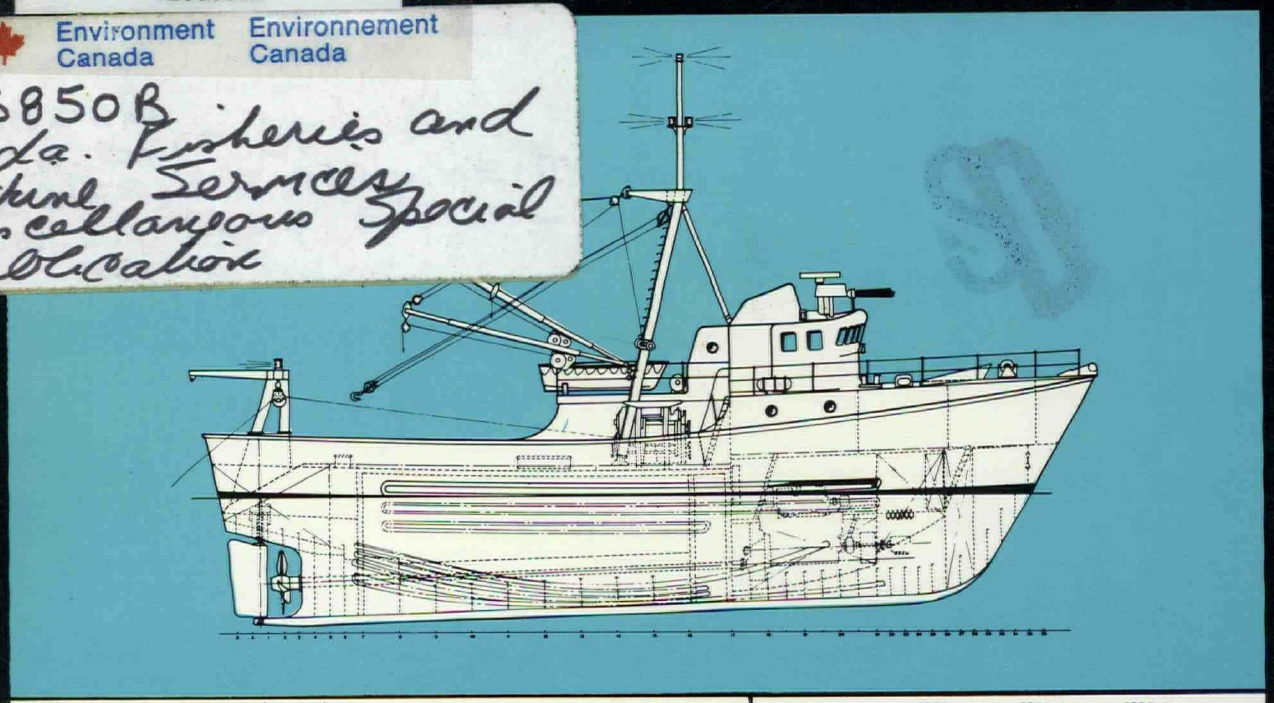
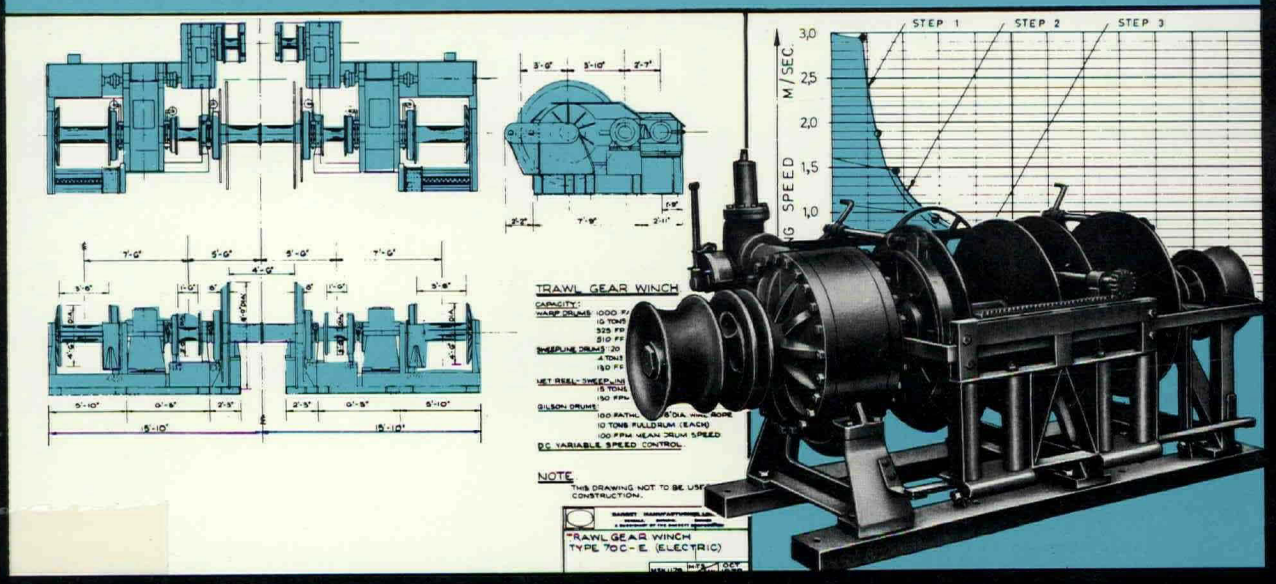
Hydraulics Manual for Fishermen

Oil-Conditioning Components

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Hydraulics Manual for Fishermen[1]

Booklet



Oil-Conditioning Components

Department of Fisheries and the Environment
Fisheries and Marine Service
Fishermen's Services Branch
Ottawa, Canada K1A 0E6

DEPARTMENT OF FISHERIES AND THE ENVIRONMENT
FISHERIES AND MARINE SERVICE
Ottawa 1978

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FOREWORD

If the fisherman is to achieve a good standard of living he must obtain a good profit from his catch. He has little control over the number of fish available or the demand for his product; his expertise is catching fish. To do this efficiently it is necessary to have good but not necessarily the most expensive equipment. However, the equipment must be safe, efficient, reliable, durable, and economical. Deck machinery helps men handle nets and process fish and this machinery needs a source of power. Because the power must be transmitted, the prime mover and transmission have to be as reliable as the machinery. It is a common opinion that machines and prime movers are reliable but that the weak link is the transmission, particularly when it is hydraulic. There is some justification for this opinion because in the past many mistakes have been made in the design and installation of hydraulic transmissions. However, transmission of power by hydraulics is especially suited to the needs of deck machinery. Properly designed and installed it is safe and dependable, and is good enough for use in large aircraft. But to be successful, a hydraulic transmission must be designed, installed, and maintained by knowledgeable people.

This Manual consists of six separate Booklets. They outline the ideas, materials, and methods used to create a safe, efficient, and reliable hydraulic power transmission. Generally, the discussion of each topic is brief and, no doubt, some points are missed; however, the intention is to help the practical worker understand hydraulics. Although written mainly for mechanics, the Manual should also be of value to system designers and draftsmen because it emphasizes practical requirements. The mechanic must have some knowledge of the principles behind the design of hydraulic power transmissions, appreciate the great need for cleanliness inside the system, and the necessity to keep the operating temperature at a reasonable level. He should understand how the various components work, and how to carry out necessary troubleshooting and repair procedures. Special knowledge and skill are needed by the hydraulic systems mechanic and this Manual will supply some of that knowledge. Skill will be obtained when he applies this knowledge to his work.

Fishermen's Services Branch
Fisheries and Marine Service
Department of Fisheries and the Environment

1. INTRODUCTION

The principles of hydraulic power transmission require that the power-transmitting substance be liquid. That is, it must be virtually incompressible and flow readily. However, when the needs of the components in a system are considered, the liquid chosen must provide good lubrication, prevent corrosion, and give long service. Petroleum base oils with these properties are available and special additives to fight rust, oxidation, and wear can be added. It is important to use the correct hydraulic oil and to keep it in good condition, as oil deteriorates with time and use and becomes a poor power-transmitting medium. Because of rapidly increasing prices and the pollution problems associated with its disposal, oil should be kept usable for as long as possible (Fig. 1).

Hydraulic oil delivered by a supplier is uncontaminated and not likely to contain harmful amounts of water, air, or solid particles such as sand or metal. If it can be kept free of contaminants and if its temperature is kept under control, the oil will have a long useful life and so will the system components. Therefore, additional components are installed in the hydraulic circuit to prevent overheating and the presence of abrasive particles in the oil. These oil-conditioning components do not play a direct part in the transmission of power, but without them oil and other power-transmitting components quickly deteriorate and fail.

2. TEMPERATURE-CONTROLLED SYSTEM

2.1 Cause of Overheating

Manufacturers strive to make power transmission equipment as efficient as possible so that most of the power produced by the engine is delivered to the machine. Some of the power delivered to a hydraulic pump is always needed to overcome friction within the transmission. This lost power is converted into heat and the equipment warms up. The same effect takes place in any machine and hydraulic systems are no exception. Hydraulic system designers make circuits as efficient as possible but, in addition to the power used in overcoming friction within the power-transmitting components, power is also used in overcoming the internal friction of the oil itself.

Friction in the components, piping, and oil itself generates heat. This is not entirely bad because if a system were perfect (100% efficient), and no heat were generated, the best operating temperature would not be reached. If, however, the system is improperly designed and too much heat is generated, the temperature of the oil can easily rise above a reasonable operating level.

2.2 Effects of Heat

Like all transmissions, hydraulic power systems have a best operating temperature range, usually between 43°C (110°F) and 60°C (140°F). Within this range, oil viscosity and running clearances in components have acceptable values and the life of oil seals and oil is not seriously affected. If the operating temperature rises or falls very much out of this range, running conditions are affected and the system becomes less efficient.

2.2.1 Cold Oil The most important effect of low-temperature operation is that the oil thickens and does not flow as readily. If the oil is fluid enough to flow into the pump inlet, the low-temperature condition soon disappears because the additional power lost in

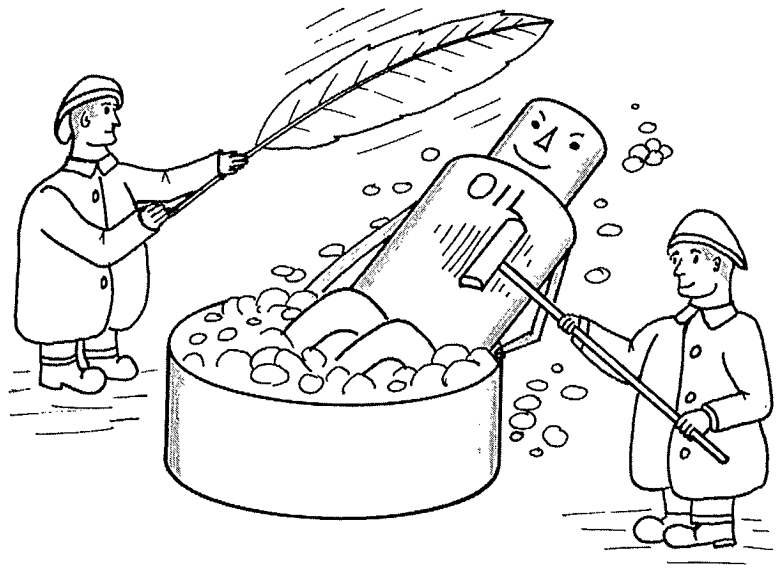


FIG. 1. Keep oil cool and clean

friction (caused by thick oil) helps the system to warm up quickly.

2.2.2 Hot Oil Overheating presents a greater problem than overcooling because when the operating temperature rises past the optimum range the oil becomes too thin. Oil that is too thin slips very easily through the small clearances inside components and unacceptable internal leakage results. This oil lost in additional leakage would, under normal circumstances, go to the actuator. Thus, overheating reduces the flow of working oil to the actuator. But bearing clearances also change, friction increases, and the heating process is intensified. Synthetic rubber seals get hard, become ineffective, and oil leaks out of the components and onto the deck. High temperature causes gum, sludge, and varnish to form in the oil, the lubricating qualities diminish and it becomes less and less suitable as a power-transmitting liquid.

2.3 Heat Transfer Principles

When a transmission generates heat, its temperature rises. As soon as the transmission temperature rises above the temperature of the surrounding air, heat flows from the transmission into the air and quickly dissipates. As the transmission temperature rises, heat flows more quickly into the surroundings until the temperature is high enough to push heat out as fast as it is generated. At this point the transmission temperature stops rising. All transmissions have a natural, steady, operating temperature, but often this is too high for the requirements of a practical system.

Heat escapes through the surface of a transmission and the larger the surface area, the faster the heat loss. The oil carries most of the heat generated in the power-transmitting components around the circuit, so the surface of the pipes and reservoir also helps to release the unwanted heat. If little heat is generated, the system may be able to keep the maximum oil temperature at a reasonable level without additional means of cooling. When large amounts of power are transmitted, it is not possible to get rid of the heat without going to an unacceptably high temperature unless an oil cooler is fitted in the system. The extra surface area of the cooler provides additional area for the escape of heat so that high temperatures do not result.

2.4 Oil Cooler Types

The oil cooler removes heat from the transmission as fast as it is generated and keeps the operating temperature at an acceptable level. The two most popular cooling methods are: (1) removal of heat from flowing oil by means of cool flowing water, the oil-to-water method; (2) removal of heat from flowing oil by means of fast flowing air, the oil-to-air method. The water, oil, and air must actively flow through the coolers if they are to be effective. Without adequate quantities of flowing water or air the coolers become almost useless.

2.5 Oil-to-Water Cooler

This is popularly known as the shell-and-tube type cooler (Fig. 2) because it consists of a bundle of small bore tubes encased in a larger cylinder that acts as a shell. These coolers are constructed mainly of brass because it is a good conductor of heat. Oil flows through the shell, around the outside of the tubes, and is in contact with the inside of the shell and the outer surface of the tubes. The cooling water flows through the bore of the tubes. These tubes should be a 90% copper, 10% nickel alloy because, with the seawater normally used for cooling, it gives much longer service than the standard brass construction sometimes found. Zinc plugs should be fitted in the water-filled headers of the cooler. Seawater eats away these zinc plugs in preference to the copper alloy tubes, and the tubes last longer.

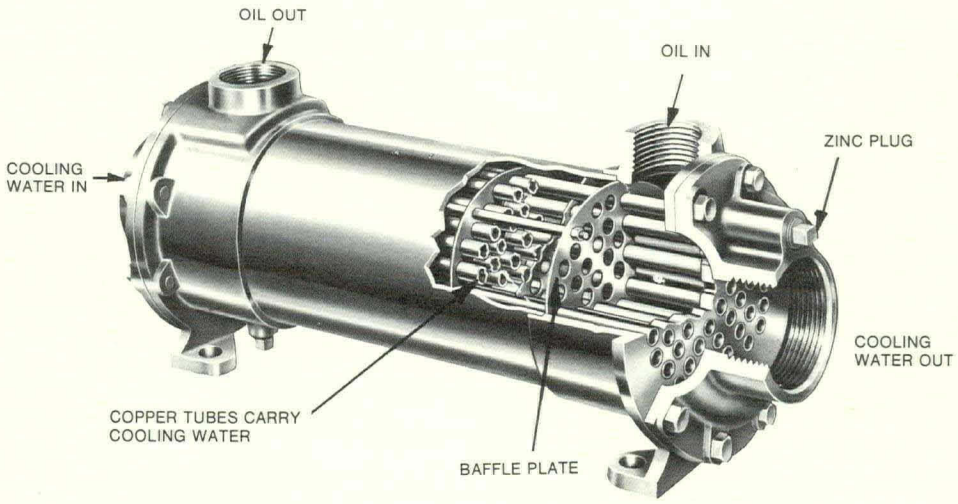


FIG. 2. Single-pass shell and tube oil cooler

2.5.1 Number of Passes It is usual to classify oil coolers as single-, two-, or four-pass units. The oil enters the cooler at one end of the shell and leaves at the other end. The oil flow in a cooler is always single-pass, but baffle plates fitted inside the shell force the oil to zigzag back and forth across the tubes several times before reaching the outlet. The water flow in the cooler may be single pass, two pass, or four pass. In a single-pass cooler the water enters the tubes at one end of the cooler and flows straight through to the outlet at the other end. To remove heat most effectively, the direction of water flow must be opposite to the direction of oil flow. With a two-pass cooler the water enters tubes at one end of the cooler, flows the length of the shell, then returns in other tubes and comes out at the end at which it entered. In the four-pass version, the water flows the length of the shell four times, in a different set of tubes each time, before leaving the cooler at the end it entered.

2.5.2 Pressure Rating Oil coolers are low-pressure components and are installed in the pipe that returns the oil to the reservoir after it has done its work in the actuator, that is, in the return line. Allowable pressure in the shell is approximately 200 pounds per square inch (psi) and water line allowable pressure may be as high as 150 psi. However, it is always advisable to check maximum operating pressures before a cooler is selected.

2.6 Oil-to-Air Cooler

A good example of a liquid-to-air cooler is the automobile radiator where air cools water, but in hydraulics air cools oil. This cooler is also constructed from brass and takes the form of upper and lower header tanks connected by a number of finned tubes. The oil flows inside the tubes from one header to the other and the cooler can be either a single- or two-pass unit. The "number of passes" now means the number of times the oil flows up and down from one header to the other. The tubes are finned on the air side to increase the surface area and help the heat escape. The efficiency of the cooler depends on both the oil and air moving rapidly, and a fan is usually fitted to force the air over the fins and extract the heat quickly.

The marine environment can affect some cooler materials drastically, so the cooler must be made from materials that give long, trouble-free life.

2.7 Cooler Application

The shell-and-tube cooler is generally best for shipboard use. It is stronger, more compact, and more durable than the radiator type. Where an adequate supply of cooling water is not readily available, the shell-and-tube cooler cannot be used and either a keel cooler or an oil-to-air cooler can be considered.

2.8 Keel Cooler

A keel cooler (Fig. 3) is often used on ships, and is so named because it is fitted outside the hull of the vessel and attached to the bottom. It is similar in action to the shell-and-tube cooler, but in the keel cooler the hot liquid flows through the tubes, which are immersed in the sea. For a cooler to be effective both hot and cold liquids must pass through or across the tubes at a reasonable speed, and as the speed of the

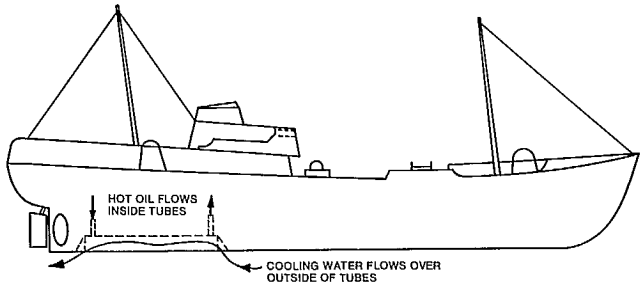


FIG. 3. Keel cooler installation

water past the cooler depends on the ship's speed, the keel cooler is most effective when the ship is moving fast. Unfortunately, heavy deck machinery tends to be used only when the ship is moving slowly or is stopped, and the speed of the water past the cooler is consequently slow. Such conditions reduce the efficiency of the keel cooler when it is needed most, and extra care must be taken when selecting this type of cooler for use with deck machinery.

2.9 Auxiliary Equipment for Coolers

The coolant flow rate must be controlled in each type of cooler. If not controlled, the coolant flows through the cooler at maximum rate, and the system will generally run cold and below its best operating temperature.

In the oil-to-air cooler a powered fan moves the air. Sometimes the fan is driven directly by the engine but often a separate electric or hydraulic motor is more convenient. Whatever is used, the fan speed should be controllable so the air flow, and consequently, oil temperature is properly regulated.

The oil-to-water cooler requires a control valve fitted in the water inlet line. If the valve were fitted in the water outlet line the tubes would be pressurized to the water supply pressure; and this would increase the chances of water leaking into the oil, particularly when the hydraulic power system is shut down and hydraulic oil pressure falls to rest pressure. The valve is normally closed and opens when the system oil gets too hot. It is known as a temperature sensitive, water flow-rate control valve.

3. NEED FOR A CLEAN SYSTEM

The principles of hydraulic power transmission were discovered in experiments done in the 17th and 18th centuries. The liquid used in those experiments was clean water. Water was easily obtained and ocean water would not clog the scientist's equipment. Over the years, as these fundamental principles were put to practical use, it was realized that water was not satisfactory for this purpose and petroleum oil became the liquid most commonly used in hydraulic power transmission systems. The need for a clean liquid has, however, not been challenged and it has always been assumed that oil used in hydraulic power systems is clean. In systems that operate at low pressure and low power, the type of oil and whether it is particularly clean may not be too important. But when oil pressure and power levels of systems are increased it is essential not only to use the correct type of oil, but to use oil that is absolutely clean. It must be clean when put into the transmission and kept clean. In modern systems pressure usually exceeds 1000 psi and power levels can be more than 200 horse power (HP).

If hydraulic systems are to be practical, they must operate in a great variety of locations, and some of these are very dirty. Hydraulic power systems are not affected by external dirt, they could be buried in dirt and still operate without damage. It is the interior that must be kept clean. When we speak of a clean hydraulic system we refer only to the inside, the working parts of components, the bore of pipes and tubing, and of course, the cleanliness of hydraulic oil inside the circuit.

There are many good reasons for having power transmission systems compact. One big advantage of a hydraulic power transmission system is that it can transmit a large amount of power from a small package, and this is because hydraulics can work at high pressure. However, one disadvantage of operating at high pressure is that the oil can leak more readily through clearances in the components and they lose efficiency. A loss of efficiency means an increase in heat generated in the system, and must be avoided. Maximum efficiency is obtained by making running clearances as small as practical and, in high-performance hydraulic components, clearances are always less than .001 inch (in.) and can be as small as .00002 in. Solid particles inside the system should be smaller than these clearances or they will not pass through. Particles larger than this could eventually block the passage of lubricating oil and cause the parts to seize.

3.1 Contamination of Hydraulic Systems

Starting with new, clean oil does not mean it will stay clean. An understanding of the way oil becomes dirty in service enables effective steps to be taken to keep oil clean.

3.1.1 Built-in Contamination A hydraulic power transmission is a network of pumps, valves, actuators, and oil-conditioning components connected by pipes. The system is often assembled on site in conditions far from clean, and it is sometimes difficult to prevent dirt and other contaminants from entering. Nevertheless, built-in contamination must not be tolerated. If tradesmen installing the system are aware that absolute cleanliness inside the circuit is necessary, and if they are familiar with methods to achieve this state of cleanliness, built-in dirt can be practically eliminated. New, clean oil in a clean circuit is a giant stride to effective control of contamination. To start with a clean system controls further contamination. The theory that initial cleanliness is not important, because the system can be cleaned as the transmission operates, is completely wrong.

3.1.2 Bedding In Clean oil in a clean circuit is not sufficient to ensure that oil will stay clean. When a new or rebuilt system starts up, the components bed in under actual running conditions of speed and pressure. This bedding-in process causes small particles of metal to rub off and enter the oil. Unless promptly removed, they scratch the surfaces of other components, release more metal contaminants into the circuit, and increase contamination.

3.1.3 Starting Up When a hydraulic system is shut down, the oil tends to drain out of bearings and other running clearances and allows metal-to-metal contact. At start-up the metal surfaces may rub together momentarily before an oil film builds up to separate them. This situation is worse in cold weather because the oil is thicker and takes longer to flow into small gaps. The momentary rubbing together of metal surfaces can cause wear and release abrasive particles into the circuit. Even under running conditions, momentary high shock loads on the system can cause the oil film, which separates and lubricates surfaces, to break down and allow wear to take place.

3.1.4 Airborne Contamination After clean oil is in the hydraulic circuit, the system must be sealed to prevent dirt, even airborne dust, from entering. If the seals are inadequate, fine but destructive airborne material can enter.

3.1.5 Shaft Seals Shaft seals are fitted to prevent oil leaking from the component and are designed to prevent dirt that falls onto the shaft from entering the component. Normally the seals are effective but, as they wear, dirt can enter. This situation is more likely to occur with the push–pull action of cylinder rods and control valve plungers than with rotating shafts of pumps and motors, but can occur at any point in the circuit where oil pressure is less than the pressure of the outside air.

3.1.6 Begin with a Clean System The hydraulic system can be contaminated with solid particles in many different ways, so it is important to start with clean oil and a clean circuit. It is a continuing battle to keep the oil in good condition but by starting with a clean system the components will wear less quickly and have a longer life.

3.2 Oil Filter

The small abrasive particles of metal generated by wear in the components, and the particles of sand and grit that find their way into the circuit, are the solid contaminants of the system. They are carried around the circuit by the rapidly flowing oil and can be removed by filtering the oil. The filter is simply a large sieve containing millions of small holes, and is designed to prevent the passage of anything but the most minute particles. These should be small enough not to harm the power-transmitting components. To remove all the particles larger than the smallest clearance likely to be found in hydraulic system components (i.e. .00002 in.) is not practical. That is the goal, but the best that can be accomplished is to remove as many particles as possible with filters of reasonable size and price and still achieve long life from the system.

3.3 Filter Construction

The hydraulic system filter is like a large sieve but its construction is very different (Fig. 4). To be effective, a filter must not only remove harmful solids (and do so without causing undue restriction to the oil flow), but also provide a large filter area for oil to flow through. A large flat screen is not practical. It is necessary to fold the screen into pleats, and shape it into a tube. This makes a component of reasonable size and strength, which is easy to handle. The ends are capped and the element is housed inside a metal can bolted to a filter head containing the oil connection ports. The inlet port usually directs oil to the outside of the element. Oil is strained and cleaned as it passes into the core of the element, which is connected to the outlet port. If the flow of oil through a filter is reversed there is a good chance the element will break up, because it is made to carry flow in one direction only. The filter material has to be suitable for hydraulic oil and be economical to produce. Most hydraulic system filter elements are constructed from a resin impregnated paper that is completely satisfactory for oil, but may soften and fail if used to filter liquids containing water.

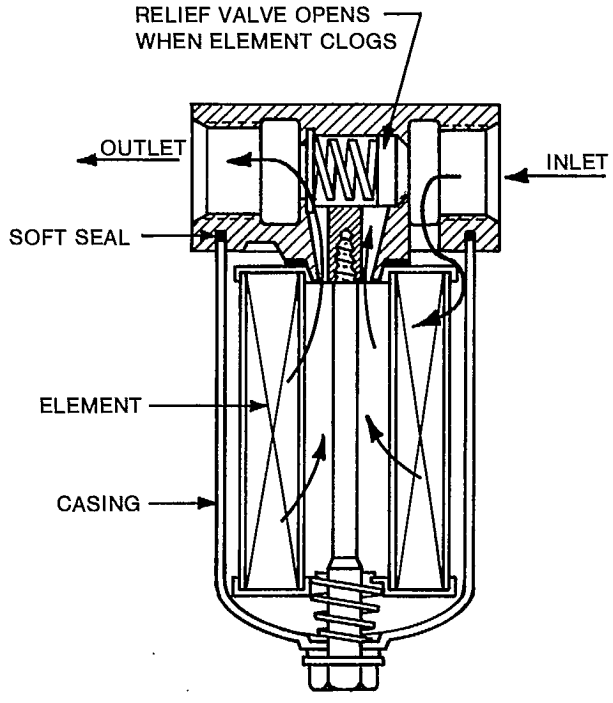


FIG. 4. Construction of hydraulic oil filter

3.4 Filter Element Protection

Small particles of contamination are continually generated and enter the oil. The filter traps the particles at one place and prevents their recirculation. In operation, the holes in the filter element are gradually blocked and there are fewer and fewer passages for oil to flow through. As the filter builds up a greater resistance to oil flow, extra pressure is required to force the oil through. Eventually the filter element will collapse unless the pressure drop across the element is prevented from rising too high. The maximum allowable pressure drop across the filter element ranges from about 3 to 50 psi, depending on the type and manufacturer. A relief valve is often built into the filter head to protect the element. The relief valve is intended only to prevent the element from collapsing under momentary high pressure which could be caused by cold oil or surges. If the element clogs to the extent that the relief valve is open continuously, unfiltered oil circulates and the system life will be shortened.

Filters are available with indicators to show the condition of the element. They measure pressure drop across the element as it gets dirty. All these devices are affected by oil temperature and some by back pressure on the filter, so readings must be carefully evaluated. Always know the back pressure when the filter is clean, then there is a reference point to measure the increase in pressure as the element clogs. Don't take a reading of the indicator when the oil is cold because thick oil makes the element seem dirtier than it really is.

3.5 Degree of Filtration

This indicates the largest solid particles that will pass through the element. It is only an indication because filters generally cannot screen all particles above a certain size on their first pass through the filter. Most particles will be caught but the hydraulic system can handle a few larger particles for a short time without

damage. Hydraulic power transmissions usually require oil filtered to 10 microns. This means the largest solid particle allowed in the circuit measures 10 microns (.0004 in.), smaller than the eye can see. (The human eye cannot see particles smaller than 40 microns.) Oil cannot be judged suitable for a system by its appearance or its feel.

3.6 Filter Location in Hydraulic Circuit

The filter is usually installed in the return line to the reservoir where the oil is at low pressure. A low-pressure filter is smaller, lighter in construction, and less expensive than one in a high-pressure line. However, in transmissions subject to severe service, designers sometimes add a high-pressure filter in the discharge line from the pump to protect downstream components if the pump should wear abnormally. The return-line filter is retained to prevent contamination from other components reaching the reservoir and damaging the pump.

It is sometimes suggested that the filter should be placed in the pump suction line, because contamination is most likely to enter the system at the reservoir and the pump is always damaged first. It is true that a suction-line filter would prevent contamination from reaching the pump but it would also restrict flow and this restriction would become more serious as the filter element got dirty. As atmospheric pressure is the maximum pressure usually available to force the oil into the pump, this additional restriction can cause a vacuum at the pump inlet that can cause cavitation in the pump. Cavitation is the formation and collapse of bubbles in the oil and cannot be tolerated by the pump. Suction-line filters are sometimes used successfully but only where conditions are particularly suited to them.

The suction-line filter is sometimes confused with the suction-line strainer but they are not the same. The filter is intended to remove very fine particles from the oil, while the strainer is a coarse filter and removes particles larger than .005 in. Suction-line strainers are used quite commonly. They cause less restriction than suction-line filters and still give some protection to the pump, but it must be ensured that they do not threaten the free flow of oil to the pump. Strainers must not cause more than 0.5 psi pressure drop in the oil at its operating viscosity and flow rate.

3.7 Selecting Hydraulic System Filter

When selecting a filter four things must be known:

1) *Type of oil.* Materials in the filter element and seals must be suitable for use in the oil and not deteriorate quickly.

2) *Degree of filtration.* This is the largest size of particle allowed to contaminate the oil and is usually specified by hydraulic power transmission component manufacturers.

3) *Filter flow rate.* The filter handles all the flow fed to it and is called a full-flow filter. Filters that handle only part of the flow that enters the inlet port are also available but full-flow filters are more effective and should be used whenever possible. Filters installed in the suction and discharge lines of the pump must handle the maximum pump flow rate, but those fitted in the return line to the reservoir may have to handle flow larger than the pump flow rate. A larger flow occurs when the actuator is a double-acting cylinder, because an increased flow rate is pushed from the cylinder cap end port as the rod retracts. Always select a filter that can handle the flow without causing a large drop in pressure. A large pressure drop wastes and shortens the period between filter element changes.

4) *Maximum system pressure at filter.* The filter casing must safely withstand maximum pressure, including surges, likely to occur at its position in the circuit.

4. HYDRAULIC SYSTEM RESERVOIR

The components and pipes of a hydraulic power system must be completely full of oil at all times. Air inside the circuit is as undesirable as dirt, water, and too much heat, so air has to be removed from the oil and prevented from reentering. The reservoir keeps air out by ensuring the system is always full of oil (Fig. 5).

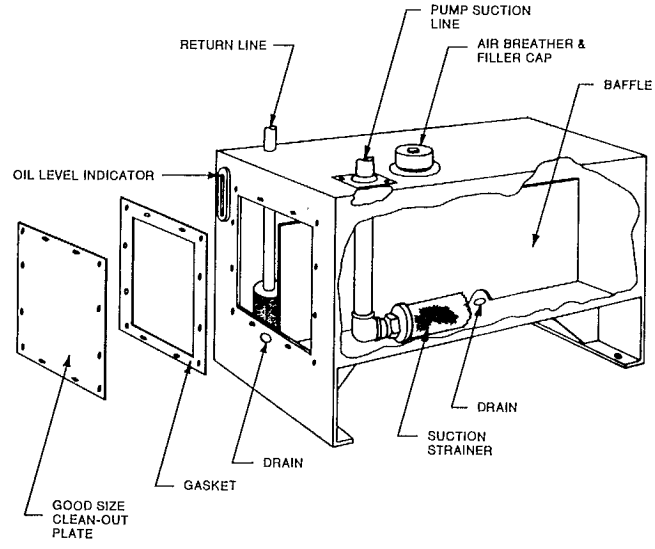


FIG. 5. Standard hydraulic system reservoir assembly

4.1 Reservoir as Storage Tank

Although the main function of the reservoir is to keep air out of the oil, it is the only place in the hydraulic system where air and oil are allowed contact. Atmospheric pressure is needed to push oil into the pump. This air–oil surface should be regarded as a necessary evil and treated carefully. The reservoir has

to hold sufficient oil to prevent the pump suction port from becoming uncovered. If this occurs, air enters the pump and quickly causes trouble. Simply covering the suction port does not guarantee that air will not enter the pump. Oil has to be deep enough to prevent a vortex in the suction port (as happens when water drains from a bathtub). The reservoir must also contain enough oil to allow for increases in circuit volume as the system operates. Additional oil must be allowed to make up for any leaks that develop, and allowance must be made for its shrinking and expansion as it is cooled and heated. The reservoir must be sized so that when the oil is cold and the circuit requires maximum volume there is enough oil in the reservoir to adequately cover the pump suction. When circuit volume is reduced to the smallest amount and the oil is hot, the reservoir must hold this extra oil without overflowing.

4.2 Sizing of Reservoir

A popular rule-of-thumb for establishing the size of reservoir is that it must hold a 2- to 3-minute (min) supply of oil for the pump. Thus, if the pump delivers 10 gallons per minute (gpm) a 20- to 30-gallon reservoir is adequate. Approximately 1/10 the tank volume should be kept as air space to allow for expansion and tilting of the reservoir due to the ship motion.

This rule-of-thumb is reasonable if the reservoir is a suitable shape and the pump flow does not exceed 25 gpm or so. When pump flow rate exceeds 25 gpm, a reservoir sized to supply 2- or 3-minute oil flow is excessively large. Many systems use pumps that supply more than 100 gpm and according to the rule-of-thumb would require a 250- to 300-gallon reservoir. This represents a large expenditure in hydraulic oil and a lot of deadweight. Unless abnormal circumstances exist, the hydraulic reservoir need never hold more than 100 gallons and usually a much smaller reservoir is adequate, even for very high-flow systems. In practice, the size of the reservoir is often governed by the greatest change in volume of oil that occurs in the system as it operates.

4.3 Reasons for Changes in Circuit Oil Volume

The quantity of oil in a circuit changes when the volume of oil contained by components changes. The greatest volume changes occur in cylinders and accumulators. In comparison to these changes, expansion and contraction of oil and other system components due to temperature and pressure effects are small, but should be taken into consideration.

4.3.1 Unequal Displacement of Cylinders A cylinder rod retracted inside its cylinder takes space that is filled with oil when the rod extends, and this oil comes from the reservoir. Larger diameter rods in long stroke cylinders need several extra gallons to make up the volume as the rod extends. When the rod retracts the oil returns to the reservoir. Hydraulic motors and rotary actuators are equal displacement units. They push out as much oil as they receive and do not cause a change in reservoir level.

4.3.2 Oil Stored in Accumulator If the hydraulic circuit includes an accumulator, the reservoir must hold additional oil. An accumulator stores oil under pressure and when it discharges, oil returns to the reservoir.

4.4 Reservoir as Oil Conditioner

Oil returns to the reservoir at high speed, about 15–20 feet per second (ft/s). There it is slowed down and kept at rest before starting another tour of the circuit. Unless decelerated carefully, the rapidly moving oil creates a great deal of turbulence in the reservoir and mixes with the air in it. An air–oil mixture is completely unsuitable for both pumps and motors and the reservoir must be built to prevent this. The reservoir must provide time for the oil to release any small amounts of air it may contain before reentering the pump. The reservoir should help cool the oil and it must keep it clean. The reservoir must certainly not cause any further contamination. The oil goes directly from the reservoir to the pump inlet, therefore, when it leaves the reservoir, it must be clean, cool, and free of air.

4.5 Avoidance of Turbulence in Reservoir

Air must not mix with the oil, so be sure only bubble-free oil reaches the pump.

1) Turbulence is mainly caused by oil moving too rapidly into the reservoir. To reduce turbulence, slow down the oil before it gets to the reservoir by using piping as large as possible.

2) Be sure the return line discharges the oil well beneath the surface. Oil directed onto the surface causes splashing, turbulence, and entrainment of air.

3) A simple perforated metal can fitted on the end of the return pipe and submerged in the oil will act as a diffuser to decelerate the oil. The rapidly returning oil enters the can, hits the blank end, is forced to turn sharply, and exits through the perforations. The diffuser size should be calculated to give the oil a speed of 1 ft/s as it passes out the perforations. Use material that is 60% sheet metal and 40% holes. This diffuser is a simple effective device that allows the use of small reservoirs (Fig. 6).

4) Another cause of turbulence is oil sloshing in the reservoir as the ship pitches and rolls. Baffles inside the reservoir reduce this turbulence. One baffle is usually sufficient in a hydraulic reservoir. It is a flat plate positioned down the center of the reservoir to separate the returning oil from the suction oil. It must not restrict oil flow in the reservoir but allow the longest possible time for the oil to rest and rid itself of any

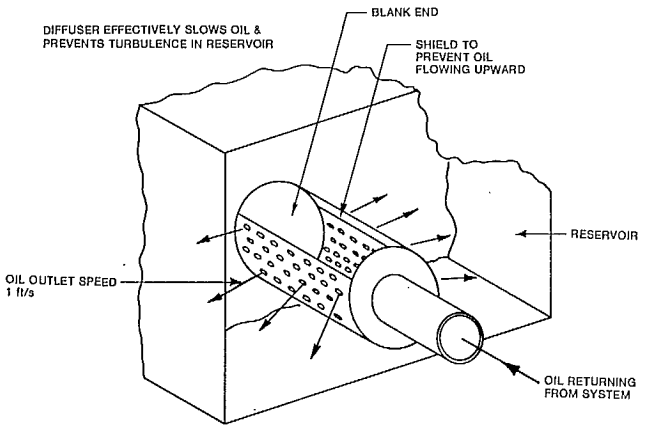


FIG. 6. Typical return-line diffuser

impurities. The baffle must never protrude above the surface of the oil. If it does, the level in the suction side goes down as oil is pumped out, the return side level rises and oil pours over the baffle causing turbulence. The height of the baffle should be about two thirds the minimum depth of the oil, and allowance should be made for the rise and fall of the oil level when the system is in operation.

5) Oil rests for a longer time in a large reservoir before it is reused and, consequently, turbulence is reduced. However, the lack of space in a fishing boat, the dead weight, and the cost of a large reservoir of oil, make this method of reducing turbulence undesirable.

4.6 Reservoir Used as Oil Cooler

The ability of the reservoir to help cool the oil depends mainly on its size. There are formulas to predict the amount of heat horsepower the reservoir will release. One formula divides the "wetted" area of the reservoir (in square feet) exposed to the atmosphere by 10 to give the horsepower that is dissipated when oil is kept at a temperature 33 Celsius degrees (60 Farenheit degrees) above air temperature. The wetted area of the reservoir is the surface area of the reservoir that is wetted by the oil. This includes the bottom if it is clear of the deck but not the lid because it is not in contact with the oil.

4.7 Sealing the Reservoir

Shipboard reservoirs always have lids, if only to prevent the ship motion from spilling oil, but a lid on a hydraulic system reservoir is more important for another reason. Airborne dust and dirt can cause damage and failure of hydraulic system components, therefore, only clean air can be allowed to contact the oil surface.

The lid, aided by a gasket, forms a completely airtight seal on the reservoir. But the reservoir must breathe as oil level and temperature change, so a very fine filter is installed in the lid to filter the air. Air can enter the reservoir only through the air filter. If the reservoir lid does not seal properly, or if there are other holes for unfiltered air to enter, the air filter is useless. Oil is added to the system through an opening in the reservoir lid. This opening has to be sealed, but often it is combined with the air filter opening, and a combined air filter and filling cap, called a filler-breather cap, is used.

4.8 Reservoir Accessories

In addition to an air filter and oil filler cap each reservoir needs the following accessories:

1) At least one oil level indicator on the reservoir where it is easily seen. Often two indicators are fitted on opposite sides of a reservoir to allow readings to be taken, which can be averaged to give the contents of the reservoir when the ship is listing.

2) A clean-out panel to permit the interior of the reservoir to be serviced occasionally. Sometimes the lid serves as the clean-out panel but usually this panel is fitted at one end of the reservoir and it must be sealed with a gasket. The panel must be retained by studs welded to the reservoir. Studs screwed into tapped holes are not leakproof and must not be used.

3) An oil temperature gauge.

4) A drain cock to drain oil and any water that may collect in the bottom of the reservoir.

5) A temperature controller is always installed in the reservoir, where a water-cooled oil cooler is in the circuit, to regulate the flow of cooling water which in turn controls the oil temperature.

6) A suction-line strainer, which is a coarse filter. One of these is usually fitted on the suction line leading to each pump from the reservoir. This is to protect each pump from large (greater than .005 in.) material accidently entering the reservoir. A suction-line strainer can restrict oil flowing into a pump inlet and, therefore, it must have a large enough mesh to create almost zero pressure drop when first installed.

7) A magnet is sometimes installed to pick up any magnetic particles such as chips of iron and steel. Strainers and magnets collect the larger solid contaminants and prevent them from reaching the pump. They do not in any way replace a filter of the correct rating for the system, nor does their presence suggest that dirt may be permitted to enter the reservoir.

8) Often an oil-level switch is useful. This is an electrical switch mounted inside the reservoir and actuated by a float. The switch sets off an alarm if the oil level becomes dangerously low.

4.9 Reservoir Construction

A hydraulic reservoir is made of sheet steel because steel is strong and a good conductor of heat. Mild steel is less expensive than stainless steel and more popular. Sheet metal is processed to remove all

rust and scale, then cut and welded to the required shape. A tall narrow tank is more suitable than a low flat model. A tall tank keeps the oil deep, and more effectively prevents sloshing. A baffle divides the interior of the reservoir into two equal spaces, one for suction and one for return lines. A large, removable clean-out panel is essential on every reservoir. It is important that the reservoir be uncomplicated so the interior can be thoroughly cleaned more easily after construction. After fabrication and cleaning, the inside of the reservoir is oiled to prevent formation of rust. An internally dirty or rusty reservoir is not acceptable.

4.10 Rust Prevention

High humidity can cause rust to form above the oil level inside a mild steel reservoir. This is due to the condensation of moisture from the air when the hydraulic system cools after operation. Rusting of the interior of the reservoir can be prevented by coating it with one of the following:

1) A special oil resistant paint is sometimes used, but it may not always adhere properly and can flake off to become a contaminant.

2) Phosphating is a chemical process that applies a thin, harmless, spongy coating to the inside of the reservoir. The porous coating becomes soaked with oil and keeps moisture from reaching the bare metal.

If a mild steel reservoir has to be treated to increase its rust resistance, it becomes more expensive. When special rust resistance is needed, it is worthwhile to consider a stainless steel reservoir as an alternative.

5. HYDRAULIC SYSTEM PIPING

Hydraulic power transmission components must be connected together with piping that transmits oil power efficiently and reliably. Hydraulic power piping systems are subjected to pressures ranging from less than atmospheric pressure, a vacuum, to several thousand psi. High pressures occur only in the lines connecting one power-transmitting component with another, and low pressures are always present in the lines that carry oil to and from the reservoir. It is important to remember that the oil in the high-pressure parts of the circuit also flows through the low-pressure lines, and must be kept clean. The bore of all hydraulic power piping for both high and low pressures, must be thoroughly clean or it becomes another source of contamination.

5.1 Hydraulic Power Transmission Piping Materials

There are three types of piping material used in hydraulic power transmissions: (1) tubing, (2) flexible hose, and (3) pipe.

1) *Hydraulic tubing* is made specifically for use in hydraulic power systems from cold drawn, annealed and pickled, low carbon steel. This tubing can easily be formed to suit all installations and fittings. It is made seamless or with a welded seam and both types are made for all pressure ratings. Hydraulic tubing is easily identified. When cleaned it has a bright finish and a highly polished bore that is free from scale and defects. When received from the supplier the bore of hydraulic tubing should be covered with a sticky rust preventive compound and the ends should be plugged. Reject any tubing that has rust in the bore.

Tubing size is always given by the outside diameter (OD). The sizes used in hydraulic systems range from ¼ in. OD, the smallest, through ⅜, ½, ⅝, ¾, ⅞, 1, and 1¼ in. OD, although the ⅝, ⅞, and 1¼ in. sizes are not as widely available as the others. Larger diameters can also be obtained. Remember that the bore of tubing is always less than the outside diameter by twice the wall thickness. Several wall thicknesses are available for each size tubing to meet different maximum operating pressures, but the thicker the wall the smaller the bore.

2) One advantage of *flexible hose* or piping material is that it is generally the easiest to install, but it takes more space than rigid piping materials. It is essential that flexible hose be used to connect components that move relative to each other, and often the hose flexibility helps to eliminate the transmission of vibration, noise, and shock. Flexible hose used for hydraulic systems is fundamentally a synthetic rubber tube wrapped in steel wire or tough fabric braids to make it strong enough to resist high pressures. Steel couplings are attached to the ends of the hose to make it suitable for coupling to other components. Because of its construction, flexible hose has flexibility limits that decrease as its size and pressure rating increase. Hose rated for high pressure is not usually recommended for lines subject to vacuum conditions. Be sure the hose material is suitable for use with hydraulic oil. A Buna N elastomer material is commonly used with standard mineral base oils. Flexible hose is unlikely to rust but is not as durable as steel piping. It has to be treated carefully and kept away from anything that may damage or chemically attack the materials. The hose size is usually, but not always, given by bore diameter and is available in the common "inch" sizes up to 2-in. bore for high-pressure service. Larger sizes are available for low-pressure service.

3) *Pipe* is the most common piping material but its application to hydraulic power transmission is probably the most common cause of contamination. When delivered, pipe is usually dirty and the bore is covered with rust and scale. This contamination must be removed before use. Often this is difficult but it is absolutely necessary if a reliable system is to be constructed. Another disadvantage is that the most common method of joining pipes is by a tapered screw thread cut on the

pipe ends. This pipe thread makes it difficult to create leakproof, high pressure joints. When these two problems are overcome, pipe becomes a useful and reliable means of transmitting oil power, particularly when the lines are large.

Only steel pipe may be used in hydraulic systems. The types of steel recommended by the hydraulic industry standards authority are low carbon varieties described under ASTM specifications A106 grade B and A53 grade B, type F or S depending on pipe size and working pressure.

When pipe was standardized, size was given by bore diameter. For example, a 1-inch pipe had a 1-inch bore. The OD had to be large enough to make the pipe rigid and provide a wall thickness suitable for a screw thread for joining purposes, so pipe always had an OD larger than its size. As system pressures increased the wall thickness of "standard" pipe increased and "thick wall" pipe was introduced to withstand higher pressures. Because it is not convenient to change the OD, the wall was made thicker by decreasing the pipe bore and the bore of extra strong pipe can be less than nominal size. Today, pipe is available in three ranges of wall thickness called schedules. Schedule 40 is standard pipe with a bore approximately the same as the size. Schedule 80 pipe has a thick wall and originally was named "extra strong" pipe. Schedule 160 pipe has a thicker wall and a bore less than its size. Double extra strong pipe can also be obtained with a very thick wall that reduces the pipe bore to about half nominal size. When pipe heavier than standard (schedule 40) is needed, remember the bore may be considerably smaller than the pipe size suggests.

5.2 Guide to Selecting Hydraulic Lines

The work of forcing oil through hydraulic circuit piping results in a drop in the pressure, and this loss means there is less pressure to drive the hydraulic actuator. In addition, piping losses reduce the efficiency of a hydraulic system, therefore, it is sensible to keep losses as small as possible. If the piping bore is large, losses are reduced. As large pipes are heavy and take up much space, a compromise between efficiency and size is necessary.

5.2.1 Pump Suction Line Many experts in the hydraulic power industry consider the pump suction line the most important line in the circuit. This may seem surprising because it is not a high-pressure line and often is under vacuum conditions. The pump suction line is important because it transports oil from the reservoir to the pump inlet port, and ensures that the oil arrives in good condition. In a properly designed reservoir oil is decelerated and prepared for delivery to the pump. The pump suction line must not adversely affect the resulting good condition of the oil. It must be large enough and have as few bends as possible so that it offers a minimum resistance to the flow of oil.

5.2.1.1 ***Atmospheric Pressure*** Atmospheric pressure is usually the only pressure available to force oil through the pump suction line, and very little pressure loss in the line can be tolerated. If atmospheric pressure could be completely expended in pressure drop in the line, the drop would be 15 psi, but for several reasons this cannot be done.

5.2.1.2 ***Dissolved Air*** All oils contain a small amount of dissolved air, which is invisible. Under normal pressure conditions the air remains dissolved and can be forgotten. However, if the oil is placed under vacuum conditions the air tends to come out of solution and circulate as bubbles.

5.2.1.3 ***Vapor Bubbles*** When a liquid boils, vapor bubbles form in the liquid. Normally oil boils at a high temperature but when subjected to vacuum conditions it boils at much lower temperatures. On a mountain top air pressure is much lower and oil will boil at a much lower temperature. The same applies to oil in a vacuum and vapor bubbles form as the oil enters the pump inlet if the pressure is too low.

5.2.1.4 ***Number of Pipe Joints*** There should be as few joints in the pump suction line as possible. Joints make steps or discontinuities in the line bore that cause turbulence and pressure loss, but in addition air may be drawn into the pump at each joint, and this possibility increases as the vacuum inside the line increases.

5.2.1.5 ***Aeration and Cavitation*** If a suction line is too small there is a possibility that air will be drawn in and also that air, normally dissolved in the oil, will come out of solution. Introduction of air bubbles into the oil is called aeration. Formation of vapor bubbles in the oil due to vacuum conditions is known as cavitation. The effects of both aeration and cavitation are the same and are disastrous in the hydraulic system. Air and vapor bubbles enter at very low pressure and collapse under the pressure developed in the pump. This shocklike collapse causes an implosion (the opposite of an explosion) and shock waves and high temperatures are generated in the oil. These actually chip away minute pieces of the internal parts of the pump, and cause the decay and break down of the oil.

5.2.1.6 ***Suction Line Oil Speed*** Because the pressure drop in the suction line has to be small, flow along the line must be gentle. A good guide to ensure a gentle flow is to size the bore of the suction line so oil has a maximum speed of 5 ft/s. To calculate the speed of oil in the line divide the pump flow (US gpm) by the line bore size in inches multiplied by itself, then multiply

by 0.4. This gives oil speed in feet per second, that is:

$$\text{Speed of oil (ft/s)} = \frac{\text{US gpm}}{d^2} \times 0.4$$

5.2.1.7 ***Straight Suction Line*** Anything that disturbs the smoothness of the flow inside piping lowers the pressure in the oil. The pump suction line must be as straight as possible and contain the least number of joints and sharp bends to keep line loss low and avoid the risk of cavitation and aeration in the oil.

5.2.1.8 ***Flexible Suction Line*** The pump and reservoir should not be rigidly connected by the pump suction line. If they are, joints in the line will be strained as expansion and contraction occur due to heating and cooling, and the risk of leaks will be increased. Also, vibration of the pump will tend to cause joints to loosen and increase the system noise level. A suction line constructed wholly or partly from hose provides sufficient flexibility. Another method is to make the suction line completely from steel but have it pass through a snug fitting rubber grommet where it leaves the reservoir. The grommet provides sufficient flexibility as well as an airtight seal in the reservoir lid.

5.2.1.9 ***Suction Line Location*** The end of the pump suction line must be well below the lowest oil level permitted in the reservoir.

5.2.2 Pressure Piping Pipes that carry oil from the pump to the actuator must withstand high pressure and not create too much resistance to flow. The need for very low pressure drop (important when selecting a pump suction line) is not as critical for pressure lines because the oil is under pressure and there is no danger of it foaming. A large pipe subject to high pressure needs a thick wall and may become too heavy and bulky to be practical. Therefore, a greater pressure drop is permitted to keep the size of this type of line reasonable. A useful rule to use when sizing the bore of pressure lines is to allow the oil to flow at 15 ft/s, then the formula used to calculate suction line oil speed can be used to calculate the pipe bore (see Section 5.2.1.6).

When a pipe bore capable of handling the flow rate has been chosen, a wall thickness that will safely withstand the maximum pressure must be selected. This is most easily done by referring to charts that show permissible working pressures of various line bores and wall thicknesses. These charts are published in many hydraulic power transmission information books.

5.2.3 Return-Line Piping These low-pressure lines are usually sized for flow at 15 ft/s, but, if practical, should be made larger to reduce the speed of oil entering the reservoir.

5.2.4. Drain Lines These low-pressure lines drain small internal leakage of components back to the reservoir. Do not underestimate the importance of drain lines because the back pressure generated by leakage oil can be high enough to cause malfunction of the components. Always make drain lines at least as large as the tapping in the component and run them directly and individually to the reservoir.

5.3 Hydraulic Fittings

It is not good hydraulic power practice to join piping materials by welding, brazing, soldering, or any other permanent method. They must be screwed or bolted together or to other components, so the cleanliness of the bore can be controlled before and after the joint is made. The wall thickness of tubing is too thin to allow threading, and fittings must be attached to the ends of the tubing to provide a threaded connection with other components. Flexible hose also requires fittings attached to the ends for coupling purposes. However, the wall thickness of pipe is suitable for threading, or flanges can be attached to the end of the pipe.

5.3.1 Pipe Threads The most common method of connecting hydraulic system components is with taper pipe thread but it has several disadvantages. The taper pipe thread is popular because of the belief that leaks can be stopped simply by tightening the thread onto the taper, but this does not always work and an overtightened fitting can split the body of the female part of the coupling. The hydraulic power industry is replacing taper pipe thread with a parallel thread (usually called a straight thread) in conjunction with a simple O ring to prevent leakage (Fig. 7).

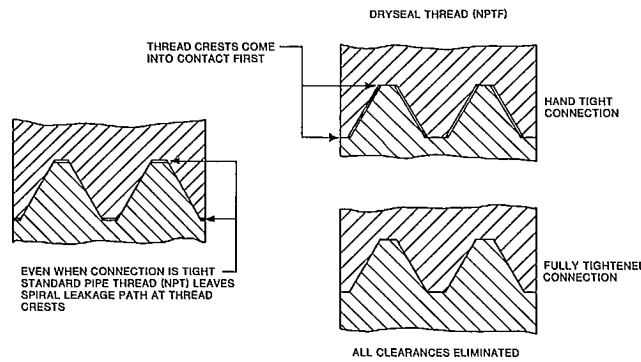


FIG. 7. Difference between standard and Dryseal pipe threads

The taper pipe thread for general plumbing work is not the same as that used in hydraulic power transmission practice, although the two thread types have the same number of threads per inch (TPI), the same taper, and can be screwed together. When two parts with the American Standard Taper Thread are connected, the flanks of the threads are in contact but a spiral leakage path remains along the crests and roots of the threads that has to be filled with a sealant. A

good quality thread can be sealed and take high pressure, but a poor quality thread can resist all efforts to stop leakage. American Dryseal Taper Thread is used in high quality hydraulic components. The advantage is that when two parts are screwed together the roots and crests of the threads come into contact before the flanks engage, so the spiral leakage path is eliminated. A sealant is not needed for a Dryseal joint, but a good lubricant is essential to prevent the threads from jamming when tightened.

Avoid taper pipe threads whenever possible but if they must be used insist on American Dryseal Taper Thread. Select hydraulic industry style flanges for connecting large diameter pipes and straight thread fittings with O-ring seals for smaller lines.

5.3.2 Tube Fittings A tube fitting slides onto the end of a tube and clamps it, so it will not break or pull off under pressure and vibration. One end of the fitting body is threaded for attachment to other components, and at the other end a good high-pressure seal is obtained by pressing the tube and the fitting together. Most tube fitting designs use a metal-to-metal joint but a few use a softer material between the two to provide a positive seal. The tube material is usually a ductile steel as it can form an effective and safe joint with the tube fittings. It is essential that only approved steel hydraulic tubing be used with these fittings. There are two widely used groups of tube fittings. They are either flared or flareless depending on whether the end of the tube is belled out to make the joint between the tube and the fitting.

5.3.2.1 ***Flared Fittings*** With this type, the end of the tube is flared outward to mate with the conical male end of the fitting. There are two styles of flared fittings in wide use, only one of which should be used in hydraulic systems. The main difference between the two is that one has a flare angle of 37° and the other a flare angle of 45°. Hydraulic power transmission systems use only the 37° flare fitting, because it gives a longer sealing surface and does not deform the tube end as much as the 45° flare. The 45° flare is used in automotive brake and fuel systems and in the refrigeration industry. The 37° flare is an old and proven method of attaching tubing to fittings and each fitting assembly consists of three pieces, a body, sleeve, and nut. The sleeve clamps the flare onto the body and protects the flare from the rubbing action of the nut as it is tightened. A special flaring tool is needed to prepare the end of the tube but this is a minor inconvenience.

The Flodar Self-Flaring fitting dispenses with the need for a special tool by forming a 25° flare as the fitting is tightened on the tube end (Fig. 8).

5.3.2.2 ***Flareless Fittings*** These fittings do not require a flare on the tube end and can be assembled without special tools. They grip the tube either by biting into the outer surface (bite-type fittings) or by causing a slight collapse of the tube by compressing it (compression-type fittings). Like the flared fittings, flareless types usually consist of three parts, a body, nut, and a sleeve that bites or clamps.

5.3.2.3 ***Selection of Tube Fittings*** All types of tube fittings are reliable and each has advantages, but with such a wide range there is a problem selecting the most suitable type. The following are a few rules to help in the selection:

1) It is most important to select fittings that are readily available.

2) The fittings must be available in shapes such as straight connectors, elbows, tees, crosses, and bulkhead connectors.

3) Reducing size fittings must be easily obtained.

4) Fittings must be suitable for connecting onto hose couplings.

5) The most widely used tube fitting is the 37° flare type, but special flaring tools are necessary with these. Other types of fittings do not require special tools but may be harder to obtain.

6) The true cost of fittings is their purchase price

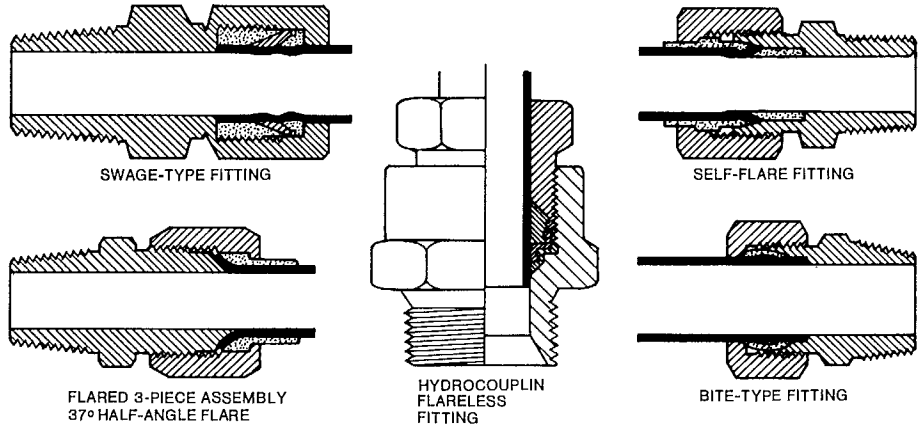


FIG. 8. Typical tube fittings

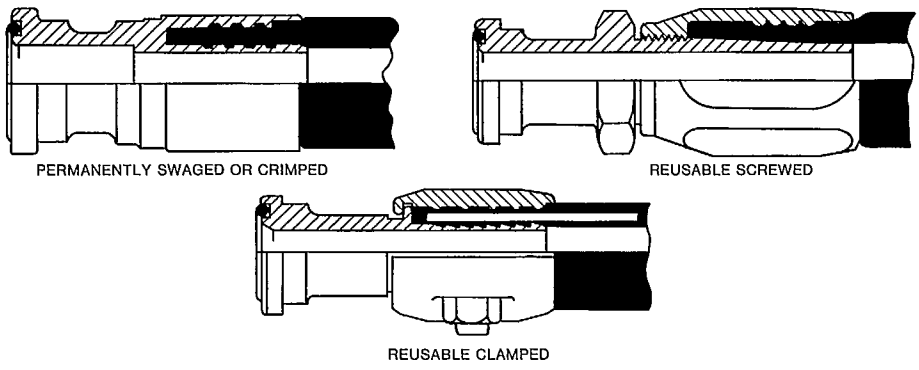


FIG. 9. Methods of attaching hose to fittings

plus the cost of installation. One type of fitting may be priced lower than another, but if installation time is doubled the higher priced fitting could be the better buy. The need for special tools and a large number of loose pieces in the fitting assembly increases the cost of installation.

5.3.3. Hose Fittings Flexible hose must have couplings attached to the ends to connect the hose to other components. There are two methods of attaching these couplings. The reusable coupling is either clamped or screwed onto the hose end. This type of fitting can be salvaged and used again with new hose. With the other method hose couplings are permanently crimped or swaged to the hose, and must be scrapped when the hose is replaced. The free end of each coupling has one of a variety of threaded ends of flanges to make it suitable for connection to other components (Fig. 9).

5.3.4 Pipe Fittings Properly prepared pipe needs fittings in the shape of elbows, tees, and crosses to form bends and branch connections. Pipe fittings are available for either low-pressure or high-pressure service. Low-pressure hydraulic pipe fittings are made from malleable cast iron only, and have the standard taper pipe thread. These are common plumbing fittings and are suitable for low-pressure hydraulic service provided they are not galvanized. The galvanizing (zinc plating) flakes off in service and contaminates the circuit. Low-pressure iron fittings must be thoroughly cleaned before use and have undamaged threads. High-pressure pipe fittings are made from forged steel or mild steel bar stock. Forged steel fittings for the general piping industry are readily available and rated for working pressures of 2000, 3000, or 6000 psi. These are non-shock ratings which means that if maximum system pressure is 1800 psi for example, a 3000 psi fitting should be chosen instead of one rated 2000 psi. Similarly, if maximum system pressure is 2800 psi, a 6000 psi fitting should be chosen. Forged steel pipe fittings designed for the general piping industry are made with American Standard Taper Thread, and can be used in hydraulic power transmission systems if they are clean and have undamaged threads. However, pipe fittings of mild steel bar stock or forged steel made specifically for the hydraulics industry are preferred. They always have the American Dryseal Taper Thread to help achieve a leakproof seal. The pressure rating of hydraulic pipe fittings makes them generally suitable for schedule 80 pipe. It is often convenient to attach flanges by welding or screw threads to the ends of pipes larger than 1 inch. Welding is permissible because the pipe bore can be cleaned after welding, and is preferred to a threaded joint. Where a joint is made by flanges bolted together a leakproof seal is obtained by means of an O ring. It is held in a groove in the face of one flange and compressed against the other when the flanges are pulled together. The pipe flanges for hydraulic power transmission are not the same as those for the general piping industry. They have been specially designed for high-pressure oil, have the O-ring seal, and are much smaller than those in general piping work (Fig. 10).

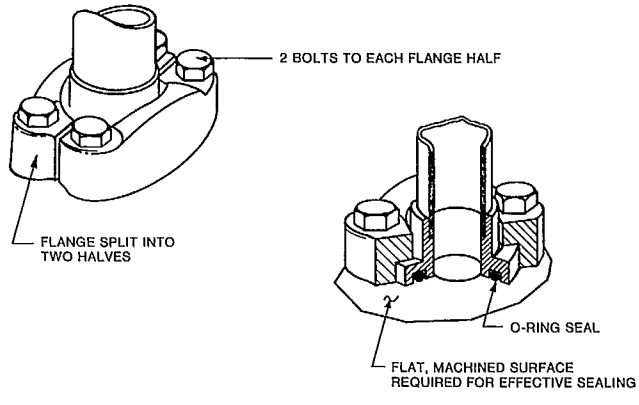


FIG. 10. SAE 4-bolt, split-flange oil connection

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