SAUER DANFOSS

Applications Manual

Section 3

Fluids and Filtration

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3.1 Fluid Quality

3.1.1 General Requirements

This section outlines Sauer-Sundstrand's fluid quality requirements for fluid which is used in piston hydraulic units. (See Section 3.6 for a glossary of fluid-related terms).

The ability of a hydraulic system to maintain desired performance for the expected life depends on the quality of fluid being used. Fluid quality can be measured in three general categories: physical properties, chemical properties, and performance properties. Table 3-2 provides a summary list of fluid property requirements recommended for high quality mineral base hydraulic fluids. The fluid physical property, viscosity, is covered in detail in section 3.1.3.

Sauer-Sundstrand's field experience indicates that most hydraulic failures result from a breakdown of fluid quality as the result of overheating or water or air contamination resulting in excessive wear or corrosion. Selecting fluids with good thermal, hydrolytic, and shear stability will often times prevent the onset of excessive wear or corrosion (See table 3-2 for recommended thermal, hydrolytic, and shear stability properties). Cleanliness of the fluid, although not a fluid property, is extremely important in meeting life expectancy of the equipment (recommended levels of fluid cleanliness are outlined in section 3.1.4).

Premium grade antiwear hydraulic fluids are recommended for the satisfactory performance of Sauer-Sundstrand axial piston units and are highly recommended for series 51 bent axial motors. Other fluids that have been used successfully include the following: premium turbine oils, CD engine oils, automatic transmission fluids, and tractor fluids. Some Dexron III fluids and tractor fluids have exhibited a susceptibility to yellow metal etching (See PIB-9613), therefore, extreme caution is advised when using either of these fluids. If you are currently using Dexron III or tractor fluids successfully, we are not recommending an immediate change, but do recommend fluid analyses to monitor fluid changes that may indicate a problem. The limits of metal contamination that are considered acceptable are as follows (exceeding any single one of these limits may indicate a wear or corrosion problem):

Metal Contamination Limits	
Pb = 10 ppm	Fe = 50 ppm
Si = 15 ppm	Al = 10 ppm
Cu = 50 ppm	Cr = 5 ppm
Sn = 10 ppm	Sb = 5 ppm

Table 3-1

Fire-resistant fluids are also suitable, often at modified conditions, as well as environmentally acceptable (biodegradable) fluids. For more information regarding fluids that are fire-resistant or environmentally acceptable, see sections 3.3 and 3.4.

3.1.2 Recommended Hydraulic Fluid Property Requirements for Use in Axial Piston Pumps

The fluids defined by table 3-2 are high quality mineral base oils formulated with additives to meet the requirements listed. Fluids meeting these requirements will very likely provide acceptable unit life, but field testing is the only true indication of fluid performance. Some mineral based, synthetic, fire resistant, and biodegradable fluids, not measuring up to these recommendations, have exhibited successful performance. Also, fluids meeting specification DIN 51524 parts 2 and 3 have provided acceptable unit life.

See section 3.3 for modified operating parameters of fire resistant fluids and section 3.4 for a listing of successfully applied biodegradable fluids (Reference bulletin ATI-E 9101).

Recommended Hydraulic Fluid Property Requirements

FLUID PROPERTY	SPECIFICATION	REQUIREMENTS
Pump Wear		
Dennison T5D vane pump and P46 piston pump	HF-0	Pass
*Vickers 35 V Q25 vane pump	Vickers M-2950-S	Pass
Viscosity		
Viscosity index	ASTM D-2270	90 minimum
Pour point	ASTM D-97	Start-up to be 30˚F above maximum 1600 sCt
Pour point of fluid or Kinematic Viscosity	ASTM D-445	6.4 sCt minimum at operating temperature.
Specific Gravity	....	.84 - .90 at 60˚F
Hydrolytic Stability	ASTM D-2619	
Copper specimen weight loss	....	0.20 mg/cm^2 maximum
Acidity of water layer	....	4.0 mg KOH maximum
*Copper specimen weight loss	....	0.5 mg/cm^2 maximum
*Acidity of water layer	....	6.0 mg KOH maximum
Sauer Sundstrand 22 Series Pump Performance	South West Research Institute Test or JDQ 84	Pass
Thermal Stability		
Results after 168 hrs. at 275˚F	Cincinnati Milacron P68, P69, P70	
Sludge	....	25 mg/100 ml maximum
Copper weight loss	....	10 mg maximum
Copper rod color (CM)	....	5 maximum
Steel rod color (CM)	....	5 maximum
Oxidation Stability	ASTM D-943	
After 1000 hrs. minimum	....	Total Acid Number (TAN) = 2.0
Filterability	Dennison TP - 02100	
Filtration time w/o water	....	600 seconds maximum
Filtration time w/2% water	....	Not to exceed double the time w/o water
Rust	ASTM D-665, procedures A & B	Pass
Foam	ASTM D-892	
Allowable foam after 10 minutes		None
Aniline Point	ASTM D-611	100˚C Minimum
Demulsibility	ASTM D-1401	40/40/0 (30 min) maximum at 55˚C

*Applies only to Series 51 Product

Table 3-2

3.1.3 Viscosity and Temperature Requirements

Specifications for viscosity and temperature limits must be met simultaneously.

The **viscosity** of a fluid is extremely important for acceptable performance. Viscosity depends on the fluid selection and the operating temperature of the system. The fluid must have low enough viscosity to allow flow through the filter and hydraulic lines without excessive resistance. However, a fluid that is too thin (low viscosity) will not maintain an adequate oil film between sliding surfaces, and wear due to a lack of lubrication will result. Also, a fluid that is too thin will result in loss of efficiency and excessive heat generation.

Normal recommended operating viscosities are typically 12 to 60 cSt (70-278 SUS) for optimum system performance. Maximum life for bearings, however, typically require a fluid viscosity not less than 25 cSt (164 SUS).

Each Sauer-Sundstrand product technical information bulletin includes viscosity recommendations for best life and efficiency. For viscosity guidelines for a particular Sauer-Sundstrand product, refer to the technical information bulletin for that product.

Viscosity index improved (multi-viscosity) fluids may noticeably shear down in service when used in hydrostatic transmissions. This will lower the operating viscosity below the originally specified value. The lowest *expected* viscosity must be used when selecting fluids. Consult your fluid supplier for details on viscosity sheardown.

Fluid **temperature** affects the viscosity of the fluid and resulting lubricity and film thickness. High temperatures can also limit seal life, as most nonmetallic materials are adversely affected by use at elevated temperature. Fluids may break down or oxidize at high temperatures, reducing their lubricity and resulting in reduced life of the unit. Cavitation is also more likely at high temperatures. See product technical information bulletins for recommended temperature limits. These temperature limits apply at the hottest point in the transmission, normally the case drain.

Heat exchangers should be sized to keep the fluid within the recommended temperature limits. This is normally done by selecting the worst continuous operating condition, and sizing for all the transmission loss being cooled in the hottest ambient environment, at the continuous temperature rating. For many machines, this occurs at the highest transmission output speed obtainable. Testing to verify that these temperature limits are maintained is recommended.

Excessive heat may be generated by other circuit components. Circuit designs should avoid depending on high pressure relief valves as the maximum pressure limiter of the system, as frequent operation of these relief valves will generate intolerable heat. Circuit components with high internal leakage also contribute to heat problems. Circuits containing flow control valves such as flow dividers are susceptible to heat generation since they function by restricting oil flow with a pressure drop.

Cold oil will generally not affect durability of Sauer-Sundstrand transmission components, but may affect the ability to flow oil and transmit power. In general, cold starts may be made at a temperature 30°F warmer than the pour point of the fluid, or the minimum temperature specified by the most sensitive component in the system.

3.1.4 Contamination Levels

Contamination in hydraulic fluid includes water, air, solid particles, or any other fluid component which impairs the function of the fluid.

When **water** is present in oil-base hydraulic fluids, the effects are detrimental. Water in a system may result in corrosion, cavitation, and altered fluid viscosity. Depending on the fluid, water may also react with the fluid to create harmful chemical by-products or destroy important additives. Left unchecked, water contamination may result in microbial growth. At this stage, system components may already have been damaged.

Air in a system is also regarded as a contaminant. Air *increases* the compressibility of the fluid, resulting in a "spongy" system that is less responsive (see Section 3.5 for a more detailed description of fluid compressibility). Also, air creates a loss of transmitted power, higher operating temperatures, increased noise levels, and loss of lubricity.

Solid particle contamination results from particles ingested externally into the system. The size and quantity of these particles must be controlled in order to ensure adequate life of the system components. Allowable contamination can be described by cleanliness levels established under the ISO 4406 standard. These levels are shown in Figure 3-1. The chart designates a "code number" for a range describing the number of particles of a particular size in one mL of fluid. Note that for most levels, each step from one level to another corresponds to either doubling the number of particles or reducing the number of particles by half.

Typically, the cleanliness level for a fluid is denoted by two code levels. Each level describes the amount of particles for a given particle size. For example, by defining a fluid cleanliness level of 18/13, the code "18" specifies the number for particles larger than 5 µm and the code "13" specifies the number of particles larger than 15 µm in one mL of the inspected fluid. Note that the code number decreases as the particle size increases. This is expected since large particles generally cause the most damage.

Recently, the ISO 4406 standard has been changed to include a designation for the number of particles larger than 2 µm. A fluid with a cleanliness level of 21/18/13 would then have between 10 000 and 20 000 particles greater than 2 µm (code 21). At present, the Sauer-Sundstrand fluid cleanliness recommendations reflect only the particle count per mL of 5 µm and 15 µm size particles.

Acceptable contamination levels at machine start-up for the system loop should be equal or better than Curve C, in Figure 3-1. Curve C represents a 22/17 cleanliness level. The machine may be exercised at minimal load but should not be worked until such time as the cleanliness level meets or exceeds Curve B, which corresponds to a 21/15 cleanliness level. The time required to reach Curve B will be a function of the built-in contaminants at initial assembly (hoses and fittings) and the use of production line flushing and/or circuit elements that flush the system internally (such as loop flushing shuttle valves). The machine may be shipped at this level. The circuit should continue to clean up during a relatively short period of normal operation to meet the oil cleanliness level of Curve A, which is the recommended cleanliness level for continuous operation and normal unit life. Curve A corresponds to an 18/13 cleanliness level.

ISO Solid Contaminant Code

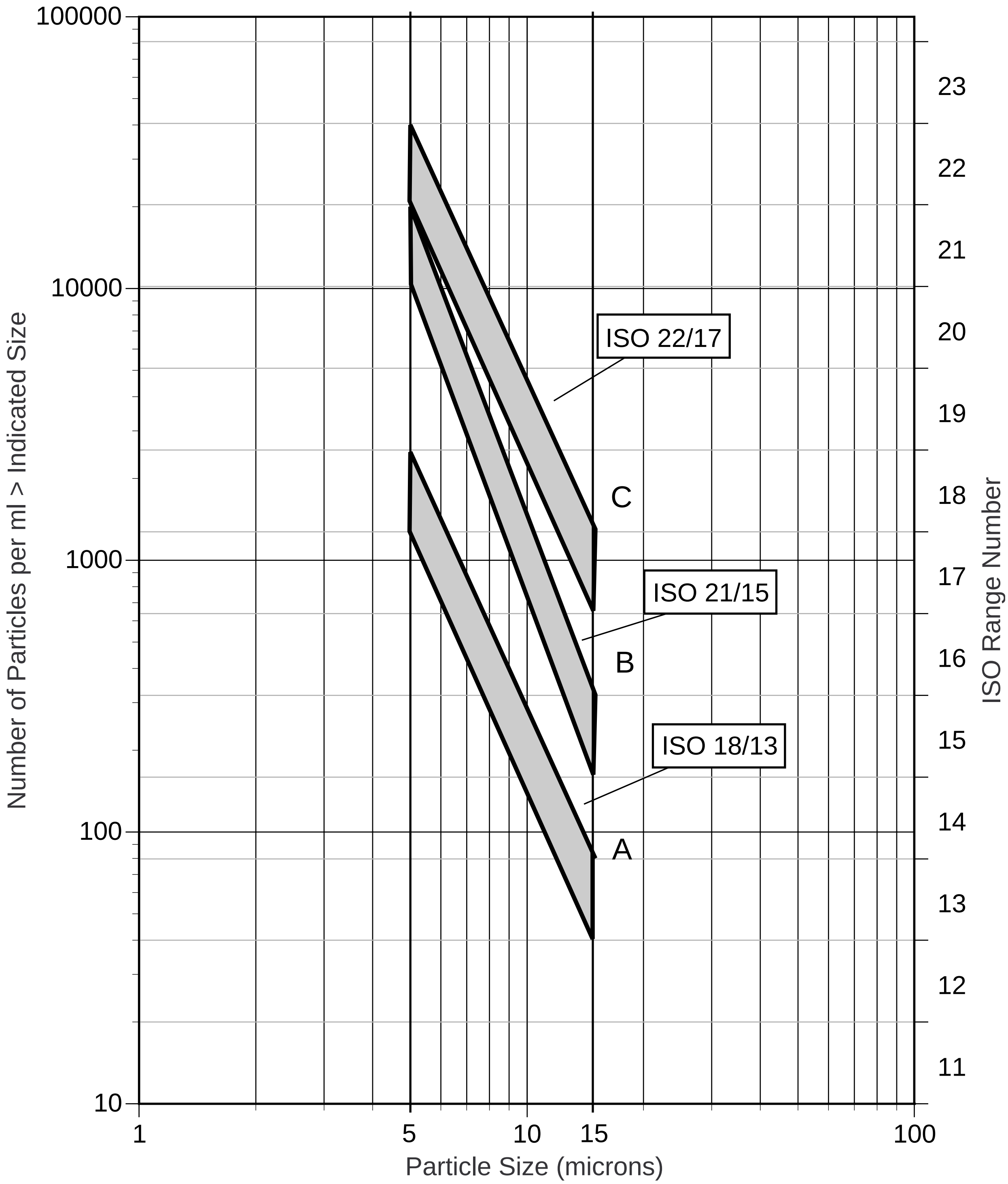


Figure 3-1

When specifying a cleanliness level, it is important to consider the most sensitive component in the system. For example, some control valves may require *lower* contamination limits than specified in Figure 3-1. Controls with small area screens or low force level valves may be susceptible to malfunction from contamination.

The contaminant sensitivity of components generally increases with higher pressure, temperature, or speed. A better fluid contaminant profile may be required for systems which operate near the extremes of their ratings.

Contamination can be controlled by properly designing, installing, and maintaining hydraulic components. For example, reservoirs must be designed to limit the entry of contamination during servicing and operation. A sealed reservoir with a low pressure air vent valve will reduce the introduction of contaminants while maintaining inlet and case drain pressures below the maximum recommended levels.

Hoses, pipes, and fluid couplings must be designed to prevent the entry of air and must be of adequate size. Excessive turbulence will cause air and fluid vapor bubbles to be released, causing cavitation and erosion and associated life reduction.

The purpose of the filter in a system is to clean the oil at initial start-up and to maintain acceptable levels of particle contaminants as they are ingested or generated during operation of the system. Filtration is a matter of controlling the particle sizes and their respective quantities to appropriate levels. Filtration is covered in detail in section 3.2.

3.2 Filtration

3.2.1 General Information

Fluid cleanliness in a hydraulic system is essential for proper operation. Inadequate filtration will damage the system and reduce its operating life. Fluid cleanliness can be maintained only by designing a system capable of removing contaminants from the system.

The selection of a filter depends on a number of factors, including the contaminant ingression rate (the generation of contaminants in the system), the required fluid cleanliness, and the desired maintenance interval. Filters are selected to meet the above requirements using rating parameters of filter efficiency and capacity. **Filter efficiency** describes how well the filter removes contaminants from the fluid and is described in detail in section 3.2.2. **Filter capacity** is a measure of how much contaminant the filter is capable of removing before filter replacement becomes necessary.

There are, in addition, other issues related to filter selection. Considerations of fluid compatibility, temperature, flow, and pressure drop also need to be addressed.

Since each system is unique, the filtration requirement for each system will also be unique and must be determined by test in each case. It is essential that monitoring of prototypes and evaluation of components and performance throughout the test program be the final criteria for judging the adequacy of the filtration system.

Filter manufacturers can also provide information related to filter specifications and capabilities.

For information on filters with respect to circuit design, refer to section 4.1.8.

3.2.2 Filter Efficiency

Filter efficiency is a measure of how effective the filter is at removing contaminants from the fluid. Filter efficiency is based on a quantity known as the beta ratio (β_x). **Beta ratio** is defined as the ratio of the number of particles per unit volume before the filter to the number of particles per unit volume after the filter:

$$\beta_x = \frac{\text{Number of particles before filter / unit volume > "x" } \mu\text{m}}{\text{Number of particles after filter / unit volume > "x" } \mu\text{m}}$$

The x denotes the size of particle being considered. A β_{10} value equal to 20 means that for every 20 particles 10 µm or larger entering the filter, 1 particle passes through the filter and 19 particles are captured. The ratio of upstream to downstream particles is the value which characterizes the beta ratio, not the actual number of particles. For example, the filter above will remove 950 particles of size 10 µm or larger from each mL of fluid having a contamination level of 1000 particles per mL at the filter inlet. For a fluid having a contamination level of 2000 particles, 1900 particles per mL are captured. In both cases the ratio of upstream to downstream particles is the same; only the rate of particle capture for a given flow rate is different.

It follows from the definition that the higher the beta ratio, the more effective the filter is at removing contaminants. This relationship can be expressed as a **filter efficiency**. The equation for calculating filter efficiency is as follows:

$$E_x = 100 \bullet \left(1 - \frac{1}{\beta_x}\right)$$

For the example given, the filter efficiency is calculated to be

$$E_{10} = 100 \bullet \left(1 - \frac{1}{20}\right) = 95\%$$

Therefore, 95% of the particles 10 µm or larger are captured by the filter.

The relationship between beta ratio and filter efficiency is not linear. An increase in beta ratio always corresponds to a theoretical increase in efficiency, but the efficiency increase is less for filters with relatively high beta ratios. Table 3-3 and Figure 3-2 illustrate this relationship. For example, a beta ratio increase from a value of $\beta_x = 2$ to a value of $\beta_x = 4$ corresponds to an efficiency increase of 25%. However, the same beta ratio increment from $\beta_x = 10$ to $\beta_x = 12$ corresponds to an efficiency increase of less than 1%. For beta ratios larger than 75, the increases in efficiency are even less. For this reason, claims of beta ratios greater than 75 have no meaning since any performance improvements are not measurable.

β	Efficiency	% Change
1.0	0.0	
1.1	9.1	
1.2	16.7	83.33
1.3	23.1	38.46
1.4	28.6	23.81
1.5	33.3	16.67
1.6	37.5	12.50
1.7	41.2	9.80
1.8	44.4	7.94
1.9	47.4	6.58
2.0	50.0	5.56
2.2	54.5	9.09
2.4	58.3	6.94
2.6	61.5	5.49
2.8	64.3	4.46
3.0	66.7	3.70
3.2	68.8	3.12
3.4	70.6	2.67
3.6	72.2	2.31
3.8	73.7	2.02
4.0	75.0	1.79
4.5	77.8	3.70
5.0	80.0	2.86
6.0	83.3	4.17
7.0	85.7	2.86
8.0	87.5	2.08
9.0	88.9	1.59
10.0	90.0	1.25
12.0	91.7	1.85
14.0	92.9	1.30
16.0	93.8	0.96
18.0	94.4	0.74
20.0	95.0	0.59
30.0	96.7	1.75
40.0	97.5	0.86
50.0	98.0	0.51
60.0	98.3	0.34
70.0	98.6	0.24
75.0	98.7	0.10
80.0	98.8	0.08
90.0	98.9	0.14
100.8	99.0	0.12
200.0	99.5	0.50

Table 3-3

Beta ratio and **filter efficiency** are measures to determine how well a filter removes particles of a minimum size. Filters can also be evaluated in terms of **filter fineness**. Filter fineness specifies the minimum particle size for a given beta ratio. Filters are then compared on the basis of the particle size associated with the beta ratio. $\beta_x = 75$ is a common beta ratio used for this comparison:

$\beta_x = 75$ (= 98.67% efficient)

As an example, a 10µm filter (read as a "ten micron filter") is capable of removing 98.67% of the particles 10 µm or larger. The smaller the fineness value, the more effective the filter is at removing particles. It is important that the beta ratio associated with the fineness value be understood for valid comparisons between filters. A 5µm filter will remove more particles than a 10µm filter.

Often filter manufacturers specify multiple values for filter fineness. For example, a 2/20/75 filter rating specifies the particle sizes associated with beta ratios of 2, 20, and 75. A filter with a 5µm/10µm/15µm filter rating will then remove 50% of the particles larger than 5 µm ($\beta_5 = 2$), 95% of the particles larger than 10 µm ($\beta_{10} = 20$), and 98.67% of the particles larger than 15µm ($\beta_{15} = 75$).

Selecting a filter to meet ISO fluid cleanliness requirements should be performed by the filter manufacturer since there is no reliable correlation between system cleanliness requirements (ISO 4406) and hydraulic filter performance. However, some general guidelines for closed circuit hydrostatic systems are as follows:

- For a filter in the suction line of a closed circuit system, a filter fineness of $\beta_{35-45} = 75$ will usually achieve the required 18/13 cleanliness level. A filter with $\beta_{10} = 1.5 - 2.0$ generally reaches the same level of performance.

- A filter placed in the charge circuit of a closed circuit system should have a filter fineness of $\beta_{15-20} = 75$ or a $\beta_{10} = 10$ rating. A 100 µm - 125 µm screen should be used ahead of the charge pump to protect it against coarse contamination.

As mentioned, the above statements serve only as guidelines. Filter selection requires working closely with the filter manufacturer to select a filter that will meet the cleanliness requirement. Adequate testing must be included in the selection process.

If a filter proves to be incapable of meeting the required cleanliness level, either a filter with a higher beta ratio must be selected or the flow through the filter must be increased. Filters with high beta ratios usually have higher differential pressure for the same flow rate. Improving cleanliness by changing filter media but not the size of the filter will result in increased pressure differential along with reduced capacity and service.

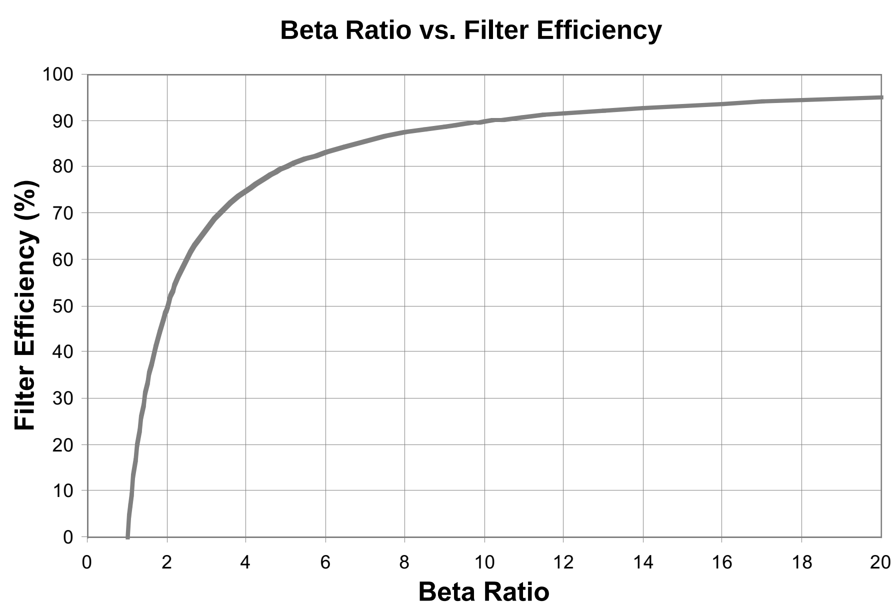


Figure 3-2

3.2.3 Pump Inlet Screening

Most open circuit systems require some inlet filtration by specifying a screen of a certain mesh. A screen is a single-layer filter with an opening size dependent on the mesh specified. It typically passes all contaminant sizes smaller than the pore size opening. A more efficient filter on the discharge side of the pump captures those contaminants passed by the screen. Depending on wire size, a standard wire cloth filter media of 200 mesh will limit the passing of particles larger than 74 µm and a 150 mesh will limit the passing of particles larger than 100 µm. Depending on the flow rate and contaminant ingression rates, screen area is critical in order to keep inlet pump vacuum within limits.

As screen pores become blocked the pressure drop across the screen increases. As with filters, good maintenance procedures are necessary.

3.2.4 Maintenance Requirements

To ensure optimum life of any Sauer-Sundstrand product, regular maintenance of the fluid and filter must be performed. Maintenance and hours between changes will vary with every application. The actual recommendation depends upon the original system cleanliness, the type of reservoir, environment of use, and the circuit. A general recommendation is to change the filter after an initial running of 50 hours or less, with subsequent changes per the vehicle/machine manufacturer recommendations, or at the following intervals:

- System with sealed reservoir: 2000 hrs.
- System with breather type reservoir: 500 hrs.

It may be necessary to change the fluid more frequently than the above intervals if the fluid becomes contaminated with any foreign matter or if the fluid has been subjected to temperature levels in excess of the maximum recommended limits. Never reuse fluid.

It is important to check the reservoir daily for proper fluid level. The presence of water, either in suspension (a cloudy milky appearance), or free water in the bottom of the reservoir, must be eliminated.

The filter should be changed whenever the fluid is changed or whenever the capacity of the filter has been reached. A filter has reached its capacity when the pressure differential across the filter becomes excessive. In general, pressure drop across a filter element depends on the filter media, flow rate through the filter, fluid viscosity, and the amount of contaminants captured. As the pores become blocked with particles, flow becomes restricted and pressure drop across the filter increases. As shown in Figure 3-3, this pressure drop starts in an approximately linear manner until rising exponentially. Once this zone is reached, it is time to change the filter. Any further increase in contaminant will result in a large increase in pressure drop.

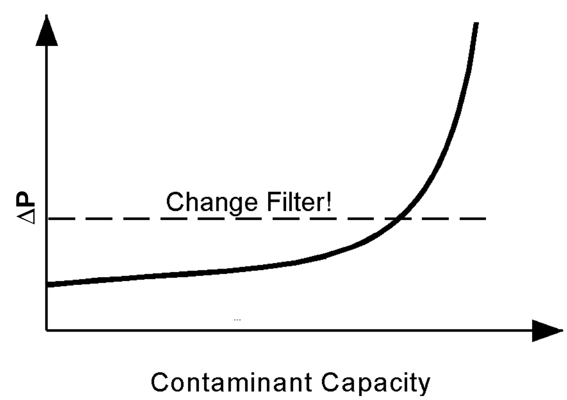


Figure 3-3

A contamination indicator will sense the pressure drop and provide a signal to indicate when the filter needs to be changed. If a suction filter is used with no indicator built into the system, inlet vacuum must be checked and the filter must be replaced if the vacuum approaches the limit specified in the product technical information bulletin for the appropriate Sauer-Sundstrand component.

3.2.5 Filter Bypass

As stated previously, the differential pressure across the filter increases due to contamination. The pressure drop also rises with fluid viscosity. Since the viscosity is high when the fluid is cold, the pressure drop is also high during cold starts. For these reasons, it is recommended that a filter bypass be installed in the circuit.

A filter bypass, shown in Figure 3-4, provides an alternative (unfiltered) flow around the filter when a preset differential pressure is reached. Although the effective filter efficiency is reduced while the bypass is open during cold starts, clean oil is bypassing the filter. The degree to which fluid quality degrades will depend on the amount of time the bypass is open and the rate of contaminants entering the system. Working with an open bypass should be limited only until the temperature attains a reasonable number. This would typically be less than 15 minutes.

It is important to understand that if used as explained above, a bypass is always better than the sudden release of contaminants due to damage of the filter element caused by an excessive pressure differential. If no contamination indicator is present, this damage would go unnoticed and the system would continue to operate in the "bypass" mode, leading to premature failure due to contamination.

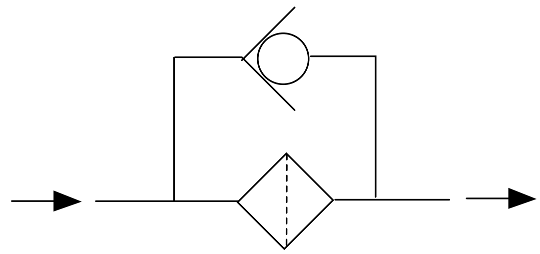


Figure 3-4

3.3 Fire-Resistant Fluids

Fire resistant fluids require special considerations in application of Sauer-Sundstrand units. Materials used in elastomeric seals, filter elements, hoses, and metal and plastic parts may be attacked by these fluids, which may require modification or render the unit unsuitable. System designers must verify that these conditions are satisfactory for each individual application. Consult ANSI B93.5, your fluid supplier, and Sauer-Sundstrand for information on use of fire-resistant fluids.

Because of high specific gravity, these fluids are more susceptible to pump inlet condition problems and generally require reduced vacuum. Also, because of poor air release properties, larger reservoirs are recommended to increase dwell time and reduce aeration of fluids.

Water-based fluids may reduce effective filter pore size and restrict flow. It is advisable to provide increased filter flow capacity and verify that the pressure drop will stay within required limits.

Fluids with water content may require grounding the hydraulic units in order to prevent galvanic action.

Fluid and system maintenance is more critical when using fire-resistant fluids than with petroleum-based fluid. These fluids can change in composition and viscosity over time and affect the ability of hydraulic units and associated equipment to function properly. Frequent monitoring of the fluid properties is required as well as timely maintenance procedures.

It is necessary to modify operating parameters of transmissions when used with a non-petroleum-based fluid. Modified parameters are suggested below. Assuming proper maintenance, and that conditions of material compatibility, inlet condition, and filter suitability are satisfied, the modified limits of speed, pressure, and/or temperature will produce the life normally expected with petroleum-based fluids.

As operating conditions and fluid properties may vary, testing is required to verify actual unit life of hydraulic units operating with fire-resistant fluids. Contact Sauer-Sundstrand if there are questions regarding use of fire-resistant fluids.

Modified Operating Parameters For Fire-Resistant Fluids

Fluid Type	Speed (% Catalog)	Pressure (% Catalog)	Maximum Temp. ° F
Phosphate Ester or Ester w/Oil	100%	100%	180°
Polyolester	85%	85%	150°
Invert Emusion (60 oil/40 water)	65%	70%	140°
HWCF (95 water/5 oil)	65%	40%	122°

See Section 2 for information on ratings and unit life. Contact Sauer-Sundstrand prior to using Series 51 bent axis variable motor in a system using fire-resistant fluids.

Table 3-4

Typically, we have de-rated Water-Glycol fluids to 65% of catalog speed and 60% of catalog pressure. Max temp is 140 deg F.

Phosphate Ester or Ester with Oil requires viton or EPR seals in dynamic locations. Consult the fluid manufacturer to obtain a recommendation for the particular fluid used. These fluids attack some plastics, zinc, and cadmium. The high specific gravity of these fluids requires an inlet vacuum of 2 in. Hg maximum. Use an elevated reservoir and increased inlet line size or pressure reservoir for these fluids. Some of these fluids have caused high wear of aluminum parts in transmissions.

Polyester fluids have been used successfully with standard units. Some fluids are prone to an increase in acid number and this condition must be monitored closely. This class of fluid sometimes produces unusually rapid wear of metal on bearing surfaces, especially in the presence of high temperature and pressure or speed. Certain controls may require hardened parts to achieve acceptable life.

Invert Emulsion fluids can break down with repeated freezing and thawing. Also, heating above 150°F can cause emulsion breakdown. High specific gravity requires an inlet vacuum of 3 in. Hg maximum. Use an elevated reservoir and increased inlet line size. Monitoring of fluid water content is necessary; frequent additions may be necessary in order to overcome evaporation losses. These fluids also show poor vapor phase corrosion inhibition.

Water Glycol attacks zinc and cadmium, and produces solvent action on some paints. Wear of aluminum in transmission parts sometimes occurs in the presence of these fluids. Their high specific gravity requires an increase in absolute inlet pressure. Keep inlet vacuum below 2 in. Hg. Use an elevated reservoir and increased inlet line size. Stability regarding pH and water content can be a problem.

HWCF (95-5) has been used successfully at the reduced operating parameters indicated above. There can be bacterial control problems and corrosion problems. Fluid pH stability can be a problem and can cause wear and chemical reaction with aluminum. Also, there may be a solvent action on some paints. A positive head reservoir is required to maintain a positive inlet pressure when operating, and to keep air out of internal passageways when shut down.

3.4 Environmentally Acceptable Fluids

3.4.1 General Description

Increased environmental awareness has led fluid suppliers to develop environmentally acceptable (EA) fluids which can be substituted for the most commonly used petroleum based fluids and are biodegradable and non-toxic. **"Biodegradable"** means the fluid will degrade naturally by soil organisms when exposed to air. **"Non-toxic"** means the fluid does not pose a threat to fish or animal life.

There are three basic types of EA fluids, although only two are used with any regularity. Vegetable based (i.e., rapeseed/canola) fluids have experienced good success in industrial applications and some mobile applications where maximum fluid temperatures are held constantly below 180°F. Vegetable based fluids possess excellent anti-wear and lubricating properties. Synthetic ester based EA fluids are available where higher fluid temperatures are expected. Each of the vegetable and synthetic ester based EA fluids can be operated at the same speed and pressure levels as mineral based hydraulic fluids.

> *Note: Every fluid supplier's EA product is unique and therefore a blanket endorsement of one fluid type or another is impossible. Component and system qualification by test is required.*

Some fluid characteristics and considerations for usage are as follows:

Temperature - Rapeseed fluids require lower fluid temperatures than most other fluids. This is due to the accelerated oxidation, as measured by the Total Acid Number (TAN) at elevated temperatures. To avoid accelerated aging and oxidation of rapeseed oils, a maximum fluid temperature limit of 180°F is recommended. Operation at temperatures above 180°F will likely require more frequent fluid changes. At cold temperature extremes, preheating the fluid may be required to achieve adequate fluid flow. Synthetic ester based fluid can be operated at temperatures similar to mineral based fluids.

Filtration - Filtration requirements and maintenance are the same as with traditional hydraulic fluids. At low temperatures, however, gelling can plug the filter media.

Material compatibility - EA fluids require no special seals or hose material. Viton and Buna N seals are good recommendations. Within temperature limits, the fluids are compatible with steel and copper alloys.

Maintenance - Sauer-Sundstrand recommends a rapeseed oil to be changed after the first 500 hours after start up, and every 1000 hours thereafter. Ester based fluids should be changed every 2000 hours. The maximum interval for subsequent oil changes are typically shorter than mineral based oil change intervals.

3.4.2 Affect on Sauer-Sundstrand Components

Sauer-Sundstrand has collected both field and in-house lab test experience with many fluids in several different transmission systems. Sauer-Sundstrand publications ATI-E9101 is a detailed bulletin on the subject of EA fluids and does identify specific fluids for Sauer-Sundstrand products. Extended testing on some products has led to hardware design improvements to improve compatibility with EA fluids. They include:

• Compatible 15 Series products include variable pumps, tandem pumps, fixed motors, inline transmissions, and "U" style transmissions with Serial Number 94-12 and later.

• Compatible Series 40 products include 25cc variable pumps, 25cc tandem pumps, 25cc fixed motors, and 25cc "U" style transmissions with Serial Number 94-12 and later.

Results from tests using these hydrostatic products show that rapeseed oils (HTG) and synthetic ester oils (HE) show no adverse effect on the performance of the units listed above when operating within the fluid limits specified by the fluid manufacturer. However, since Sauer-Sundstrand units are tested with mineral oil, all housings should be completely drained before installation of EA fluids.

Sauer-Sundstrand components often share the same hydraulic fluid with other components, including steering pumps, hydraulic valves, and final drive gear sets. Each component supplier should be consulted to determine the impact of EA fluids on these other components.

Conversion kits are available from Sauer-Sundstrand to make the above pumps and motors with date codes prior to 94-12 compatible with many EA fluids.

3.5 Fluid Compressibility

3.5.1 Description

While fluids are usually considered incompressible, the pressures that can occur in hydrostatic systems are of a magnitude that fluid compressibility can be significant. In applications that experience system pressure fluctuations resulting in random high pressure rise rates, consideration must be given to fluid compressibility when sizing a charge pump to ensure adequate charge pressure. See Section 1.3 for charge pump sizing.

The amount that a specific fluid compresses for a given pressure increase is related to a fluid property known as the bulk modulus. The **bulk modulus** is a measure of a fluid's resistance to being compressed. For a given pressure increase and fluid volume, a fluid with a large bulk modulus will experience a smaller reduction in volume than a fluid with a low bulk modulus. Mathematically, bulk modulus is defined as

$$BM = \frac{\Delta P}{\Delta V / V}$$

where:

BM	=	bulk modulus of the fluid	(psi)
ΔP	=	change in pressure	(psi)
ΔV	=	change in volume	(in^3)
V	=	volume of oil experiencing the change in pressure	(in^3)

Note that units for bulk modulus are the same as the units for pressure.

Fluid compressibility becomes a concern for a closed circuit hydrostatic system which has large volumes of oil under pressure, such as long or large system lines, and experiences high system pressure spikes during operation.

To understand the nature of the problem that can be associated with fluid compressibility, consider what happens when a system experiences an increase in load. An increase in load requires more torque from the motor, and consequently, an increase in system pressure. When the system pressure increases, the fluid in the high pressure side of the hydrostatic loop is compressed.

To illustrate, Figure 3-5 shows a simple model consisting of a cylinder whose piston compresses the fluid to create a pressure of 500 psi. If the piston is forced to move a small distance to the left, the fluid compresses even more, resulting in the pressure increasing to 1000 psi. The fluid at this pressure now occupies a smaller volume than the fluid did at 500 psi. At the same time, the volume on the rod side of the piston increases. If we imagine that the rod side of the piston is also filled with fluid, then a void is created on this side of the piston when the fluid against the piston face is compressed. To keep the rod side of the piston full of fluid, additional fluid must be added to this side of the piston.

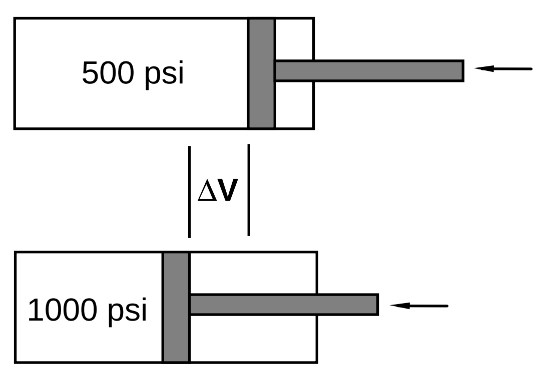


Figure 3-5

This model can be extended to conditions in a closed loop hydrostatic system that experiences sudden pressure fluctuations. Like the cylinder in the model, the fluid in the high pressure line is compressed when system pressure increases. Also, like the rod end of the piston, this compression creates a void in the volume of conduit between the pump and motor. A portion of the pump flow is therefore needed to replenish fluid in this void. This means less flow is available to the motor. As a result, the motor speed is reduced for a short time, and there is an instantaneous reduction of return flow at the motor outlet. This loss of flow on the low pressure side of the hydrostatic loop must be replenished by the charge pump. If the charge pump is not adequately sized to meet this additional flow requirement, there will be a loss in charge pressure. Although the loss of charge pressure may exist for only a very short time, severe damage at the pump will result with continued use.

The effects due to compressibility will depend on the length and size of the system lines (the volume of fluid in the lines), the duration of the pressure spike, the magnitude of the pressure spike, and the bulk modulus of the fluid.

The bulk modulus of a fluid varies with pressure, fluid type, temperature, and the percentage of entrained air. (Most fluids have include some amount of entrained air. The amount of entrained air is usually estimated). In determining the effective bulk modulus, however, the fluid bulk modulus should be modified to allow for aeration in the fluid and for conduit expansion.

The additional charge flow requirement due to fluid compressibility is determined using the following equation:

$$Q = \frac{\Delta P\ (V)}{BM\ (\Delta t)}$$

where:

- Q = instantaneous flow rate
- ΔP = change in pressure
- V = total volume under high pressure
- Δt = time duration for pressure change
- BM = effective bulk modulus of the fluid

Typical values for fluid bulk modulus adjusted for entrapped air are:

- small level 200 000 psi
- moderate level 150 000 psi
- 2% air 100 000 psi

3.5.2 Example Calculation

A system with 30 feet of one inch I.D. hose has an abrupt change in system pressure from 2000 psid to 5000 psid. This change occurs in 100 milliseconds. Calculate the charge flow requirement due to the effects of fluid compressibility only.

Change in pressure =

5000 - 2000 = 3000 psid.

Volume under pressure of

30 ft of 1 inch hose (L x A)

$$= \frac{(30)(12)(3.14)(1)}{(4)}$$

$= 282\ in^3$

Using a Bulk Modulus of 150 000 psi,

$$Q = \frac{(3000)(282)}{(150\ 000)(0.1)} = 56.5\ in^3/sec$$

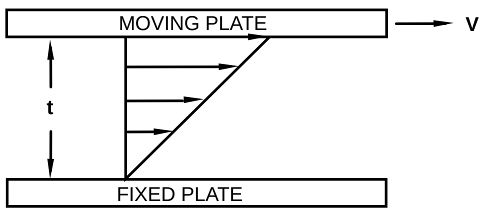
$$= \frac{(56.5)(60)}{(231)} = 14.68\ gpm$$

3.6 Fluids and Filters Glossary

This glossary includes many of the terms frequently used when discussing fluids and filters.

absolute viscosity (μ) (also **dynamic viscosity**)

is a measure of a fluid's internal resistance to flow. It is sometimes referred to as dynamic viscosity, and is equal to kinematic viscosity multiplied by the density of the fluid. Absolute viscosity can be described by the motion of fluid between two plates. The theoretical description is shown below:



Mathematically, the absolute viscosity is defined as the ratio of shear stress to shear rate, or

$$\mu = \frac{\tau}{v/t}$$

where

μ = absolute viscosity

τ = shear stress at the plate-fluid interface

v = velocity of the moving plate

t = thickness of the fluid

Units include the Reyn (1 lbf sec/ft^2) and the Poise (1 dyne sec/cm^2, where 1 dyne = 1 gm cm/sec^2).

ANSI

acronym for the American National Standards Institute. Examples of ANSI fluid-related standards include the following:

ANSI / B93.2	Fluid power systems and products glossary
ANSI / B93.5	Practice for The Use of Fire Resistant Fluids in Industrial Hydraulic Fluid Power Systems
ANSI / B93.19	Method for Extracting Fluid Samples from the Lines of an Operating Hydraulic Fluid Power System
ANSI / B93.20	Procedure for Qualifying and Controlling Cleaning Methods for Hydraulic Fluid Sample Containers
ANSI / B93.44	Methods for Extracting Fluid Samples from a Reservoir of an Operating Hydraulic Fluid Power System

anti-wear

a fluid additive which increases the film strength of the fluid. Anti-wear additives are used in those applications where loading is high or components are especially sensitive to wear. Anti-wear properties of a fluid refer to the fluid's resistance to wear in boundary lubrication conditions.

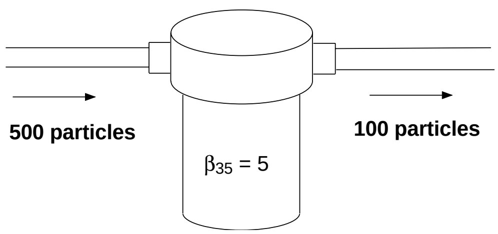
asperity

a microscopic projection on the metal surface of a hydraulic component. Asperities are not normally harmful to components, provided an adequate film thickness is present between metal surfaces. However, during boundary (partial) lubrication, asperities of opposing surfaces may come in contact with each other and create contamination particles.

beta ratio (β_x)

the ratio of the number of particles per unit volume upstream of a filter to the number of particles downstream of a filter for particles greater than or equal to a certain size. (The particle size is denoted by the "x" subscript in the symbol). The beta ratio represents the effectiveness of a filter to remove particles from a fluid passing through the filter and is measured according to the ISO 4572 Multipass Test Procedure.

The beta ratio is related to the filter efficiency by the equation $E_x = 100\,[1-1/\beta_x]$.



Example: A filter with "$\beta_{35} = 5$" means for every five particles greater than or equal to 35µm encountering the filter, one of those particles passes through the filter. This filter has a filter efficiency of $E_{35} = 100(1-1/5) = 80\%$.

boundary lubrication

a condition of incomplete lubrication between two rubbing surfaces without the development of a continuous lubrication film to completely separate the two surfaces. During boundary lubrication, the fluid film is "punctured" by the asperities of the two opposing surfaces. Some of the asperities may then be torn away from the parent material and become contamination particles.

Boundary lubrication is reduced by selecting a fluid which has good viscosity characteristics and additives which increase the fluid's film strength.

bulk modulus (BM)

measure of a fluid's resistance to being compressed. While fluids are generally considered "incompressible," fluids will experience measurable compression under high pressure. For a given pressure increase and fluid volume, a fluid with a large bulk modulus will experience a smaller reduction in volume than a fluid with a lower bulk modulus. Mathematically, the bulk modulus is defined as

$$BM = \frac{\Delta P}{\Delta V / V}$$

where
BM = bulk modulus of the fluid
ΔP = change in pressure
ΔV = change in volume
V = volume of fluid experiencing the change in pressure

The units for bulk modulus are the same as the units for pressure. Note that bulk modulus is the reciprocal of compressibility.

bypass

an alternative (unfiltered) flow path around a filter element to pass flow when a preset differential pressure across the filter is reached.

cavitation

a condition that occurs when the inlet pressure of a pump is reduced to the point that air pockets or bubbles form at the inlet. Cavitation is damaging to a pump when the air bubbles created at the inlet collapse at the high pressure outlet. Failure to adhere to pump suction limits may result in cavitation and subsequent damage to the pump.

centipoise (cP)

1/100 of a Poise, a unit for absolute (dynamic) viscosity. One poise is equal to 1 dyne • sec/cm^2. The centipoise is also expressed in millipascal sec.
Note: 1 cP = 0.145 microreyn

centistoke (cSt)

1/100 of a Stoke, a unit for kinematic viscosity. One stoke is equal to 1 cm^2/sec. The centistoke is also expressed in mm^2/sec.
Note: 1 cSt = 0.00155 Newt. See definition for Saybolt Universal Second for conversion to SUS.

compressibility

the measure of a fluid's change in volume of a unit volume when subjected to a unit change in pressure, or

$$\text{Compressibility} = \frac{\Delta V / V}{\Delta P} = \frac{1}{BM}$$

where
ΔV = change in volume
V = volume of fluid experiencing the change in pressure
ΔP = change in pressure
BM = bulk modulus of the fluid

Compressibility is the inverse of bulk modulus. A fluid with a high bulk modulus has a low compressibility.

contaminant loading

process of filling and blocking the pores of a filter element with contaminant particles.

contaminant absorption capacity

the weight amount of contaminant particles a filter can absorb before the differential pressure drop across the filter reaches a level that requires filter replacement.

contamination

any component of a fluid which impairs the function of the fluid. Contamination in a broad sense includes solid particles, water, air, or reactive chemicals. When referring to fluid cleanliness in regards to the ISO 4406 standard, contamination refers to the number of foreign particles present in the fluid.

dynamic viscosity

See absolute viscosity.

emulsion

a mixture of oil and water in which the oil and water exist as a continuous phase (vs. two separate phases).

EP additive

abbreviation for extreme pressure additive. Fluids with EP additives react with metal surfaces to form a hard protective film and are therefore suitable for high-load conditions.

filter capacity

See contaminant absorption capacity.

filter efficiency (E_x)

effectiveness of a filter at removing contaminants of a particular size from a fluid. Filter efficiency is the percentage of particles that are removed from the fluid when passing through the filter. Filter efficiency is related to the beta ratio (β_x) of a fluid by the equation $E_x = 100 \cdot (1 - 1/\beta_x)$. Filters with high beta ratios have high filter efficiencies. Note that like the beta ratio, the symbol for filter efficiency includes a subscript to indicate the particle size.

Example: The filter efficiency for a filter beta ratio of $\beta_{35} = 5$ is $E_{35} = 100 \cdot (1\text{-}1/5) = 80\%$. This means the filter is capable of removing 80% of 35µm particles passing through the filter.

filter fineness

a method of describing a filter by specifying the particles size for a given beta ratio. The particle size is denoted by "x" subscript in the symbol for beta ratio, β_x. The smaller the particle size, the more efficient the filter is at removing contaminants. A beta ratio value of 75 is frequently used when specifying a filter fineness.

Example: $\beta_{35} \geq 75$ equals a filter fineness of 35µm. The filter is able to remove at least 98.67% of the particles 35µm or larger. By comparison, a filter with $\beta_{15} \geq 75$ is even more efficient at removing contaminants; this is referred to as a "15 micron filter."

HWCF

abbreviation for high water content fluid. HWCFs are composed of formulations containing high percentages of water, typically greater than 80%.

hydrolytic stability

resistance of a fluid to property changes due to chemical reactions with water.

immiscible

incapable of being mixed without remaining as separate phases.

ingression

a general term for the intake of contaminants external to a system.

ISO

designation for the International Organization for Standardization. Examples of fluid-related ISO standards include:

ISO 3938: method for reporting analysis data for contamination
ISO 4406: solid contamination codes for hydraulic fluid cleanliness
ISO 4572: Multi-Pass Test Procedure for the evaluation of filters (beta ratio)

kinematic viscosity (υ)
the quotient of absolute viscosity divided by the fluid density. Kinematic viscosity is the viscosity most often used in industry. Units for kinematic viscosity include the Stoke (1 Stoke = 1 cm^2/sec), the Newt (1 Newt = 1 in^2/sec), and the Saybolt Universal Second (SUS).

lubricity
ability of a fluid to lubricate (reduce shear stress between rubbing surfaces). Lubricity is also referred to as film strength.

micron
one micrometer, or one-millionth of a meter. The micron is the unit used to measure the size of contamination particles within a fluid. As a basis for comparison, measurements for some "common" objects are as follows:

grain of table salt	100 microns
human hair	70 microns
limit of visibility	40 microns

Note: the symbol for a micron (micrometer, μm) is often designated simply as μ.

microreyn
a unit for absolute viscosity equal to one-millionth of a Reyn.
Note: 1 microreyn = 6.90 cP

miscible
capable of being mixed to form a continuous fluid phase.

Newt
a unit for kinematic viscosity equal to 1 in^2/sec (the Newt is not commonly used).
Note: 1 Newt = 645 cSt

pressure filtration
filtration in which the filter is positioned downstream of the pump.

pour point
the lowest temperature at which a fluid will flow under specific test conditions. The minimum start-up temperature for a hydraulic system should be the higher of either 30°F above the pour point of the fluid or the minimum temperature specified by the most sensitive component in the system.

Reyn
a unit for absolute viscosity equal to 1 lbf • sec/in^2. A more convenient unit is the microreyn, which is equal to one-millionth of a Reyn.

RO inhibitor
abbreviation for rust and oxidation inhibitor. Fluids with RO inhibitors are more capable of offsetting the negative effects of air and water in a system.

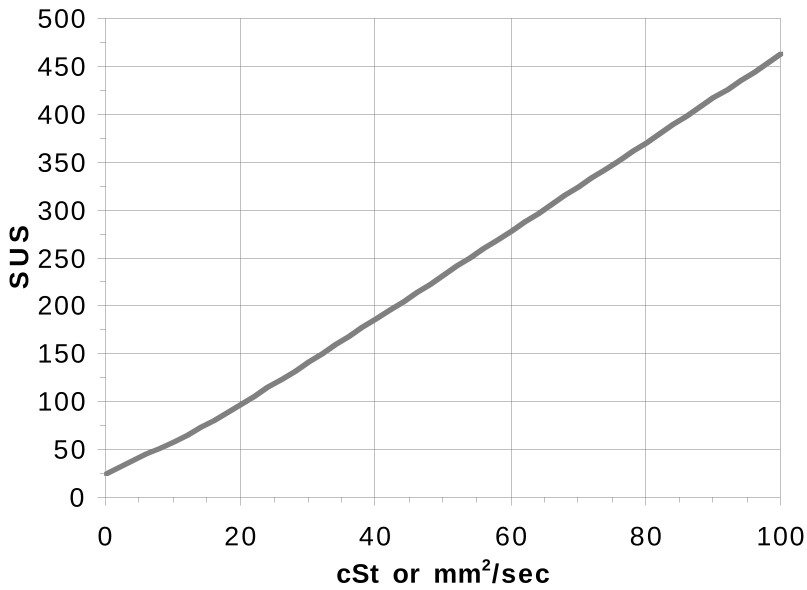
Saybolt Universal Second (SUS)
a measure of kinematic viscosity. Unit of measure equal to the time required for 60 mL of the fluid to pass through a standard orifice. The static head and fluid temperature are also specified.

Approximate conversions between SUS and centistokes are as follows:

cSt = 0.226 • (SUS) - (195 / SUS) for SUS ≤ 100

cSt = 0.220 • (SUS) - (135 / SUS) for SUS > 100

The graph below shows the relationship between centistokes and Saybolt Seconds:



sheardown
measure of a fluid's decrease in viscosity due to mechanically working and shearing the fluid.

specific gravity (SG)

the ratio of a fluid's density to the density of water, or

$$SG = \rho/\rho_{water}$$

The density of water used in the definition is the density at a specified temperature. Fluids with specific gravities above 0.9 may require special inlet conditions to avoid cavitation.

stability

the resistance of a fluid to changes in its properties.

Stoke

a unit for viscosity equal to 1 cm^2 / sec. Because the stoke is a large unit, kinematic viscosity is usually reported in centistokes (cSt), where 100 cSt equal 1 Stoke.

suction filtration

filtration in which the filter is positioned upstream of the charge pump inlet.

thermal stability

resistance of a fluid to chemical breakdown due to high temperatures.

viscosity

a measure of a fluid's resistance to flow. A hydraulic fluid has a low viscosity when "thin" and a high viscosity when "thick."

The viscosity of a fluid changes with changes in temperature. In general, the viscosity of a fluid decreases with increasing temperature and increases with decreasing temperature. The sensitivity of fluid's viscosity with changes in temperature is designated by the fluid's viscosity index.

The term "viscosity" may refer to either dynamic viscosity (μ) or kinematic viscosity (υ). Kinematic viscosity is equal to the absolute viscosity divided by the density of the fluid.

viscosity index (VI)

the measure of a fluid's viscosity change with respect to temperature change. A fluid with a high viscosity index is less sensitive to temperature and exhibits a small change in viscosity over a temperature range. The definition for viscosity index is as follows:

$$VI = \frac{L - U}{L - H}$$

where

U = viscosity at 100°F of the fluid whose viscosity index is to be calculated.
L = viscosity at 100°F of a 0-VI fluid which has the same viscosity at 210°F as the fluid of interest.
H = viscosity at 100°F of a 100-VI fluid which has the same viscosity at 210°F as the fluid of interest.

The unit for viscosity in the above equation is the Saybolt Universal Seconds (SUS). The original VI scale ranged from 0 to 100, which represented the worst and best fluids at the time when the scale was created. Many fluids today have improved viscosity-temperature characteristics, so values above 100 are not uncommon. Most fluids, however, have a VI value between 90 and 110.

Note that viscosity index is a unitless quantity.

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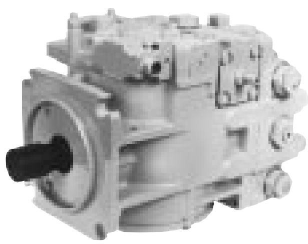
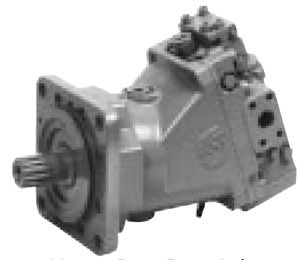
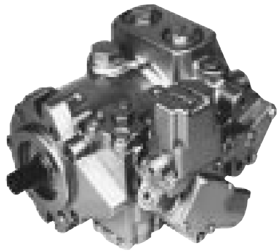


Heavy Duty Axial Piston
Pumps and Motors

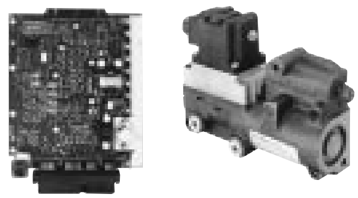


Heavy Duty Bent Axis
Variable Motors

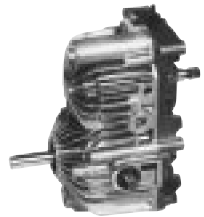
Cartridge Motors/
Compact Wheel Drives



Medium Duty Axial Piston
Pumps and Motors



Microcontrollers and
Electrohydraulic Controls



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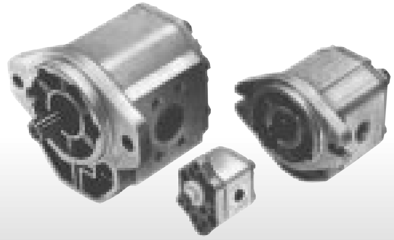
Packages

Open Circuit Axial Piston Pumps



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