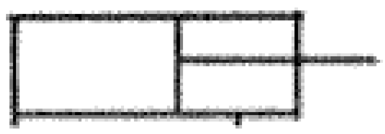
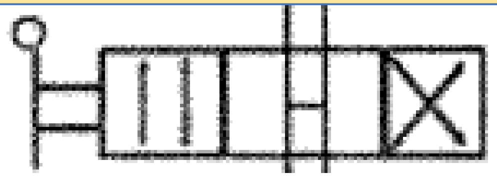
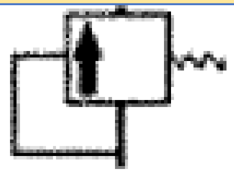
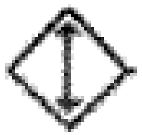
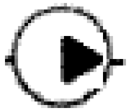
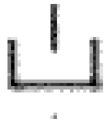
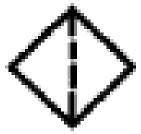
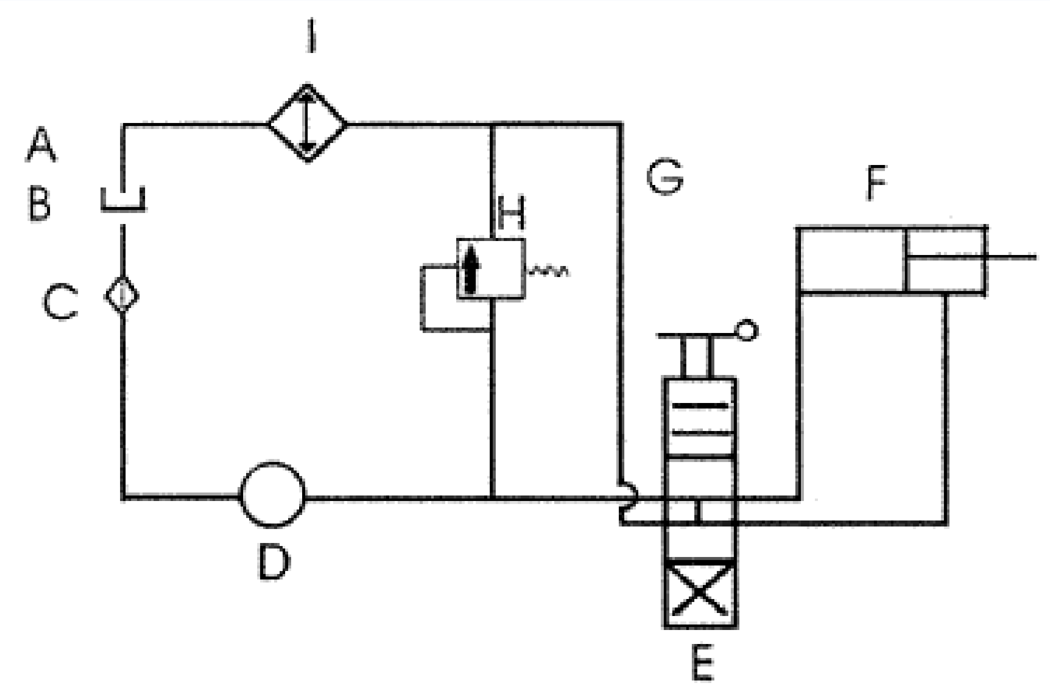
Quiz 1

- Date??
- Topics??

Designing a Simple Hydraulic Circuit

						
F = Actuator or Cylinder	E = DCV or Direction Control Valve	H = Pressure relief valve	I = Cooler	D = Hydraulic pump	B = Vented tank	C = Filter

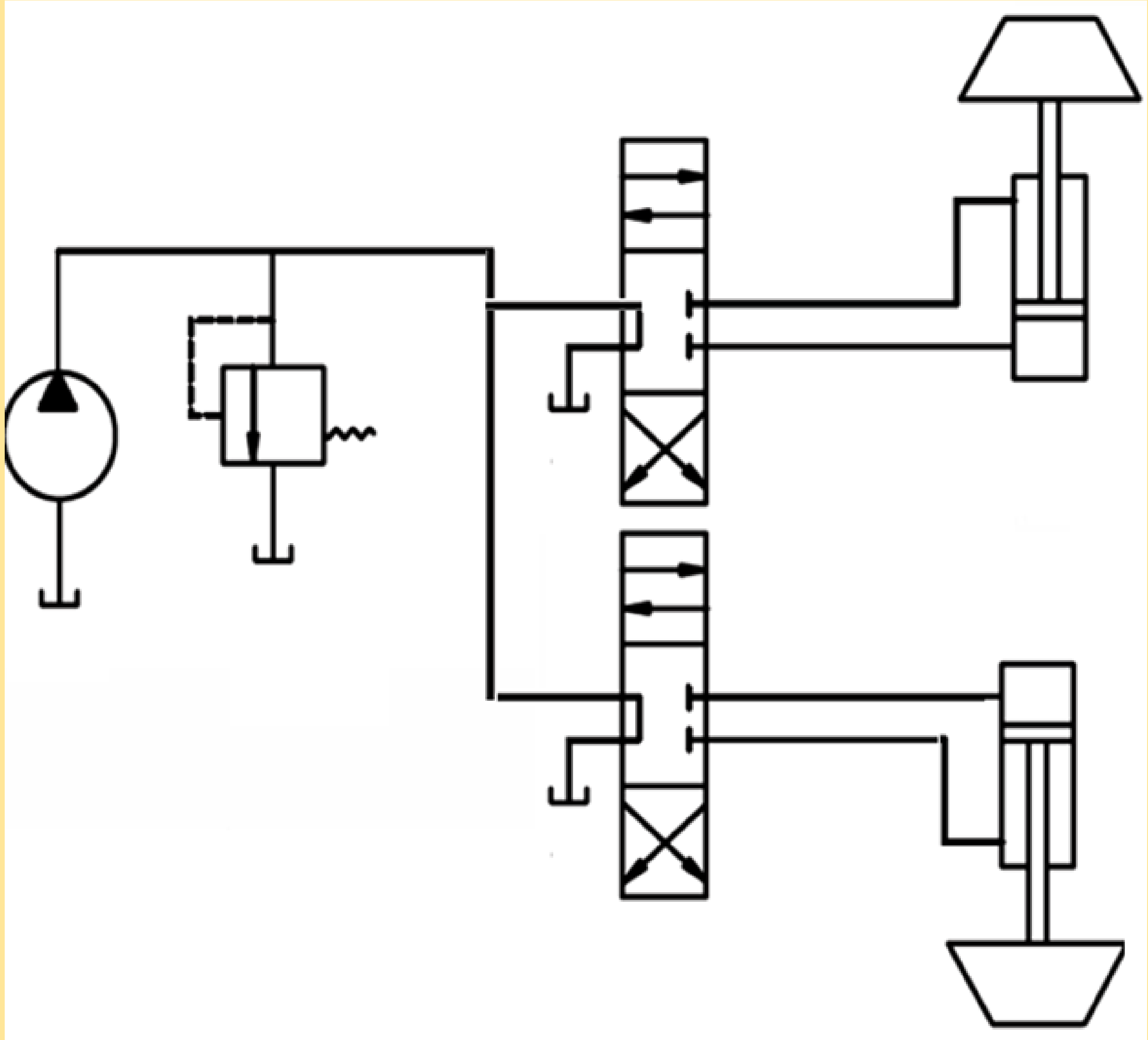


Hydraulic Circuit Analysis-Sample Exercise

A hydraulic circuit is required to perform its functional objective. That is to lift the two weights which are placed at the actuator ends (figure given below).

Identify the pressure drops that will occur in each element of this circuit. Also, write the equation of the pressure drops.

(hint: the total pressure needed is the combined pressure that is buildup in the pump and the pressure losses in the circuit)



Homework # 2 (individual submission)

- Design a simple hydraulic circuit that can lift a mass of 1000Kg. Make suitable assumptions where it is needed.
- Discuss the differences between hydraulic and pneumatic circuits

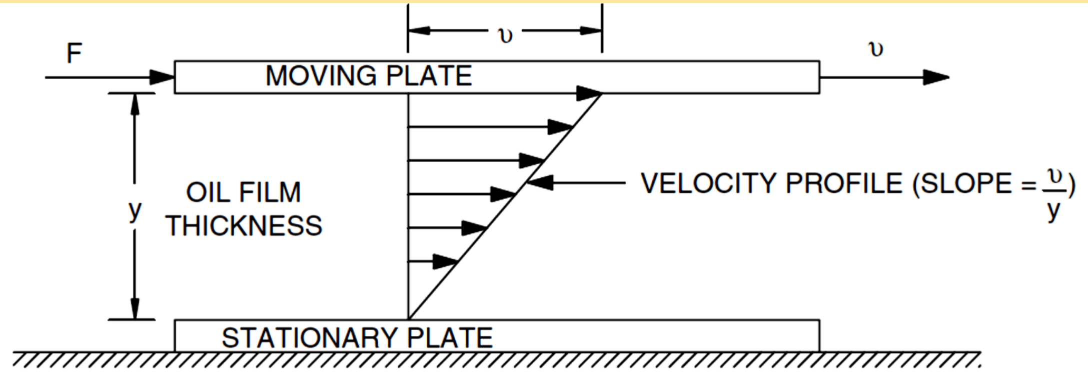
- **Any similarity of homework submitted will be considered as cheating**
- **So each student must produce His own version of the HW**

Overview

- **Hydraulic fluids properties**
- **Hydraulic fluids used**
- **Types of hydraulic system**
- **Elements of hydraulic systems;**
  - **Reservoir**
  - **Pressure and flow control valves**
  - **Hydraulic filters**
  - **Pipes/lines/fittings**
  - **Pumps**
  - **Direction control valves**
  - **Cylinder / Actuators**
  - **Motors**
  - **Accumulators**
- **Flow of fluid in lines**

Fluid Properties: Viscosity

- **Viscosity is the fluid's resistance to shear.**
- ***Dynamic* viscosity** (or absolute viscosity) is defined as the ratio between the shear stress and the slope;



$$\mu = \frac{\tau}{v/y} \quad \text{or} \quad \mu = \frac{F \times y}{v \times A}$$

$$\tau = \frac{F}{A} \qquad \text{slope} = \frac{\Delta v}{\Delta y}$$

The units of dynamic viscosity are $g/(\mathrm{s} \cdot \mathrm{cm})$. The name given these units is the ***poise***. Dividing by 100, we obtain the common unit for dynamic viscosity, the ***centipoise***.

- ***Kinematic* viscosity** is simply the dynamic viscosity divided by the fluid density measured at the same temperature as the dynamic viscosity measurement

$$\nu = \frac{\mu}{\rho}$$

where μ = dynamic viscosity [g/(s · cm)]
ρ = density (g/cm^3)

The units for kinematic viscosity are cm^2/s, which is a *stoke*. Dividing by 100, we obtain the common unit for kinematic viscosity, the *centistoke* (cS).

Viscosity issues/problems

Too low viscosity

1. It can result in a loss of pump (and motor) efficiency due to increased internal leakage. (Clearances are not sealed.)
2. It can cause increased component wear due to breakdown of the lubrication film.
3. At high operating speeds and high operating pressures, the lubrication film can breakdown completely, which will cause the moving parts to "spot weld" together and ultimately cause a complete failure.

Too high viscosity

1. Pump cavitation—the oil is so "thick" that it does not flow readily into the pump. The pump is filled partly with oil and partly with air, a condition known as *cavitation* .
2. High pressure drops occur due to friction in the lines.

Viscosity index

- Viscosity index is a dimensionless number that represents how the viscosity of a hydraulic fluid changes with temperature. (given as 5W-30)
- The greater the viscosity index (VI), the smaller the change in fluid viscosity for a given change in temperature, and vice versa.
- Thus, a fluid with a low VI will experience a relatively large fluctuation in viscosity as temperatures change. High-VI fluids, in contrast, are less affected by temperature changes.
- Typical mineral-oil fluids used in hydraulics have a VI of around 100, although products range from below 100 to well beyond 200.
- Synthetic oils usually have a higher VI than do mineral oils.
- It is important to use a fluid with the recommended viscosity when running a machine. When viscosity is too low and fluid too thin, users will see problems like higher wear and overheating. Too thick and the machine is hard to start and has low mechanical efficiency, and can even lead to problems like cavitation.

Bulk Modulus

- It is often assumed that liquids are incompressible. However, there are instances in which the oil compression at the pressures found in hydraulic circuits must be taken into consideration. The degree of oil compressibility is expressed by the ***bulk modulus***

$$\beta = \frac{-\Delta P}{(\Delta V / V)}$$

β = bulk modulus (psi)
ΔP = change in pressure (psi)
ΔV = change in volume when ΔP is applied (in^3)
V = original volume (in_3)

An example problem will illustrate a typical bulk modulus measurement. A pressure of 2500 psi is applied to a 10 in^3 sample of oil. The measured change in volume is 0.1 in^3. What is the bulk modulus?

$$\beta = \frac{-2500}{(9.9 - 10)/10}$$

$$= 250,000 \text{ psi}$$

Compressibility

It is the reciprocal of bulk modulus. The compressibility of the oil in the previous example is;

$$E = \frac{1}{250,000} = 4 \times 10^{-6} \frac{\text{in}^2}{\text{lb}_f}$$

Specific Gravity

It is the ratio of the density of the fluid to the density of water at 4°C and standard atmospheric pressure and is generally denoted as;

$$S_g = \frac{\rho}{\rho_w}$$

where ρ = density of fluid (slug/ft^3)
ρ_w = density of water (slug/ft^3)

Specific weight

It is defined as the weight per unit volume and is given by;

$$\gamma = \frac{mg}{V}$$

where
m = mass
V = volume
g = gravitational constant

Since $\rho = m/V$, $\longrightarrow \gamma = \rho g \longrightarrow S_g = \frac{\rho g}{\rho_w g} = \frac{\gamma}{\gamma_w}$

where γ_w = specific weight of water

Oxidation

- Oxidation is the reaction between the oil and oxygen. The compounds formed are referred to as *resins* and *sludges*. The rate of formation is a function of the amount of oxygen present (water-contaminated oil forms more sludges) and the temperature. Higher temperatures increase the reaction rate.
- Several steps can be taken to reduce oxidation.

1. Keep sources of oxygen (air and water) out of the system.
2. Remove particulates with a good filtration system. These particulates can act as sites for the oxidation reaction to occur.
3. Avoid the use of cadmium, zinc, and copper in contact with hydraulic oil. For example, never use galvanized pipe or fittings. These metals can act as catalysts that promote the oxidation reaction.

Corrosion and Rust Resistance

- **Corrosion** is defined as a chemical reaction between the fluid and a metal surface. With corrosion, part of the metal is lost from the surface, and resultant surface pits or voids are filled with the oxidation products that caused the corrosion. Since a portion of the metal is removed, the part becomes weaker. Also, the removed metal contaminates the oil.

- **Rust** is the oxidation of a ferrous metal. Rusting typically takes place in the reservoir above the oil level.

- Problems with corrosion and rusting can be minimized by the following common-sense precautions.

1. Restrict the introduction of air, water, and chemicals into the hydraulic fluid.
2. Select a fluid with good oxidation and rust inhibiting additives.
3. Provide filtration (i.e., a well designed and maintained system) to remove by-products of rusting and corrosion.

Fire Resistance

- Fire resistance is a key consideration in hydraulic systems used on aircraft, marine and mining equipment, and some manufacturing equipment.
- Three parameters are important in discussing the fire resistance of a fluid:
  1. Flash point
  2. Fire point
  3. Autogenous ignition temperature (AIT)

Foam Resistance

Hydraulic oil can be formulated with antifoaming additives. These are needed when there is an opportunity for air to be entrained in the oil. A properly designed system has the reservoir sized and placed so that the entire system is always completely filled with oil.

Hydraulic fluids used

1. Mineral-based fluids

- These are the most widely used.
- The properties of these fluid depend on the;
  - Additives used
  - The quality of the crude oil and
  - The refining process
- Common additives include;
  - Rust and oxidation inhibitors
  - Anticorrosion agents
  - Demulsifiers
  - Antiwear (AW)
  - Extreme pressure (EP) agents
  - VI improvers
  - Defoamants.
- Mineral-based fluids offer;
  - Low-cost
  - High quality

2. Water-based fluids

- These are used for fire-resistance due to their high-water content.
- High temperatures application may cause the water in the fluids to evaporate, which causes the viscosity to rise.
- Several system components must be checked for compatibility, including pumps, filters, plumbing, fittings and seal materials.
- Water-based fluids can be more;
  - Expensive
  - Lower wear resistance

3. Synthetic fluids

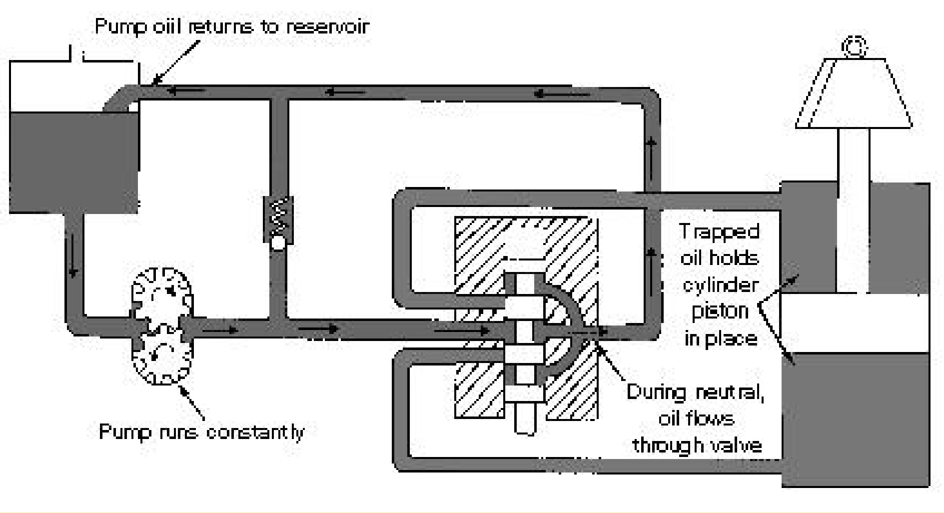
- These are man-made lubricants and many offer excellent lubrication characteristics in high-pressure and high- temperature systems.
- Some of the advantages of synthetic fluids;
  - Fire-resistance
  - Lower friction
  - Natural detergency
  - Thermal stability
- The disadvantage to these types of fluids;
  - Expensive than conventional fluids
  - Slightly toxic
  - Often not compatible with standard seal materials.

Types of hydraulic systems

- Open center system
  - Series connection
  - Series/parallel connections
  - Flow divider
- Closed center system
  - Fixed displacement pump & accumulator
  - Variable displacement pump

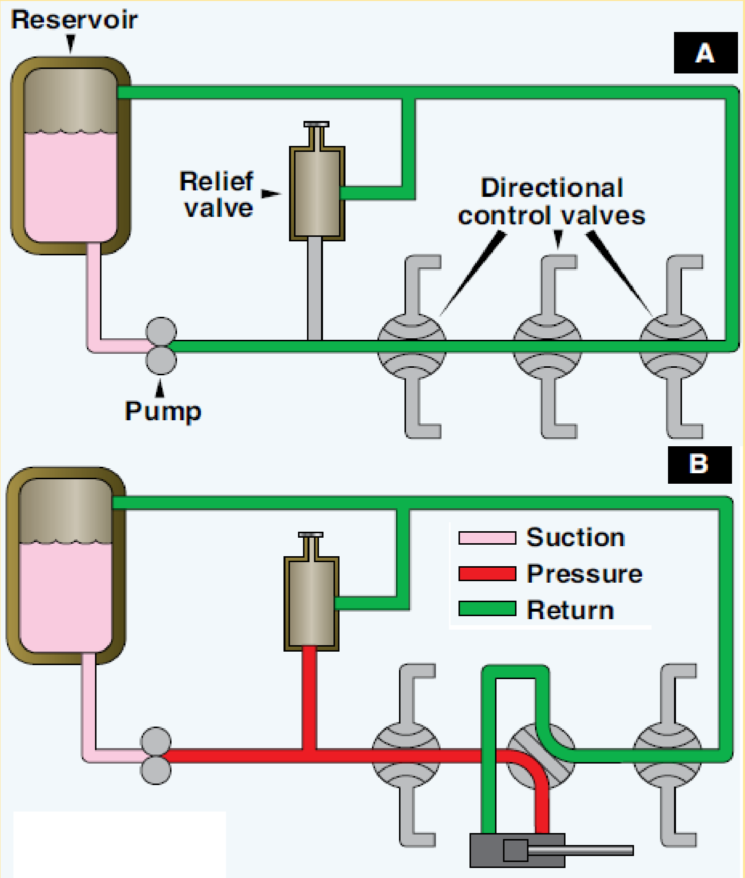
Open Center Hydraulic Systems

- An open centre system is one having fluid flow, but no pressure in the system when the actuating mechanisms are idle. The pump circulates the fluid from the reservoir, through the selector valves, and back to the reservoir.
- Figure shows the system in the neutral position. An open-centre system is efficient on single functions but is limited with multiple functions.
- The selector valves of the open centre system are always connected in series with each other. In this arrangement, the system pressure line goes through each selector valve. Fluid is always allowed free passage through each selector valve and back to the reservoir until one of the selector valves is positioned to operate a mechanism.

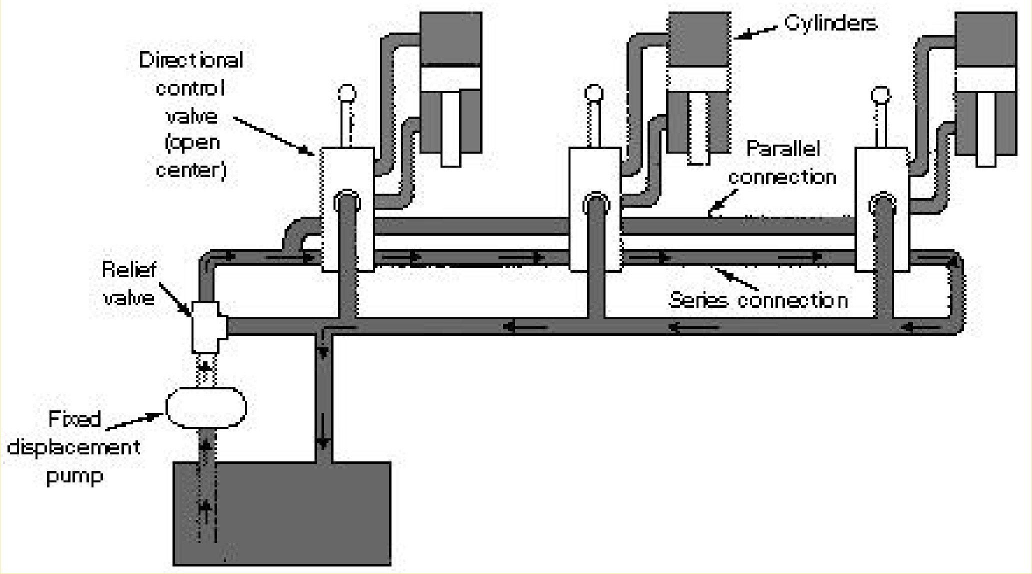


Open Center Hydraulic Systems

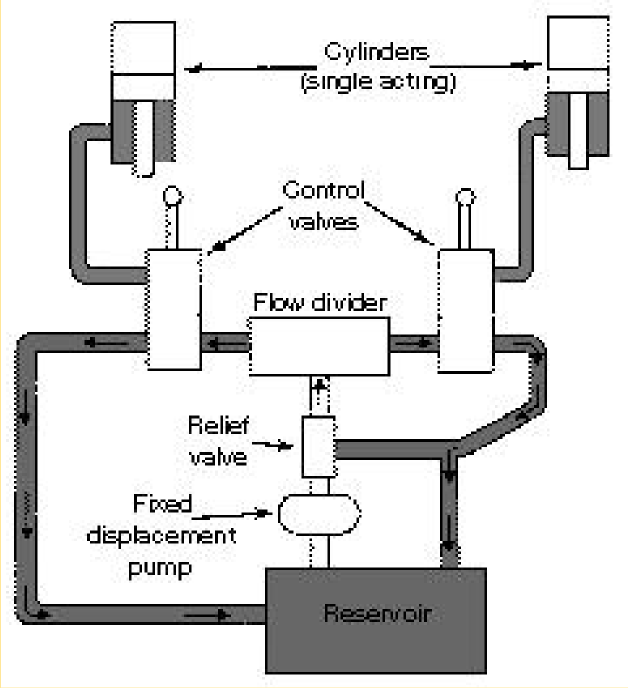
Series connection



Series/parallel connections

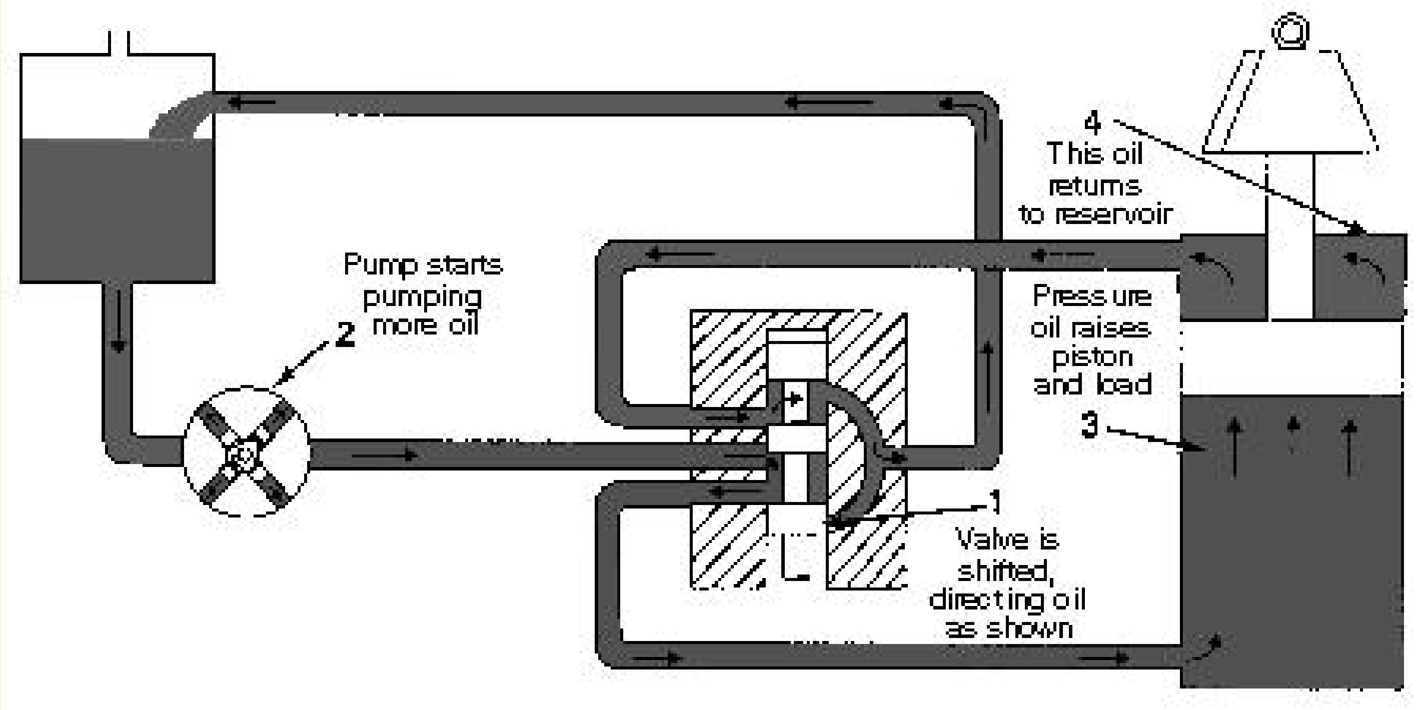


Flow divider



Closed Center Hydraulic Systems

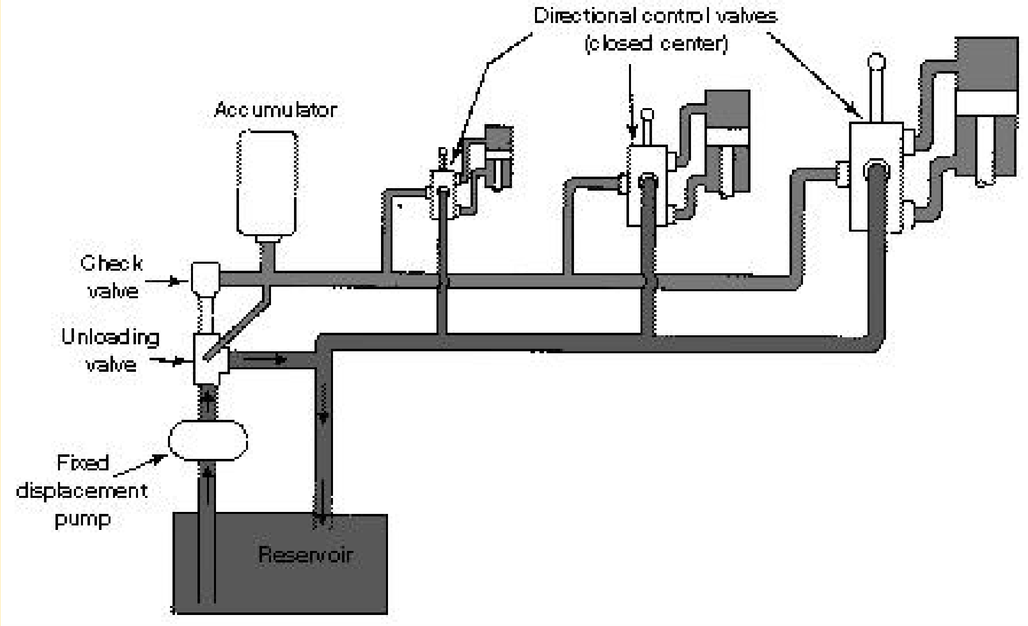
- In this system, a pump can rest when the oil is not required to operate a function. This means that a control valve is closed in the centre, stopping the flow of the oil from the pump. Figure below shows a closed-centre system.



Closed Center Hydraulic Systems

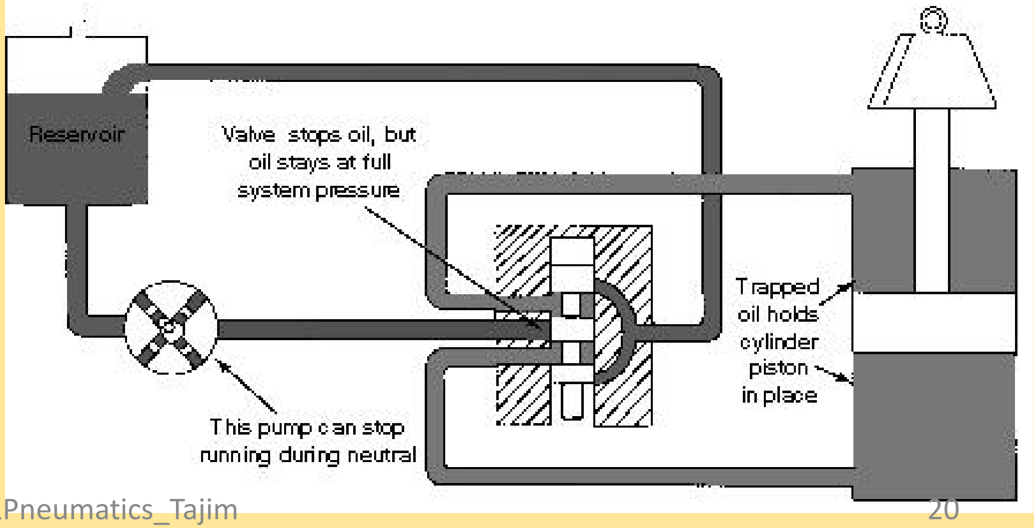
Fixed-displacement pump & accumulator

- Figure below shows a closed centre system. In this system, a pump of small but constant volume charges an accumulator. When an accumulator is charged to full pressure, an unloading valve diverts the pump flow back to a reservoir. A check valve traps the pressured oil in the circuit.



Variable-displacement pump

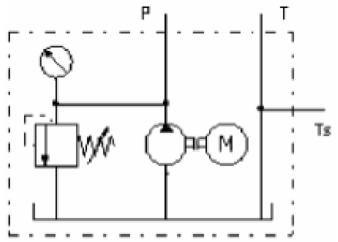
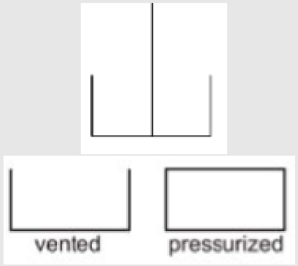
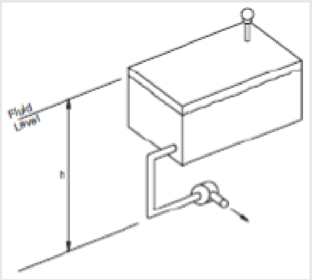
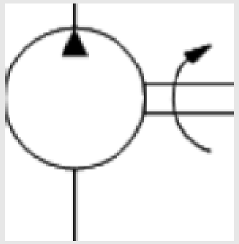
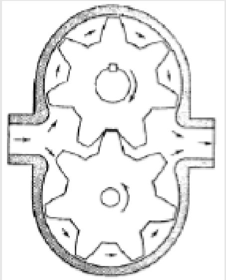
- Figure below shows a closed-centre system with a variable-displacement pump in the neutral mode. When in neutral, oil is pumped until the pressure rises to a pre-set level. A pressure regulating valve allows the pump to shut off by itself and maintain this pressure to the valve. When the control valve is operating, oil is diverted from the pump to the bottom of a cylinder. The drop in pressure caused by connecting the pump's pressure line to the bottom of the cylinder causes the pump to go back to work, pumping oil to the bottom of the piston and raising the load.



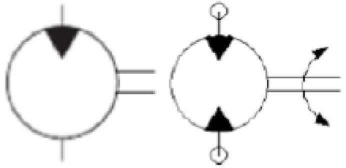
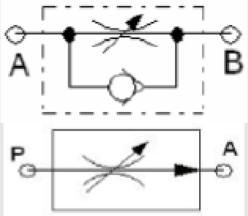
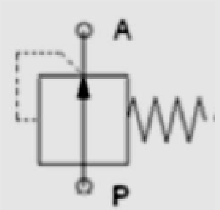
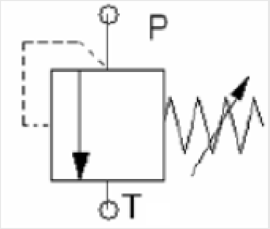
Homework 3a (ungraded)

- What is VI and how to read VI charts
  - Each student has to explain in front of the class

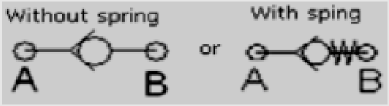
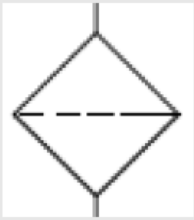
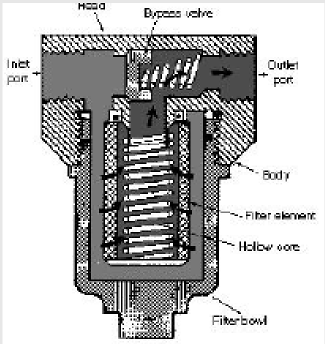
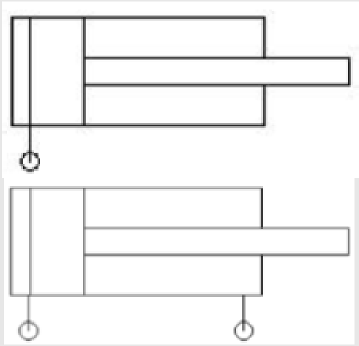
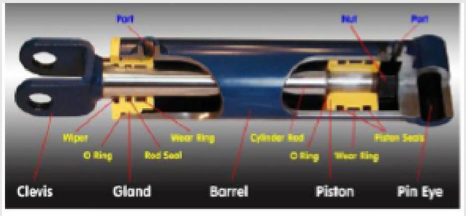
ELEMENTS OF HYDRAULIC SYSTEMS

Elements	Function	Symbol	Diagram
Hydraulic power pack (a) Electric motor (b) Hydraulic pump (c) Tank or reservoir (d)Pressure relief valve	The hydraulic power pack combines the pump, the motor, and the tank. The hydraulic power pack unit provides the energy required for the hydraulic system.		
Reservoir	The main function of the reservoir is to provide a source of room temperature oil at atmospheric pressure. a reservoir is nothing more than an oil storage tank connected to atmosphere through a breather and having pump and return lines to deliver and accept oil. a reservoir has additional functions including de-aerating and acting as a heat exchanger.		
Hydraulic Pump	The pump is the heart of a hydraulic system. The pump pulls oil out of the tank and pushes it through a directional control valve to the cylinder. The oil expelled from the bottom of the cylinder is guided back to the tank by the valve. It is the external force or restriction to the oil flow that produces the pressure, not the pump. The flow rate of the fluid and hence the speed of the piston is produced by the pump and this depends on the size, type and speed of the pump.		

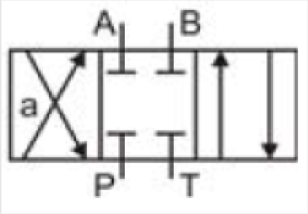
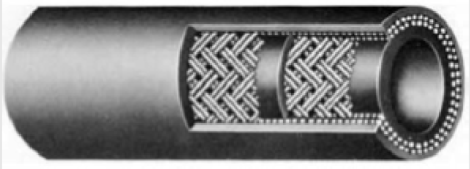
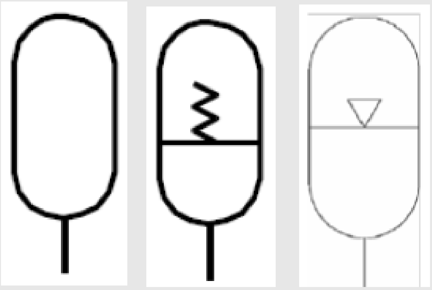
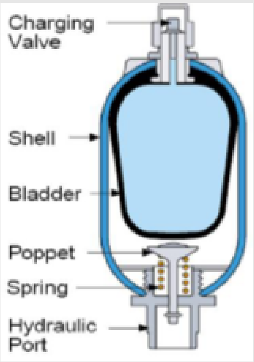
ELEMENTS OF HYDRAULIC SYSTEMS

Hydraulic Motors	Hydraulic motors are used to convert the hydraulic energy into mechanical energy by generating a rotary movement in either one or two directions. The ISO symbol of the hydraulic motor with a single direction of rotation is shown in left figure and with two directions of rotation is shown in right figure		
Flow Control Valves	These valves are used to control the speed of a cylinder or a motor by controlling the amount of fluid flow rate passing through it.		
Pressure Regulating Valve	Pressure regulator valves are used to reduce the input pressure to a specified output pressure. These valves are used mainly in hydraulic systems where several different pressures are required.		
Pressure Relief Valve	Pressure relief valve is used mainly as safety valve. It prevents the maximum permissible pressure in the hydraulic system from being exceeded. If the maximum pressure is reached at the valve inlet, the valve outlet is opened and the oil will flow out to the tank. The valve remains open until the built-in spring closes it after reaching the preset pressure in accordance with the spring characteristic.		

ELEMENTS OF HYDRAULIC SYSTEMS

Check valve (Non-return valve)	It used to allow the flow only in one direction; which means that the flow in the opposite direction will be completely blocked.		
Filters	A filter removes small foreign particles from a hydraulic fluid and is most effective as a safeguard against contaminates. Filters are located in a reservoir, a pressure line, a return line, or in any other location where necessary. They are classified as full flow or proportional flow.		
Hydraulic cylinder or actuators	These are used to convert hydraulic energy into mechanical energy (to give a linear force in one direction). Forward stroke is achieved by hydraulic pressure. Return stroke is achieved by the effect of the gravity or the load. Single acting or double acting		

ELEMENTS OF HYDRAULIC SYSTEMS

Direction control valves	DCV or dc valves are used to direct the flow from a source to a system consisting of actuators and other valves and devices. It would have at least of two positions like an electrical on-off switch. However, depending on the operational requirements and system it may be of three or higher positions too. 4/3 Directional Valve (Close Centre) is shown.		
Pipes/lines	There are three types of lines used for pressurized fluid: (1) pipe (2) seamless tubing (3) hose.		
Fittings	Flow through long straight pipes is not common in practical fluid power system as typically flow goes through right-angle fittings and short sections of bent.		
Accumulators	Hydraulic accumulators are used for temporarily storing pressurized oil. Accumulators are used to supply transient peak power, which reduces the flow rate requirement for the power supply and to act as shock absorbers for smoothing out pressure wave spikes. Accumulators are the equivalent to a capacitor in an electrical system and to a spring in a mechanical system.		

Design of Hydraulic Circuit

Case study 1

1.1 Problem Definition: Package lifting device

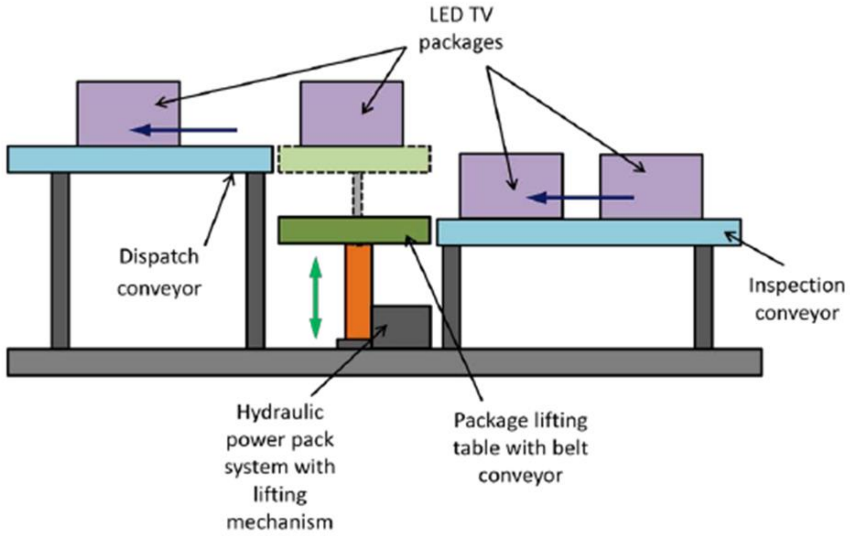


Figure 5.8.1 Schematic of a Package lifting system for LED TVs

For a dispatch station of a LED TV production house, design a package lifting device to lift packages containing 21" to 51" LED TVs from the inspection conveyor to the dispatch conveyor. Draw the hydraulic circuit diagram. List the components. Readers are requested to assume suitable data.

1.2Solution

By applying the principle of hydraulics and after studying the various sensors, pumps, valves and hydraulic actuators, the proposed hydraulic circuit is shown in Figure 5.8.1. Components required are listed in table 5.8.1.

Table 5.8.1 List of Components

S. No.	Item No.	Quantity	Description
1	1A	1	Two direction Hydraulic Motor with constant displacement volume
2	0Z1	1	Hydraulic Power Pack
3	0Z2	1	Pressure gauge
4	1V1	1	Shut-off valve
5	1V2	1	Pressure relief valve
6	1S	1	Flow sensor
7		5	Hose line
8		2	Branch Tee

1.3 Proposed hydraulic circuit and its operation

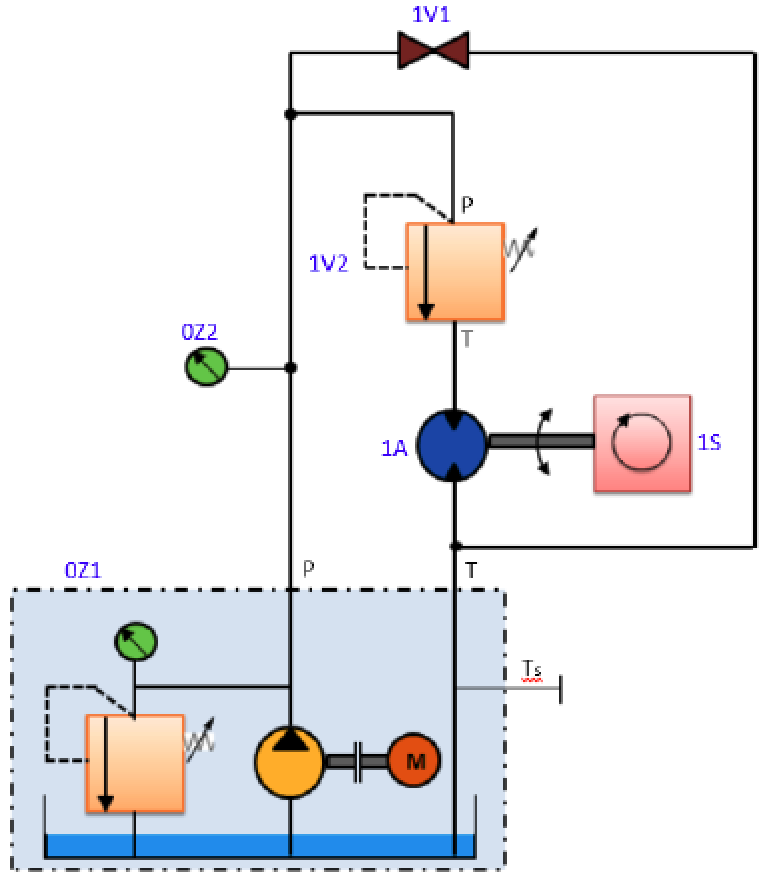


Figure 5.8.2 Hydraulic circuit design for package lifting device

Figure 5.8.2 shows the circuit design for package lifting device. The two direction hydraulic motor is run by using a hydraulic power pack. Required valves and pressure sensors are also included for desired control action. Readers are requested to carefully read the circuit and comprehend the circuit.

Once the hydraulic circuit has been assembled and checked, valve 1V1 and pressure relief valve 1V2 can be operated in sequence to obtain the rotary motion of hydraulic motor in required direction (clockwise/counter clockwise). This rotary motion can further be converted into linear motion by using suitable motion converter mechanism viz. Rack and pinion mechanism. Linear motion is used to lift the packages. It is required to develop a PID based controller to control the operation of the valves. The pressure gauge and flow sensor are used to monitor the operation continuously.

Quiz # 1

Maximum 10 minutes

Objectives of Today's Lecture

- Review of Fluid Mechanics basic equations such as;
  - Reynold's equation
  - Darcy-Weisbach equation
  - Bernoulli's equation
- Flow in confined spaces/places
- Briefly discuss the type of losses and where these occur?
- Problem solving session

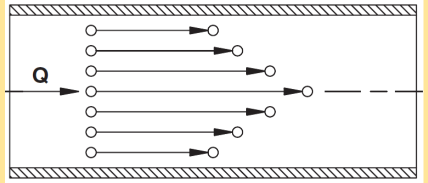
Fluid mechanics review

Since fluid power is also about fluid flow, so it is important to review the fluid mechanics concepts, such as;

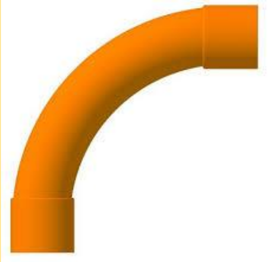
- Reynolds number
  - Laminar and Turbulent flow
- Darcy-Weisbach equation
  - Head loss due to friction
- Bernoulli’s equation
  - Inverse relationship between the pressure and speed at a point in a fluid is called **Bernoulli's principle**

Flow in confined spaces

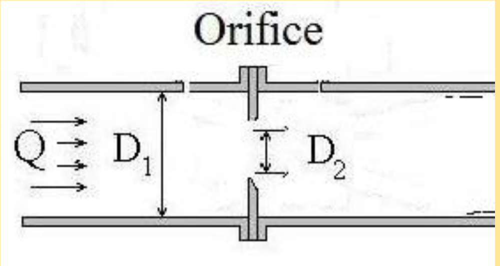
- Flow in Pipes
  - flow area remain same/constant



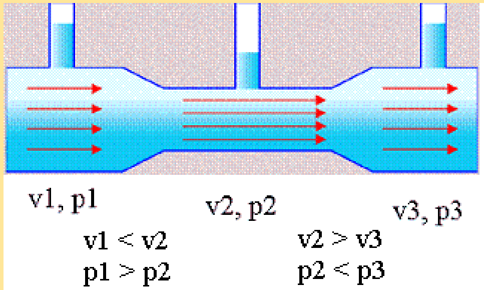
- Flow in Bends
  - flow direction is changed



- Flow in Orifice
  - sudden expansion or contraction of flow area



- Flow in Venturi
  - steady expansion or contraction of flow area



Losses in Hydraulic System

Generated head losses can be due to **viscous or frictional forces** or **due to both.**

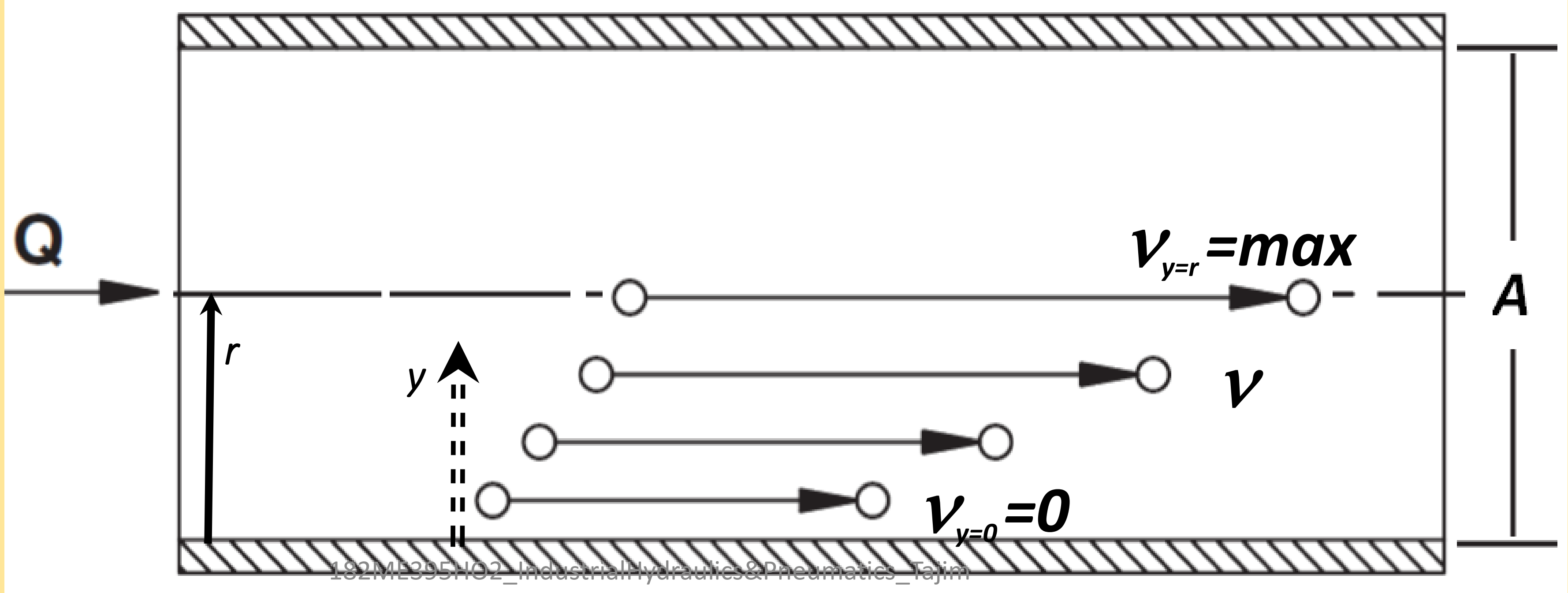
These can occur in the following as;

- **Losses in Pipes** (major losses)
- **Losses in Fittings** (minor losses)
- Losses in Pumps (leakage losses?)
- Losses in Valves (pressure relief, regulating, DCs) (minor losses)
- Losses in Actuators (cylinders/motors)

What happens when fluid flows inside a pipe?

When a fluid flows through a conductor (pipe, tube, or hose), having a flow rate ***Q***, the layer of fluid particles next to the wall has zero velocity v=0 (at ***y***=0).

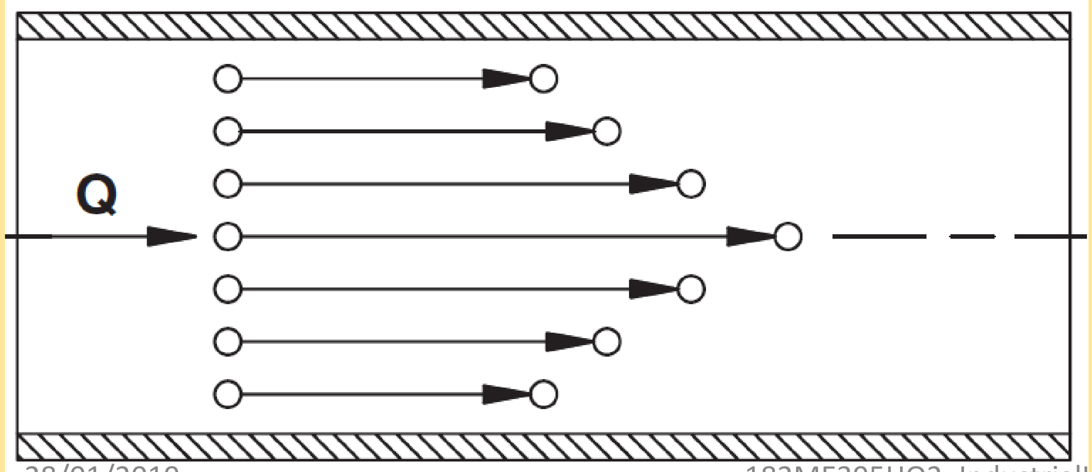
As distance from the wall increases, the velocity of the fluid increases and is at a maximum in the centre of the conductor. This results in development of the velocity profile and is because of viscosity. The more viscous the fluid, the greater the change in velocity with distance from the wall.



Fluid Flow

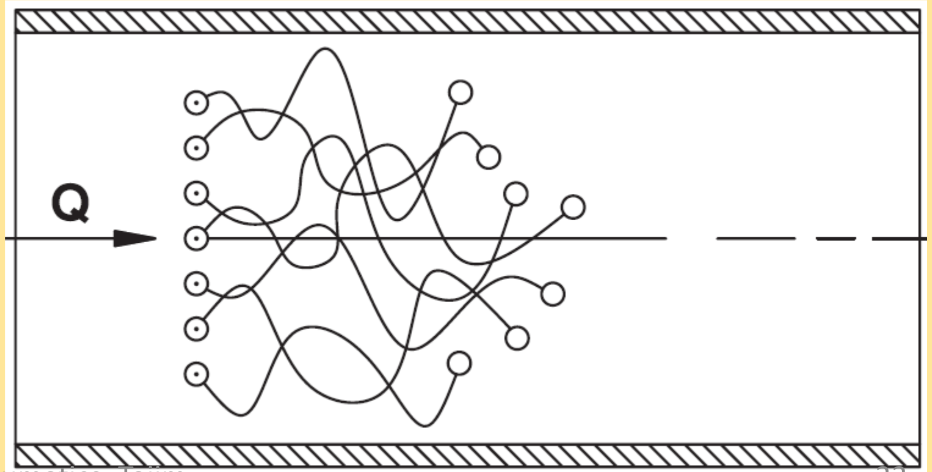
Laminar

- Flow is said to be ***laminar*** if the layers of fluid particles remain parallel as the flow moves along the conductor (pipe).
- When flow is dominated by viscosity forces, it is called a laminar flow.



Turbulent

- Flow is said to be ***turbulent*** if the fluid layers break down as the flow moves along the conductor (pipe).
- When flow is dominated by inertia forces, then the flow is called a turbulent flow.



Reynolds Number

- Osborn Reynolds performed a series of experiments in 1833 to define the transition between laminar and turbulent flow.
- He found that laminar flow is a function of inertial and viscous forces
- He name the function as the Reynolds number.
- The Reynolds number is a dimensionless ratio of inertia force to viscous force.
- Reynolds number is defined by;

$$N_R = \frac{vD\rho}{\mu}$$

v = fluid velocity
D = conductor inside diameter
ρ = fluid mass density
μ = dynamic viscosity

Reynolds number

Reynolds discovered the following rules with his tests:

1. If ***NR* < 2000**, flow is ***laminar***.

2. If ***NR* > 4000**, flow is ***turbulent***.

The region **2000 < *NR* < 4000** is defined as the ***transition region*** between laminar and turbulent flow.

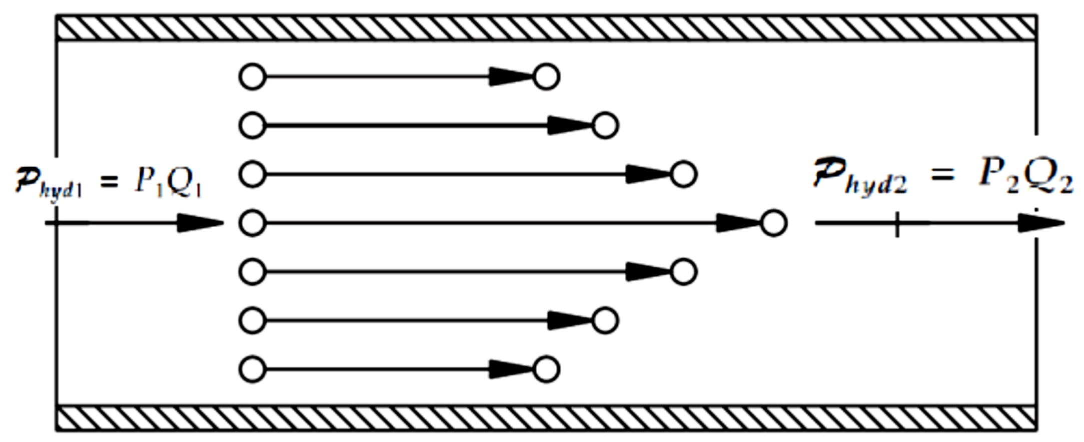
It is convenient in many cases to use the following formula for Reynolds number (in US units):

$$N_R = \frac{7740 v D}{\nu}$$

v = fluid velocity (ft/s)
D = conductor inside diameter (in)
ν = kinematic viscosity (cS)

Head Loss: Darcy's Equation

Friction is the main cause of the loss of fluid energy as the fluid flows through a conductor (pipe). Friction causes a pressure drop in the line. This pressure drop is sometimes referred to as a *head loss.*



In case of no leakage of the fluid from the walls of the pipe; the flow rate at the input will be same as of flow rate at the outlet;

$$Q_1 = Q_2$$

In a cylindrical pipe of uniform diameter *D*, flowing full, the pressure loss (or head loss $\boldsymbol{h_L}$) Δp is proportional to length *L.* The pressure drop or head loss due to friction in the pipe can be found by using **Darcy Equation**;

$$h_L = f\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right)$$

h_L = head loss (ft)
f = friction factor (dimensionless)
D = conductor inside diameter (ft)
L = conductor length (ft)
v = average fluid velocity (ft/s)
g = gravitational constant (ft/s²)

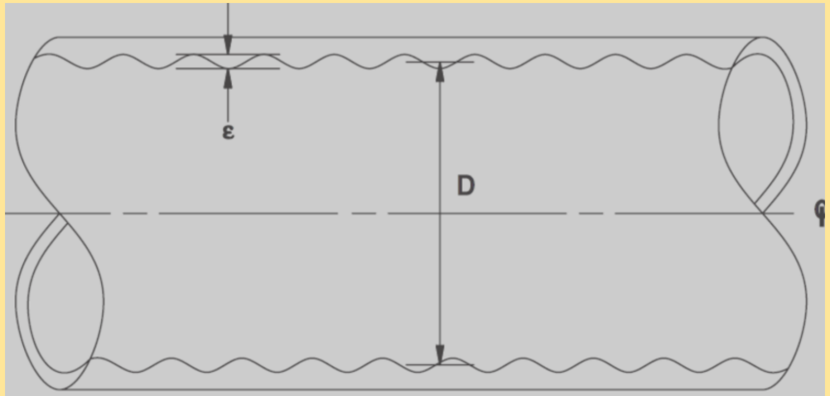
Head loss for Laminar & Turbulent flow; (friction factor; *f*)

The friction factor for **laminar flow** is given by;

$$\boxed{f = \frac{64}{N_R}}$$

When flow is **turbulent**, the friction factor is a function of Reynolds number and the relative roughness of the conductor (or pipe).
Relative roughness is defined as the conductor inside surface roughness ε divided by the conductor inside diameter *D*.

$$\boxed{\text{Relative roughness} = \frac{\varepsilon}{D}}$$



The friction factor in the turbulent flow range can also be calculated using;

$$\boxed{f = \frac{0.1364}{N_R^{0.25}}}$$

The above equation is also know as **Blasius equation** for friction factor and is valid for smooth pipes and when the Reynolds number is less than 100,000. For typical hydraulic circuit, the flow velocity is kept at 15 m / s. So it is safe to use the above equation.

Darcy Equation: Losses due to friction

Substituting ***f*** for laminar flow, into Darcy's equation gives the Hagen-Poiseuille equation;

$$h_L = \frac{64}{N_R}\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right)$$

The Hagen-Poiseuille equation is also written in the form

$$\Delta P = \frac{128\mu L Q}{\pi D^4}$$

ΔP = pressure drop
μ = absolute viscosity
L = length
Q = volume flow rate
D = diameter

Example1: Laminar or Turbulent

Problem:

Suppose oil with kinematic viscosity ***v = 36.5 cSt*** is flowing through a tube with inside diameter ***D = 0.5 in***. The flow rate is ***Q = 8 GPM***. Is the flow ***laminar*** or ***turbulent***?

Solution:

First? What is given and what is to be found?

Step1:

Determine the average fluid velocity;

$$v = \frac{Q}{A} = \frac{8 \text{ GPM} \times 231 \text{ in}^3/\text{gal}}{\pi (0.5)^2/4 \text{ in}^2} = 9430 \text{ in/min} = 13.1 \text{ ft/s}$$

Note:
1 GPM = 231 in^3/min

Example1: Laminar or Turbulent (continue..)

Step 2:

Now, using Reynold's number equation, it can be find out if the flow is laminar or turbulent;

$$N_R = \frac{7740 v D}{\nu} = \frac{7740(13.1)(0.5)}{36.5} = 1390$$

$N_R < 2000$, therefore flow is laminar.

- $1.00\ ft^2/s = 929.034116$ Stokes $= 92903.4116$ Centistokes
- 1 Centistokes $= 1.00 / 92903.4116\ (ft^2/s) = 1.0764 \times 10^{-5}\ ft^2/s$

So,

- 36.5 Centistokes $= 36.5 \times 1.0764\ ft^2/s$

Putting these values in Reynold's equation;

$N_R = (\upsilon \times D)/\nu$

$N_R = (\upsilon \times D/12)/\ 36.5 \times 1.0764 \times 10^{-5}\ ft^2/s$

$N_R = 7740 \times (\upsilon \times D)\ [\cancel{ft/s \times ft}]\ /\ 36.5\ \cancel{ft^2/s} = 7740 \times (\upsilon \times D)\ /\ 36.5$

Is there any mistake in the calculations?

Reynold's Number (another example)

Problem:

What flow of this oil can be pumped through a **0.5** *in* diameter tube and the flow will still be laminar?

Solution:

What is given and what is to found; If $N_R < 2000$, flow is laminar.

Step1: Solve for velocity;

$$N_R = \frac{7740 v D}{\nu} \Rightarrow v = \frac{N_R \nu}{7740 D} = \frac{2000(36.5)}{7740(0.5)} = 18.86 \text{ ft/s} = 13,580 \text{ in/min}$$

Step2: Solve for flow rate;

$$Q = vA/231 = \frac{13,580 \text{ in/min} \times 0.195 \text{ in}^2}{231 \text{ in}^3\text{/gal}} = 11.5 \text{ GPM}$$

Friction losses: Darcy Equation

Problem:

The kinematic viscosity of a hydraulic fluid is 0.0001 m^2/s. If it is flowing in a 20-mm diameter commercial steel pipe, find the friction factor in each case:

(a) The velocity is 2 m/s.

(b) The velocity is 10 m/s.

(c) The velocity is 20 m/s.

Solution:

a) If the velocity is 2 m/s, then

$$\mathrm{Re} = \frac{vD\rho}{\mu} = \frac{vD}{\mu / \rho} = \frac{vD}{\nu} = \frac{2 \times 0.02}{0.0001} = 400$$

The flow is laminar. Now

$$f = \frac{64}{\mathrm{Re}} = \frac{64}{400} = 0.16$$

(b) If the velocity is 10 m/s, then

$$\mathrm{Re} = \frac{vD\rho}{\mu} = \frac{vD}{\mu / \rho} = \frac{vD}{\nu} = \frac{10 \times 0.02}{0.0001} = 2000$$

Theflow is laminar. Now

$$f = \frac{64}{\mathrm{Re}} = \frac{64}{2000} = 0.032$$

Friction losses: Darcy Equation

Problem: The oil tank for the hydraulic system shown in figure below is pressurized at 68 kPa gauge pressure. The inlet to the pump is 3 m below the oil level. The pump flow rate is 0.001896 m^3/s. Find the **head loss due to friction** at point 2. The specific gravity of oil is 0.9 and kinematic viscosity of oil is 100 cS. Assume the pressure drop across the strainer to be 6.9 kPa. Also given, the pipe diameter is 38 mm and the total length of the pipe is 6 m. Assume velocity $\boldsymbol{v_1}$=0 as the oil tank area to be large. The velocity at point 2, $\boldsymbol{v_2}$ is 1.67 m/s

Solution: The head loss is; $H_L = \frac{f \cdot L_p}{D_p} \times \frac{v^2}{2g}$ Given values are; $L_p = \text{Total length of pipe} = 6\,\text{m}$, $D_p = \text{Diameter of pipe} = 0.38\,\text{m}$

Value of f (friction factor) depends on the value of Reynolds number.

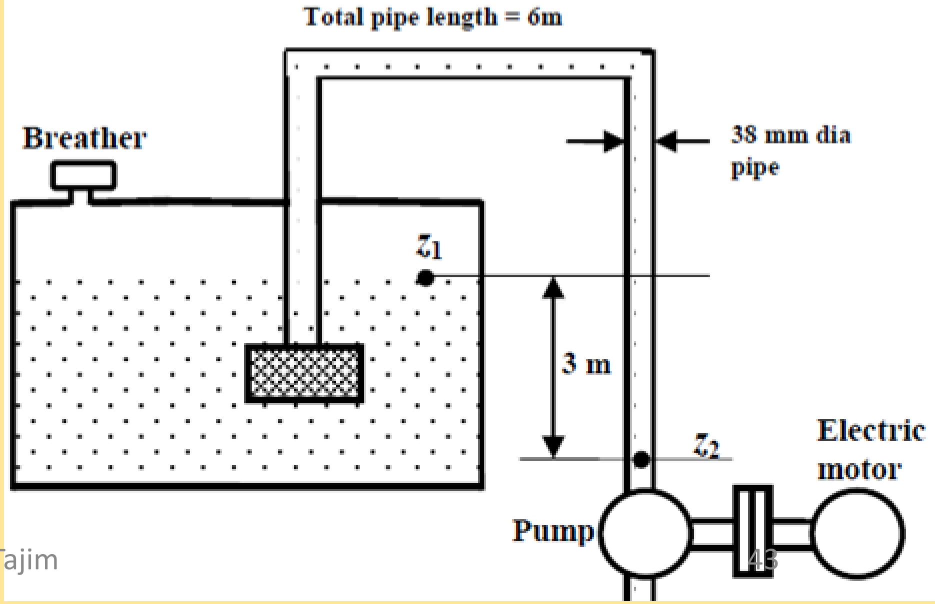
$$\text{Re} = \frac{vD_p}{\nu} = \frac{1.67 \times 0.038}{100 \times 10^{-6}}$$
$$= 634.6 < 2000, \text{flow is laminar}$$

Now

$$f = \frac{64}{\text{Re}} = \frac{64}{634.6} = 0.1$$

So head loss due to friction is

$$H_L = \frac{0.1 \times 6}{0.038} \times 0.142 = 2.24\,\text{m}$$



Friction losses: Darcy Equation

Problem:

The kinematic viscosity of a hydraulic fluid is 0.0001 m^2/s. If it is flowing in a 30-mm diameter pipe at a velocity of 6 m/s, find the head loss due to friction in units of bars for a 100-m smooth pipe. The oil has a specific gravity of 0.90.

$$\mathrm{Re} = \frac{vD\rho}{\mu} = \frac{vD}{\mu/\rho} = \frac{vD}{\nu} = \frac{6\times 0.03}{0.0001} = 1800$$

We can express the head loss in bar as

$$H_\mathrm{L} = \frac{64}{\mathrm{Re}}\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right)$$

$$= \frac{64}{1800}\left(\frac{100}{0.030}\right)\left(\frac{6^2}{2\times 9.81}\right)$$

$$= 217.5\ \mathrm{m}$$

Hence,

$$\Delta p = \gamma H_\mathrm{L}$$

$$= 1000\ \mathrm{kg/m^3} \times 0.90 \times 9.81\ \mathrm{m/s^2} \times 217.5$$

$$= 1.92\ \mathrm{MN/m^2}$$

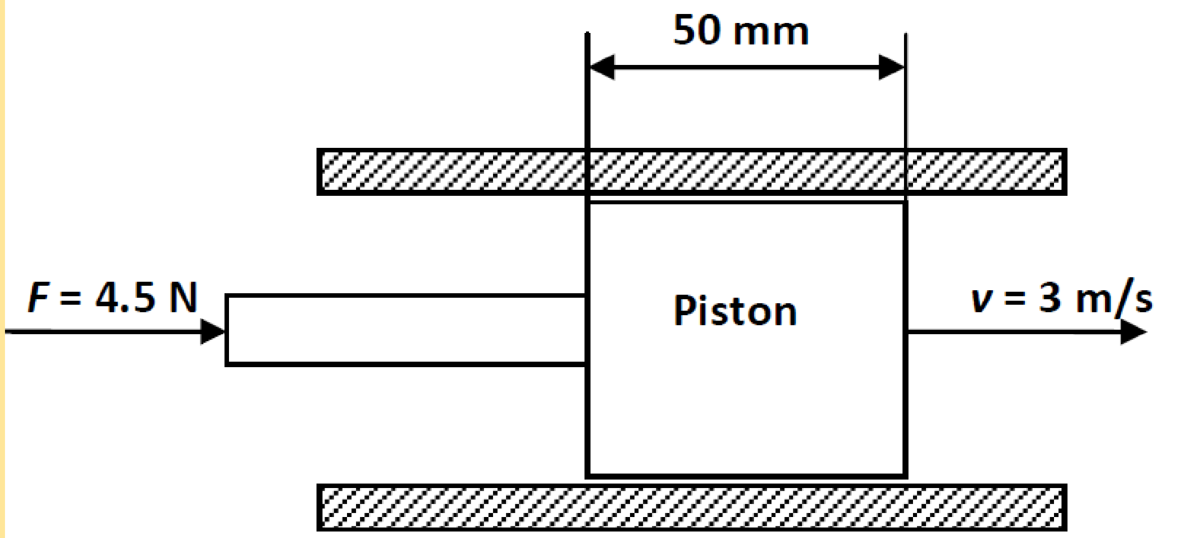
$$= 1.92\ \mathrm{MPa}$$

$$= 19.2\ \mathrm{bar}$$

Problems to be solved by the students

Problem 1: To find viscosity (chapter 2NPTL)

A ***4.5 N*** force moves a piston inside a cylinder at a velocity of ***3 m/s*** as shown in figure below. The piston of ***10.16 cm*** diameter is centrally located in the cylinder having an internal diameter of ***10.17 cm***. An oil film separates the piston from the cylinder. Find the absolute viscosity of the oil.

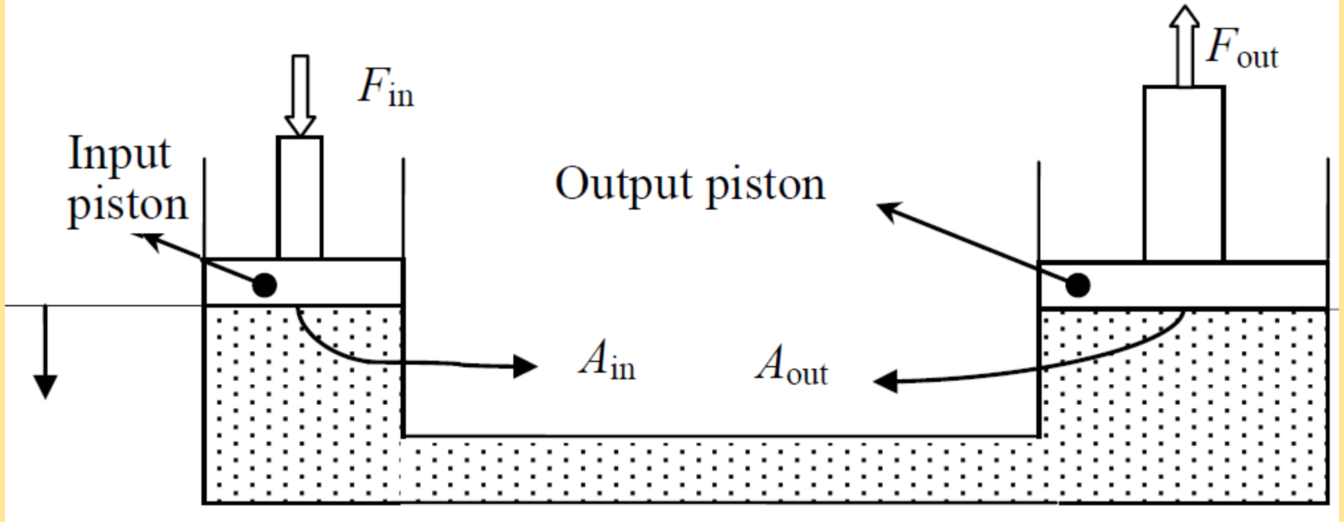


Problems to be solved by the students

Problem 2: Pascal's Law

An input cylinder with a diameter of 30 mm is connected to an output cylinder with a diameter of 80 mm (Figure below). A force of 1000 N is applied to the input cylinder. (chapter 4NPTL)

- (a) What is the output force?
- (b) How far do we need to move the input cylinder to move the output cylinder 100 mm?



Problems to be solved by the students

Problem 3: A pump produces a flow rate of 75 LPM. It has been established that the fluid velocity in a discharge line should be between 6 and 7.5 m/s. Determine the minimum and maximum pipe inside diameter that should be used. (chapter 5NPTL)

Problem 4: Reynold's number

The kinematic viscosity of a hydraulic fluid is 0.0001 m^2/s. If it is flowing in a 30-mm diameter pipe at a velocity of 6 m/s, what is the Reynolds number? Is the flow laminar or turbulent?

Head losses in fittings

Losses in fitting

In fluid mechanics, an engineer is introduced to the concept of a *K* factor for a fitting. Tests have shown that head losses in fittings are proportional to the square of the velocity of the fluid.

$$h_L = \frac{Kv^2}{2g}$$

The circuit described in Example Problem 2.3 (from textbook) has an elbow ($K = 0.9$) at the motor. Fluid flows from the hose through the elbow into the motor. What is the pressure drop in this fitting for Q = 15 GPM, Q = 37.5 GPM.

Fitting	*K* Factors
Standard tee	1.8
Standard elbow	0.9
45° elbow	0.42
Return bend (U-turn)	2.2

What is Cavitation?

- https://www.youtube.com/watch?v=eMDAw0TXvUo

- How to avoid cavitation?

https://www.designworldonline.com/7-ways-avoid-cavitation/