The Handbook of Hydraulic Filtration

Parker

ENGINEERING YOUR SUCCESS.

The Handbook of Hydraulic Filtration is intended to familiarize the user with all aspects of hydraulic and lubrication filtration from the basics to advanced technology.

It is dedicated as a reference source with the intent of clearly and completely presenting the subject matter to the user, regardless of the individual level of expertise.

The selection and proper use of filtration devices is an important tool in the battle to increase production while reducing manufacturing costs. This Handbook will help the user make informed decisions about hydraulic filtration.

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Contamination Basics

Contamination Causes Most Hydraulic Failures

The experience of designers and users of hydraulic and lube oil systems has verified the following fact: over 75% of all system failures are a direct result of contamination!

The cost due to contamination is staggering, resulting from:

- **Loss of production (downtime)**
- **Component replacement costs**
- **Frequent fluid replacement**
- **Costly disposal**
- **Increased overall maintenance costs**
- **Increased scrap rate**

Functions of Hydraulic Fluid

Contamination interferes with the four functions of hydraulic fluids:

- **To act as an energy transmission medium.**
- **To lubricate internal moving parts of components.**
- **To act as a heat transfer medium.**
- **To seal clearances between moving parts.**

If any one of these functions are impaired, the hydraulic system will not perform as designed. The resulting downtime can easily cost a large manufacturing plant thousands of dollars per hour. Hydraulic fluid maintenance helps prevent or reduce unplanned downtime. This is accomplished through a continuous improvement program that minimizes and removes contaminants.

Contaminant Damage

- **Orifice blockage**
- **Component wear**
- **Formation of rust or other oxidation**
- **Chemical compound formation**
- **Depletion of additives**
- **Biological growth**

Hydraulic fluid is expected to create a lubricating film to keep precision parts separated. Ideally, the film is thick enough to completely fill the clearance between moving parts. This condition results in low wear rates. When the wear rate is kept low enough, a component is likely to reach its intended life expectancy, which may be millions of pressurization cycles.

The actual thickness of a lubricating film depends on fluid viscosity, applied load, and the relative speed of the two surfaces. In many components, mechanical loads are to such an extreme that they squeeze the lubricant into a very thin film, less than 1 micrometer thick. If loads become high enough, the film will be punctured by the surface roughness of the two moving parts. The result contributes to harmful friction.

filtration fact

Properly sized, installed, and maintained hydraulic filtration plays a key role in machine preventative maintenance planning.

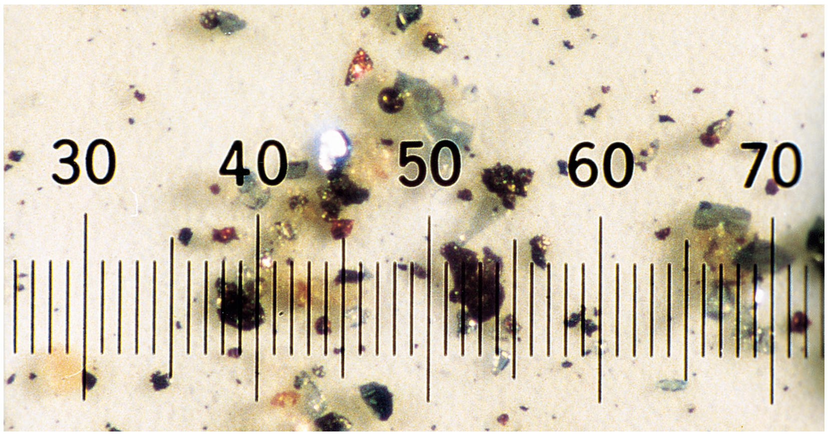
filtration fact

The function of a hydraulic filter is to clean oil, but the ultimate purpose is to reduce operating costs.

Contamination Basics

Micrometer Scale

Particle sizes are generally measured on the micrometer scale. One micrometer (or "micron") is one-millionth of one meter, or 39 millionths of an inch. The limit of human visibility is approximately 40 micrometers. Keep in mind that most damage-causing particles in hydraulic or lubrication systems are smaller than 40 micrometers. Therefore, they are microscopic and cannot be seen by the unaided eye.



Actual photomicrograph of particulate contamination.

Typical Hydraulic Component Clearances	
Component	**Microns**
Anti-friction bearings	0.5
Vane pump (vane tip to outer ring)	0.5-1
Gear pump (gear to side plate)	0.5-5
Servo valves (spool to sleeve)	1-4
Hydrostatic bearings	1-25
Piston pump (piston to bore)	5-40
Servo valves flapper wall	18-63
Actuators	50-250
Servo valves orifice	130-450

Relative Sizes of Particles		
Substance	**Micron**	**Inches**
Grain of table salt	100	.0039
Human hair	70	.0027
Lower limit of visibility	40	.0016
Milled flour	25	.0010
Red blood cells	8	.0003
Bacteria	2	.0001

filtration fact

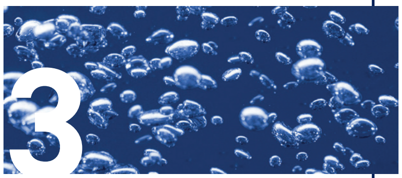
The disposal cost of a drum of waste oil can be 2x - 3x the cost of a drum of new oil.

Contamination Types and Sources

Types of Contamination

Particulate
Chips (5μm+)
Silt (0-5μm)

Water
(Free & Dissolved)



Air

1 Particulate Contamination

Types

Particulate contamination is generally classified as "silt" or "chips." Silt can be defined as the accumulation of particles less than 5μm over time. This type of contamination also causes system component failure over time. Chips on the other hand, are particles 5μm+ and can cause immediate catastrophic failure. Both silt and chips can be further classified as:

Hard Particles

- **Silica**
- **Carbon**
- **Metal**

Soft Particles

- **Rubber**
- **Fibers**
- **Micro organisms**

filtration fact

System Contamination Warning Signals

- *Solenoid burn-out.*
- *Valve spool decentering, leakage, "chattering".*
- *Pump failure, loss of flow, frequent replacement.*
- *Cylinder leakage, scoring.*
- *Increased servo hysteresis.*

Sources

- **Built-in during manufacturing and assembly processes.**
- **Added with new fluid.**
- **Ingested from outside the system during operation.**
- **Internally generated during operation.**

filtration fact

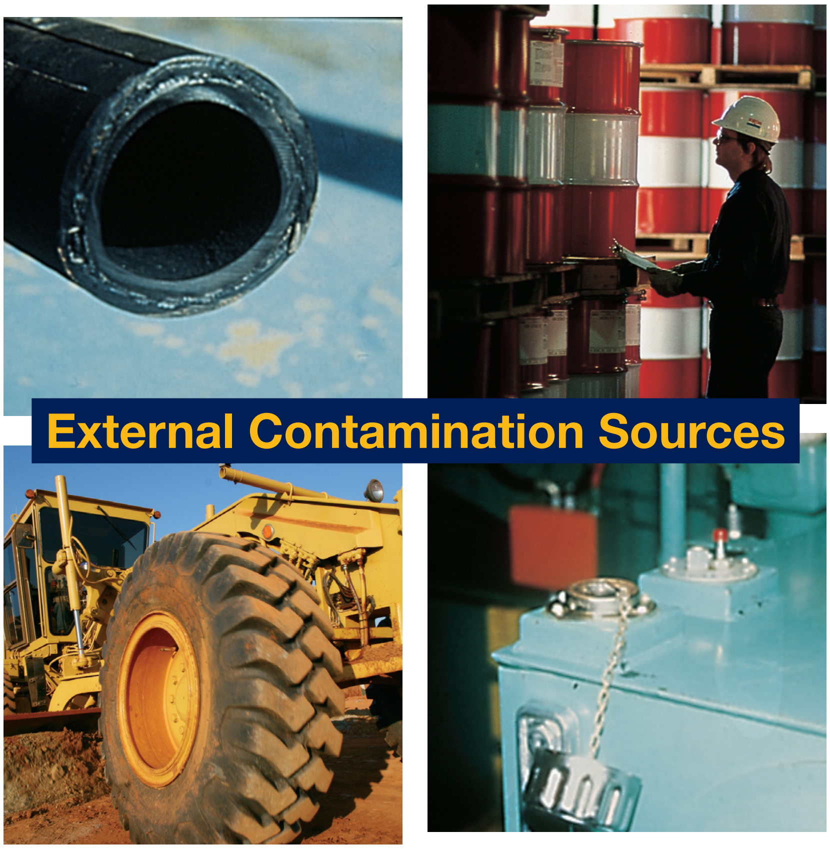
New fluid is not necessarily clean fluid. Typically, new fluid right out of the drum is not fit for use in hydraulic or lubrication systems.

Prevention

- **Use spin-on or desiccant style filters for reservoir air breathers.**
- **Flush all systems before initial start-up.**
- **Specify rod wipers and replace worn actuator seals.**
- **Cap off hoses and manifolds during handling and maintenance.**
- **Filter all new fluid before it enters the reservoir.**

Jammed piston caused by excessive particulate contamination in a piston pump.

1 Particulate Contamination *(cont.)*



If not properly flushed, contaminants from manufacturing and assembly will be left in the system.

These contaminants include dust, welding slag, rubber particles from hoses and seals, sand from castings, and metal debris from machined components. Also, when fluid is initially added to the system, contamination is introduced.

During system operation, contamination enters through breather caps, worn seals, and other system openings. System operation also generates internal contamination. This occurs as component wear debris and chemical by-products react with component surfaces to generate more contamination.

Ingression Rates for Typical Systems	
Mobile Equipment	10^{8}-10^{10} per minute*
Manufacturing Plants	10^{6}-10^{8} per minute*
Assembly Facilities	10^{5}-10^{6} per minute*

* Number of particles greater than 10 microns ingressed into a system from all sources.

Generated Contamination

Cavitation Wear - Restricted inlet flow to pump causes fluid voids that implode causing shocks that break away critical surface material.

Fatigue Wear - Particles bridging a clearance cause a surface stress riser that expands into a spall due to repeated stressing of the damaged area.

Abrasive Wear - Hard particles bridging two moving surfaces, scraping one or both.

Corrosive Wear - Water or chemical contamination in the fluid causes rust or a chemical reaction that degrades a surface.

Erosive Wear - Fine particles in a high speed stream of fluid eat away a metering edge or critical surface.

Adhesive Wear - Loss of oil film allows metal to metal contact between moving surfaces.

filtration fact

Most system ingression enters a system through the old-style reservoir breather caps and the cylinder rod glands.

2 Water Contamination

Types

There is more to proper fluid maintenance than just removing particulate matter. Water is virtually a universal contaminant, and just like solid particle contaminants, must be removed from operating fluids. Water can be either in a dissolved state or in a "free"state. Free, or emulsified, water is defined as the water above the saturation point of a specific fluid. At this point, the fluid cannot dissolve or hold any more water. Free water is generally noticeable as a "milky" discoloration of the fluid.

Sources

- **Reservoir opening leakage**
- **Condensation**
- **Heat exchanger leakage**

Visual Effects of Water in Oil

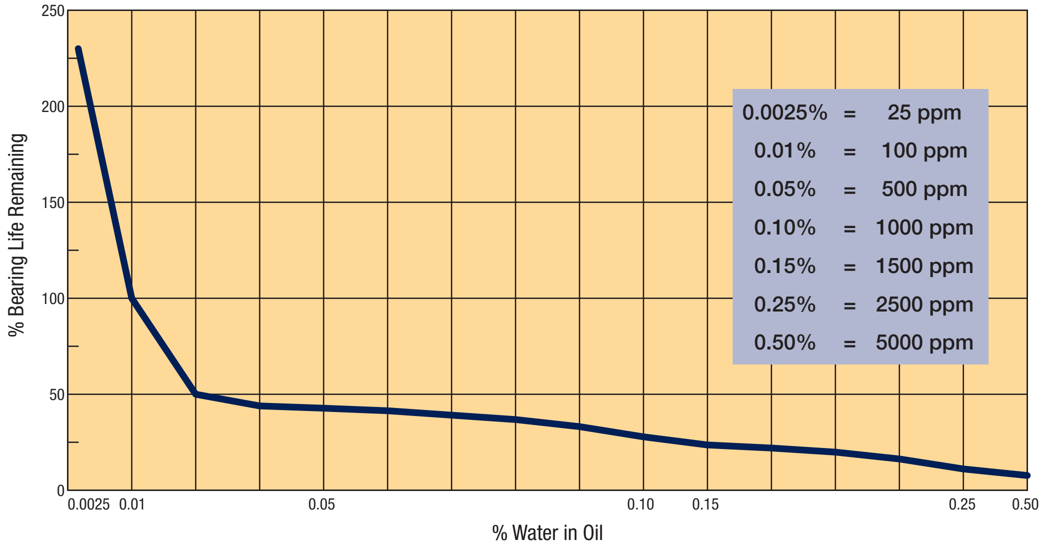
filtration fact

Hydraulic fluids have the ability to 'hold' more water as temperature increases. A cloudy fluid may become clearer as a system heats up.

Typical Saturation Points		
Fluid Type	**PPM**	**%**
Hydraulic Fluid	300	0.03
Lubrication Fluid	400	0.04
Transformer Fluid	50	0.005

2 Water Contamination *(cont.)*

Effect of Water in Oil on Bearing Life



Effects of water in oil on bearing life (based on 100% life at 0.041% water in oil).
Reference: "Machine Design" July 86, "How dirt and Water Effect Bearing Life" by Timken Bearing Co.

Anti-wear additives break down in the presence of water and form acids. The combination of water, heat and dissimilar metals encourages galvanic action. This could result in pitted or corroded metal surfaces. Further complications occur as temperature drops and the fluid has less ability to hold water. As the freezing point is reached, ice crystals form, adversely affecting total system function. Operating functions may also become slowed or erratic.

Electrical conductivity becomes a problem when water contamination weakens the insulating properties of a fluid, thus decreasing its dielectric kV strength.

Fluids are constantly exposed to water and water vapor while being handled and stored. For instance, outdoor storage of tanks and drums is common. Water may settle on top of fluid containers and be drawn into the container during temperature changes. Water may also be introduced when opening or filling these containers.

Water can enter a system through worn cylinder or actuator seals or through reservoir openings. Condensation is also a prime water source. As the fluids cool in a reservoir or tank, water vapor will condense on the inside surfaces, causing rust or other corrosion problems.

filtration fact

A simple 'crackle test' will tell you if there is free water in your fluid. Apply a flame under the container. If bubbles rise and 'crackle' from the point of applied heat, free water is present in the fluid.

2 Water Contamination *(cont.)*

Damage

- Corrosion of metal surfaces
- Accelerated abrasive wear
- Bearing fatigue
- Fluid additive breakdown
- Viscosity variance
- Increase in electrical conductivity

Prevention

Excessive water can usually be removed from a system. The same preventative measures taken to minimize particulate contamination ingression in a system can be applied to water contamination. However, once excessive water is detected, it can usually be eliminated by one of the following methods:

Absorption

This is accomplished by filter elements that are designed specifically to take out free water. They usually consist of a laminate-type material that transforms free water into a gel that is trapped within the element.

These elements fit into standard filter housings and are generally used when small volumes of water are involved.

Centrifugation

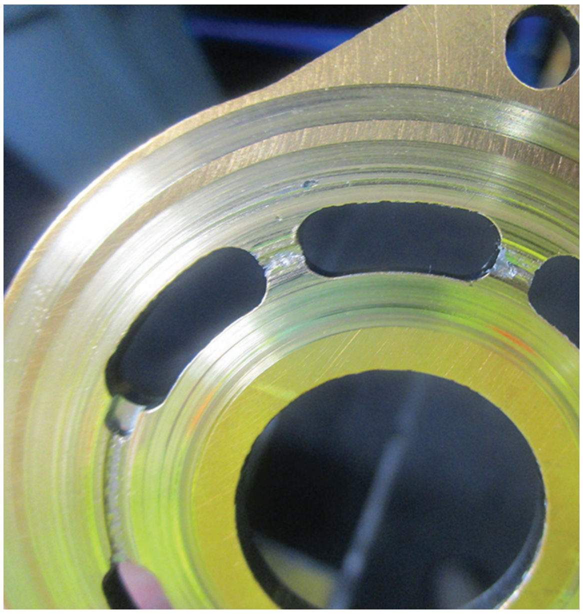
Separates water from oil by a spinning motion. This method is also only effective with free water, but for larger volumes.

Vacuum Dehydration

Separates water from oil through a vacuum and drying process. This method is also for larger volumes of water, but is effective with both the free and dissolved states.

filtration fact

Free water is heavier that oil. Thus it will settle to the bottom of the reservoir where much of it can be removed by opening the drain valve.



Typical results of pump wear due to particulate and water contamination.

3 Air Contamination

Types

Air in a liquid system can exist in either a dissolved or entrained (undissolved, or free) state. Dissolved air may not pose a problem, providing it stays in solution. When a liquid contains undissolved air, problems can occur as it passes through system components. There can be pressure changes that compress the air and produce a large amount of heat in small air bubbles. This heat can destroy additives, and the base fluid itself.

If the amount of dissolved air becomes high enough, it will have a negative effect on the amount of work performed by the system. The work performed in a hydraulic system relies on the fluid being relatively incompressible, but air reduces the bulk modules of the fluid. This is due to the fact that air is up to 20,000 times more compressible than a liquid in which it is dissolved. When air is present, a pump ends up doing more work to compress the air, and less useful work on the system. In this situation, the system is said to be 'spongy.'

Damage

- **Loss of transmitted power**
- **Reduced pump output**
- **Loss of lubrication**
- **Increased operating temperature**
- **Reservoir fluid foaming**
- **Chemical reactions**
- **Pump Cavitation**

Air in any form is a potential source of oxidation in liquids. This accelerates corrosion of metal parts, particularly when water is also present. Oxidation of additives also may occur. Both processes produce oxides which promote the formation of particulates, or form a sludge in the liquid. Wear and interference increases if oxidation debris is not prevented or removed.

Sources

- **System leaks**
- **Pump aeration**
- **Reservoir fluid turbulence**

Prevention

- **System air bleeds**
- **Flooded suction pump**
- **Proper reservoir design**
- **Return line diffusers**

filtration fact

Absorption filter elements have optimum performance in low flow and low viscosity applications.

Fluid Cleanliness Standards

Particle Counting

In order to detect or correct problems, a contamination reference scale is used. Particle counting is the most common method to derive cleanliness level standards. Very sensitive optical instruments are used to count the number of particles in various size ranges. These counts are reported as the number of particles greater than a certain size found in a specified volume of fluid.

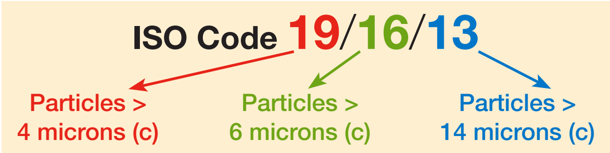
The ISO 4406:1999 (International Standards Organization) cleanliness level standard has gained wide acceptance in most industries today. This standard references the number of particles ≥ 4, 6, and 14 micrometers in a known volume, usually 1 milliliter or 100 milliliters. The number of 4+ and 6+ micrometer particles is used as a reference point for “silt” particles. The 14+ size range indicates the quantity of larger particles present which contribute greatly to possible catastrophic component failure.

filtration fact

The ISO code index number can never increase as the particle sizes increase (Example: 18/20/22).

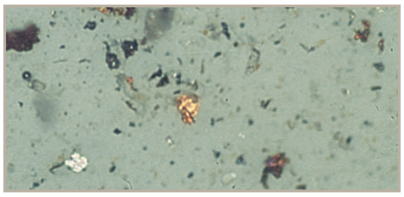
An ISO classification of 19/16/13 can be defined as

Range Number	Micron(c)	Actual Particle Count Range (per ml)
19	4+	2,500-5,000
16	6+	320-640
13	14+	40-80

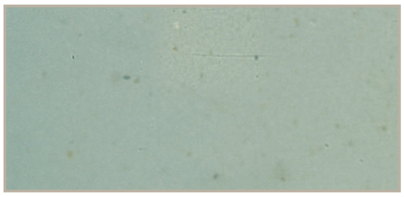


ISO 4406 Chart

Range Number	Number of particles per ml	
	More than	Up to and including
24	80,000	160,000
23	40,000	80,000
22	20,000	40,000
21	10,000	20,000
20	5,000	10,000
19	2,500	5,000
18	1,300	2,500
17	640	1,300
16	320	640
15	160	320
14	80	160
13	40	80
12	20	40
11	10	20
10	5	10
9	2.50	5
8	1.30	2.5
7	0.64	1.3
6	0.32	0.64



ISO 22/19/17 fluid (100x mag.)



ISO 17/14/11 fluid (100x mag.)

Fluid Cleanliness Standards

Component Cleanliness Level Requirements

Many manufacturers of hydraulic and load bearing equipment specify the optimum cleanliness level required for their components. Subjecting components to fluid with higher contamination levels may result in much shorter component life.

In the table below, a few components and their recommended cleanliness levels are shown. It is always best to consult with component manufacturers and obtain their written fluid cleanliness level recommendations. This information is needed in order to select the proper level of filtration. It may also prove useful for any subsequent warranty claims, as it may draw the line between normal use and excessive or abusive operation.

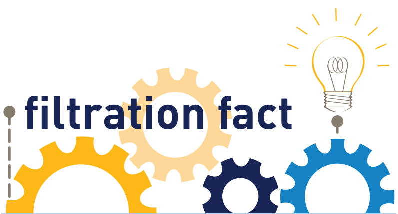
SAE AS4059 Revision F (Table 1)
Cleanliness Classes for Differential Particle Counts (Particles/100mL) (3)

Classes						
	(1)	5, incl. to 15, incl. µm	15, excl. to 25, incl. µm	25, excl. to 50, incl. µm	50, excl. to 100, incl. µm	>100 µm
	(2)	6, incl. to 14, incl. µm (c)	14, excl. to 21, incl. µm (c)	21, excl. to 38, incl. µm (c)	38, excl. to 70, incl. µm (c)	>70 µm (c)
00		125	22	4	1	0
0		250	44	8	2	0
1		500	89	16	3	1
2		1000	178	32	6	1
3		2000	356	63	11	2
4		4000	712	126	22	4
5		8000	1425	253	45	8
6		16000	2850	506	90	16
7		32000	5700	1012	180	32
8		64000	11400	2025	360	64
9		128000	22800	4050	720	128
10		256000	45600	8100	1440	256
11		512000	91200	16200	2880	512
12		1024000	182400	32400	5760	1024

(1) Size Range, Microscope particle counts, based on longest dimension as measured per AS598 or ISO 4407.
(2) Size Range, APC Calibrated Per ISO 11171 or an Optical or Electron Microscope with image analysis software, based on projected area equivalent diameter.
(3) Contamination classes and particle count limits are identical to NAS 1638.

Fluid Cleanliness Required for Typical Hydraulic Components

Components	ISO Code
Servo control valves	17/14/11
Proportional valves	18/15/12
Vane and piston pumps/motors	19/16/13
Directional & pressure control valves	19/16/13
Gear pumps/motors	20/17/14
Flow control valves, cylinders	21/18/15
New unused fluid	21/18/15



Knowing the cleanliness level of a fluid is the basis for contamination control measures.

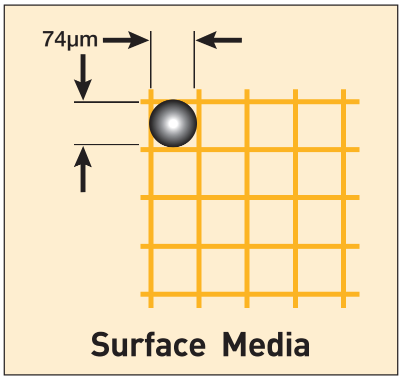
Filter Media Types and Ratings

The filter media is the part of the element which removes the contaminant.

Media usually starts out in sheet form, and is then pleated to expose more surface area to the fluid flow. This reduces pressure differential while increasing dirt holding capacity. In some cases, the filter media may have multiple layers and mesh backing to achieve certain performance criteria. After being pleated and cut to the proper length, the two ends are fastened together using a special clip, adhesive, or other seaming mechanism. The most common media include wire mesh, cellulose, fiberglass composites, or other synthetic materials. Filter media is generally classified as either surface or depth.

filtration fact

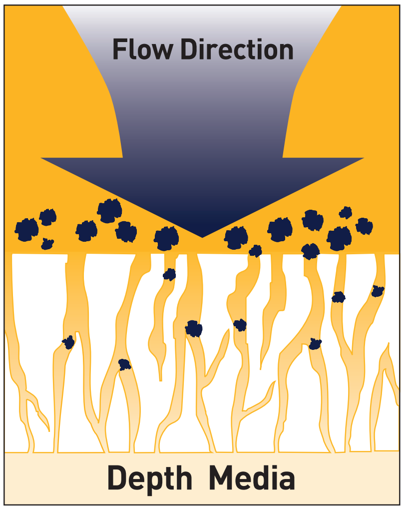
Surface media can be cleaned and re-used. An ultrasonic cleaner is usually the best method. Depth media typically cannot be cleaned and it is not re-usable.



Surface Media

For surface type filter media, the fluid stream basically has a straight through flow path. Contaminant is captured on the surface of the element which faces the fluid flow. Surface type elements are generally made from woven wire.

The process used in manufacturing wire cloth can be accurately controlled insuring that the surface type media has a consistent pore size. This consistent pore size is the diameter of the largest hard spherical particle that will pass through the media under specified test conditions. However, the build-up of contaminant on the element surface will allow the media to capture particles smaller than the pore size rating. Likewise, particles that have a smaller diameter, but may be longer in length (such as a fiber strand), may pass downstream of a surface media.



Depth Media

For depth type filter media, fluid must take indirect paths through the material which makes up the filter media. Particles are trapped in the maze of openings throughout the media. Because of its construction, a depth type filter media has many pores of various sizes. Depending on the distribution of pore sizes, this media can have a very high captive rate at very small particle sizes.

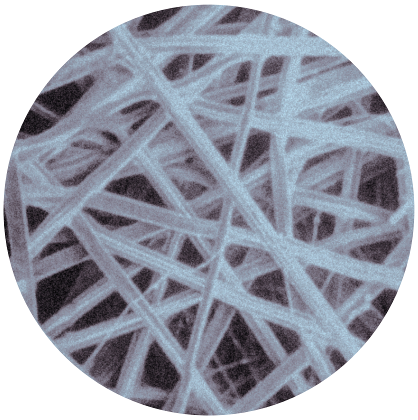
The nature of filtration media and the contaminant loading process in a filter element explains why some elements last much longer than others. In general, filter media contain millions of tiny pores formed by the media fibers. The pores have a range of different sizes and are interconnected throughout the layer of the media to form a tortuous path for fluid flow.

Filter Media Types and Ratings

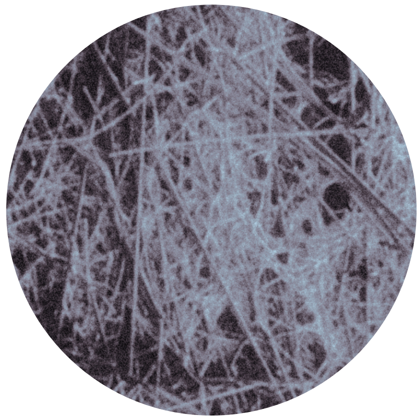
Types of Depth Media

The two basic depth media types that are used for filter elements are cellulose and fiberglass.

The pores in cellulose media tend to have a broad range of sizes due to the irregular size and shape of the fibers. In contrast, fiberglass media consists of fibers that are very uniform in size and shape. The fibers are generally thinner than cellulose fibers, and have a uniform circular cross section. These typical fiber differences account for the performance advantage of fiberglass media. Thinner fibers mean more actual pores in a given space. Furthermore, thinner fibers can be arranged closer together to produce smaller pores for finer filtration. Dirt holding capacity, as well as filtration efficiency, are improved as a result.

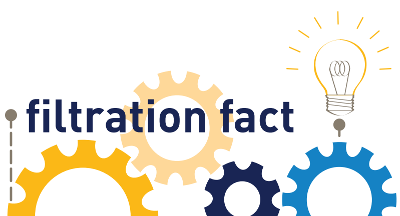


Typical coarse fiberglass construction (100x)

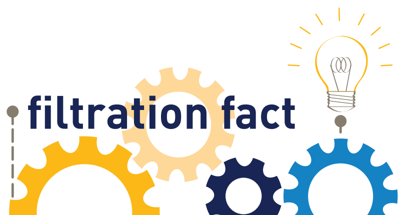


Typical fine fiberglass construction (100x)

General Comparison of Filter Media					
Media Material	Capture Effciency	Dirt Holding Capacity	Differential Pressure	System Life	Initial Cost
Fiberglass	High	High	Moderate	High	Moderate
Cellulose (paper)	Moderate	Moderate	High	Moderate	Low
Wire Mesh	Low	Low	Low	Moderate	High



Color is not a good indicator of a fluid's cleanliness level.



Most machine and hydraulic component manufacturers specify a target ISO cleanliness level to equipment in order to achieve optimal performance standards.

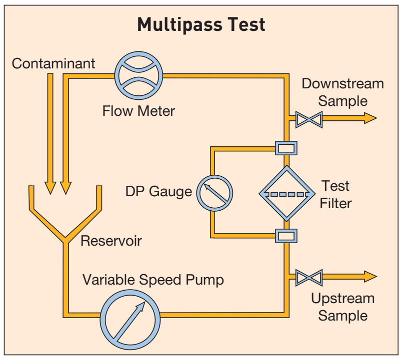
Filter Media Types and Ratings

The Multipass Test

The filtration industry uses the ISO 16889 "Multipass Test Procedure" to evaluate filter element performance. This procedure is also recognized by ANSI* and NFPA**. During the Multipass Test, fluid is circulated through the circuit under precisely controlled and monitored conditions. The differential pressure across the test element is continuously recorded, as a constant amount of contaminant is injected upstream of the element. On-line laser particle sensors determine the contaminant levels upstream and downstream of the test element. This performance attribute (The Beta Ratio) is determined for several particle sizes. Three important element performance characteristics are a result of the Multipass Test:

1. Dirt holding capacity.
2. Pressure differential of the test filter element.
3. Separation or filtration efficiency, expressed as a "Beta Ratio".

* ANSI - American National Standards Institute
** NFPA - National Fluid Power Association



Beta Ratio

The Beta Ratio (also known as the filtration ratio) is a measure of the particle capture efficiency of a filter element. It is therefore a performance rating.

As an example of how a Beta Ratio is derived from a Multipass Test. Assume that 50,000 particles, 10 micrometers and larger, were counted upstream (before) of the test filter and 10,000 particles at that same size range were counted downstream (after) of the test filter. The corresponding Beta Ratio would equal 5, as seen in the following example:

$$B_x = \frac{\text{\# of particles upstream}}{\text{\# of particles downstream}}$$

"x" is at a specific particle size

$$B_{10} = \frac{50,000}{10,000} = 5$$

The example would read "Beta ten equal to five." Now, a Beta Ratio number alone means very little. It is a preliminary step to find a filter's particle capture efficiency.

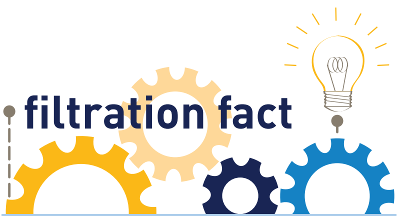
This efficiency, expressed as a percent, can be found by a simple equation:

$$\text{Efficiency}_x = \left(1 - \frac{1}{\text{Beta}}\right) 100$$

$$\text{Efficiency}_x = \left(1 - \frac{1}{5}\right) 100$$

$$= 80\%$$

In the example above, the particular filter tested was 80% efficient at removing 10 micrometer and larger particles. For every 5 particles introduced to the filter at this size range, 4 were trapped in the filter media.



Filter media ratings expressed as a Beta Ratio indicates a media's particle removal efficiency.

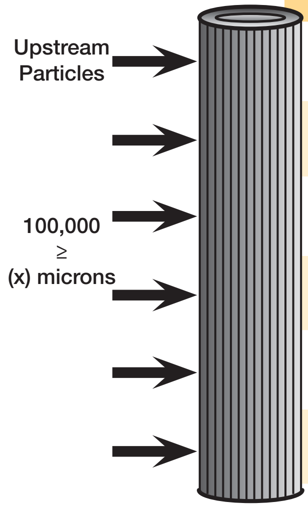
Filter Media Types and Ratings

The Beta Ratio/ Efficiencies table shows some common Beta Ratio numbers and their corresponding efficiencies.

Beta Ratios/Efficiencies

Beta Ratio (at a given particle size)	Capture Efficiency (at same particle size)
1.01	1.0%
1.1	9.0%
1.5	33.3%
2.0	50.0%
5.0	80.0%
10.0	90.0%
20.0	95.0%
75.0	98.7%
100	99.0%
200	99.5%
1000	99.9%

Beta Ratio



Downstream Particles		Beta Ratio (x)	Efficiency (x)
50,000 →	$\frac{100,000}{50,000}$ =	2	50.0%
5,000 →	$\frac{100,000}{5,000}$ =	20	95.0%
1,333 →	$\frac{100,000}{1,333}$ =	75	98.7%
1,000 →	$\frac{100,000}{1,000}$ =	100	99.0%
500 →	$\frac{100,000}{500}$ =	200	99.5%
100 →	$\frac{100,000}{100}$ =	1000	99.9%

filtration fact

Multipass test results are very dependent on the following variables:

- *Flow rate*
- *Terminal pressure differential*
- *Contaminant type*

Filter Media Selection

A number of interrelated system factors combine to determine proper media and filter combinations. To accurately determine which combination is ideal for your system all these factors need to be accounted for. With the development of filtration sizing software, this information can be used to compute the optimal selection. However, in many instances the information available may be limited. In these cases "rules of thumb", based on empirical data and proven examples, are applied to try and identify an initial starting point.

The charts on the following pages are designed for just those instances. Be aware that rules of thumb utilize "standard" values when looking at components, ingressions, and other system parameters. Your specific system may or may not fit into this "standard" classification.

One of the more important points of the charts is to emphasize element efficiency. Note that as less efficient elements are utilized, more passes are required to obtain the same ISO cleanliness level as a more efficient element.

Secondly, the charts indicate the effect of system pressure on the required ISO code. As system pressure increases, the oil film thickness between component parts decreases. This reduction in clearance allows smaller micron particles to have harmful effects. The charts attempt to provide flexibility by providing several possible solutions for each component/system pressure combination.

Selection software can be an extremely useful tool in the selection and specification of the proper filtration product. With computer aided selection, the user can quickly determine the pressure loss across a given element, and/or housing combination, within specific operating parameters. The tedious process of plotting viscosity at various points and calculating a pressure drop is eliminated. Additionally, selection software can predict system performance and element life – ideal for predictive maintenance programs.

filtration fact

There is no direct correlation between using a specific media and attaining a specific ISO cleanliness classification. Numerous other variables should be considered, such as particulate ingression, actual flow through filters and filter locations.

How to use the selection charts:

1. Choose the appropriate chart for your system, hydraulic or lubrication.
2. Starting in the left column, the components are listed by order of sensitivity. Find the most sensitive component used in your system.
3. Following the color band to the right of the component selected, choose the pressure range that the system operates within. This step is not required for lubrication systems.
4. Follow the color band to the right of the pressure range selected for the suggested ISO code for the system
5. To the right of the ISO code, in the same color band, are the media efficiencies required for the corresponding filter placements. Depending on the selection there will be one to three options available.
6. Be sure that the filter placements recommendation is on the same level as the media efficiency selected.

Filter Media Selection

Lubricating Systems				
Component Type	**Suggested Cleanliness Code**	**Media Efficiency $Beta_x$>200**	**Number of Filter Placements**	**Minimum Filter Placements**
Ball Bearings	16/13/11	2	1.5	P or R, & O
		2	1	P or R
Roller Bearings	17/14/12	5	2	P & R
		2	0.5	O
Journal Bearings	Low	5	1.5	P or R ,& O
Gear Boxes		10	2.5	P, R & O

Hydraulic Systems					
Component Type	**System Pressure**	**Suggested Cleanliness Code**	**Media Efficiency $Beta_x$>200**	**Number of Filter Placements**	**Minimum Filter Placements**
Servo Valves	<1000	17/14/12	2	1	P
			5	2	P & R
	1000-3000	16/13/11	2	1.5	P & O
	>3000	16/12/10	2	2	P & R
Proportional Valves	<1000	18/15/13	2	1	P
			5	1.5	P & O
			10	2.5	P, R & O
	1000-3000	18/14/12	2	1	P
			5	2	P & R
	>3000	17/14/11	2	1.5	P & O
			5	2.5	P, R & O
Variable Volume Pumps	<1000	19/16/14	5	1	P or O
			10	2	P & R
	1000-3000	18/16/14	2	0.5	O
			5	1.5	P or R, & O
			10	2.5	P, R & O
	>3000	18/15/13	2	1	P or R
			5	2	P & R
Vane Pumps Fixed Piston Pumps Cartridge Valves	<1000	20/17/15	5	0.5	O
			10	1.5	P or R, & O
	1000-3000	19/17/14	5	1	P or R
			10	1.5	P or R, & O
	>3000	19/16/13	5	1.5	P or R, & O
			10	2.5	P, R & O
Gear Pumps Flow Controls Cylinders	<1000	21/18/16	10	1	P or R
			20	2.5	P, R & O
	1000-3000	20/17/15	10	1.5	P or R, & O
	>3000	20/17/14	5	0.5	O
			10	1.5	P or R, & O

P = Full flow pressure filter (equals one filtration placement);
R = Full flow return filter (equals one filtration placement);
O = Off-line (flow rate 10% of reservoir volume equals .5 of a filtration placement)
* Number of filtration placements in system, more placements are the option of the specifier.

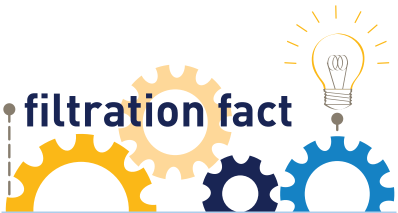
Filter Element Life

Contaminant Loading

Contaminant loading in a filter element is simply the process of blocking the pores throughout the element. As the filter element becomes blocked with contaminant particles, there are fewer pores for fluid flow, and the pressure required to maintain flow through the media increases. Initially, the differential pressure across the element increases very slowly because there is an abundance of media pores for the fluid to pass through, and the pore blocking process has little effect on the overall pressure loss. However, a point is reached at which successive blocking of media pores significantly reduces the number of available pores for flow through the element.
At this point the differential pressure across the element rises exponentially. The quantity, size, shape and arrangement of the pores throughout the element accounts for why some elements last longer than others.

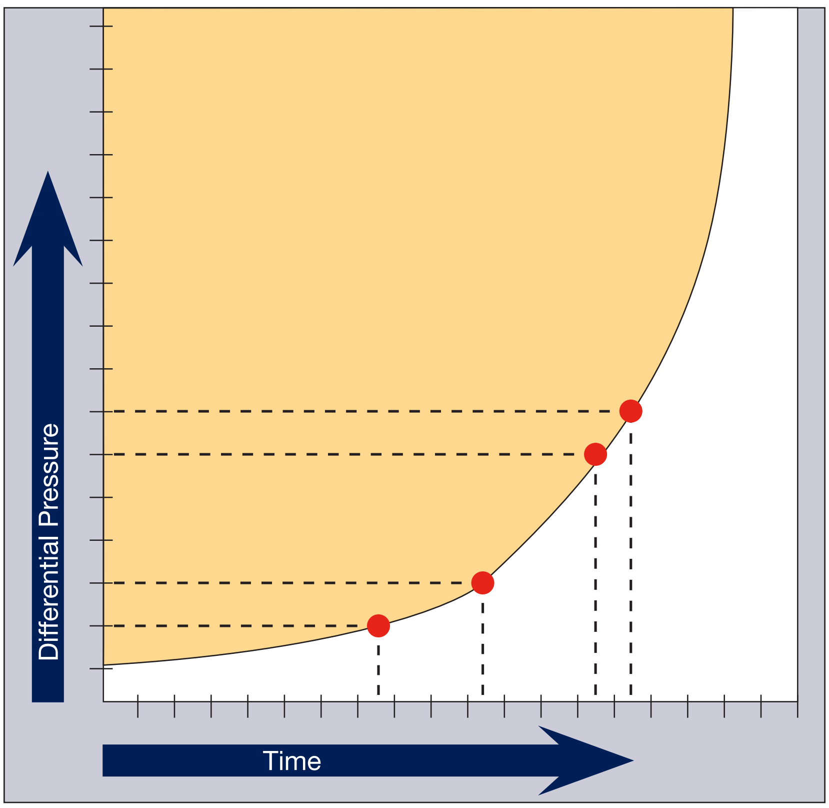
For a given filter media thickness and filtration rating, there are fewer pores with cellulose media than fiberglass media. Accordingly, the contaminant loading process would block the pores of the cellulose media element quicker than the identical fiberglass media element.

The multilayer fiberglass media element is relatively unaffected by contaminant loading for a longer time. The element selectively captures the various size particles, as the fluid passes through the element. The very small pores in the media are not blocked by large particles. These downstream small pores remain available for the large quantity of very small particles present in the fluid.



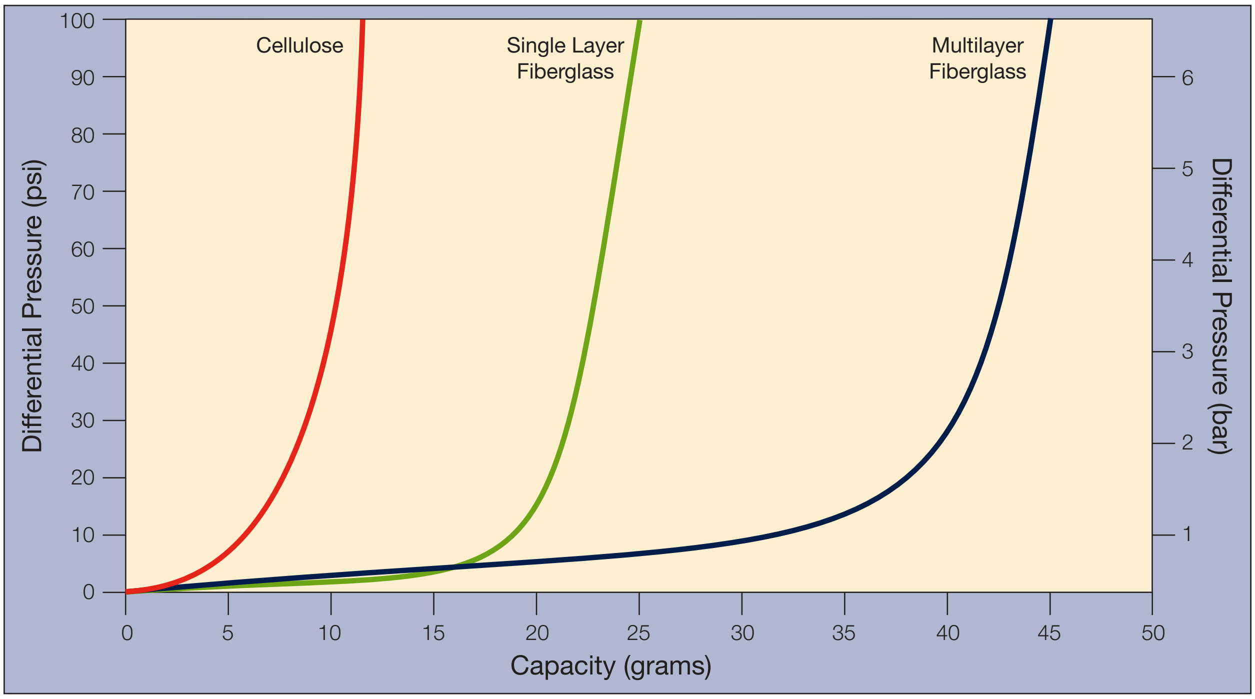
As an element loads with contamination, the differential pressure will increase over time; slowly at first, then very quickly as the element nears it's maximum life.

Element Contamination Loading Curve



Filter Element Life

Element Types Life Comparison



Filter Element Life Profile

Every filter element has a characteristic pressure differential versus contaminant loading relationship. This relationship can be defined as the "filter element life profile." The actual life profile is obviously affected by the system operating conditions. Variations in the system flow rate and fluid viscosity affect the clean pressure differential across the filter element and have a well-defined effect upon the actual element life profile.

The filter element life profile is very difficult to evaluate in actual operating systems. The system operating versus idle time, the duty cycle and the changing ambient contaminant conditions all affect the life profile of the filter element. In addition, precise instrumentation for recording the change in the pressure loss across the filter element is seldom available. Most machinery users and designers simply specify filter housings with differential pressure indicators to signal when the filter element should be changed.

The Multipass Test data can be used to develop the pressure differential versus contaminant loading relationship, defined as the filter element life profile. As previously mentioned, such operating conditions as flow rate and fluid viscosity affect the life profile for a filter element. Life profile comparisons can only be made when these operating conditions are identical and the filter elements are the same size. Then, the quantity, size, shape, and arrangement of the pores in the filter element determine the characteristic life profile. Filter elements that are manufactured from cellulose media, single layer fiberglass media, and multilayer fiberglass media all have a very different life profile. The graphic comparison of the three most common media configurations clearly shows the life advantage of the multilayer fiberglass media element.

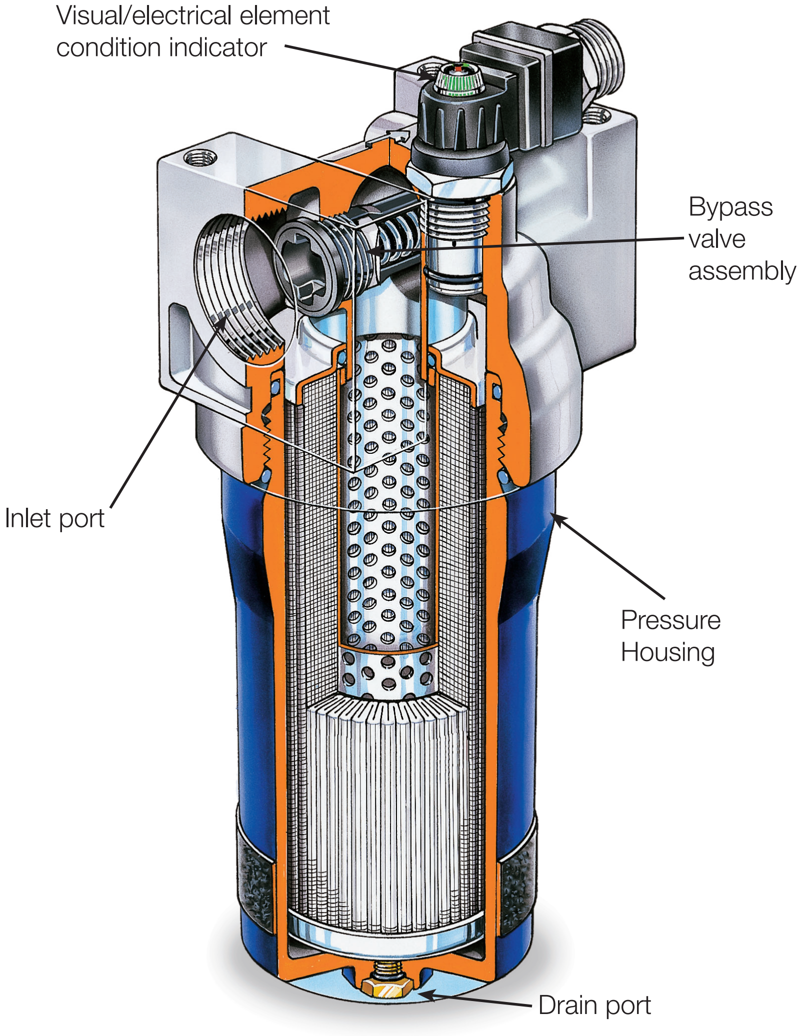
Filter Housing Selection

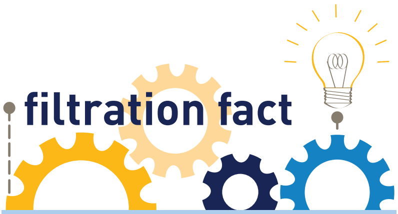
Filter Housings

The filter housing is the pressure vessel which contains the filter element. It usually consists of two or more subassemblies, such as a head (or cover) and a bowl to allow access to the filter element. The housing has inlet and outlet ports allowing it to be installed into a fluid system. Additional housing features may include mounting holes, bypass valves, drain ports, and element condition indicators.

Pressure Ratings

Location of the filter in the circuit is the primary determinant of pressure rating. Filter housings are generally designed for three locations in a circuit: suction, pressure, or return lines. One characteristic of these locations is their maximum operating pressures. Suction and return line filters are generally designed for lower pressures up to 500 psi (34 bar).





An element loading with contaminant will continue to increase in pressure differential until either:

- *The element is replaced*
- *The bypass valve opens*
- *The element fails*

The primary concerns in the housing selection process include mounting methods, porting options, indicator options, and pressure rating. All, except the pressure rating, depend on the physical system design and the preferences of the designer. Pressure rating of the housing is far less arbitrary. This should be determined before the housing style is selected.

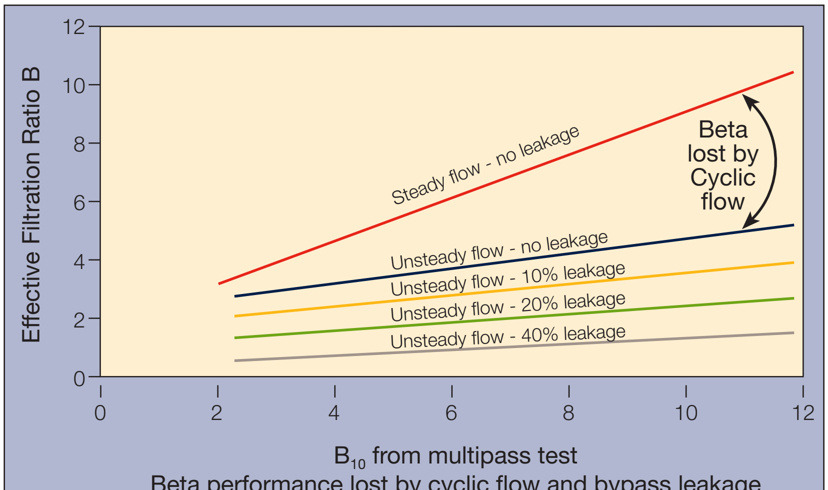
Pressure filter locations may require ratings from 1500 psi to 6000 psi (103 bar to 414 bar). It is essential to analyze the circuit for frequent pressure spikes as well as steady state conditions. Some housings have restrictive or lower fatigue pressure ratings. In circuits with frequent high pressure spikes, an alternative housing may be required to prevent fatigue related failures.

Filter Housing Selection

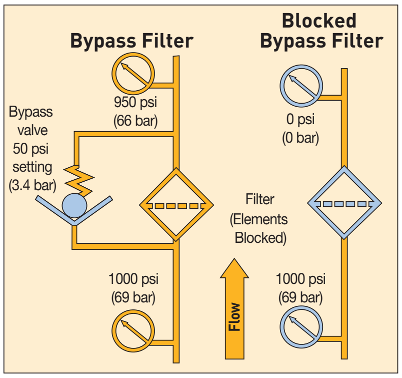
The Bypass Valve

The bypass valve is used to prevent the collapse or burst of the filter element when it becomes highly loaded with contaminant. It also prevents pump cavitation in the case of suction line filtration. As contaminant builds up in the element, the differential pressure across the element increases. At a pressure well below the failure point of the filter element, the bypass valve opens, allowing flow to go around the element.

Some bypass valve designs have a "bypass to tank" option. This allows the unfiltered bypass flow to return to tank through a third port, preventing unfiltered bypass flow from entering the system. Other filters may be supplied with a "no bypass" or "blocked" bypass option. This prevents any unfiltered flow from going downstream. In filters with no bypass valves, higher collapse strength elements may be required, especially in high pressure filters. Applications for using a "no bypass" option include servo valve and other sensitive component protection. When specifying a non-bypass filter design, make sure that the element has a differential pressure rating close to maximum operating pressure of the system. When specifying a bypass type filter, it can generally be assumed that the manufacturer has designed the element to withstand the bypass valve differential pressure when the bypass valve opens.



Beta performance lost by cyclic flow and bypass leakage



After a housing style and pressure rating are selected, the bypass valve setting needs to be chosen. The bypass valve setting must be selected before sizing a filter housing. Everything else being equal, the highest bypass cracking pressure available from the manufacturer should be selected. This will provide the longest element life for a given filter size. Occasionally, a lower setting may be selected to help minimize energy loss in a system, or to reduce back-pressure on another component. In suction filters, either a 2 or 3 psi (0.14 bar or 0.2 bar) bypass valve is used to minimize the chance of potential pump cavitation.

filtration fact

Always use an element condition indicator with any filter, especially those that do not have a bypass valve.

Element Condition Indicators

The element condition indicator signals when the element should be cleaned or replaced. The indicator usually has calibration marks which also indicates if the filter bypass valve has opened. The indicator may be mechanically linked to the bypass valve, or it may be an entirely independent differential pressure sensing device. The three types of indicators used visual, electrical, and analog. A visual indicator must be monitored locally to ensure proper change out intervals. An electrical switch indicator sends a signal to a remote location when the set point is reached. An analog indicator provides constant feedback throughout the life of the filter via a 4-20mA or 0-5V output. Generally, indicators are set to trip anywhere from 5%-25% before the bypass valve opens.

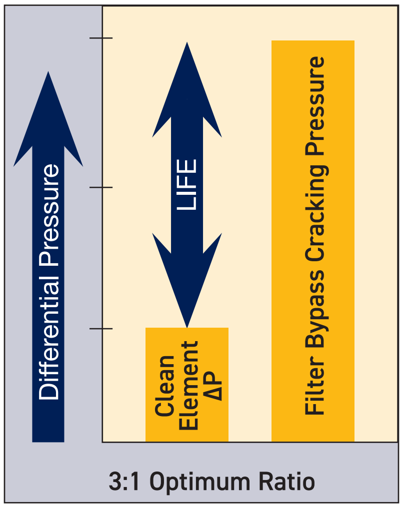



Housing and Element Sizing

The filter housing size should be large enough to achieve at least a 2:1 ratio between the bypass valve setting and the pressure differential of the filter with a clean element installed. It is preferable that this ratio be 3:1 or even higher for longer element life.

For example, the graph on the next page illustrates the type of catalog flow/pressure differential curves which are used to size the filter housing. As can be seen, the specifier needs to know the operating viscosity of the fluid, and the maximum flow rate (instead of an average) to make sure that the filter does not spend a high portion of time in bypass due to flow surges. This is particularly important in return line filters, where flow multiplication from cylinders may increase the return flow compared to the pump flow rate.

Filter Element Sizing



filtration fact

Pressure differential in a filter assembly depends on:

- *Housing and element size*
- *Media grade*
- *Fluid viscosity*
- *Flow rate*

filtration fact

It is recommended to use an element condition indicator with any filter, especially those that do not incorporate a bypass valve.

Filter Housing Selection

Housing and Element Sizing

If the filter described in the graph was fitted with a 50 psid (3.4 bar) bypass valve the initial (clean) pressure differential should be no greater than 25 psid (1.7 bar) and preferably 16 ⅔ psid (1.1 bar) or less. This is calculated from the 3:1 and 2:1 ratio of bypass setting and initial pressure differential.

Most standard filter assemblies utilize a bypass valve to limit the maximum pressure drop across the filter element. As the filter element becomes blocked with contaminant, the pressure differential increases until the bypass valve cracking pressure is reached. At this point, the flow through the filter assembly begins bypassing the filter element and passes through the bypass valve. This action limits the maximum pressure differential across the filter element. The important issue is that some of the system contaminant particles also bypass the filter element. When this happens, the effectiveness of the filter element is compromised and the attainable system fluid cleanliness degrades. Standard filter assemblies normally have a bypass valve cracking pressure between 25 and 100 psi (1.7 and 6.9 bar). The relationship between the starting clean pressure differential across the filter element and the bypass valve pressure setting must be considered. A cellulose element has a narrow region of exponential pressure rise. For this reason, the relationship between the starting clean pressure differential and the bypass valve pressure setting is very important. This relationship in effect determines the useful life of the filter element.

In contrast, the useful element life of the single layer and multilayer fiberglass element is established by the nearly horizontal, linear region of relatively low pressure drop increase, not the region of exponential pressure rise. Accordingly, the filter assembly bypass valve cracking pressure, whether 25 or 75 psi (1.7 or 5.2 bar), has relatively little impact on the useful life of the filter element. Thus, the initial pressure differential and bypass valve setting is less a sizing factor when fiberglass media is being considered.

3:1 RATIO

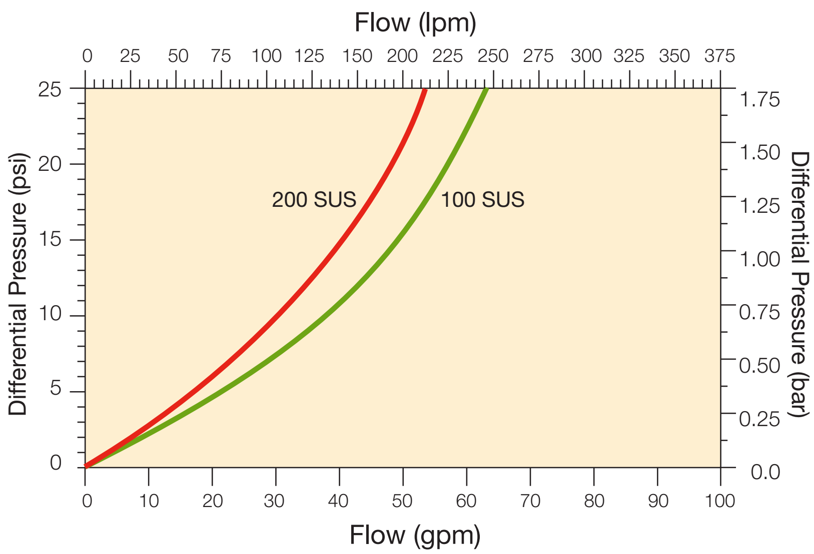
50/3 = 16 2/3 psid (1.1 bar)

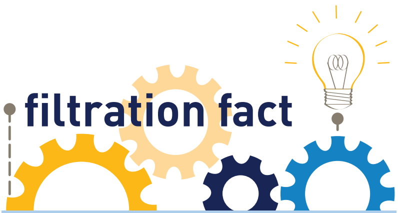
2:1 RATIO

50/2 = 25 psid (1.7 bar)

At 200 SUS fluid, the maximum flow range would be between 42 gpm and 54 gpm (159 lpm and 204 lpm)

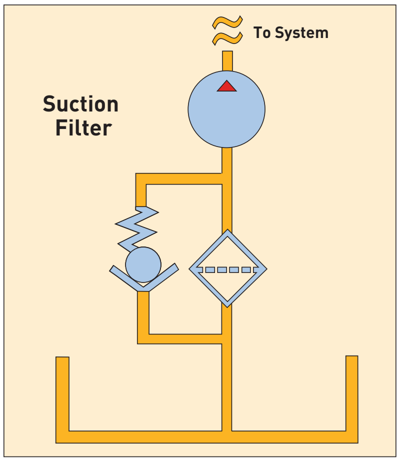
Typical Flow/Pressure Curves for Specific Media

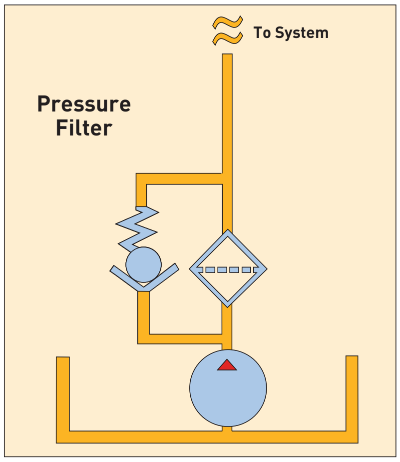


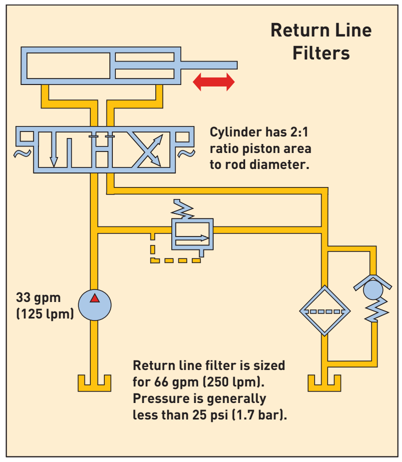


Always consider low temperature conditions when sizing filters. Viscosity increases in the fluid may cause considerable increase in pressure differential through the filter assembly.

Types & Locations of Filters







Suction Filters

Suction filters serve to protect the pump from fluid contamination. They are located before the inlet port of the pump. Some may be inlet "strainers", submersed in the fluid. Others may be externally mounted. In either case, they utilize relatively coarse elements, due to cavitation limitations of pumps. For this reason, they are not used as primary protection against contamination. Some pump manufacturers do not recommend the use of a suction filter. Always consult the pump manufacturer for inlet restrictions.

filtration fact

The use of suction filters and strainers has greatly decreased in modern filtration.

Pressure Filters

Pressure filters are located downstream from the system pump. They are designed to handle the system pressure and sized for the specific flow rate in the pressure line where they are located.

Pressure filters are especially suited for protecting sensitive components directly downstream from the filter, such as servo valves. Located just downstream from the system pump, they also help protect the entire system from pump generated contamination.

filtration fact

Suction strainers are often referred to by "mesh" size:

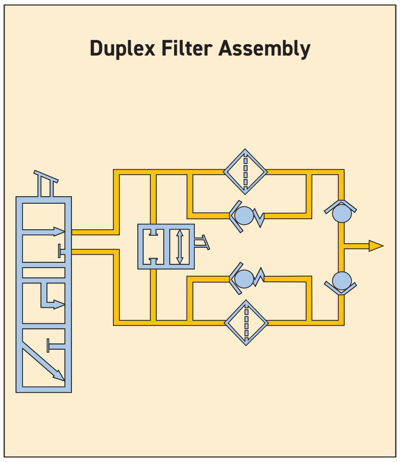
- *60 mesh = 238 micron*
- *100 mesh = 149 micron*
- *200 mesh = 74 micron*

Return Filters

When the pump is a sensitive component in a system, a return filter may be the best choice. In most systems, the return filter is the last component through which fluid passes before entering the reservoir. Therefore, it captures wear debris from system working components and particles entering through worn cylinder rod seals before such contaminant can enter the reservoir and be circulated. Since this filter is located immediately upstream from the reservoir, its pressure rating and cost can be relatively low.

In some cases, cylinders with large diameter rods may result in "flow multiplication". The increased return line flow rate may cause the filter bypass valve to open, allowing unfiltered flow to pass downstream. This may be an undesirable condition and care should be taken in sizing the filter.

Types & Locations of Filters



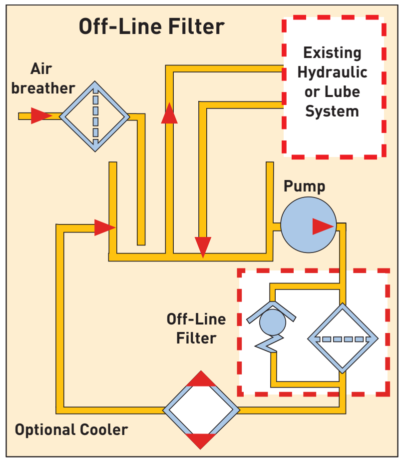
Duplex Filters

Both pressure and return filters are commonly found in a duplex version. It's most notable characteristic is continuous filtration. They are made with two or more filter chambers and include the necessary valving to allow for continuous, uninterrupted filtration. When a filter element needs servicing, the duplex valve is shifted, diverting flow to the opposite filter chamber. The dirty element is changed, while filtered flow continues to pass through the filter assembly. The valve is typically an open cross-over type, which prevents any flow blockage.

Off-Line Filtration

Recirculating, kidney loop, or auxiliary filtration, this filtration system is totally independent of a machine's main hydraulic system. Off-line filtration consists of a pump, filter, electrical motor, and the appropriate hardware connections. These components are installed off-line as a small sub-system separate from the working lines, or included in a fluid cooling loop. Fluid is pumped out of the reservoir, through the filter, and back to the reservoir in a continuous fashion. With this "polishing" effect, off-line filtration is able to maintain a fluid at a consistent cleanliness level.

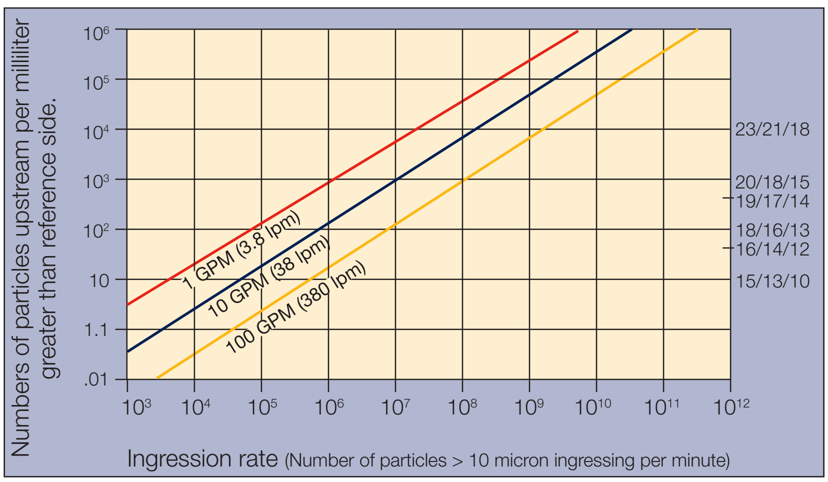
As with a return line filter, this type of system is best suited to maintain overall cleanliness, but does not provide specific component protection. An off-line filtration loop has the added advantage that it is relatively easy to retrofit on an existing system that has inadequate filtration. Also, the filter can be serviced without shutting down the main system. Most systems would benefit greatly from having a combination of suction, pressure, return, and off-line filters. The table to the right may be helpful in making a filtration location decision.



filtration fact

Rule of thumb: size the pump flow of an off-line system at a minimum of 10% of the main reservoir volume.

Flow Rate Effect on Off-Line Filtration Performance



Source based on Fitch, E.C., Fluid Contamination Control, FES, Inc., Stillwater, OK, 1988.

Types & Locations of Filters

Comparison of Filter Types and Locations		
Filter Location	**Advantages**	**Disadvantages**
Suction (externally mounted)	• Last chance protection for the pump. • Much easier to service than a sump strainer.	• Must use relatively coarse media and/or large housing size to keep pressure drop low due to pump inlet conditions. • Cost is relatively high • Does not protect downstream components from pump wear debris • May not be suitable for many variable volume pumps • Minimum system protection
Pressure	• Specific component protection • Contributes to overall system cleanliness level • Can use high efficiency, fine filtration, filter elements • Catches wear debris from pump	• Housing is relatively expensive because it must handle full system pressure • Does not catch wear debris from downstream working components
Return	• Catches wear debris from components and dirt entering through worn cylinder rod seals before it enters the reservoir • Lower pressure ratings result in lower costs • May be in-line or in-tank for easier installation	• No protection from pump generated contamination • Return line flow surges may reduce filter performance • No direct component protection • Relative initial cost is low
Off-Line	• Continuous "polishing" of the main system hydraulic fluid, even if the system is shut down. • Servicing possible without main system shut down • Filters not affected by flow surges allowing for optimum element life and performance • The discharge line can be directed to the main system pump to provide supercharging with clean, conditioned fluid • Specific cleanliness levels can be more accurately obtained and maintained • Fluid cooling may be easily incorporated.	• Last chance protection for the pump. • Relative initial cost is high • Requires additional space • No direct component protection

filtration fact

Any laboratory fluid analysis should always include a particle count and corresponding ISO code.

Fluid Analysis

Fluid analysis is an essential part of any maintenance program. Fluid analysis ensures that the fluid conforms to manufacturer specifications, verifies the composition of the fluid, and determines its overall contamination level.

Laboratory Analysis

The laboratory analysis is a complete look at a fluid sample. Most qualified laboratories will offer the following tests and features as a package:

- **Viscosity**
- **Neutralization number**
- **Water content**
- **Particle counts**
- **Spectrometric analysis (wear metals and additive analysis reported in parts per million, or ppm)**
- **Trending graphs**
- **Photomicrograph**
- **Recommendations**

In taking a fluid sample from a system, care must be taken to make sure that the fluid sample is representative of the system.

To accomplish this, the fluid container must be cleaned before taking the sample and the fluid must be correctly extracted from the system. There is a National Fluid Power Association (NFPA) standard for extracting fluid samples from a reservoir of an operating hydraulic fluid power system. (NFPA T2.9.1-1972). There is also the American National Standard method (ANSI B93.13-1972) for extracting fluid samples from the lines of an operating hydraulic fluid power system for particulate contamination analysis. Either extraction method is recommended.

In any event, a representative fluid sample is the goal. Sampling valves should be opened and flushed for at least fifteen seconds. The clean sample bottle should be kept closed until the fluid and valve is ready for sampling. The system should be at operating temperature for at least 30 minutes before the sample is taken.

A complete procedure follows in the appendix.

Patch Test

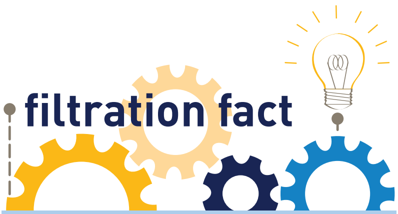
A patch test is nothing more than a visual analysis of a fluid sample. It usually involves taking a fluid sample and passing it through a fine media "patch". The patch is then analyzed under a microscope for both color and content, and compared to known ISO standards. By using this comparison, the user can get a "go, no-go" estimate of a system's cleanliness level.

Another less common deviation of the patch test would be the actual counting of the particles seen under the microscope. These numbers would then be extrapolated into an ISO cleanliness level.

The margin of error for both of these methods is relatively high due to the human factor.

Portable Particle Counter

A most promising development in fluid analysis is the portable laser particle counter. Laser particle counters are comparable to full laboratory units in counting particles down to the 2 + micron range. Strengths of this technology include accuracy, repeatability, portability, and timeliness. A test typically takes less than a minute. Laser particle counters will generally give only particle counts and cleanliness classifications. Water content, viscosity, and spectrometric analysis tests would require a full laboratory analysis.



*The **only** way to know the condition of a fluid is through fluid analysis. Visual examination is not an accurate method.*

Appendix

Sampling Procedure

Obtaining a fluid sample for particle counts and/or analysis involves important steps to make sure you are getting a representative sample. Often erroneous sampling procedures will disguise the true nature of system cleanliness levels. Use one of the following methods to obtain a representative system sample.

I. For systems with a sampling valve

A. Operate system for at least 1/2 hour.

B. With the system operating, open the sample valve allowing 200 ml to 500 ml (7 to 16 ounces) of fluid to flush the sampling port. (The sample valve design should provide turbulent flow through the sampling port.)

C. Using a wide mouth, pre-cleaned sampling bottle, remove the bottle cap and place in the stream of flow from the sampling valve. Do NOT "rinse" out the bottle with initial sample. Do not fill the bottle more than one inch from the top.

D. Close the sample bottle immediately. Next, close the sampling valve. (Make prior provision to "catch" the fluid while removing the bottle from the stream.)

E. Tag the sample bottle with pertinent data: include date, machine number, fluid supplier, fluid number code, fluid type, and time elapsed since last sample (if any).

II. Systems without a sampling valve

There are two locations to obtain a sample in a system without a sampling valve: in-tank and in the line. The procedure for both follows:

A. In the Tank Sampling

1. Operate the system for at least 1/2 hour.
2. Use a small hand-held vacuum pump bottle thief or "basting syringe" to extract a sample. Insert sampling device into the tank to one half of the fluid height. You will probably have to weigh the end of the sampling tube. Your objective is to obtain a sample in the middle portion of the tank. Avoid the top or bottom of the tank. Do not let the syringe or tubing come in contact with the side of the tank.
3. Put extracted fluid into an approved, pre-cleaned sample bottle as described in the sampling valve method above.
4. Cap immediately.
5. Tag with information as described in sampling valve method.

B. In-Line Sampling

1. Operate the system for at least 1/2 hour.
2. Locate a suitable valve in the system where turbulent flow can be obtained (ball valve is preferred). If no such valve exists, locate a fitting which can be easily opened to provide turbulent flow (tee or elbow).
3. Flush the valve or fitting sample point with a filtered solvent. Open valve or fitting and allow adequate flushing. (Take care to allow for this step. Direct sample back to tank or into a large container. It is not necessary to discard this fluid.)
4. Place in an approved and pre-cleaned sample bottle under the stream of flow per sampling valve methods above.
5. Cap sample bottle immediately.
6. Tag with important information per the sampling valve method. Note: Select a valve or fitting where the pressure is limited to 200 PSIG (14 bar) or less.

Regardless of the method being used, observe common sense rules. Any equipment which is used in the fluid sampling procedure must be washed and rinsed with a filtered solvent. This includes vacuum pumps, syringes and tubing. Your goal is to count only the particles already in the system fluid. Dirty sampling devices and non-representative samples will lead to erroneous conclusions and cost more in the long run.

filtration fact

Additives in hydraulic fluid are generally well below 1 micron in size and are unaffected by standard filtration methods.

Test Laboratory: Parker Metamora, Ohio   Test date: 11-Feb-21   Operator: josh

FILTER AND ELEMENT IDENTIFICATION

Element ID: #####   Housing ID: ####

Project: ______   Minimum element bubble point (inches H_2O) ______   Number of Pleats: ______

Specification: ______   Media P/N: ______   Pleat Height: ______

Supplier P/N: ______   Filter Area: 0   Pleat Length: ______

OPERATING CONDITIONS

Test fluid

Type: MIL-5606A   Supplier: Mobil   Batch No.: ______

Viscosity at the test temperature (mm²/s): 15   Temperature (°F): 104.0

Antistatic: ______   Type: Stadis 450   Conductivity (pS/m): ______

Test Contaminant

Type: A3   Supplier: ______   Batch No.: 14086M

Test System

Flow Rate (Gal/min.): 50.00   Initial Volume (L): 53.4

Base upstream concentration (mg/L): 13.27   Final Volume (L): 53.4

Injection System

Injection Parameters	Initial	Final	Average injection parameters	
System Volume (L)	79.8	67.81	Injection Flow (mL/min):	250
Concentration (mg/L)	9830.9756	10265.25	Concentration (mg/L)	10048.1

Counting System

	Counter and Sensor References:	Flowrate (mL/minute):	Dilution Ratio:
Upstream	Klotz PCS 1.0 / Model LDS-30/30	20	3 :1
Downstream	Klotz PCS 1.0 / Model LDS-30/30	20	3 :1

Counter calibration: Method: ISO11171 Secondary   Date: 09/2019

Validation Date: 04/15/2020

Comments: LR:9278 BB:7.3

TEST RESULTS

Element Integrity

Bubble point to ISO 2942: ______   Wetting fluid: ______

Differential pressure

Filter Housing (psid): 25.2   Clean Element (psid): 1.6 ← Element pressure drop at test initiation

Clean Assembly (psid): 26.8   Final DeltaP Element (psid): 101.7 ← Element pressure drop at test termination

Test Goal Terminal DP(psid): 126.8

Differential pressure versus contaminant added

Time interval	Test time (minutes)	Element DeltaP (psid)	Injected Mmass (g)	Time interval	Test time (minutes)	Element DeltaP (psid)	Injected Mmass (g)
10%	0:04:47	2.0	12.03	60%	0:28:44	15.6	72.17
20%	0:09:35	2.7	24.06	70%	0:33:31	27.2	84.19
30%	0:14:22	3.4	36.08	80%	0:38:19	45.8	96.22
40%	0:19:09	5.7	48.11	90%	0:43:06	71.0	108.25
50%	0:23:57	9.2	60.14	100%	0:47:53	101.7	120.28

Retention capacity

ISOMTD mass injected (g): 120.28   ISOMTD retained capacity (g): 119.27 ← Element dirt holding capacity

80% upstream concentration (mg/L): 18.03   Dust holding capacity (mg/in²): ______

Filtration ratio ßx(c)   (If the size valu see multiple values on Graph C2: Beta vs. Size)

Average Filtration Ratio:	2	10	75	100	200	1000 ← Beta Ratio
Size (µm(c))	<4	<4	5.1	5.4	6.2	7.9 ← Corresponding Particle Size

ISO 16889 - FILTER ELEMENT MULTIPASS REPORT SHEET

Test File Name: XXYY **Equipment ID: 19-076; Version: 3.16v228; Filter: ######**

TEST RESULTS II

Particle counts (per mL) and filtration ratio

Time interval		d > 4 µm(c)	d > 5 µm(c)	d > 6 µm(c)	d > 7 µm(c)	d > 8 µm(c)	d > 10 µm(c)	d > 12 µm(c)	d > 13 µm(c)	d > 15 µm(c)	d > 18 µm(c)	d > 20 µm(c)	d > 25 µm(c)	d > 30 µm(c)	d > 35 µm(c)	d > 40 µm(c)	d > 50 µm(c)
	Initial	13.9	5.3	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10%	Up	30235.8	17998.7	11843.6	8063.6	5595.4	2717.8	1444.1	1097.1	671.8	350.2	228.5	75.1	27.5	20.1	12.7	5.3
	Down	1437.2	297.2	65.6	16.4	6.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	21.0	60.6	180.5	491.5	859.0	5632.8	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
20%	Up	30027.1	17999.4	11887.8	8121.8	5633.2	2802.1	1509.1	1154.6	715.4	383.4	254.6	90.7	36.4	20.1	13.5	6.3
	Down	1597.5	359.3	88.8	21.8	4.7	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	18.8	50.1	133.9	372.4	1209.3	8325.3	31491.6	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
30%	Up	30872.3	18453.8	12145.1	8290.1	5759.5	2863.3	1541.3	1187.4	732.3	399.3	269.1	95.4	41.7	23.2	15.2	8.9
	Down	1787.6	436.3	114.0	30.3	6.7	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	17.3	42.3	106.5	273.5	865.2	4981.6	16091.8	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
40%	Up	30853.6	18534.5	12208.3	8384.3	5812.7	2862.4	1548.2	1199.9	749.4	404.1	269.3	107.2	47.2	24.4	16.1	9.6
	Down	1683.4	436.2	125.8	36.3	8.6	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	18.3	42.5	97.0	231.3	678.9	5990.6	16208.0	25155.8	15709.7	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
50%	Up	30272.6	18368.6	12169.2	8322.2	5771.7	2859.2	1518.9	1150.2	715.4	397.4	271.3	101.9	48.6	26.0	17.7	8.1
	Down	1394.3	388.9	113.6	33.5	9.3	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	21.7	47.2	107.1	248.1	623.8	4351.5	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
60%	Up	29521.7	18117.9	12074.9	8310.8	5808.7	2853.9	1544.7	1180.3	720.2	390.8	262.9	101.6	45.9	23.9	16.7	9.9
	Down	897.4	255.6	76.0	23.3	6.4	0.8	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	32.9	70.9	158.8	356.7	903.1	3745.2	10809.7	12388.1	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
70%	Up	29241.5	18104.8	12143.6	8353.7	5800.1	2881.3	1555.9	1192.3	736.1	393.2	267.0	97.4	47.0	23.2	13.2	8.7
	Down	521.8	156.4	47.5	16.0	4.6	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	56.0	115.7	255.5	522.6	1256.8	6728.0	10901.5	25144.1	15523.9	8290.9	5631.3	2053.8	100000.0	100000.0	100000.0	100000.0
80%	Up	28809.7	17988.6	12139.6	8379.8	5882.7	2941.6	1560.0	1189.8	738.8	390.0	262.9	98.5	45.6	24.2	13.6	8.1
	Down	355.4	105.7	32.4	10.5	3.0	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	81.1	170.1	374.6	800.4	1993.5	7724.1	16400.3	24986.0	15514.9	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
90%	Up	28764.8	18021.6	12100.4	8360.5	5804.8	2873.2	1546.2	1180.2	732.3	400.5	262.1	109.0	49.2	28.8	19.2	12.3
	Down	256.1	76.2	22.9	7.0	2.5	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	112.3	236.6	528.3	1197.0	2349.1	6719.9	16279.7	12425.6	15424.0	8434.9	5519.4	2295.2	1035.7	606.1	404.5	258.1
100%	Up	28860.7	18082.9	12207.6	8423.2	5878.2	2941.4	1593.9	1221.0	751.6	405.6	271.3	94.9	42.6	23.7	15.3	6.6
	Down	191.5	54.9	16.6	4.9	1.8	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	150.7	329.4	736.4	1729.0	3298.0	12374.5	26799.0	20530.3	12636.5	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
Average	Up	29746.0	18167.1	12092.0	8301.0	5774.7	2859.6	1536.2	1175.3	726.3	391.4	261.9	97.2	43.2	23.8	15.3	8.4
	Down	1012.2	256.7	70.3	20.0	5.4	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ß	29.4	70.8	171.9	415.2	1071.5	6001.2	19837.1	29945.5	29088.7	41248.7	27597.1	10239.3	9093.3	5002.3	3226.0	1764.5

Filter element tested

Particle size

% of terminal ΔP

Upstream particle count

Downstream particle count

Published filtration efficiency

Single particle >50µ detected

Viscosity Conversion Chart

cSt (Centistokes)	SUS (Saybolt Universal Seconds)*
10	46
20	93
25	116
30	139
32.4	150
40	185
50	232
70	324
90	417

Comparisons are made at 100° F (38° C) for other viscosity conversion approximations, use the formula: $cSt = \frac{SUS}{4.635}$

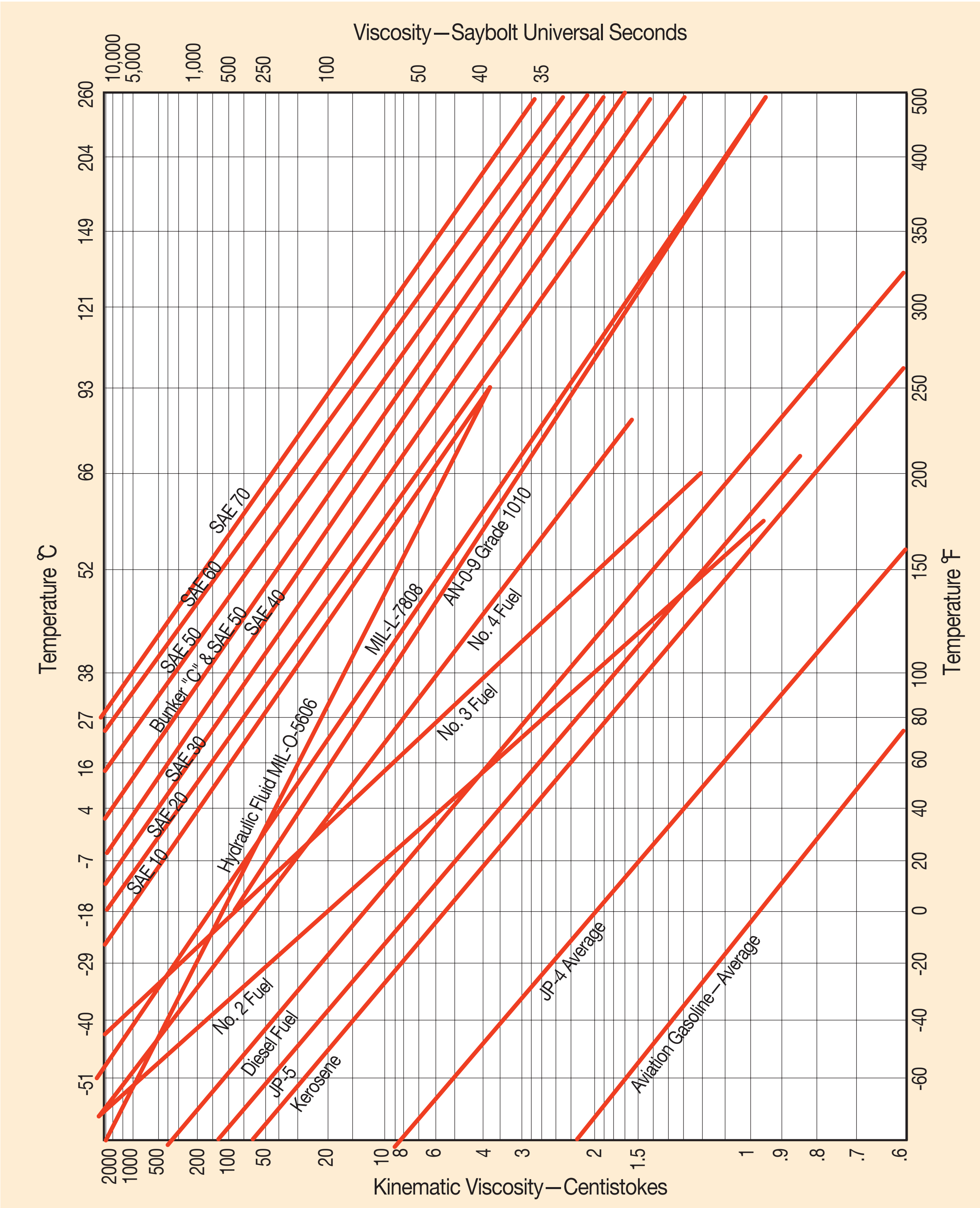
*NOTE: Saybolt universal seconds may also be abbreviated SSU.

Metric Conversion Table

to Convert	Into	Multiply by
Inches	Millimeters	25.40
Millimeters	Inches	.03937
Gallons	Liters	3.785
Liters	Gallons	.2642
Pounds	Kilograms	.4536
Kilograms	Pounds	2.2046
PSI	Bar	.06804
Bar	PSI	14.5
Centigrade	Fahrenheit	(°C x 91/45) + 32
Fahrenheit	Centigrade	(°F-32) / 1.8
Microns	Inches	.000039
Microns	Meters	.000001

Appendix

Viscosity vs. Temperature



Notes

 HTM5 (8/2023)

Parker Hannifin Corporation
Hydraulic & Fuel Filtration Division
16810 Fulton County Road #2
Metamora, OH 43540
phone 419 644 4311
www.parker.com/hydraulicfilter