MODULE 1

FLUID POWER: It may be defined as the technology that deals with the generation, control and transmission of power using pressurized fluids

TYPES OF FLUID SYSTEMS:

Fluid Transport systems: The objective of the fluid transport systems is to transport fluids from one place to another place to achieve some useful purpose

Fluid Power systems: The Fluid power system is primarily designed to perform work. That is these systems use pressurized fluids to produce some useful mechanical movements to accomplish the desired work.

Method of transmitting power:

- Electrical power transmission
- Mechanical power transmission
- Fluid power transmission
  - Hydraulic power transmission
  - Pneumatic power transmission

ADVANTAGES OF FLUID POWER:

1. Easy and Accuracy to Control With the use of simple levels and push buttons, the fluid power system can facilitate easy starting, stopping, speeding up or slowing down and positioning forces that provide any desired power
2. Multiplication of small forces to achieve greater forces for performing work
3. It easily provides infinite and step less variable speed control which is difficult to obtain from other drives
4. Accuracy in controlling small or large forces with instant reversal is possible with hydraulic systems
5. Constant force is possible in fluid power system regardless of special motion requirements. Whether the work output moves a few millimeters or several meters per minute.
6. As the medium of power transmission is fluid, it is not subjected to any breakage of parts as in mechanical transmission.
7. The parts of hydraulic system are lubricated with the hydraulic liquid itself.
8. Overloads can easily controlled by using relief valves than is possible with overload devices on the other systems. Air equipments reduces the danger of fire and explosion hazard in industries such as painting and mining.
9. Because of the simplicity and compactness the cost is relatively low for the power transmitted.
10. No need of lubrication

DISADVANTAGES:

1. Leakage of oil or compressed air
2. Busting of oil lines, air tanks
3. More noise in operation

APPLICATIONS OF FLUID POWER:

1. **Agriculture:** Tractors and farm equipments like ploughs, mowers, chemical sprayers, fertilizer spreaders, hay balers
2. **Automation:** Automated transfer machines
3. **Aviation:** Fluid power equipments like landing wheels on aeroplane and helicopter, aircraft trolleys, aircraft engine test beds.
4. **Building Industry:** For metering and mixing of concrete ingredients from hopper.
5. **Construction Equipment:** Earthmoving equipments like excavators, bucket loaders, dozers, crawlers, post hole diggers and road graders.
6. **Defense** : Missile-launch systems and Navigation controls
7. **Entertainment:** Amusement park entertainment rides like roller coasters
8. **Fabrication Industry:** Hand tools like pneumatic drills, grinders, bores, riveting machines, nut runners
9. **Food and Beverage:** All types of food processing equipment, wrapping, bottling
10. **Foundry:** Full and semi automatic molding machines, tilting of furnaces, die casting machines
11. **Glass Industry:** Vacuum suction cups for handling
12. **Material Handling:** Jacks, Hoists, Cranes, Forklift, Conveyor system

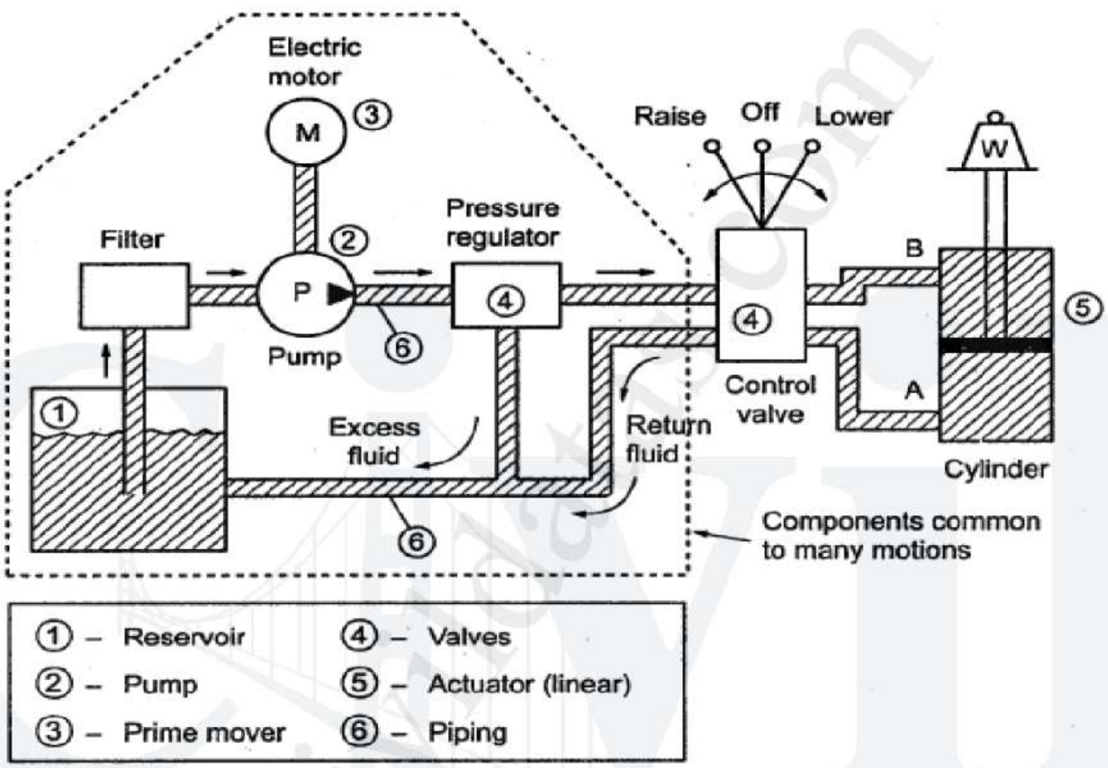
HYDRAULIC SYSTEM:

An electric motor drives the hydraulic pump so that the fluid is pumped from the tank at the required pressure. The fluid circulated into the system should be clean to reduce the wear of the pump and cylinder; hence a filter is used immediate to the storage tank. Since the pump delivers constant volume of fluid for each revolution of the shaft the fluid pressure rises indefinitely until a pipe or pump itself fails. To avoid this some kind of pressure regulators is used to spill out the excess fluid back to the tank. Cylinder movement is controlled by a 3 position change over control valve. One side of the valve is connected to a pressurized fluid line and the fluid retrieval line and other side of the valve is connected to port A and port B of the cylinder. Since the hydraulic circuit is a closed one, the liquid transferred from the storage tank to one side of the piston, and the fluid at the other side of the piston is retrieved back to the tank.

Raise: To lift the weight, the pressurized fluid line has to be connected to port A and the retrieval line has to be connected to the port B, by moving the valve position to "raise".

Lower: To bring down the weight, the pressurized fluid line has to be connected to port B and the retrieval fluid line has to be connected to port A, by moving the valve position to "lower".

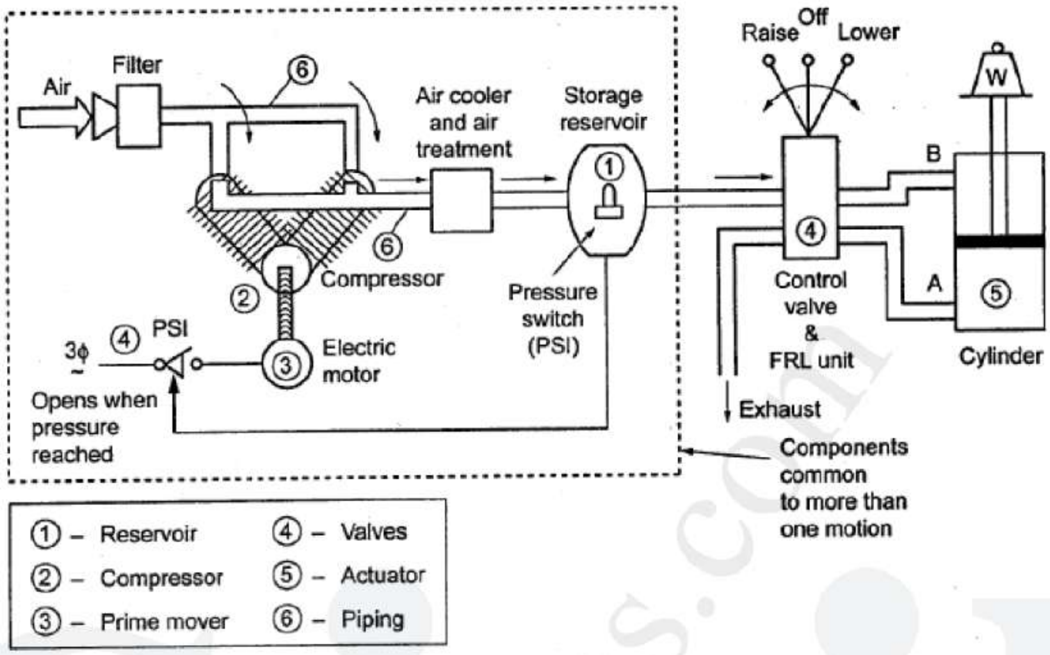
Off: The weight can be stopped at a particular position by moving the valve position to off. This disconnects the port A and port B from the pressurized line and the retrieval line which locks the fluid in the cylinder.



General arrangement of a hydraulic system

PNEUMATIC POWER SYSTEM:

Air is drawn from the atmosphere through the air filter and raised to the required pressure by an air compressor. Air contains significant amount of water vapour and also the air temperature is raised considerably by the compressor. So the air must be cooled before using it in the system, which results in condensation. The compressed air is stored in the reservoir which has water outlet at the bottom of the reservoir and a pressure switch to control the pressure of the compressed air. Pressure switch stops the motor when the required pressure is attained and starts the motor when the pressure falls down the mark. The cylinder movement is controlled by the pneumatic valve. One side of the pneumatic valve is connected to the compressed air line and silencers for the exhaust air and the other side of the valve is connected to port A and port B of the cylinder.



Raise: To lift the weight, the compressed air line has to be connected to port A and the port B is connected to the exhaust air line by moving the valve position to raise.

Lower: To bring down the weight, the compressed air line is connected to port B and the port A is connected to exhaust air line by moving the valve position to lower.

Off: The weight can be stopped at a particular position by moving the valve position to off. This disconnects the port A and port B from the pressurized line and the retrieval line which locks the air in the cylinder.

COMPARISON BETWEEN HYDRAULIC, PNEUMATIC AND ELECTRO MECHANICAL POWER SYSTEM

Hydraulic System	Pneumatic System	Electro-Mechanical System
Pressurized Liquid is used	Compressed Air is used	Energy is transmitted through mechanical components
Energy stored in Accumulator	Energy stored in Tank	Energy stored in Batteries
Hydraulic Valves are used	Pneumatic Valves are used	Variable Frequency drives
Transmission through Hydraulic cylinders, Actuators	Transmission through Pneumatic cylinders, Actuators	Transmission through Mechanical components like Gears, Cams

Hydraulic System	Pneumatic System	Electro-Mechanical System
Flow rate is 2 to 6 m/s	Flow rate is 20-40 m/s	Excellent with minimum loss
More Precision	Less Precision	More Precision
Large force can be generated	Limited force can be achieved	Large force can be realized but poor in efficiency
Medium Cost	High cost	Low Cost
Dangerous and fire hazardous because of leakage	Noisy	Easy to work

FUNCTIONS OF FLUIDS IN A FLUID POWER SYSTEM:

1. Transfer fluid power efficiently
2. Lubricate the moving parts
3. Absorb, Carry and Transfer heat generated within the system
4. Be compatible with hydraulic components
5. Remain stable against physical and chemical changes

VARIOUS HYDRAULIC FLUIDS:

- **Water:** The least expensive hydraulic fluid is water. Water is treated with chemicals before being used in a fluid power system. This treatment removes undesirable contaminates.

  Advantages: Inexpensive, Readily available, Fire resistance

  Disadvantage: No lubricity, Corrosive, Temperature limitations

- **Petroleum Oils:** These are the most common among the hydraulic fluids which are used in a wide range of hydraulic applications. The characteristic of petroleum based hydraulic oils are controlled by the type of crude oil used. Naphthenic oils have low viscosity index so it is unsuitable where the oil temperatures vary too widely. The aromatics have a higher presence of benzene and they are more compatible with moderate temperature variation. Paraffinic oils have a high viscosity index and they are more suitable for the system where the temperature varies greatly.

  Advantages: Excellent lubricity, Reasonable cost, Non-corrosive

  Disadvantage: Tendency to oxidize rapidly, Not fire resistance

- **Water Glycols**: These are solutions contains 35 to 55% water, glycol and water soluble thickener to improve viscosity. Additives are also added to improve anticorrosion, anti wear and lubricity properties.

  Advantages: Better fire resistance, Less expensive, Compatible with most pipe compounds and seals

  Disadvantage: Low viscosity, Poor corrosion resistance, not suitable for high loads

- **Water Oil Emulsions:** These are water-oil mixtures. They are of two types oil-in-water emulsions or water-in-oil emulsions. The oil-in-water emulsion has water as the continuous base and the oil is present in lesser amounts as the dispersed media. In the water-in-oil emulsion, the oil is in continuous phase and water is the dispersed media.

  Advantages: High viscosity index, Oxidation stability, Film strength

  Disadvantage: Depletion of water due to evaporation decreases fire resistance,
  Demulsification may be problem with water-in-oil emulsions.

- **Phosphate Ester:** It results from the incorporation of phosphorus into organic molecules. They have high thermal stability. They serve as an excellent detergent and prevent building up of sludge.

  Advantages: Excellent fire resistance, Good lubricity, Non corrosive

  Disadvantage: Not compatible with many plastics and elastomers, Expensive

PROPERTIES OF FLUIDS:

1. Viscosity: It is a measure of the fluid's internal resistance offered to flow. Viscosity is the most important factor from the stand point of flow. If the viscosity of the hydraulic oil is higher than recommended, the system will be affected in the following manner.

1. The viscous oil may not be able to pass through the pipes.
2. The working temperature will increases because there will be internal friction.
3. The consumption of power will increase

If the viscosity of the oil is lesser than recommended then,

1. The internal and external leakage will increase
2. It cannot lubricate properly and will lead to rapid wear of the moving parts.

2. Viscosity Index: This value shows how temperature affects the viscosity of oil. The viscosity of the oil decreases with increase in temperature and vice versa. The rate of change of viscosity with temperature is indicated on an arbitrary scale called viscosity index (VI). The lower the viscosity index, the greater the variation in viscosity with changes in temperature and vice versa.

3. Oxidation Stability: The most important property of an hydraulic oil is its oxidation stability. Oxidation is caused by a chemical reaction between the oxygen of the dissolved air and the oil. The oxidation of the oil creates impurities like sludge, insoluble gum and soluble acidic products. The soluble acidic products cause corrosion and insoluble products make the operation sluggish.

4. Demulsibility: The ability of a hydraulic fluid to separate rapidly from moisture and successfully resist emulsification is known as Demulsibility. If oil emulsifies with water the emulsion will promote the destruction of lubricating value and sealant properties. Highly refined oils are basically water resistance by nature.

5. Lubricity: Wear results in increase clearance which leads to all sorts of operational difficulties including fall of efficiency. At the time of selecting a hydraulic oil care must be taken to select one which will be able to lubricate the moving parts efficiently.

6. Rust Prevention: The moisture entering into the hydraulic system with air causes the parts made ferrous materials to rust. This rust if passed through the precision made pumps and valves may scratch the nicely polished surfaces. So additives named inhibitors are added to the oil to keep the moisture away from the surface.

7. Pour Point: The temperature at which oil will clot is referred to as the pour point i.e. the lowest temperature at which the oil is able to flow easily. It is of great importance in cold countries where the system is exposed to very low temperature.

8. Flash Point and Fire Point: Flash point is the temperature at which a liquid gives off vapour in sufficient quantity to ignite momentarily or flash when a flame is applied. The minimum temperature at which the hydraulic fluid will catch fire and continue burning is called fire point.

9. Neutralization Number: The neutralization number is a measure of the acidity or alkalinity of a hydraulic fluid. This is referred to as the PH value of the fluid. High acidity causes the oxidation rate in an oil to increase rapidly.

10. Density: It is that quantity of matter contained in unit volume of the substance.

11. Compressibility: All fluids are compressible to some extent. Compressibility of a liquid causes the liquid to act much like a stiff spring. The coefficient of compressibility is the fractional change in a unit volume of liquid per unit change of pressure

1.3 Additives in Hydraulic Fluids

Some of the commonly used additives and their purposes are as follows:

1. Pour point depressant: A pour point is the temperature at which a fluid ceases to flow. The minimum operating temperature in a hydraulic system should be at least 10°C above the pour point. Pour point depressants inhibit the formation of wax crystals in the mineral oils and hence enhance the pour points.There is a range of pour point depressant additives of different chemical species, important ones are polymethacrylates, polyacrylates and alkalated naphthalene.

2. Viscosity index improvers: These additives are long-chain polymers that stay in a coiled form in the hydraulic fluid. At a low operating temperature, they have no effect on viscosity. But when the temperature rises, these polymers uncoil and intermesh causing a thickness effect in the fluid, thereby not allowing the viscosity to drop down.

3. Defoamers(anti-foam additives): Certain additives, such as silicon polymer, act as defoamers. They cause a rapid breakdown of the foam by removing the entrained air bubbles. Foaming occurs in oil as a surface phenomenon. Bubbles of air are encircled by an oil film and cannot escape. These bubbles under pressure become very hot and can be the cause of system overheating.Foam usually forms in the reservoir and, if drawn into the pump suction, can cause noisy pump operation and may even damage pump parts. Control response is spongy and unreliable.Although all fluids are susceptible to foaming, the amount of foam in a system can be reduced to a minimum by the addition of chemical depressants.

4. Oxidation inhibitors: Oxidation causes the chemical reaction and formation of acidic products that leads to corrosion problems. The oxidation rate increases with temperature. Certain additives having greater affinity for oxygen are added so that they easily react with them than with oil.

5. Corrosion inhibitors: These additives form a thin film on the metal surface and shield it from coming in direct contact with the chemicals/acids in the fluid, thereby preventing corrosion problems.

6. Anti-wear additives: These are either long-chain polymer or extreme pressure (EP) additives. The long-chain polymers are adsorbed on the metal surfaces, causing a high local temperature and polish the surface. This helps in reducing the surface roughness, hence the wear problem.

7. Load-carrying capacity: The load-carrying capacity of a hydraulic fluid is a measure of the oil's capability to maintain a film of lubricant between two metal surfaces under extremes of load or pressure. All hydraulic oils have a natural load-carrying capacity that can be enhanced by special additives known as EP additives. These additives help reduce wear especially in hydraulic pumps and motors by providing lubrication when almost all the oil film has been squeezed out under heavy load conditions.

1.4 Types of Hydraulic Fluids

There are different types of hydraulic fluids that have the required properties. In general, while selecting a suitable oil, a few important factors are considered. First, its compatibility with seals, bearing and components is seen; second, its viscosity and other parameters such as fix resistance and environmental stability are also considered. There are five major types of hydraulic flow fluids which meet various needs of the system. These are briefly discussed as follows:

1. Petroleum-based fluids: Mineral oils are the petroleum-based oils that are the most commonly used hydraulic fluids. Basically, they possess most of the desirable characteristics: they are easily available and are economical. In addition, they offer the best lubrication

ability, least corrosion problems and are compatible with most seal materials. The only major disadvantage of these fluids is their flammability. They pose fire hazards, mainly from the leakages, in high-temperature environments such as steel industries, etc.
Mineral oils are good for operating temperatures below 50°C, At higher temperatures, these oils lose their chemical stability and form acids, varnishes, etc. All these lead to the loss of lubrication characteristics, increased wear and tear, corrosion and related problems. Fortunately, additives are available that improve chemical stability, reduce oxidation, foam formation and other problems.

A petroleum oil is still by far the most highly used base for hydraulic fluids. In general, petroleum oil has the following properties:

- Excellent lubricity.
- Higher demulsibility.
- More oxidation resistance.
- Higher viscosity index.
- Protection against rust.
- Good sealing characteristics.
- Easy dissipation of heat.
- Easy cleaning by filtration.
- Most of the desirable properties of the fluid, if not already present in the crude oil, can be incorporated through refining or adding additives.

A principal disadvantage of petroleum oil is that it burns easily. For applications where fire could be a hazard, such as heat treating, hydroelectric welding, die casting, forging and many others, there are several types of fire-resistant fluids available.

2. **Emulsions:** Emulsions are a mixture of two fluids that do not chemically react with others. Emulsions of petroleum-based oil and water are commonly used. An emulsifier is normally added to the emulsion, which keeps liquid as small droplets and remains suspended in the other liquid. Two types of emulsions are in use:

- **Oil-in-water emulsions:** This emulsion has water as the main phase, while small droplets of oil are dispersed in it. Generally, the oil dilution is limited, about 5%; hence, it exhibits the characteristics of water. Its limitations are poor viscosity, leading to leakage problems, loss in volumetric efficiency and poor lubrication properties. These problems can be overcome to a greater extent by using certain additives. Such emulsions are used in high-displacement, low-speed pumps (such as in mining applications).
- **Water-in-oil emulsions:** Water-in-oil emulsions, also called inverse emulsions, are basically oil based in which small droplets of water are dispersed throughout the oil phase. They are most popular fire-resistant hydraulic fluids. They exhibit more of an oil-like characteristic; hence, they have good viscosity and lubrication properties. The commonly used emulsion has a dilution of 60% oil and 40% water. These emulsions are good for operations at 25°C, as at a higher temperature, water evaporates and leads to the loss of fire-resistant properties.

3. **Water glycol:** Water glycol is another nonflammable fluid commonly used in aircraft hydraulic systems. It generally has a low lubrication ability as compared to mineral oils and is not suitable for high-temperature applications. It has water and glycol in the ratio of 1:1. Because of its aqueous nature and presence of air, it is prone to oxidation and related problems. It needs to be added with oxidation inhibitors. Enough care is essential in using this fluid as it is toxic and corrosive toward certain metals such as zinc, magnesium and

aluminum. Again, it is not suitable for high-temperature operations as the water may evaporate. However, it is very good for low-temperature applications as it possesses high antifreeze characteristics.

4. Synthetic fluids: Synthetic fluid, based on phosphate ester, is another popular fire-resistant fluid. It is suitable for high-temperature applications, since it exhibits good viscosity and lubrication characteristics. It is not suitable for low-temperature applications. It is not compatible with common sealing materials such as nitrile. Basically being expensive, it requires expensive sealing materials (viton). In addition, phosphate ester is not an environmental-friendly fluid. It also attacks aluminum and paints.

5. Vegetable oils: The increase in the global pollution has led to the use of more environmental-friendly fluids. Vegetable-based oils are biodegradable and are environmental safe. They have good lubrication properties, moderate viscosity and are less expensive. They can be formulated to have good fire resistance characteristics with certain additives. Vegetable oils have a tendency to easily oxidize and absorb moisture. The acidity, sludge formation and corrosion problems are more severe in vegetable oils than in mineral oils. Hence, vegetable oils need good inhibitors to minimize oxidation problems.

6. Biodegradable hydraulic fluids: As more and more organizations are understanding their social responsibility and are turning toward eco-friendly machinery and work regime, a biodegradable hydraulic fluid is too becoming a sought after product in the dawn of an environmentalist era. Biodegradable hydraulic fluids, alternatively known as bio-based hydraulic fluids, Bio-based hydraulic fluids use sunflower, rapeseed, soybean, etc., as the base oil and hence cause less pollution in the case of oil leaks or hydraulic hose failures. These fluids carry similar properties as that of a mineral oil–based anti-wear hydraulic fluid,

Hypothetically, if a company plans to introduce bio-based fluids into the hydraulic components of the machinery and the permissible operating pressure of hydraulic components is reduced to 80%, then it would inversely lead to a 20% reduction in breaking-out force owing to the 20% reduction in excavator's operating pressure. It is so because a reduction in the operating pressure of a system leads to a reduction in actuator force.

Besides, the transformation would not only include the cost of fluid and flushing of machinery to transcend from a mineral oil to vegetable oil repeatedly but also include the derating costs of machinery.

1.5 Factors Influencing the Selection of a Fluid

The selection of a hydraulic fluid for a given system is governed by the following factors:

1. Operating pressure of the system.
2. Operating temperature of the system and its variation.
3. Material of the system and its compatibility with oil used.
4. Speed of operation.
5. Availability of replacement fluid.
6. Cost of transmission lines.
7. Contamination possibilities.
8. Environmental condition (fire proneness, extreme atmosphere like in mining, etc.).
9. Lubricity.
10. Safety to operator.
11. Expected service life.

REQUIRED QUALITIES OF GOOD HYDRAULIC OIL:

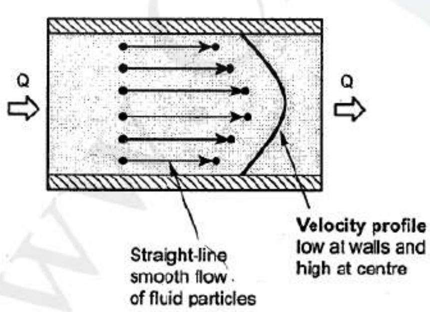
1. Stable viscosity characteristics
2. Good lubricity
3. Compatibility with system materials
4. Stable physical and chemical properties
5. Good heat dissipation capability
6. High bulk modulus and degree of incompressibility
7. Good flammability
8. Low volatility
9. Good demulsibility
10. Better fire resistance
11. Non toxicity and good oxidation stability
12. Better rust and corrosion prevent qualities
13. Ready availability and inexpensive

FLUID FLOW:

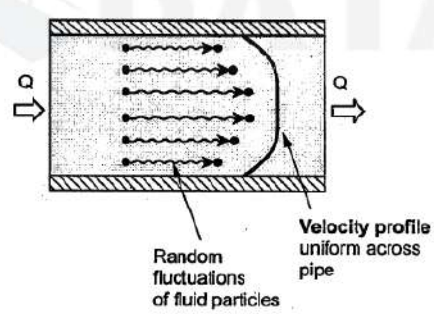
Laminar Flow: It is one in which paths taken by the individual partials do not cross one another and moves along well defined paths. The laminar flow is characterized by the fluid flowing in smooth layers of lamina. This type of flow is also known as streamline or viscous flow because the particles of fluid moving in an orderly manner and retaining the same relative positions in successive cross sections.

Examples:

1. Flow of oil in measuring instruments
2. Flow of blood in veins and arteries



Laminar flow



Turbulent flow

Turbulent Flow: It is that flow in which fluid particles move in a zigzag way. It is characterized by continues small fluctuations in the magnitude and direction of the velocity of the fluid particles. It causes more resistance to flow, Greater energy loss and increase fluid temperature due to greater energy loss.

Examples: High velocity flow in a pipe of large size

REYNOLDS NUMBER:

Osborne Reynolds in 1883 conducted experiments to ascertain the conditions under which a flow through pipe is laminar or turbulent. He applied the dimensional analysis on variables and introduced a dimensionless number called Reynolds number Re. It is given by the following equation to determine whether the flow is laminar or turbulent.

$$\mathbf{Re} = \frac{\rho VD}{\mu} = \frac{VD}{\nu}$$

ρ = Density of fluid (kg/m^3)

V = Velocity of Flow (m/sec)

D = Inside diameter of pipe (m)

υ = Kinematic viscosity of fluid (m^2/sec)

μ = absolute viscosity of fluid (Ns/m^2)

Experiments showed that the flow is laminar when Reynolds number (Re) is less than 2000 and turbulent for Re greater than 4000. And for 4000 < Re < 2000 then the flow is in transition from laminar to turbulent. It is always desirable to maintain laminar flow in hydraulic system because the chaotic turbulent flow causes more energy loss.

DARCY – WEISBACH EQUATION:

The energy loss due to friction in a hydraulic system results in a loss of potential energy. This potential energy loss leads to a pressure drop or head loss in the system. Pressure or head loss due to friction in pipes carrying fluids are derived using the Darcy-Weisbach Equation.

$$\mathbf{H_L} = f \left(\frac{L}{D}\right)\left(\frac{V^2}{g}\right)$$

H_L – Head Loss

f - Friction Factor

L - Length of pipe

D – Inner Diameter

V – Velocity of Flow

g – Acceleration due to gravity

During laminar flow the friction is relatively independent of the surface conditions of the inside diameter of the pipe.

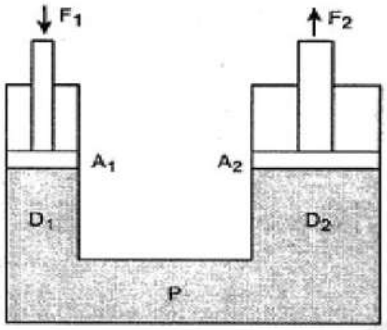
The friction factor 'f' for laminar flow can be found by the equation

$$\mathbf{f} = \frac{64}{\mathrm{Re}} \textbf{ when Re < 2000}$$

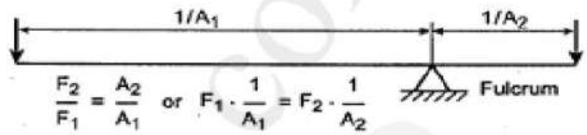
PASCAL'S LAW :

This law states that the pressure generated at any point in a confined fluid acts equally in all directions.

Consider two oil containers both in cylindrical form and connected together contain some oil, as shown Both the cylinders have a piston having different diameters says D_1 and D_2 respectively, where D_1 is smaller than D_2.



Principle of Bramah's press



A hydraulic lever

If a force F_1 is applied to the small-diameter piston, then this will produce an oil pressure P_1 at the bottom of the piston 1. Now this pressure is transmitted through the oil to the large-diameter piston 2. Because the piston 2 has a larger area (A_2), the pressure at the bottom of the piston 2 will be P_2. Now this pressure P_2 will push up the piston 2 to create an output force F_2.

We know that according to Pascal's law, $P_1 = P_2$

or $$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

or $$\boxed{\frac{F_2}{F_1} = \frac{A_2}{A_1}}$$

where A_1 = Area of the smaller piston $= \frac{\pi}{4} D_1^2$, and

A_2 = Area of the larger piston $= \frac{\pi}{4} D_2^2$.

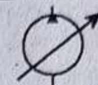
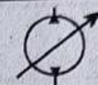
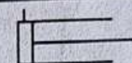
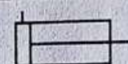
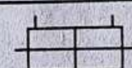
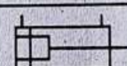
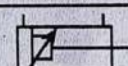
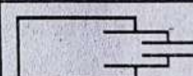
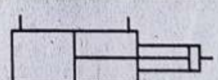
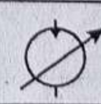
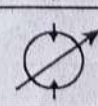
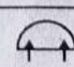
CONTINUITY EQUATION: It states that if no fluid is added or removed from the pipe in any length then the mass passing across different sections shall be same.

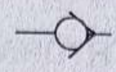
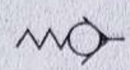
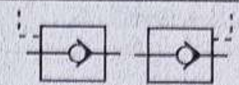
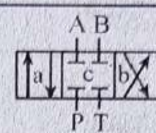
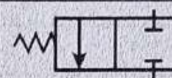
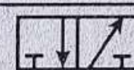
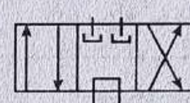
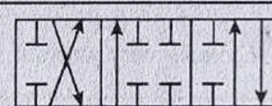
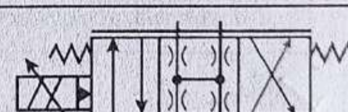
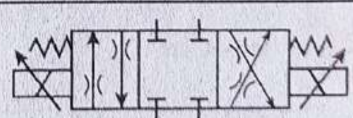
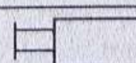
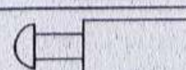
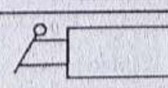
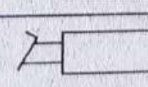
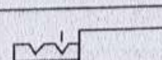
$$A_1 V_1 = A_2 V_2$$

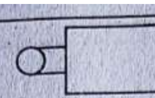
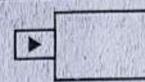
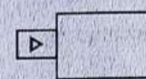
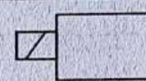
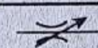
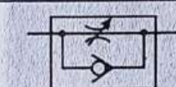
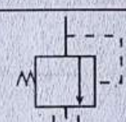
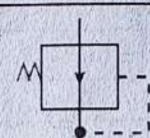
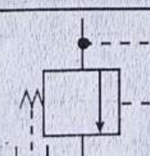
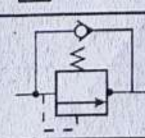
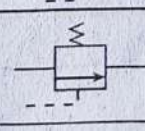
BERNOULLI'S EQUATION: It states that in a ideal incompressible fluid when the flow is steady and continuous the sum of potential energy, kinetic energy and pressure energy is constant across all cross sections of the pipe.

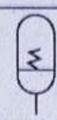
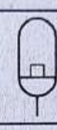
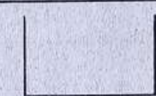
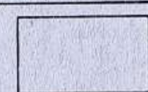
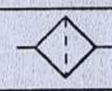
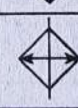
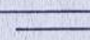
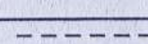
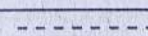
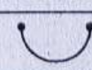
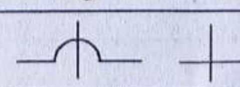
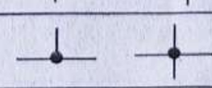
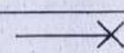
$$Z_1 + \frac{V_1^2}{2g} + \frac{P_1}{w} = Z_2 + \frac{V_2^2}{2g} + \frac{P_2}{w}$$

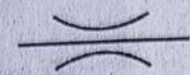
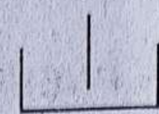
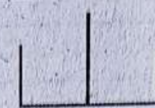
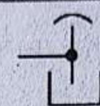
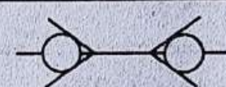
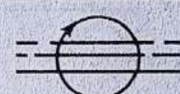
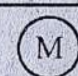
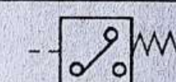
HYDRAULIC SYMBOLS

PUMPS	
Fixed displacement Unidirectional	
Fixed displacement Bidirectional	
Variable displacement Unidirectional	
Variable displacement Bidirectional	
CYLINDERS	
Single acting	
Double acting	
Double rod end	
Cylinder with cushion	
Cylinder with adjustable cushion	
Telescopic	
Intensifier	
FLUID MOTORS	
Fixed displacement Unidirectional	
Fixed displacement Bidirectional	
Variable displacement Unidirectional	
Variable displacement Bidirectional	
Hydraulic Oscillator	

DIRECTIONAL VALVES	
Check valve without spring	
Check valve with spring	
Pilot operated check valve	
Complete valve symbol a. initiating action b. return action c. spring centre condition	 P-Pump port T-Tank port A, B - Service ports
2/2 directional valve	
3/2 directional valve	
4/3 directional valve	
6/3 directional valve	
Electro-hydraulic servo valve	
Proportional directional valve	
OPERATING ACTUATORS	
Manual	
Push button	
Lever	
Pedal	
Detent	

Cam follower	
Roller operated	
Hydraulic pilot	
Pneumatic pilot	
Solenoid	
FLOW CONTROL VALVES	
Adjustable, non-compensated	
Adjustable with bypass	
Adjustable and pressure compensated with by pass	
Adjustable temperature and pressure compensated	
PRESSURE VALVES	
Pressure relief valve	
Pressure reducing valve	
Sequencing valve	
Counterbalance valve	
Unloading valve	

ACCUMULATOR	
Accumulator	
Spring loaded accumulator	
Gas charged accumulator	
Weighted accumulator	
RESERVOIR	
Vented	
Pressurised	
FLUID CONDITIONERS	
Filter–Strainer	
Heater	
Cooler	
CONDUCTORS	
Power line	
Pilot line	
Drain line	
Flexible line	
Connector	
Line crossing	
Line joining	
Plugged port	

Restriction, fixed	
Line to reservoir above fluid	
Line to reservoir below fluid	
Vented Manifold	
Quick disconnect coupling, without check	
Quick disconnect coupling, with two checks	
Rotating coupling	
Electric motor	
Pressure gauge	
Pressure switch	
Flow meter	
Temperature gauge	
Float Switch