Pumps Hydraulic and Terms

Presented by
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Pumps Hydraulic and Terms

- Terminology and Theory
- Pump selection
- NPSH
    - Cavitations and its effect
- Affinity Law at work
- Different type of Pump set up
- Water Hammer

Overview of hydraulic selection requirement.

- Steps to select a pump
  - Determine flow rate
  - Design the pipe system
  - Determine the differential head – static + dynamic
  - Flow & Head = the pump duty point
  - Nett positive suction head – NPSH check
  - Select the pump.
  - Determine the BKW and then select the motor.

In order to select a pump two types of data are required:

- Product/Fluid data like:
  - Viscosity,
  - Density/specific gravity,
  - temperature,
  - vapour pressure and solids content.

- Performance data :
  - capacity or flow rate,
  - and inlet/discharge pressure - head.

Products / Fluid data

Viscosity

The viscosity of a fluid - how resistive the fluid is to flow.
This resistance to flow transform the kinetic energy of the fluid into thermal energy.

Absolute (or Dynamic) Viscosity
Measure of how resistive the flow of a fluid is between two layers of fluid in motion. SI unit (mPa.s) - expressed as 1 centipoise (cP) where 1 mPa.s = 1 cP. Water at 1 atmosphere and 20°C () has the value of 1 mPa.s or 1 cP.

Kinematic Viscosity
Measure of how resistive the flow of a fluid is under the influence of gravity.
SI unit of kinematic viscosity is (mm2/s) – expressed as 1 centistoke (cSt), where 1 mm2/s = 1 cSt. Water at 1 atmosphere and 20°C () has the value of 1 mm2/s = 1 cSt.

$$\text{Kinematic Viscosity (cSt)} = \frac{\text{Absolute Viscosity (cP)}}{\text{Specific Gravity}}$$

Types of Fluid

Newtonian Fluids

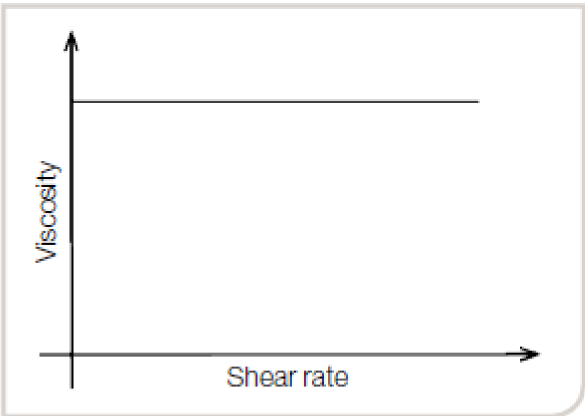


Fig. 2.1.2b Newtonian Fluids

Non-Newtonian Fluids

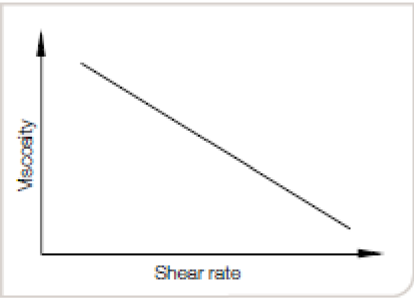


Fig. 2.1.2e Psuedoplastic Fluids

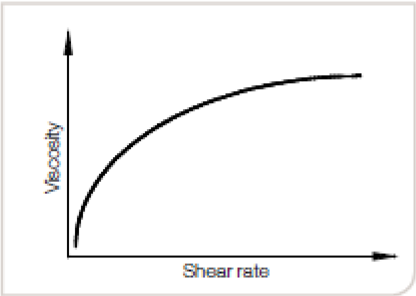


Fig. 2.1.2f Dilatant Fluids

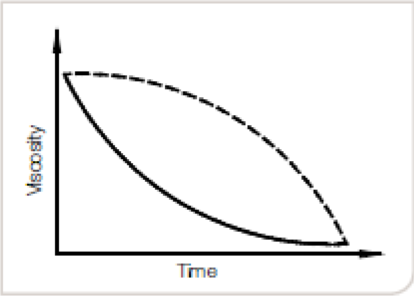


Fig. 2.1.2g Thixotropic Fluids

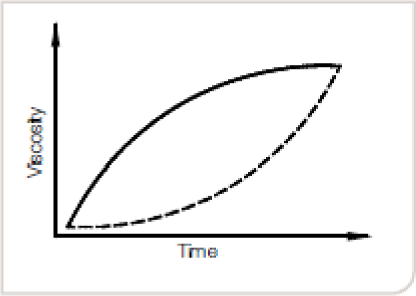


Fig. 2.1.2h Anti-thixotropic Fluids

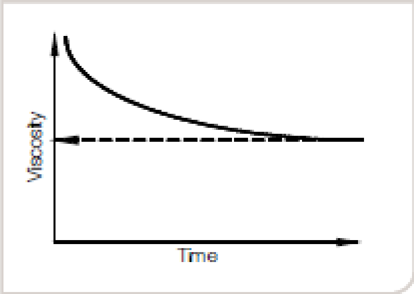


Fig. 2.1.2i Rheomalactic Fluids

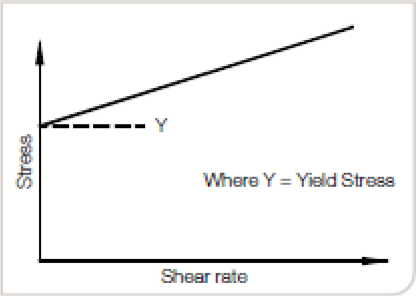
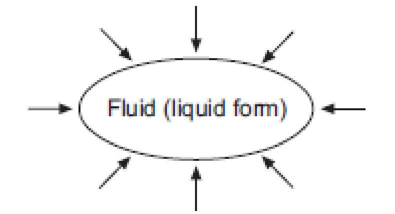


Fig. 2.1.2j Plastic Fluids

Specific Gravity
The specific gravity of a fluid is the ratio of its density to the density of water.

Temperature
The temperature of the fluid at the pump inlet is usually of most concern as vapour pressure can have a significant effect on pump performance.

Vapour Pressure
Fluids will evaporate unless prevented from doing so by external pressure.



Pvp = Vapour pressure (external pressure required to maintain as a fluid)

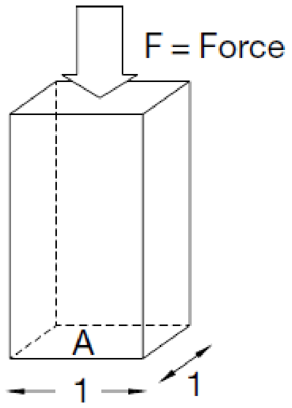
Performance Data

Capacity (Flow Rate)
The capacity (or flow rate) is the volume of fluid or mass that passes a certain area per time unit.

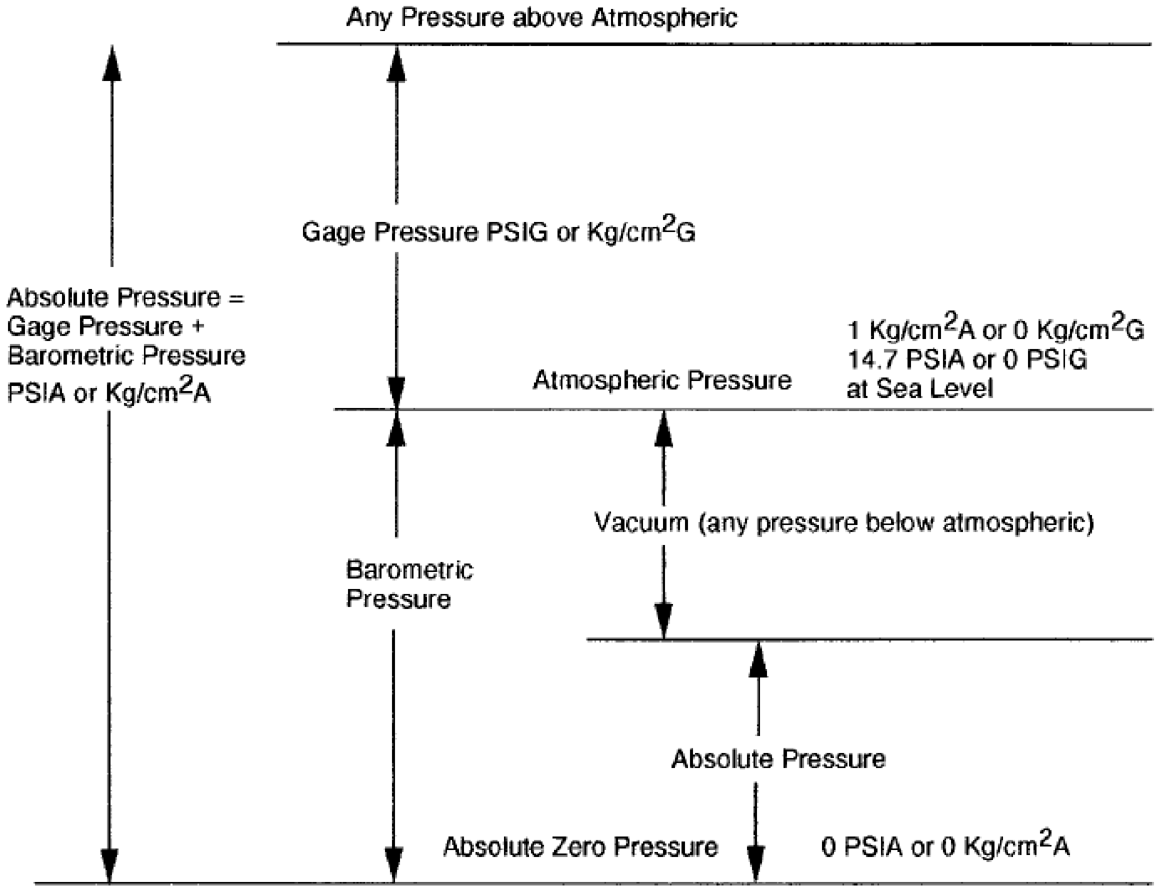
Who provides this information?

- Process Engineer or the customer

Pressure



Pressure (P) = $\frac{\text{Force (F)}}{\text{Area (A)}}$



A pump capable of delivering 35 m (*115 ft*) head will produce different pressures for fluids of differing specific gravities.

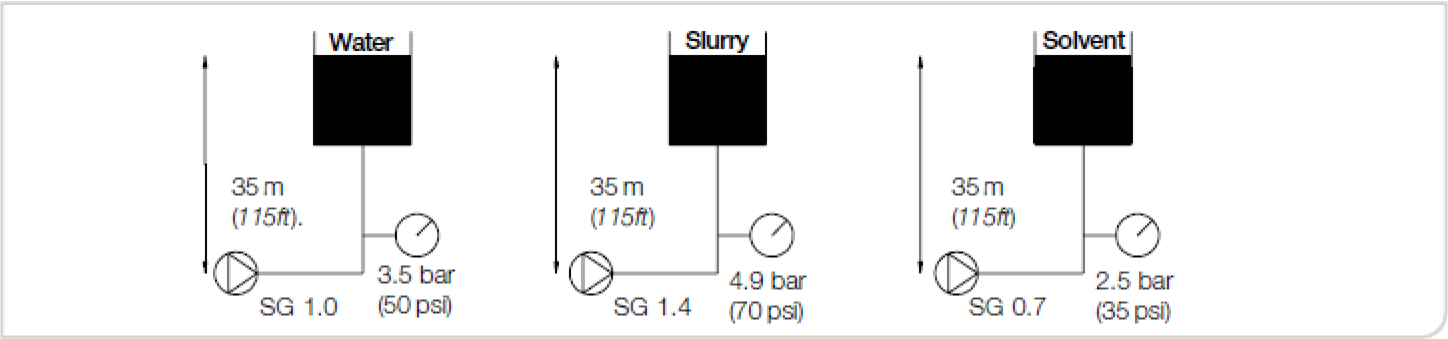


Fig. 2.2.2d Relationship of elevation to pressure

A pump capable of delivering 3.5 bar (*50 psi*) pressure will develop different amounts of head for fluids of differing specific gravities.

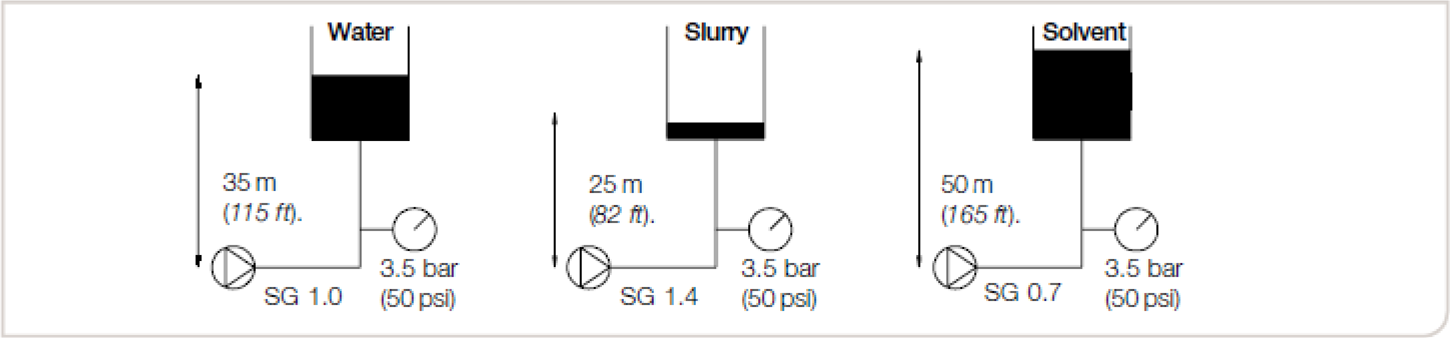


Fig. 2.2.2e Relationship of elevation to pressure

The above demonstrates why we must always think in terms of feet (metric is meters) of liquid rather than pressure when working with centrifugal pumps. A given pump with a given impeller diameter and speed will raise a liquid to a certain height regardless of the weight of the liquid, as shown in Fig. 1.

Head

The static head corresponding to any specific pressure is dependent upon the weight of the liquid according to the following formula:

$$Head\ in\ Feet = \frac{Pressure\ in\ PSI \times 2.31}{Specific\ Gravity}$$

$$Head\ in\ Meters = \frac{Pressure\ in\ Kg/cm^2 \times 10}{Specific\ Gravity}$$

TIPS!

H = velocity at the periphery of the impeller

$$H = \frac{V^2}{2g}$$

Where H = Total head developed in feet. (metric is meters)
V = Velocity at periphery of impeller in feet per sec. (metric is meters/sec)
g = 32.2 ft/sec^2 (metric is 9.81 meters/sec^2)

$$V = \frac{RPM \times D}{229}$$

or

$$V = \frac{RPM \times D}{19108}$$

Where D = Impeller diameter in inches.

Where D = Impeller diameter in mm.

Approx. Head of a centrifugal pumps

What type of head are there?

STATIC SUCTION HEAD is the vertical distance in feet from the centerline of the pump to the free level of the liquid to be pumped when the source of supply is above the centerline of the pump.

OR

STATIC SUCTION LIFT is the vertical distance in feet from the centerline of the pump to the free level of the liquid to be pumped when the source of supply is below the centerline of the pump.

+

STATIC DISCHARGE HEAD is the vertical distance in feet between the pump centerline and the point of free discharge or the surface of the liquid in the discharge vessel.

=

TOTAL STATIC HEAD is the vertical distance in feet between the free level of the source of supply and the point of free discharge or the free surface of the discharge liquid.

+

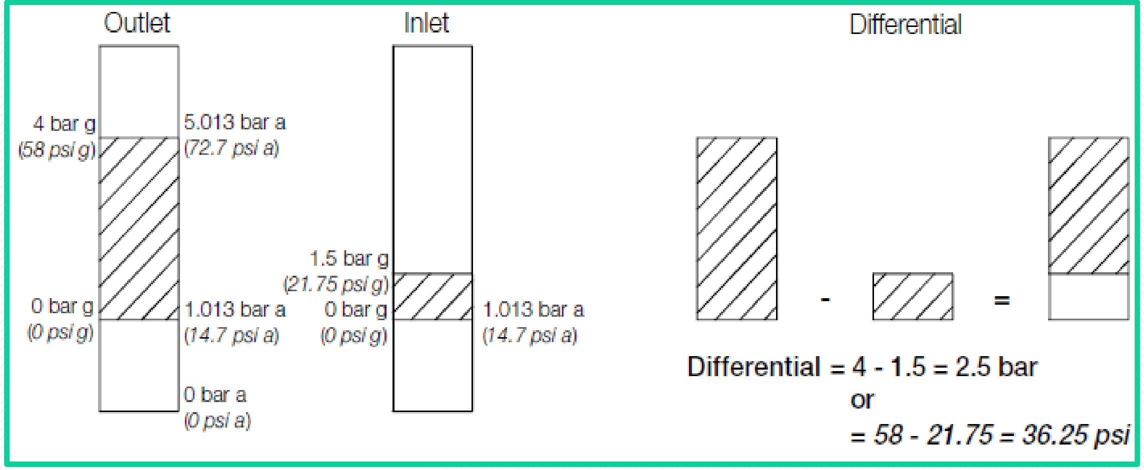
FRICTION HEAD (h_f) is the head required to overcome the resistance to flow in the pump, pipe, and fittings. It is dependent upon the size and type of pipe, flow rate, and the characteristics of the liquid. See FRICTION LOSSES section above.

=

TOTAL DYNAMIC HEAD (TDH)

Positive Condition

Example: Inlet Pressure above Atmospheric Pressure



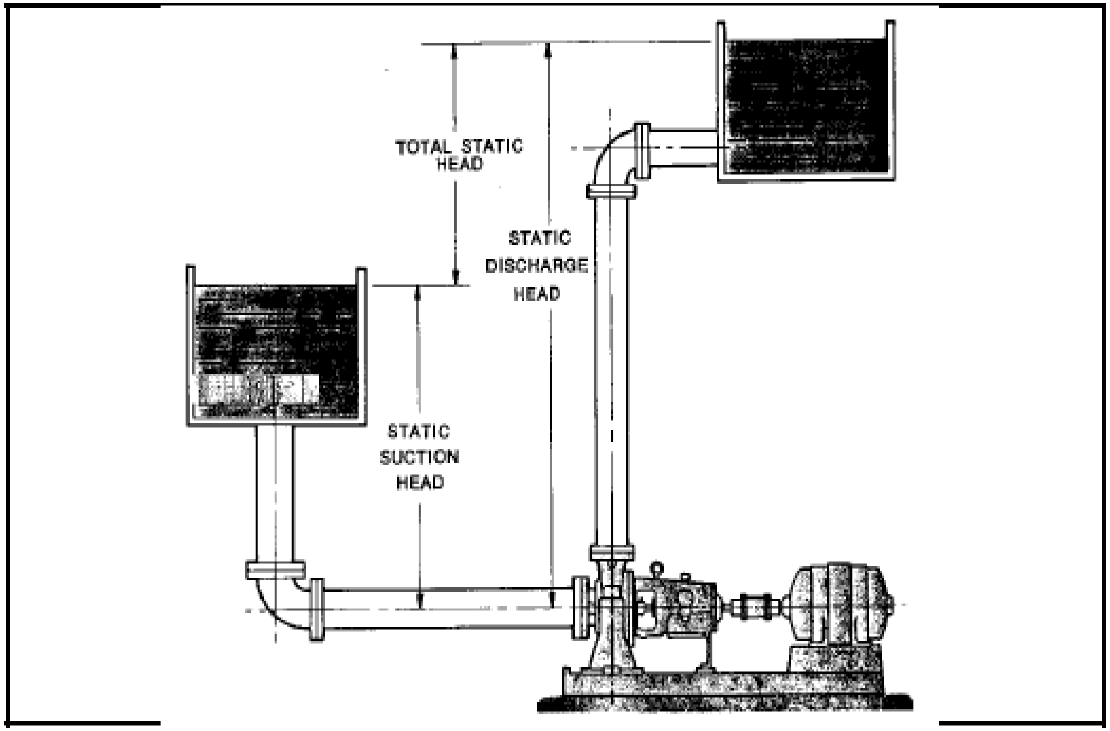
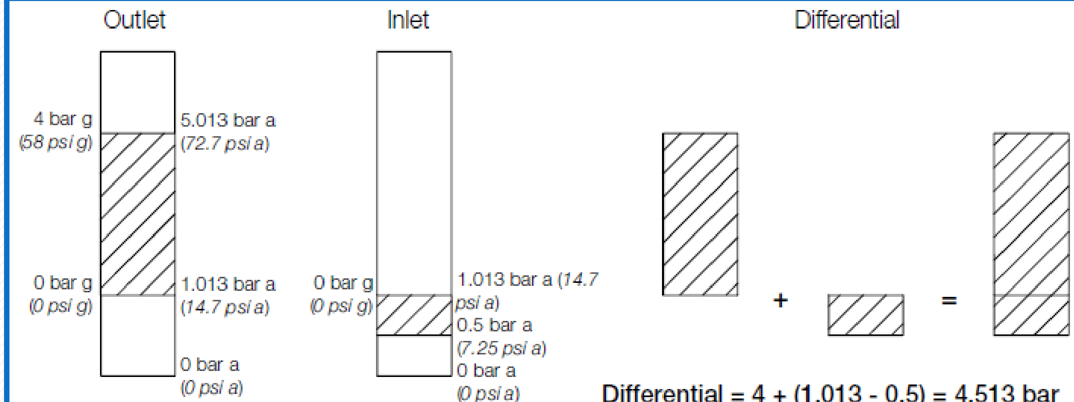


Figure 2b Suction Head (Showing Static Heads in a Pumping System Where the Pump is Located Below the Suction Tank. Static Suction Head.)

$$TDH = h_d - h_s \text{ (with a suction head)}$$

Negative Condition

Example: Inlet Pressure below Atmospheric Pressure



Differential = 4 + (1.013 - 0.5) = 4.513 bar
or
= *58 + (14.7 -7.25) = 65.45 psi*

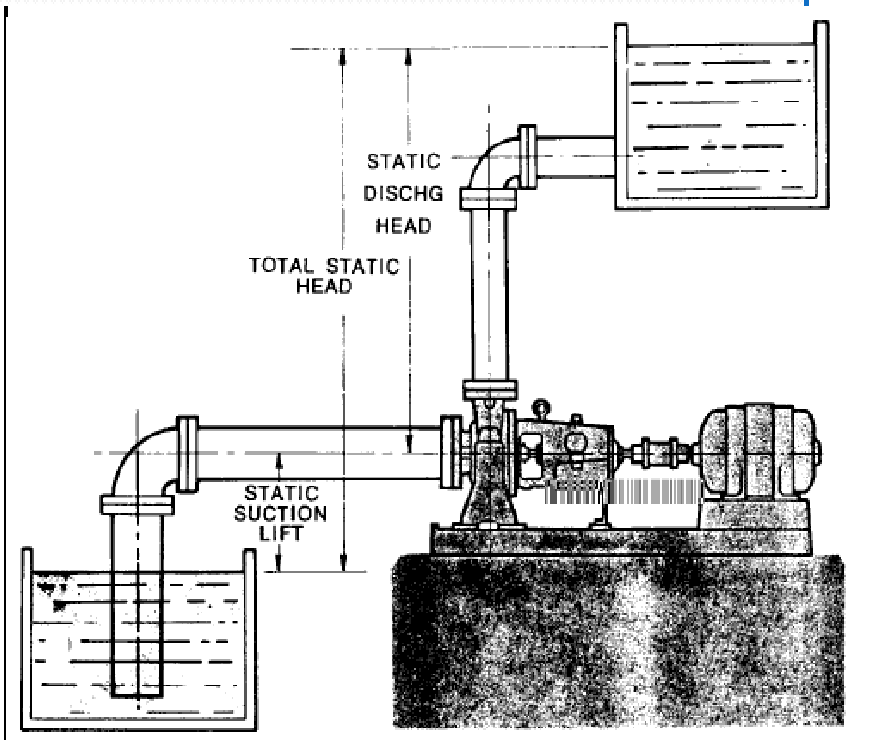


Figure 2a Suction Lift (Showing Heads in a Pumping System Where the Pump is Located Above the Suction Tank. Static Suction Head.)

TDH = $h_d + h_s$ (with a suction lift)

TDH calculation – Example : 100 m ³/hr

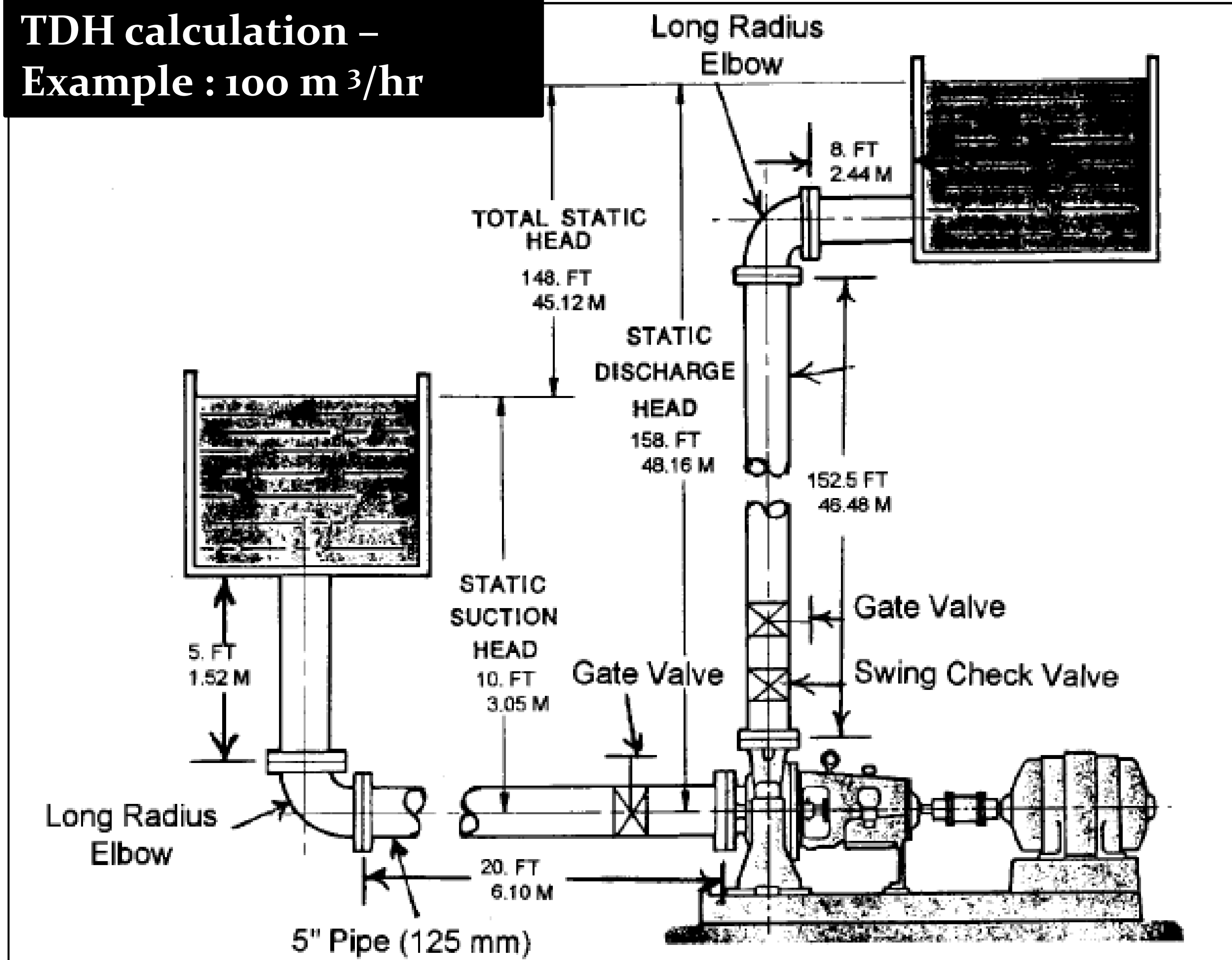


Figure 3 A Typical Pumping System

TDH = Total Static Head + Dynamic Head + Friction Head

Totals Static head = 48.16M - 3.05M = 45.12M

+

Dynamic Head (+ve condiction) = Discharge side – Suction side

$(V^2 / 2g)$ - 100mm Discharge pipe @ 100 m^3/hr = $3.5^2 / (2 \times 9.81) = 0.624$ m

$(V^2 / 2g)$ - 125mm Suction pipe @ 100 m^3/hr = $2.25^2 / (2 \times 9.81) = 0.26$ m

Therefore: 0.624 – 0.26 = 0.365m

(normally this is negligible for high head application but it should be considered for low head application)

Frictional head calculation :

EQUIVALENT LENGTH OF PIPE

ITEM	SIZE	Metric
Discharge		
Gate Valve	4" (100 mm)	1.50 Meters
Swing Check Valve	4" (100 mm)	8.20 Meters
Long Radius Elbow	4" (100 mm)	1.10 Meters
Piping	4" (100 mm)	48.92 Meters
Total length of 4" (100 mm) pipe =		59.72 Meters
Suction		
Gate Valve	5" (125 mm)	1.80 Meters
Long Radius Elbow	5" (125 mm)	1.20 Meters
Piping	5" (125 mm)	7.62 Meters
Total length of 5" (125 mm) pipe =		10.62 meters

Friction in 100 mm pipe for 100 M^3/HR is 9 Meters per 100 meters of pipe.

Metric $\frac{59.72}{100} \times 9 = 5.38$ *Meters*

Friction in 125 mm pipe for 100 M^3/HR is 3 Meters per 100 Meters of pipe.

Metric $\frac{10.92}{100} \times 3 = 0.32$ *Meters*

Therefore:

Friction Head (Metric) = 5.38 Meters + 0.32 Meters = 5.7 Meters

TDH (Metric) = 45.12 Meters + 0.365 Meters + 5.7 Meters = 51.19 Meters

Note: A safety factor needs to be applied to the above-calculated TDH for an allowance to cover future aging/deterioration of pipe internals, local conditions, previous experience, and installation requirements.

The safety factor used is estimated by the design engineer taking into consideration all of the above allowances.

In this case, let us assume that all the pipe, valves, and fittings are 316 stainless steel. An acceptable safety factor for this material would be 1.07

Therefore, the adjusted TDH would be as follows:

Metric TDH = 51.19 Meters x 1.07 = 55 Meters

Duty point = 100 M3/HR at 55 Meters

System Curves

FIGURE 7

SYSTEM HEAD CURVE, ALL FRICTION

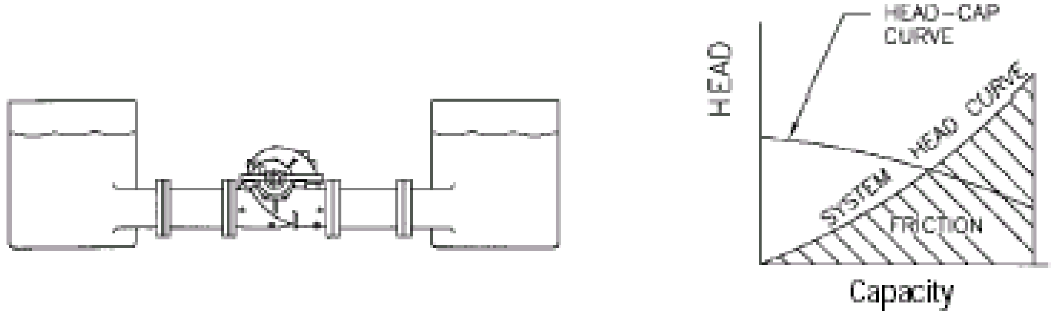
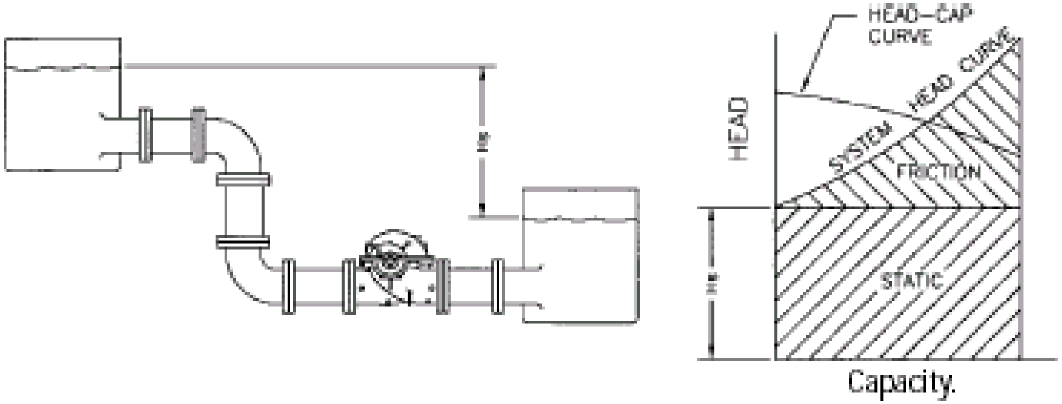
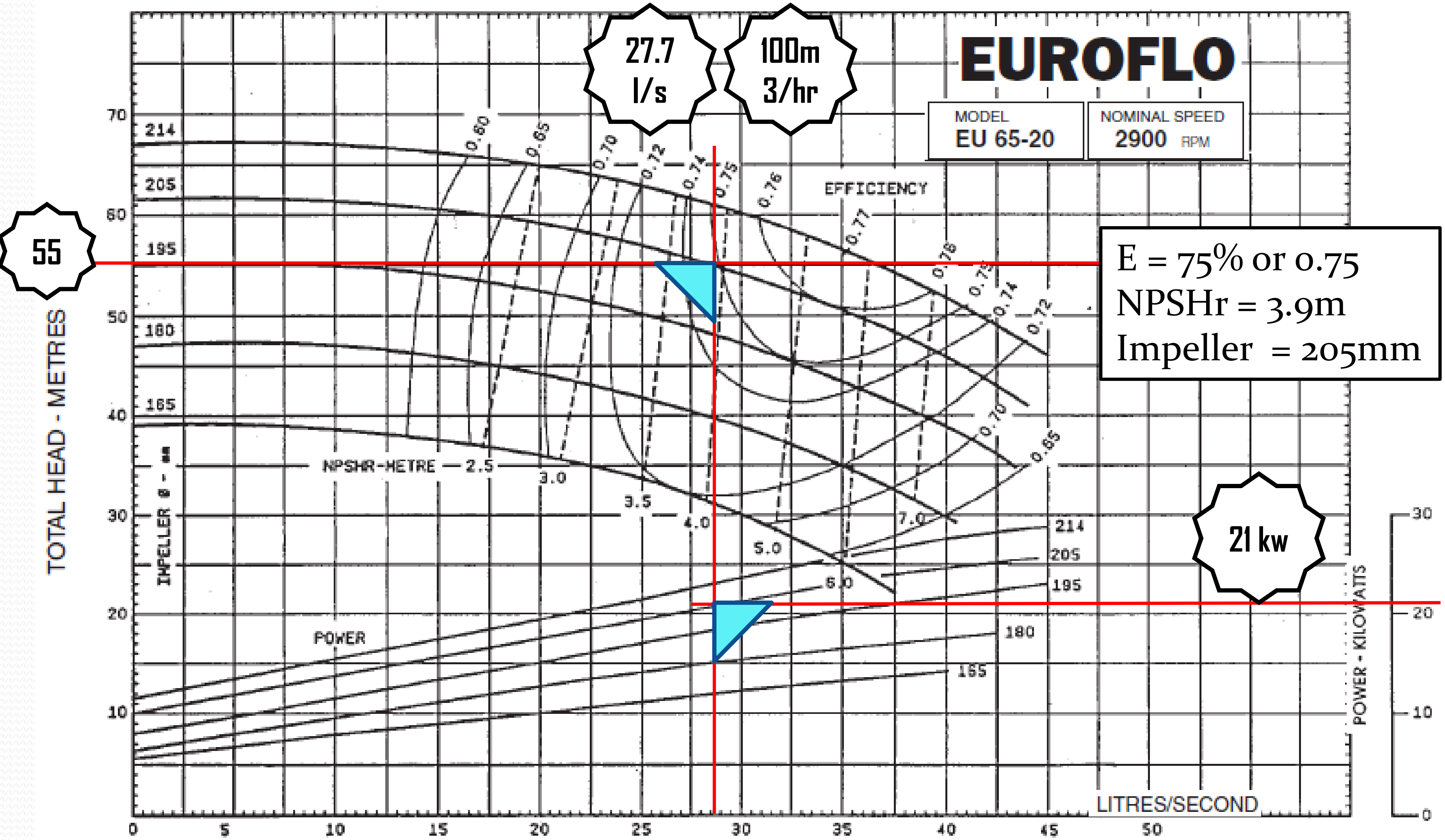


FIGURE 8

SYSTEM HEAD CURVE, STATIC HEAD PLUS FRICTION

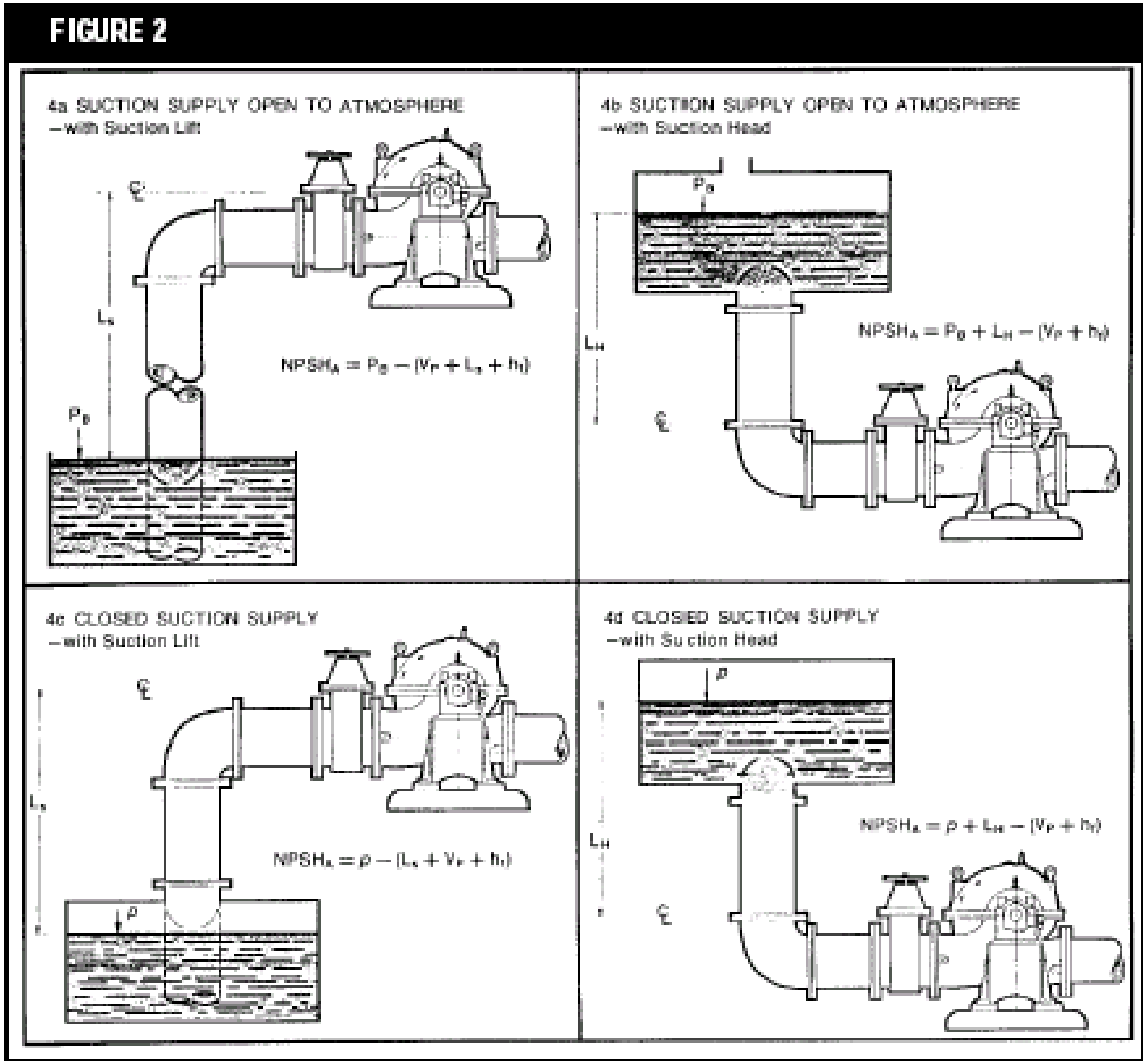


Overview of hydraulic selection requirement.

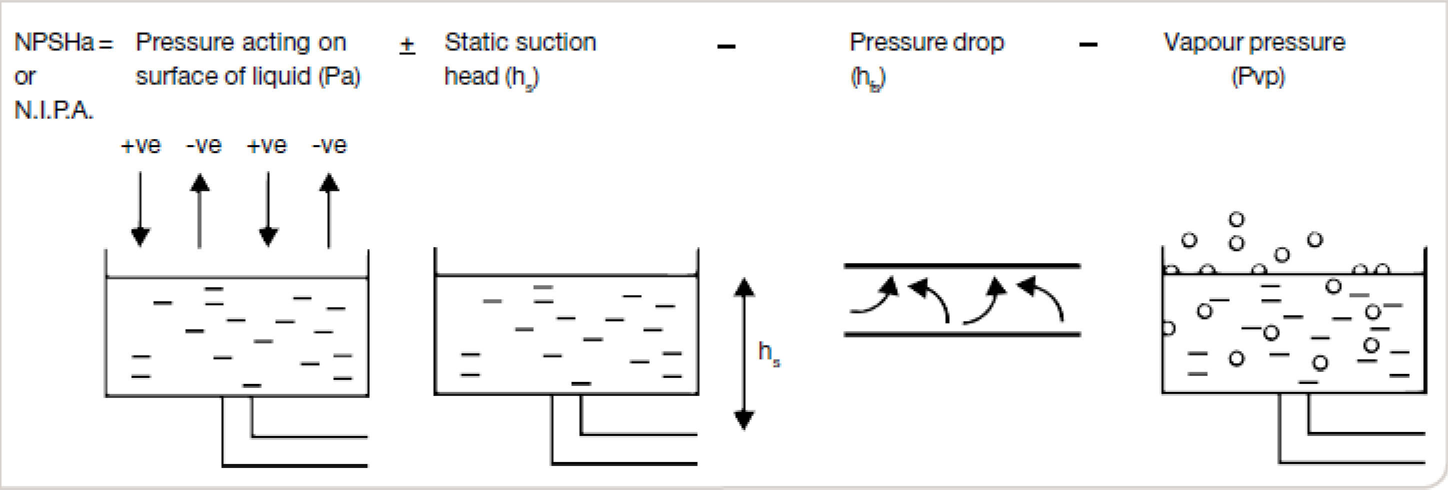


N.P.S.H_A VS N.P.S.H_R

- N.P.S.H_a – Net Positive Suction Head$_{Avaliable}$
  - Simply is the measure of the suction head to prevent the vaporization of fluid at the lowest pressure point in the pump as it goes thru the impeller.
- N.P.S.H_r – Net Positive Suction Head$_{Required}$
  - It is the function of the pump design. It various with speed and capacity and the figure is provide by the manufacture.
- The Rule – (N.P.S.H_A > N.P.S.H_R)+ safety margin
- Failure to comply will result in **CAVITATION**



Calculation of system net positive suction head available ($NPSH_A$) for typical suction conditions. P_B = barometric pressure in feet absolute, V_P = vapor pressure of the liquid at maximum pumping temperature in feet absolute, p = pressure on surface of liquid in closed suction tank in feet absolute, L_s = maximum suction lift in feet, L_H = minimum static suction head in feet, h_f = friction loss in feet in suction pipe at required capacity.



NPSHa or N.I.P.A. = Pa ± h_s - h_{fs} - Pvp

Where:

Pa	= Pressure absolute above fluid level (bar).
h_s	= Static suction head (m).
h_{fs}	= Pressure drop in suction line (m).
Pvp	= Vapour pressure (bar a).

Where:

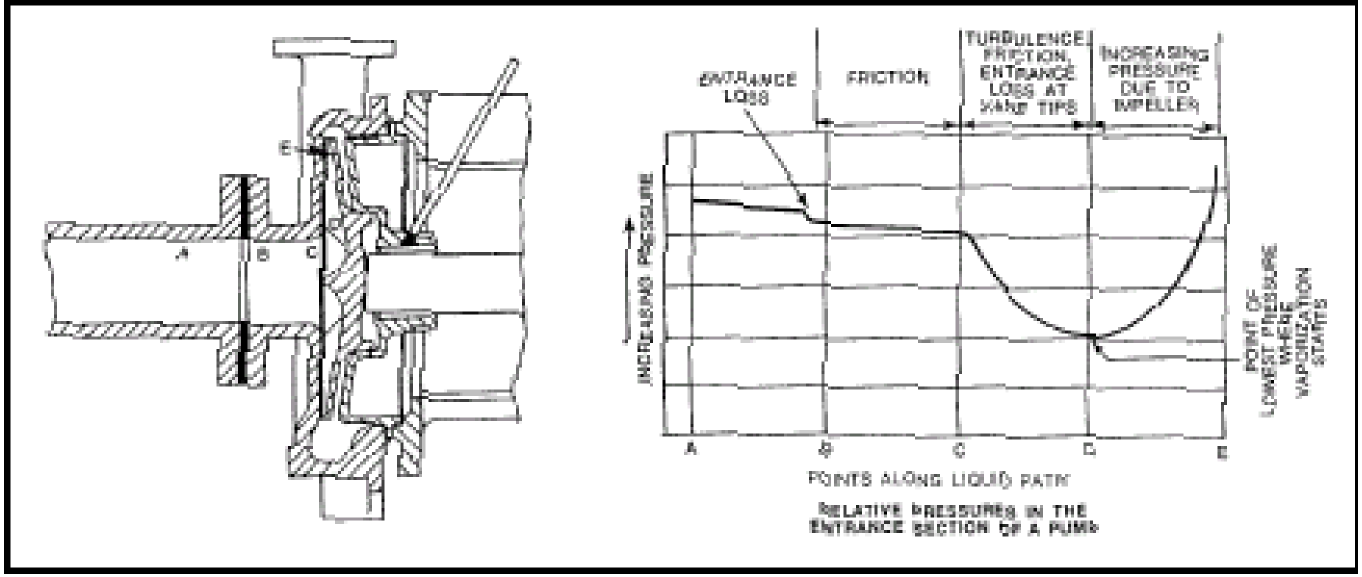
Pa	*= Pressure absolute above fluid level (psi).*
h_s	*= Static suction head (ft).*
h_{fs}	*= Pressure drop in suction line (ft).*
Pvp	*= Vapour pressure (psia).*

It is important the units used for calculating NPSHa or N.I.P.A. are consistent i.e. the total figures should be in m or *ft*.

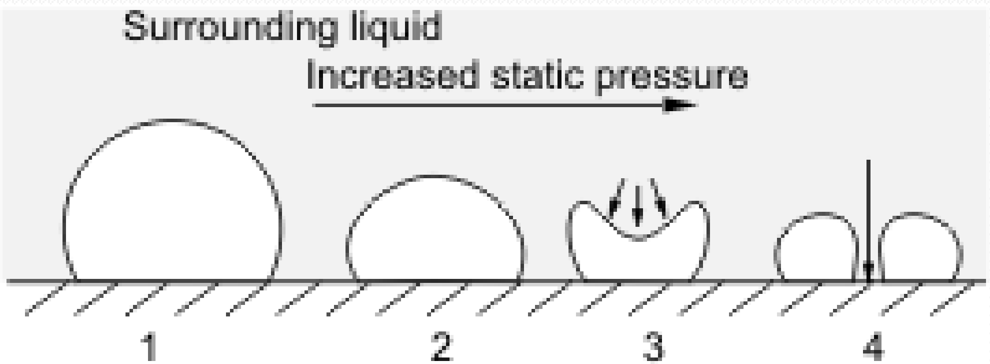
For low temperature applications the vapour pressure is generally not critical and can be assumed to be negligible.

What is Cavitation?

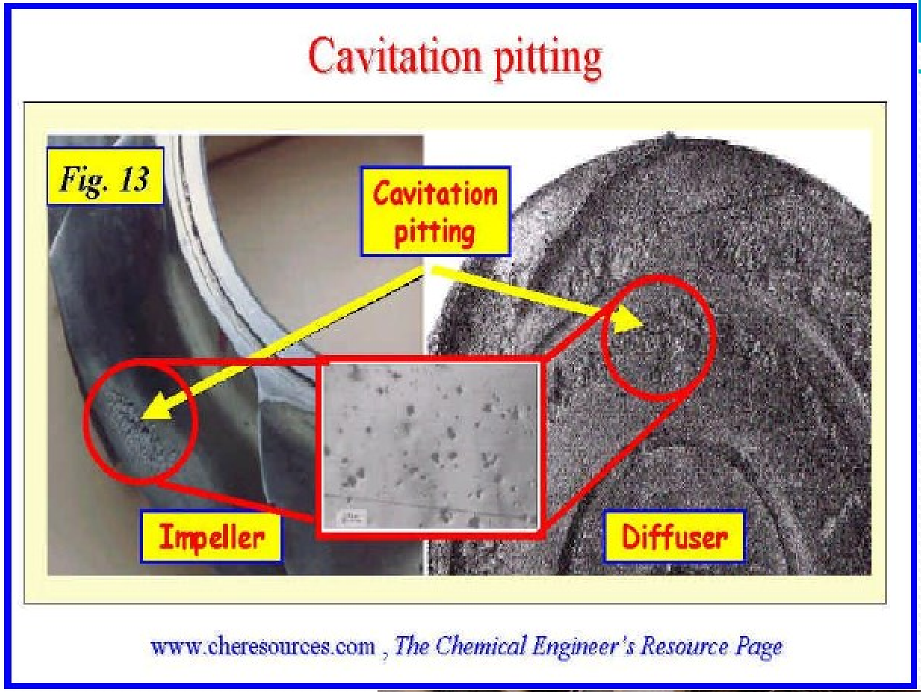
FIGURE 3

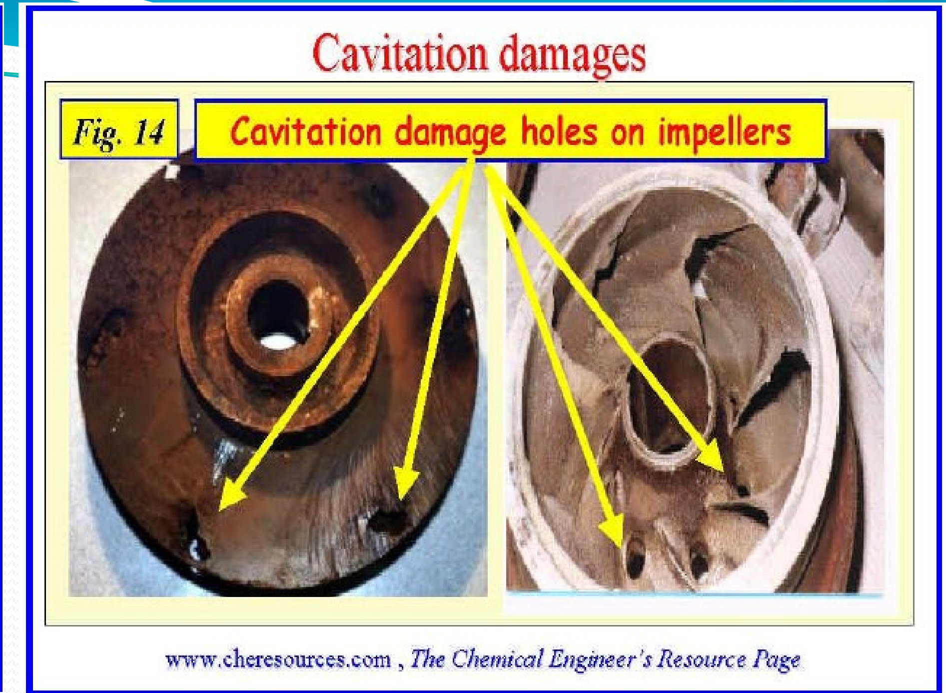


The pressure profile across a typical pump at a fixed flow condition.



Cavitation bubble imploding close to a fixed surface generating a jet (4) of the surrounding liquid.


Cavitation pitting
Fig. 13
Cavitation pitting
Impeller
Diffuser
www.cheresources.com , The Chemical Engineer's Resource Page


Cavitation damages
Fig. 14
Cavitation damage holes on impellers
www.cheresources.com , The Chemical Engineer's Resource Page

The **Hydraulic Horsepower (i.e. not considering efficiency losses) is expressed by the formula:**

HHP = (Q x H x SpGr) / 3960. (English Units)

HKW= (Q x H x SpGr) / 367. (Metric Units)

The **Brake Horsepower (i.e. including efficiency losses) is expressed by the formula:**

BHP = (Q x H x SpGr) / (3960 x E). Or

BKW= (Q x H x SpGr) / (367 x E) (metric)

where Q = Flow rate in GPM. or m3/hr (Metric)
H = Head in Feet. Or Meter (metric)
SpGr = Specific Gravity of the liquid pumped.
E = Efficiency of the pump.

Example:
Flow = 100m3/hr
Head is 55m, SpGr is 1.0,
Pump Efficiency is 75%
BKW = 100 x 55x 1.0 / 367 x .75 = 19.98 kw
– power absorted at the duty point.

Safety Factory for selecting motor

Motor Nameplate Rating		
HORSEPOWER (BHP)	KILOWATTS (BKW)	PERCENTAGE OF RATED PUMP POWER
≤ 25	≤ 18.5	125
30 - 75	22 - 55	115
≥ 100	≥ 75	110

Torque

Torque is defined as the moment of force required to produce rotation and is usually expressed in units of Nm (Newton metres), Kgfm (Kilogram metres) or '(')

It should be noted that PD pumps are basically constant torque machines and therefore it is important that the transmission chosen is capable of transmitting the torque required by the pump.
This is particularly important for variable speed drives which should be selected initially on torque rather than power.

Torque (Nm) =
Required power (kW) x 9550 / Pump speed (rev/min)
or
Torque (Kgfm) =
Required power (kW) x 974 / Pump speed (rev/min)
Or
Torque (ftlb) =
Required power (hp) x 5250 / Pump Speed (rev/min)

AFFINITY LAW

For change of speed N_1 to N_2

- New Flow(Q_2)
  - $Q_2 = Q_1 \times N_2 / N_1$
- New Head (H_2)
  - $H_2 = H_1 \times (N_2 / N_1)^2$
- New Power (P_2)
  - $P_2 = P_1 \times (N_2 / N_1)^3$

For change of Diameter D_1 to D_2

- New Flow(Q_2)
  - $Q_2 = Q_1 \times D_2 / D_1$
- New Head (H_2)
  - $H_2 = H_1 \times (D_2 / D_1)^2$
- New Power (P_2)
  - $P_2 = P_1 \times (D_2 / D_1)^3$

Reducing Impeller Diameter

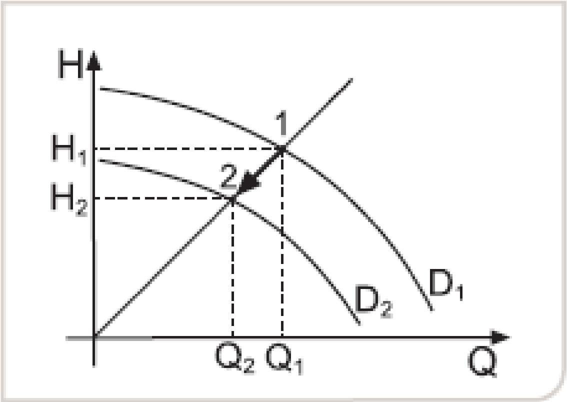


Fig. 7.3.2d Reducing impeller diameter

Diameter/capacity:

$$\frac{Q_1}{Q_2} = \frac{D_1^3}{D_2^3} \Rightarrow D_2 = D_1 \times \sqrt[3]{\frac{Q_2}{Q_1}} \text{ [mm]}$$

Diameter/head:

$$\frac{H_1}{H_2} = \frac{D_1^2}{D_2^2} \Rightarrow D_2 = D_1 \times \sqrt{\frac{H_2}{H_1}} \text{ [mm]}$$

Diameter/power:

$$\frac{P_1}{P_2} = \frac{D_1^5}{D_2^5} \Rightarrow D_2 = D_1 \times \sqrt[5]{\frac{H_2}{H_1}} \text{ [mm]}$$

Controlling Pump Speed

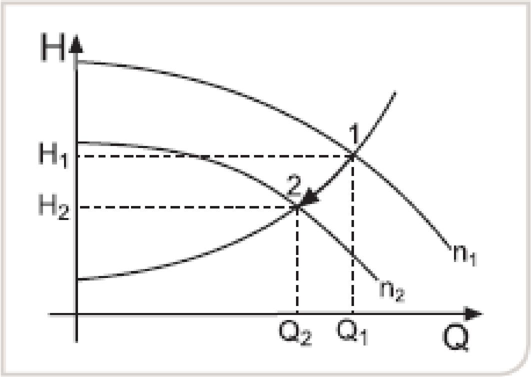


Fig. 7.3.2g Controlling pump speed

Speed/capacity:

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2} \Rightarrow n_2 = n_1 \times \frac{Q_2}{Q_1} \text{ [rev/min]}$$

Speed/head:

$$\frac{H_1}{H_2} = \frac{n_1^2}{n_2^2} \Rightarrow n_2 = n_1 \times \sqrt{\frac{H_2}{H_1}} \text{ [rev/min]}$$

Speed/power:

$$\frac{P_1}{P_2} = \frac{n_1^3}{n_2^3} \Rightarrow n_2 = n_1 \times \sqrt[3]{\frac{P_2}{P_1}} \text{ [rev/min]}$$

Speed control will not affect the efficiency providing changes do not exceed 20%.

Multi-stage Centrifugal Pump

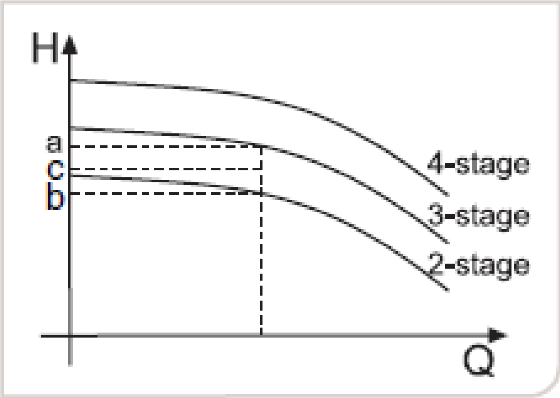


Fig. 7.3.2e Reducing impeller diameter

$$D_2 = D_1 \times \sqrt{\frac{c-b}{a-b}} \ [mm]$$

Where:

D_1 = Standard diameter before reducing.
a = Max. duty point.
b = Min. duty point.
c = Required duty point.

The formula is for guidance purposes only. It is, therefore, recommended to add a safety factor of 10-15% to the new diameter.

Throttling Discharge Line

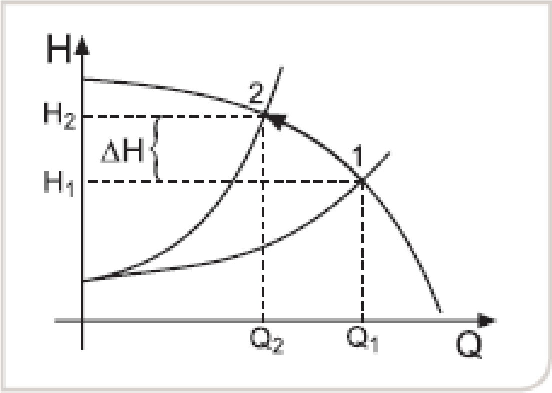


Fig. 7.3.2f Throttling discharge line

Pumps Coupled in Series

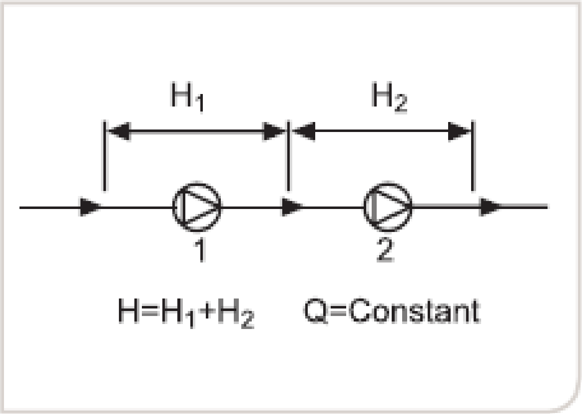
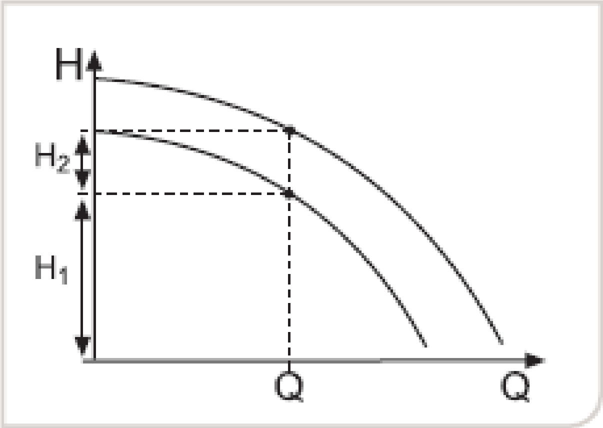


Fig. 7.3.3a Principle of connection

The capacity (Q) will always be constant throughout the pump series. The head can vary depending on the pump sizes.

The outlet of pump 1 is connected to the inlet of pump 2. Pump 2 must be able to withstand the outlet head from pump 1.



If two different pumps are connected in series, the pump with the lowest NPSH value should be installed as the first pump (for critical suction conditions).

The capacity in the pump installation should not exceed the max. capacity of the smallest pump. Otherwise there will be a pressure drop in the smallest pump.

A multi-stage centrifugal pump is in principle several pumps that are coupled in series but built together as one pump unit.

Pumps Coupled in Parallel

The head (H) will always be constant in the pump installation. The capacity can vary depending on the pump sizes.

The pumps receive the fluid from the same source and have a common discharge line.

When the capacity is increased by means of pumps coupled in parallel, the equipment and pressure drop in the installation must be determined according to the total capacity of the pumps.

For two different pumps, If the capacity Q_1 is smaller than the capacity Q_2, it is possible to install a non-return valve in the discharge line of pump 1 to avoid pump 2 pumping fluid back through pump 1.

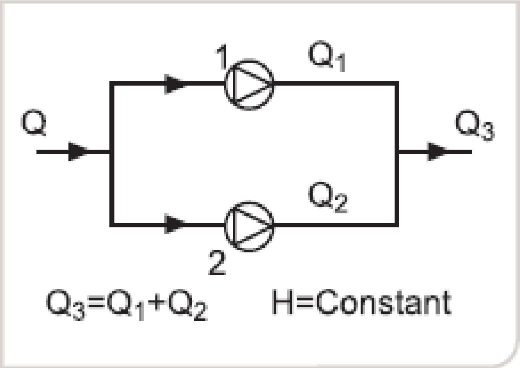


Fig. 7.3.3c Principle of connection

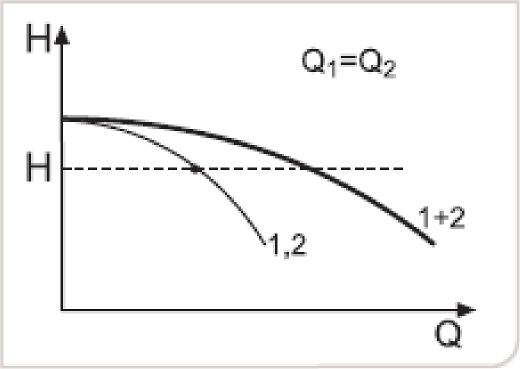


Fig. 7.3.3d Connection of two similar pumps

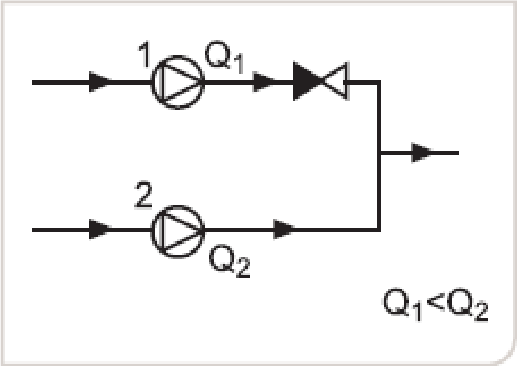


Fig. 7.3.3f Connection of two different pump sizes

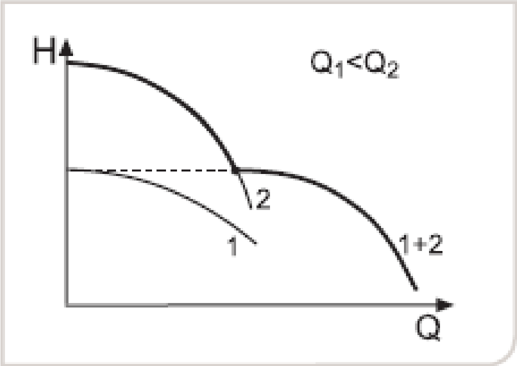


Fig. 7.3.3e Connection of two different pumps

Water Hammer

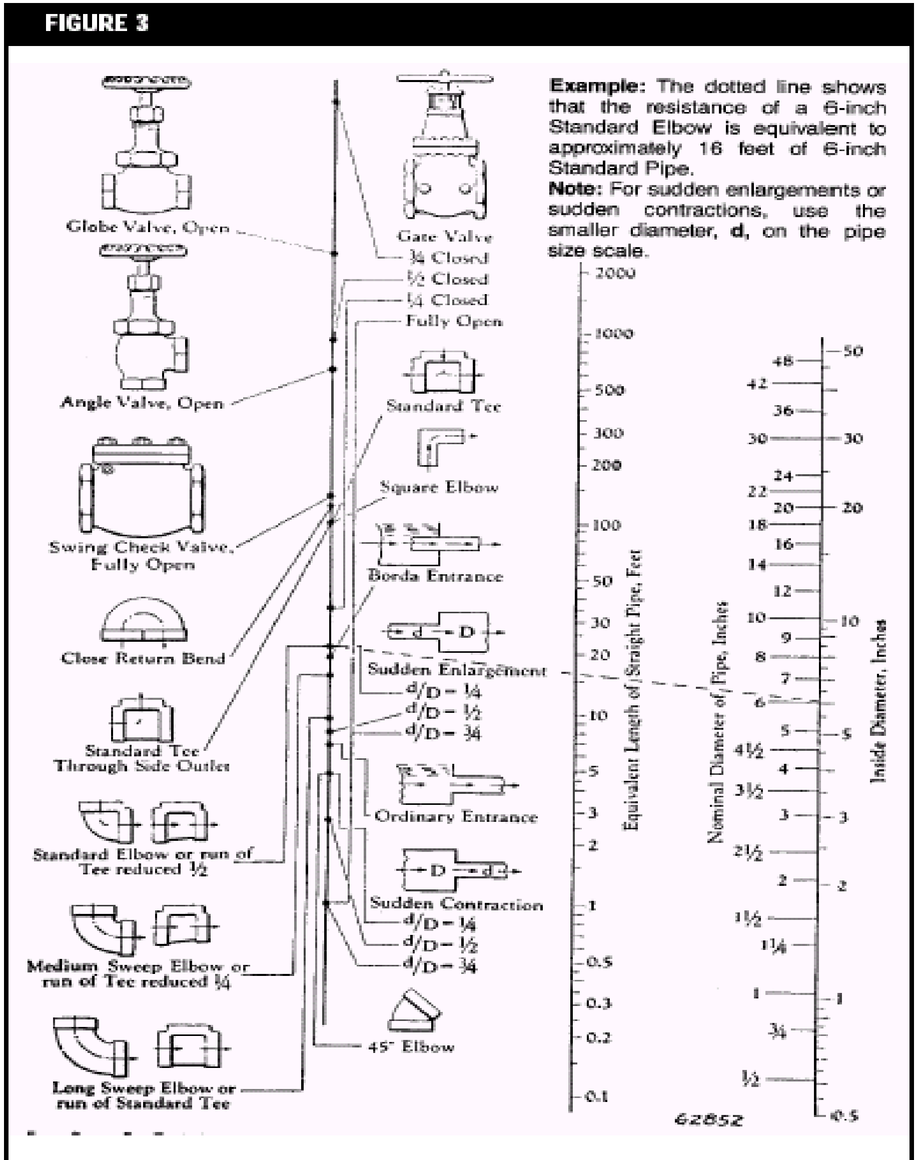
The pressure shock is really a pressure wave with a velocity of Propagation much higher than the velocity of the flow, often up to 1400 m/s for steel tubes.

The following causes changes in fluid velocity:

- Valves are closed or opened.
- Pumps are started or stopped.
- Resistance in process equipment such as valves, filters,meters, etc.
- Changes in tube Dimensions.
- Changes in flow direction.

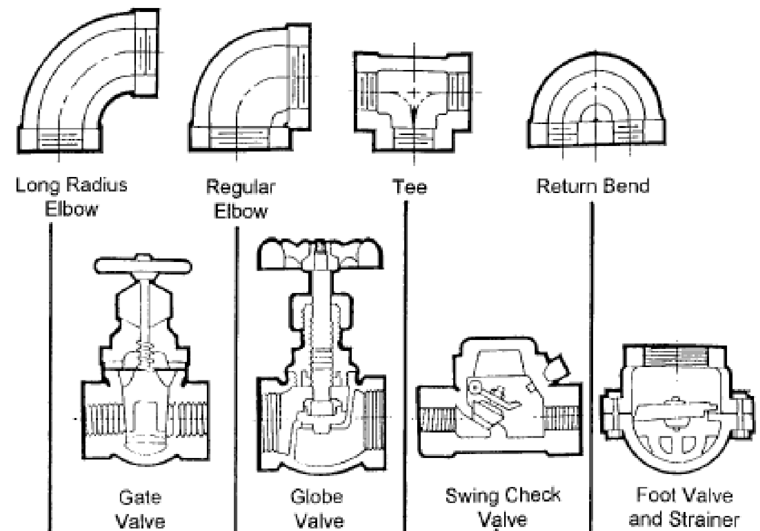
Effects of pressure waves:

- Noise in the tube.
- Damaged tube.
- Damaged pump, valves and other equipment.
- Cavitation.



Resistance of valves and fittings to flow of fluids in equivalent length of pipe *(Hydraulic Institute Standards)*

METRIC - FRICTION LOSS FOR VALVES AND FITTINGS



Pipe Size mm	Long Radius Elbow	Gate Valve	Regular Elbow	Globe Valve	Tee	Swing Check Valve	Return Bend	Foot Valve and Strainer
20	0.3	0.3	0.5	6.7	1.5	1.5	1.5	1.5
25	0.3	0.3	0.5	8.2	1.8	2.0	2.0	2.3
32	0.3	0.6	0.8	11.3	2.4	2.6	2.6	2.7
40	0.4	0.6	0.9	13.4	2.7	3.1	3.1	3.4
50	0.5	0.8	1.1	17.4	3.4	4.0	4.0	4.6
65	0.6	0.9	1.4	20.1	4.3	5.2	4.6	5.5
80	0.8	1.1	1.5	26.0	5.2	6.1	5.5	6.7
100	1.1	1.5	2.1	34.0	6.7	8.2	7.3	8.8
125	1.2	1.8	2.7	43.0	8.2	10.0	9.5	11.0
150	1.5	2.1	3.4	49.0	10.0	12.2	11.0	14.0
200	2.1	3.1	4.3	67.0	13.4	16.5	15.0	18.0
250	2.4	3.7	5.5	85.4	16.5	20.0	19.0	22.0

Equivalent length of straight pipe in meters.

➜ **Note:** No allowance has been made for the age of the pipe, differences in inside diameters, and condition of inside surfaces. Safety factors used should be based upon local conditions, previous experience, and installation requirements.

Figure 5 Equivalent Length of Straight Pipe in Meters for Calculating Friction Loss