Fluid

A continuous, amorphos substance whose molecules move freely past one another and that has the tendency to assume the shape of its container; a liquid or gas.

Density

Density of a fluid is defined as the ratio of mass of fluid to its volu

Density or mass density

$$\rho = \frac{m}{V}$$

$$\text{weight density} = \frac{W}{V} = \frac{mg}{V} = \rho g$$

Specific Weight

- Specific weight or weight density of a fluid is the ratio between the weight of a fluid to its volume.
- It is denoted by w

Mathematically,

$$w = \frac{\text{Weight of fluid}}{\text{Volume of fluid}}$$

$$= \frac{(\text{Mass of fluid}) \times \text{Acceleration due to gravity}}{\text{Volume of fluid}}$$

$$= \frac{\text{Mass of fluid} \times g}{\text{Volume of fluid}}$$

$$\boxed{W = \rho \times g}$$

Specific Gravity

It is the ratio of density or weight density of a given fluid to the density or weight density of a standard fluid.

$$S = \frac{\text{Density / wt. density of given fluid}}{\text{Density / wt. density of standard fluid}}$$

$$S_{liq} = \frac{\text{Density / wt. density of given liquid}}{\text{Density or wt. density of water}}$$

$$\boxed{\rho = S \times 1000}$$

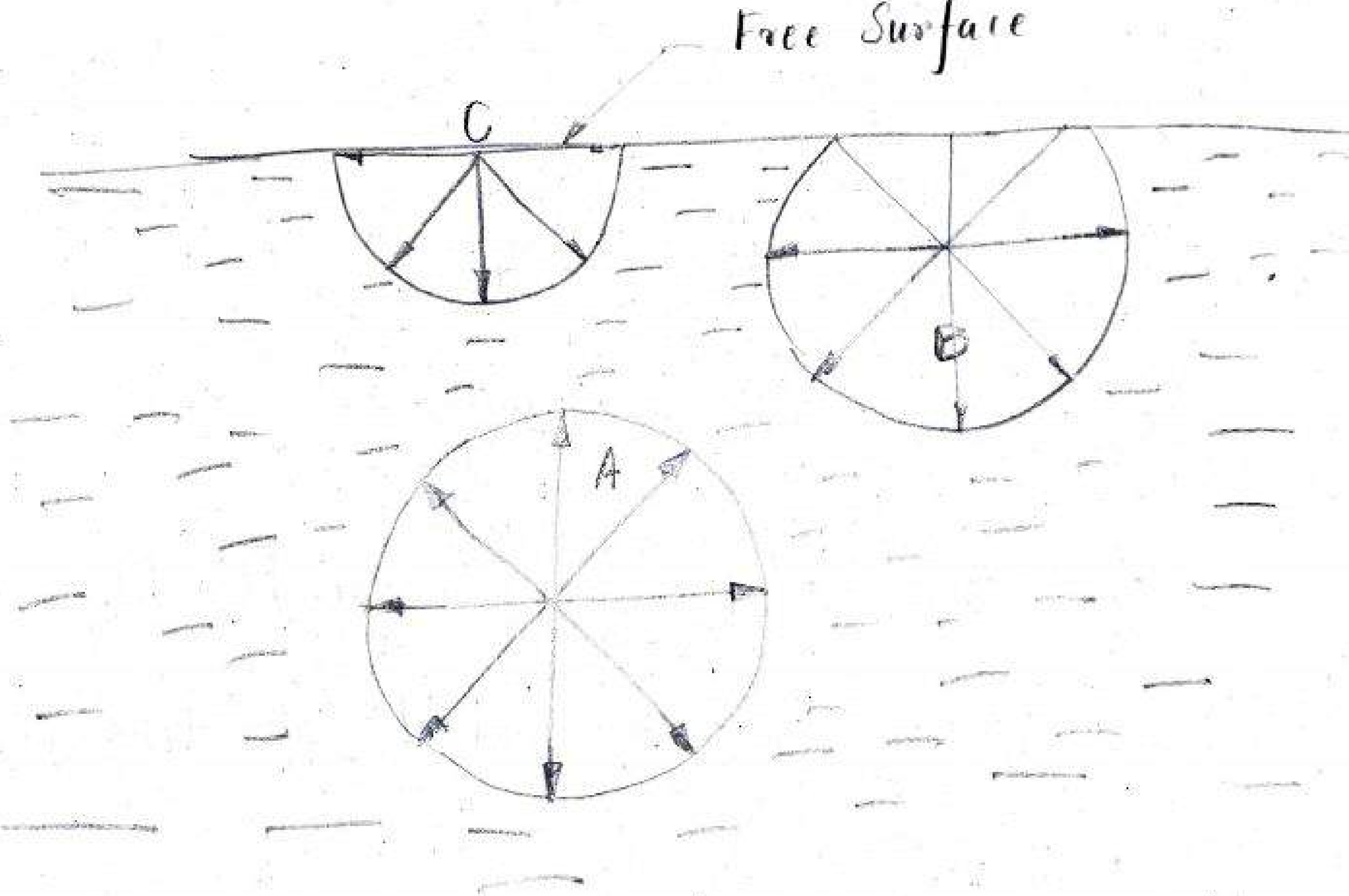
Specific Volume

- The volume of a fluid occupied by a unit mass or volume per unit mass of a fluid is called specific volume.

$$\text{Specific volume} = \frac{\text{Volume of fluid}}{\text{Mass of fluid}}$$

$$= \frac{1}{\dfrac{\text{Mass of fluid}}{\text{Volume of fluid}}}$$

$$= \frac{1}{\rho}$$



Free Surface
C
B
A

Surface Tension

Surface tension is defined as the tensile force acting on the surface of a liquid in contact with a gas or on the surface between two immiscible liquid such that the contact surface behaves like a membrane under tension.

Surface Tension of a liquid droplet

Consider a small spherical droplet of a liquid of radius are let-

σ = Surface tension of liquid

p = pressure intencity inside the droplate.

d = dimeter of droplate.

Tensile force due to surface tension acting around the circumference of the cut portion $= \sigma \times \pi d$

Pressure force on the area (F) $= p \times \frac{\pi}{4} d^2$

for equilibrium $= p \times \frac{\pi}{4} d^2$

$= \sigma \times \pi d$

$\Rightarrow p = \frac{4\sigma}{d}$

Surface tension on a hollow bobble

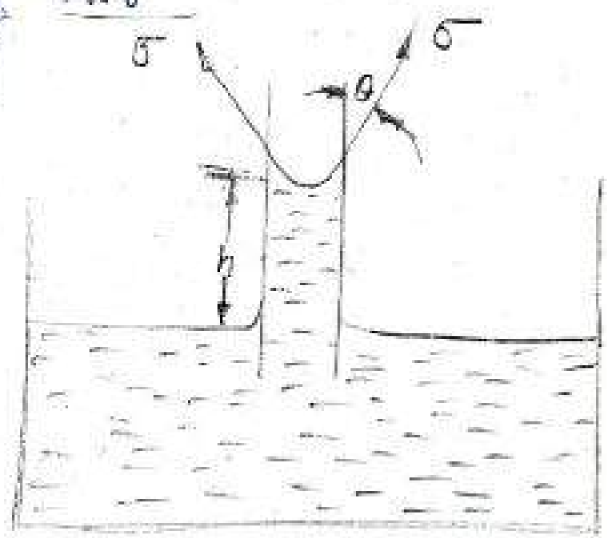
Pressure force on the area (F) $= p \times \frac{\pi}{4} d^2$

for equilibrium $= p \times \frac{\pi}{4} \times d^2$

Capillarity —

It is denoted by as the phenomenon of rise or fall of a liquid surface in a small tuble related to the adjecent general level of liquid when the tube is held vertically in the liquid.

Expression for capillary rise



$$h = \frac{4\sigma}{\rho g d}$$

$$h = \frac{4\sigma \cos\theta}{\rho g d}$$

Q// Calculate the capilary rise in a glass tube of 2.5mm diameter when emerged vertically in i) Water, ii) Mercury

Take surface tension 0.0725 N/m for water and 0.52 N/m for mercury.

The angle of contact for mercury 130°.

6/ The capillary rise in the glass tube is not exercised 0.2mm of water. Determine its minimum size given that surface tension for water in contact with air is 0.0725 N/m.

given,

$h = 0.2mm$

$= 0.0002m$

$\sigma = 0.0725 \ N/m$

We know that,

$$h = \frac{4\sigma}{\rho g d}$$

$$h\rho g d = 4\sigma$$

$$\Rightarrow d = \frac{4\sigma}{h\rho g} = \frac{4 \times 0.0725}{0.0002 \times 1000 \times 9.8}$$

$$= 0.147 \ m$$

=

$d = 2.5 mm$

$= 0.0025 m$

for water,

$\sigma = 0.0725 \ N/m$

$\rho = 1000$

$$h = \frac{4 \times 0.0725}{1000 \times 9.8 \times 0.0025}$$

$= 0.011 m$

for mercury,

$\sigma = 0.52 \ N/m$

$\rho = 13.6 \times 1000$

$= 13600$

$$h = \frac{4 \times 0.52 \times \cos 130^\circ}{13600 \times 9.8 \times 0.0025}$$

$= -0.004 m$

Q/ Calculate the capilary effect in a glass tube of 4mm diameter when emerged in i) Water, ii) Mercury

The surface tension of water and mercury with are 0.073575 N/m and 0.51 N/m. The angle of contact for water is 0. and for the mercury is 130°. Take density of water 998 kg/m³.

Given,

$d = 4mm$

$= 0.004m$

for water,

$\sigma = 0.07357$

$\rho = 998 \ kg/m^3$

$$h = \frac{4 \times 0.073575}{998 \times 9.8 \times 0.004}$$

$= 0.007 \ m$

for mercury,

$$h = \frac{4 \times 0.51 \times \cos 130^\circ}{13600 \times 9.8 \times 0.004}$$

$= -0.0024 \ m$

Newton's Law of Viscosity

It states that the shear stress fluid element layer is directly propessonal to the rate of shear strain.

$$\tau \propto \frac{du}{dy}$$

$$\Rightarrow \tau = \mu \frac{du}{dy}$$

μ → Viscosity

Ideal fluid

A fluid which is incompressible and having no viscosity is called ideal fluid.

Real fluid

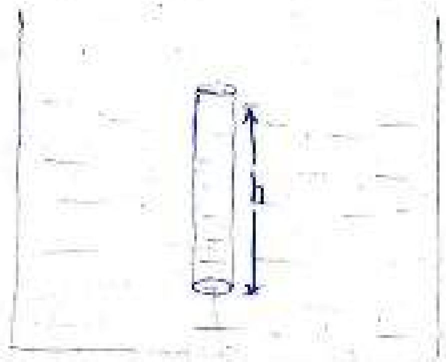
A fluid which poses viscosity is known as real fluid.

SI = $N.S/m^2$

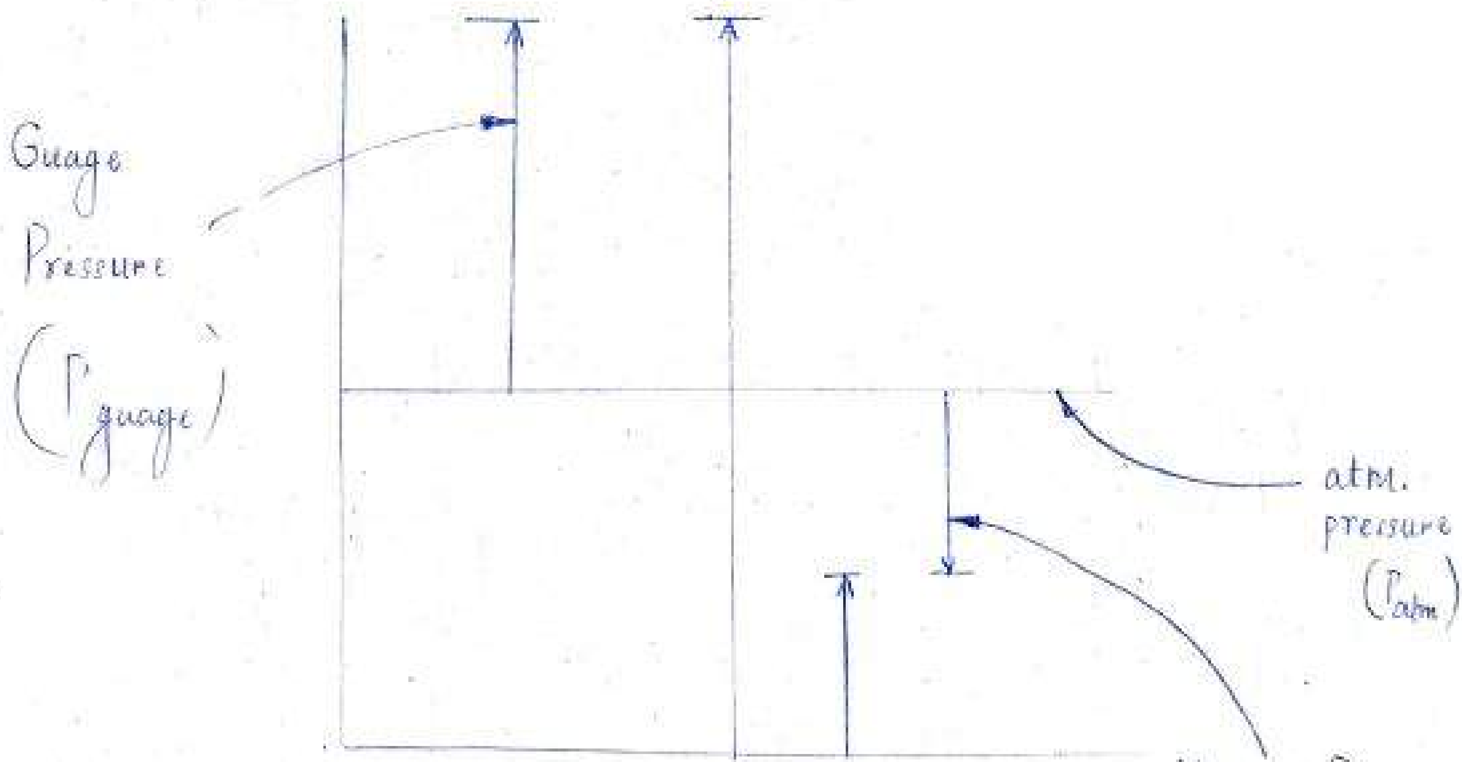
CGS = $Dyne.S/cm^2$

$1\ Dyne\text{-}S/cm^2 = 1$ Poise

Pressure at any point in liquid



$$P = \rho g h$$



$$P_{abs} = P_{atm} + P_{gauge}$$

$$P_{abs} = P_{atm} - P_{vacuum}$$

Pressure Measuring Device

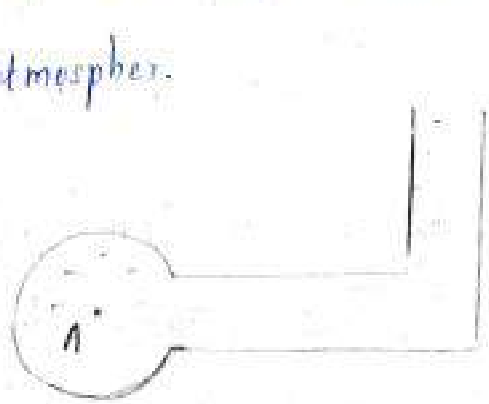
Manometer.

Simple
- Piezometer
- Simple U-tube manometer
- Single Column manometer

Diferenti
- Differential U-tube Manometer
- Inverted U-tube Manometer

Piezometer

It is the simplest form of manometer it consist of a glass tube in which one end is connected to a point where the pressure is to be measure and other end remains open to the atmospher.

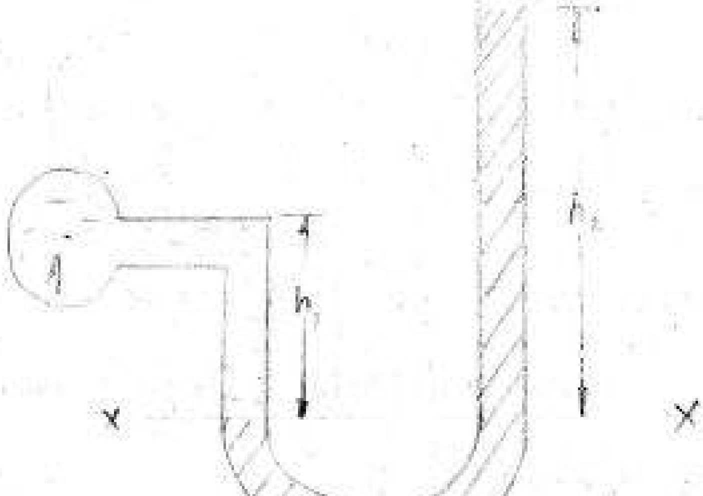


pressure at point A. $\boxed{P_A = \rho g h}$

Simple U-tube manometer

It consist of a glass-tube bent in 'U' shape in which one end is connected to a point where the pressure is to be measured and other end remains open to the atmosphere

Here, we take a liquid having greater specific gravity then the given liquid.



In this type of manometer we can measure the pressure by balancing the two columns of manometer.

Let

ρ_1 = density of given liquid

ρ_2 = density of heavy liquid

h_1 = rise of height of given liquid

h_2 = rise of height of heavy liquid

Total pressure in left column = $P_A + \rho_1 g h_1$

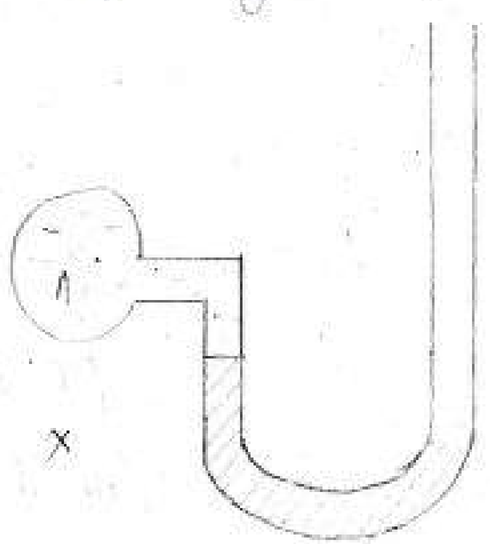
right column = $\rho_2 g h_2$

We know that pressure is same at all point in free surface.

So,

$$\underset{(L)}{P_A + \rho_1 g h_1} = \underset{(R)}{\rho_2 g h_2}$$

$$\Rightarrow P_A = \rho_2 g h_2 - \rho_1 g h_1$$



(for vacuum pressure)

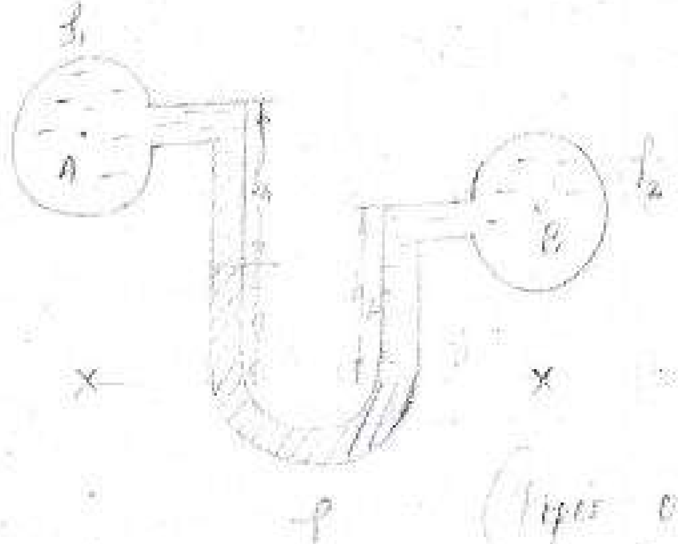
(L) (R)

$= P_A + \rho_1 g h_1 + \rho_2 g h_2 = 0$

$\Rightarrow P_A = -(\rho_1 g h_1 + \rho_2 g h_2)$

Differential 'U' Tube manometer

It is used to measure the difference of pressure in a single-pipe or in two different pipes.



(Pipes of different level)

Let ρ_1 = density of liquid in pipe A

ρ_2 = density of liquid in pipe B

ρ = density of heavy liquid

h_1 - rise of height of liquid in pipe A
h_2 = rise of height of liquid in pipe B
h = rise of height of heavy liquid

Total pressure of left limb

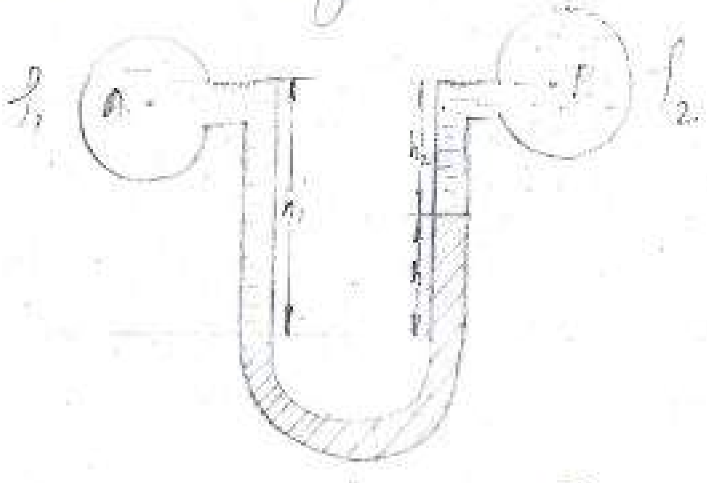
$$= P_A + \rho_1 g h_1 + \rho g h$$

Total pressure of right limb

$$= P_B + \rho_2 g h_2$$

As the pressure is same at all the points in free surface so left side pressure must be equal with right side pressure.

$$\Rightarrow P_A - P_B = \rho_2 g h_2 - (\rho_1 g h_1 + \rho g h)$$



(L) (R)

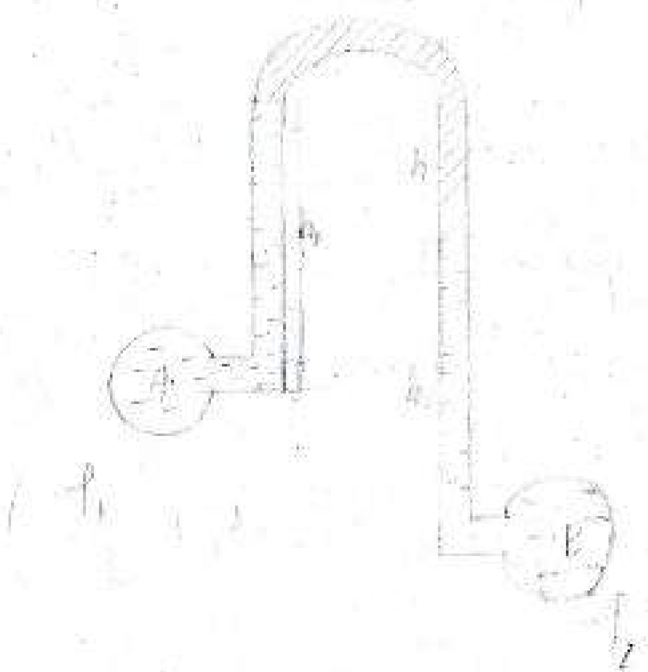
$$P_A + \rho_1 g h_1 = P_B + \rho_2 g h_2 + \rho g h$$

$$\Rightarrow P_A - P_B = \rho_2 g h_2 + \rho g h \; (-\rho_1 g h_1)$$

Inverted 'U'-tube manometer

It is used to measure the low-pressure different ~~pipes~~ in a pipe or ~~into~~ two different pipes.

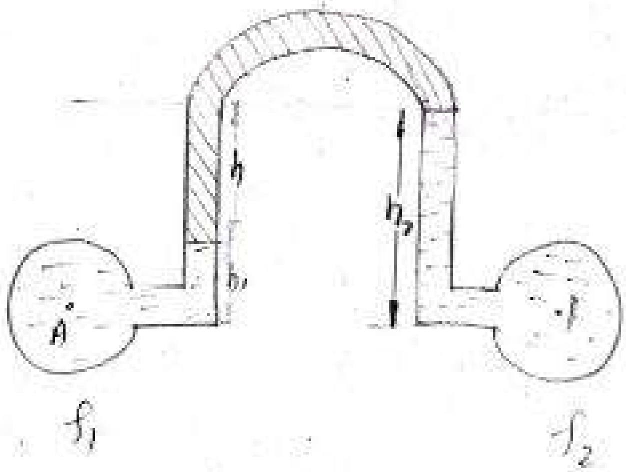
Here, we use a liquid having sp. gr lower than that flowing in the pipes.



(L)

$$P_A - \rho_1 g h_1 = P_B - \rho_2 g h_2 - \rho g h$$

$$\Rightarrow P_A - P_B = \rho_1 g h_1 - (\rho_2 g h_2 + \rho g h)$$



(L)

(R)

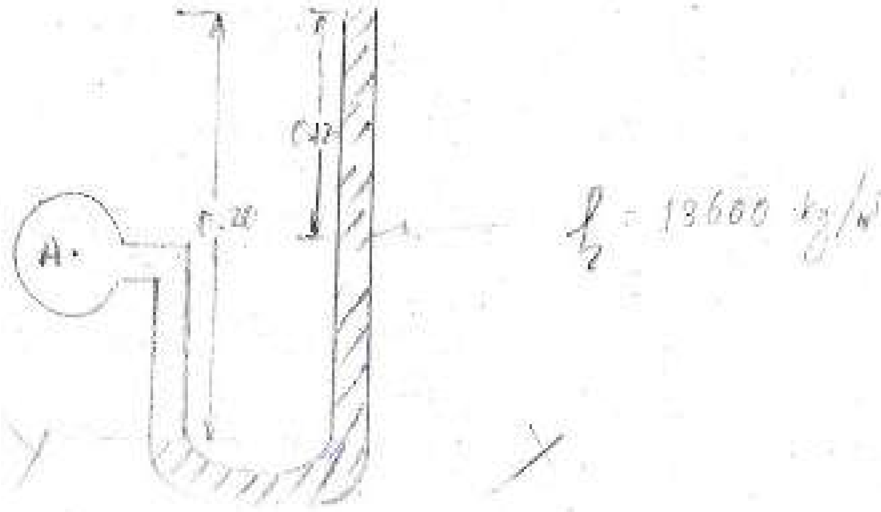
$P_A - \rho_1 g h_1 - \rho g h$ $\qquad$ $P_B - \rho_2 g h_2$

$\Rightarrow P_A - P_B = \rho_2 g h_2 - \rho_1 g h_1 - \rho g h$

Q//

This right limb of a simple U-tube ~~momen~~ manometer containing mercury is open to the ~~component~~ atmosphere while the left limb is connected to a pipe in which a fluid of specific gravity 0.9 flowing.
The centre of the pipe is 12 cm below the level ~~by~~ of mercury in right limb.
Find the pressure of fluid ~~of~~ in the pipe ~~of~~ if

the difference of mercury level in the two limbs is 20 cm.

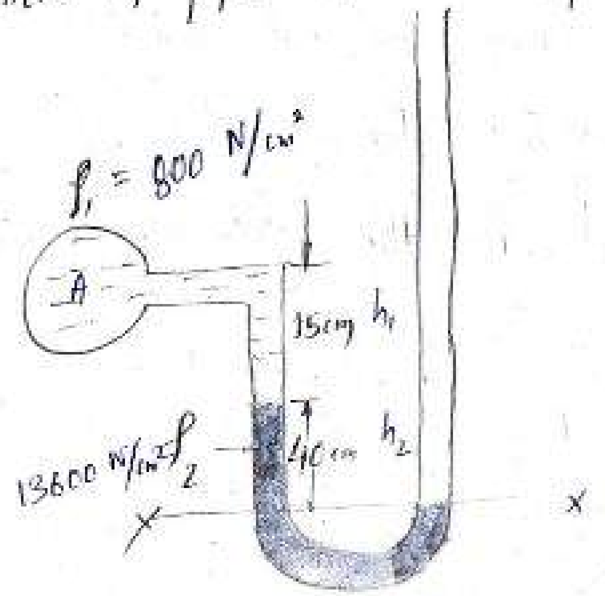


$$P_A + (900 \times 9.81 \times 0.08) = (13600 \times 9.81 \times 0.2)$$

$$\Rightarrow P_A = (13600 \times 9.81 \times 0.2) - (900 \times 9.81 \times 0.08)$$

$$= 25977\ N/m^2$$

Q// A simple U-tube manometer containing mercury ~~containing~~ connected to a pipe in which ~~containing~~ fluid of specific gravity 0.8 and heavy vacuum pressure is flowing the other and of the manometer is open to the atmosphere. Find the vacuum pressure in pipe if the difference of mercury level in the two limbs to 40 cm and the height of fluid in the left from the centre of pipe in 15 cm below.



(L) (R)

$P_A + \rho_1 g h_1 + \rho_2 g h_2 = 0$

$\Rightarrow P_A = -(\rho_1 g h_1 + \rho_2 g h_2)$

$= -((0.8 \times 1000) \times 9.81 \times 0.15) + ((13.6 \times 1000) \times 9.81 \times 0.4)$

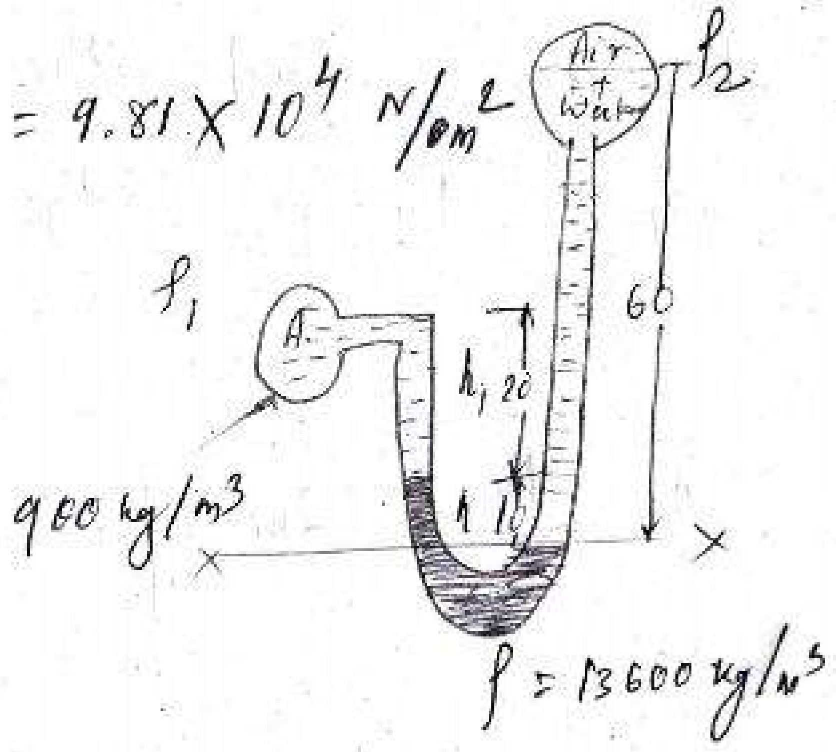
$= -\{(800 \times 9.81 \times 0.15) + (13600 \times 9.81 \times 0.4)\}$

$= -54543.6\ N/cm^2$

Q// A differential manometer is connected as the two points A and B of two pipes as shown in figure. the pipe A contains a

Q/ A differential manometer is connected at the two points A and B as shown in fig at B air pressure is 9.81 N/cm^2 (abs). Find the absolute pressure at A.

$P_B = 9.81 \times 10^4 \ N/m^2$



$$P_A + \rho_1 g h_1 + \rho g h = P_B + \rho_2 g h_2$$

$$\Rightarrow P_A + (900 \times 9.81 \times 0.2) + (13600 \times 9.81 \times 0.1)$$

$$= P_B + (0.6 \times 9.81 \times 1000)$$

$$\Rightarrow P_A + (1765.8 + 13341.6) = P_B + 5886$$

$$\Rightarrow P_A + 15107.4 = 9.81 \times 10^4 + 5886$$

$$\Rightarrow P_A + 15107.4 = 103986$$

$$\Rightarrow P_A = 103986 - 15107.4$$

$$= 88878.6 \ N/m^2$$

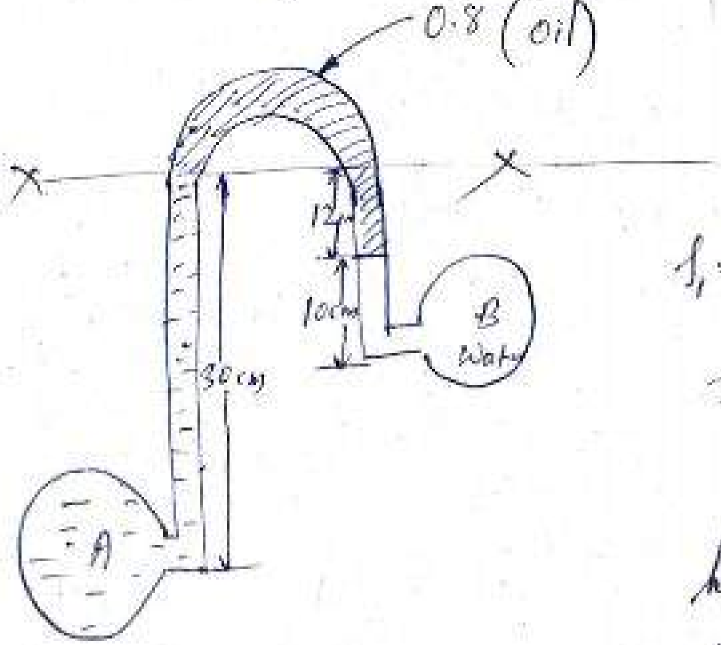
2.18 Water is flowing through two different pipes to which an inverted different manometer having an oil of sp. gr. 0.8 is connected. The pressure head in the pipe A is 2m of water, find the pressure in the pipe B for the manometer reading.

$$A = \frac{P_A}{\rho g} = 2m \text{ of water}$$

$\Rightarrow P_A = A \times \rho g$

$= 2 \times 1000 \times 9.81$

$= 19620\ N/m^2$



$\rho_1 = \rho_2 = 1000\ kg/m^3$

$\rho = 0.8 \times 1000$

$= 8000\ kg/m^3$

$h_1 = 0.3\ m$

$h_2 = 0.1\ m$

$h = 0.12\ m$

(L) (R)

$P_A - \rho_1 g h_1 = P_B - \rho_2 g h_2 - \rho g h$

$\Rightarrow P_A - (1000 \times 9.81 \times 0.3) = P_B - (1000 \times 9.81 \times 0.1) - (800 \times 9.81 \times 0.12)$

$\Rightarrow P_A - 2943 = P_B - 981 - 941.76$

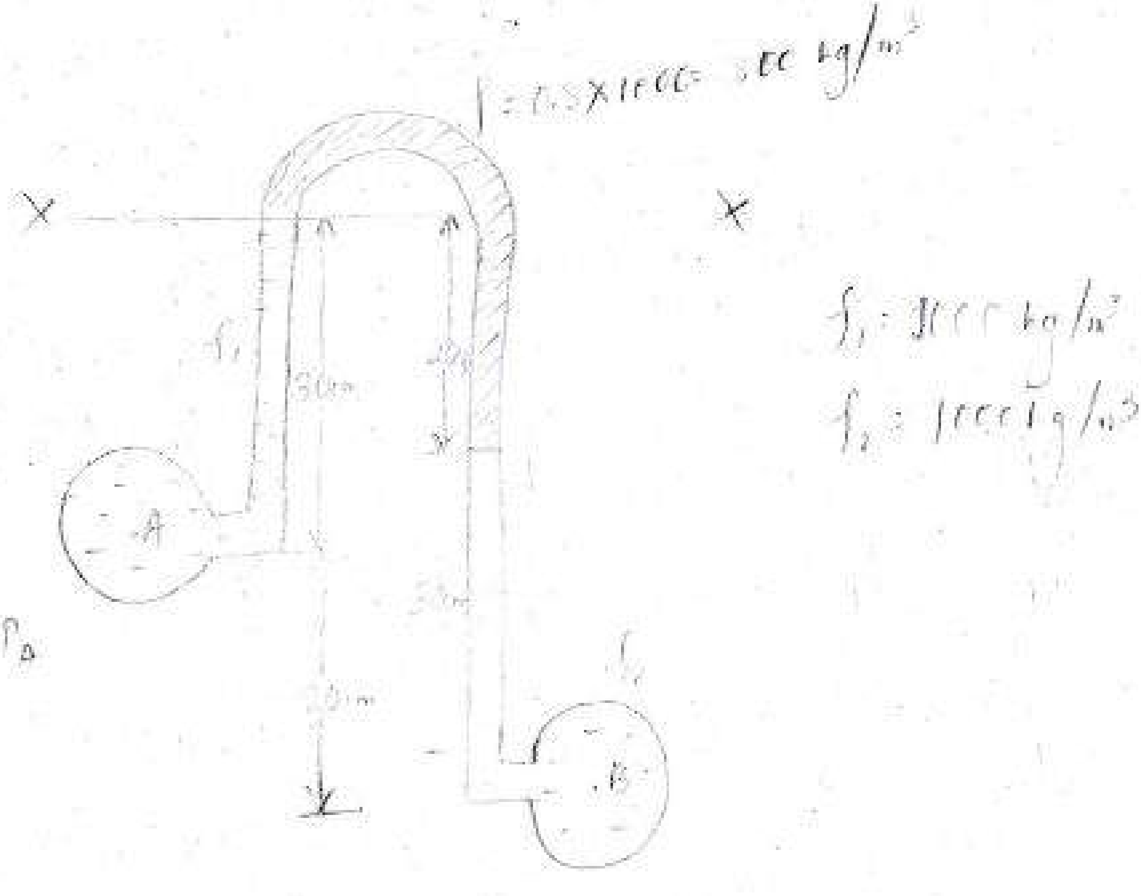
$\Rightarrow 19620 - 2943 = P_B - 1922.76$

$\Rightarrow$ ~~16677~~ $= P_B = 16677 + 1922.76$

$=$ ~~14754.24~~ $18599.76\ N/m^2$

2.19

An inverted differential manometer is connected to two pipes A and B which convey water. The fluid in manometer is oil of sp. gr. 0.8 For the manometer readings shown in the figure. Find the pressure difference between A and B.



Given

s.p. gr. = 0.8

$\rho_s = 0.8 \times 1000 = 800\ kg/m^3$

(L) (R)

$$P_A - \rho_1 g h = P_B - \rho_2 g h_2 - \rho g h$$

$$\Rightarrow P_A - 1000 \times 9.81 \times 0.3 = P_B - (1000 \times 9.81 \times 0.3) - (800 \times 9.81 \times 0.2)$$

$$\Rightarrow P_A - 2943 = P_B - 2943 - 1569.5$$

~~$\Rightarrow P_A - P_B = 2943 - 4512.6$~~

$$\Rightarrow P_A - 2943 = P_B - 4512.6$$

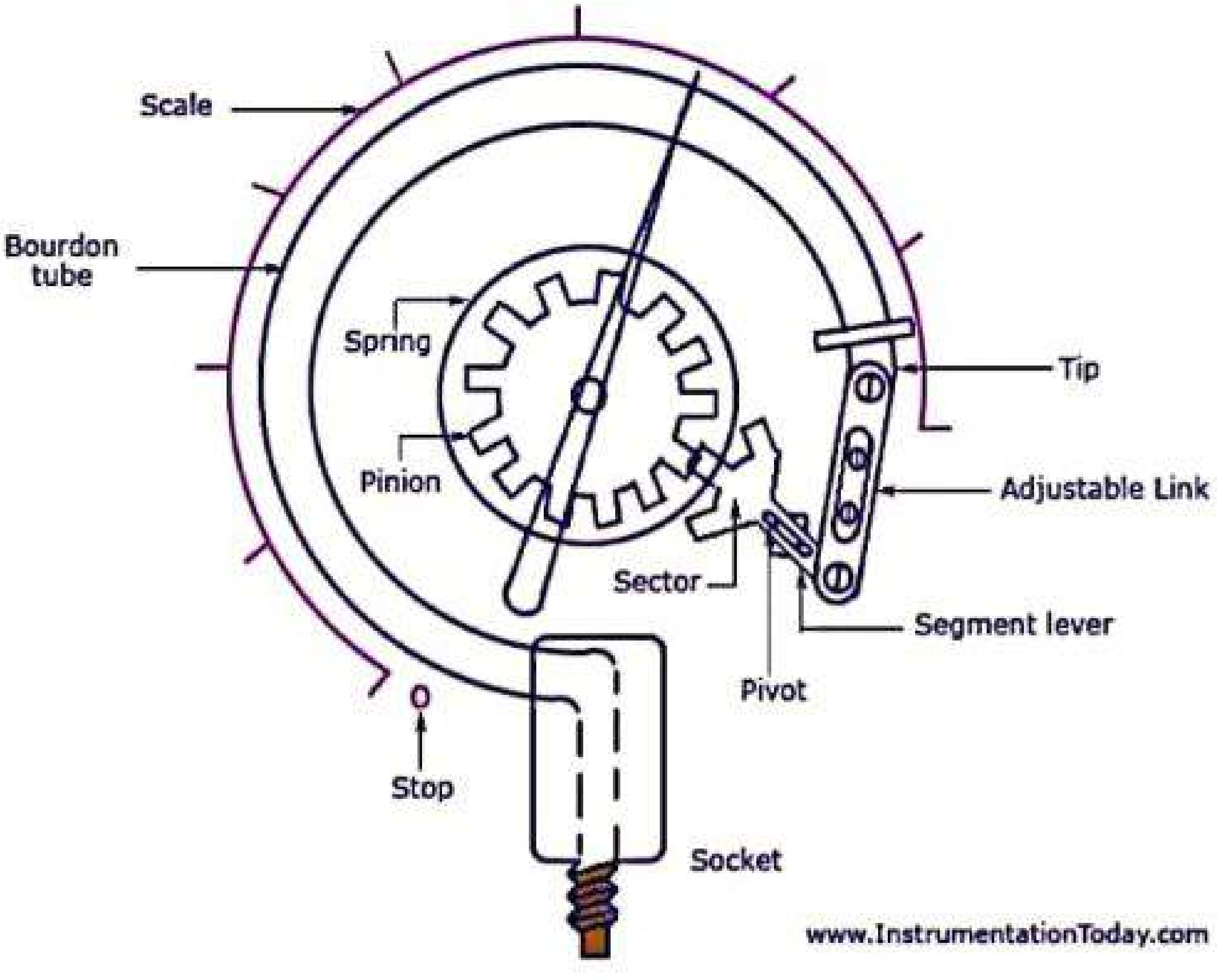
$$\Rightarrow P_A - P_B = 2943 - 4512.6$$

$$\Rightarrow P_A - P_B = -1569.6 \ N/m^3$$

$$\Rightarrow P_B - P_A = 1569.6 \ N/m^2$$

Bourdon Tubes are known for its very high range of differential pressure measurement in the range of almost 100,000 psi (700 MPa). It is an elastic type pressure transducer.

The device was invented by Eugene Bourdon in the year 1849. The basic idea behind the device is that, cross-sectional tubing when deformed in any way will tend to regain its circular form under the action of pressure. The bourdon pressure gauges used today have a slight elliptical cross-section and the tube is generally bent into a C-shape or arc length of about 27 degrees. The detailed diagram of the bourdon tube is shown below.



Bourdon Tube Pressure Gauge

As seen in the figure, the pressure input is given to a socket which is soldered to the tube at the base. The other end or free end of the device is sealed by a tip. This tip is connected to a segmental lever through an adjustable length link. The lever length may also be adjustable. The segmental lever is suitably pivoted and the spindle holds the pointer as shown in the figure. A hair spring is sometimes used to fasten the spindle of the frame of the instrument to provide necessary tension for proper meshing of the gear teeth and thereby freeing the system from the backlash. Any error due to friction in the spindle bearings is known as lost motion. The mechanical construction has to be highly accurate in the case of a Bourdon Tube Gauge. If we consider a cross-section of the tube, its outer edge will have a larger surface than the inner portion. The tube walls will have a thickness between 0.01 and 0.05 inches.

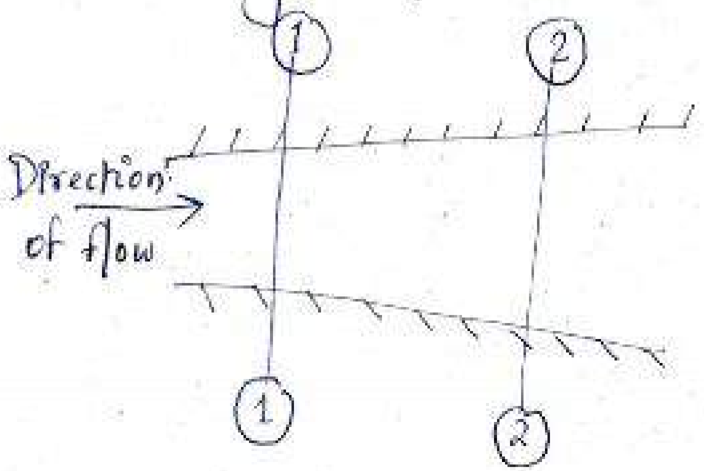
Working

As the fluid pressure enters the bourdon tube, it tries to be reformed and because of a free tip available, this action causes the tip to travel in free space and the tube unwinds. The simultaneous actions of bending and tension due to the internal pressure make a non-linear movement of the free tip. This travel is suitable guided and amplified for the measurement of the internal pressure. But the main requirement of the device is that whenever the same pressure is applied, the movement of the tip should be the same and on withdrawal of the pressure the tip should return to the initial point.

A lot of compound stresses originate in the tube as soon as the pressure is applied. This makes the travel of the tip to be non-linear in nature. If the tip travel is considerably small, the stresses can be considered to produce a linear motion that is parallel to the axis of the link. The small linear tip movement is matched with a rotational pointer movement. This is known as multiplication, which can be adjusted by adjusting the length of the lever. For the same amount of tip travel, a shorter lever gives larger rotation. The approximately linear motion of the tip when converted to a circular motion with the link-lever and pinion attachment, a one-to-one correspondence between them may not occur and distortion results. This is known as angularity which can be minimized by adjusting the length of the link.

Other than C-type, bourdon gauges can also be constructed in the form of a helix or a spiral. The types are varied for specific uses and space accommodations, for better linearity and larger sensitivity. For thorough repeatability, the bourdon tubes materials must have good elastic or spring characteristics. The surrounding in which the process is carried out is also important as corrosive atmosphere or fluid would require a material which is corrosion proof. The commonly used materials are phosphor-bronze, silicon-bronze, beryllium-copper, inconel, and other C-Cr-Ni-Mo alloys, and so on.

Continuity Equation



Let V_1 = Average velocity at ①

ρ = density at section ①

A_1 = Area of pipe at section ①

V_2, ρ_2, A_2 are corresponding values at section ②

Then rate of flow at section ① $= \rho_1 A_1 V_1$

Rate of flow at section ② $= \rho_2 A_2 V_2$

According to law of conservation of mass

Rate of flow at section ① = Rate of flow at section ②

$$\Rightarrow \rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

from this equation is aplicable to the compressible as well as incompressible fluids and is called Continuity Equation. If fluid is incompressible, then $\rho_1 = \rho_2$ and continuity equation reduced to

$$A_1 V_1 = A_2 V_2$$

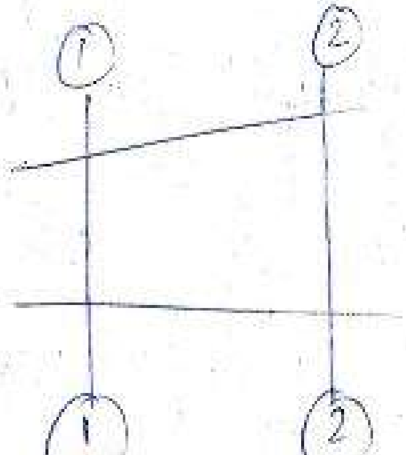
Q//

The diameters of a pipe of the section are 1 and 2 10 cm and 15 cm respectively find the discharge through the pipe if the velocity of water flowing through the section ① is 5 litre per second. Determine also the velocity at section ②.

$d_1 = 0.1 m$

$a_1 =$

$V_1 = 5 m/s$



$d_2 = 0.15 m$

$a_2 =$

$v_2 =$

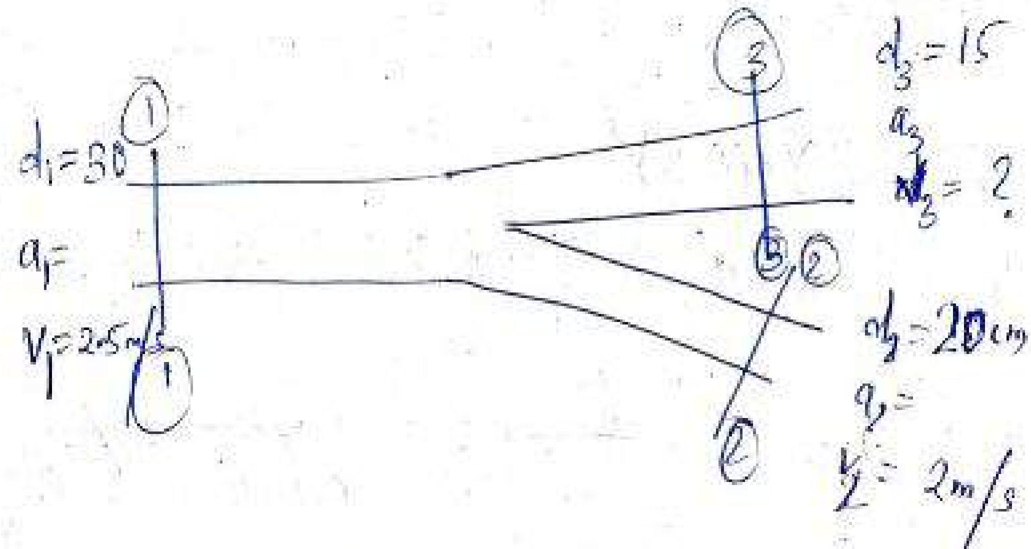
$$a_2 = \frac{\pi}{4} \times d(0.15)^2 = 0.0176 \, m^2$$

$$a_1 = \frac{\pi}{4} \times d^2 = \frac{\pi}{4} \times (0.1)^2 = ~~7.83 m^2~~ \; 0.007 m^2$$

$$Q = a_1 V_1 = ~~7.83~~ \; 0.007 \times 5 = ~~39.15 \; m^3/s~~ \; 0.03925 \; m^3/s$$

$$V_2 = \frac{a_1 V_1}{a_2} = \frac{0.007 \times 5}{0.0176} = 2.058 \; m/s$$

Q// A 30 cm diameter pipe conveying water branches into two pipes of diameters 20 cm and 15 cm respective value if the average velocity in the 30 cm diameter pipe is 2.5 m/s find the discharge in this pipe. Also determine the velocity in 15 cm pipe if the average velocity in 20 cm diameter pipe is 2 m per second.



$$a_1 = \frac{\pi}{4} \times d_1^2 = \frac{\pi}{4} \times (0.3)^2 = 0.070 \ m^2$$

$$V_1 = 2.5 \ m/s$$

$$Q_1 = a_1 V_1 = 0.070 \times 2.5 = 0.176 \ m^3/s$$

$a_2 = \frac{\pi}{4} \times d_2^2 = \frac{\pi}{4} \times (0.2)^2 = 0.0314\ m^2$

$v_2 = 2\ m/s$

$Q_2 = a_2 v_2 = 0.0314 \times 2 = 0.062\ m^3/s$

~~$A_1 V_1 = A_2 V_2 + A_3$~~

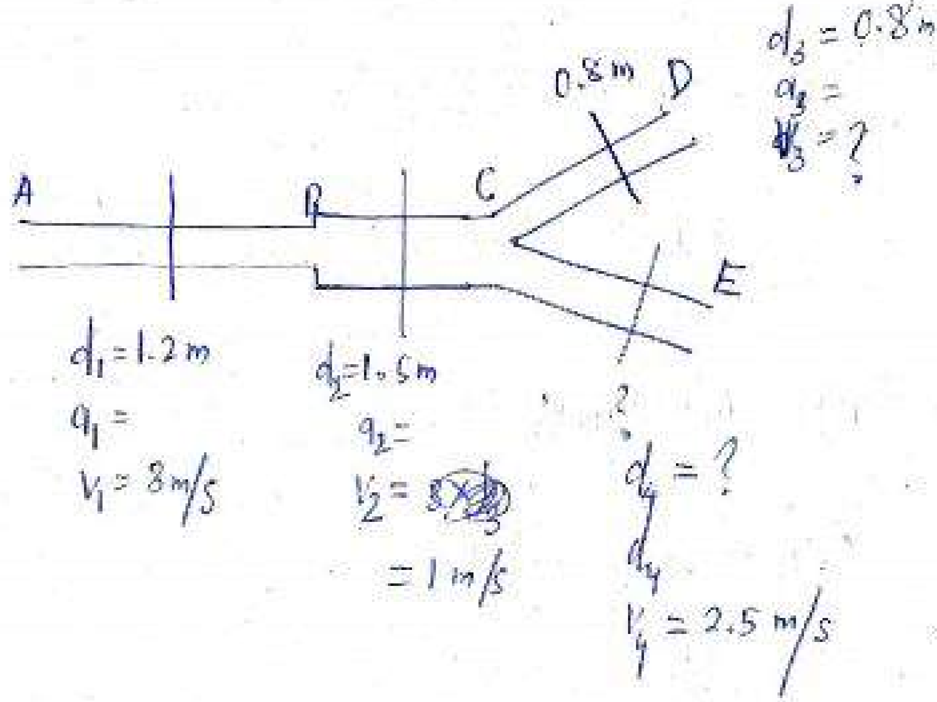
$a_3 = \frac{\pi}{4} \times d_3^2 = \frac{\pi}{4} \times (0.15)^2 = 0.017\ m^2$

$a_1 v_1 = a_2 v_2 + a_3 v_3$

$\frac{a_1 v_1 - a_2 v_2}{a_3} = v_3$

$\Rightarrow \frac{0.176 - 0.062}{0.017} = 6.705\ m/s$

Q) Water flows through a pipe AB 1.2m diameter at 3 m/s and then passes through a pipe BC 1.5m diameter. At 'C' the pipe branches. Branch CD is 0.8m in diameter and carries 1/3 of the flow in AB. The flow velocity in branch CE is 2.5 m/s. Find the volume rate of flow in AB, velocity in BC, velocity in CD and diameter of CE.



$a_1 = \frac{\pi}{4} \times d^2 = \frac{\pi}{4} \times (1.2)^2 = 1.130\ m^2$

$V_1 = 3\ m/s$

$Q_1 = a_1 V_1 = 1.130 \times 3 = 3.393\ m^3/s$

$a_2 = \frac{\pi}{4} \times (1.5)^2 = 1.967$

$Q_1 = Q_2$

$3.393 = a_2 V_2$

$\Rightarrow V_2 = \frac{3.392}{1.967} = 1.97\ m/s$

$Q_1 \times \frac{1}{3} = Q_3$

$\Rightarrow = \frac{3.393}{3}$

$= 1.131 \ m^3/s$

$a_3 = \frac{\pi}{4} \times (0.8)^2 = 0.5023$

$V_{CD} = \frac{Q_{CD}}{A_{CD}}$

$= \frac{1.131}{0.5023}$

$= 2.25 \ m/s$

$Q_{BC} = Q_{CD} + Q_{CE}$

$\Rightarrow 3.393 = 1.31 + (A_{CE} \times V_{CE})$

$\Rightarrow 2.262 = \frac{\pi}{4} D_{CE}^2 \times 2.5$

$\Rightarrow D_{CE} = \sqrt{\frac{2.262}{2.5} \times \frac{4}{\pi}}$

$= 1.073 \ m$

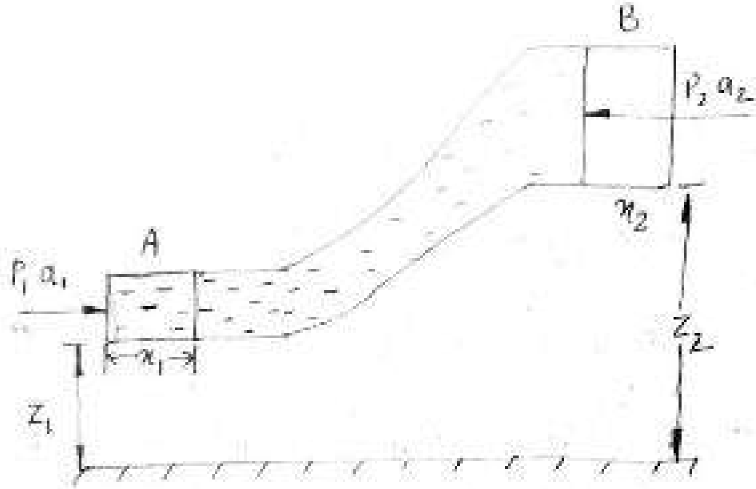
Derivation of Bernoulli's Equation

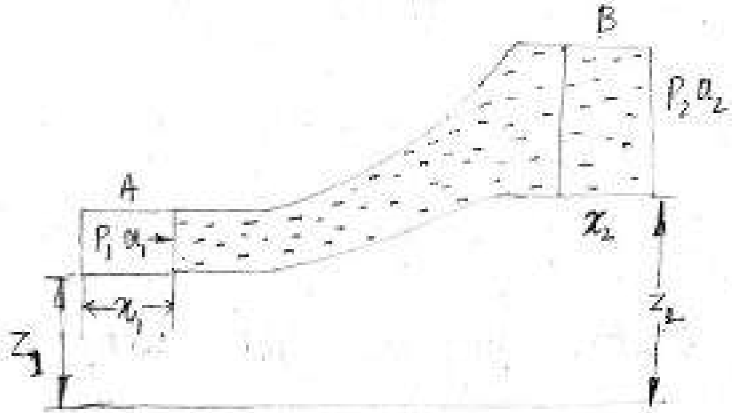
Bernoulli's equation can be derived by the application of work-energy principle which states that "Workdone on a body is equal to the change in its kinetic energy". Consider a steady and incompressible liquid flowing through a pipe of variable area of cross-section.

A mass of liquid 'm' occupies a length 'x' at the cross-section 'A' & feels a force '$p_1 a_1$' in the forward direction (towards right) where P_1 is the pressure at A & 'a' is the area of cross-section of the pipe at A.

Same mass of liquid will occupy a length x_2 at B where the pressure & cross-sectional area P_2 & a_2 respectively.

At B, the liquid experiences a force $P_2 a_2$ in the backward direction.





Work done by the liquid at A, $W_1 = P_1 a_1 x_1$

Work done by the liquid at B, $W_2 = -P_2 a_2 x_2$

(-ve sign due to opposite direction)

In addition to this work, some work is done against gravitation in changing height of liquid from Z_1 (at A) to Z_2 (at B)

Workdone against gravitation,

$$W_3 = -mg(Z_2 - Z_1)$$

Net workdone on liquid,

$$W = W_1 + W_2 + W_3$$

$$= P_1 a_1 x_1 - P_2 a_2 x_2 - mg(Z_2 - Z_1)$$

Since volume of the liquid at A & B is same,

$$a_1 x_1 = a_2 x_2 = \frac{m}{\rho}$$

$$\therefore W = P_1 \frac{m}{\rho} - P_2 \frac{m}{\rho} - mg(Z_2 - Z_1)$$

$$= (P_1 - P_2)\frac{m}{\rho} - mg(Z_2 - Z_1)$$

Let v_1 & v_2 be the velocity of the liquid at section A & B respectively.

$\therefore$ Change in kinetic engergy $= \frac{1}{2} m v_2^2 - \frac{1}{2} m v_1^2$

According to workenergy principle,

$$(P_1 - P_2)\frac{m}{\rho} - mg(Z_2 - Z_1) = \frac{1}{2} m v_2^2 - \frac{1}{2} m v_1^2$$

$$\Rightarrow (P_1 - P_2)\frac{1}{\rho} - g(Z_2 - Z_1) = \frac{1}{2} v_2^2 - \frac{1}{2} v_1^2$$

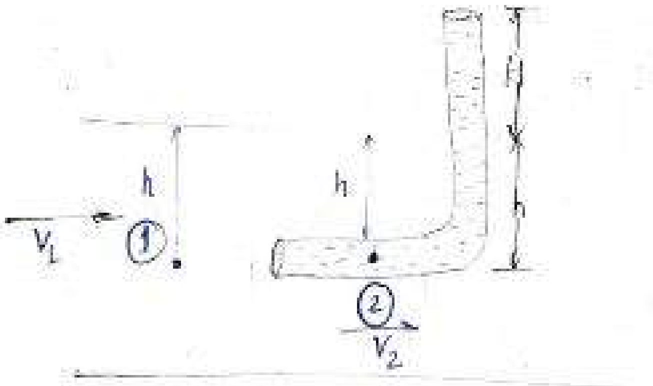
$$\Rightarrow \frac{P_1}{\rho} + \frac{1}{2} v_1^2 + g Z_1 = \frac{P_2}{\rho} + \frac{1}{2} v_2^2 + g Z_2$$

$$\Rightarrow \boxed{\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + Z_2}$$

Pitot Tube

It is used to measure the velocity of flow through a pipe.

It consist of a glass-tube bent in 'L' shape as shown in the figure



Now applying Bernoulli's equation at point (1) & (2)

Consider two points (1) & (2) at the pipe and just at the inlet of the pitot tube.

Now applying Bernoulli's eq^n at point

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

As the two points (1) and (2) are on same horizontal axis Z_1 is equal to Z_2

$$\Rightarrow \frac{P_1}{\rho g} + \frac{V_1^2}{2g} = \frac{P_2}{\rho g} + \frac{V_2^2}{2g}$$

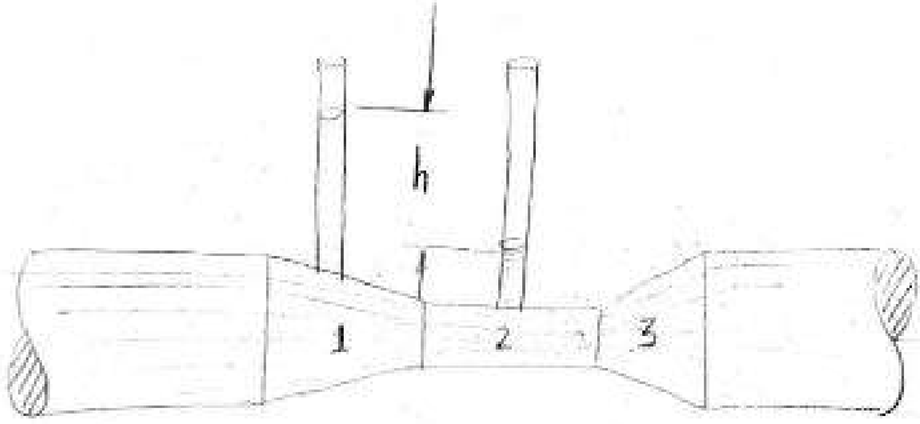
$$\Rightarrow h + \frac{V_1^2}{2g} = h + H + 0$$

$$\Rightarrow V_1^2 = 2gH$$

$$\Rightarrow V_1 = \sqrt{2gH}$$

The above expression is for the derivation of theoritical velocity for the actual velocity we have to multiply ~~we have~~ ~~to~~ a co-efficient C_v which known as co-efficient of velocity.

$$V = C_v \sqrt{2gh}$$



Consider two sections 1 & 2 at the pipe & at the throat of the venturimeter respectively.

Let,

d_1 = dimeter of the pipe at section 1

a_1 = area of section 1

V_1 = velocity at section 1

P_1 = Pressure at section 1.

d_2, a_2, V_2, P_2 = corresponding values at section 2.

Applying Bernoulli's Eqn at section 1 & 2

$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

As the pipe is horizontal

$$z_1 = z_2$$

$$\therefore \frac{P_1}{\rho g} + \frac{v_1^2}{2g} = \frac{P_2}{\rho g} + \frac{v_2^2}{2g}$$

$$\Rightarrow \frac{P_1 - P_2}{\rho g} = \frac{v_2^2 - v_1^2}{2g}$$

Let, $\frac{P_1 - P_2}{\rho g} = h$ (Shown by a differential manometer)

$$\Rightarrow h = \frac{v_2^2 - v_1^2}{2g}$$

$$\Rightarrow 2gh = v_2^2 - v_1^2 \quad \text{——— (1)}$$

Applying continuity equation at section 1 & 2

$$a_1 v_1 = a_2 v_2$$

$$\Rightarrow v_1 = \frac{a_2 v_2}{a_1}$$

Now putting the value of v_1 in eq^n —— (1)

$$2gh = v_2^2 - \left(\frac{a_2 v_2}{a_1}\right)^2$$

$$\Rightarrow 2gh = v_2^2 - \frac{a_2^2}{a_1} v_2^2$$

$$\Rightarrow 2gh = v_2^2\left(1 - \frac{a_2^2}{a_1^2}\right)$$

$$\Rightarrow 2gh = v_2^2\left(\frac{a_1^2 - a_2^2}{a_1^2}\right)$$

$$\Rightarrow v_2^2 = \frac{a_1^2}{a_1^2 - a_2^2} 2gh$$

$$\Rightarrow v_2 = \sqrt{\frac{a_1^2}{a_1^2 - a_2^2}}$$

$$\Rightarrow v_2 = \sqrt{2gh} \frac{a_1}{\sqrt{a_1^2 - a_1^2}}$$

Now

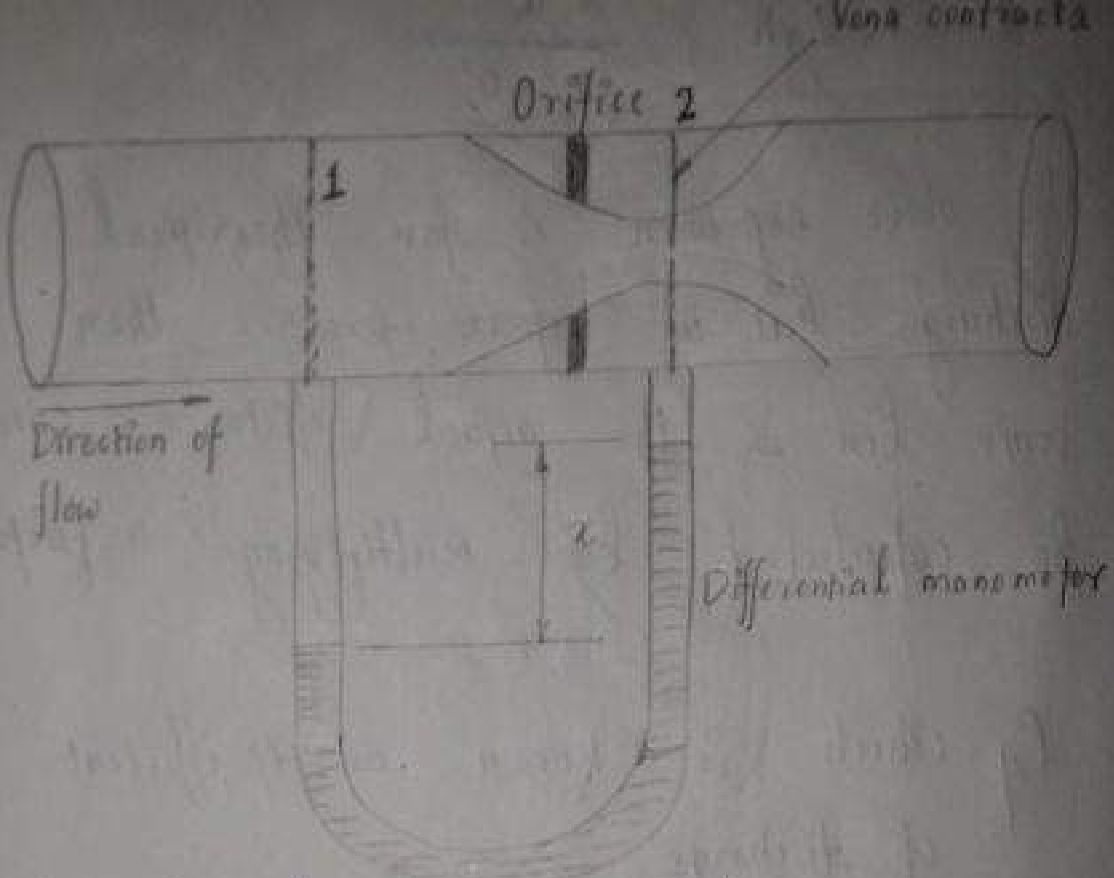
Discharge $Q = a_2 v_2$

$$\Rightarrow Q = \sqrt{2gh} \cdot \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}}$$

The above expression is for theoritical discharge but in actual practice there is some loss & the actual distance can be calculated by multiplying a factor.

C_d - which is known as co-efficient of discharge.

$$\boxed{Q_{act} = C_d \sqrt{2gh} \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}}}$$



Let d_1 = diameter at section 1

p_1 = pressure at section 1

v_1 = velocity at section 1

a_1 = area at section 1

d_2, p_2, v_2, a_2 are the corresponding values at section 2.

Applying Bernolli's equation at section 1 and 2

We get,

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

$$\Rightarrow \left(\frac{P_1}{\rho g}+z_1\right)-\left(\frac{P_2}{\rho g}+z_2\right)=\frac{v_2^2-v_1^2}{2g}$$

$$\Rightarrow h=\frac{v_2^2-v_1^2}{2g}$$

$$\Rightarrow v_2=\sqrt{2gh+v_1^2}$$

Where h is the differential head.

Let a_2 is the area of the orifice.

Coefficient of contraction.

$$C_c=\frac{a_2}{a_0}$$

By continuity equation, we have

$$a_1 v_1 = a_2 v_2$$

$$\Rightarrow v_1=\frac{a_0 C_c}{a_1} v_2$$

Hence $$v_2=\sqrt{2gh+\frac{a_0^2 C_c^2 v_2^2}{a_1^2}}$$

$$\Rightarrow \quad V_2 = \frac{\sqrt{2gh}}{\sqrt{1 - \frac{a_0^2}{a_1^2} C_c^2}}$$

Thus, discharge

$$Q = a_2 V_2 = V_2 a_0 C_c$$

$$= \frac{a_0 C_c \sqrt{2gh}}{\sqrt{1 - \frac{a_0^2}{a_1^2} C_c^2}}$$

If C_d is the co-efficient of discharge for orifice meter, which is defined as

$$C_d = C_c \frac{\sqrt{1 - \frac{a_0^2}{a_1^2}}}{\sqrt{1 - \frac{a_0^2}{a_1^2} C_c^2}}$$

$$\Rightarrow C_c = C_d = \frac{\sqrt{1 - \frac{a_0^2}{a_1^2} C_c^2}}{\sqrt{1 - \frac{a_0^2}{a_1^2}}}$$

Hence.

$$Q = C_d \frac{a_0 a_1 \sqrt{2gh}}{\sqrt{a_1^2 - a_0^2}}$$

The co-efficient of discharge of the orifice meter is much smaller than that of a venturimeter.

Co-efficient of contraction (CC)

It is defined as the ratio of the area of the jet at vena-contracta to the area of orifice.

$$C_c = \frac{\text{Actual Area}}{\text{Theoritical Area}}$$

$$= \frac{a_c}{a}$$

a_c = Actual Area

a = theoritical area

The value of C_c varies from 0.61 to 0.69.

Hydraulic Co-efficient

(1) Co-efficient of velocity:

It is defined as the ratio of actual velocity of a jet of liquid at venacontracta to the theoritical velocity.

$$C_v = \frac{\text{Actual Velocity}}{\text{Theory Velocity}}$$

$$= \frac{V}{\sqrt{2gh}}$$

V - actual ve.

The value of C_v varies from 0.95 to 0.99.

Q. 69.

Coefficient of discharge

It is defined as the ratio of actual discharge from an orifice to the ~~of~~ theoritical discharge from the orifice.

$$C_d = \frac{\text{Actual Discharge}}{\text{Theorical discharge}}$$

$$= \frac{\text{Actual area}}{\text{Therorical area}} \times \frac{\text{actual velocity}}{\text{Theoritical velocity}}$$

$$\Rightarrow \boxed{C_d = C_c \times C_v}$$

Values of C_d varies from 0.61 - 0.65

Q) The head of water over an orifice of diameter of 40 mm is 10 meter. Find the actual discharge and actual velocity of $\mathcal{L}$ at venacontracta.

$C_d = 0.6$

$C_v = 0.98$

Th. area(d) = 40 mm = 0.04 m

$H = 10m$

$a = \frac{\pi}{4} d^2 = \frac{\pi}{4} \times (0.04)^2 = 0.001 m^2$

$= 0.001256 m^2$

$$C_v = \frac{v}{\sqrt{2gh}}$$

$$\Rightarrow v = C_v \sqrt{2gh}$$

$$= 0.98 \times \sqrt{2 \times 9.81 \times 10}$$

$$= 13.72.$$

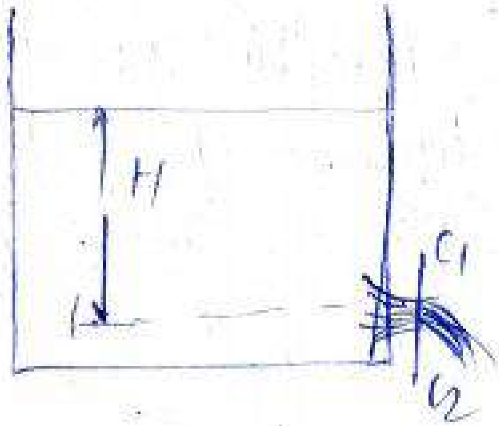
Actual discharge = ~~area~~ Actual area × Actual Velocity

$$= 0.001 \times 13.72 =$$

$$C_d = \frac{\text{Act. discharge}}{\text{Theoratical Area} \times \text{Th. Velocity}}$$

=

Vena contracta is at a distance of half of diameter of the orifice and at this section the stream lines are straight and paralal to each other. Beyond this section the jet dinesses and is attracted in downword direction by the gravity.



Consider two points one and two inside the tank and at the vena contracta respectively.

Hydro dynamics

Types of fluid flow

Steady / Unsteady

Uniform / Non-uniform

Laminar / Turbulent

Incompressible / Compressible

Rotational / Irrotational

One, two, three dimensional.

Steady flow

Flow which does not vary with time.
Fluid properties remains constant with time.

Unsteady flow

The type of flow in which the fluid properties changes with time, fluid propertise are volume, pressure, temperature etc.

Rotational flow

Rotational flow is when the particles of fluid are all rotating about their own axis in addition to their other movement.

Irrotational flow

Irrotational flow is when the indivisual particles are not rotating around their axis.

Turbulent flow

Turbulent flow is characterized by the irregular movement of particles of the fluid

One dimentional flow

One dimentional flow is the flow in which parameters (velocity, pressure, density, viscocity and temperature) vary only in one direction and the flow is a function of only one co-ordinate Axis and time.

Two dimensional flow

The velocity at every point is parallel to a fixed plane, and is the same everywhere on a given normal to that plane.

Tree-dimentional flow

In this type of flow all flow parameters (velocity) are functions of three space coordinates (x, y, z) & time.

Uniform flow

Flow of a fluid in which each particle moves along its line of flow with constant speed and in which the cross section of each steam tube remains unchanged.

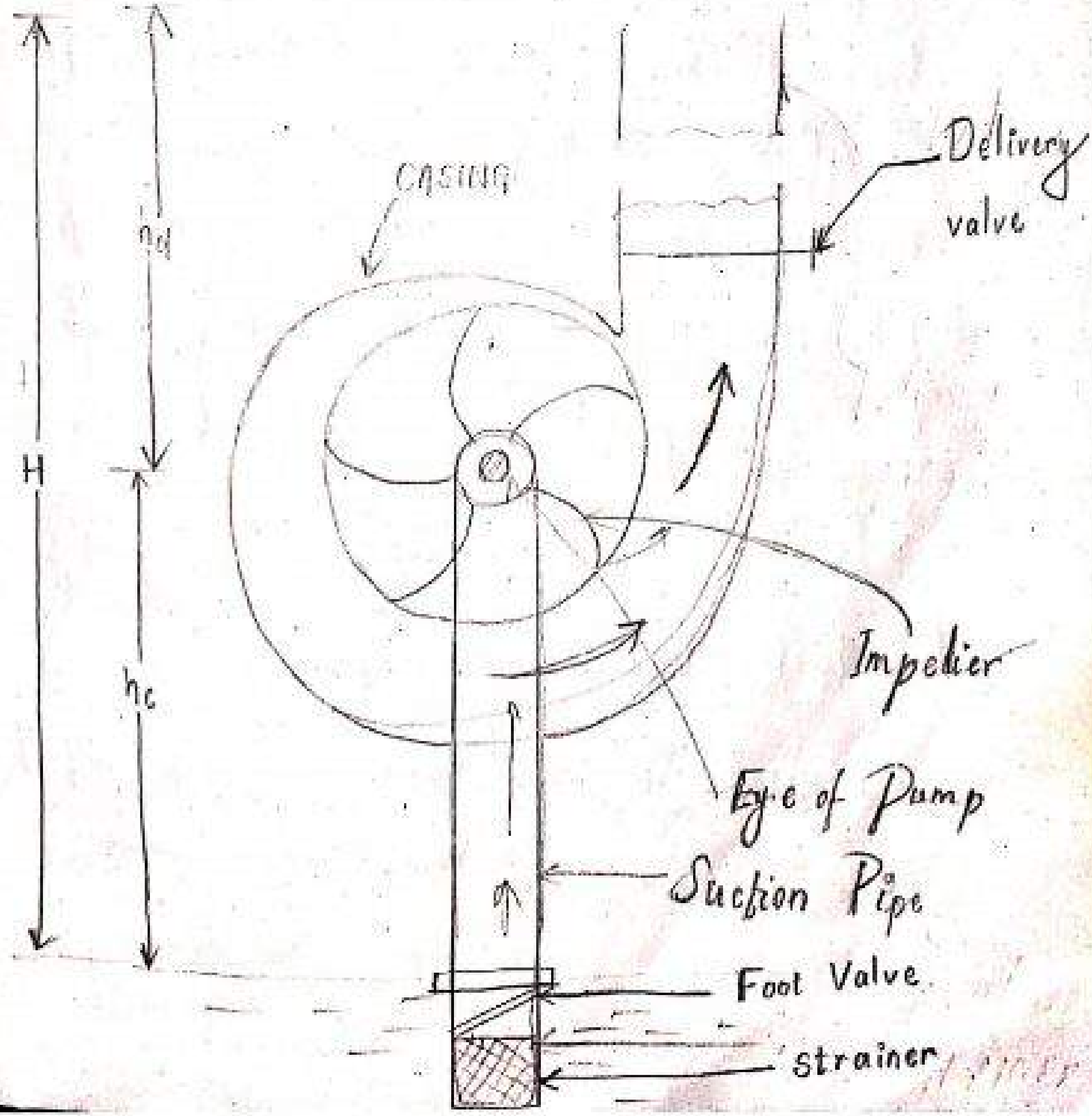
Non-Uniform flow

When there is a change in velocity of the flow at different points in a flowing fluid, for a given time.

Centrifugal Pump

If in a pump the mechanical energy is converted into pressure energy by means of centrifugal force acting on the fluid the hydraulic machine is called centrifugal pump.

Main parts of centrifugal pump



Centrifugal Pump

Main parts of a centrifugal pump:

1. Impellers.
2. Casing
3. Suction pipe with foot valve and a strainer.
4. Delivery Pipe.

Impellers

→ The rotating part of a centrifugal pump is called 'impeller'

→ It consist of a series of backward curved vanes.

→ The impeller is mounted on a shaft which is connected to the shaft of a electric motor.

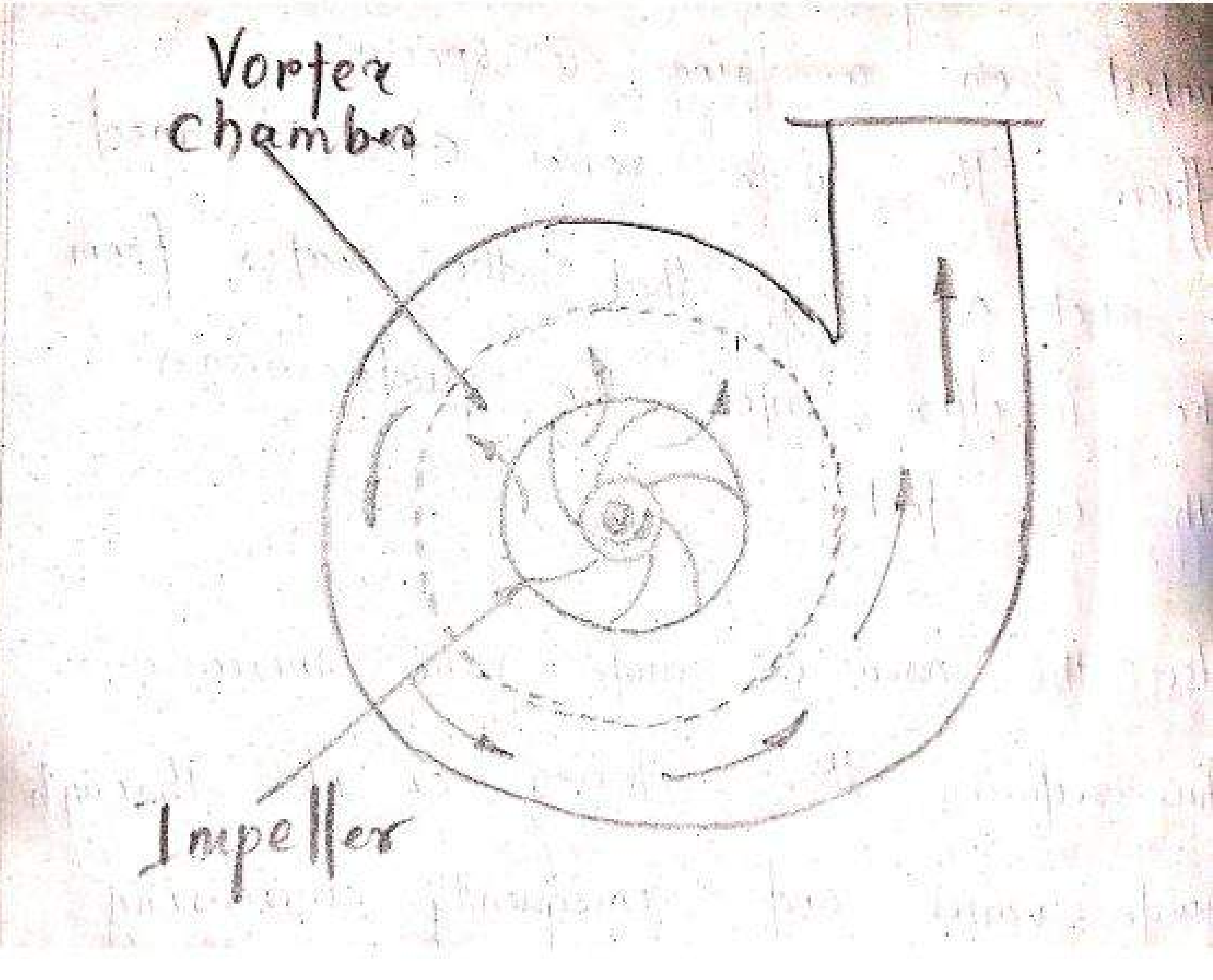
Casing

→ The casing of a centrifugal pump is similar to the casing of a reaction turbine.

→ It is an air-tight passage surrounding the impeller and is designed in such a way that the kinetic energy of the water discharged at the outlet of the impeller is converted into pressure energy before the water leaves the casing and enters the delivery pipe.

The following three types of the casings are commonly ~~used~~ adopted:

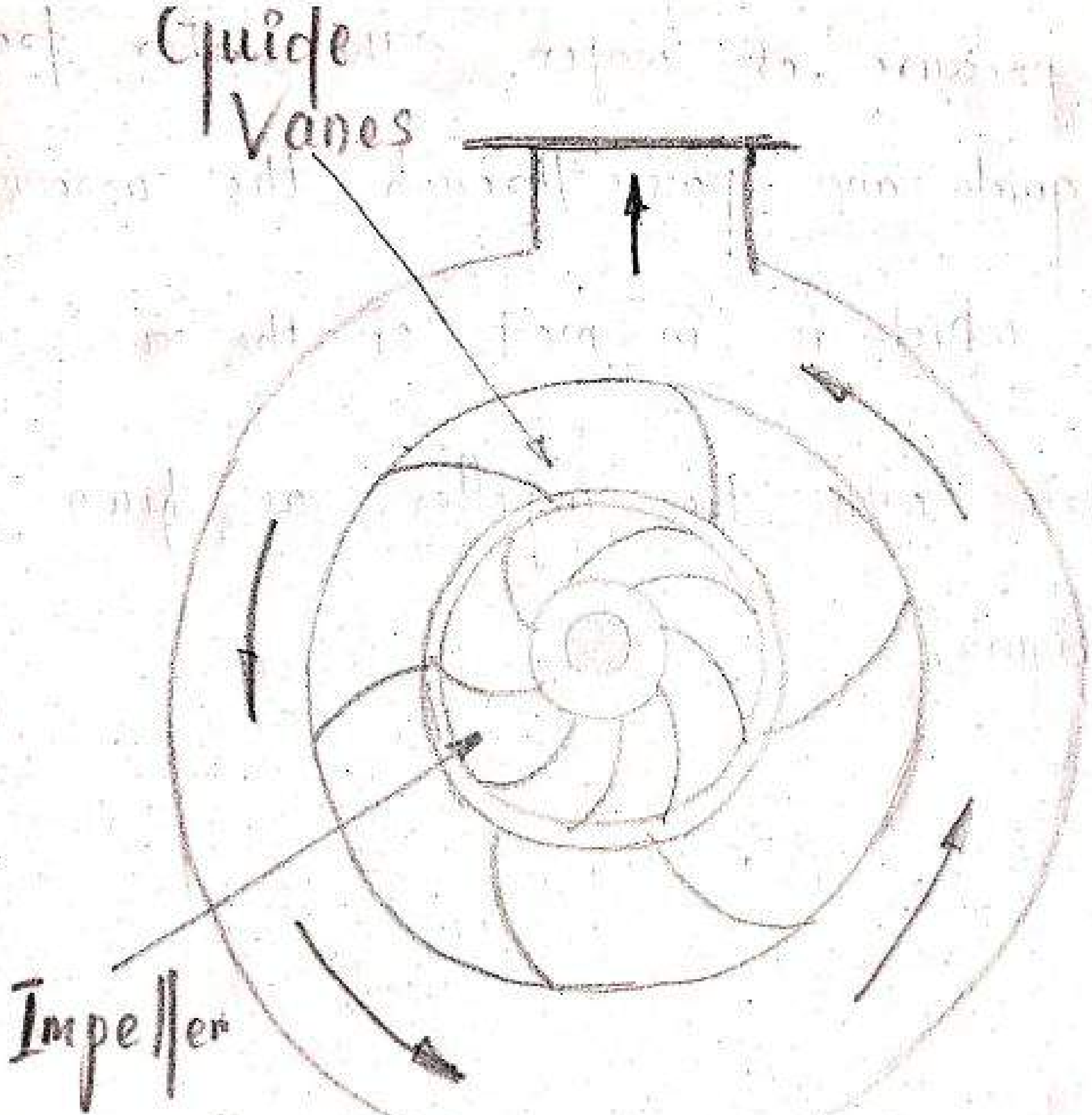
a) Volute casing
b) Vortex casing
c) Casing with guide blades



Vortex Chamber
Impeller

Volute Casing

It is of spiral type in which area of flow increases gradually. The increase in area of flow decreases the velocity of flow. The decrease in velocity increases the pressure of water following through the casing. It has been observed that in case of volute casing, the efficiency of the pump increases slightly as a large amount of energy is lost due to the formation of eddies in this type of casing.


Guide Vanes
Impeller

(b) Vortex Casing

It is circular chamber is introduced between the casing and the impeller as shown in figure, the casing is known as Votex casing. By introducing the circular chamber, the loss of energy due to the formation of eddies is reduced to a considerable extent. Thus the efficiency of pump is more than the efficiency when only volute casing is provided.

c) Casing with guide Blade

This casing is shown in figure, in which the impeller is surrounded by a series of guide blades mounted on a ring is known as diffuser. The guide vanes are designed in such a way that the water from the impeller enters the guide vanes without stock.

Also the area of guide vanes increases, thus reducing the velocity of flow through guide vanes and consequently increasing the pressure of water. The water from the guide vanes passes through the surrounding casing which is in most of the cases concentric with the impeller as shown in figure.

Suction Pipe with a foot valve and a strainer

- A pipe whose one end is connected to the inlet of the pump and other end dips into water in a sump is known as suction pipe.
- A foot valve which is a non-return valve or one-way type of valve is fitted at the lower end of the suction pipe.
- The foot valves opens only in upword direction.
- A strainer is also fitted at the lower end of the suction pipe.

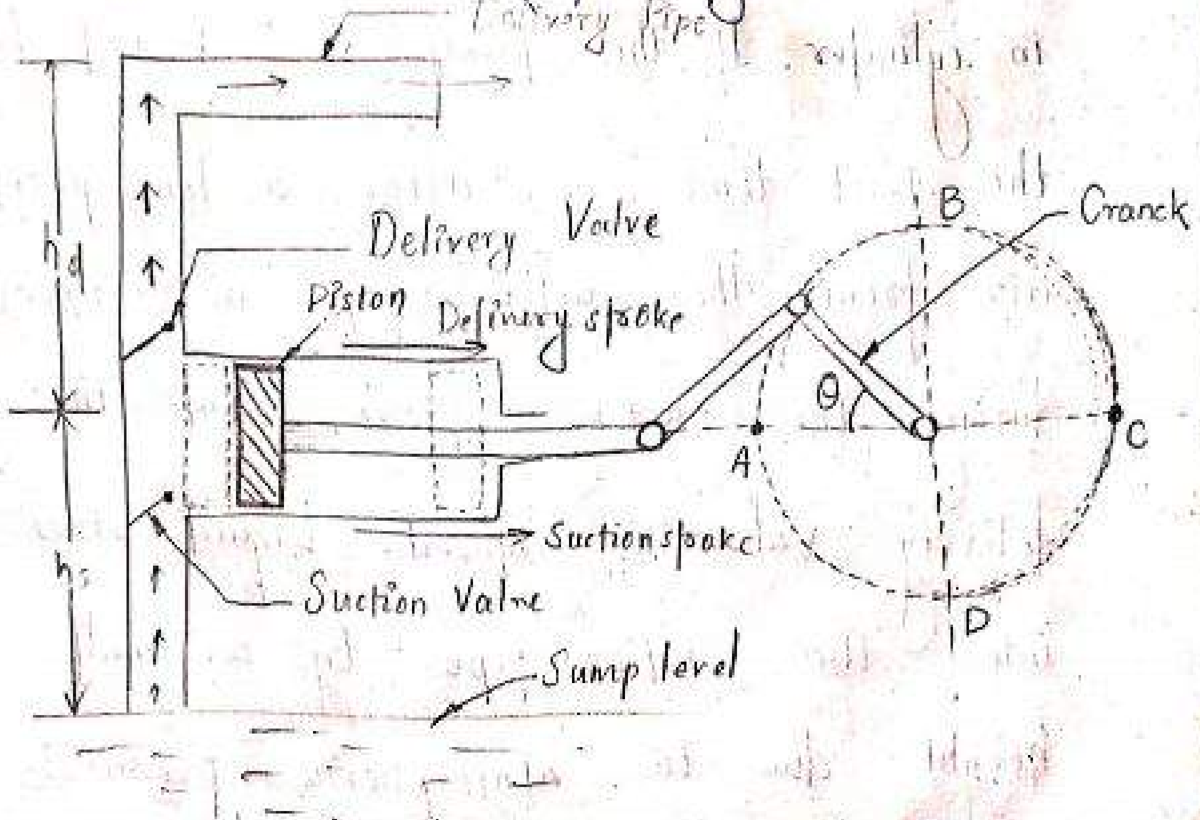
Delivery Pipe

- A pipe whose one end is connected to the outlet of the pump and other end delivers the water at a required height is known as delivery pipe.

Reciprocating Pump:

If the mechanical energy is converted into hydraulic energy (pressure energy) by sucking the liquid into a cylinder in which a piston is reciprocating (moving backwords & forword). Which exerts the thrust on the thrust on the liquid & increases. It's hydraulic energy (pressure energy). the pump is known as 'reciprocating pump'.

Main Parts Of Reciprocating Pump



(1) A cylinder with a piston rod, connecting rod & a crank

(2) Suction Pipe

(3) Delivery Pipe

(4) Suction Valve

(5) Delivery Valve

Working of reciprocating pump:-

→ When the piston moves from the left to right a suction pressure is produced in cylinder. If the pump is started for the first time or after a long period. air from the suction pipe is sucked during the suction stroke, while the delivery value is closed. Liquid rises into the suction pipe by a small height due to atmospheric pressure on the sump liquid.

* During the delivery stroke, air in the cylinder pushed out into the delivery pipe by the thrust of the piston, while the suction valve is closed. When all the air from the suction pipe has been exhausted, the liquid from the sump is able to rise & enter the cylinder.

* During the delievery stroke it is displaced into the delivery pipe. Thus the liquid is delivered into the delivery tank inter mittently, i.e. during the delivery stroke ~~ongle~~ only.

According to use of piston sides, reciprocating pumps are two types :-

① Single acting reciprocating pump :-

If there is only one suction & one delivery pipe & the liquid is fitted only on one side of the piston so it is called a single acting reciprocating ~~valve~~ pump.

(ii) Double acting reciprocating pump

A double acting reciprocating pump has two suction & two delivery pipes, liquid is receiving on both sides of the piston in the cylinder & is delined into the respective delivery pipes.

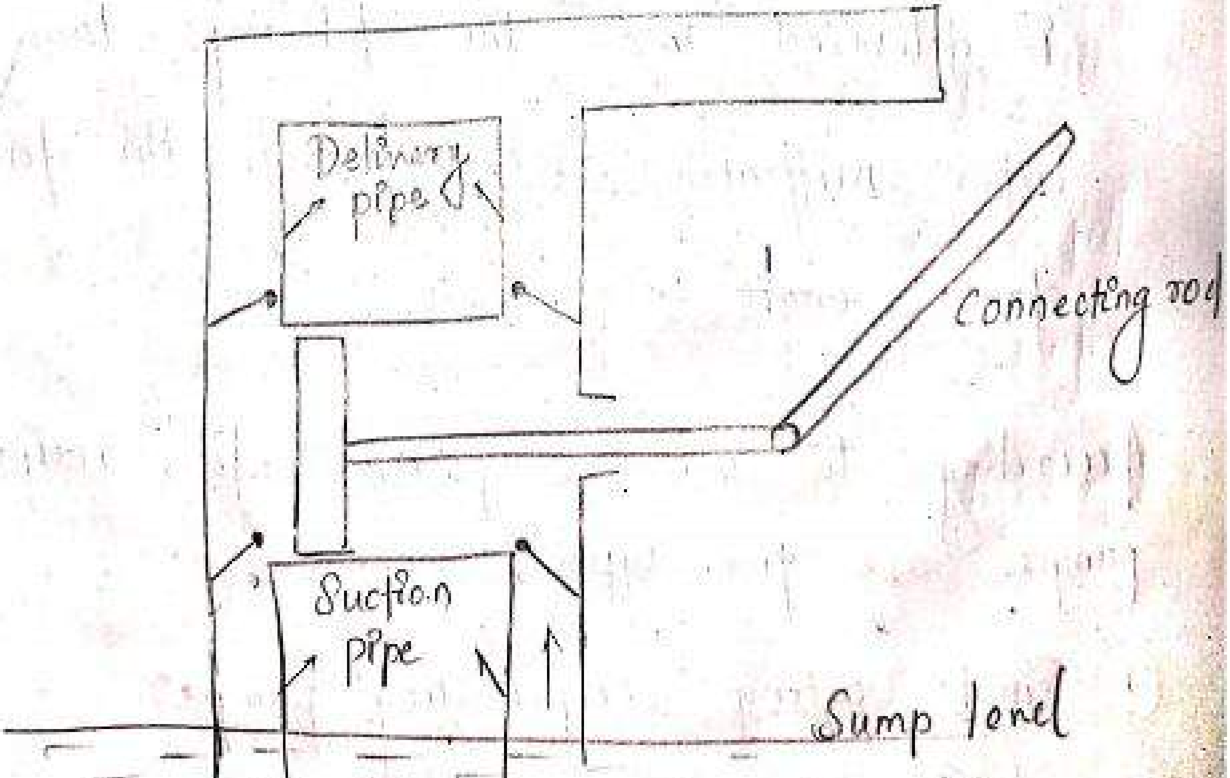


Fig. A shows the valve in its normal state & its corresponding symbol. The valve is held in this piston by the force of the spring in this position, the flow from the inlet port P is blocked from going to the outlet port A. Fig. B shows the valve in its actuated corresponding symbol. The valve is shifted into this piston by applying a force to overcome the resistance of the spring.

In this position, the flow is allowed to go to the outlet port around the smaller diameter portion of the spool.

The symbol shown in Figure C has two block

▶ 19.3 WORK DONE BY THE CENTRIFUGAL PUMP (OR BY IMPFLLER) ON WATER

In case of the centrifugal pump, work is done by the impeller on the water. The expression for the work done by the impeller on the water is obtained by drawing velocity triangles at inlet and outlet of the impeller in the same way as for a turbine. The water enters the impeller radially at inlet for best efficiency of the pump, which means the absolute velocity of water at inlet makes an angle of 90° with the direction of motion of the impeller at inlet. Hence angle $\alpha = 90°$ and $V_{w_1} = 0$. For drawing the velocity triangles, the same notations are used as that for turbines. Fig. 19.3 shows the velocity triangles at the inlet and outlet tips of the vanes fixed to an impeller.

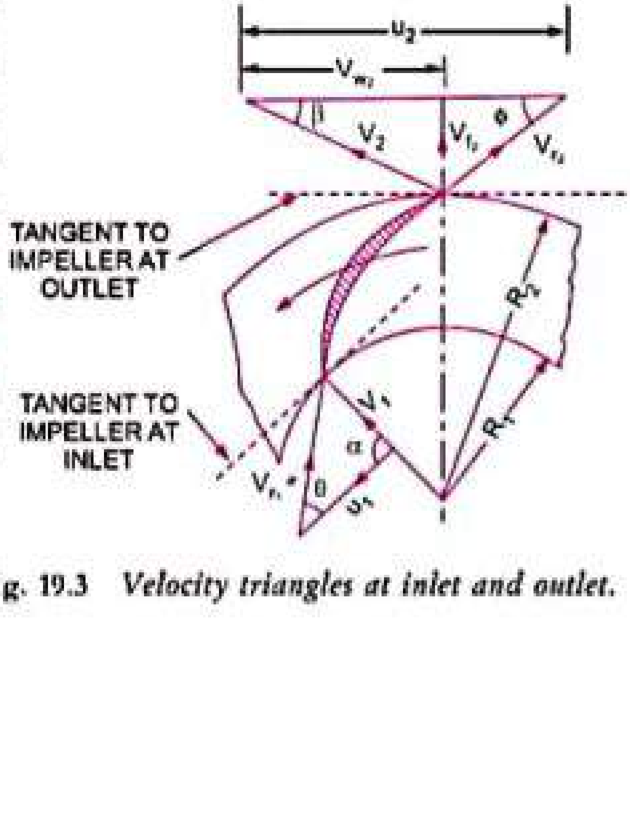


Fig. 19.3 *Velocity triangles at inlet and outlet.*

Let N = Speed of the impeller in r.p.m.,

D_1 = Diameter of impeller at inlet,

u_1 = Tangential velocity of impeller at inlet,

$$= \frac{\pi D_1 N}{60}$$

D_2 = Diameter of impeller at outlet,

u_2 = Tangential velocity of impeller at outlet

$$= \frac{\pi D_2 N}{60}$$

V_1 = Absolute velocity of water at inlet,

V_{r_1} = Relative velocity of water at inlet,

α = Angle made by absolute velocity (V_1) at inlet with the direction of motion of vane,

θ = Angle made by relative velocity (V_{r_1}) at inlet with the direction of motion of vane, and V_2, V_{r_2}, β and ϕ are the corresponding values at outlet.

As the water enters the impeller radially which means the absolute velocity of water at inlet is in the radial direction and hence angle $\alpha = 90°$ and $V_{w_1} = 0$.

A centrifugal pump is the reverse of a radially inward flow reaction turbine. But in case of a radially inward flow reaction turbine, the work done by the water on the runner per second per unit weight of the water striking per second is given by equation (18.19) as

$$= \frac{1}{g}[V_{w_1}u_1 - V_{w_2}u_2]$$

$\therefore$ Work done by the impeller on the water per second per unit weight of water striking per second

$$= -\text{[Work done in case of turbine]}$$

$$= -\left[\frac{1}{g}\left(V_{w_1}u_1 - V_{w_2}u_2\right)\right] = \frac{1}{g}\left[V_{w_2}u_2 - V_{w_1}u_1\right]$$

$$= \frac{1}{g}V_{w_2}u_2 \qquad (\because \quad V_{w_1} = 0 \text{ here}) \quad ...(19.1)$$

Work done by impeller on water per second

$$= \frac{W}{g}.V_{w_2}u_2 \qquad ...(19.2)$$

where W = Weight of water = $\rho \times g \times Q$

where Q = Volume of water

and Q = Area × Velocity of flow = $\pi D_1 B_1 \times V_{f_1}$

$$= \pi D_2 B_2 \times V_{f_2} \qquad ...(19.2A)$$

where B_1 and B_2 are width of impeller at inlet and outlet and V_{f_1} and V_{f_2} are velocities of flow at inlet and outlet.

Equation (19.1) gives the head imparted to the water by the impeller or energy given by impeller to water per unit weight per second.

▶ 19.4 DEFINITIONS OF HEADS AND EFFICIENCIES OF A CENTRIFUGAL PUMP

1. Suction Head (h_s). It is the vertical height of the centre line of the centrifugal pump above the water surface in the tank or pump from which water is to be lifted as shown in Fig. 19.1. This height is also called suction lift and is denoted by 'h_s'.

2. Delivery Head (h_d). The vertical distance between the centre line of the pump and the water surface in the tank to which water is delivered is known as delivery head. This is denoted by 'h_d'.

3. Static Head (H_s). The sum of suction head and delivery head is known as static head. This is represented by 'H_s' and is written as

$$H_s = h_s + h_d. \qquad ...(19.3)$$

4. Manometric Head (H_m). The manometric head is defined as the head against which a centrifugal pump has to work. It is denoted by 'H_m'. It is given by the following expressions :

(*a*) H_m = Head imparted by the impeller to the water – Loss of head in the pump

$$= \frac{V_{w_2} u_2}{g} - \text{Loss of head in impeller and casing} \qquad ...(19.4)$$

$$= \frac{V_{w_2} u_2}{g} \text{ ...if loss of pump is zero} \qquad ...(19.5)$$

(*b*) H_m = Total head at outlet of the pump – Total head at the inlet of the pump

$$= \left(\frac{p_o}{\rho g} + \frac{V_o^2}{2g} + Z_o\right) - \left(\frac{p_i}{\rho g} + \frac{V_i^2}{2g} + Z_i\right) \qquad ...(19.6)$$

where $\frac{p_o}{\rho g}$ = Pressure head at outlet of the pump = h_d

$\frac{V_o^2}{2g}$ = Velocity head at outlet of the pump

= Velocity head in delivery pipe = $\frac{V_d^2}{2g}$

Z_o = Vertical height of the outlet of the pump from datum line, and

$\frac{p_i}{\rho g}, \frac{V_i^2}{2g}$, Z_i = Corresponding values of pressure head, velocity head and datum head at the inlet of the pump,

i.e., h_s, $\frac{V_s^2}{2g}$ and Z_s respectively.

(*c*) $$H_m = h_s + h_d + h_{f_s} + h_{f_d} + \frac{V_d^2}{2g} \qquad ...(19.7)$$

where h_s = Suction head, h_d = Delivery head,

h_{f_s} = Frictional head loss in suction pipe, h_{f_d} = Frictional head loss in delivery pipe, and

V_d = Velocity of water in delivery pipe.

5. Efficiencies of a Centrifugal Pump. In case of a centrifugal pump, the power is transmitted from the shaft of the electric motor to the shaft of the pump and then to the impeller. From the impeller, the power is given to the water. Thus power is decreasing from the shaft of the pump to the impeller and then to the water. The following are the important efficiencies of a centrifugal pump :

(*a*) Manometric efficiency, η_{man} (*b*) Mechanical efficiency, η_m and

(*c*) Overall efficiency, η_o.

(*a*) **Manometric Efficiency (η_{man}).** The ratio of the manometric head to the head imparted by the impeller to the water is known as manometric efficiency. Mathematically, it is written as

$$\eta_{man} = \frac{\text{Manometric head}}{\text{Head imparted by impeller to water}}$$

$$= \frac{H_m}{\left(\frac{V_{w_2} u_2}{g}\right)} = \frac{gH_m}{V_{w_2} u_2} \quad ...(19.8)$$

The power at the impeller of the pump is more than the power given to the water at outlet of the pump. The ratio of the power given to water at outlet of the pump to the power available at the impeller, is known as manometric efficiency.

The power given to water at outlet of the pump $= \frac{WH_m}{1000}$ kW

The power at the impeller $= \frac{\text{Work done by impeller per second}}{1000}$ kW

$$= \frac{W}{g} \times \frac{V_{w_2} \times u_2}{1000} \text{ kW}$$

$$\eta_{man} = \frac{\frac{W \times H_m}{1000}}{\frac{W}{g} \times \frac{V_{w_2} \times u_2}{1000}} = \frac{g \times H_m}{V_{w_2} \times u_2}.$$

(*b*) **Mechanical Efficiency (η_m).** The power at the shaft of the centrifugal pump is more than the power available at the impeller of the pump. The ratio of the power available at the impeller to the power at the shaft of the centrifugal pump is known as mechanical efficiency. It is written as

$$\eta_m = \frac{\text{Power at the impeller}}{\text{Power at the shaft}}$$

The power at the impeller in kW $= \frac{\text{Work done by impeller per second}}{1000}$

$$= \frac{W}{g} \times \frac{V_{w_2} u_2}{1000} \quad \text{[Using equation (19.2)]}$$

$$\eta_m = \frac{\frac{W}{g}\left(\frac{V_{w_2} u_2}{1000}\right)}{\text{S.P.}} \quad ...(19.9)$$

where S.P. = Shaft power.

(*c*) **Overall Efficiency (η_o).** It is defined as ratio of power output of the pump to the power input to the pump. The power output of the pump in kW

$$= \frac{\text{Weight of water lifted} \times H_m}{1000} = \frac{WH_m}{1000}$$

Power input to the pump = Power supplied by the electric motor
= S.P. of the pump.

$$\therefore \quad \eta_o = \frac{\left(\frac{WH_m}{1000}\right)}{\text{S.P.}} \quad ...(19.10)$$

Also $\eta_o = \eta_{man} \times \eta_m$. ...(19.11)

▶ 19.9 PRIMING OF A CENTRIFUGAL PUMP

Priming of a centrifugal pump is defined as the operation in which the suction pipe, casing of the pump and a portion of the delivery pipe upto the delivery valve is completely filled up from outside source with the liquid to be raised by the pump before starting the pump. Thus the air from these parts of the pump is removed and these parts are filled with the liquid to be pumped.

The work done by the impeller per unit weight of liquid per sec is known as the head generated by the pump. Equation (19.1) gives the head generated by the pump as $= \frac{1}{g} V_{w_2} u_2$ metre. This equation is independent of the density of the liquid. This means that when pump is running in air, the head generated is in terms of metre of air. If the pump is primed with water, the head generated is same metre of water. But as the density of air is very low, the generated head of air in terms of equivalent metre of water head is negligible and hence the water may not be sucked from the pump. To avoid this difficulty, priming is necessary.

▶ 19.11 CAVITATION

Cavitation is defined as the phenomenon of formation of vapour bubbles of a flowing liquid in a region where the pressure of the liquid falls below its vapour pressure and the sudden collapsing of these vapour bubbles in a region of higher pressure. When the vapour bubbles collapse, a very high pressure is created. The metallic surfaces, above which these vapour bubbles collapse, is subjected to these high pressures, which cause pitting action on the surface. Thus cavities are formed on the metallic surface and also considerable noise and vibrations are produced.

Cavitation includes formation of vapour bubbles of the flowing liquid and collapsing of the vapour bubbles. Formation of vapour bubbles of the flowing liquid take place only whenever the pressure in any region falls below vapour pressure. When the pressure of the flowing liquid is less than its vapour pressure, the liquid starts boiling and vapour bubbles are formed. These vapour bubbles are carried along with the flowing liquid to higher pressure zones where these vapours condense and bubbles collapse. Due to sudden collapsing of the bubbles on the metallic surface, high pressure is produced and metallic surfaces are subjected to high local stresses. Thus the surfaces are damaged.

▶ 20.4 SLIP OF RECIPROCATING PUMP

Slip of a pump is defined as the difference between the theoretical discharge and actual discharge of the pump. The discharge of a single-acting pump given by equation (20.1) and of a double-acting pump given by equation (20.5) are theoretical discharge. The actual discharge of a pump is less than the theoretical discharge due to leakage. The difference of the theoretical discharge and actual discharge is known as slip of the pump. Hence, mathematically.

$$\text{Slip} = Q_{th} - Q_{act} \quad \text{...(20.8)}$$

But slip is mostly expressed as percentage slip which is given by,

$$\text{Percentage slip} = \frac{Q_{th} - Q_{act}}{Q_{th}} \times 100 = \left(1 - \frac{Q_{act}}{Q_{th}}\right) \times 100$$

$$= (1 - C_d) \times 100 \qquad \left(\because \frac{Q_{act}}{Q_{th}} = C_d\right) \quad \text{...(20.9)}$$

where C_d = Co-efficient of discharge.

20.4.1 Negative Slip of the Reciprocating Pump.

Slip is equal to the difference of theoretical discharge and actual discharge. If actual discharge is more than the theoretical discharge, the slip of the pump will become –ve. In that case, the slip of the pump is known as negative slip.

Negative slip occurs when delivery pipe is short, suction pipe is long and pump is running at high speed.

▶ 20.5 CLASSIFICATION OF RECIPROCATING PUMPS

The reciprocating pumps may be classified as :

1. According to the water being in contact with one side or both sides of the piston, and
2. According to the number of cylinders provided.

If the water is in contact with one side of the piston, the pump is known as single-acting. On the other hand, if the water is in contact with both sides of the piston, the pump is called double-acting. Hence, classification according to the contact of water is :

(*i*) Single-acting pump, and (*ii*) Double-acting pump.

According to the number of cylinder provided, the pumps are classified as :

(*i*) Single cylinder pump, (*ii*) Double cylinder pump, and

(*iii*) Triple cylinder pump.

▶ 20.9 AIR VESSELS

An air vessel is a closed chamber containing compressed air in the top portion and liquid (or water) at the bottom of the chamber. At the base of the chamber there is an opening through which the liquid (or water) may flow into the vessel or out from the vessel. When the liquid enters the air vessel, the air gets compressed further and when the liquid flows out the vessel, the air will expand in the chamber.

An air vessel is fitted to the suction pipe and to the delivery pipe at a point close to the cylinder of a single-acting reciprocating pump :

(*i*) to obtain a continuous supply of liquid at a uniform rate,

(*ii*) to save a considerable amount of work in overcoming the frictional resistance in the suction and delivery pipes, and (*iii*) to run the pump at a high speed without separation.

Fig. 20.9 shows the single-acting reciprocating pump to which air vessels are fitted to the suction and delivery pipes. The air vessels act like an intermediate reservoir. During the first half of the suction stroke, the piston moves with acceleration, which means the velocity of water in the suction pipe is more than the mean velocity and hence the discharge of water entering the cylinder will be more than the mean discharge. This excess quantity of water will be supplied from the air vessel to the cylinder in such a way that the velocity in the suction pipe below the air vessel is equal to mean velocity of flow. During the second half of the suction stroke, the piston moves with retardation and hence velocity of flow in the suction pipe is less than the mean velocity of flow. Thus, the discharge entering the cylinder will be less than the mean discharge. The velocity of water in the suction pipe due to air vessel is equal to mean velocity of flow and discharge required in cylinder is less than the mean discharge. Thus, the excess water flowing in suction pipe will be stored into air vessel, which will be supplied during the first half of the next suction stroke.

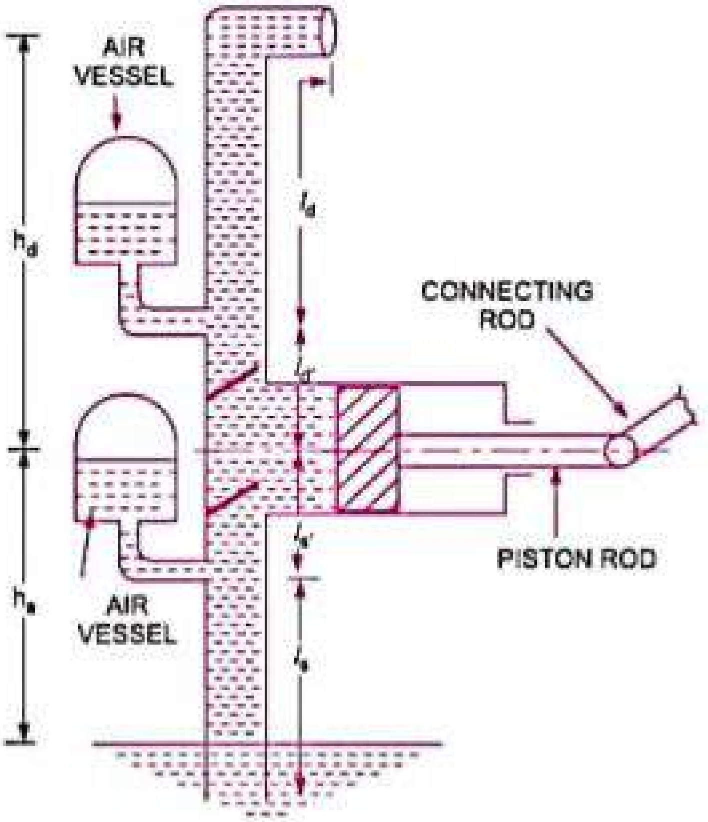


Fig. 20.9 *Air vessels fitted to reciprocating pump.*

When the air vessel is fitted to the delivery pipe, during the first half of delivery stroke, the piston moves with acceleration and forces the water into the delivery pipe with a velocity more than the mean velocity. The quantity of water in excess of the mean discharge will flow into the air vessel. This will compress the air inside the vessel. During the second half of the delivery stroke, the piston moves with retardation and the velocity of water in the delivery pipe will be less than the mean velocity. The water already stored into the air vessel will start flowing into the delivery pipe and the velocity of flow in the delivery pipe beyond the point to which air vessel is fitted will become equal to the mean velocity. Hence, the rate of flow of water in the delivery pipe will be uniform.

▶ 21.2 THE HYDRAULIC PRESS

The hydraulic press is a device used for lifting heavy weights by the application of a much smaller force. It is based on Pascal's law, which states that the intensity of pressure in a static fluid is transmitted equally in all directions.

The hydraulic press consists of two cylinders of different diameters. One of the cylinder is of large diameter and contains a ram, while the other cylinder is of smaller diameter and contains a plunger as shown in Fig. 21.1. The two cylinders are connected by a pipe. The cylinders and pipe contain a liquid through which pressure is transmitted.

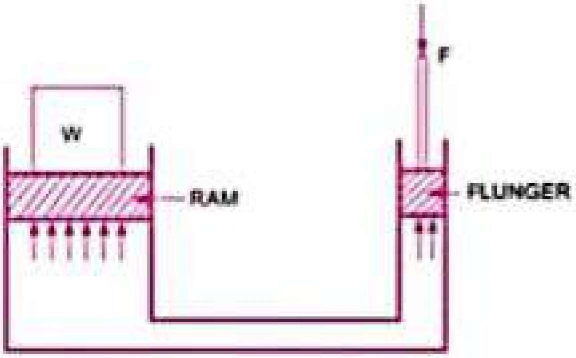


Fig. 21.1 *The hydraulic press.*

When a small force F is applied on the plunger in the downward direction, a pressure is produced on the liquid in contact with the plunger. This pressure is transmitted equally in all directions and acts on the ram in the upward direction as shown in Fig. 21.1. The heavier weight placed on the ram is then lifted up.

Let W = Weight to be lifted,

F = Force applied on the plunger,

A = Area of ram,
a = Area of plunger, and
p = Pressure intensity produced by force F.

$$= \frac{\text{Force } F}{\text{Area of plunger}} = \frac{F}{a}$$

Due to Pascal's law, the above intensity of pressure will be equally transmitted in all directions. Hence, the pressure intensity at the ram will be $= p = \frac{F}{a}$.

But the pressure intensity on ram is also $= \frac{\text{Weight}}{\text{Area of ram}} = \frac{W}{A}$.

Equating the pressure intensity on ram, $\frac{F}{a} = \frac{W}{A}$

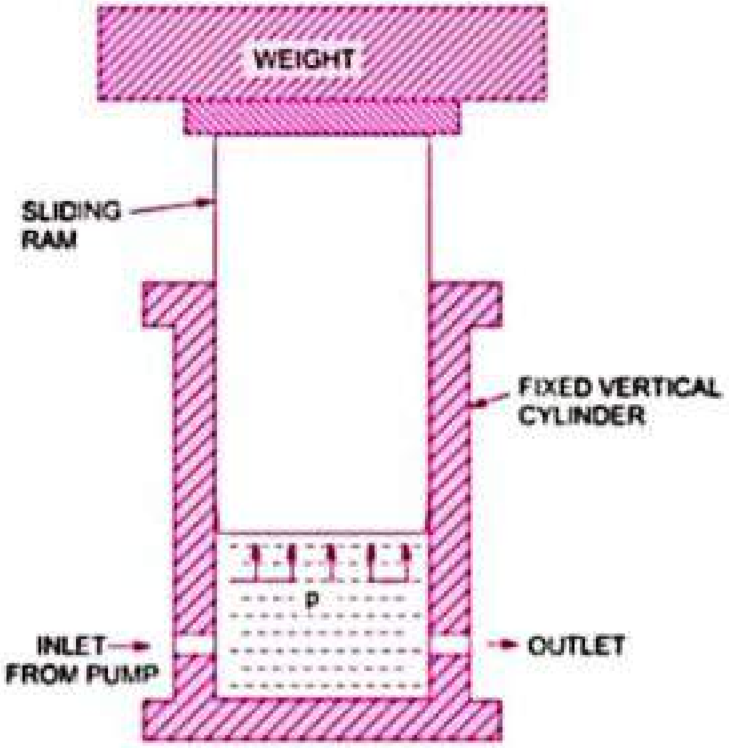
$$\therefore \quad W = \frac{F}{a} \times A. \qquad \text{...(21.1)}$$

▶ 21.3 THE HYDRAULIC ACCUMULATOR

The hydraulic accumulator is a device used for storing the energy of a liquid in the form of pressure energy, which may be supplied for any sudden or intermittent requirement. In case of hydraulic lift or the hydraulic crane, a large amount of energy is required when lift or crane is moving upward. This energy is supplied from hydraulic accumulator. But when the lift is moving in the downward direction, no large external energy is required and at that time, the energy from the pump is stored in the accumulator.

Fig. 21.4 shows a hydraulic accumulator which consists of a fixed vertical cylinder containing a sliding ram. A heavy weight is placed on the ram. The inlet of the cylinder is connected to the pump, which continuously supplies water under pressure to the cylinder. The outlet of the cylinder is connected to the machine (which may be lift or crane etc.)

The ram is at the lowermost position in the beginning. The pump supplies water under pressure continuously. If the water under pressure is not required by the machine (lift or crane), the water under pressure will be stored in the cylinder. This will raise the ram on which a heavy weight is placed. When the ram is at the uppermost position, the cylinder is full of water and accumulator has stored the maximum amount of pressure energy. When the machine (lift or crane) requires a large amount of energy, the hydraulic accumulator will supply this energy and ram will move in the downward direction.



21.3.2 Differential Hydraulic Accumulator.

It is a device in which the liquid is stored at a high pressure by a comparatively small load on the ram. It consists of a fixed vertical cylinder of small diameter as shown in Fig. 21.5. The fixed vertical cylinder is surrounded by closely fitting brass bush, which is surrounded by an inverted moving cylinder, having circular projected collar at the base on which weights are placed.

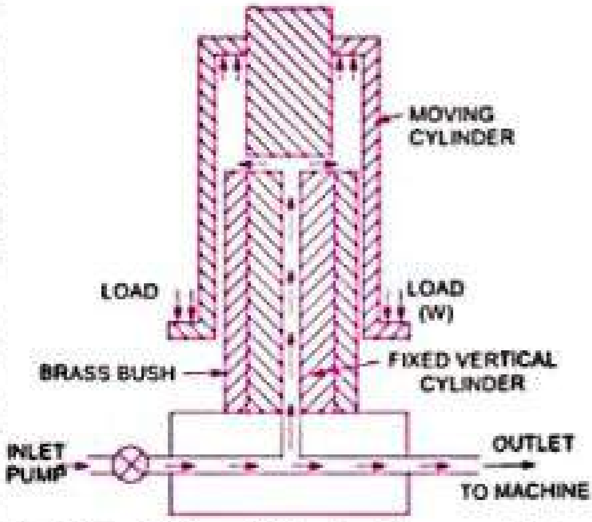


Fig. 21.5 *Differential hydraulic accumulator.*

The liquid from the pump is supplied to the fixed vertical cylinder. The liquid moves up through the small diameter of fixed vertical cylinder and then enters the inverted cylinder. The water exerts an upward pressure force on the internal annular area of the inverted moving cylinder, which is loaded at the base. The internal annular area of the inverted moving cylinder is equal to the sectional area of the brass bush. When the inverted moving cylinder moves up, the hydraulic energy is stored in the accumulator.

Let p = Intensity of pressure of liquid supplied by pump,

a = Area of brass-bush,

L = Vertical lift of the moving cylinder,

W = Total weight placed on the moving cylinder including the weight of cylinder.

Then $W = p \times a$

$$\therefore \quad P = \frac{W}{a} \qquad \text{...(21.7)}$$

From equation (21.7), it is clear that pressure intensity can be increased with a small load W, by making area 'a' small.

Now total energy stored in the accumulator = Total weight × Vertical lift

$$= W \times L \text{ Nm.} \qquad \text{...[21.7 (a)]}$$

▶ 21.4 THE HYDRAULIC INTENSIFIER

The device, which is used to increase the intensity of pressure of water by means of hydraulic energy available from a large amount of water at a low pressure, is called the hydraulic intensifier. Such a device is needed when the hydraulic machines such as hydraulic press requires water at very high pressure which cannot be obtained from the main supply directly.

A hydraulic intensifier consists of fixed ram through which the water, under a high pressure, flows to the machine. A hollow inverted sliding cylinder, containing water under high pressure, is mounted over the fixed ram. The inverted sliding cylinder is surrounded by another fixed inverted cylinder which contains water from the main supply at a low pressure as shown in Fig. 21.6

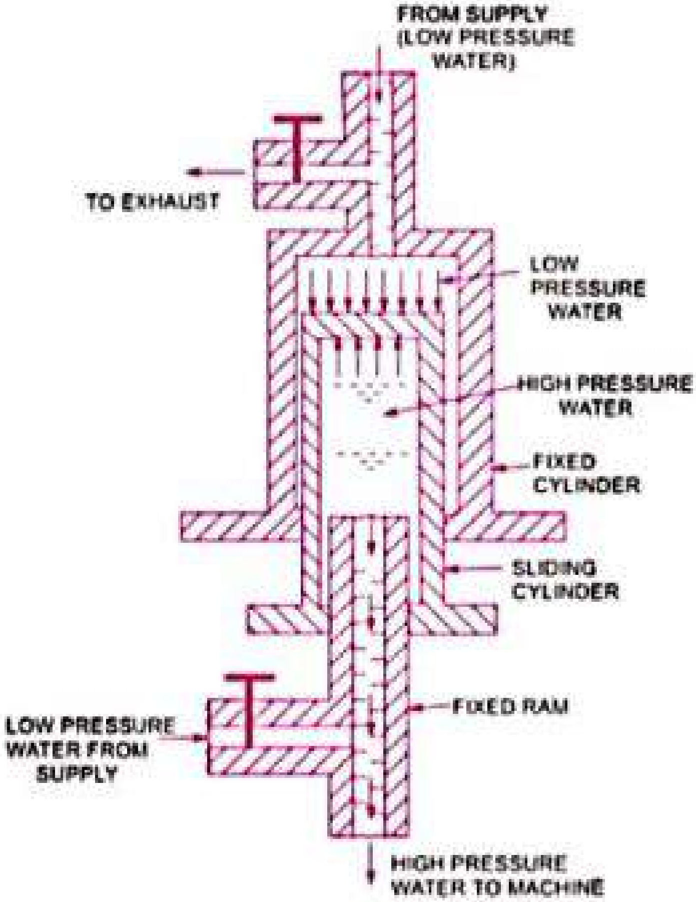


Fig. 21.6 *The hydraulic intensifier.*

A large quantity of water at low pressure from supply enters the inverted fixed cylinder. The weight of this water pressure the sliding cylinder in the downward direction. The water in the sliding cylinder gets compressed due to the downward movement of the sliding cylinder and its pressure is thus increased. The high pressure water is forced out of the sliding cylinder through the fixed ram, to the machine as shown in Fig. 21.6.

Let p = Intensity of pressure of water from supply to the fixed cylinder (low pressure water),

A = External area of the sliding cylinder,

a = Area of the end of the fixed ram, and

p^* = Intensity of the pressure of water in the sliding cylinder (high pressure water).

The force exerted by low pressure water on the sliding cylinder in the downward direction

$$= p \times A.$$

The force exerted by the high pressure water on the sliding cylinder in the upward direction

$$= p^* \times a.$$

Equating the upward and downward forces,

$$p \times A = p^* \times a.$$

$$p^* = \frac{p \times A}{a}. \quad \text{...(21.8)}$$

▶ 21.5 THE HYDRAULIC RAM

The hydraulic ram is a pump which raises water without any external power for its operation. When large quantity of water is available at a small height, a small quantity of water can be raised to a greater height with the help of hydraulic ram. It works on the principle of water hammer.

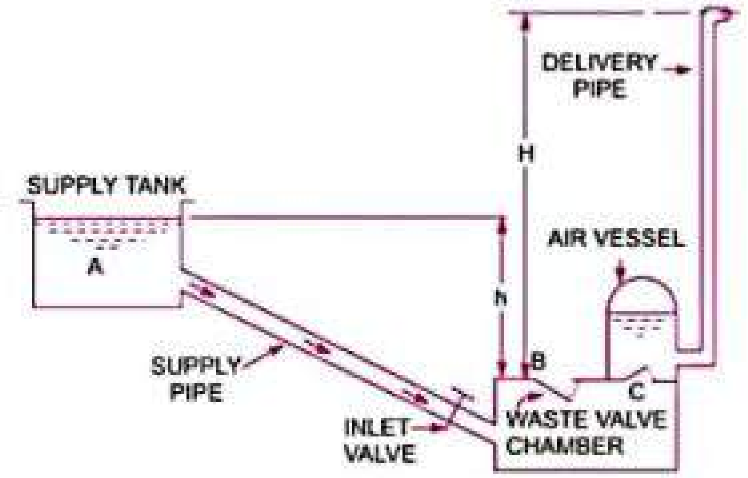


Fig. 21.7 *The hydraulic ram.*

Fig. 21.7 shows the main components of the hydraulic ram. When the inlet valve fitted to the supply pipe is opened, water starts flowing from the supply tank to the chamber, which has two valves at *B* and *C*. The valve *B* is called waste valve and valve *C* is called the delivery valve. The valve *C* is fitted to an air vessel. As the water is coming into the chamber from supply tank, the level of water rises in the chamber and waste valve *B* starts moving upward. A stage comes, when the waste valve *B* suddenly closes. This sudden closure of waste valve creates high pressure inside the chamber. This high pressure force opens the delivery valve *C*. The water from chamber enters the air vessel and compresses the air inside the air vessel. This compressed air exerts force on the water in the air vessel and small quantity of water is raised to a greater height as shown in Fig. 21.7.

▶ 21.6 THE HYDRAULIC LIFT

The hydraulic lift is a device used for carrying passenger or goods from one floor to another in multi-storeyed building. The hydraulic lifts are of two types, namely,

1. Direct acting hydraulic lift, and 2. Suspended hydraulic lift.

21.6.1 Direct Acting Hydraulic Lift. It consists of a ram, sliding in fixed cylinder as shown in Fig. 21.8. At the top of the sliding ram, a cage (on which the persons may stand or goods may be placed) is fitted. The liquid under pressure flows into the fixed cylinder. This liquid exerts force on the sliding ram, which moves vertically up and thus raises the cage to the required height.

The cage is moved in the downward direction, by removing the liquid from the fixed cylinder.

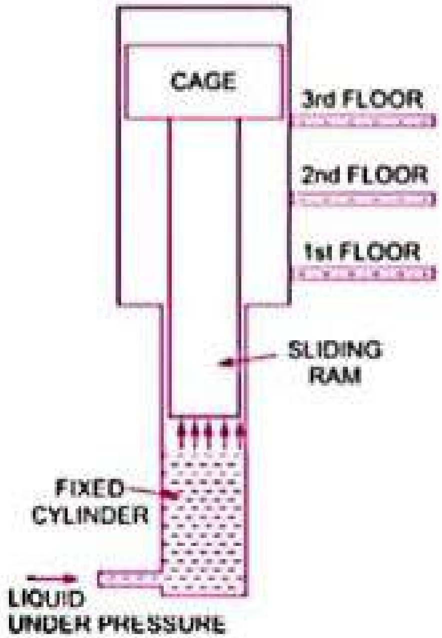


Fig. 21.8 *Suspended hydraulic lift.*

21.6.2 Suspended Hydraulic Lift. Fig. 21.9 shows the suspended hydraulic lift. It is a modified form of the direct acting hydraulic lift. It consists of a cage (on which persons may stand or goods may be placed) which is suspended from a wire rope. A jigger, consisting of a fixed cylinder, a sliding ram and a set of two pulley blocks, is provided at the foot of the hole of the cage. One of the pulley block is movable and the other is a fixed one. The end of the sliding ram is connected to the movable pulley block. A wire rope, one end of which is fixed at *A* and the other end is taken round all the pulleys of the movable and fixed blocks and finally over the guide pulleys as shown in Fig. 21.9. The cage is suspended from the other end of the rope. The raising or lowering of the cage of the lift is done by the jigger as explained below.

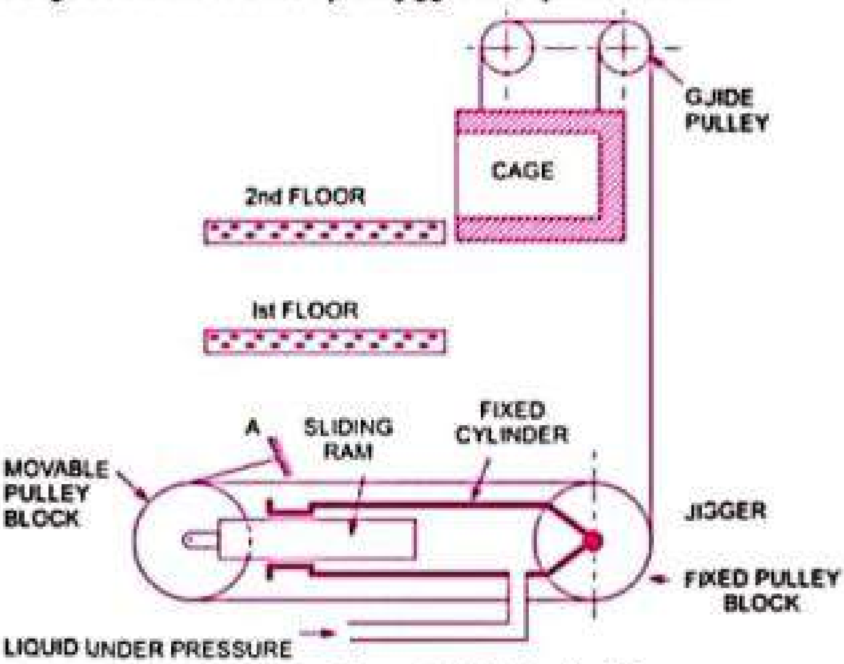


Fig. 21.9 *Suspended hydraulic lift.*

When water under high pressure is admitted into the fixed cylinder of the jigger, the sliding ram is forced to move towards left. As one end of the sliding ram is connected to the movable pulley block and hence the movable pulley block moves towards the left, thus increasing the distance between two pulley blocks. The wire rope connected to the cage is pulled and the cage is lifted. For lowering the cage, water from the fixed cylinder is taken out. The sliding ram moves towards right and hence movable pulley blocks also moves towards right. This decreases the distance between two pulley blocks and the cage is lowered due to increased length of the rope.

Problem 21.16 *A hydraulic lift is required to lift a load of 8 kN through a height of 10 metres, once in every 80 seconds. The speed of the lift is 0.5 m per second. Determine :*

(i) Power required to drive the lift, *(ii) Working period of lift in seconds, and*

(iii) Idle period of the lift in seconds.

Solution. Given :

Load lifted, $W = 8 \text{ kN} = 8 \times 1000 = 8000 \text{ N}$

Height, $H = 10 \text{ m}$

Time for one operation, $t = 80 \text{ s}$

Speed of lift, $v = 0.5 \text{ m/s}$.

(*i*) Work done in lifting the load in 80 seconds

$$= W \times H = 8000 \times 10 = 80000 \text{ Nm}$$

$\therefore$ Work done/s $= \dfrac{80000}{80} = 1000$ Nm/s

$\therefore$ Power required to drive the lift $= \dfrac{1}{1000} \times$ Work done/s $= \dfrac{1}{1000} \times 1000 =$ **1.0 kW. Ans.**

(*ii*) Working period of the lift $= \dfrac{\text{Height of the lift}}{\text{Velocity of lift}} = \dfrac{10}{0.50} =$ **20 sec. Ans.**

(*iii*) Idle period of the lift = Total time − Working period of lift

= 80 − 20 = **60 sec. Ans.**

4th Auto HPC

HYDRAULIC CIRCUITS

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A fluid power system can be broken into three segments. The power input segment consisting of the prime mover & the pump. The control segment consisting of valves that control the direction, pressure & flow rate. The power output segment, consisting of the actuators & the load. The important categories of control valves are –

1. Directional control valve (DCV)
2. Pressure control valve (PCV)
3. Flow control valve (FCV)

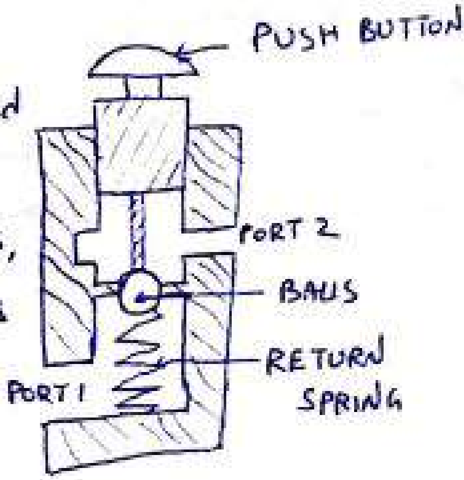
→ DCV control the direction of flow in a circuit, which among other things, can control the direction of the actuator.

→ PCV control the pressure level, which controls the output force of a cylinder or the output torque of a motor.

→ FCV control the flow rate of the liquid which controls the speed of the actuators.

Valve configuration

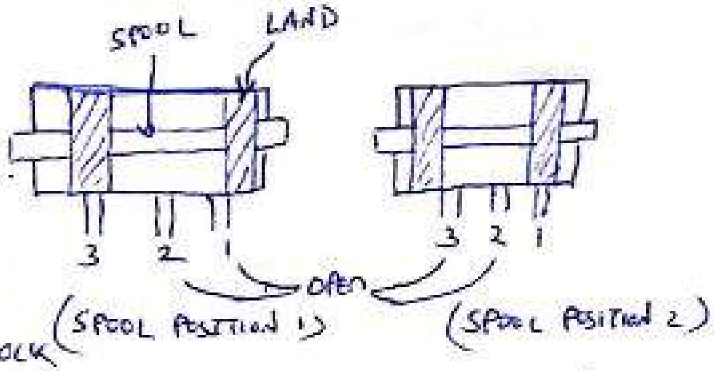
1. POPPET OR SEAT VALVES



Normally this valve is in the closed condition & hence there is no connection between port 1 & port 2. In poppet valves, balls are used in conjunction with valves seats to control the flow. When the push button is depressed the ball is pushed out of it's seats & hence the flow is permitted from port 1 to port 2.

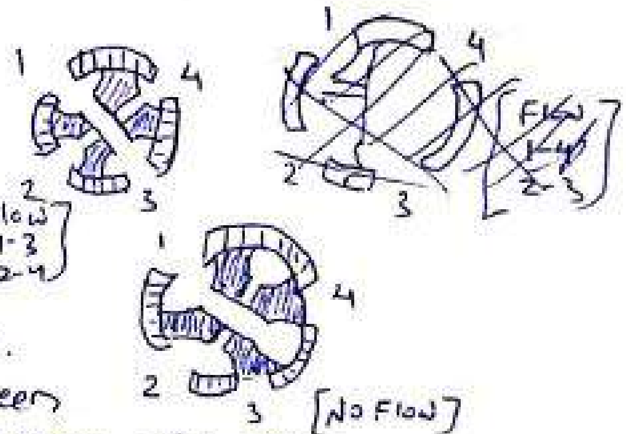
When the push button is released spring & fluid pressure force the ball back up against its seat & so closes off the flow. These types of valves are simple in design & less expensive. The force required to operate the poppet valves are more, so they are suitable mostly for low pressure applications

2. SLIDING SPOOL VALVES

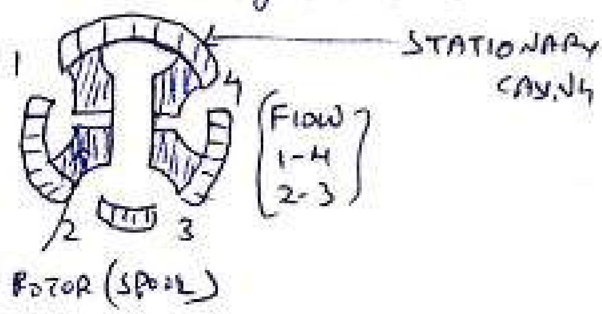


These types of valves are most frequently used in hydraulic system. A spool moves horizontally within the valve body to control the flow. The raised areas called lands block or, open port to give the required operation. In first position the port 1 & port 2 is opened & port 3 is blocked so the flow is permitted between ports 1 & 2. In the second position the ports 2 & 3 are open & port 1 is blocked so the flow is permitted between 2 & 3. By using this type of valves different operations can be achieved with a common body & different spool. It is used for high pressure application

3. ROTARY SPOOL VALVES

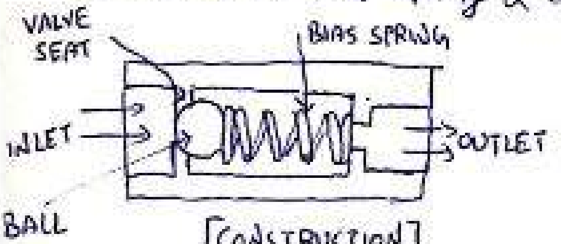


These valves have a rotating spool which engages with ports in the valve casing to give the required operation. When the spool rotates, it opens & closes ports to allows & prevent the fluid flow through it. There are four ports 1, 2, 3 & 4. In the first position there is flow between 1 & 3, 2 & 4. In second position flow between 2 & 3, 1 & 4. In third position all the ports are blocked by the spool & no flow.

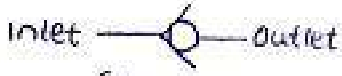


DIRECTION CONTROL VALVES – These valves are used to control the direction of flow in a hydraulic circuit. According to the construction of internal moving parts it is classified as Poppet type & sliding spool type. It may be further classified as one way, two way, three way & four way valves, depending upon the number of port connections available. On the basis of actuating devices, it can be classified as manually operated, mechanically operated, solenoid operated & Pilot operated.

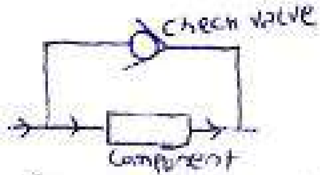
CHECK VALVES – The simplest direction control valve is a check valve. It allows flow in one direction & blocks flow in the opposite direction. It consists of a ball with a light bias spring that holds the ball against the valve seat. Flow coming into the inlet pushes the ball off the seat against the light force of the spring & continues to the outlet.



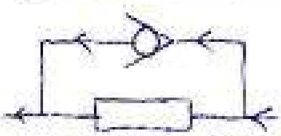
[CONSTRUCTION]



[SYMBOL]

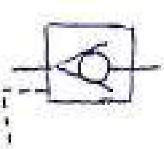


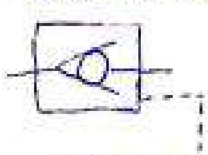
[FLOW THROUGH COMPONENT]


[COMPONENT BYPASS]

If flow tries to comes in from left it cannot pass through the check valve. It is therefore forced to go through the component. When the flow comes in from the right, however the flow goes through the check valve & the component is bypassed. This occurs because the check valve is designed to have less resistance to flow than the component in this direction.

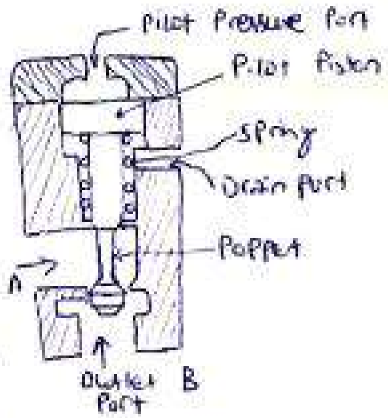
PILOT OPERATED CHECK VALVE


[PILOT-TO-OPEN CHECK VALVE]


[PILOT-TO-CLOSE CHECK VALVE]

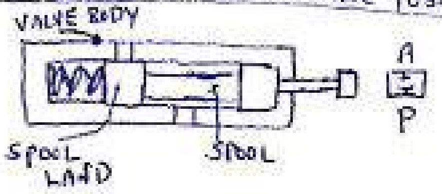
One commonly used type is the Pilot to open check valve. Pilot lines are hydraulic lines that are used for control purposes. They typically send system pressure to component, so that the component can react to pressure changes. The free flow in the normal direction from a Port A to Port B is achieved in a usual manner. But the reverse flow is blocked as the fluid pressure pushes the poppet into the closed position. In order to permit the fluid flow in the reverse direction that is from Port B to Port A, a pilot pressure is applied through the pilot pressure port. The pilot pressure pushes the pilot piston & the poppet down. Thus the fluid flow in the reverse direction is also obtained. The purpose of the drain port in the circuit is to prevent oil from creating a pressure building in the bottom of the pilot piston. The pilot lines are shown in dashed lines.

TWO WAY DIRECTIONAL CONTROL VALVE

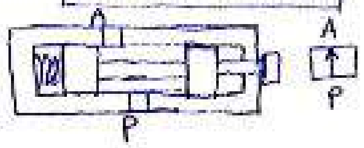


A spool valve consists of a cylindrical spool that slides back & forth inside the valve body to either connect or block flow between ports. The larger diameter portion of the spool, the land, blocks flow by covering a port. This particular valve has two ports, labeled P & A. P is connected to the pump line & A is the outlet to the system.

A. Valve in the normal position



B. Valve actuated



C. Symbol

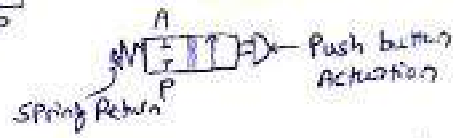
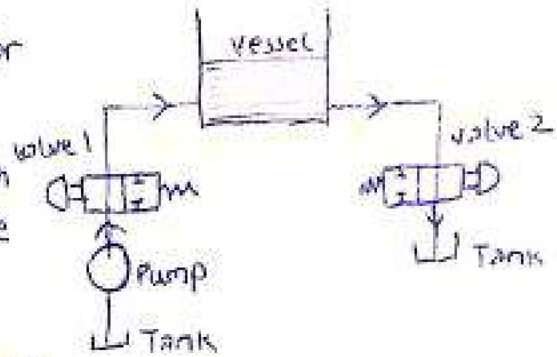


Fig. A shows the valve in its normal state & its corresponding symbol. The valve is held in this position by the force of the spring. In this position, the flow from the inlet port P is blocked from going to the outlet port A. Fig. B shows the valve in its actuated state & its corresponding symbol. The valve is shifted into this position by applying a force to overcome the resistance of the spring. In this position, the flow is allowed to go to the outlet port around the smaller diameter portion of the spool. The symbol shown in Fig. C has two blocks, one for each position of the valve. Valves may have more than two positions. The spring is on the closed position side of the symbol, which indicates that it is a normally closed valve. The symbol for the method of actuation is shown on the opposite side of the valve. In this case, the valve is push button actuated. Thus, the graphic symbol in Fig. C represents a two way, two positions, normally closed DCV with push button actuation & spring return.

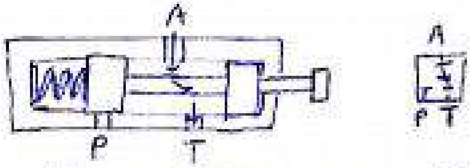


* Let consider an example of an application for a two way valve. Here pair of two way valves is used to fill & drain a vessel. Although two tanks are shown in this schematic, there may in fact be only one tank in the actual system. When valve 1 & valve 2 are in the closed position then the line from pump & tank are blocked to hold the fluid in the vessel. When the valve 1 is shifted to the open position & valve 2 remains closed. This will fill the vessel.

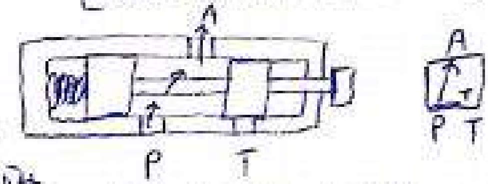
When valve 2 is shifted to the open position & valve 1 remains closed. This will drain the vessel. The above figure shows that valve 1 & valve 2 are in open position so that fluid is filled & drain from the vessel. There are other types of construction for two way valves in addition to the spool type are ball valves & gate valves.

THREE WAY DIRECTION CONTROL VALVES

Three way valves also either block or, allow flow from an inlet to an outlet. They also allow outlet to flow back to the tank when the pump flow is blocked, while a two-way does not. A three way valve have three ports a pressure inlet port (P), an outlet to the system (A) & a return to the tank (T). In its normal position, just as with the two way DCV, the valve is held in position with spring.



[VALVE IN NORMAL POSITION]



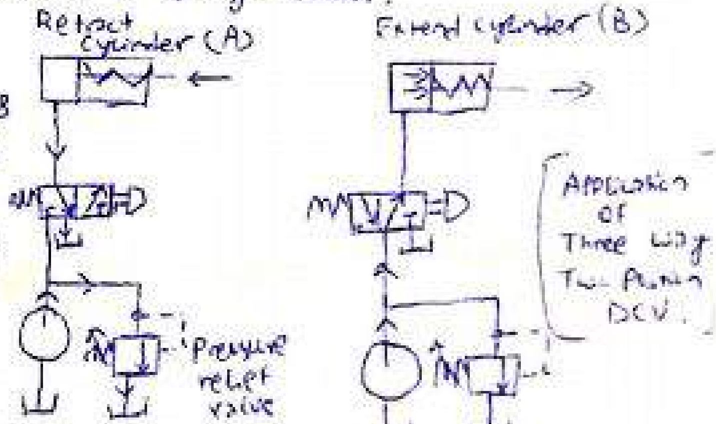
[VALVE ACTUATED]

[SYMBOL]

In normal position, the pressure port (P) is blocked & the outlet (A) is connected with the tank (T). This depressurizes or vents the outlet port.

In actuated position, the pressure port is connected with the outlet & the tank port is blocked. This sends flow & pressure to the system. The spring is shown on the normal side of the valve symbol & the actuation type is shown in opposite side by push button. The symbol indicates that this is a three way two position normally closed DCV with push button & spring return.

The most common application for a three way valve in a hydraulic circuit is to control a single acting cylinder. Part A shows the valve in normal position in which pressure port is blocked & the outlet is return to the tank. This allows the force of the spring to act on the piston & retract the cylinder. The cylinder will remain retracted as long as the valve is in this position.

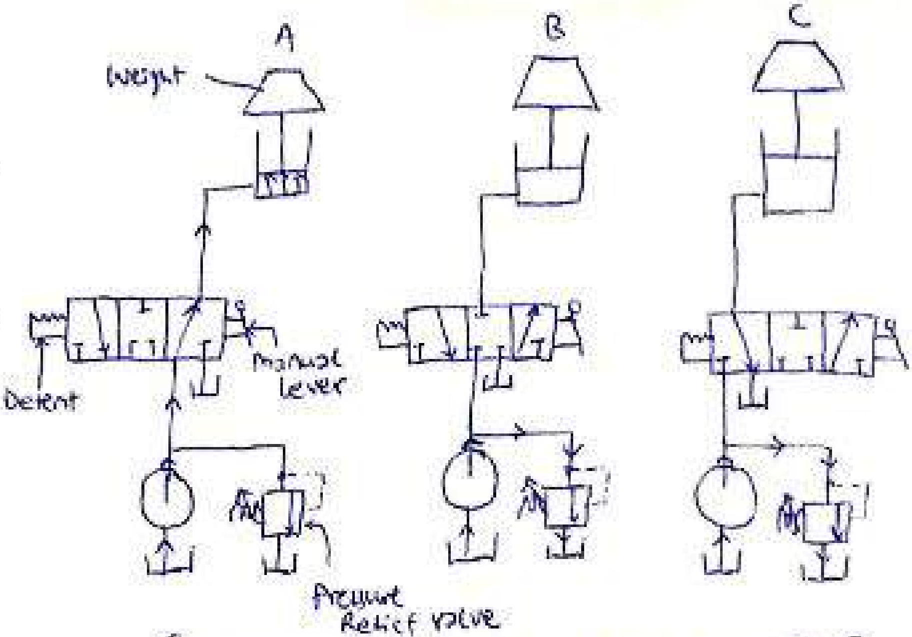


In part B the valve is shifted to that the pressure port is connected to the outlet & the tank port is blocked. This applies pump flow & pressure to the piston & extends the cylinder against the relatively light force of the spring. A two way valve couldn't be used in this application. It wouldn't allow the cylinder to retract when it is in the closed position because the closed position of a two way doesn't have a return to the tank. A pressure relief valve, a device that limits the maximum pressure in a hydraulic circuit, is included in the previous circuit. These valves are required components in every hydraulic system.

A - Extend cylinder

B - Hold cylinder

C - Retract cylinder

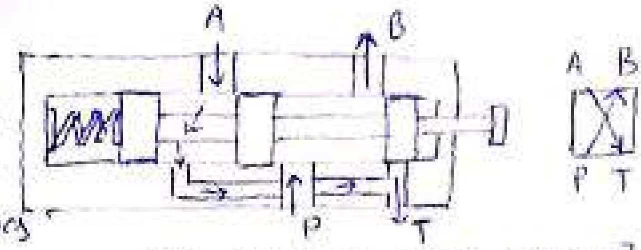


[Application of Three way three position DCV]

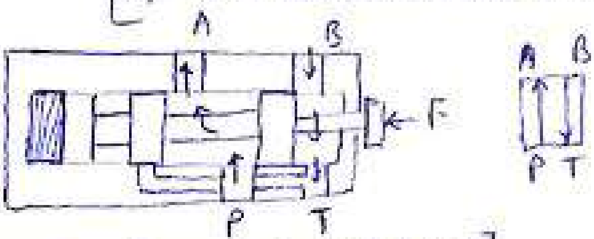
The above figure shows application of three way three position DCV using gravity return type single acting cylinder. A third position valve called neutral may be desirable for this application. This position shown as the center position in the symbol blocks all three ports. This holds the cylinder in a mid-stroke position because the hydraulic fluid, which is relatively incompressible, is trapped between the valve & the cylinder. Many cylinder applications require this feature. This introduces another type of actuation manual lever & detent. A detent is a mechanism that holds the valve in any position into which it is shifted. Detented valves have no normal position because they will remain indefinitely in the last position indicated.

Four way Directional control valves

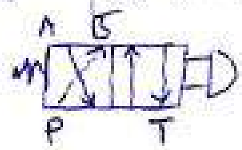
Four way valves are the most commonly used directional control valves in hydraulic circuits because they are capable of controlling double acting cylinders & bidirectional motors. Figure shows the operation of a typical four way, two positions DCV. A four way has four ports, usually labeled P, T, A & B. P is the pressure inlet & T is the return to tank. A & B are outlets to the system. In the normal position, pump flow is sent to port 'A' & port 'B' is connected to the tank.



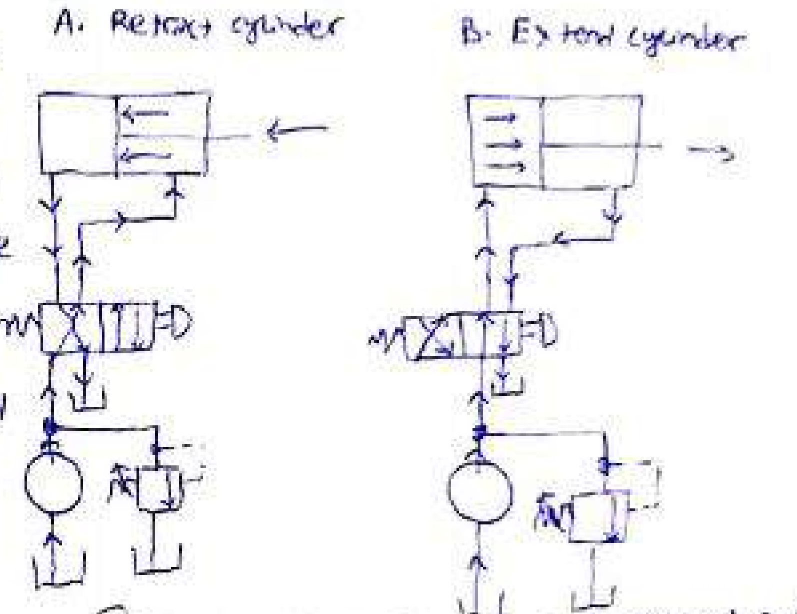
[A. VALVE IN NORMAL POSITION]



[B. VALVE ACTUATED]



Four way DCV control two flows of fluid at the same time, while two way & three way DCV control only one flow at the time.

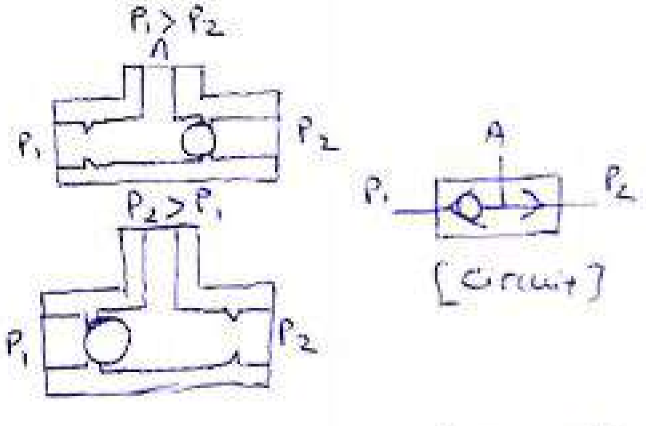


The most common application for a four way DCV is to control a double acting cylinder as shown in the figure. When the valve is in the normal position, the pump line is connected to the rod end of the cylinder & the blind end is connected to the tank. The cylinder will therefore retracted, the pump flow will go to the system.

[APPLICATION OF FOUR WAY, TWO POSITION DCV]

In Fig. B, the pump line is connected to the blind end of the cylinder & the rod end is connected to the tank. This will cause the cylinder to extend. When the cylinder is fully extended, pump flow will again go over the pressure relief valve to the tank.

SHUTTLE VALVES



These valves allow two alternate flow sources to be connected to one branch circuit. They have two inlets (P_1 & P_2) & one outlet (A). Outlet A received flow from whichever inlet is at a higher pressure. If the pressure at P_1 is greater than that at P_2, the ball slides to the right & allows P_1 to send flow to outlet A. If the pressure at P_2 is greater than at P_1, the ball slides to the left & P_2 supplies flow to outlet A.

Directional control Valve Actuation

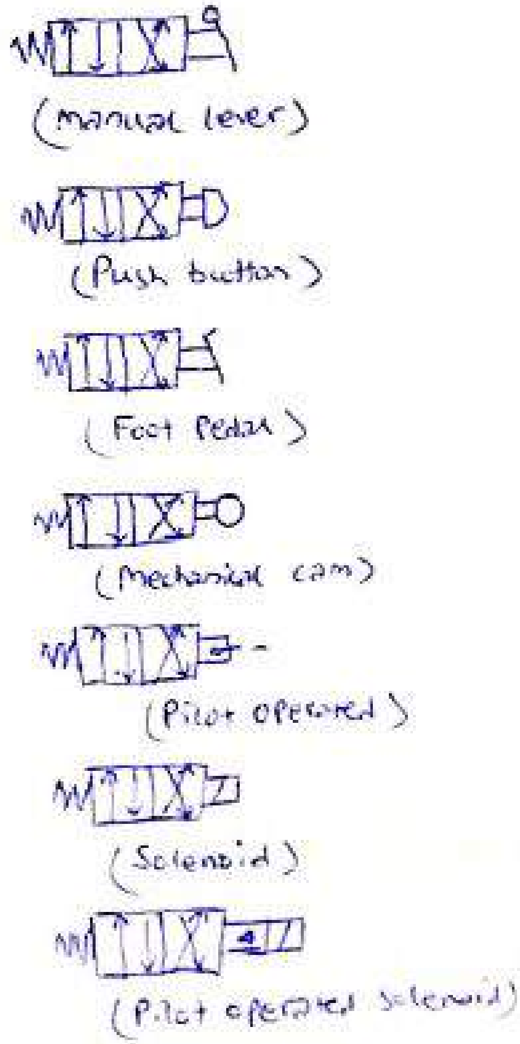
Various methods used to shift the valve are shown in figure. All shown controlling a spring return four way two position valve. Manual lever is a popular method of actuation for DCVs used in mobile equipment applications such as back hoes, bulldozers & farm equipment. Push button actuation is more prevalent in industrial applications.

Foot pedal actuation, which could be used in an application in which hands free shifting of the DCV is required.

Cam actuated valves shift when depressed by some mechanical component of the machine. Pilot operated valves are shifted with system pressure. Pilot operated check valves use system pressure to hold a check valve open or closed when pressure is applied to the pilot line.

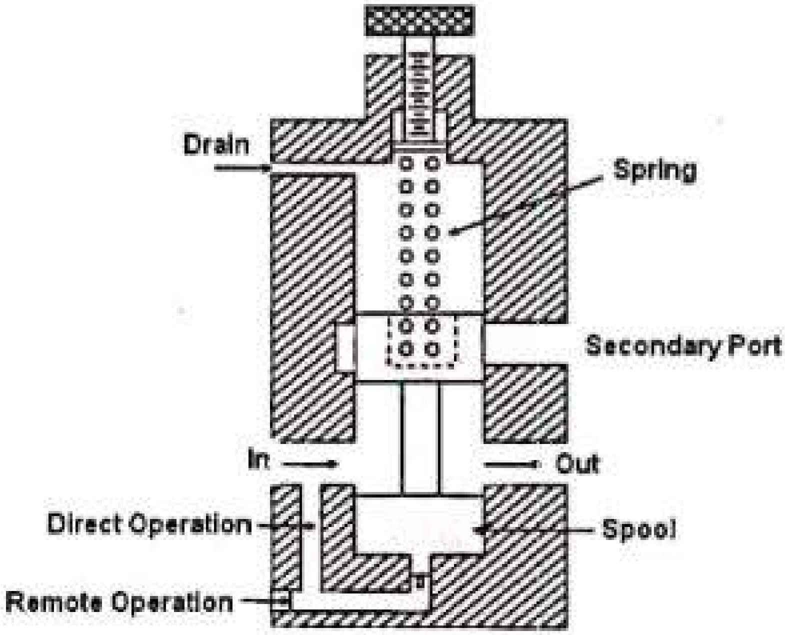
Solenoid actuated DCV are shifted using electrical current, which induces a magnetic force that shifts the valve spool. Solenoid valves are widely used in industrial applications on electronically controlled machinery.

The pilot operated solenoid valves are essentially two valves in one package. The solenoid is used to actuate a small pilot DCV, which in turn uses the pressure of the system to shift the main valve. This method of actuation is necessary on large valves that operate in systems at high pressures. They are necessary because the solenoid alone can't generate enough force to shift a large valve against a high pressure. The solenoids can, however, generate enough force to shift the small pilot valve, which can then use the pressure of the system to shift the main valve.



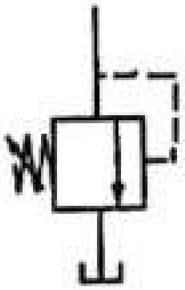
The sequence valve is to direct flow in a predetermined of sequence. The sequence valve operates on the principle that when system pressure over comes the spring setting, the valve spool moves up allowing flow to the secondary port that is connected with the second operating hydraulic cylinder.

The figure shows the symbol comparison of pressure relief valve and sequence valve.

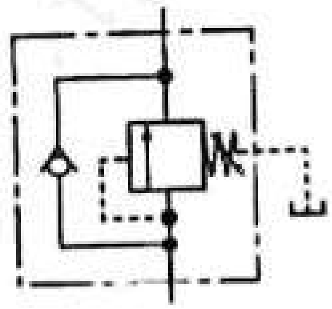


Instead of sending flow back to the tank, however, a sequence valve allows flow to a branch circuit when a preset pressure is reached. The check valve allows the sequence valve to be by passed in the reverse direction. The component enclosure line indicates that the check is an integral part of the component. The sequence valve has an external drain line, therefore a line must be connected from the sequence valves drain port to the tank.

Pressure Relief Valve



Sequence valve



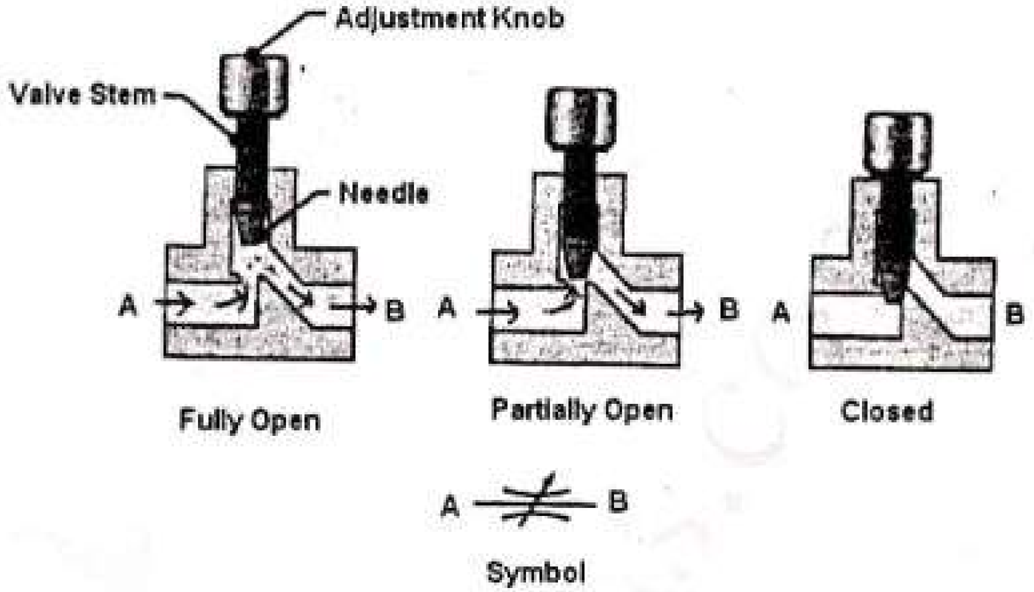
The below figure shows the circuit of tube bending machines uses sequence valve for clamping and bending tubes in sequence. As per the required sequence first the work piece has to be clamped, then bend to required shape, bending cylinder retract and clamping cylinder retract to unclamp the work piece. In this circuit, the bending cylinder will extend only after the clamp cylinder is fully extended and the clamp cylinder will retract only after the bending cylinder is fully retracted.

1. Needle flow control valve

2. Pressure compensated flow control valve

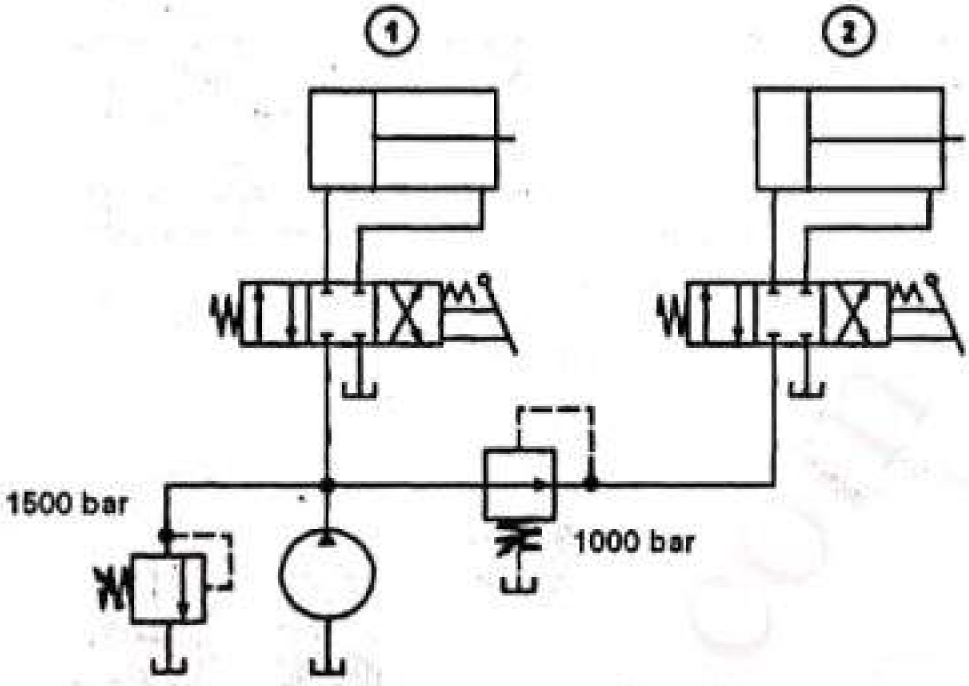
3.12.1 NEEDLE VALVE

The simplest type of flow control valve is needle valve as shown in Figure.



Needle Valve

This valve is basically just an adjustable orifice than can be closed to reduce the flow rate in a circuit. The orifice size is adjustment by turning the adjustment knob, which raises or lowers the valve stem and needle. The first figure shows the valve fully open, allowing nearly unrestricted flow. The valve is partially closed and is restricting the flow in the next figure. In the last figure, the valve is completely closed and is therefore allowing no flow. The symbol for a needle valve is shown in D. Needle valves are often used as manual shut-off in applications that require good metering characteristics. In most fluid applications, a needle valve with an integral check valve is used to control the flow rate as shown in below Figure. Part A shows the flow going through the valve from A to B. In this direction, it cannot go through the check and must therefore go through the restriction. In part B, the flow is coming from the opposite direction B to A and can pass through the check valve. The flow is virtually unrestricted in this direction. This flow control valve therefore only controls the flow rate from A to B. From B to A, the flow is uncontrolled because the restriction is by passed through the check.



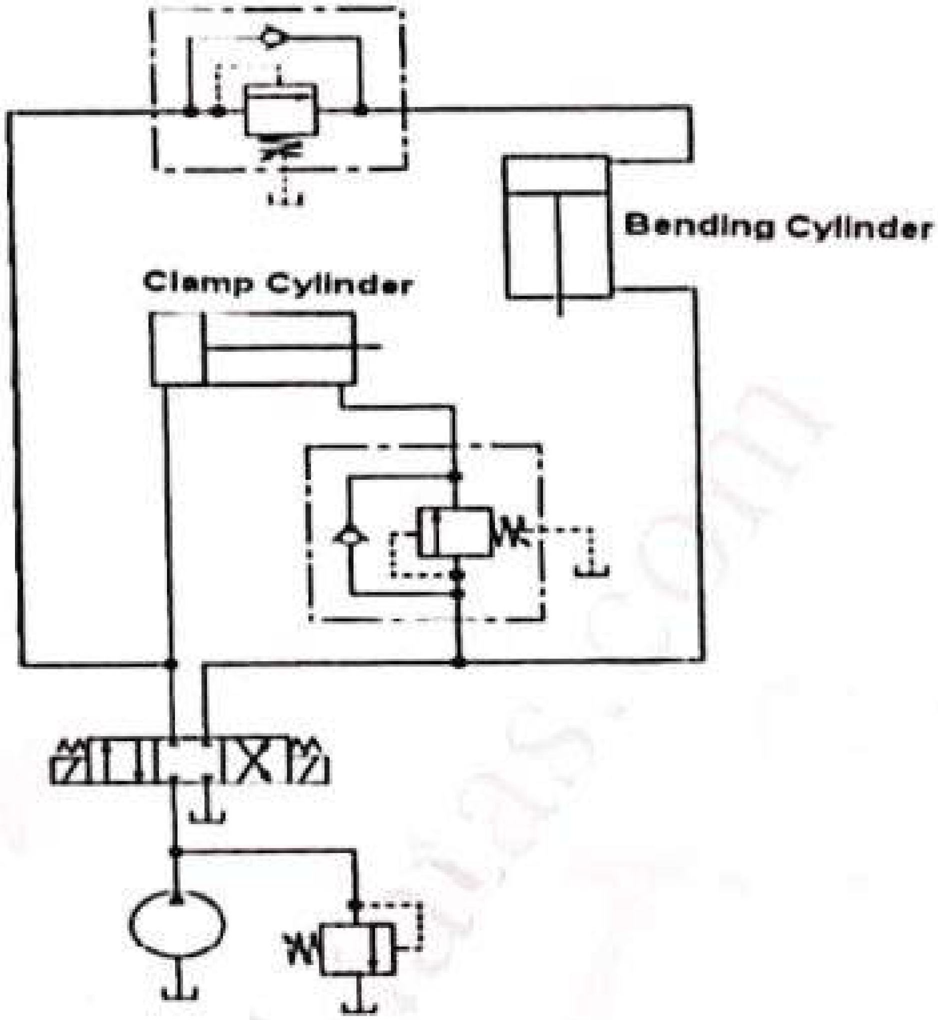
Pressure Reducing Valve Application

The above figure shows an application for a pressure reducing valve. Here, two cylinders are connected in parallel. The circuit is designed to operate at a maximum pressure of 1500 bar, which is determined by the relief valve setting. This is the maximum pressure that cylinder will see. For a reason determined by the function of the machine, cylinder 2 is limited to a maximum pressure of 1000 bar. This is accomplished by placing a pressure reducing valve in the circuit in the location as shown.

If the pressure in the circuit rises above 1000 bar, the pressure reducing valve will close partially to create a pressure drop across the valve. The valve then maintains the pressure drop so that outlet pressure is not allowed to rise above 1500 bar setting. The disadvantage of this method of pressure control is that the pressure drop across the reducing valve represents lost energy that is converted to heat. If the pressure setting of the reducing valve is set very low relative to the pressure in the rest of the system, the pressure drop will be very high, resulting in excessive heating of the fluid. When the hydraulic fluid becomes too hot, its viscosity reduces, causing increased component wear.

3.9 SEQUENCE VALVES

When the operation of two hydraulic cylinders is required to be performed in sequence by using a single direction valve, a special valve is required for this purpose and it is known as the sequence valve.

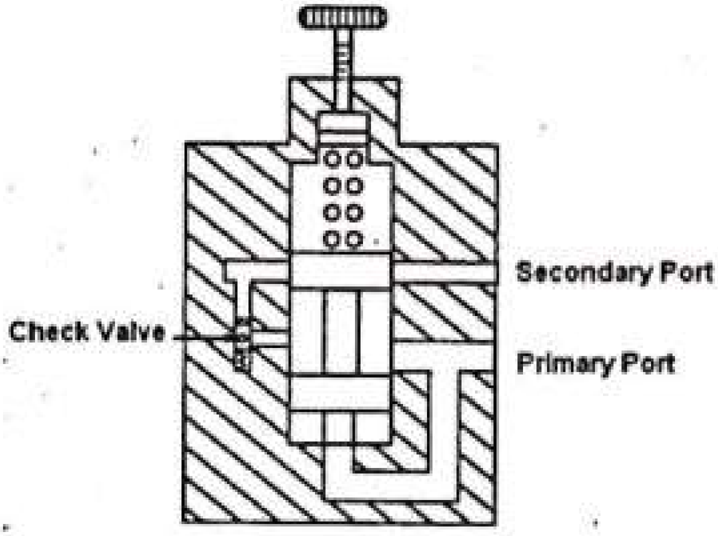


Sequence Valve For Tube Bending Machine

3.10 COUNTER BALANCE VALVES

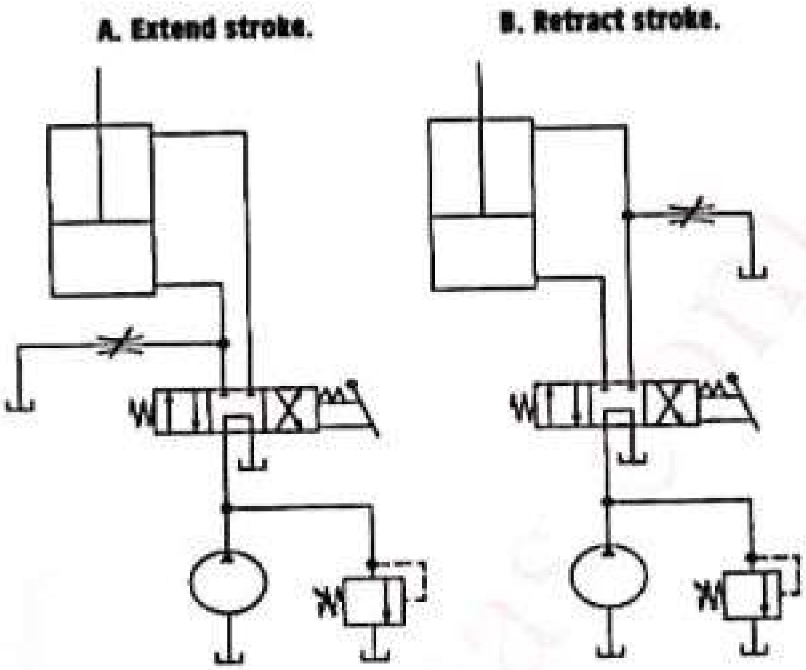
A counter balance valve is used to maintain back pressure on a vertical cylinder to prevent it from falling due to gravity.

This valve operates on the principle that the line of flow from the bottom of the vertical cylinder into the valve remains closed till a pilot pressure is achieved. As soon as the pressure is developed, it over comes the spring force and the line of flow finds a free passage between primary port and secondary port. When the DCV is shifted to extend the cylinder, the weight may cause the cylinder to accelerate too quickly. When this occurs, the load is driving the cylinder, as apposed to the



3.15 BLEED-OFF CONTROL VALVE

In addition to meter-in and meter-out flow control, there is a less commonly used flow control configuration known as bleed-off.



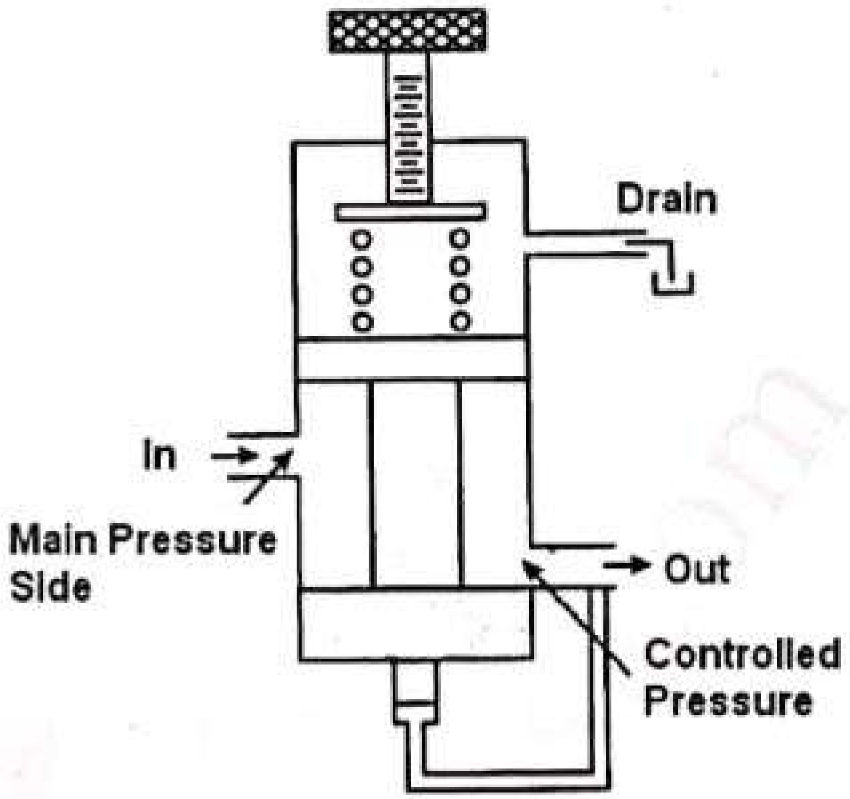
Cylinders with Bleed- Off Control

In this type of flow control, an additional line is run through a flow control back to the tank. To slow down the actuator, some of the flow is bled off through this line, thereby reducing the flow to the actuator 'Figure A' shows bleed off control of the extend stroke, 'Figure B' shows control of the retract stroke. Note that the operation of a bleed-off flow control valve is opposite to a meter-in or meter-out flow control valve. Opening a bleed-off flow control valve slows down an actuator, while opening a meter-in or meter-out flow control valve increases actuator speed.

3.16 FLOW DIVIDER

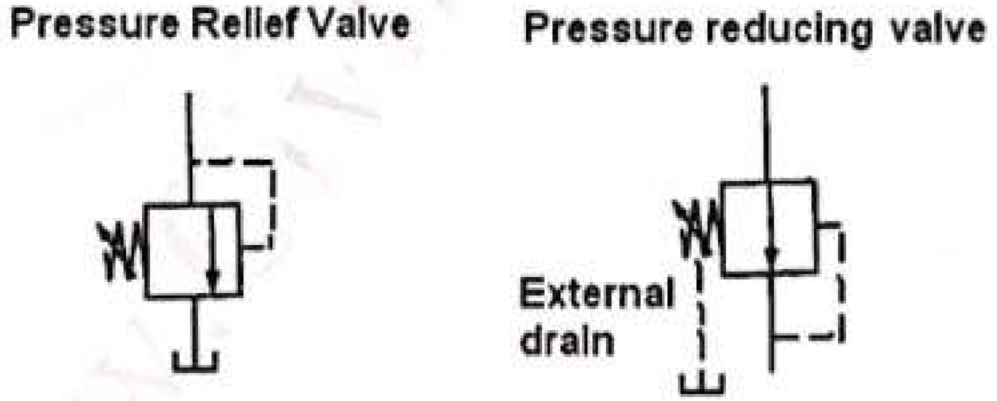
Flow dividers divide the flow from a pump into two or more streams of equal flow rates. They maintain equal flow rates in the branch circuits even if the pressures in the branches are not equal. Without flow divider, the flow from the pump would follow the path of least resistance.

There are two commonly used flow divider designs balanced spool and rotary. The Figure shows a simplified cut away of a balanced spool flow divider. The spool is free to slide back and forth in the housing and will naturally assume a position so that the pressure on either side of the spool will be equal. The spool is therefore pressure balanced. For example if the pressure at outlet 1 was greater than the pressure at outlet 2, the spool would slide to the right to partially cover outlet 2. By partially restricting the more lightly loaded outlet, the flow divider adds more resistance to this path. This acts to equalize the resistance of each path.



Pressure Reducing Valve

The below Figure compares the symbol for a relief valve and a reducing valve. The reducing valve is normally open, while relief valve is normally closed.

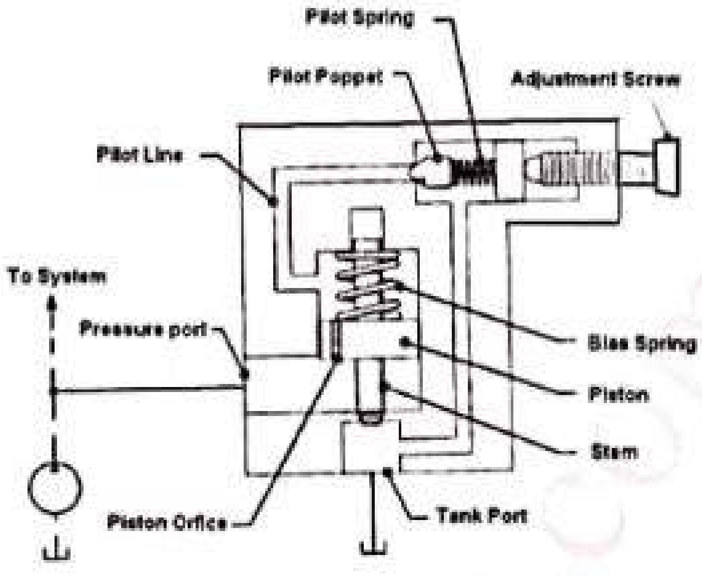


Symbol Comparison

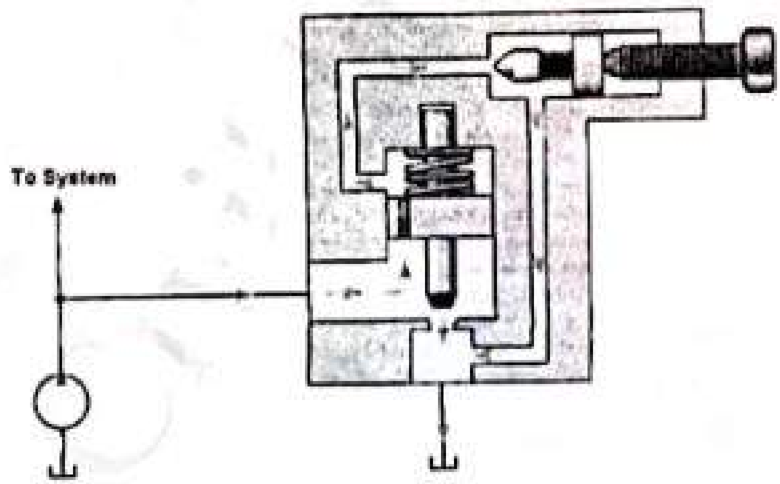
54/79

The reducing valve reads the pressure down stream while the relief valve reads the pressure upstream. The reducing valve has an external drain line, while a relief valve does not. When a valve has an external drain, a line must be connected from the valves drain port to the tank. Drain lines, like pilot lines are shown as dashed lines.

Just like the direct acting type, the pilot operated type has a pressure port that is connected into the pump line and a tank port that is connected to tank.

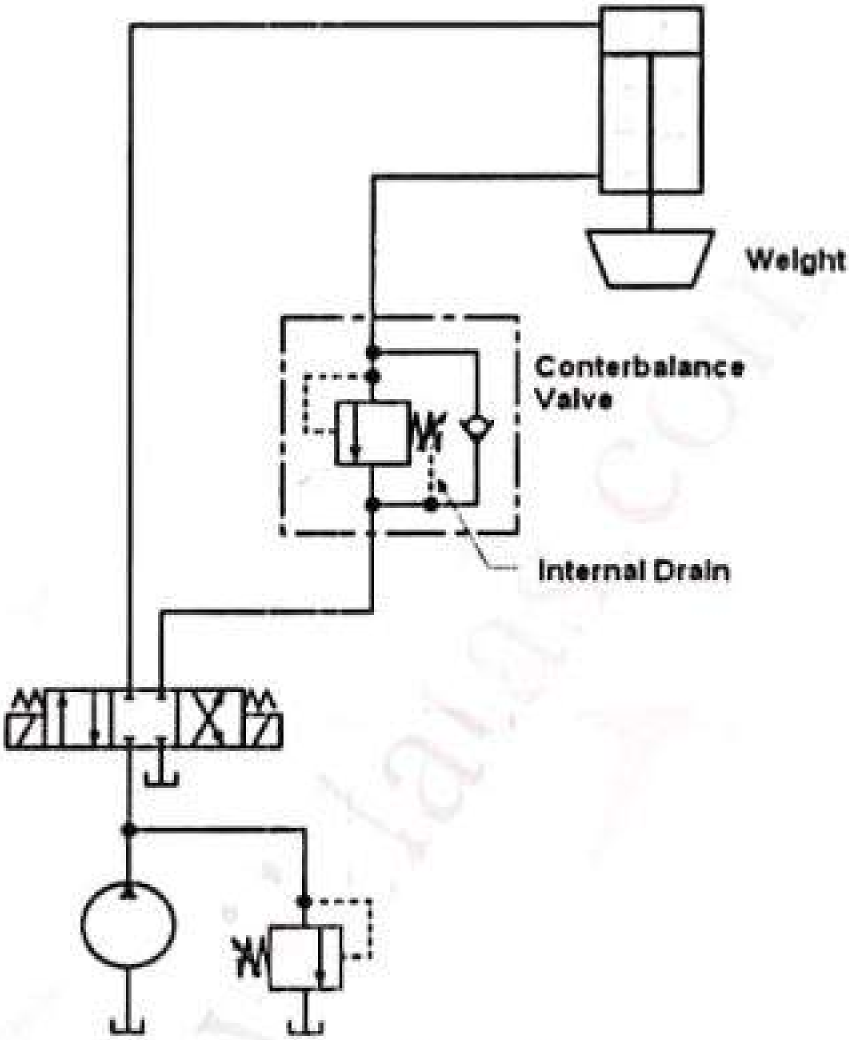


A - Pilot Operated Pressure Relief Valve – Closed



B - Pilot Operated Pressure Relief Valve- Open

The pilot relief is usually a poppet type. The main relief consists of a piston and stem. The main relief piston has a hole called the orifice drilled through it. This allows pressure to be applied to the top side of the piston, as well as the bottom side. The piston has equal areas exposed to pressure on the top and bottom and is therefore balanced it will have equal force on each side. It will remain stationary in the closed position. The piston has a light bias spring to ensure that it will stay closed. When the pressure is less that the relief valve setting, the pump flow goes to the system. The pressure is also applied to the pilot poppet through the pilot line. If the pressure in the system becomes high enough, it will move the pilot poppet off its seat. A small amount of flow begins to go through the pilot line back to tank. Once flow begins through the piston orifice and pilot line, a pressure drop is induced across the piston due to the restriction of the piston orifice. This pressure drop then causes the piston more controllable situation of the cylinder driving load. This can cause damage to the load, or even to the cylinder itself, when the load is stopped quickly at the end of its travel. This can be remedied by placing a counter balance valve on the rod end of the cylinder as shown in below figure.



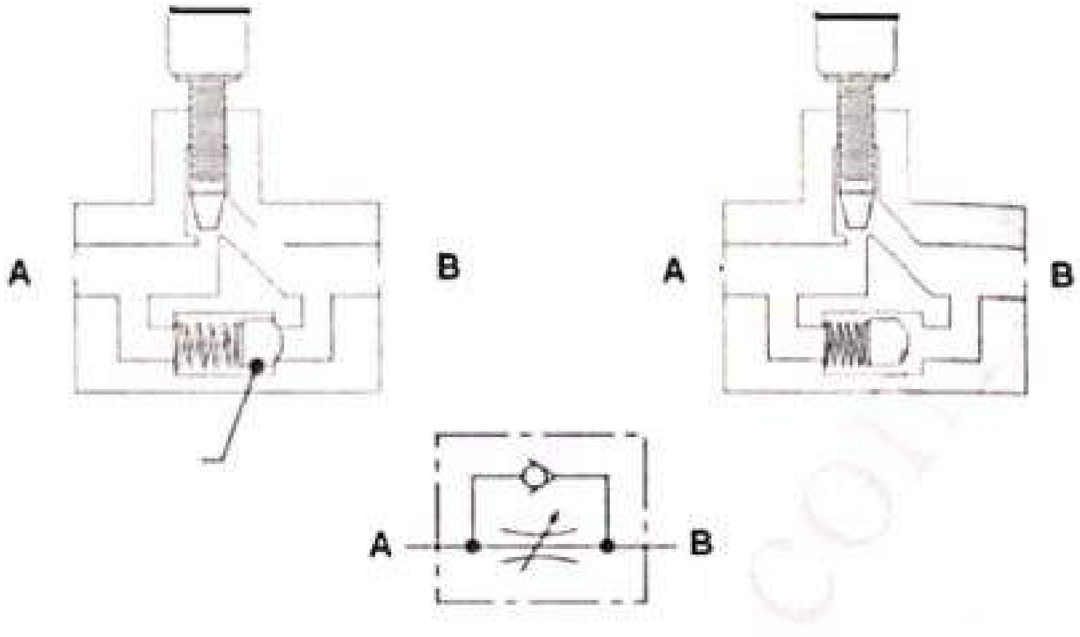
Counterbalance Circuit

When the DCV is shifted to lower the weight, the cylinder will not extend until a preset pressure is reached in the rod end. This provides a back pressure against the rod end of the piston, which acts to stabilize the downward movement of the cylinder. The check valve allows the counter balance valve to be passed when the cylinder is retracted. A counter balance valve has an internal drain, unlike the sequence valve, which has an external drain.

3.11 BRAKE VALVES

Brake valves, like counter balance valves, are used to prevent loads from accelerating uncontrollably. Counter balance valves are used with cylinders, brake valves are used with hydraulic motors. Brake valves are most commonly used in circuits in which the motor must lower a large weight, such as in a winch application. A simple winch circuit is shown in Figure.

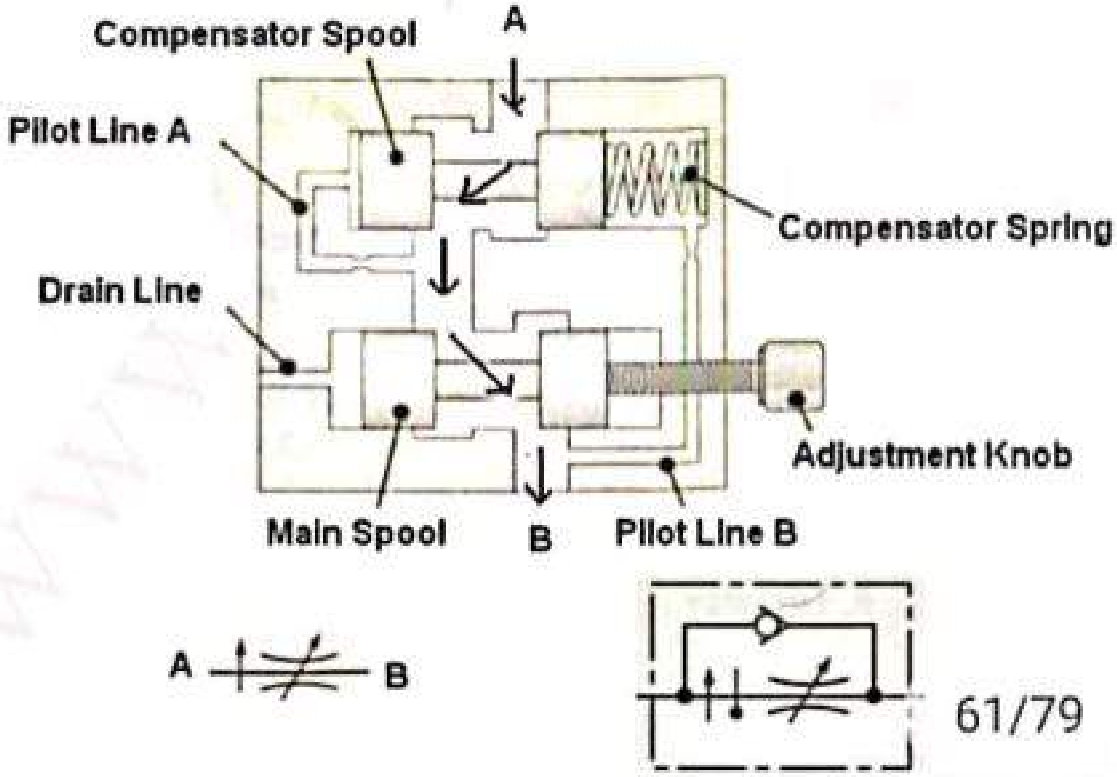
When the weight is lowered, it may tend to drive the motor, instead of the motor lowering the weight. This is known as an over running load. In this situation, the load will probably accelerate too quickly. The motor is being driven by the load and is basically acting as a pump. When this occurs, the



Needle Valve with Integral Check Valve

3.12.2 PRESSURE COMPENSATED FLOW CONTROL VALVE

The flow control valves blocks the flow in term there is a pressure drop across the valve. This pressure drop affects the motion of the actuators and also increases the temperature of the fluid. To eliminate the above problems pressure compensated flow control valve is designed as shown in below Figure .



Pressure Compensated Flow Control Valve

3.5 PRESSURE CONTROL VALVES

The force of a cylinder is proportional to the pressure in a system and the area over which the pressure is applied. Controlling the pressure level in a circuit will therefore allow us to control the output force of a cylinder pressure control valves control the max pressure level and also protect the circuit from excessive pressure, which could damage components and possibly cause serious injury. Some types of pressure control valves simply react to pressure changes rather than control the pressure.

3.6 PRESSURE RELIEF VALVES

Pressure relief valves limit the max pressure in a hydraulic circuit by providing an alternate path for fluid flow when the pressure reaches a preset level.

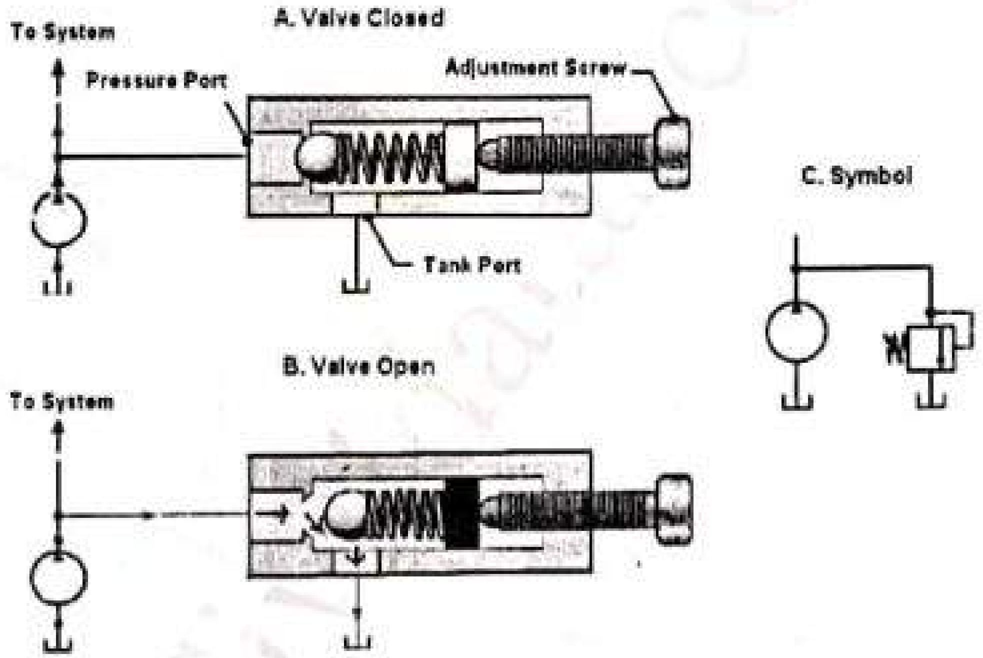
The basic types are

1 Direct acting pressure relief valve

2 Pilot operated pressure relief valve

3.6.1 DIRECT ACTING PRESSURE RELIEF VALVES

All relief valves have a pressure port that is connected to the pump line and a tank port that is connected to the tank. The Figure shows the direct acting press relief valve, a ball or poppet is subjected to pump pressure on one side and the force of a spring on the other. When the pressure in the system creates a force on the ball that is less than the spring force, it remains on its seat and the pump flow will go to the systems as shown in Fig. A. When the pressure is high enough to create a force greater than the spring force, the ball will move off its seat and allow pump flow to go back to the tank through the relief as shown in Fig. B. The pressure at which the relief valve opens can be adjusted by changing the amount of spring compression, which changes the amount of force applied to the ball on the spring side.



Direct Acting Pressure Relief Valve

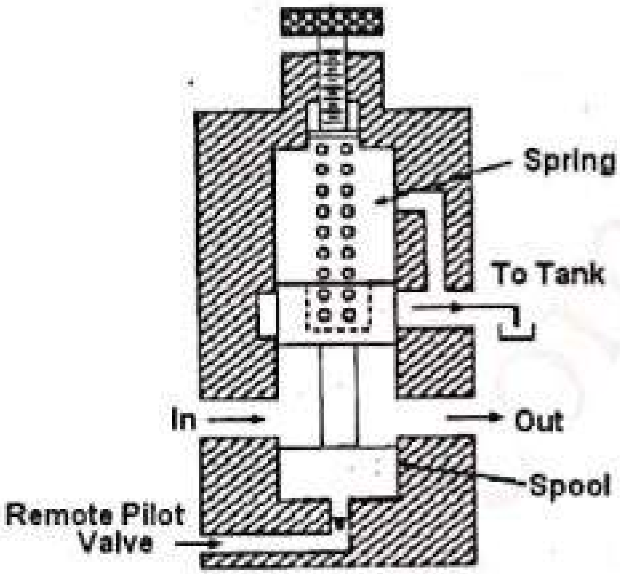
This is accomplished with an adjustment screw or knob. This type of relief valve is called direct acting because the ball is directly exposed to pump pressure. The graphic symbol for an adjustable pressure relief valve, along with a pump is shown in Fig. C. The symbol shows that the valve is normally closed on one side of the valve; pressure is fed in to try to open the valve, while on the other side the spring is trying to keep it closed. The arrow through the spring signifies that it is adjustable, allowing adjustment of the pressure level at which the relief valve opens.

3.6.2 PILOT OPERATED PRESSURE RELIEF VALVE

The Figure A, B shows the pilot operated pressure relief valve, rather than a direct acting relief valve, is used to control the maximum pressure. A pilot operated relief valve consists of a small pilot relief valve and a main relief valve. It operates in a two stage process. First the pilot relief valve opens when a preset maximum pressure is reached, which then causes the main relief valve to open.

3.7 UNLOADING VALVES

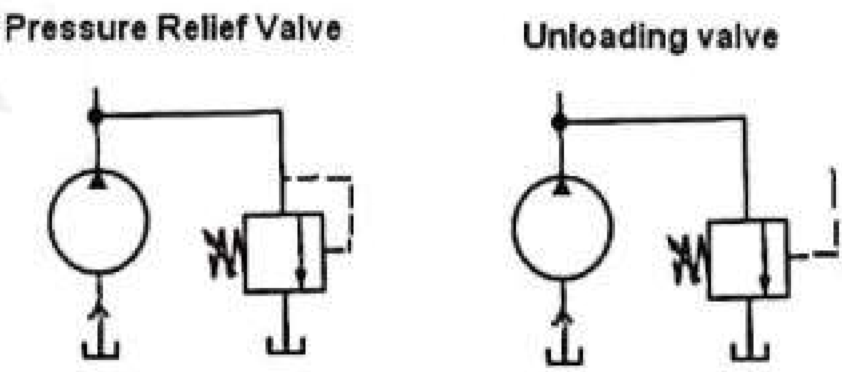
In the case of pressure relief valve, the pump delivers full pump flow at the pressure relief valve setting and thus operates at maximum horse power conditions.



Unloading Valve

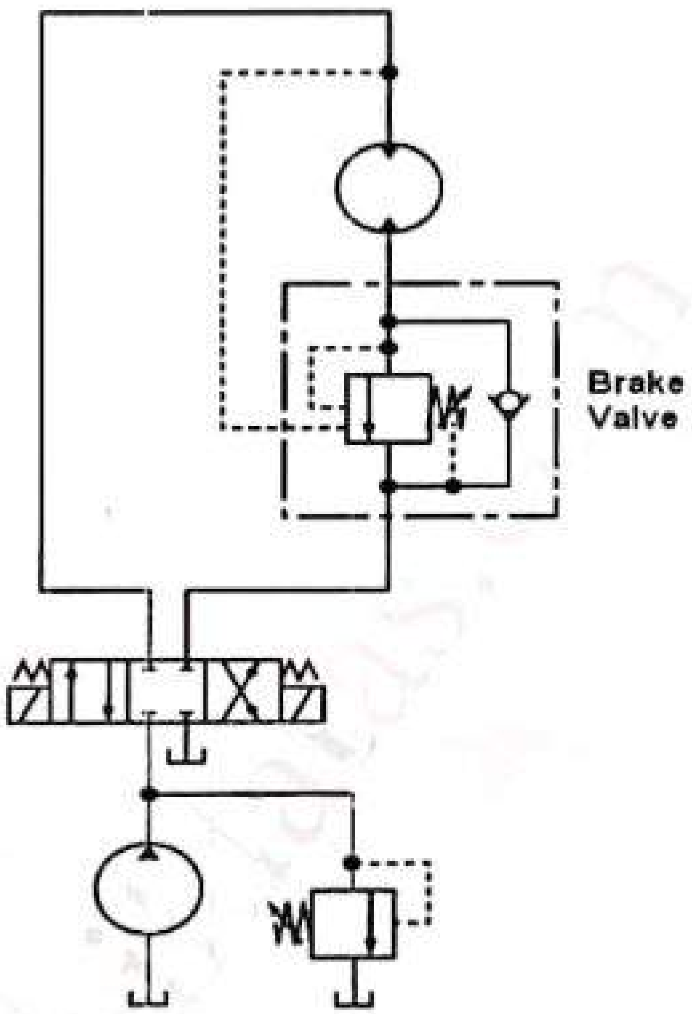
The 'In' port of the unloading valve is connected to the line which is to be unloaded. The pilot port is connected to the line which is supposed to send the pressure impulse for unloading the valve. As soon as the system pressure reaches the setting pressure which is available at the pilot port, it lifts the spool against the spring force. The valve is held open by pilot pressure and the delivery from the pump starts going into the reservoir. When the pilot pressure is released, the spool is moved down by the spring and the flow is directed through the valve into the circuit. The unloading valve is useful to control the amount of flow at any given time in systems having more than one fixed delivery pump.

The symbol for each is shown in 'Figure A' for comparison. Both send flow back to the tank when a preset pressure is reached. However, an unloading valve reads the pressure in an external line, rather than in its own line, as indicated by the dashed pilot lines. 'Figure B' shows the application for an unloading valve. This circuit can be used in an application in which high flow (speed) and low



A - Symbol Comparison

pressure at the outlet will be higher than the pressure at the inlet. The brake valve senses the pressure in both the inlet and outlet lines of the motor, just as it is with a pump.



Brake Valve In Winch Application

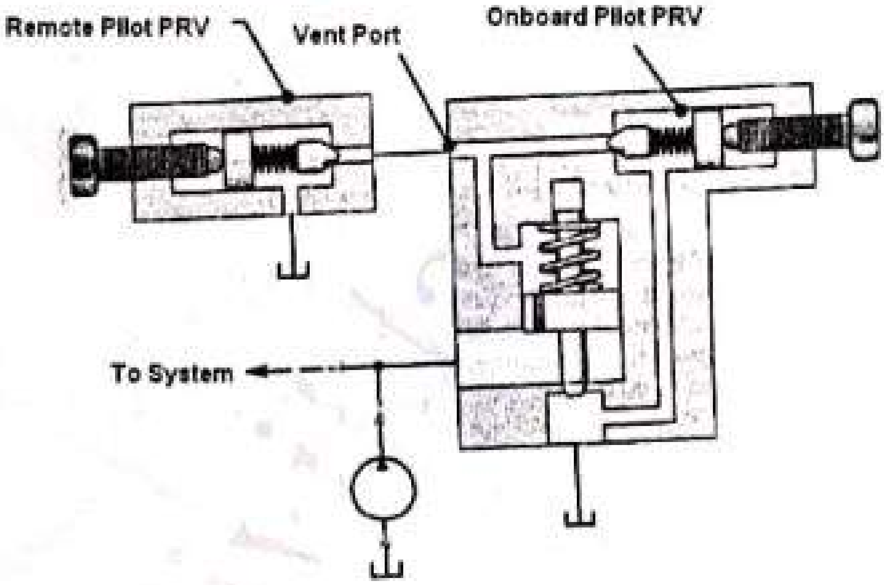
Whenever the pressure at the outlet is lower than the pressure at the inlet, the motor is functioning normally and the brake valve allows nearly unrestricted flow out of the motor. When the pressure at the outlet is higher than at the inlet, however, the brake valve closes partially to provide enough of a back pressure on the outlet of the motor to keep the load in control. The check valve allows the valve to be by passed when the weight is being raised.

3.12 FLOW CONTROL VALVES

Flow control valves control the flow rate of fluid in a circuit. They accomplish this by incorporating a variable orifice into the circuit that acts like a faucet; closing the flow control valve orifice reduces the flow rate and opening the orifice increases the flow rate. The speed of an actuator depends directly upon the flow rate in the system. Controlling the flow rate therefore allows us to control the speed of actuators. A variable displacement pump's flow output can be varied, even while it is being driven at a constant speed. This will also control the actuator's speed. In spite of this, flow control valves are commonly used because they are much less expensive and easier to control than variable pumps.

Types

and stem to lift off its seat and the flow goes directly from the pressure port to the tank. The symbol for the pilot operated relief valve is the same as that used for the direct acting relief valve. The advantages are usually smaller than a direct acting type for the same flow and pressure ratings. They also generally have a wider range for the maximum pressure setting. Another advantage is that they can be operated remotely. This is achieved by connecting a direct acting relief valve to the vent port of the pilot operated relief valve as shown in Figure C. Notice that the vent port is connected into the pilot line. The direct acting relief valve, called the remote in this arrangement, acts as a second pilot relief valve. Flow can now go back to tank through either the onboard pilot or the remote pilot. Whichever pilot is set to a lower pressure will cause the relief valve to open. Flow through either pilot will cause the main poppet to lift off its seat and allow full flow back to the tank. The advantage of this type of arrangement is that the on board pilot can be set to the absolute maximum pressure that the circuit is designed for, while the remote can be set for a lower



C - Pilot Operated Pressure Relief Valve with Remote Control

pressure dictated by the current operating parameters. This method of pressure control has two key advantages

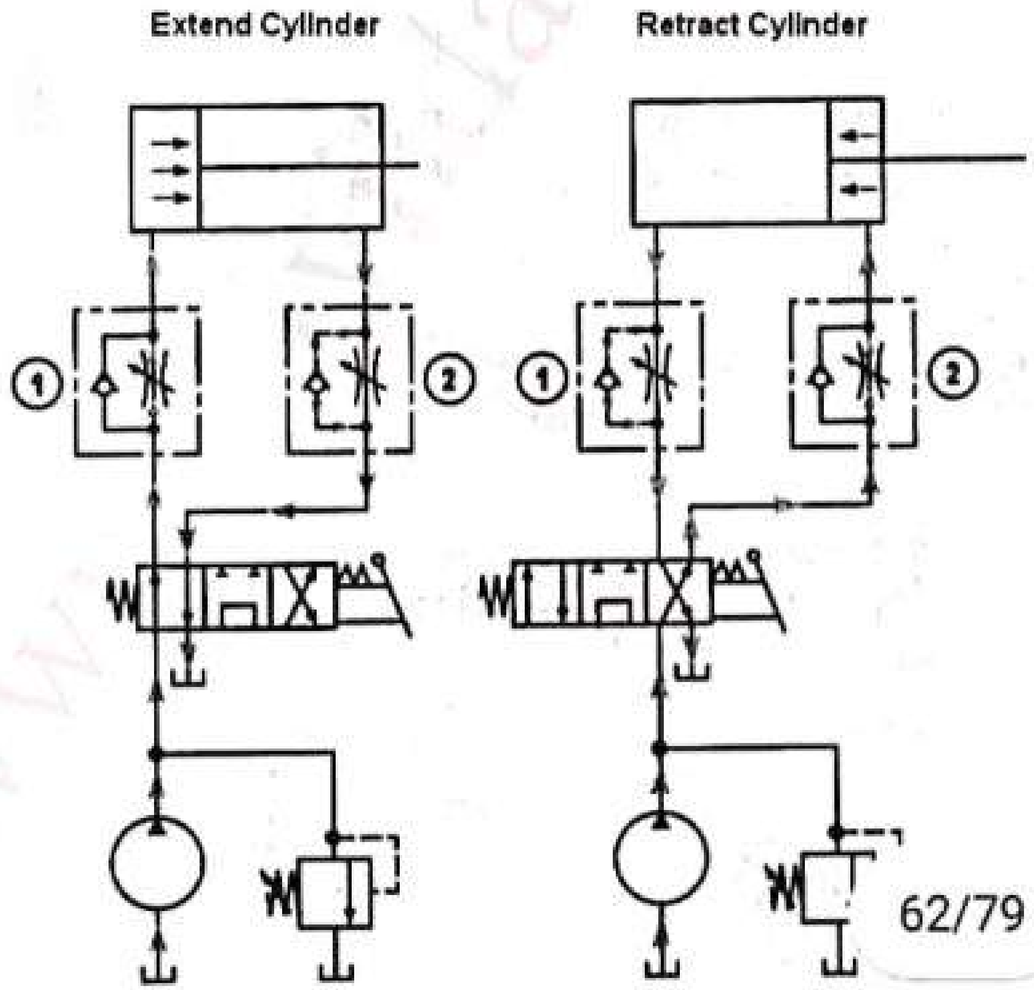
1. The on board pilot can be made in accessible so that if the machine operator were to inadvertently set the pressure of the remote too high, the pressure would never rise above the absolute maximum setting determined by the on board pilot.
2. The remote pilot can be located away from the circuit in a safe location that is easily accessible to the operator. In the symbol the lines associated with the remote are dashed because they are control pilot lines.

The pressure at which the relief valve begins to open is known as the cracking pressure. At this pressure, the poppet just begins to lift off its seat and some of the pump flow begins to go through the relief valve back to the tank. The rest of the flow goes to the system. The pressure at which the relief valve is completely open is known as the full flow pressure. The difference between the cracking pressure and the full flow pressure is often called the pressure over ride in manufacture's literature.

This type of flow control valves automatically adjusts the size of the orifice in response to changes in system pressure. It accomplishes this through the use of a spring loaded compensator spool that reduces the size of the orifice when the upstream pressure increases relative to the downstream pressure. Once the valve is set, the pressure compensator will act to keep the pressure drop across the valve nearly constant. This in turn keeps the flow rate through the valve nearly constant. This valve consists primarily of a main spool and a compensator spool. The adjustment knob controls the main spool's position, which controls the orifice size at the outlet. The pressure upstream of (before) the main spool is ported to the left side of the compensator spool through pilot line A. Pressure downstream of (after) the main spool is ported to the right side of the compensator spool through pilot line B. The compensator spring bases the compensator spool to the fully open position. If the pressure upstream of the main spool increases too much relative to the downstream pressure (ie the pressure drop becomes too high), the compensator spool will move to the right against the force of the spring. Thos acts to keep the pressure drop across the main spool and consequently the flow rate nearly constant.

3.13 METER-IN FLOW CONTROL

A cylinder with meter-in flow control of the extend stroke is shown is below Figure.



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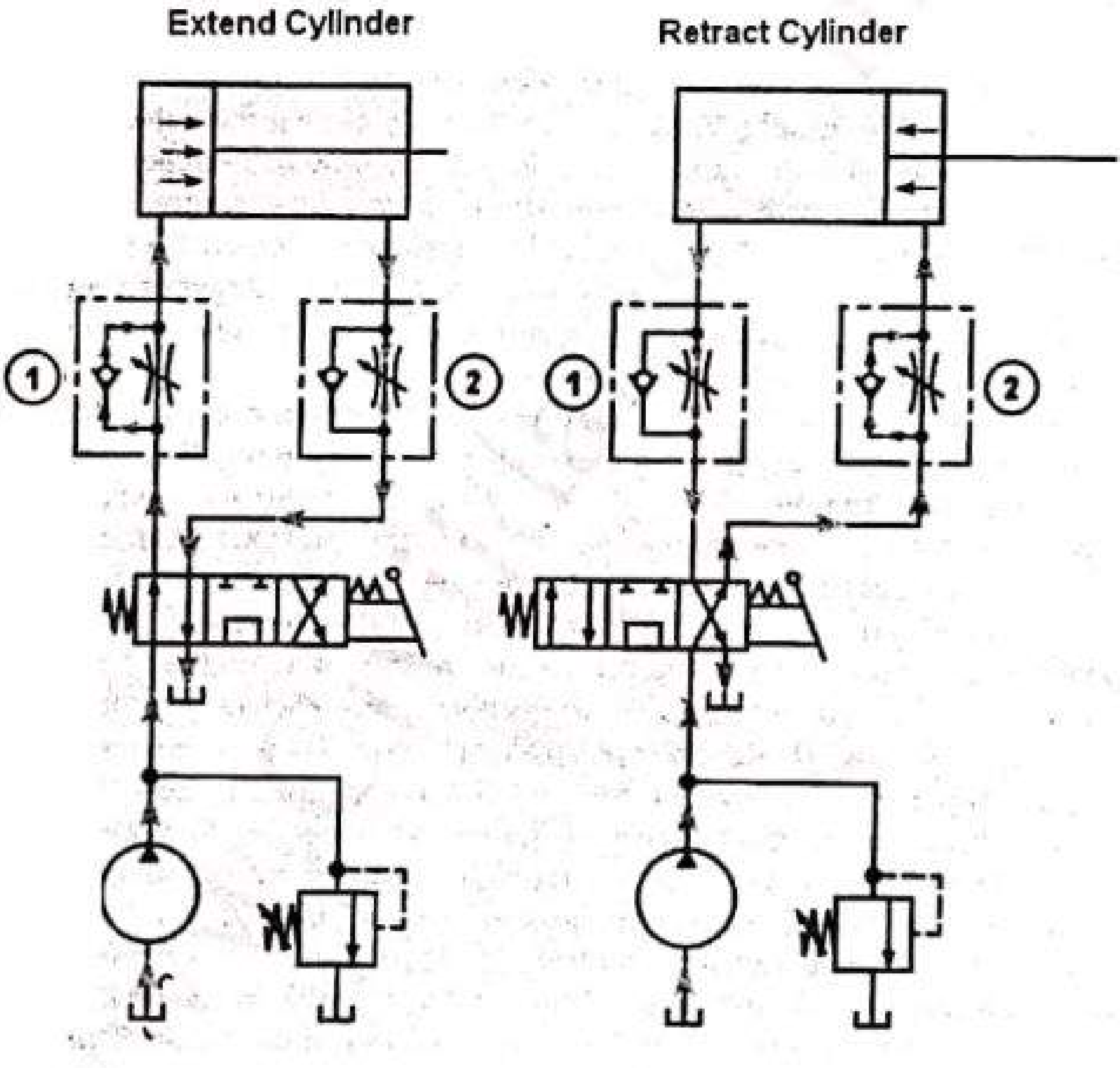
Cylinders with Meter-In Flow Control

When the cylinder is extending, the flow coming from the pump cannot pass through the check valve and is forced to go through the metering orifice (part A). When the cylinder is retracting, the needle valve is being by passed through the check (part B). The net result is that the flow control valve is controlling the extend speed, while the retract speed of the cylinder is uncontrolled. It is common to control only the working stroke of a cylinder, while allowing the return stroke move at full speed.

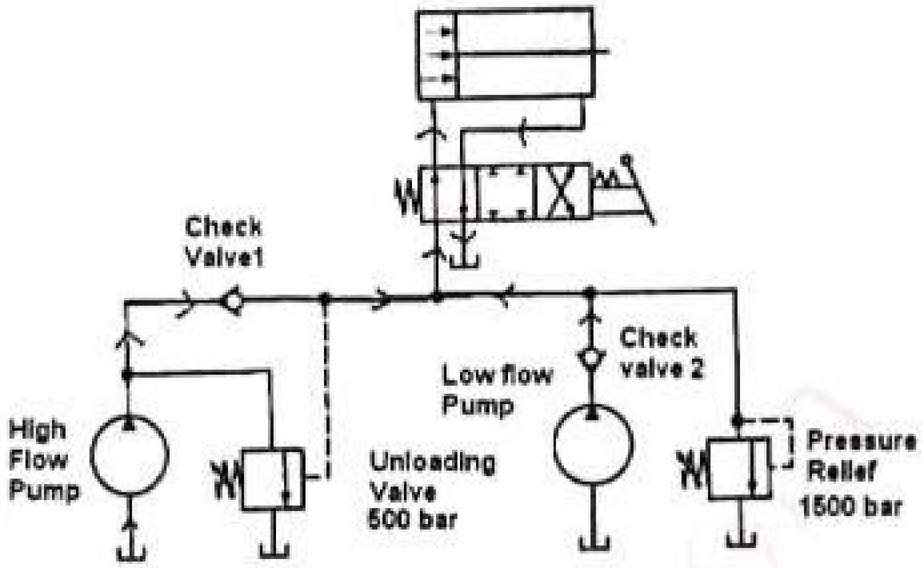
3.14 METER-OUT FLOW CONTROL

The Figure shows a cylinder with meter-out flow control of the extend stroke.



Cylinders with Meter-Out Flow Control

The flow control valve in this circuit is placed in the rod end line. When the cylinder is extending, the flow coming from the cylinder cannot pass through the check and is forced to go through the metering orifice (part A). When the cylinder is retracting, the metering orifice is being by passed through the check (part B). The net result is the same as with the previous circuit. The extend speed is controlled, while the retract speed is uncontrolled. However, in this circuit we control the flow rate act of the cylinder, while in the previous circuit we controlled the flow rate into the cylinder.



B - Unloading Valve Circuit

pressure (force) is required for a part of the cylinder's stroke, while low flow and high pressure are required for the rest for example a metal stamping machine. In this machine it may be desirable for the cylinder to move into position very quickly, and then slow down when it reaches the work piece. The first part of the cycle requires only minimal pressure because the only resistance is the flow resistance of the components and the friction of the cylinder. The second part of the cycle requires high pressure because the cylinder is deforming the metal. This circuit supplies the cylinder with from both the high flow pump and the low flow pump when the pressure is below 500 bar. When the pressure reaches 500 bar, the unloading valve opens and unloads the high flow pump back to tank at low pressure. Only the low flow pump supplies the cylinder with flow at pressure from 500 bar to 1500 bar. If the pressure reaches 1500 bar, flow from the low flow pump is forced over the relief valve at this pressure. Check valve 1 isolates the high flow pump from the system pressure while it is being unloaded. Check valve 2 prevents the flow the high flow pump from flowing into the low flow pump line. This would reverse the low flow pump, which would cause damage to the power unit.

3.8 PRESSURE REDUCING VALVE

This type of valve is used to maintain reduced pressure in specified locations of hydraulic systems. It is normally an open valve. It is actuated by down stream pressure and tends to close as this pressure reaches the valve setting. The figure shows the construction of the valve. This valve is one which uses a spring loaded spool to control the down stream pressure. If down stream pressure is below the valve pressure, fluid will flow freely from the inlet to the out let. When the outlet pressure increases the valve setting, the spool moves to partially block the outlet port. If the valve is closed completely by the spool, it could cause the down stream pressure to build above the valve setting. To avoid this, a drain line is provided to drain the fluid to the tank.

PIPE

- A pipe can be defined as a functional connection for fluid flow in the fluid power system.

- In hydraulic system, iron pipes may be used for low to medium pressure range. But, heavy wall thickness, lack of annealing and inability to absorb high pressure are certain problems with iron pipes.

- Stainless steel pipes are used in application that require resistance to corrosion.

PIPE

- The term pipes, tubes, and hoses are generally synonymous, each have their own specific characteristic for a specific application.

HOSE

- A hydraulic hose is specifically designed to convey hydraulic fluid to or among hydraulic components, valves, actuators and tools.

- It is typically flexible, often reinforced and usually constructed with several layers of reinforcement.

HOSE

- Since hydraulic systems frequently operate at high or very high pressure.
- A hydraulic hose is used anywhere in a hydraulic system requiring a flexible connection between two fluid ports.

FITTING

- Hydraulic fittings are used to connect hoses, pipe in hydraulic system.
- It should be leak free connection.

TYPES OF FITTING

1. <u>ELBOW FITTING:-</u>

➢Used to change the direction of flow (90º , 45º, 60º)

TYPES OF FITTING

2. <u>TEE FITTING:-</u>

➢Used where more than one branch is required.

TYPES OF FITTING

3. CROSS FITTING:-

➢It is four way fitting that are essentially the combination of two tees.

TYPES OF FITTING

4. WYES FITTING:-

   ➢ It is used to allow one pipe to join another pipe at some degree or angle.

FLANGE

- It is used to connect pipes.
- Pipe is threaded or welded to the flanges.
- Used for high pressure.

NIPPLES FITTING

- It is a short piece of pipe, male thread at each end, that are used to connect straight pipe.

COUPLING

- It is a very short length of pipe or tube, with a socket at one end or both ends that allows two pipes or tubes to be joined together.
- It is also used to change pipe size.

MATERIALS

- Brass
  - It work well in hot water application and highly resistance to corrosion.
- Copper :
  - Reddish brown in colour.
  - Used in household plumbing pipe.
- Stainless steel:-
  - Good strength, good durability, good corrosion resistance
  - Used in hydraulic system

OIL FILTER

- Oil filter are used in hydraulic system to remove particles contamination.

- It helps to remove the particles and clean the oil on the continuous basis.

- It protects hydraulic system components from damage due to contamination of oil or other fluid in used caused by particles.

OIL FILTER

- SUCTION SIDE FILTER (Before pump):
  - These filter are designed to protect the pump from harmful contaminates that are within hydraulic fluid.
- PRESSURE SIDE FILTER (After pump):
  - These filters are designed to clean the fluid as it exits the pump to protect more sensitive system components such as control valves and actuators.
- RETURN SIDE FILTER:
  - These filters are designed to capture wear debris from the hydraulic system, working components before returning the fluid back to reservoir.

OIL FILTER

GASKET

- A gasket is a mechanical seal which fills the space between two or more mating surface to prevent leakage.

- The primary function of gaskets is to seal the irregularities of each face of flange so that there will be no leakage of the service fluid from the flange joints.

GASKET'S MATERIAL

- Non metallic gasket (soft):
  - Graphite, rubber, Teflon, asbestos, cork etc. (for low pressure & low temperature)
- Metallic gasket:
  - Soft iron, low carbon steel, stainless steel, monel, Inconel (for high pressure & high temperature)
- Composite gasket (Semi-metallic):
  - Combination of metal and non-metal materials.

GASKET'S MATERIAL

Metallic Gasket

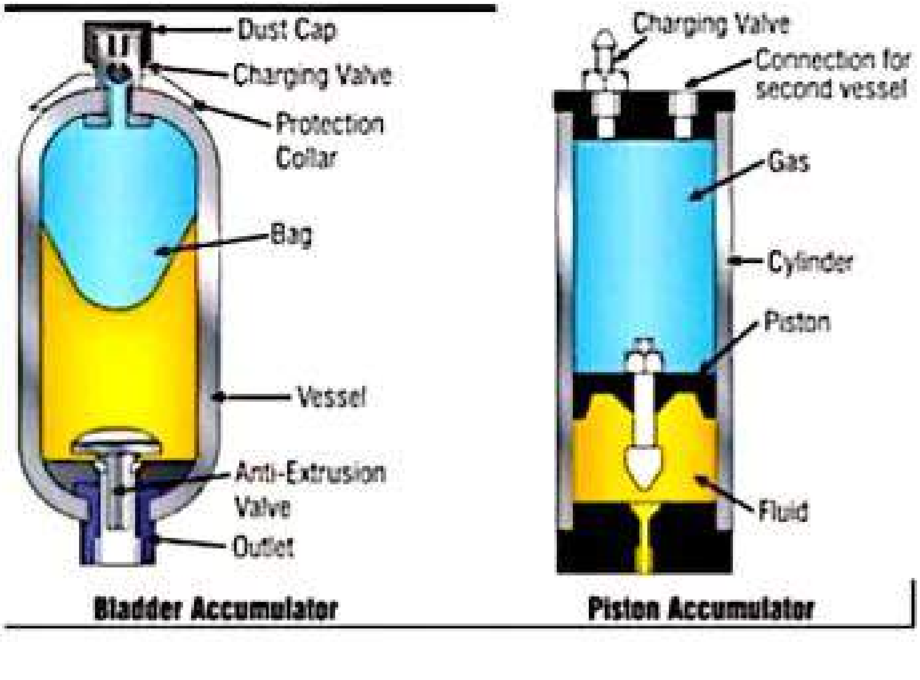
Non metallic gasket

Composite gasket

ACCUMULATOR

- Hydraulic accumulators are energy storage device. It is similar to rechargeable batteries in electrical system.
- It store and discharge energy in the form of pressurized fluid and used to improve hydraulic system efficiency.
- It is a pressure vessel that holds hydraulic fluid and a compressible gas (nitrogen).
- The housing or shell is made of materials like steel, stainless steel, aluminium.

ACCUMULATOR



ACCUMULATOR

- Inside it, a movable barrier (piston/rubber bladder) which separates the oil from gas.
- Initially gases are filled in bladder present in accumulator. This fills most of the accumulator.
- In operation hydraulic system raises system pressure and forces fluid to enter the accumulator.
- The bladder moves and compresses the gas volume because fluid pressure is more than gas pressure.

ACCUMULATOR

- Movements stops when system and gas pressure are balanced.
- When downstream action such as actuator movement, hydraulic system pressure falls and accumulator releases the stored pressurized fluid to the circuit.