2

HYDRAULIC OILS, FLUID PROPERTIES, AND FILTER

Contents

2.1 Hydraulic Oils and Fluid Properties

- A hydraulic fluid power system may be defined as a means of power transmission in which a relatively incompressible fluid is used as the power transmitting media. The primary purpose of a hydraulic system is the transfer of energy from one location to another and the conversion of this energy to useful work. Hydraulic power is usually generated by pumps and the energy generated is converted to useful work by hydraulic cylinders or other actuators (linear or rotary). The transmission of this energy is accomplished by movement of the hydraulic fluid through metal tubes or elastomeric hoses, while the control of the power is achieved through values. As no hydraulic system can perform the assigned task without the hydraulic fluid, this fluid is of utmost importance in a hydraulic system.
- The broad tasks of hydraulic oil can be classified broadly as follows:
    - To transfer hydraulic energy
    - To lubricate all parts
    - To avoid corrosion
    - To remove impurities and abrasion
    - To dissipate heat

2.2 Types of Hydraulic Fluids

- Different types of hydraulic fluids have the required properties. In general, while selecting a suitable fluid, a few important factors are to be considered.
    - Its compatibility with seals, bearing, and other components.
    - Its viscosity and environmental stability are also considered.

2.2.1 Petroleum-based fluids:

- Mineral oils are the petroleum-based oils that are the most commonly used hydraulic fluids. They possess most of the desirable characteristics: they are easily available and are economical.
- Also, 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.
- 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 the 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.

2.2.2 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 oil-based in which small droplets of water are dispersed throughout the oil phase.

    They are the 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.

2.2.3 Water glycol:

- Water glycol is another non-flammable 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 a 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.

2.2.4 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. Being expensive, it requires expensive sealing materials (Viton).
- Also, phosphate ester is not an environmental-friendly fluid. It also attacks aluminum and paints.

2.2.5 Vegetable oils:

- The increase in global pollution has led to the use of more environmental-friendly fluids.
- Vegetable-based oils are biodegradable and are environmentally 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 tend 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.

2.2.6 Biodegradable:

- 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 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 mineral oil to vegetable oil repeatedly but also include the derating costs of machinery.

2.2.7 Fire Resistance:

- There are many hazardous applications where human safety requires the use of a fire-resistant fluid. Examples include coal mines, hot metal processing equipment, aircraft, and marine fluid power systems.
- A fire-resisting fluid is one that can be ignited but does not support combustion when the ignition source is removed.
- Flammability is defined as the ease of ignition and the ability to propagate the flame.

- The following are the usual characteristics tested to determine the flammability of hydraulic fluids:
  - **Flashpoint:** The temperature at which an oil surface gives off sufficient vapors to ignite when a flame is passed over the surface.
  - **Fire point**: The temperature at which an oil releases sufficient vapors to support combustion continuously for 5 s when a flame is passed over the surface.
  - **Autogenously ignition temperature:** The temperature at which ignition occurs spontaneously.
- The fire-resistant fluids are designated as follows:
  - **HFA:** A high-water-content fluid or HWCF (80% or more), for example, water-oil emulsions.
  - **HFB:** This is a water-oil emulsion containing petroleum oil and water.
  - **HFC:** This is a solution of water and glycol.
  - **HFD:** This is a synthetic fluid, for example, phosphates or phosphate–petroleum blends.
- The commonly used hydraulic liquids are petroleum derivatives; consequently, they burn vigorously once they reach a fire point. For critical applications, artificial or synthetic hydraulic fluids are used that have fire resistance.
- Fire-resistant fluids have been developed to reduce fire hazards. There are four different types of fire-resistant hydraulic fluids in common use:
  - **Water–glycol solution:** This type consists of an actual solution of 40% water and 60% glycol. These solutions have high-viscosity-index values, but as the viscosity rises, the water evaporates. The operating temperature ranges run from −20°C to about 85°C.
  - **Water-in-oil emulsions:** This type consists of about 40% water completely dispersed in a special oil base. It is characterized by small droplets of water surrounded by oil. The operating temperature range runs from −30°C to about 80°C. As is the case with water-glycol solutions, it is necessary to replenish evaporated water to maintain proper viscosity.
  - **Straight synthetics:** This type is chemically formulated to inhibit combustion and in general has the highest fire-resistant temperature. The disadvantages of straight synthetics include low viscosity index, incompatibility with most natural or synthetic rubber seals, and high cost.
  - **High-water-content fluids (HWCFs):** This type consists of about 90% water and 10% concentrate (designated as 90/10). The concentrate consists of fluid additives that improve viscosity, lubrication, rust protection, and protection against bacteria growth. The maximum operating temperature should be held to 50°C to minimize evaporation.
- The advantages of HWCF are as follows:
  - Fire resistance due to a high flash point of about 150°C.
  - Lower system operating temperature due to good heat dissipation.
  - Biodegradable and environmental-friendly additives.
  - High viscosity index.
  - Cleaner operation of the system.
  - Low cost of concentrate and storage.

- The disadvantages of HWCF are as follows:
    - Greater contamination due to higher densities of fluids.
    - High evaporation loss.
    - Faster corrosion due to oxidation.
    - pH value to be maintained between 7.5 and 9.0.
    - Promotion of bacterial growth and filtration difficulties due to the acidic nature of fluids.
- Performance of HWCFs can be improved using additives such as
    - Anti-wear additives.
    - Corrosion inhibitors.
    - Emulsifying agents.
    - Deionization agents.
    - Anti-vaporizing agents.
    - Anti-foaming additives.
    - Biocides to kill water-borne bacteria.
    - Flocculation promoters.
    - Oxidation inhibitors.

2.3 Properties of Fluids

- For a fluid to perform efficiently, it must possess certain properties. The various properties required for an ideal hydraulic fluid are as follows:
    - Ideal viscosity
    - Good lubrication capability
    - Demulsibility
    - Good chemical and environmental stability
    - Incompressibility
    - Fire resistance
    - Low flammability
    - Low volatility
    - Good heat dissipation
    - Low density
    - System compatibility
    - Foam resistance
- It is almost impossible to achieve all these properties in hydraulic fluid. Although we can select a good fluid with desirable properties, some of the characteristics of a fluid change with usage.
- For example, it is common for the temperature of a fluid to rise due to friction in the system, which reduces the viscosity of the fluid, which in turn increases leakage and reduces lubrication ability.
- A fluid gets oxidized and becomes acidic with usage. Certain additives are added to preserve the desirable properties and to make the fluid more stable.
- Some of the desirable properties and their influence on the hydraulic fluid are discussed briefly in the following sub-sections.

2.3.1 Ideal Viscosity

- The most basic desirable property of the hydraulic fluid is optimum viscosity. It is a measure of a fluid's resistance to flow.
- When the viscosity is low, the fluid flows easily. On the other hand, when viscosity is high, the fluid flows with difficulty. The low viscous fluid is thin and can flow easily, whereas a high viscous fluid is thick and cannot flow easily.

- The viscosity of fluid should be high enough to seal the working gap between the parts and prevent leakage but should be low enough to cause easy flow throughout the system.
- A high-viscosity fluid requires high energy to overcome the internal friction, resulting in excess heat generation.
- On the other hand, low-viscosity fluid flows easily but causes leakages and reduces volumetric and overall efficiency. Therefore the hydraulic fluid should have an optimum viscosity.

  High viscosity:

  - High resistance to flow.
  - Increased power consumption due to frictional loss.
  - High temperature is caused by friction.
  - Increased pressure drop because of the resistance.
  - Possibility of sluggish or slow operation.
  - Difficulty in separating air from oil in a reservoir.
  - Greater vacuum at the pump inlet, causing cavitation. Higher system noise level.

  Low viscosity:

  - Increased internal leakage.
  - Excessive water.
  - Possibility of decreased pump efficiency, causing slower operation of the actuator. Increased temperature resulting from leakage losses.

- There are two basic methods of specifying the viscosity of fluids: absolute and kinematic viscosity. Viscosity index is an arbitrary measure of fluid resistance to viscosity change with temperature changes. Thus, viscosity is affected by temperature changes.
- As temperature increases, the viscosity of a fluid decreases. A fluid that has a relatively stable viscosity at temperature extremes has a high viscosity index. A fluid that is very thick while cold and very thin while hot has a low viscosity index.

2.3.2 Lubrication Capability

- Hydraulic fluids must have good lubricity to prevent friction and wear between the closely fitted working parts such as vanes of pumps, valve spools, piston rings, and bearings.
- Wear is the removal of surface material due to the frictional force between two metal-to-metal contacts of surfaces. This can result in a change in dimensional tolerances, which can lead to improper functioning and failure of the components.
- Hydraulic oil should have a good lubricating property. That is, the film so formed should be strong enough that it is not wiped out by the moving parts.

2.3.3 Demulsibility

- The ability of hydraulic fluid to separate rapidly from moisture and successfully resist emulsification is known as "deductibility."
- If an oil emulsifies with water, the emulsion promotes the destruction of lubricating and sealant properties. Highly refined oils are water-resistant by nature.

2.3.4 Good Chemical and Environmental Stability (Oxidation and Corrosion Resistance)

- For a good hydraulic fluid, a good chemical and environmental stability are desirable. Most fluids are vulnerable to oxidation, as they come in contact with oxygen in the air.
- Mineral oils or petroleum-based oils (widely used in hydraulic systems) contain carbon and hydrogen molecules, which easily react with oxygen.
- The oxidation products are highly soluble in oil and being acidic they can easily corrode metallic parts.
- The soluble acidic products cause corrosion, whereas insoluble products make the operation sluggish. Oxidation leads to deterioration in the chemical nature of the fluid, which may form some chemical sleds, gum, or varnish at a low velocity or stagnation points in the system.
- Many factors influence the rate of oxidation, such as temperature, pressure, moisture, and so on. Temperature is the most affecting one, as the rate of oxidation increases severely with a temperature rise.
- The moisture entering the hydraulic system with air causes the parts made of ferrous materials to rust. Rust is a chemical reaction between iron or steel and oxygen.
- Corrosion, on the other hand, is the chemical reaction between a metal and an acid. The result of rusting and corrosion is the “eating away” of the metal surfaces of the hydraulic components. Rust and corrosion cause excessive leakage between moving parts.
- Rust and corrosion can be prevented by incorporating additives that plate on the metal surface to prevent the chemical reaction.

2.3.5 Neutralization Numbers

- The neutralization number is a measure of the acidity or alkalinity of hydraulic oil. This is referred to as the pH value of the oil. High acidity causes the oxidation rate in oil to increase rapidly.

2.3.6 Low Flammability

- A fire-resistant fluid is one that can get ignited in the presence of an ignition source but does not support combustion when the source is removed. This characteristic is defined as flammability.
- It refers to the ease with which a fluid gets ignited and propagates the flame. Hence, it is desirable to have low flammability for hydraulic fluid.

2.3.7 Foam Resistance

- Air can be present in a hydraulic fluid in two forms: dissolved and entrained. For example, if the return line to the reservoir is not submerged, the jet of oil entering the liquid surface will carry air with it.
- This causes air bubbles to form in the oil. If these bubbles rise to the surface too slowly, they will be drawn into the pump intake.
- This can cause pump damage due to cavitation.
- Another adverse effect of entrained and dissolve air is a great reduction in the bulk modulus of the hydraulic fluid.

2.3.8 Low Volatility

- A fluid should possess low vapor pressure or a high boiling point. The vapor pressure of a fluid varies with temperature and hence the operating temperature range of the system is important in determining the stability of the fluid.

2.3.9 Good Heat Dissipation

- Hydraulic fluid should have a high heat dissipation capability. The temperature of a fluid shoots up if its heat dissipation characteristics are poor.
- Too high fluid temperature can cause a system to malfunction. If the fluid overheats, it may cause the following:
    - i) Give off vapor and cause cavitation of the pump.
    - ii) Increase the rate of oxidation causing its rapid deterioration by producing sleds, varnishes, etc., thus shortening its useful life.
    - iii) Reduce viscosity of the fluid resulting in increased leakage, both internal and external.
    - iv) Cause thermal distortion in components.
    - v) Damage seals and packaging owing to embrittlement.
- Hydraulic systems should be designed so that a heat balance occurs at a satisfactory operating temperature.

2.3.10 Low Density

- - The relative density of mineral oil is 0.9 (the exact value depends on the base oil and the additive used). Synthetic fluids can have a relative density greater than 1. T
- - The relative density is important when designing the layout of pumps and reservoirs.

2.3.11 System Compatibility

- - A hydraulic fluid should be inert to materials used in or near the hydraulic equipment. If the fluid in any way attacks, destroys, dissolves, or changes the parts of the hydraulic system, the system may lose its functional efficiency and may start malfunction.

2.3.12 Stable Chemically and Physically

- Fluid characteristics should remain unchanged during an extended useful life and storage.
- The fluid in a working hydraulic system is subjected to violent usage-large pressure fluctuations, shock, turbulence, aeration, cavitation, water, and particulate contamination, high shear rates, and large temperature variations.
- Since many aspects of stability are chemical, the temperatures to which the fluid will be exposed is an important criterion in the selection of a. hydraulic fluid.

2.3.13 Good Heat Dissipation

- An important requirement of the fluid is to carry heat away from the working parts. Pressure drops, mechanical friction, fluid friction, leakages, all generate heat.

- The fluid must carry the generated heat away and readily dissipate it to the atmosphere or coolers. Therefore high thermal conductivity and high specific heat values are desirable in the fluid chosen.

2.3.14 High Bulk Modulus

- In general, oil is taken as incompressible. However, in practice, all materials are compressible and so is oil.
- The bulk modulus is a measure of the degree of compressibility of the fluid and is the reciprocal of compressibility.
- The higher the bulk modulus, the lesser the material will be compressed with increasing pressure.
- Bulk modulus is an important characteristic of a hydraulic fluid because of control problems, especially in servo hydraulics.

2.3.15 Low Coefficient of Expansion

- A low coefficient of expansion is usually desirable in hydraulic fluid to minimize the total volume of the system required at the operating temperature.

2.4 Physical Characteristics of Hydraulic Fluid

2.4.1 Density

- Density may be defined as the mass of oil per unit volume. The unit will be kg/cm3 or kg/m3.

$$\boldsymbol{Density\ (\rho) = \frac{mass}{volume}}$$

- The density of any liquid is generally measured by an instrument called a hydrometer. If one dips the instrument into the liquid or oil, the density can be directly read.
- Hydraulic oils that are used in industrial hydraulic systems may have a density of 0.8 to 0.9 gm/cm3.

Table 2.1 - Density characteristics of hydraulic fluids

Fluid	**Density (kg/m^3)**
Shell Tellus ISO 32 mineral oil	875
Shell HFB 60%oil,40%oil	933
Shell HFC 60%glycol,40%water	1084
Shell HFD phosphate ester	1125
Shell Naturelle HFE 32	918

2.4.2 Specific Gravity

- The specific gravity of oil is defined as the ratio of densities of oil and water. The specific gravity of fluid is important in those cases where the overall system weight must be kept minimum.

$$\boldsymbol{Specific\ Gravity = \frac{Density\ of\ oil}{Density\ of\ water}}$$

- As per standards, the density of water is accepted as 1. Hence if we say that the specific gravity of oil is 0.80, then the logical inference is that the oil in question has a density of 0.8 gm/cm3.
- Specific gravity and density may seem to be the same; we must understand the mathematical relationship so that while solving problems we are not confused.
- A heavy fluid can cause pump cavitation and resultant malfunction of the system.

2.4.3 Specific Weight

- The specific weight of hydraulic oil is calculated by multiplying the density of oil by the acceleration due to gravity.

$$\boldsymbol{Specific\ Weight\ (\gamma) = \frac{Weight}{Volume}}$$

2.4.4 Viscosity

- Viscosity is a very important property of oil. It is the measure of the ability of e-liquid to flow. It can be defined as the resistance to flow.
- To understand the physical concept of viscosity, let us take a few simple examples. When or - swims in a pool of water, one experiences resistance to the motion.
- One might have noticed that when a liquid kept in a container is stirred and left to itself.6c motion will disappear after some time. This indicates that there is some kind d frictional force in all types of fluids. This force is called the viscous force.

2.5 Filters and Strainers

- For proper operation and long service life of a hydraulic system, oil cleanliness is of prime importance. Hydraulic components are very sensitive to contamination.
- The cause of the majority of hydraulic system failures can be traced back to contamination. Hence, the filtration of oil leads to proper operation and long service life of a hydraulic system.
- Strainers and filters are designed to remove foreign particles from the hydraulic fluid. They can be differentiated by the following definitions:

  Filters: They are devices whose primary function is the retention, by some fine porous medium, of insoluble contaminants from the fluid.

  - Filters are used to pick up smaller contaminant particles because they can accumulate them better than a strainer.

- Generally, a filter consists of fabricated steel housing with an inlet and an outlet. The filter elements are held in position by springs or other retaining devices.
- Because the filter element is not capable of being cleaned, that is, when the filter becomes dirty, it is discarded and replaced by a new one. 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 device whose function is to remove large particles from a fluid using a wire screen.
- The smallest sized particle that can be removed by a strainer is as small as 0.15 mm or 150 μm.

Hydraulic strainers: A strainer is a coarse filter. Fluid flows more or less straight through it. A strainer is constructed of a fine wire mesh screen or screening consisting of a specially processed wire of varying thickness wrapped around metal frames.

- It does not provide as fine a screening action as filters do, but offers less resistance to flow and is used in pump suction lines where pressure drop must be kept to a minimum.
- A strainer should be as large as possible or wherever this is not practical, two or more may be used in parallel.

Causes of Contamination

The causes of contamination are as follows:

- Contaminants are left in the system during assembly or subsequent maintenance work.
- Contaminants generated when running the system such as wear particles, sludge, and varnish due to fluid oxidation and rust and water due to condensation.
- Contaminants are 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.

2.6 Types of Filters

- Filters may be classified as follows:
  1. **According to the filtering methods:**
  - **Mechanical filters:** 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.
  - **Absorption filters:** These filters are porous and permeable materials such as paper, wood pulp, diatomaceous earth, cloth, cellulose, and asbestos. Paper filters are impregnated with a resin to provide added strength. In this type of filter, the particles are absorbed as the fluid permeates the material. Hence, these filters are used for extremely small particle filtration.
  - **Adsorbent filters:** 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.

2. **According to the size of pores in the material:**

- **Surface filters:** These are nothing but simple screens used to clean oil passing through their pores. The screen thickness is very thin and dirty unwanted particles are collected at the top surface of the screen when the oil passes, for example, strainer.
- **Depth filters:** These contain a thick-walled filter medium through which the oil is made to flow and the undesirable foreign particles are retained. Much finer particles are arrested and the capacity is much higher than surface filters.

3. **According to the location of filters:**

- **Intake or inline filters (suction strainers):** These are provided first before the pump to protect the pump against contaminations in the oil as shown in Fig. 2.1. These filters are designed to give a low-pressure drop, otherwise, the pump will not be able to draw the fluid from the tank. To achieve a low-pressure drop across the filters, a coarse mesh is used. These filters cannot filter out small particles.

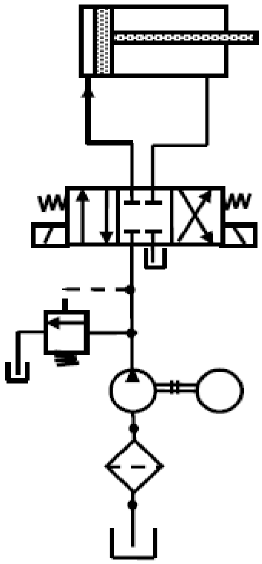


Fig.2.1 - Suction filter

  - Advantages:
    - A suction filter protects the pump from dirt in the reservoir. Because the suction filter is outside the reservoir, an indicator telling when the filter element is dirty can be used.
    - The filter element can be serviced without dismantling the suction line or reservoir (easy to maintain).
  - Disadvantages:
    - A suction filter may starve the pump if not sized properly.

- **Pressure line filters (high-pressure filters):** These are placed immediately after the pump to protect valves and actuators and can be a finer and smaller mesh (Fig. 2.2). They should be able to withstand the full system pressure. Most filters are pressure line filters.

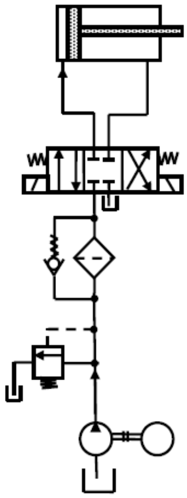


Fig.2.2 - Pressure filter

- Advantages
  - A pressure filter can filter very fine contaminants because the system pressure is available to push the fluid through the element.
  - A pressure filter can protect a specific component from the harm of deteriorating particles generated from an upstream component.
- Disadvantages
  - The housing of a pressure filter must be designed for high pressure because it operates at full system pressure. This makes the filter expensive.
  - If pressure differential and fluid velocity are high enough, dirt can be pushed through the element or the element may tear or collapse.

- **Return line filters (low-pressure filters):** These filters filter the oil returning from the pressure-relief valve or the system, that is, the actuator to the tank (Fig. 2.3). They are generally placed just before the tank. They may have a relatively high-pressure drop and hence can be a fine mesh. These filters have to withstand low pressure only and also protect the tank and pump from contamination.

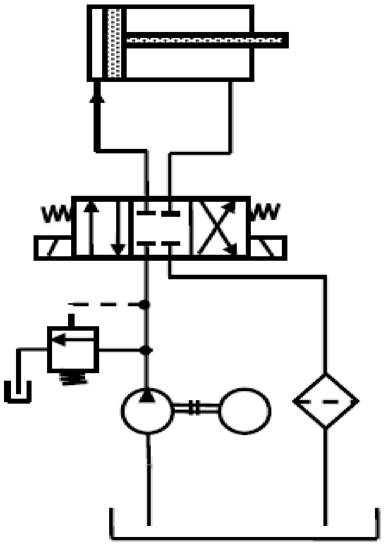


Fig.2.3 - Return line filter

i. Advantages

1. A return line filter catches the dirt in the system before it enters the reservoir.
2. The filter housing does not operate under full system pressure and is, therefore, less expensive than a pressure filter.

ii. Disadvantages

1. There is no direct protection for circuit components.
2. In return line full-flow filters, flow surges from discharging cylinders, actuators, and accumulators must be considered when sizing.

4. Depending on the amount of oil filtered by a filter:

- **Full flow filters:** In this type, complete oil is filtered. The 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 (Fig. 2.4). This is an efficient filter. However, it incurs large pressure drops. This pressure drop increases as the filter get blocked by contamination.

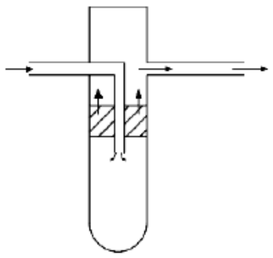


Fig.2.4 - Full-flow filter

- **Proportional filters (bypass filters):** In some hydraulic system applications, only a portion of oil is passed through the filter instead of the entire volume, and the main flow is directly passed without filtration through a restricted passage (Fig. 2.5).

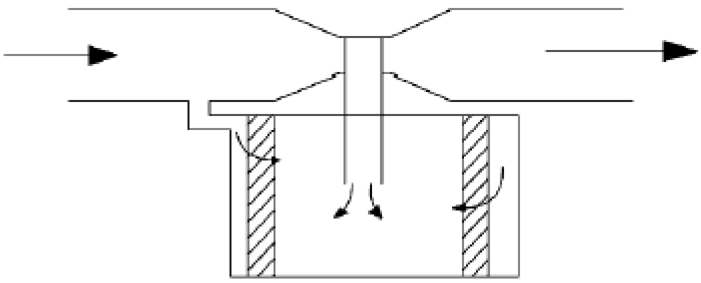


Fig.1.5 – Proportional filter

Beta Ratio of Filters

- Filters are rated according to the smallest size of particles they can trap. Filter ratings are identified by nominal and absolute values in micrometers.
- A filter with a nominal rating of 10 μm is supposed to trap up to 95% of the entering particles greater than 10 μm in size.

- The absolute rating represents the size of the largest pore or opening in the filter and thus indicates the largest size particle that could go through. Hence, the absolute rating of a 10 μm nominal size filter would be greater than 10 μm.
- A better parameter for establishing how well a filter traps particles is called the beta ratio or beta rating.
- The beta ratio is determined during laboratory testing of a filter receiving a steady-state flow containing fine dust of selected particle size.
- The test begins with a clean filter and ends when the pressure drop across the filter reaches a specified value indicating that the filter has reached the saturation point. This occurs when contaminant capacity has been reached.
- By mathematical definition, the beta ratio equals the number of upstream particles of size greater than Nμm divided by the number of downstream particles having a size greater than Nμm where N is the selected particle size for the given filter. The ratio is represented by the following equation:

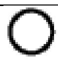
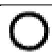
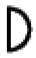
$$\textbf{Beta ratio} = \frac{\textbf{No. of upstream particles of size} > \textbf{N μm}}{\textbf{No. of downstream particles of size} > \textbf{N μm}}$$

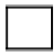
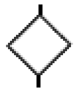
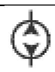
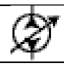
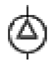
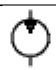
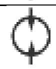
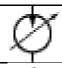
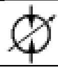
- A beta ratio of 1 would mean that no particle above specified N is trapped by the filter. A beta ratio of 50 means that 50 particles are trapped for everyone that gets through. Most filters have a beta ratio greater than 75:

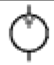
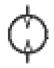
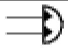
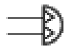
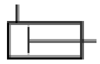
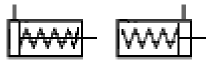
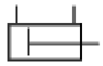
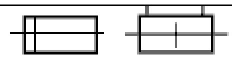
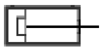
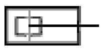
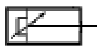
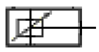
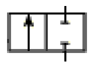
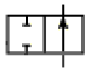
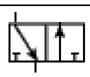
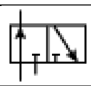
$$\textbf{Beta ratio} = \frac{\textbf{No. of upstream particles} - \textbf{No. of downstre am particles}}{\textbf{No. of upstream particles}}$$

2.7 Hydraulic and Pneumatic Symbols

Table 2.2 – Hydraulic and Pneumatic symbols

Lines	
Continuous line (for) flow line	
The dashed line (for) pilot, drain	
Envelope (for) long and short dashes around two or more component symbols.	
Circular	
Large circle - pump, motor	
Small circle - Measuring devices	
Semi-circle - rotary actuator	

Square	
-One square - pressure control function -Two or three adjacent squares - directional control	
Diamond	
Diamond - Fluid conditioner (filter, separator, lubricator, heat exchanger)	
Miscellaneous Symbols	
Spring	
Flow Restriction	
Triangle	
Solid - Direction of Hydraulic Fluid Flow	▼
Open - Direction of Pneumatic flow	▽
Pumps and Compressors	
Fixed Displacement hydraulic pump symbols	
Unidirectional	
Bidirectional	
Unidirectional	
Bidirectional	
Compressor symbol	
Motors	
Fixed displacement hydraulic motor symbol	
Unidirectional	
Bidirectional	
A variable displacement hydraulic motor symbol	
Unidirectional	
Bidirectional	
Pneumatic motor symbol	

Unidirectional	
Bidirectional	
Rotary Actuator symbol	
Hydraulic	
Pneumatic	
Cylinders	
Single-acting cylinder symbols	
Returned by an external force	
Returned by spring or extended by spring force	
Double-acting cylinder symbols	
The single-piston rod (fluid required to extend and retract)	
Double-ended piston rod	
Cylinders with cushions symbols	
Single fixed cushion	
Double fixed cushion	
Single adjustable cushion	
Double adjustable cushion	
Directional Control Valve symbols	
Directional control valve (2 ports / 2 positions)	
Normally closed directional control valve with 2 ports and 2 finite positions	
Normally open directional control valve with 2 ports and 2 finite positions	
Directional control valve (3 ports / 2 positions)	
Normally closed directional control valve with 3 ports and 2 finite positions	
Normally open directional control valve with 3 ports and 2 finite positions	
Directional control valve (4 ports / 2 positions)	

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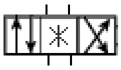
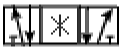
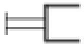
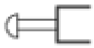
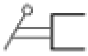
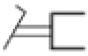
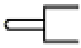
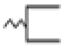
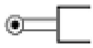
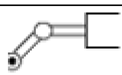
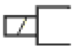
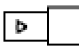
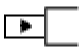
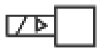
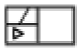
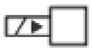
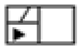
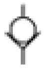
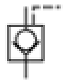
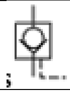
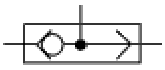
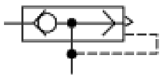
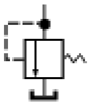
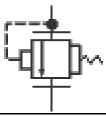
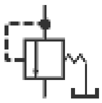
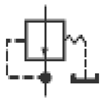
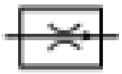
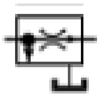
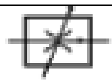
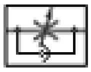
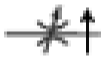
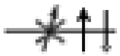
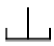
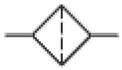
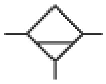
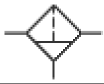
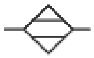
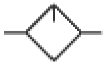
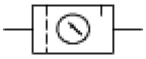
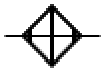
Directional control valve with 4 ports and 2 finite positions	
Directional control valve (4 ports / 3 positions)	
Directional control valve with 4 ports and 3 finite positions (center position can have various flow paths)	
Directional control valve (5 ports / 2 positions) normally a pneumatic valve	
Directional control valve with 5 ports and 2 finite positions	
Directional control valve (5 ports / 3 positions) Normally a pneumatic valve	
Directional control valve with 5 ports and 3 finite positions	
Control Method Operator symbols for valves	
Manual Control	
General symbol of a valve's manual operator (without showing the control type)	
Pushbutton	
Lever	
Foot pedal	
Mechanical Valve Control	
Plunger or tracer	
Spring (used on one side of a valve to hold it in the normally open or normally closed state)	
Roller	
Roller (one direction only)	
Electrical/Solenoid Valve Control	
Solenoid (the one side's winding shown)	
Pilot Operation (uses pressure to actuate valve)	
Pneumatic actuated pilot	
Hydraulic actuated pilot	

Pilot operated two-stage valve (uses a second lesser force to actuate the pilot actuation of the valve)	
Pneumatic: Solenoid first stage	
Pneumatic: Air pilot second stage	
Hydraulic: Solenoid first stage	
Hydraulic: Hydraulic pilot second stage	
Check valves, Shuttle valves, Rapid Exhaust valves	
Check valve symbol-free flow one direction, blocked flow in other direction	
Pilot operated check valve symbol, pilot to close	
Pilot operated check valve symbol, pilot to open	
Shuttle valve	
Rapid exhaust valve/Pneumatic	
Pressure Control Valves	
Pressure Relief Valve (safety valve) normally closed	
Line pressure is limited to the setting of the valve, a second part is directed to the tank.	
Proportional Pressure Relief Valve	
Line pressure is limited to and proportional to an electronic signal	
Sequence Valve	
When the line pressure reaches the setting of the valve, the valve opens permitting flow to the secondary port. The pilot must be externally drained into the tank.	
Pressure Reducing Valve (Hydraulic Pressure Regulator)	

Pressure downstream of the valve is limited to the setting of the valve	
Flow Control Valves	
Throttle valve	
Adjustable output flow	
Flow Control valves	
Flow control valve with fixed output (variations in inlet pressure do not affect the rate of flow	
Flow control valve with fixed output and relief port to a reservoir with relief for excess flow (variations in inlet pressure do not affect the rate of flow)	
Flow control valve with variable output	
Flow control valve with fixed orifice	
Flow control valve with metered flow toward right free flow to left	
Flow control valve with pressure compensated flow control fixed output flow regardless of load	
Flow control valve with pressure and temperature compensated	
Shut-Off Valve	
Shut-Off Valve Simplified symbol	
Accumulators	
Accumulator symbol (Stores Pressure)	
Reservoir (Tank)	
Reservoir symbol (Holds Fluid medium of your system)	

Filters, Water Traps, Lubricators, and Miscellaneous Apparatus	
Filter or Strainer	
Water Trap	
Filter with water trap	
Air Dryer	
Lubricator	
Conditioning unit (FRL, Pressure Regulator)	
Heat Exchangers	

2.8 References

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