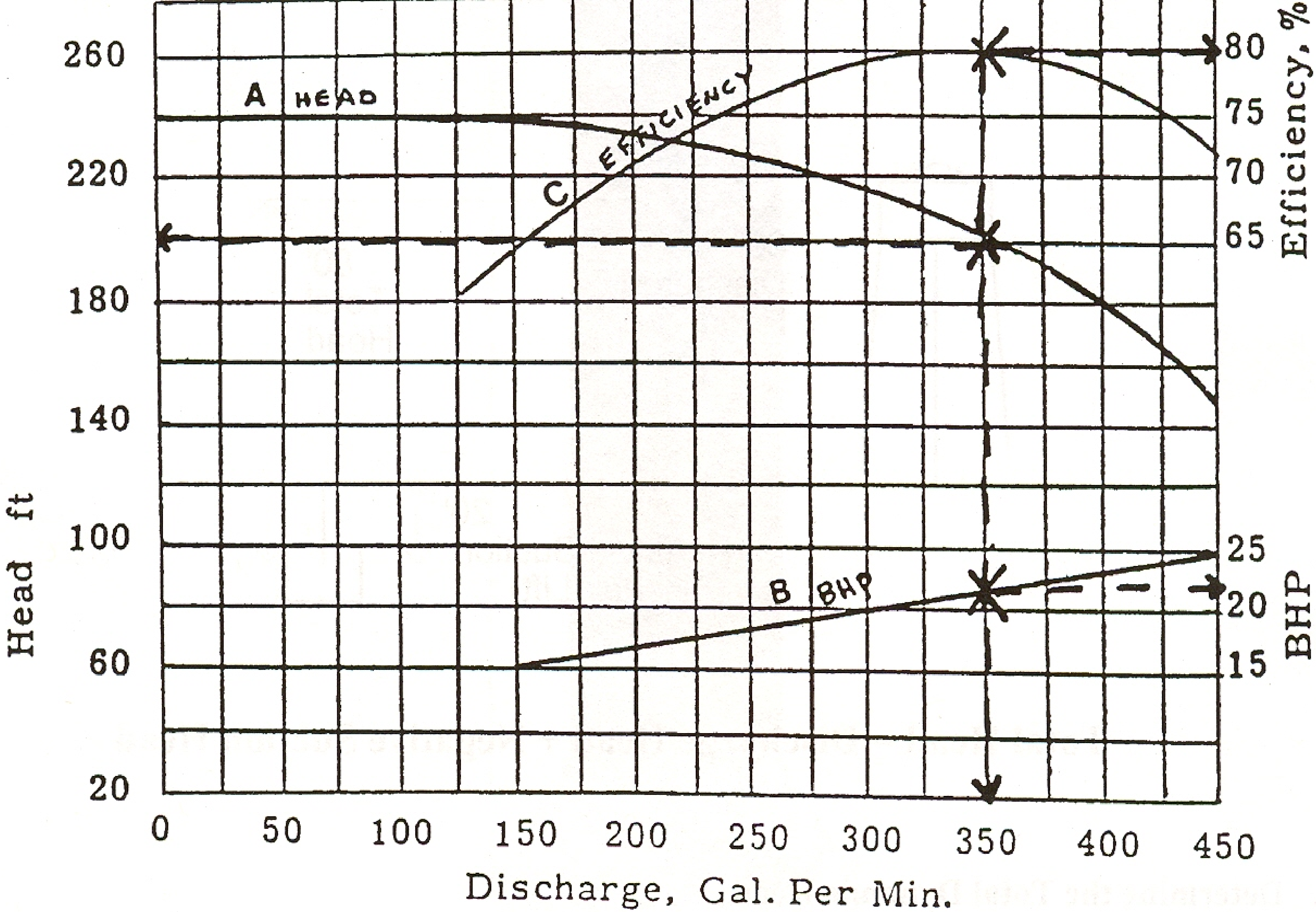
- Motor or wire hp (mhp) = electrical energy in hp supplied to motor; motor efficiency determines brake hp
- Brake hp (bhp) = mechanical energy in hp supplied to pump shaft from motor; pump efficiency determines water hp
- Water hp (whp) = mechanical energy in hp transferred to water by pump



Horsepower Requirements

- Water hp: energy transferred to water by pump
  - hp = (Q [gpm] x 8.34 lb/gal x TDH [ft])/33,000 ft-lb/min
  - whp = (Q x TDH)/3,960
- Brake hp: energy transferred to shaft of pump from shaft of motor
  - bhp = whp/Eff_{pump}
- Motor or wire hp: energy required in electrical input to the motor
  - mhp = bhp/Eff_{pump}
  - Used to calculate cost of pump operation

Pump Curves

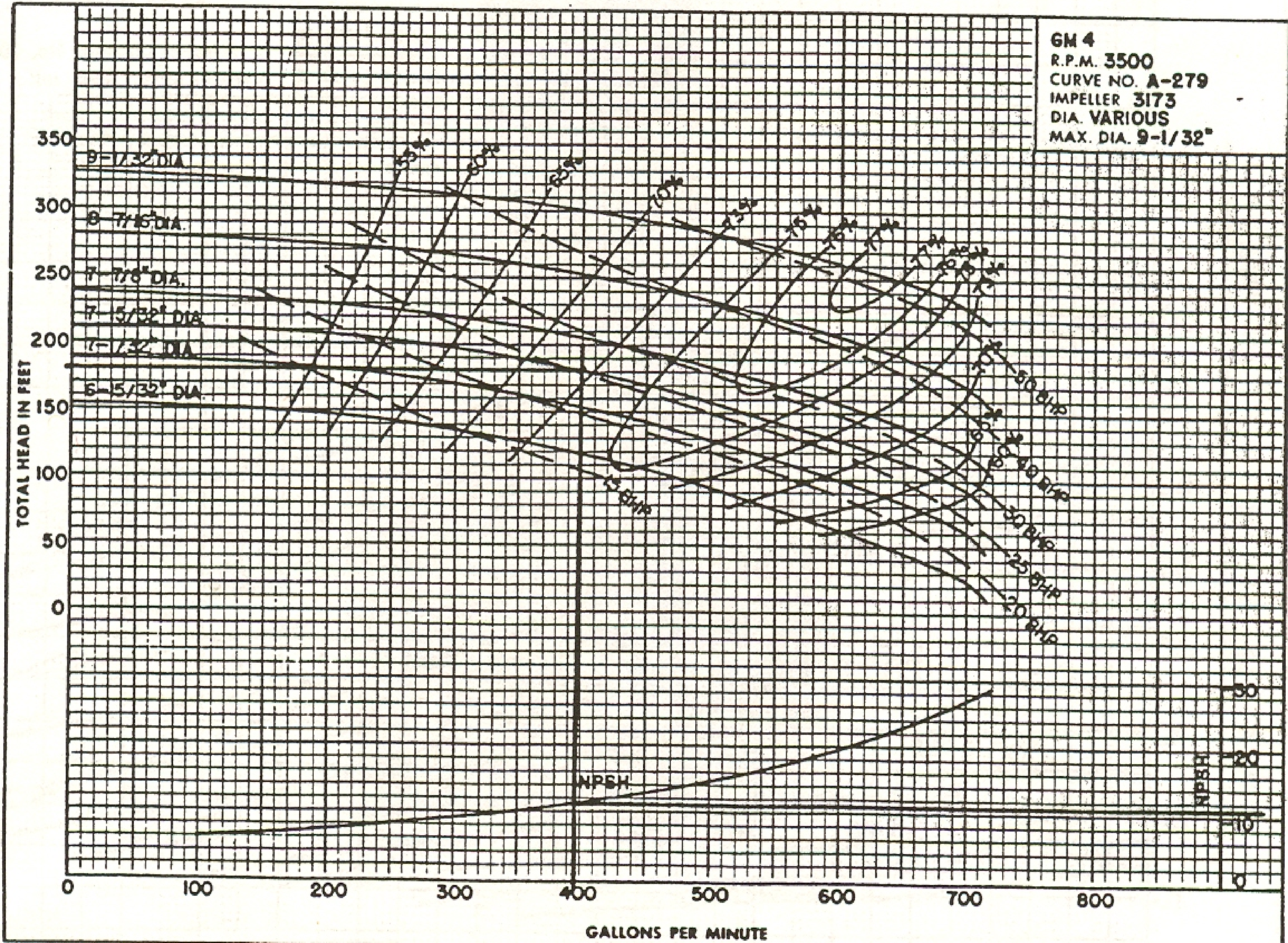


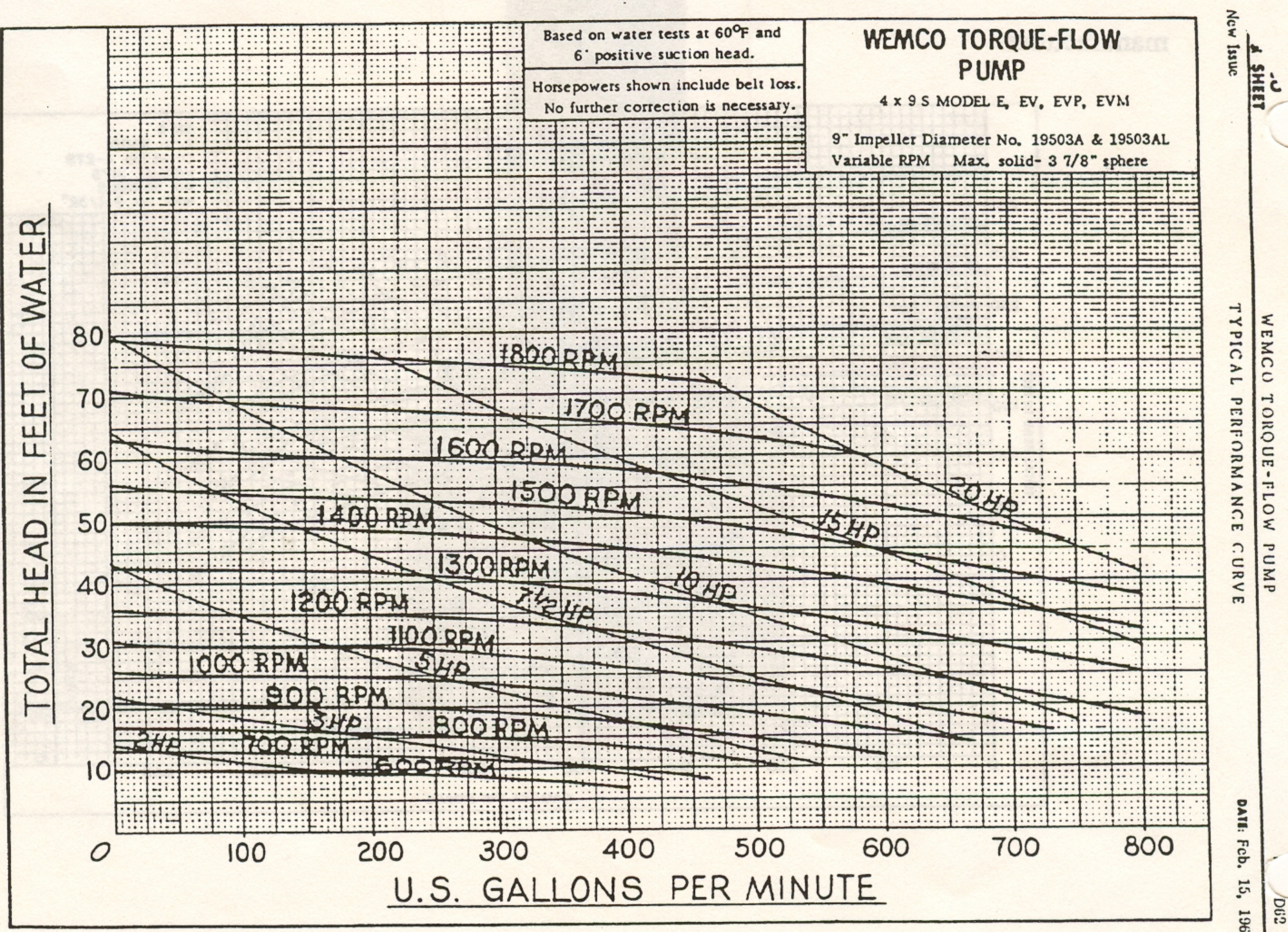
260
220
180
140
100
60
20
Head ft
A HEAD
C EFFICIENCY
B BHP
80
75
70
65
Efficiency, %
25
20
15
BHP
0
50
100
150
200
250
300
350
400
450
Discharge, Gal. Per Min.

PUMP CURVE

Pump Curve Characteristics

- Head capacity curve: Curve A
  - Shows relationship between head (ft) and capacity, or flow (gpm)
- Brake horsepower curve: Curve B
  - Indicates power in hp required for pump to meet head and flow conditions from Curve A
- Efficiency curve: Curve C
  - Provides efficiency of the pump


GM 4
R.P.M. 3500
CURVE NO. A-279
IMPELLER 3173
DIA. VARIOUS
MAX. DIA. 9-1/32"
9-1/32" DIA.
8-7/16" DIA.
7-7/8" DIA.
7-15/32" DIA.
7-1/32" DIA.
6-15/32" DIA.
55%
60%
65%
70%
73%
75%
76%
77%
15 BHP
20 BHP
25 BHP
30 BHP
40 BHP
50 BHP
NPSH
TOTAL HEAD IN FEET
GALLONS PER MINUTE
350
300
250
200
150
100
50
0
100
200
300
400
500
600
700
800
30
20
10
0


Based on water tests at 60°F and 6' positive suction head.
Horsepowers shown include belt loss. No further correction is necessary.
WEMCO TORQUE-FLOW PUMP
4 x 9 S MODEL E, EV, EVP, EVM
9" Impeller Diameter No. 19503A & 19503AL
Variable RPM Max. solid- 3 7/8" sphere
TOTAL HEAD IN FEET OF WATER
80
70
60
50
40
30
20
10
1800 RPM
1700 RPM
1600 RPM
1500 RPM
1400 RPM
1300 RPM
1200 RPM
1100 RPM
1000 RPM
900 RPM
800 RPM
700 RPM
600 RPM
20 HP
15 HP
10 HP
7½ HP
5 HP
3 HP
2 HP
0
100
200
300
400
500
600
700
800
U.S. GALLONS PER MINUTE
WEMCO TORQUE-FLOW PUMP
TYPICAL PERFORMANCE CURVE
New Issue
SHEET
DATE: Feb. 15, 1967
D62

Affinity Laws

- Impeller diameter and pump speed (rpm) for pump curve must match impeller diameter and speed of pump
- Can use affinity laws to compensate
  - For changes in diameter
    - $Q_2 = Q_1 \times D_2/D_1$
    - $H_2 = H_1 \times (D_2/D_1)^2$
    - $hp_2 = hp_1 \times (D_2/D_1)^3$
  - For changes in speed
    - $Q_2 - Q_1 \times rpm_2/rpm_1$
    - $H_2 = H_1 \times (rpm_2/rpm_1)^2$
    - $hp_2 = hp_1 \times (rpm_2/rpm_1)^3$

Shut-Off Head

- The maximum amount of head or pressure a pump can develop
- Flow drops to 0 when a pump reaches shut-off head
- Pump curve not valid if pump cannot generate rated shut-off head
  - Could be due to worn impeller or worn wear rings
  - Could also be due to pump running at lower rpm than rating

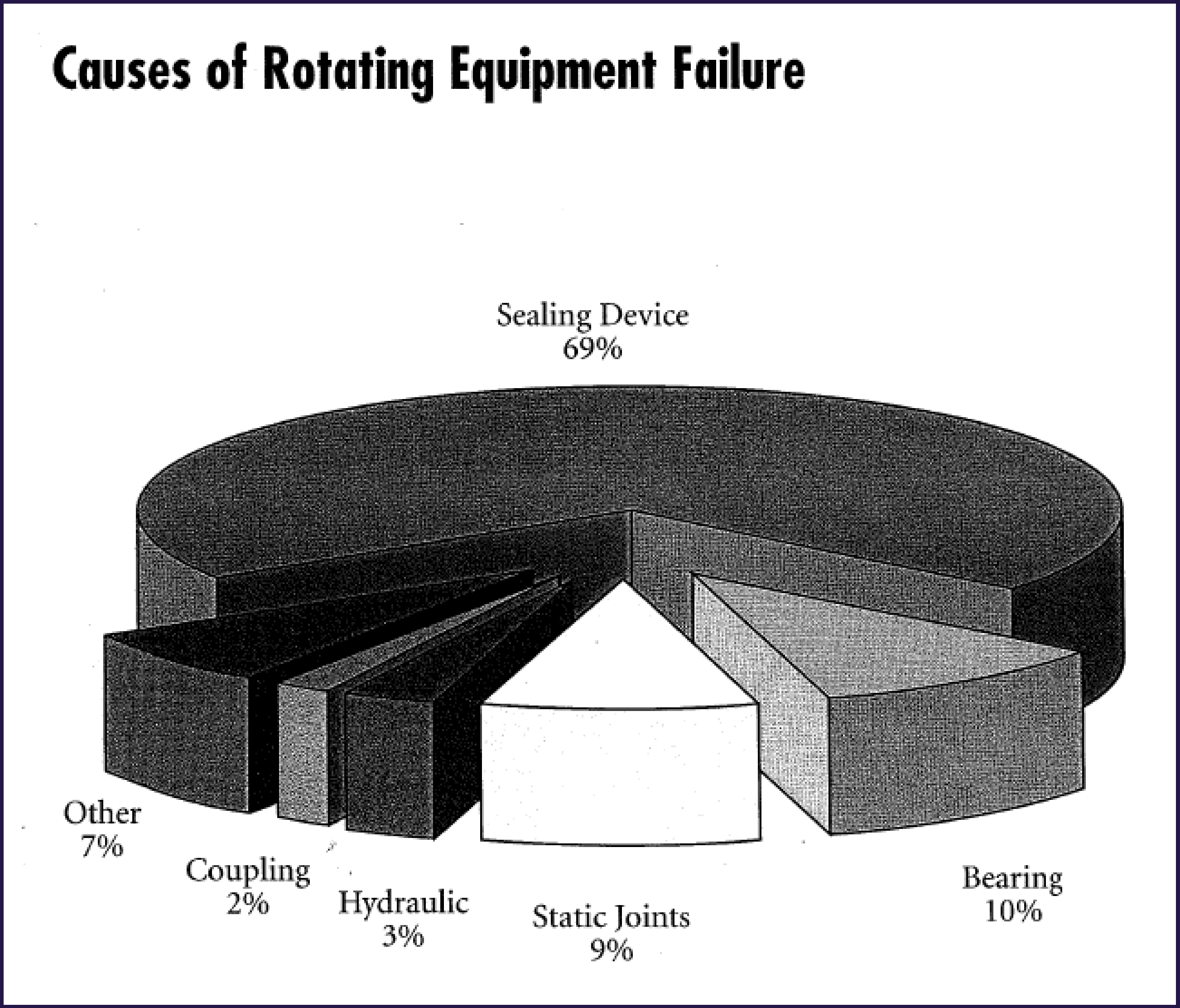
Mechanical Systems Operation and Maintenance (O&M)

Maintenance and Troubleshooting

- The part that fails is seldom the root cause of the failure. Until you correct the root cause, repeat failures will occur.

Maintenance and Troubleshooting

- Packing and glands
- Mechanical seals
- Bearings
- Shafts
- Submersible well systems


Causes of Rotating Equipment Failure
Sealing Device
69%
Other
7%
Coupling
2%
Hydraulic
3%
Static Joints
9%
Bearing
10%

Packing Problems

Troubleshooting Failure of Compression Packings

Problem	Probable cause	Remedial action
Pump fails to deliver any fluid	Loss of prime resulting from a loose or defective packing that allows air to enter pump housing	Tighten or replace packing. Prime pump as in normal startup.
Pump delivers only a small quantity of fluid	Air entering stuffing box to cause partial loss of prime Adjustment of packing needed	Check for leakage through stuffing box with pump operating (outflow of fluid). If leakage is not observed after gland adjustment, three possibilities exist: 1. Lantern ring clogged or displaced to block sealing liquid line 2. Sealing liquid line is blocked 3. Worn shaft or shaft sleeve under packing that allows air passage into pump chamber.
	Air entering stuffing box to cause partial loss of prime Defective packing	Replace packing after inspection of surface condition of shaft or shaft sleeve.
Pump pressure is less than normal	Defective packing	Replace packing after checking shaft.
Pump operates normally initially followed by a drop in discharge volume	Air entering stuffing box Loose or defective packing	Make gland adjustment and observe leakage and pump delivery. If no change, replace packing.
Pump requires excess power	Excessive packing tightness	Reduce gland pressure and retighten normally with leakage. If no leakage is visible, check packing and shaft.
Stuffing box leaks excessively	Defective packing	Replace packing.
	Improper type of packing Improperly installed packing	Replace packing material after checking compatibility with pumped fluid.
	Shaft deterioration through damage or wear	Remachine and refinish or replace shaft.
Stuffing box overheats	Excess packing tightness	Reduce gland pressure.
	Insufficient packing lubrication	Reduce gland pressure; remove packing for inspection, replacement, or both.
	Improper type of packing	Recheck material selection and install new packing of suitable type.
	Insufficient flow of cooling water to stuffing box jackets	Check water supply lines for closed valves or blocked lines.
	Improperly packed stuffing box	Replace packing following recommended procedure.
Packing wear rate is excessive	Shaft or shaft sleeve wear or surface finish deterioration	Remachine and refinish or replace shaft.
	Insufficient packing lubrication Marginal or no lubrication	Repack with packing looseness that allows some leakage.
	Improperly installed packing	Remove old packing, clean stuffing box, and replace packing following recommended procedure.
	Improper type of packing	Recheck material selection and install new packing of suitable type.
	Movement of packing to prevent its seating-in caused by pressure pulsation in external seal liquid line	Eliminate source of pulsation.

Source: Harold Woodhouse, Dean Hill

Mechanical Seals: Common Failures

- Run dry
- Deadheading
- Temperature
- Alignment
- Vibration
- Particulate/abrasives
- Chemical incompatibility

GUIDLINES FOR THE PROPER INSTALLATION OF MECHANICAL SEALS

PREPARATION OF THE PUMP

(a) It is important that the seal chamber or stuffing box is clean and free of all foreign matter.

(b) The shaft or shaft sleeve on which the seal is installed must be to exact size, straight, smooth, and free of sharp corners, nicks, scratches or burrs.

(c) The Face of the Stuffing boxes must be clean, smooth and square with the axis of the shaft.

(d) Make sure all holes are plugged in the stuffing box that are not to be used in the appliance operation.

(e) End fit up of Horizontal split case pumps must match perfectly. The gasket between the halves that extend must be flush with the surface on which the mechanical seal gland and gasket is to seal. Make sure there are no burrs or sharp corners.

(f) The maximum permitted shaft end play is .005".

(g) Check the shaft for alignment with a dial indicator. Excessive misalignment may mean a bent shaft or faulty bearings.

(h) If a shaft sleeve is used, make certain the sleeve is properly gasketed to the shaft to prevent any leakage under the sleeve.

(i) Check pump impeller and wear rings for proper clearance. SHAFT MUST TURN FREELY. Vibrations caused by rubbing and improper clearances can cause seal failure.

INSTALLATION OF SEAL

(a) Cleanliness in seal installation is imperative to keep any foreign matter out of the seal chamber. Always handle mechanical seals with extreme care. Be sure no foreign matter is on either seal face.

(b) Make sure the new seal goes on exactly the same way the old seal came off. Be sure to identify all parts as they are removed and reinstalled.

(c) Where set screws are used as a drive between seal and shaft, the shaft should be counter sunk to receive the cup point. Make sure all set screws are tight.

(d) Use four (4) equal spaced gland bolts when possible. TIGHTEN BOLTS EVENLY. When possible, follow API-ASME Code for unfired vessels in selecting gland bolt size. Check clearances between shaft and gland with feeler guages. The gland must be accurately centered.

(e) Test seals statically under pressure before starting pump. Make adjustments if required to stop any leakage through gland gasket if noticed.

(f) NEVER OPERATE MECHANICAL SEALS DRY. Be sure suction and discharge of pump is open and a positive head of fluid is present before starting pump. This applies even when just checking for proper rotation and adjustment of electrical connections.

SEAL PROBLEM SOLVING

	PROBLEM	POTENTIAL CAUSE	SOLUTION
A.*	CRACKED, CHIPPED, BROKEN CERAMIC OR SILICON SEAT	SEAL RAN DRY. VERY HOT SEAL FACE CAME IN CONTACT WITH COOLER LIQUID.	CHECK TO INSURE SEAL CHAMBER IS FULL OF LIQUID BEFORE STARTING UP APPLIANCE. AT HIGH TEMPERATURE, INSURE FLUSHING AT SEAL FACES.
B.*	CARBON OR METAL SEAL FACE IS SCORED AND/OR GROOVED	ABRASIVE PARTICLES ARE IN THE SYSTEM, CAUSING ABRASION TO SEAL FACES.	HAVE SYSTEM CLEANED AND FLUSHED, INSTALL ABRASIVE SEPARATOR OR GO TO S.C. OR T.C. HARD FACE.
C.*	CARBON OR METAL SEAL FACE WEARS UNEVENLY.	SEAL NOT PROPERLY INSTALLED OR SHAFT MISALIGNMENT.	MAKE SURE OF PROPER INSTALLATION AND CHECK SHAFT ALIGNMENT.
D.*	FLEXIBLE BELLOWS TORN	COUPLING MISALIGNMENT	REALIGN APPLIANCE AND MOTOR.

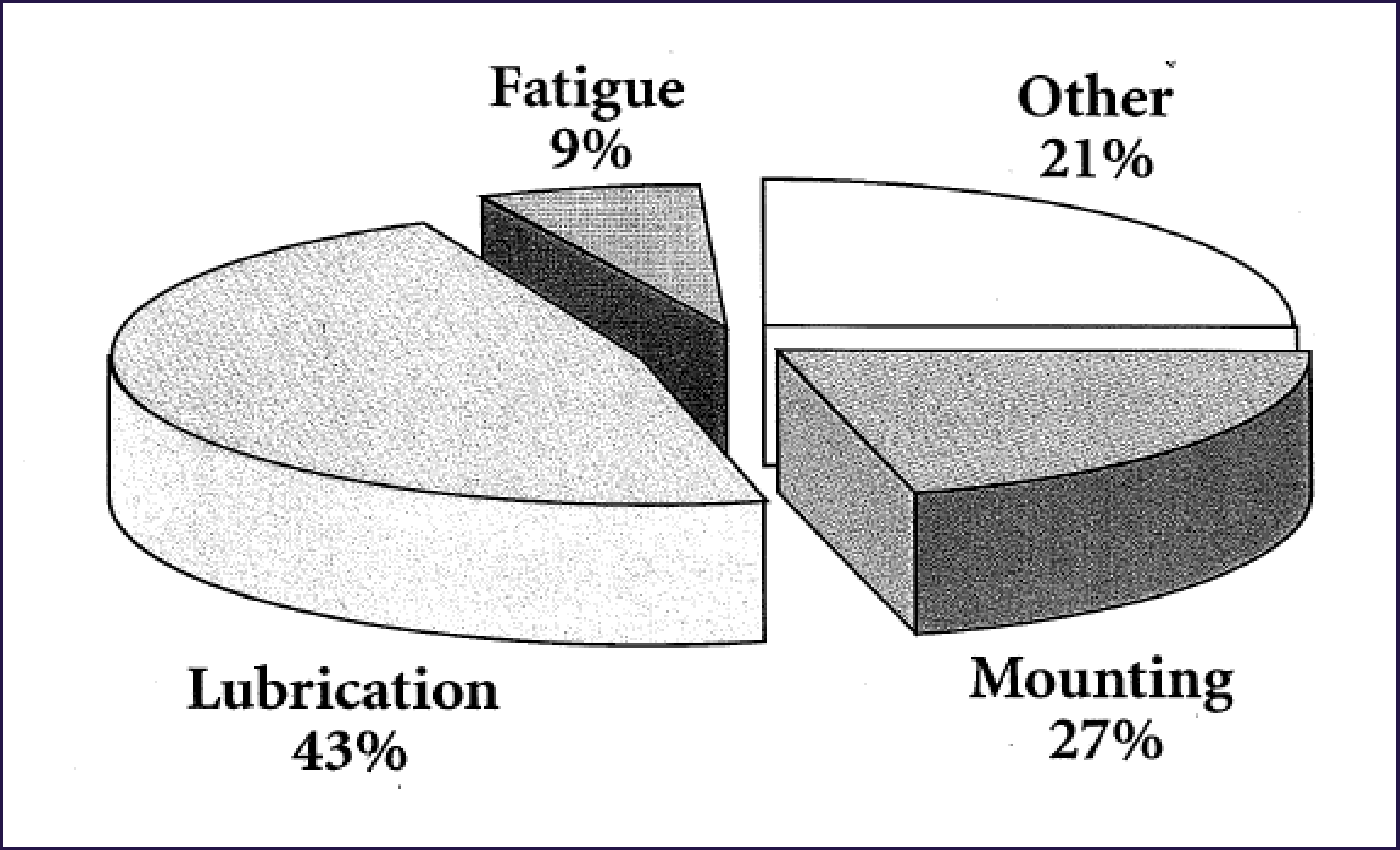
note: *
In A,B,C,D, above, always make sure that the seal when fully compressed is not longer than the length of of the stuffing box or seal enclosure in which it is installed. Over compression is a major cause of seal failure.

E.	RETAINER DRIVE TABS WORN OR BROKEN.	CAVITATION, VIBRATION, LOSS OF FLUID AT SEAL FACES OR COUPLING MISALIGNMENT.	INSURE PROPER LUBRICATION AT SEAL FACES, OR REALIGN PUMP & MOTOR.
F.	BELLOWS HARD OR BRITTLE. EXCESSIVE CARBON WEAR.	TEMPERATURE TOO HIGH ? CHECK FOR PUMP CAVITATION	USE VITON OR TEFLON MEMBERS, HIGH TEMPERATURE CARBON, METAL OR TUNGSTEN CARBIDE SEAT.
G.	SHORT SEAL LIFE IN TREATED SYSTEMS	TEMPERATURE HIGHER THAN EXPECTED OR DESIGNED FOR.	CONSULT WITH ENGINEERING WITH TEMPERATURE AND PPM FOR PROPER SEAL RECOMMENDATION.
H.	SEAL FRETS OR WEARS OUT SHAFT.	CHECK BEARINGS FOR SHAFT WHIP, AXIAL MOVEMENT. BE SURE TO CHECK STRAIGHTNESS.	REPLACE BEARINGS OR SHAFT.
I.	BELLOWS SOFT AND STICKY, PERHAPS DISSOLVING.	BELLOWS NOT COMPATIBLE WITH MATERIAL BEING PUMPED.	CONSULT ENGINEERING FOR ALTERNATE RECOMMENDATION.

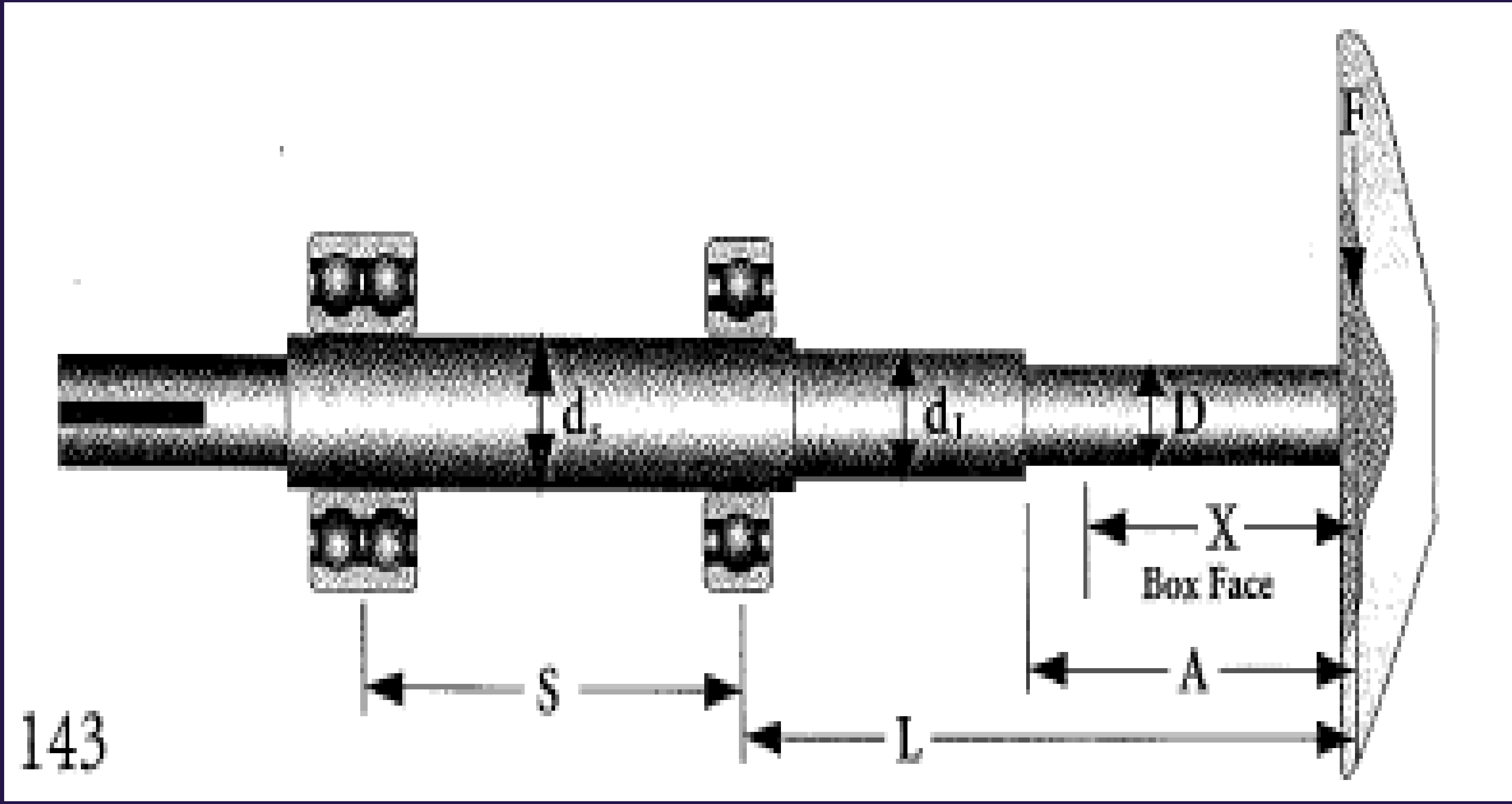
ELASTOMERS AND MEMBERS

Quantum uses BUNA-N (NITRILE) as the standard elastomer. Buna-N has a service range -50 to +212 F.
Quantum uses VITON (Dupont) as an alternative standard material for temperatures in excess of +212 F to +400 F.

Bearings



Radial, Axial, and Thrust Loads



Bearing Maintenance

- Lubricate per manufacturer's recommendations
- Sealed or shielded bearings are factory lubricated and rated for 10,000 hours and up
- Overgreasing is not recommended
- When placing on shaft, be aware of creating flat spots

Bearings: Common Failures

- Lack of lubrication/temperature
- Dirt
- Improper installation (flat spots)
- Fatigue
- Vibration

Static Joints: Common Failures

- No pipe support
- Overtorqueing bolts
- Improper alignment (bases and supports)

Hydraulic Common Failures

- Cavitation wear
- System design
- Particulate matter
- System add-ons

Couplings: Common Failures

- Misalignment
- Improper sizing (hp vs. rpm)
- Fatigue

General Start-Up of Pumps

- **Start-up of a Centrifugal Pump:** The suction valve should be open and generally operators understand this, but the positioning of the discharge valve is somewhat of a mystery. When given the choice of placing the valve in the fully open, fully closed or partially open position, there seems to be very little consensus among operators when procedure does not dictate one of the three. The most appropriate position to place a discharge valve in during pump start-up is approximately 25% open.

- **Pump Throttling:** There is a widespread misunderstanding within operations that a pump can be throttled through pinching off of the suction valve. While you may recognize this to be inappropriate, a survey of the operators in your plant would uncover a significant percentage that do not know this.

Submersible Pump Troubleshooting

Motor Does Not Start

Possible Cause	Checking Procedures	Corrective Action
A. No power or incorrect voltage.	Check voltage at line terminals The voltage must be ± 10% of rated voltage.	Contact power company if voltage is incorrect.
B. Fuses blown or circuit breakers tripped.	Check fuses for recommended size and check for loose, dirty or corroded connections in fuse receptacle. Check for tripped circuit breakers.	Replace with proper fuse or reset circuit breakers.
C. Defective pressure switch.	Check voltage at contact points. Improper contact of switch points can cause voltage less than line voltage.	Replace pressure switch or clean points.
D. Control box malfunction.	For detailed procedure, see pages 44-45.	Repair or replace.
E. Defective wiring	Check for loose or corroded connections or defective wiring.	Correct faulty wiring or connections.
F. Bound pump.	Check for misalignment between pump and motor or a sand bound pump. Amp readings will be 3 to 6 times higher than normal until the overload trips.	Pull pump and correct problem. Run new installation until the water clears.
G. Defective cable or motor.	For detailed procedure, see pages 42-44.	Repair or replace.

Submersible Pump Troubleshooting

Motor Starts Too Often

A. Pressure switch.	Check setting on pressure switch and examine for defects.	Reset limit or replace switch.
B. Check valve - stuck open.	Damaged or defective check valve will not hold pressure.	Replace if defective.
C. Waterlogged tank.	Check air charge.	Repair or replace.
D. Leak in system.	Check system for leaks.	Replace damaged pipes or repair leaks.

Submersible Pump Troubleshooting

Motor Runs Continuously

Possible Cause	Checking Procedures	Corrective Action
A. Pressure switch.	Check switch for welded contacts. Check switch adjustments.	Clean contacts, replace switch, or adjust setting.
B. Low water level in well.	Pump may exceed well capacity. Shut off pump, wait for well to recover. Check static and drawdown level from well head.	Throttle pump output or reset pump to lower level. Do not lower if sand may clog pump.
C. Leak in system.	Check system for leaks.	Replace damaged pipes or repair leaks.
D. Worn pump.	Symptoms of worn pump are similar to those of drop pipe leak or low water level in well. Reduce pressure switch setting, if pump shuts off worn parts may be the fault.	Pull pump and replace worn parts.
E. Loose coupling or broken motor shaft.	Check for loose coupling or damaged shaft.	Replace worn or damaged parts.
F. Pump screen blocked.	Check for clogged intake screen.	Clean screen and reset pump depth.
G. Check valve stuck closed.	Check operation of check valve.	Replace if defective.
H. Control box malfunction.	See pages 44-45 for single phase.	Repair or replace.

Submersible Pump Troubleshooting

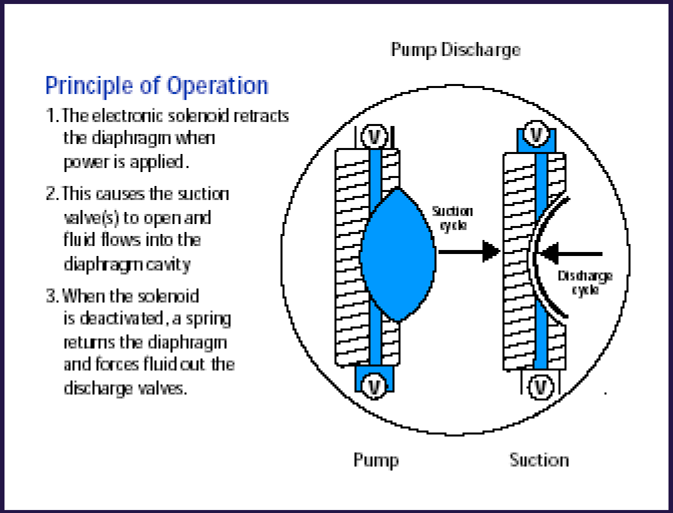
Motor Runs But Overload Protector Trips

A. Incorrect voltage.	Using voltmeter, check the line terminals. Voltage must be within ± 10% of rated voltage.	Contact power company if voltage is incorrect.
B. Overheated protectors.	Direct sunlight or other heat source can raise control box temperature causing protectors to trip. The box must not be hot to touch.	Shade box, provide ventilation or move box away from source.
C. Defective control box.	For detailed procedures, see pages 44-45.	Repair or replace.
D. Defective motor or cable.	For detailed procedures, see pages 42-44.	Repair or replace.
E. Worn pump or motor.	Check running current, See pages 13 & 22-26.	Replace pump and/or motor.

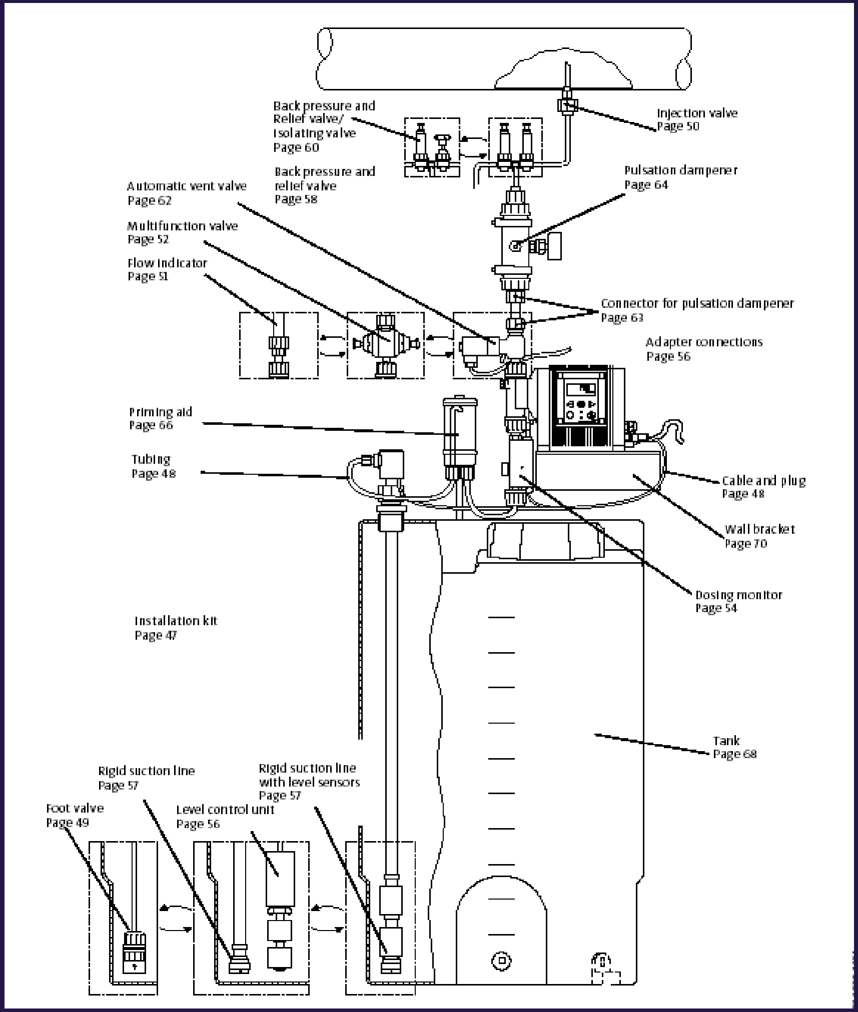
Chemical Feed Pumps

Pump Design: Positive Displacement

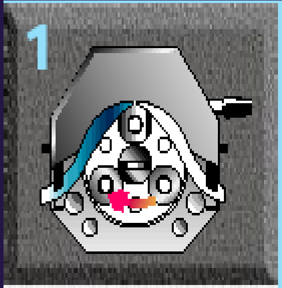
- Diaphragm pumps



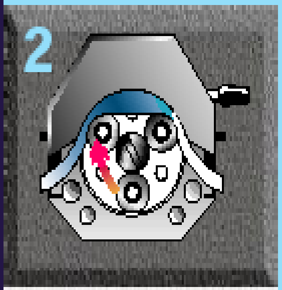
Diaphragm Pump System



Peristaltic



A Masterflex pump head consists of only two parts: the rotor and the housing. The tubing is placed in the tubing bed—between the rotor and housing—where it is occluded (squeezed).

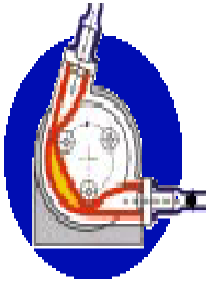


The rollers on the rotor move across the tubing, pushing the fluid. The tubing behind the rollers recovers its shape, creates a vacuum, and draws fluid in behind it.

A "pillow" of fluid is formed between the rollers. This is specific to the ID of the tubing and the geometry of the rotor. Flow rate is determined by multiplying speed by the size of the pillow. This pillow stays fairly constant except with very viscous fluids.

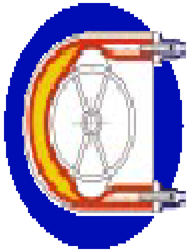
Dry-Running Design

This pump design incorporates a unique tube bed that always ensures that one roller is occluding the hose. Termed dry-running because rollers that do not operate in a lubricated bath occlude the hose. Dry running pumps are available in models capable of discharge pressures up to 60 psig. Unique dual-hose versions provide a nearly pulse-free flow stream.



Lubricated Bath Design

Used in PK series only, this design uses two sliding shoes on the rotor to occlude the hose. The rotor and hose operate in a lubricated bath that reduces friction on the hose and provides the long life typical of this type of hose pump design. These pumps are capable of operating at discharge pressures up to 220 psig (15 bar).



Questions?