MODULE 1: INTRODUCTION TO FLUID POWER SYSTEMS

Fluid power system: components, advantages and applications. Transmission of power at static and dynamic states. Pascal's law and its applications.

Fluids for hydraulic system: types, properties, and selection. Additives, effect of temperature and pressure on hydraulic fluid. Seals, sealing materials, compatibility of seal with fluids. Types of pipes, hoses, and quick acting couplings. Pressure drop in hoses/pipes. Fluid conditioning through filters, strainers, sources of contamination and contamination control, heat exchangers.

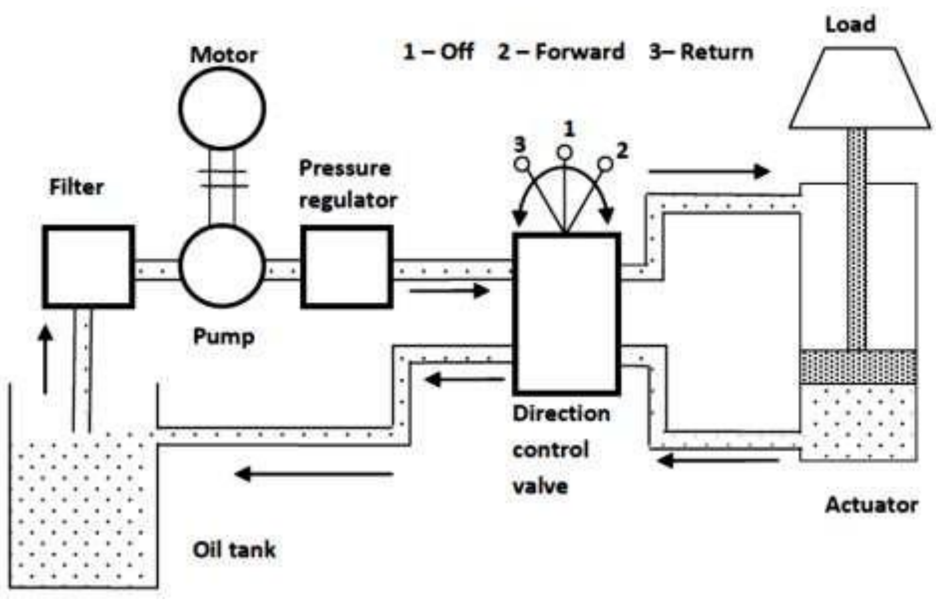
FLUID POWER SYSTEM

Fluid Power is the technology that deals with the generation, control, and transmission of power, using pressurized fluids. Fluid power is called ***hydraulics*** when the fluid is a liquid and is called ***pneumatics*** when the fluid is a gas.

Hydraulic systems use liquids such as petroleum oils, synthetic oils, and water. Pneumatic systems use air as the gas medium because air is very abundant and can be readily exhausted into the atmosphere after completing its assigned task.

COMPONENTS OF A FLUID POWER SYSTEM:

Hydraulic System:



There are six basic components required in a hydraulic system:

1) A tank (reservoir) to hold the hydraulic oil.

2) A pump to force the oil through the system.

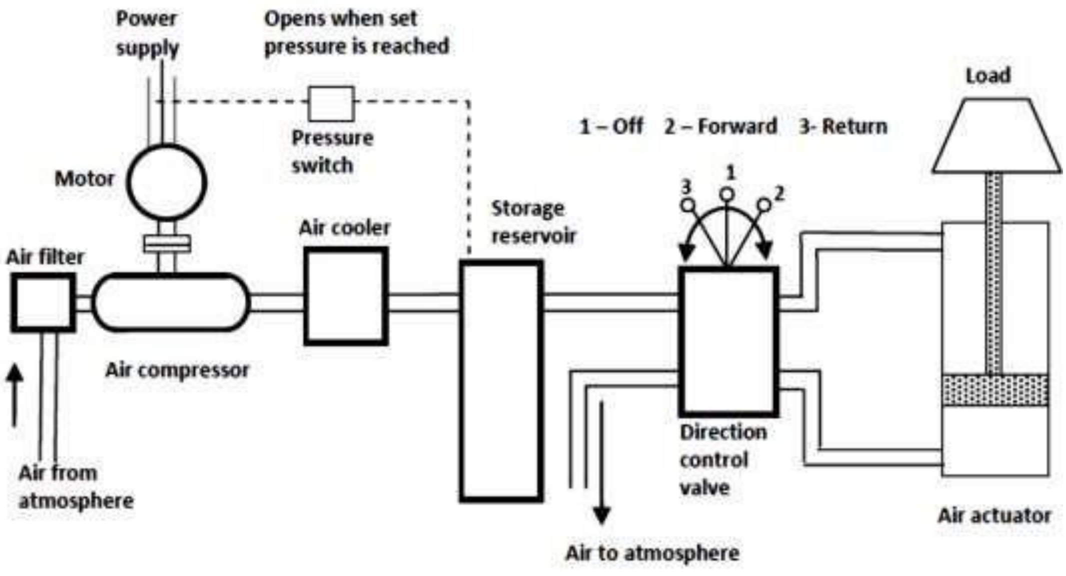
3) An electric motor or other power source to drive the pump.

4) Valves to control oil direction, pressure, and flowrate.

5) An actuator to convert the pressure of the oil into mechanical force to do the useful work.

6) Piping to carry the oil from one location to the other.

Pneumatic System:



Pneumatic systems have components that are similar to those used in hydraulic systems.

1) An air tank to store a given volume of compressed air.

2) A compressor to compress the air that comes directly from the atmosphere.

3) An electric motor or other prime mover to drive the compressor.

4) Valves to control air direction, pressure and flowrate.

5) Actuators, which are similar in operation to hydraulic actuators.

6) Piping to carry the pressurized air from one location to another.

ADVANTAGES OF FLUID POWER SYSTEM:

The advantages of a fluid power system are as follows:

1) Fluid power systems are simple, easy to operate and can be controlled accurately: Fluid power gives flexibility to equipment without requiring a complex mechanism. Using fluid power, we can start, stop, accelerate, decelerate, reverse or position large forces/components with great accuracy using simple levers and push buttons.

2) Multiplication and variation of forces: Linear or rotary force can be multiplied by a fraction of a kilogram to several hundreds of tons.

3) Multifunction control: A single hydraulic pump or air compressor can provide power and control for numerous machines using valve manifolds and distribution systems.

4) Low-speed torque: Unlike electric motors, air or hydraulic motors can produce a large amount of torque while operating at low speeds.

5) Constant force or torque: Fluid power systems can deliver constant torque or force regardless of speed changes.

6) Economical: Not only reduction in required manpower but also the production or elimination of operator fatigue, as a production factor, is an important element in the use of fluid power.

7) Low weight to power ratio: The hydraulic system has a low weight to power ratio compared to electromechanical systems. Fluid power systems are compact.

8) Fluid power systems can be used where safety is of vital importance: Safety is of vital importance in air and space travel, in the production and operation of motor vehicles, in mining and manufacture of delicate products.

APPLICATIONS OF FLUID POWER:

1) Agriculture: Tractors and farm equipments like ploughs, movers, chemical sprayers, fertilizer spreaders.

2) Aviation: Fluid power equipments like landing wheels on aeroplane and helicopter, aircraft trolleys, aircraft engine test beds.

3) Building Industry: For metering and mixing of concrete ingredients from hopper.

4) Construction Equipment: Earthmoving equipments like excavators, bucket loaders, dozers, crawlers, and road graders.

5) Defence: Missile-launch systems and Navigation controls

6) Entertainment: Amusement park entertainment rides like roller coasters

7) Fabrication Industry: Hand tools like pneumatic drills, grinders, bores, riveting machines, nut runners

8) Food and Beverage: All types of food processing equipment, wrapping, bottling

9) Foundry: Full and semi-automatic moulding machines, tilting of furnaces, die casting machines

10) Material Handling: Jacks, Hosts, Cranes, Forklift, Conveyor system

TRANSMISSION OF POWER AT STATIC AND DYNAMIC STATES:

A hydrostatic system uses fluid pressure to transmit power. Hydrostatics deals with the mechanics of still fluids and uses the theory of equilibrium conditions in fluid. The system creates high pressure, and through a transmission line and a control element, this pressure drives an actuator (linear or rotational). The pump used in hydrostatic systems is a positive displacement pump. An example of pure hydrostatics is the transfer of force in hydraulics.

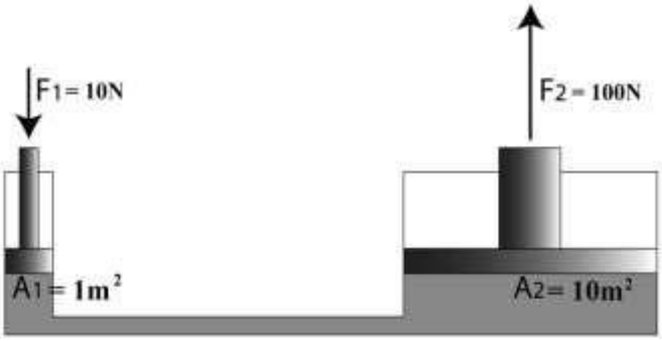
Hydrodynamic systems use fluid motion to transmit power. Power is transmitted by the kinetic energy of the fluid. Hydrodynamics deals with the mechanics of moving fluid and uses flow theory. The pump used in hydrodynamic systems is a non-positive displacement pump. An example of pure hydrodynamics is the conversion of flow energy in turbines in hydroelectric power plants.

In oil hydraulics, we deal mostly with the fluid working in a confined system, that is, a hydrostatic system.

PASCAL’S LAW (MULTIPLICATION OF FORCE):

Pascal’s law reveals the basic principle of how fluid power systems perform useful work. This law can be stated as follows:

Pressure applied to a confined fluid is transmitted undiminished in all directions throughout the fluid and acts perpendicular to the surface in contact with the fluid.



The above figure shows how Pascal's law can be applied to produce a useful amplified output force. Consider an input force of 10N is applied to a 1-m^2 area piston. This develops a 10N/m^2 pressure throughout the oil within the housing. This 10N/m^2 pressure acts on a 10-m^2 area piston producing a 100N output force. This output force performs useful work as it lifts the 100N weight.

From Pascal's law we know that, $P_1 = P_2$ i.e., $\frac{F_1}{A_1} = \frac{F_2}{A_2}$

$$\frac{10}{1} = \frac{F_2}{10} \qquad \therefore F_2 = 100\text{N}$$

FLUIDS FOR HYDRAULIC SYSTEM:

The most important material in a hydraulic system is the working fluid itself. Hydraulic fluid characteristics have a crucial effect on equipment performance and life. It is important to use a clean, high-quality fluid in order to achieve efficient hydraulic system operation.

DIFFERENT TYPES OF HYDRAULIC FLUIDS:

1) 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.

2) 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.

3) 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.

4) 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.

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

PROPERTIES OF HYDRAULIC FLUIDS:

1) Viscosity: It is a measure of the fluid's internal resistance offered to flow.

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.

3) Oxidation Stability: The most important property of 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.

5) Lubricity: The ability of the hydraulic fluid to lubricate the moving parts efficiently is called Lubricity.

6) Rust Prevention: The moisture entering into the hydraulic system with air causes the parts made of ferrous materials to rust. This rust if passed through the precision made pumps and valves may scratch the nicely polished surfaces. So 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.

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 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.

SELECTION OF HYDRAULIC FLUIDS:

A hydraulic fluid has the following four primary functions:

1) Transmit Power

2) Lubricate moving parts

3) Seal clearances between mating parts

4) Dissipate heat

In addition a hydraulic fluid must be inexpensive and readily available. From the selection point of view, a hydraulic fluid should have the following properties:

1) Good lubricity

2) Ideal viscosity

3) Chemical stability

4) Compatibility with system materials

5) High degree of incompressibility

6) Fire resistance

7) Good heat-transfer capability

8) Low density

9) Foam resistance

10) Non-toxicity

11) Low volatility

This is a challenging list, and no single hydraulic fluid possesses all of these desirable characteristics. The fluid power designer must select the fluid that is the closest to being ideal overall for a particular application.

ADDITIVES:

Various additives are added to the fluid to sustain the important characteristics. Few such additives are:

1) Anti-foaming: They are added to reduce foaming of fluid.

2) Anti-wear: Wear resistant chemicals are added to the fluid to protect critical hydraulic components from wear.

3) Corrosion inhibitor: Chemicals are added to protect surfaces from chemical attack by water.

4) Biocide: Emulsifying chemicals are added to the fluid to inhibit growth of water-borne bacteria.

5) Emulsifier: These are added to facilitate formation and stabilisation of an emulsion.

6) Lubrication Oiliness agents: Extreme Pressure (EP) agents are added to the fluid to enhance lubrication characteristics for effective full film boundary lubrication between the mating parts.

7) Flocculants: Chemicals added to dispersion of solids in a liquid to combine fine particles to form floe or small solid masses in the fluid.

8) Deionisation: Elements which provide hardness like calcium, manganese, iron, and aluminium salts are removed through deionisation of the water.

9) Oxidation inhibitor: Anti-oxidation additives are added to provide anti-oxidation characteristics. Oxidation changes the chemical characteristics of the fluid.

10) Vapour phase inhibitor: Prevention of oxidation or corrosion of metals in contact with the vapour phase of the fluid is ensured by addition of appropriate chemicals.

EFFECT OF TEMPERATURE AND PRESSURE ON HYDRAULIC FLUID:

Viscosity is the most important property of a hydraulic fluid. Temperature has an adverse effect on the viscosity of hydraulic oil. Hence it has to be seen that the operating temperature of a hydraulic system is kept at a reasonably constant level. Otherwise there will be tremendous losses in the system which will reduce the overall efficiency.

A hydraulic fluid that is too viscous generates more friction and heat and usually causes high-pressure drop, sluggish operation, low-mechanical efficiency, and high-power consumption. On the other hand low-viscosity fluids permit efficient low-drag operation, but tend to increase wear, reduce volumetric efficiency, and promote leakage.

SEAL:

The seal is an agent which prevents leakage of oil from the hydraulic elements and protects the system from dust/dirt. The major function of the seal is to maintain pressure, prevent loss of fluid from the system and to keep out contamination in the system to enhance its working life and functional reliability over a longer period.

CLASSIFICATION OF SEALS:

According to the method of sealing:

1. Positive sealing: A positive seal prevents even a minute amount of oil from getting past.
A positive seal does not allow any leakage whatsoever (external or internal).

2. Non-positive sealing: A non-positive seal allows a small amount of internal leakage, such as the clearance of the piston to provide a lubrication film.

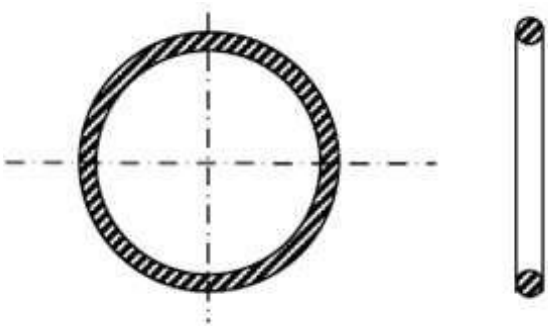
According to the relative motion existing between the seals and other parts:

1. Static seals: These are used between mating parts that do not move relative to one another. These are relatively simple. They are essentially non-wearing and usually trouble-free if assembled properly.

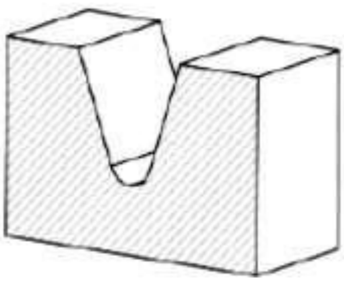
2. Dynamic seals: These are assembled between mating parts that move relative to each other. Hence, dynamic seals are subject to wear because one of the mating parts rubs against the seal.

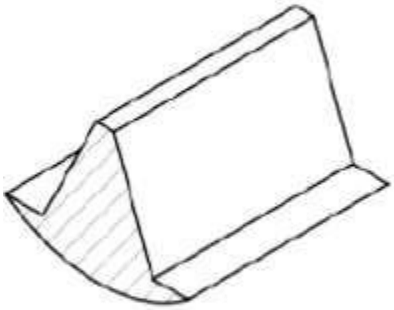
According to geometrical cross-section:

1. O-rings: O-ring is the most widely used seal for hydraulic systems. It is a moulded synthetic rubber seal that has a round cross-section in its free state. O-ring can be used for the most static and dynamic conditions. It gives effective sealing through a wide range of pressures, temperatures and movements.

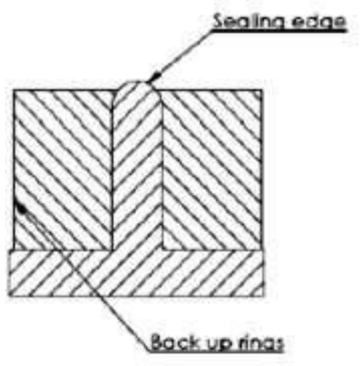


2. V-ring seal and U-ring seal: V- and U-ring seals are compression-type seals used in virtually all types of reciprocating motion applications. These include piston rods and piston seals in pneumatic and hydraulic cylinder, press rank, jacks and seals on plungers and piston in reciprocating pumps.





3. T-ring seal: T-ring seal is a dynamic seal that is extensively used to seal cylinder-pistons, piston rods and other reciprocating parts. It is made of synthetic rubber moulded in the shape of the cross-section T and reinforced by backup rings on either side. The sealing edge is rounded and seals very much like an O-ring.



4. Piston cup packings: Piston cup packings are designed specifically for pistons in reciprocating pumps and pneumatic and hydraulic cylinders. They offer the best service life for this type of application, require a minimum recess space and minimum recess machining, and can be installed easily and quickly.

5. Piston rings: Piston rings are seals that are universally used for cylinder pistons. Piston rings offer substantially less opposition to motion than synthetic rubber (elastomer) seals.

SEALING MATERIALS:

Various metallic and non-metallic materials are used for fabrication of seals that are used in hydraulic systems. Leather, metals and elastomers are very common seal materials.

1) Leather: This material is rugged and inexpensive. However, it tends to squeal (scream/screech) when dry and cannot operate above 90°C, which is inadequate for many hydraulic systems. Leather does operate well at cold temperatures to about -50°C.

2) Buna-N: This material is rugged and inexpensive and wears wells. It has a rather wide operating temperature range (-45°C to 110°C) during which it maintains its good sealing characteristics.

3) Silicone: This elastomer has an extremely wide operating temperature range (-65°C to 232°C). Hence it is widely used for rotating shaft seals and static seals. Silicone has low tear resistance and hence not used for reciprocating seal applications.

4) Neoprene**:** This material has a temperature range of 50°C to 120°C. it is unsuitable above 120°C because of its tendency to vulcanize.

5) Viton: This material contains 65% fluorine. It has become almost a standard material for elastomer-type seals for use at elevated temperatures up to 240°C. Its minimum operating temperature is 28°C.

6) Tetrafluoroethylene: This material is the most widely used plastic for seals of hydraulic systems. It is a tough, chemically inert, waxy solid, which can be processed only by compacting and sintering. It has excellent resistance to chemical breakdown up to temperatures of 370°C.

PIPES AND HOSES:

In a hydraulic system, the fluid flows through a distribution system consisting of pipes (conductors) and fittings, which carry the fluid from the reservoir through operating components and back to the reservoir.

Hydraulic systems use primarily four types of conductors:

1. Steel pipes

2. Steel tubing

3. Plastic tubing

4. Flexible Hoses

The choice of which type of conductor to use depends primarily on the system’s operating pressures and flow-rates.

QUICK ACTING COUPLINGS:

Couplings are precision components, engineered for specific uses with exact dimensions and close tolerances. There are a variety of applications in modern industrial plants for quick connect (QC) couplings both for pneumatically operated tools as well as other fluid power equipments which can be connected rapidly to their power source to permit wide versatility for production needs. For instance, in connecting or disconnecting a tractor and its hydraulically actuated agricultural component.

QCs make changes simple, do not require additional hand tools, take little time and do not require the help of additional trade or skill. They are devices which permit the rapid connection or disconnection of fluid conductors.

FLUID CONDITIONING THROUGH FILTERS AND STRAINERS:

Hydraulic components are very sensitive to contamination. The cause of majority of hydraulic system failures can be traced back to contamination. Hence for proper operation and long service life of a hydraulic system, oil cleanliness is of prime importance. Strainers and filters are designed to remove foreign particles from the hydraulic fluid.

Filters are devices whose primary function is the retention of insoluble contaminants from fluid, by some fine porous medium. Filters are used to pick up smaller contaminant particles because they are able to accumulate them better than a strainer. Particle sizes removed by filters are measured in microns. The smallest sized particle that can be removed is as small as 1 μm.

A strainer is a coarse filter, whose function is to remove large particles from a fluid using a wire screen. Fluid flows more or less straight through it. It does not provide as fine a screening action as filters do, but offers less resistance to flow. The smallest sized particle that can be removed by a strainer is as small as 0.15 mm or 150 μm.

CLASSIFICATION OF FILTERS:

Based on filtering methods:

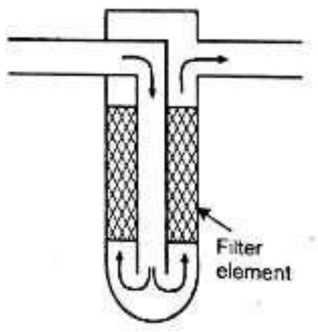
1. Mechanical: This type normally contains a metal or cloth screen or a series of metal disks separated by thin spacers. Mechanical filters are capable of removing only relatively coarse particles from the fluid.

2. Absorbent: These filters are porous and permeable materials such as paper, wood pulp, cloth, cellulose and asbestos. Paper filters are impregnated with a resin to provide added strength. In this type of filters, the particles are actually absorbed as the fluid infiltrates the material. Hence, these filters are used for extremely small particle filtration.

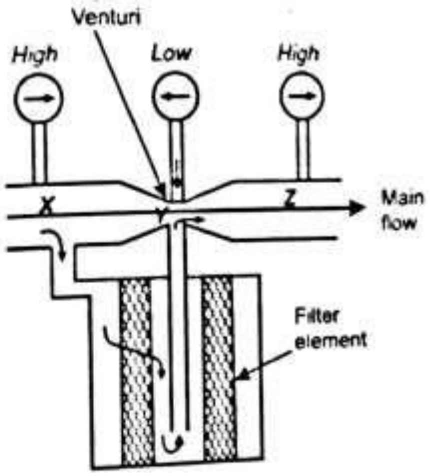
3. Adsorbent: Adsorption is a surface phenomenon and refers to the tendency of particles to cling to the surface of the filters. Thus, the capacity of such a filter depends on the amount of surface area available. Adsorbent materials used include activated clay and chemically treated paper.

Depending on the amount of oil filtered by a filter:

1. Full flow filters: In this type, complete oil is filtered. Full flow of oil must enter the filter element at its inlet and must be expelled through the outlet after crossing the filter element fully. This is an efficient filter. However, it incurs large pressure drops. This pressure drop increases as the filter gets blocked by contamination.



2. Proportional filters (bypass filters): In some hydraulic system applications, only a portion of oil is passed through the filter instead of entire volume and the main flow is directly passed without filtration through a restricted passage.



BETA RATIO OF FILTERS

Filters are rated according to the smallest size of particles they can trap. By mathematical definition, the beta ratio equals the number of upstream (before the filter) particles of size greater than Nμm divided by the number of downstream (after the filter) particles having size greater than Nμm. Where, N is the selected particle size for the given filter.

$$\text{Beta Ratio} = \frac{\text{No. of upstream particles of size} > N\mu m}{\text{No. of downstream particles of size} > N\mu m}$$

A beta ratio of 1 would mean that no particles above specified N are trapped by the filter. A beta ratio of 50 means that 50 particles are trapped for every one that gets through. Most filters have a beta ratio greater than 75.

$$\text{Beta Efficiency} = \frac{\text{No. of upstream particles - No. of downstream particles}}{\text{No. of upstream particles}}$$

$$\text{Beta Efficiency} = 1 - \frac{1}{\text{Beta Ratio}}$$

CAUSES OF CONTAMINATION:

1. Contaminants left in the system during assembly or subsequent maintenance work.

2. Contaminants generated when running the system such as wear particles, sludge and varnish due to fluid oxidation and rust and water due to condensation.

3. Contaminants introduced into the system from outside. These include using the wrong fluid when topping up and dirt particles introduced by contaminated tools or repaired components.

PROBLEMS CAUSED BY CONTAMINATION:

1. Accelerate component wear, decreasing system performance and service life.

2. Result in sluggish operation and cause moving parts to seize.

3. Damages seals resulting in leakage.

4. Act as a catalyst to accelerate hydraulic fluid oxidation and breakdown thereby shortening fluid life and reducing the useful operating temperature range of the fluid.

CONTAMINATION CONTROL:

There are many ways to reduce the effects of contaminants in a system.

1. Plumb the system with pipes, tubing and fittings that are reasonably free from rust, scale, dirt and other foreign matter.

2. Flush the entire hydraulic system, preferably with the same type of fluid to be used, before normal system operation is begun.

3. Filter the hydraulic oil before using, to minimise introducing contaminants into the system.

4. Provide continuous protection from airborne contamination by sealing the hydraulic system, or installing air filter/breather.

5. Clean or replace filter elements on a routine basis.

6. Maintain fluid viscosity and pH level within fluid suppliers' recommendations.

7. Minimise sources of water entry into the hydraulic system.

8. Avoid introducing thread sealants into the fluid stream.

HEAT EXCHANGERS:

The steady-state temperature of fluid of a hydraulic system depends on the heat-generation rate and the heat-dissipation rate of the system. If the fluid operating temperature in a hydraulic system becomes excessive, it means that the heat-generation rate is too large relative to the heat-dissipation rate. Assuming that the system is reasonably efficient, the solution is to increase the heat-dissipation rate. This is accomplished by the use of coolers, which are commonly called "heat exchangers."

In some applications, the fluid must be heated to produce a satisfactory value of viscosity. This is typical when, for example, mobile hydraulic equipment is to operate below 0°C. In these cases, the heat exchangers are called "heaters." However, for most hydraulic systems, the natural heat-generation rate is sufficient to produce high enough temperatures after an initial warm-up period.

Basically, there are two types of heat exchangers: Air cooled heat exchangers and Water cooled heat exchangers. Air coolers are used where water is not readily available and the air is at least 3° to 5°C cooler than the oil. But water coolers are more compact, reliable, and efficient and use simple temperature controls.

QUESTIONS FROM PREVIOUS YEAR QUESTION PAPERS:

DEC 2015/JAN 2016

1) With a neat sketch, explain the hydraulic circuit and laws plugged to develop the circuit.
2) What are the various functions performed by the hydraulic fluid and list its desirable properties and types of hydraulic fluid.
3) Explain Beta ratio and Beta efficiency.
4) Explain the common location of mounting filters in the hydraulic system.

JUNE/JULY 2016

1) Sketch and explain structure of a hydraulic control system.
2) What are the desirable properties of hydraulic oil? Explain them.
3) Sketch and explain full flow filter.

DEC 2016/JAN 2017

1) State Pascal's law. Explain its applications, with a neat sketch.
2) How are hydraulic seals classified? Explain positive and non-positive seals.
3) With the aid of sketches, explain the following: i) Return line filtering ii) Suction line filtering iii) Pressure line filtering

JUNE/JULY 2017

1) State Pascal's law. With a neat sketch explain basic hydraulic power system.
2) What are the desirable properties of hydraulic fluids? Explain briefly.
3) How hydraulic seals are classified? Explain any one method.
4) What is a filter? What are the methods of filtering? Explain briefly.

DEC 2017/JAN 2018

1) With a neat block diagram, explain the structure of hydraulic power system.
2) What are the advantages of hydraulic system?
3) Write any five desirable properties of a hydraulic fluid.
4) Explain three basic types of filtering methods used in hydraulic system.
5) Explain static seals and dynamic seals with examples.

JUNE/JULY 2018

1) State Pascal’s law.

2) What is seal and what are its functions? Explain sealing devices used in hydraulic systems.

3) What is a filter and how they are classified?

ONE TIME EXIT SCHEME – APRIL 2018

1) Define hydraulic system. What are its advantages and disadvantages?

2) Draw a structure of hydraulic system and explain the parts.

3) For a simple hydraulic jack the following data is given. F_1 = 100N, A_1 = 50cm^2, S_1 = 10cm Find load F_2 and displacement S_2 if area of piston that to be lifted is 500cm^2. Also find energy input and energy output.

4) What are the desirable properties of hydraulic oils?

5) Sketch and explain different filtering systems in a circuit.