Industrial Filtration

KNOW-HOW FOR MORE EFFICIENCY AND PROFITABILITY

FILTRATION IN HYDRAULIC AND LUBRICATION CIRCUITS




HYDRAULIC SYSTEMS NEED INNOVATIVE FILTER SOLUTIONS

High-performance filter systems have become an essential part of modern hydraulic and lubrication systems. They protect highly sensitive components, contribute to constant required fluid-media cleanliness, and ensure the necessary system reliability and profitability.

In this manual, we wish to comprehensively inform both prospective hydraulic technicians and seasoned experts about the latest in filtration for hydraulic and lubrication circuits, from the fundamentals, to operation, to systems maintenance.

Here you will find all the critical details from theory and practice, summarized in a compact and convenient format. If you should still have unanswered questions, we will be happy to respond to you personally. Simply contact our engineers and technicians.

We hope you enjoy this brochure.




ALWAYS A CLEAN SOLUTION

MAHLE Industriefiltration

As an innovative solutions partner, MAHLE Industriefiltration has been producing high-quality industrial filters for many decades for fluid technology, air filtration, and process technology. MAHLE Industriefiltration is an independent service area with its own engineering, production, and sales teams, integrated in the MAHLE Group, one of the 30 largest automotive suppliers in the world.

Perfection in all filter applications

Thanks to highly effective filters and filter systems, equipment, and accessories for keeping hydraulic fluids clean, MAHLE is an expert partner for both machine manufacturers and operators of mobile and stationary hydraulic equipment.

For air systems, MAHLE air filters and oil separators ensure efficient compressed air production.

MAHLE dust collectors and dust collecting systems support environmental protection and safety at work, and are used successfully for product recovery.

With the advantage of rational nonstop operation, around the clock, with automatic cleaning and disposal sequences, MAHLE automatic filters can be used for coarse or fine filtration or homogenization. They have opened up applications from cooling lubricant filtration, to food technology, to maritime operations.

MAHLE hydraulic and lubricating oil filters

Since the early 1960s, MAHLE has been active in the filtration of hydraulic and lubricating fluids. Today, this product group is a main focus of the industrial filter product line. The advanced technical know-how and outstanding quality of our products have made us one of the world’s leading manufacturers of filter systems, equipment, and accessories for fluid technology.

Our product range includes pressure filters, duplex filters, bypass filters, suction filters, return-line filters, air breathers, coalescer-filters, high-performance filter elements in standard and DIN 24550 versions, and accessories, as well as filter and service equipment for the maintenance of hydraulic and lubricating fluids. Proven in thousands of systems, our high-performance filter elements protect highly sensitive hydraulic systems and ensure that the required cleanliness class is maintained for a wide variety of fluid media.

Continuous development of materials and production technologies guarantee economical and technically optimized products of the highest quality. Our production is certified to DIN EN ISO 9001, and our environmental management is certified to DIN EN ISO 14001. This is how we design the future and success for ourselves and our customers.

MAHLE Industriefiltration, Öhringen plant

RELIABLE SYSTEMS WITH CONSTANT, LOW CLEANLINESS CLASS

One of the main causes of failures and system outages in hydraulic systems remains dirt, which leads to premature component wear. An effective cure: filters that reduce the solid contaminants in the system to a tolerable level, prevent extraneous dirt from entering the system, and maintain the properties of the hydraulic fluids over as long a period as possible. MAHLE fluid filters are also characterized by long service life and cost-saving operation, so that they increase the system's efficiency and profitability.

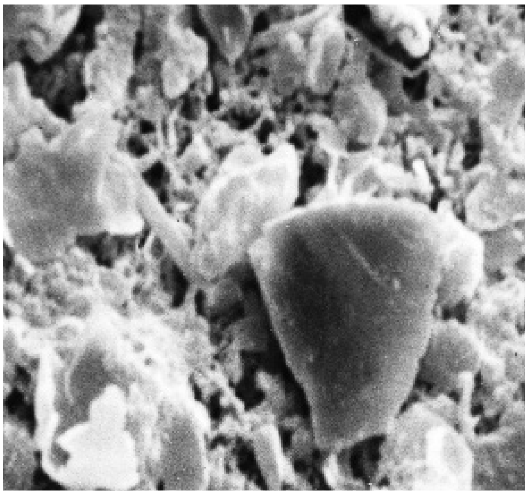
Sources of contamination

A hydraulic system is exposed to a wide variety of contaminants over its entire service life. Dirt is already being produced during the manufacture of the hydraulic components and during assembly. Added to this is the base contamination of the hydraulic fluid. Abrasion and wear during operation also compromise the system. Dirt can also penetrate from the outside, through defective seals or insufficient tank venting.

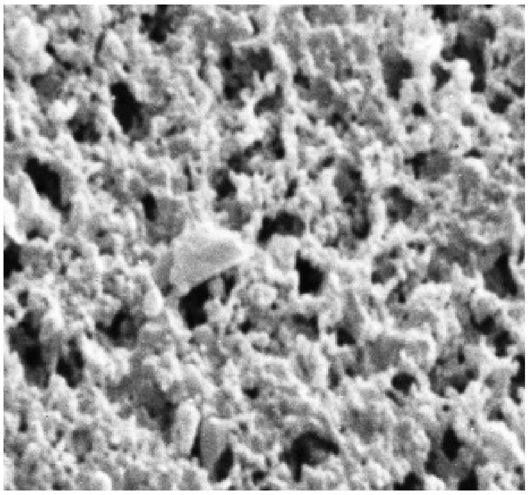
Sources of contamination are essentially divided into three categories:

- Contaminants during assembly (assembly contamination)
- Contaminants produced within the system (operational contamination)
- Contaminants from the environment and the hydraulic fluid (contaminant entry)

Anyone who is familiar with these sources of contamination can find specific remedies in MAHLE fluid filters.



Assembly contamination at 170x magnification



Tolerated residual contamination at 170x magnification

Assembly contamination

During the production of hydraulic components and the assembly of the system, different types of contamination occur, depending on the process. Examples include chips, molding sand, core remnants, fibers, burr residues, dust, paint residues, or welding residues.

These contaminants are typically coarse, and must be removed as much as possible by washing and rinsing the entire system prior to commissioning the hydraulic system. After rinsing, the run-in phase of the system should take place with no load, in order to break loose stuck contaminants and remove them via the filters.

For complex systems, it is recommended that flushing filters be installed at strategic points, in addition to the existing operational filters, in order to reduce the initial contamination as quickly as possible.

It is seldom possible to completely remove assembly and manufacturing contaminants. Vibrations and changes in temperature in the flow conditions can release residual contaminants long after a system has been commissioned. It is therefore important that the installed filters capture these contaminants, thereby protecting even very sensitive component.

Operational contamination

The mechanical and thermal effects of the hydraulic system create new dirt from the contaminants present in the components and the system. In addition, the hydraulic components are subjected to abrasion. These processes create an avalanche of dirt that builds on itself, and that must be captured by the filters and kept to a tolerable level for the system.

Contaminants from the environment

A source of contamination that is often underestimated is incorrect or missing air breathers, open maintenance covers on the hydraulic tank, or defective seals on flanges and cylinders, through which dust and dirt from the environment can penetrate into the hydraulic system, thereby continuously increasing and fueling the avalanche of dirt. The dust content of the air surrounding a hydraulic system is also often underestimated. The retention rate of the air breather must always be matched to the rating grade of the oil filter and the required cleanliness class of the oil. Leaks in components and seals must also be repaired as soon as possible, and the tank openings must be covered after maintenance and repair work, and kept closed during operation.

MAHLE Industriefiltration—The complete range for filtration

Suction filter

Pressure filter

Duplex filter

Bypass filter

Return-line filter

Air breather

Accessories

Contaminants from the hydraulic fluids

Hydraulic fluids can be severely contaminated during manufacture, filling, transport, and storage. In particular, storage in tanks and drums causes problems, because these containers are insufficiently protected against corrosion, contamination by condensate water, and dust from the environment.

Online measurements of hydraulic fluids during initial filling, as well as during maintenance (refilling) often show cleanliness classes that are well below the system's oil cleanliness requirements. In order to improve this condition, the fluid must be continuously filtered through appropriate filters, both upon initial filling and when refilling. Because the filter must achieve full effectiveness in a single pass when filling, the requirements for special filling filters are very high.

Contamination balance

Assembly contamination

Contaminants already present in the system:
- on components
- in the hydraulic fluid

Operational contamination

Contaminants generated in the system:
- due to abrasion
- due to wear

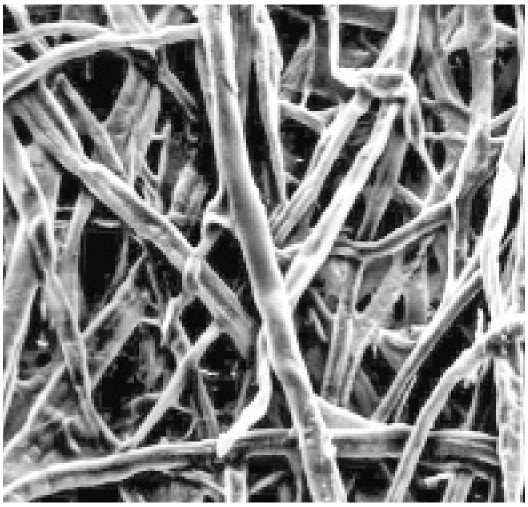
Contaminant entry

Contaminants penetrating from outside the system:
- when refilling hydraulic fluid
- through cylinders and seals
- due to venting the tank

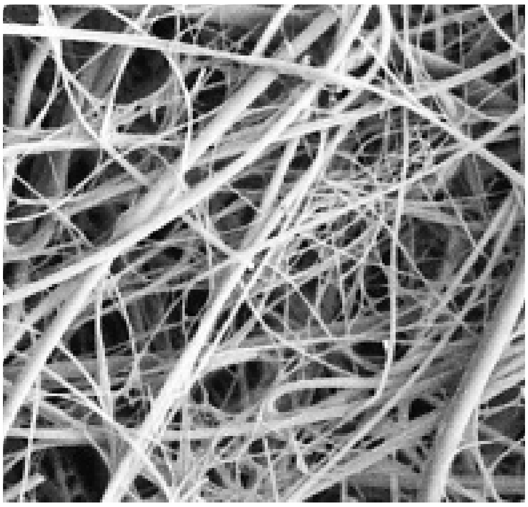
MAHLE Industriefiltration—Filter concept

SYSTEM WITH CONSTANTLY LOW CLEANLINESS CLASS

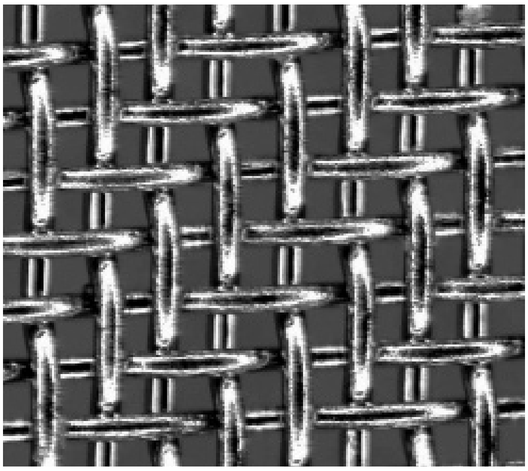
Filter media for hydraulic oil and lubricant filtration are sometimes used individually, but generally in combination with each other



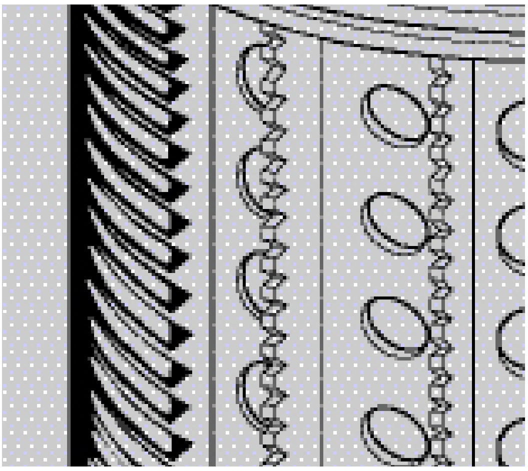
Impregnated cellulose paper



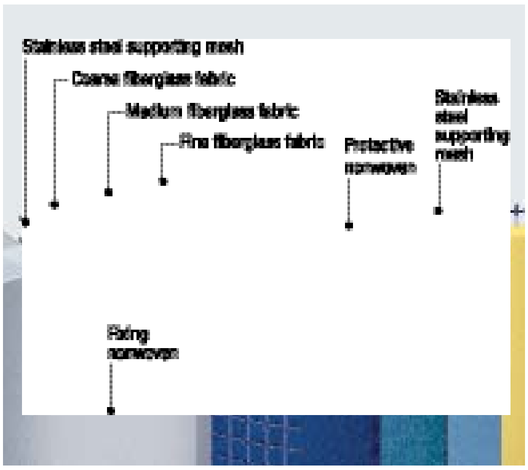
Micro glass fiber



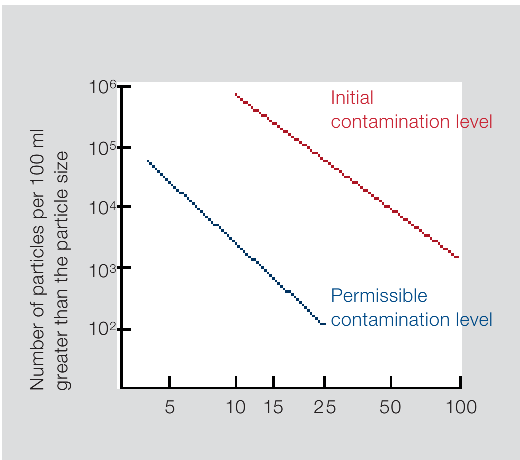
Wire mesh



Metal edges



Design of a PS pleated star



Typical relationship between the permissible contaminant level determined by design and the actual level prior to commissioning

KEEPING IT CLEAR IN HYDRAULIC AND LUBRICATION CIRCUITS

Hydraulic fluids primarily serve to transfer energy from the pump to the working cylinders, hydraulic motors, and other components. At the same time, they also need to protect the system from corrosion, dissipate heat, and lubricate components that slide against each other. The same applies for lubrication circuits. All of these requirements can only be met, however, if the hydraulic and lubricating fluids do not age prematurely and retain constant properties over a long period of time.

The filterability of hydraulic and lubricating fluids depends primarily on their viscosity, and hydraulic oils and lubricants are divided into viscosity classes according to DIN 51519 (table 1). In addition to mineral oils, non-flammable, biodegradable, and special fluids are used as lubricating and hydraulic fluids, for instance in the food industry.

Mineral oils

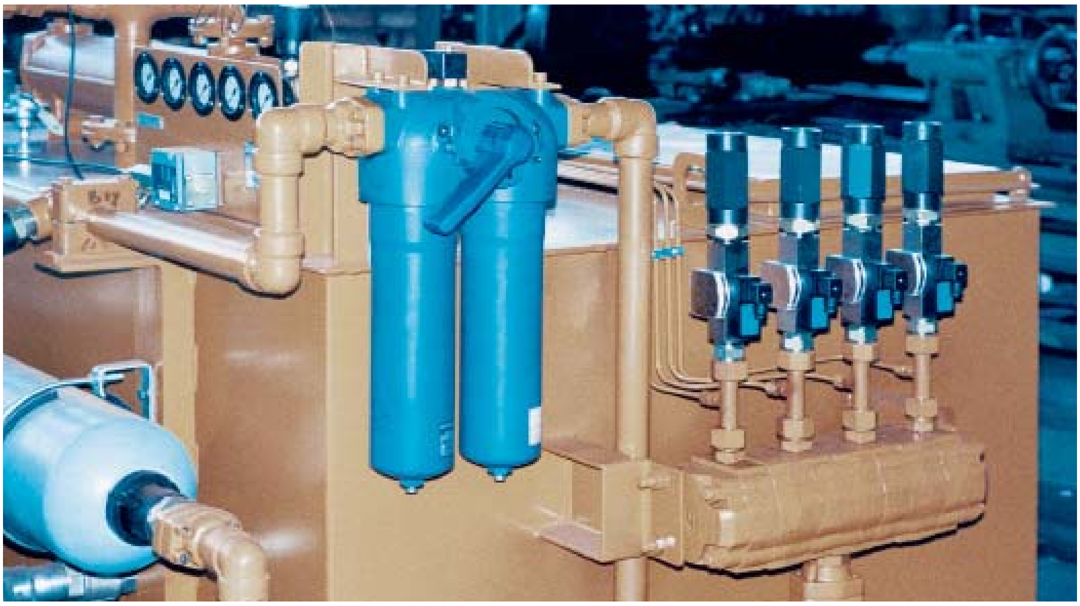
Mineral oils are primarily used in hydraulic and lubricating systems, because their properties with regard to aging, corrosion protection, temperature effects on their viscosity, lubrication properties, and water-holding capacity can be improved by supplementing a base oil with additives. Depending on the requirements, mineral hydraulic oils are classified into different quality groups according to DIN 51524 (table 2).

ISO viscosity class	Midpoint viscosity at 40.0°C mm²/s (cSt)	Limits of kinematic viscosity at 40.0°C mm²/s (cSt)	
		min.	max.
ISO VG 10	10	9.0	11.0
ISO VG 15	15	13.5	16.5
ISO VG 22	22	19.8	24.2
ISO VG 32	32	28.8	35.2
ISO VG 46	46	41.4	50.6
ISO VG 68	68	61.2	74.8
ISO VG 100	100	90.0	110.0
ISO VG 150	150	135.0	165.0
ISO VG 220	220	198.0	242.0

Common ISO viscosity classes according to DIN 51519 (excerpt), (table 1)

Type of hydraulic fluid	Requirement standard	International designation	Characteristics	Application
Hydraulic oil HL	DIN 51524 Part 1	HL, ISO 6743	oxidation-inhibiting, rust-preventing	for moderately stressed equipment
Hydraulic oil HLP	DIN 51524 Part 2	HM, ISO 6743	oxidation-inhibiting, rust-preventing wear-reducing	for high-pressure equipment
Hydraulic oil HVLP	DIN 51524 Part 3	HV, ISO 6743	like HLP, particularly favorable viscosity temperature behavior	for low or extremely variable temperatures
Hydraulic oil HLPD	–	–	like HLP, also contamination-bearing and somewhat hydrophilic	for equipment with water entry during oil filling
Hydraulic oil HVLPD	–	–	like HVLP, also contamination-bearing and somewhat hydrophilic	for equipment with water entry and low or extremely variable temperatures
HD motor oil	–	–	oxidation-inhibiting, rust-preventing, wear-reducing, contamination-bearing, hydrophilic	lor mobile hydraulic-oil equipment

Types of mineral oil-based hydraulic fluids (table 2)



Hydraulic power pack with duplex filters for the machinery industry

Non-flammable fluids

Non-flammable fluids are used in mining, pressure die casting machines, foundries, and other applications where there is a risk of burning mineral oils due to the high heat levels (table 3).

HFA fluids

Many HFA fluids have viscosities very close to that of water and are therefore used mainly in fire hazard areas, such as in mining or automated welding. Usable over a temperature range from +5°C to +55°C, these oil-in-water emulsions are similar to cutting oil emulsions used in metal machining. They are prepared by the user himself by mixing an HFA concentrate with the required volume of water. In general, the oil proportion is no greater than 20%. HFA E mineral oil emulsions are distinguished from HFA S emulsions, which contain no mineral oils.

HFB fluids

HFB fluids having a nominal viscosity close to that of hydraulic oils, have not become widespread in Germany since they are not recognized as non-flammable fluids. HFB fluids are used in Great Britain and the Commonwealth countries. They can be used from +5°C to +60°C, and their mineral oil content is < 60%.

HFC fluids

The most common examples of these aqueous polymer solutions are polyglycol-water solutions. They are supplied ready-to-use, and can be used at fluid temperatures from –20°C to +60°C, depending on the viscosity requirements. In order to keep the reduced water content resulting from evaporation as low as possible, the operating temperature should not be greater than +50°C. In any case, the water content (< 35%) and the rust protection reserve of the HFC fluid must be monitored during operation and must be maintained at the target value by adding desalinated water or rust protectant as required.

HFD fluids

Water-free, synthetic HFD fluids are categorized into fluids based on phosphoric acid esters (HFDR) and other water-free synthetic fluids, such as polyol esters or organic esters (HFDU). Their temperature range (max. from –20°C to +150°C) is determined by the viscosity-temperature curve and viscosity requirements of the drive. It is generally lower than for mineral oils, and must be checked on a case-by-case basis.

Application example: turbine system

Type of hydraulic fluid	Requirement standard	Composition	Application
HFA hydraulic fluid	DIN 24320	oil-in-water emulsion	pressurized water, such as for hydraulic presses
HFB hydraulic fluid	VDMA-standard sheet 24317	water-in-oil emulsion	not used in Germany
HFC hydraulic fluid	VDMA-standard sheet 24317	aqueous polymer solutions	for fire hazard systems up to a maximum of 60°C (at moderate) pressures
HFD hydraulic fluid	VDMA-standard sheet 24317	water-free synthetic fluids	for fire hazard systems at high temperatures and high pressures

Types of non-flammable hydraulic fluids (table 3)

Biodegradable hydraulic fluids

These environmentally friendly fluids are based on vegetable, animal, or synthetic oils, and have low biotoxicity. They are used as an alternative to mineral hydraulic fluids in agriculture and forestry, and in mobile hydraulics.

- HETG: natural ester based on vegetable oils (rapeseed oil, sunflower oil, etc.), non-water-soluble
- HEES: synthetic ester, non-water-soluble
- HEPG: polyalkylene glycols, polyglycols, or polyethylene glycols, water-soluble

Requirements and uses are set forth in VDMA-standard sheets 24568 and 24569.

Lubricating oils

Lubricating oils based on mineral oils can also be filtered using star-pleated filter elements. The most commonly used Newtonian fluids are lubricating oils for circulatory lubrication, as well as turbine and air compressor oils (table 4). Depending on the components to be lubricated, filter ratings of 10 to 25 µm are generally used. The potential flow capacity is dependent on the viscosity of the lubricating oil.

AN	DIN 51501	lubricating oil primarily used for circulatory lubrication	no greater requirements, long-term maximum temperature +50°C
C	DIN 51517 Part 1		aging-resistant mineral oil
CL	DIN 51517 Part 2		mineral oil with active agents for increasing aging resistance and corrosion protection
CLP	DIN 51517 Part 3		like CL, additional active agents for reducing wear in mixed friction range
TD	DIN 51515 Part 1	turbine oils	mineral oils with active agents for increasing corrosion protection and aging resistance
VB	DIN 51506	air compressor oils	maximum compression temperature +140°C
VBL	DIN 51506	air compressor oils	maximum compression temperature +140°C
VC	DIN 51506	air compressor oils	maximum compression temperature +180°C
VCL	DIN 51506	air compressor oils	like VC, preferred for screw and multicell compressors
VDL	DIN 51506	air compressor oils	particularly high compression temperature (+220°C), very low deposit formation

Lubricants and their areas of application (table 4)

Synthetic hydraulic fluids

Synthetic hydraulic fluids are designed mainly for special applications (e.g., for aerospace and military). They have similar filtration properties to mineral oils, but have specific advantages over them. Often, however, they are aggressive to metals and sealing materials.

Filterability of hydraulic and lubricating fluids

The necessary properties of hydraulic and lubricating fluids can be reliably ensured only by supplementing with additives. These are often composed of particles much less than 1 µm in size.

This leads to the following limit for the filtration of hydraulic fluid: dirt particles must be filtered out, while additives must remain in the hydraulic fluid with absolute certainty. The manufacturer of the hydraulic fluid must guarantee filterability in this sense.

The filterability, and thus the ability of the hydraulic fluid to flow continuously through a fine filter, depends not only on the viscosity, but also, to a large degree, on the components of the oil in the colloidal range in which the additives are present. Contaminants can lead to significant changes in the colloidal structure of the fluid, and thus cause the filter to clog.

Heavy-duty transport platform with MAHLE hydraulic filters

Cleanliness classes

Because it is not economically justifiable to remove all contaminants from hydraulic systems with very fine filters, cleanliness classes are defined for hydraulic fluids. They define the permissible number of particles—graded according to operating requirements and sensitivity of the components used.

Classification systems

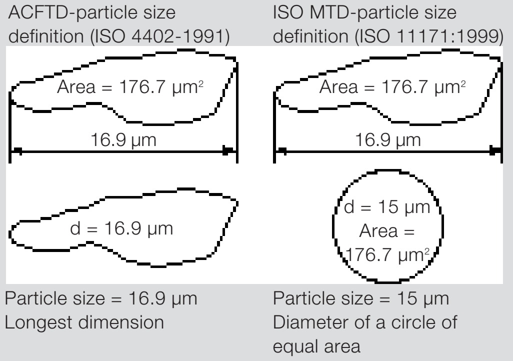
The most important divisions of cleanliness classes for particle counts are ISO 4406:1999 and the successor standards of NAS 1638, i.e., SAE AS 4059. The classification systems are oriented to the fact that the most commonly used filters today are depth filters with a balanced ratio of filtration quality and service life. Their filter media do not have uniform pore size; rather, they have a spectrum of pores. For example, for a filter element that captures 99% of all particles > 10 µm, not all particles > 10 µm will be captured, and sometimes even a few significantly larger particles can pass through.

In industrial hydraulics, particle counts are coded according to ISO 4406:1999. Now that ACFTD test dust has been replaced by ISO MTD, particle sizes also have a new definition.

Number of particles per 100 ml		Reference
greater than	up to	(code)
> $2.5 \cdot 10^8$		> 28
$1.3 \cdot 10^8$	$2.5 \cdot 10^8$	28
$6.4 \cdot 10^7$	$1.3 \cdot 10^8$	27
$3.2 \cdot 10^7$	$6.4 \cdot 10^7$	26
$1.6 \cdot 10^7$	$3.2 \cdot 10^7$	25
$8 \cdot 10^6$	$1.6 \cdot 10^7$	24
$4 \cdot 10^6$	$8 \cdot 10^6$	23
$2 \cdot 10^6$	$4 \cdot 10^6$	22
$1 \cdot 10^6$	$2 \cdot 10^6$	21
$5 \cdot 10^5$	$1 \cdot 10^6$	20
$2.5 \cdot 10^5$	$5 \cdot 10^5$	19
$1.3 \cdot 10^5$	$2.5 \cdot 10^5$	18
64,000	$1.3 \cdot 10^5$	17
32,000	64,000	16
16,000	32,000	15
8,000	16,000	14
4,000	8,000	13
2,000	4,000	12
1,000	2,000	11
500	1,000	10
250	500	9
130	250	8
64	130	7
32	64	6
16	32	5
8	16	4
4	8	3
2	4	2
1	2	1
0	1	0

ISO 4406:1999 cleanliness classes (table 5)

Definition of particle size



Particle size as the longest dimension, and as a projected area with corresponding equivalent diameter

According to ISO 11171:1999, the diameter of the equivalent projected area circle is now the defining dimension (see the overview for the definition of particle size). The ISO 4406:1999 standard was also updated with the new definition of test dust and particle size. This new edition of ISO 4406:1999 now uses a three-digit code for particles > 4 $\mu m_{(c)}$, > 6 $\mu m_{(c)}$, and > 14 $\mu m_{(c)}$. The number of particles in each class is cumulative.

The sizes > 6 $\mu m_{(c)}$ and > 14 $\mu m_{(c)}$ largely correspond to the particle sizes > 5 and > 15 µm previously used under ACFTD calibration. The range for particles > 4 $\mu m_{(c)}$, newly included in the classification, corresponds to about 0.9 µm in the old standard.

In order to distinguish the new standard from the old one, the filter ratings in the new standard end with a “c”.

The SAE AS 4059 standard defines 6 cleanliness classes: > 4, > 6, > 14, > 21, > 38 µm, and > 70 $\mu m_{(c)}$. As with the ISO standard, the values are counted cumulatively. The numbers therefore cannot be directly compared to the old values under NAS 1638. New maximum permissible particle counts have been determined. A new class, “000”, is provided for extremely high requirements.

SAE AS 4059, like ISO 4406:1999, is based on calibration with MTD dust according to ISO 11171:1999.

SAE AS 4059 cleanliness classes **Maximum permissible number of particles per 100 ml by cleanliness class**						
Calibrated according to ISO 4402 (ACFTD)		> 5 µm	> 15 µm	> 25 µm	> 50 µm	> 100 µm
Calibrated according to ISO 11171:1999 (ISO MTD)	> 4 $\mu m_{(c)}$	> 6 $\mu m_{(c)}$	> 14 $\mu m_{(c)}$	> 21 $\mu m_{(c)}$	> 38 $\mu m_{(c)}$	> 70 $\mu m_{(c)}$
Size code	A	B	C	D	E	F
Class 000	195	76	14	3	1	0
Class 00	390	152	27	5	1	0
Class 0	780	304	54	10	2	0
Class 1	1,560	609	109	20	4	1
Class 2	3,120	1,220	217	39	7	1
Class 3	6,520	2,430	432	76	13	2
Class 4	12,500	4,860	864	152	26	4
Class 5	25,000	9,730	1,730	306	53	8
Class 6	50,000	19,500	3,460	612	106	16
Class 7	100,000	38,900	6,920	1,220	212	32
Class 8	200,000	77,900	13,900	2,450	424	64
Class 9	400,000	156,000	27,700	4,900	848	128
Class 10	800,000	311,000	54,400	9,800	1,700	256
Class 11	1,600,000	623,000	111,000	19,600	3,390	512
Class 12	3,200,000	1,250,000	222,000	39,200	6,780	1,024

SAE AS 4059 cleanliness classes (table 6)

The NAS 1638, replaced by SAE AS 4059, defines 5 cleanliness classes for sizes 5–15, 15–25, 25–50, 50–100 µm, and > 100 µm. Only the particle counts that are actually counted in a class are indicated (differential counts). A cleanliness class (00, 0.1 to 12) was assigned to each size range (see table 8).

A complete specification under NAS 1638 therefore consisted of 5 numbers. Often, however, only 2 values of a selected range were given, or the worst of all 5 NAS numbers was given as an overall rating. NAS 1638 is no longer up to date, because fine particles < 5 µm are not taken into consideration.

Cleanliness class	Number of particles per 100 ml				
	5–15 µm	15–25 µm	25–50 µm	50–100 µm	>100 µm
00	125	22	4	1	0
0	250	44	8	2	0
1	500	89	16	3	1
2	1,000	178	32	6	1
3	2,000	356	63	11	2
4	4,000	712	126	22	4
5	8,000	1,425	253	45	8
6	16,000	2,850	506	90	16
7	32,000	5,700	1,012	180	32
8	64,000	11,400	2,025	360	64
9	128,000	22,800	4,050	720	128
10	256,000	45,000	8,100	1,440	256
11	512,000	91,200	16,200	2,880	512
12	1,024,000	182,400	32,400	5,760	1,024

NAS 1638 cleanliness classes (NAS 1638 was replaced by SAE AS 4059) (table 7)

Classification example

In an investigation of the contaminants in 100 ml of hydraulic oil, the following particle sizes were measured:

- 210,000 particles > 4 µm (reference number 18)
- 42,000 particles > 6 µm (reference number 16)
- 1,800 particles > 14 µm (reference number 11)

The key for the designation of solid contaminants according to ISO 4406:1999 is then as follows: 18/16/11.

Determining the ISO 4406:1999 cleanliness class			Approximately equivalent to SAE AS 4059 cleanliness class			Type of hydraulic system	Recommended filter rating according to ISO 16889	Recommended element
>4 µm(c)	>6 µm(c)	>14 µm(c)	>4 µm(c)	>6 µm(c)	>14 µm(c)			
13	11	8	3A	3B	2C	Highly reliable control system, sensitive to sludge accumulation	$\beta_{4(c)}$ p 200	Sm–N2
14 16	12 13	9 10	4A 6A	4B 5B	3C 4C	High-performance servo systems and high-pressure systems with long service life; e.g., for aerospace and machine tooling	$\beta_{5(c)}$ p 200 $\beta_{7(c)}$ p 200	Sm-x 3, PS 3 Sm-x 6, PS 6
17	15	11	7A	7B	5C	High-quality, reliable systems; general machinery	$\beta_{10(c)}$ p 200	Sm-x 10, PS 10
20	17	12	10A	9B	6C	General machinery and vehicles; medium capacity	$\beta_{15(c)}$ p 200	Sm-x 16, PS 16
23	19	13	>12A	11B	7C	General machinery and vehicles; low-pressure systems in heavy machinery	$\beta_{20(c)}$ p 200	Sm-x 25, PS 25 Mic 10

Reference values for the determination of filter rating x (µm) and the cleanliness class found in the hydraulic oil (table 8)

Selecting the filter rating and elements

Technologically advanced hydraulic systems are equipped with very sensitive controls. In order to ensure trouble-free operation, the working fluid must meet the lowest possible specific cleanliness class. Selection of the filter rating is therefore one of the most important, as well as the most difficult, filter parameters. Normally, the required cleanliness class specified by the component manufacturer should be followed.

The current cleanliness class of oil in a hydraulic system can also be determined by means of an oil analysis. In general, however, at higher pressure stages, the lower cleanliness class and higher filter rating should always be selected. Our many years of expertise in designing filter concepts makes it possible to define reference values. For many of the recommended filter ratings and elements, significantly lower cleanliness classes can even be achieved.

Definition of the $ß_x$ value

The $ß_x$ value is the measure of the effectiveness of a filter. It expresses the ratio of the particle count before and after passing through the filter. Its formula is:

$$ß_x = \frac{\text{Number of particles greater than x µm before filter}}{\text{Number of particles greater than x µm after filter}}$$

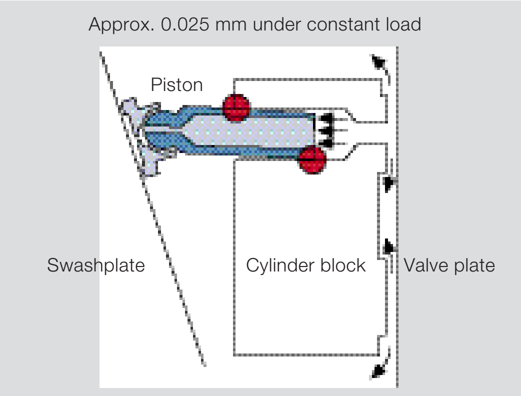
In the field of hydraulics, the filter rating x (in µm) indicates that the filter element meets the requirements of the ISO 16889 multipass test. In order to be complete, however, it also requires that the beta value always be given, e.g., $ß_{10(c)}$ p 200. The terms “nominal” and “absolute” are not defined, and should not be used. ISO 16889 cannot be used for filter ratings p 40 µm. Here the the filter rating is indicated by means of the mesh width or average pore size of a filter material.

Criteria for effectiveness

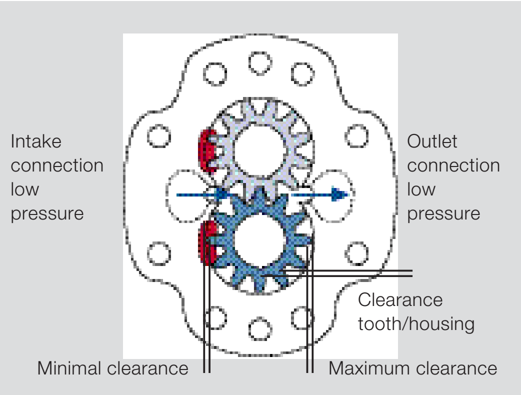
In addition to the filter rating required by the cleanliness class, other boundary conditions affect the selection of a filter:

- Planned installation location
- Planned temperature range
- Type of pressure medium, with viscosity and density
- Maximum volume flow
- Maximum pressure
- Environmental conditions

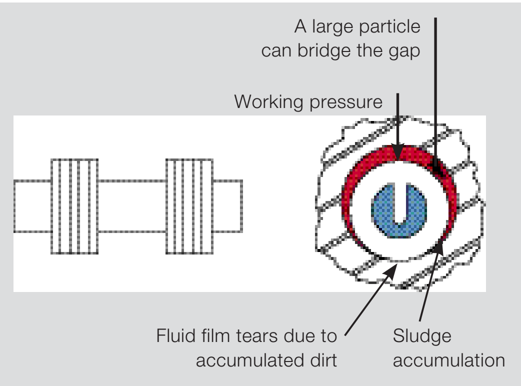
The installation location, in particular, often leaves little leeway. In order to achieve as great a filter surface as possible for a given filter size, the filter materials are pleated in the form of a star.



Critical points in an axial piston pump; at a given piston clearance, the eccentricity varies due to load and viscosity



Critical points in a gear pump; the clearance between tooth and housing changes as a function of the angle setting, so that fluid can flow in from the pressure side



Critical tolerances on a valve piston—generally working with a certain eccentricity

Hydraulic components	Gap width in µm
Vane pumps	
vane rotor ring	0.5–5
vane sides	5–15
Gear pumps	
gear side plate	0.5–5
tooth-crest housing	0.5–5
Piston pumps	
piston bore	5–40
cam-plate cylinder	0.5–5
Servo valves	1–4
Proportional valves	1–6
Directional valves	2–8
Hydrostatic bearings	1–25
Plain bearings	0.5–100
Roller bearings	0.1–3

Typical gap widths for hydraulic components (table 9)

Filter rating, dependent on component

Selection of the filter rating is also always dependent on the components to be protected. For proportional, servo, directional, and pressure control-valve systems, for example, the largest permissible particle diameter should always be smaller than the smallest gap width found in the system.

The filter is economical if the filter element has the greatest possible service life at a sufficient level of filtration quality. To this end, it may indeed allow particles that are somewhat greater than the gap width to pass. After all, dirt particles have a three-dimensional character, and are sometimes easily deformable. The working gap is also dependent on pressure: the lower the system pressure, the greater the working gap.

Filter concept

Filters should be selected such that the components of the hydraulic system are sufficiently protected according to the required cleanliness class. Starting with the sources of contamination, therefore, the entire system must be taken into consideration in order to specify the filter rating. The filter installation location and the filter must then be determined upstream from the component to be protected.

Filters for maritime operations

HIGHLY EFFECTIVE FILTRATION, WITH EXTRA PERFORMANCE AND SYSTEMS EXPERTISE

Due to the diversity of the information, data, facts, and systems parameters to be considered, technically and economically optimal filter layout is a difficult task that can truly be mastered only by experienced specialists. As an innovative development partner and reliable supplier for the leading manufacturers of hydraulic systems and equipment, we are the expert systems partner in all areas of hydraulic fluid filtration. Our filter line covers a wide range of applications and allows the specified cleanliness class to be met under all conceivable conditions.

Filter design

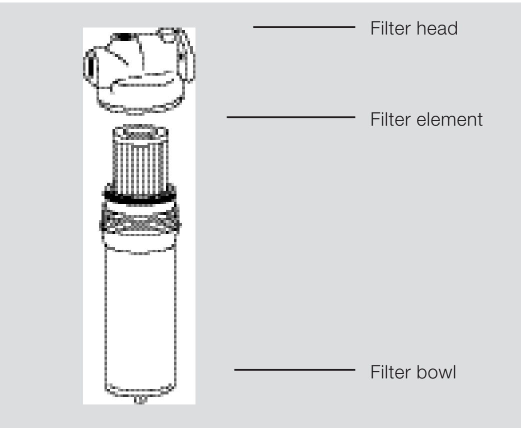
The filter design is fundamentally determined by the following system data:

- Flow rate
- Maximum operating pressure
- Required cleanliness class in the system or filter rating prescribed by the component manufacturer
- Expected environmental conditions (good, average, poor)
- Type of hydraulic system (large system with many piston rods and consumers, medium-sized system, small system)
- Working medium
- Operating temperature
- Starting temperature
- Filter type (housing + element + options)

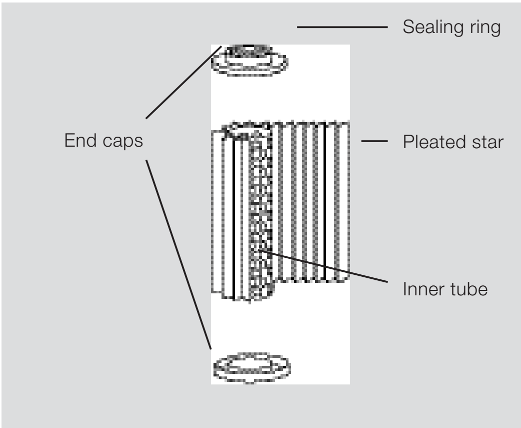
The multilayered design of our filter elements allows a broad range of applications and high dirt-holding capacity. The filtration performance of the elements remains constant, even with increasing differential pressures, and provides great protection even under pulsating loads. Long filter service life and low flow resistance guarantee economically optimal operation, and our experience from similar applications works to your benefit. Nevertheless, should preliminary experiments be necessary, simply consult with our engineers. Together we will find the best solution.

Design of hydraulic filters

MAHLE hydraulic filters have a uniform design. They consist of the filter element, a housing, and additional accessory parts depending on the application (e.g., bypass valve, maintenance indicator, reverse flow valve). The housing consists of the head and the bowl. The filter element itself is made up of the inner tube, the pleated star, and the end caps. With few exceptions, flow through the filter takes place from the outside to the inside.



Design of a filter



Design of a filter element

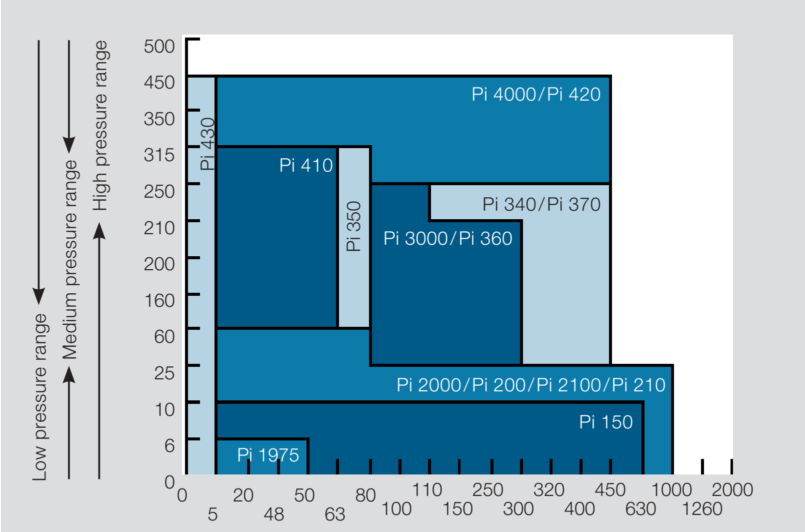
Maintenance indicator

Optimum filter economics require that the dirt-holding capacity of the filter is fully utilized. All filters should therefore be equipped with maintenance indicators. Its mechanical or electronic sensors react to changes in the pressure ratios at the filter element. The indicator registers the vacuum pressure for suction filters, the differential pressure for pressure filters, and the back pressure for return-line filters. The results are signaled by means of a gauge or visual and visual-electrical switches, depending on the design. The switching level is selected so that the filter still has a certain reserve of dirt-holding capacity.

Bypass valve

A bypass valve built into the filter head prevents excessively high flow resistance or a collapse of the filter element. It opens when the contamination level of the filter element or the viscosity of the fluid increase. In this case, only part of the flow will be filtered. Three important conditions must be defined: the opening pressure, the closing pressure, and the maximum permissible pressure drop at the nominal flow rate.

If, however, the entire volume flow needs to be permanently filtered so as to avoid premature failure of critical components, then a bypass valve does not make sense. A bypass valve installed at the bottom of the filter housing is not suitable, because sedimentary dirt will be washed into the valve.



Hydraulic pressure filters can be used above 0 bar and above the nominal value of 0 l/min. The Pi 210 and Pi 370 filters are duplex filters. The Pi 410 is a sandwich filter.

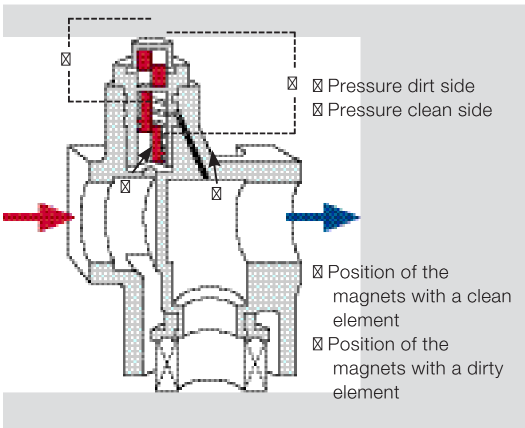
Nominal pressures and sizes of hydraulic pressure filters

Reverse flow valve

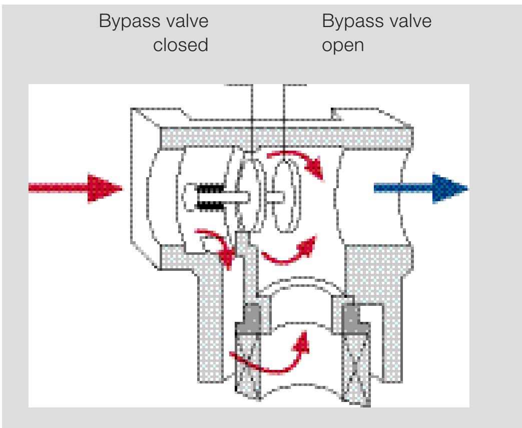
The reverse flow valve allows the filter housing to be permeated in the reverse direction, without impinging on the filter element. This is needed only for systems in which the flow direction changes. The reverse flow valve can also be combined with a bypass valve.

Cold start valve

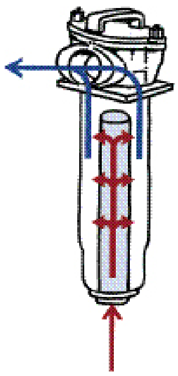
The cold start valve integrated in the filter head ensures that the hydraulic system receives only filtered fluid under all operating conditions. If the differential pressure increases past the opening pressure of the cold start valve (due to high viscosity of the fluid at cold start, for example, or if the element has not been changed out), a partial flow is fed back into the hydraulic tank via the tank connection at the filter head. Cold start valves are primarily used in mobile machinery.



Functional diagram of a differential pressure indicator



Functional diagram of a bypass valve

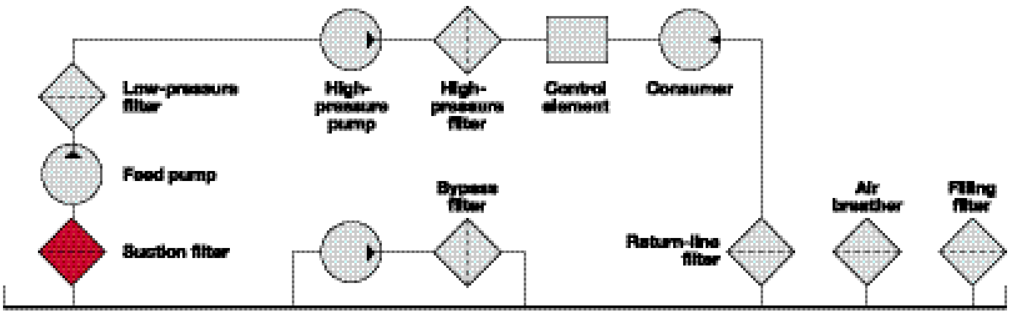


Design of a suction filter

Suction filter

Previously, suction filters were limited to capturing coarse particles, and other filters were used for fine filtration. Today's filter materials have low flow resistance, so that the filter rating extends to the range of $\beta_{20\,(c)}$ p 200. Even when installed directly upstream from the pump, suction filters still have physical limits. In order to filter at a finer level, they would need to be larger, and would cause cavitation damage to the pump due to the increasing differential pressure as the filter clogs.

Suction filters are available as in-tank filters, including a closing valve for installation below the oil level, and as line filters for installation in the suction line. Suction filters fitted as line filters are usually low-pressure filters up to 25 bar.



Filtration in the suction line

Their advantages are clear for mobile applications, such as hydrostatic drives. They typically have filters exclusively on the suction side, because the frequent reversing of the drive direction would otherwise require pressure filters with complex reverse flow valves. When using a suction filter as the sole system filter, sufficient filter surface must absolutely be supplemented by a maintenance indicator.

Nominal filter size: the nominal size is determined on the basis of the maximum suction volume flow, operating viscosity, filter rating, and recommended maximum initial pressure loss (see Page 28).

Rating: 100–20 $\mu m_{(c)}$.

Bypass: based on application.

Installation location: directly in front of the pump.

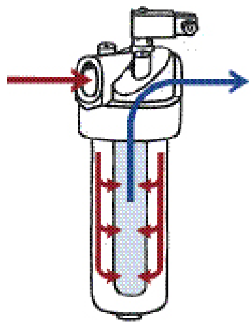
Maintenance indicator: recommended; if not feasible, be sure to clean the wire mesh according to the operating manual, or replace it every 500 hours.

Star strainer filter elements in various sizes

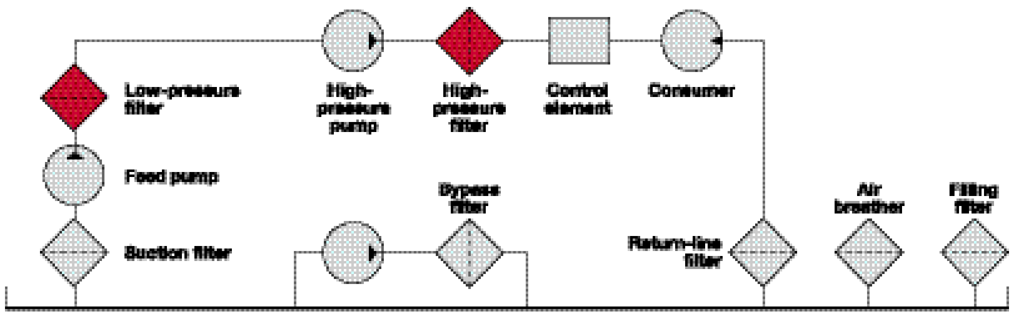
Suction filter as an in-tank filter

Pressure filter

Pressure filters are designed for use as full- or partial-flow filters in the ranges of low pressure up to 25 (60) bar, medium pressure up to 210 bar, and high pressure up to 450 bar. They are installed downstream from the pump and the pressure-limiting valve, and upstream from the components to be protected. There are various types of pressure filters: line filters, flange-mounted filters, changeout filters (spin-on cartridges), and sandwich-style filters. If there are no further potential sources of contamination downstream from the pressure filter, such as a cylinder in the circuit, then generally no additional systems filters are required in smaller systems.



Design of a pressure filter



Filtration in the pressure line

Pressure filter as a duplex filter

Duplex filters provide the most economical solution in the low- and medium-pressure ranges, with one-hand operation and loss-free switching of the fluid flow. Ready to use around the clock and without interrupting operations, duplex filters allow elements to be changed out during operation.

Nominal filter size: the nominal size is determined on the basis of the maximum volume flow, operating viscosity, filter rating, and recommended initial pressure loss (see page 28). For frequent cold starts, large systems, and poor system conditions, the next larger nominal size should be selected. The filter will then have sufficient service life, even under unexpected operating conditions. In large systems, partial-flow filtration may make sense. A protection filter should be used for sensitive components (servo valves).
Nominal pressure: the nominal pressure must be greater than the maximum operating pressure of the system.
Rating: based on the cleanliness class required.
Bypass: permissible for systems with frequent cold starts; no bypass for protection filters.
Installation location: downstream from the pump and the pressure-limiting valve, upstream from the components to be protected.
Maintenance indicator: mandatory.

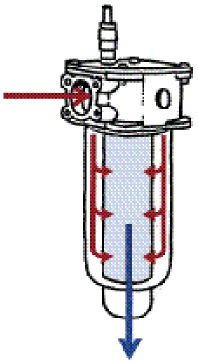
For nominal pressures up to 16 bar, a bypass valve is not required with low-pressure elements, as long as a pressure-limiting valve with a maximum of 16 bar is fitted upstream from the filter. At higher pressures, if no bypass valve is used, then high-pressure elements are fundamentally required.

Nominal pressures in bar (overpressure) Preferred values are in bold type	
10	**160**
16	200
25	**250**
40	315
63	**400**
100	500

Pressure categories according to DIN 24550, Part 1

Low-, medium-, and high-pressure filters of various series

Pressure filter as a duplex filter

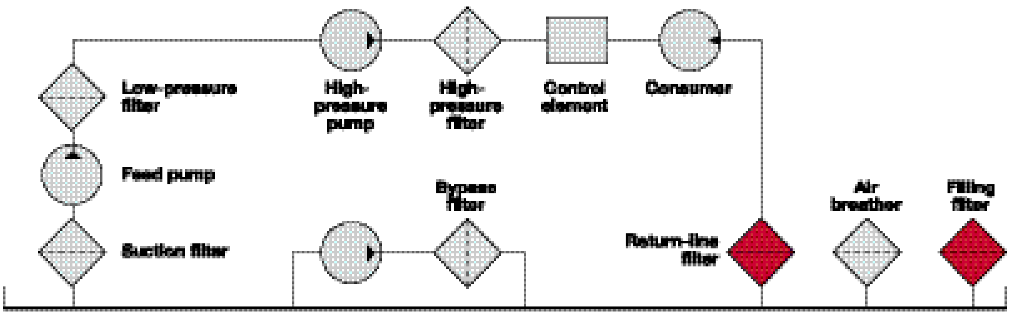


Design of a return-line filter

Return-line filter

To the extent that contaminants are not caught previously by pressure filters, return-line filters capture all of the dirt generated in the system and washed out of the hydraulic system, thereby preventing disastrous dirt circulation through the tank and the pump. Return-line filters are predominantly designed as in-tank filters. The filter head is permanently attached to the tank, and the outlet opening of the filter extends into the tank. When fitted with additional equipment, return-line filters can also be used as filling filters.

Nominal filter size: the nominal size is determined on the basis of the maximum return-line volume flow, operating viscosity, filter rating, and recommended maximum initial pressure loss (see page 28). When determining the return-line volume, the increased return volume from differential cylinders must be considered in addition to the maximum pump delivery rate. The filter will thereby have a sufficiently long service life, even under unexpected operating conditions.



Filtration in the return-line and via the filling filter

Return-line filter as a duplex filter

Return-line filters designed as duplex filters are ready for use around the clock, with one-hand operation and loss-free switching of the fluid flow, without interrupting operations. This type of filters is particularly economical since maintenance (element changeout) can be performed during operations when the dirt-holding capacity has been fully used up.

Return-line filter as a line filter

For very large systems and very large return-line volumes, in-tank filters may no longer make sense. Line filters in the low-pressure range (up to 16 bar) provide an economical alternative.

Nominal pressure 6/10 bar: the nominal pressure must take into consideration the additional increase in pressure under cold start conditions, and increased return-line volume.

Rating: adapted to the filter concept.

Bypass: always necessary in order to prevent changes in switching times in the system due to back pressure.

Installation location: immediately prior to the entry of the return line into the tank for line filters, or as an in-tank filter.

Maintenance indicator: mandatory.

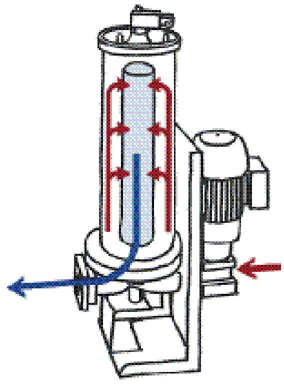
Various sizes of return-line filters

Return-line duplex filters

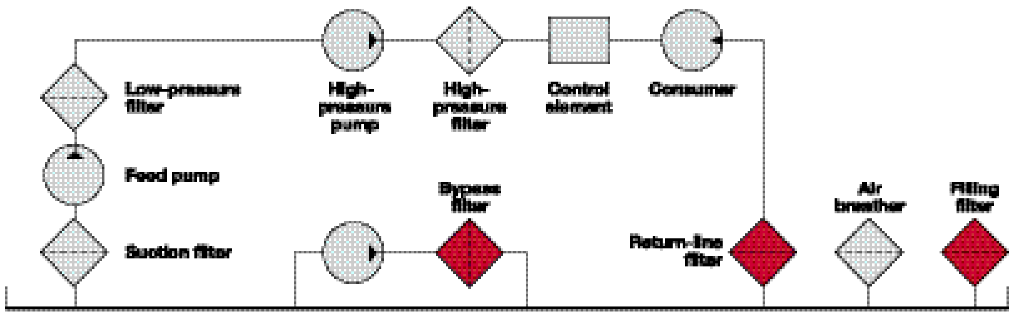
Bypass filter

Stationary bypass filters function as working filters to supplement existing pressure or return-line filters in widely branching hydraulic systems with very large tank volumes and fluctuating return-line flows. Bypass filters are the optimal solution for filtering large volumes of oil, which full-flow filters cannot clean sufficiently or economically. In addition, there are many potential combinations, e.g., with coolers.

Bypass: permissible; required when the maximum achievable operating pressure is greater than the element's collapse pressure. This is also applicable if the pump is switched off by the maintenance indicator.
Installation location: generally near the hydraulic tank.
Maintenance indicator: always necessary, preferably a mechanical/electrical indicator, so that not only the pump is switched off when the dirt-holding capacity is reached, but an optical signal also indicates this state.



Design of a bypass filter



Filtration in the bypass flow

When designed as mobile filter equipment, they can be used very flexibly for rinsing and filling systems, or as mobile bypass filters.

Nominal filter size: the filter capacity should always have a sufficient ratio to the occurring volume flows. The housing connections, in contrast, are based only on the capacity of the pump installed in the bypass filter.
Nominal pressure: 6/10 bar.
Rating: based on the recommended cleanliness class; filling filters require special design.

Systems conditions	Filtration performance [l/min.] as a percentage of the system's oil volume [l]
good	5%
average	10%
poor	20%

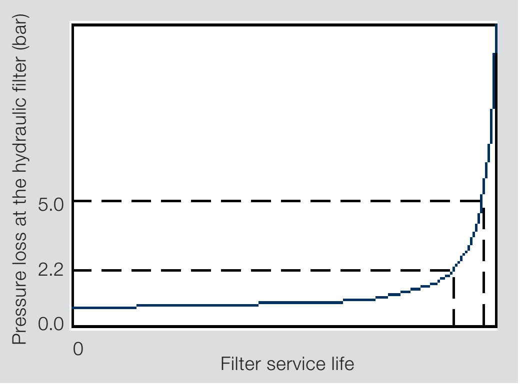
Recommended filtration performance and pump capacity

Bypass filters

Mobile filter units

Pressure loss in hydraulic filters

With increasing filter service life, the pressure loss at hydraulic filters also increases. Correct determination of the initial Dp is all the more important for complete filter design.



Pressure loss at hydraulic filters as a function of filter service life

Recommended initial Dp	
Suction filter	0.1 bar
Return-line filter	0.2–0.5 bar
Low pressure filter	0.5 bar
Medium pressure filter	0.5–0.8 bar
High pressure filter	0.8–1.0 bar

Determining the initial Dp

Determined using the appropriate diagrams in the data sheets. For oil with a viscosity of 33 mm²/s or 190 mm²/s, this can be read directly. For other viscosities, it must be calculated using the formula:

$$Dp = \frac{Dp1\ (y3-y2) + Dp2\ (y1-y3)}{(y1-y2)}$$

(Dp in bar/y in mm²/s).

Sample calculation

Determining the p for the MAHLE Pi 3430 filter: y1 = 190 mm²/s, y2 = 33 mm²/s, with element PS 3 at a flow rate of 90 l/min. and a viscosity of y3 = 100 mm²/s:

$$Dp3 = \frac{2.8\ (100-33) + 0.51\ (190-100)}{(190-33)} = 1.49\ \text{bar}$$

(For values, see diagram for determining the p for the MAHLE Pi 3430 filter)

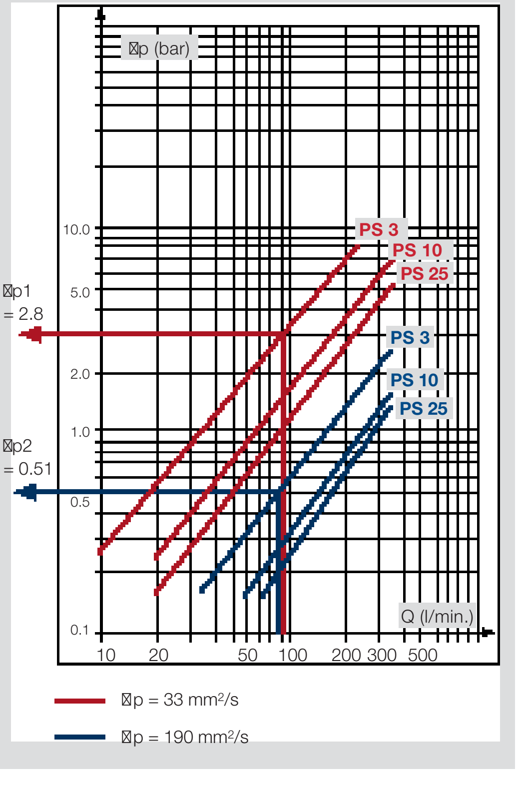


Diagram for determining the p for the MAHLE Pi 3430 filter

Air breather

Air breathers are among the most important components of a filter concept. Equipped with the appropriate changeout elements and depending on the cleanliness class required, they ensure that the air supply to tanks is free of contaminants. Considering the significant level of dirt that can enter the system through unsuitable breather devices, these filters are absolutely mandatory. The filter rating is to be selected to correspond to the system's filters. Only for small tanks and oil flow rates up to a maximum of 100 l/min. is the breather integrated in the return-line filter sufficient.

Nominal size: corresponds to the potential maximum volume variation causing an equivalent exchange of air.

Rating:

Filter rating	
air breather	**hydraulic filter**
Sm–L	Sm-x 3, PS 3
	Sm-x 6, PS 6
	Sm-x 10, PS 10
Mic–L	Sm-x 16, PS 16
	Sm-x 25, PS 25
	Mic 10

Bypass: no.

Installation location: directly at the highest point of the hydraulic tank; allow splash room for mobile systems, so that no oil can be forced out.

Maintenance indicator: recommended, with auto-shutoff function above size Q p 1,000 l/min.

Various sizes of air breathers

Air breather combined with filling strainer

SPONTANEOUS DETECTION AND IMMEDIATE REMOVAL OF FREE WATER IN HYDRAULIC FLUIDS

Water in hydraulic and lubricating oil systems not only reduces the service life of the hydraulic fluid, but also of the machine components and the entire system. Known damages include corrosion of the metallic systems parts, hydrolysis of the hydraulic fluid, bearing wear, prematurely clogged filters, and chemical breakdown of additives. In order to prevent this, MAHLE has developed a new concept for detecting and removing water, consisting of a turbidity sensor and coalescer-filter.

Reliable and cost-efficient

The consequences of detecting water too late range from extensive repairs to complete loss of production. Addressing this risk with traditional methods and systems incurred high costs and extensive calibration effort. Subsequent repair of the damage also involved considerable expense: all of the hydraulic fluid needed to be changed out, or dried out by means of vacuum evaporation or adsorption for smaller systems. With the newly developed turbidity sensor, an inexpensive device has been developed for quickly detecting water above the saturation limit. Working together with the new coalescer-filter, water in the system can be quickly and inexpensively removed using a mechanical method. The system is suitable for all fluid technology applications that are at risk of water entry, and provides a variety of potential uses, such as in hydraulic systems with water coolers, in mobile applications, such as construction equipment, in power plants, paper machines, wind energy systems, or maritime operations.

Water detection

The MAHLE PiT 400 turbidity sensor uses a pulsing light beam divided into two paths of different lengths that penetrate the hydraulic fluid and ultimately strike two receivers. It should ideally be integrated in the return line, or directly in the tank, near the return. If water enters the circuit, the light beam will weaken due to turbidity of the hydraulic fluid. The electronics will detect this change using the stored target values and send a signal or switch on a unit for separating out the water. In combination with the MAHLE coalescer-filter, water removal can be initiated immediately.

Water removal

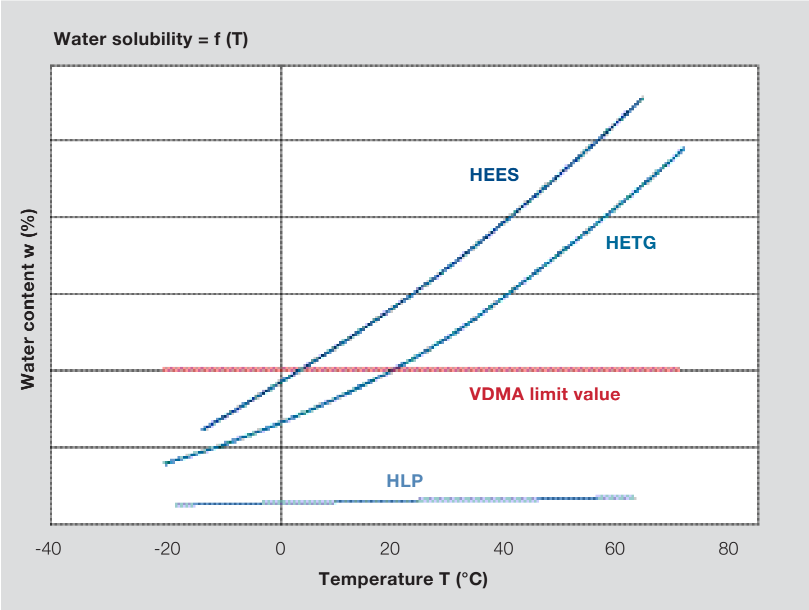
The MAHLE coalescer-filter, designed in several different layers, allows mechanical separation of fine water droplets in the hydraulic fluid. In the first process step, they are collected and coalesced into larger droplets. The resulting drops, which are several millimeters in size, then leave the coalescer layer and land on a mesh treated with a special hydrophobic agent. This is where the hydraulic fluid is separated. The water then exits the circuit due to sedimentation. For this process to be successful, it is critical that a

Turbidity sensor

Coalescer-filter

certain differential pressure is not exceeded in the coalescer and that the viscosity is considered in each case.

The coalescer can operate fully automatically. There are various control possibilities for this purpose, such as controlling the volume flow by the differential pressure using a pump, or regulating the volume flow using a pressure-limiting valve. In general: the fewer emulsifying additives are present in the hydraulic fluid, the better the coalescer functions. Conversely, therefore, expensive special oils can be replaced with cost-effective hydraulic fluids.



Because only free water causes turbidity, the water solubility must be considered as a function of the temperature. According to VDMA-standard sheet 24568, for hydraulic fluids of the HE group, water content should be maintained at less than 1,000 ppm (0.1%). No free water should be present in the HLP group

MEASURABLE HIGH QUALITY, ACCORDING TO ALL RELEVANT NORMS AND STANDARDS

Prerequisite for filter elements with the best filtration properties: materials that meet quality requirements and high production quality. Standardized tests provide valuable reference points for testing. Only manufacturers that perform them regularly can guarantee consistent standards and achieve the requirement of $ß_x\$200$ in all cases. Together with other important international testing standards, such as the multipass test, this guarantees the necessary reliability that you require for smooth operation in practice.

Bubble-point test (ISO 2942)

Because each type of element can be assigned a minimum pressure value, the bubble-point test can be used as an excellent monitor of the consistency for the production quality of filter elements.

The filter element is dipped in the testing fluid (isopropanol) with its main axis parallel to the fluid's main axis, rotated 360° after five minutes, and subjected to the indicated minimum pressure. If no permanent bubble stream occurs, then the element passes the test. The test does not, however, provide any information on measuring the filter performance or rate of separation.

Collapse/burst pressure testing (ISO 2941)

The permissible collapse pressure is defined as the pressure differential in the flow direction, which the filter element must withstand.

To this end, a defined quantity of any chemically neutral, particulate contaminant is added to the test circuit, until the pressure differential across the filter element corresponds to the permissible collapse or burst pressure. The pressure differential curve is drawn, and the filter element is passed only if there is no indication of failure and no drop in the slope of the pressure differential curve is registered.

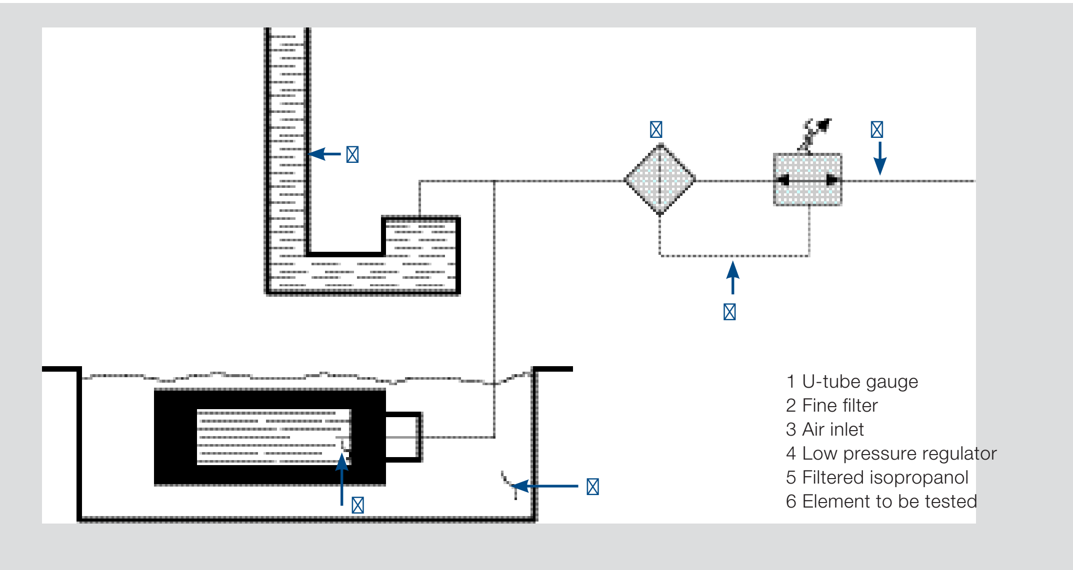


Diagram of test setup for the bubble-point test

Determining the initial differential pressure (ISO 3968)

An important aspect in designing hydraulic filters is the differential pressure (also called flow resistance). This value is derived from the total pressure drop from housing inlet to outlet, and results from housing and filter insert losses.

Factors that affect the flow resistance of a clean filter are the viscosity of the fluid, its specific weight, volume flow rate, filter insert medium, and flow paths.

A test stand, consisting of a pump, tank, heat exchanger, and measurement equipment for pressure, temperature, and volume flow (as shown schematically at the top right) is used to determine the flow resistance. p_1 is the pressure at the filter inlet, p_2 is the pressure at the filter outlet, and Dp is the flow resistance of the filter. When performing Dp volume-flow measurements on a filter, a test stand with high system pressure is not necessary. It is sufficient to maintain p_2 at a positive pressure value.

Flow-fatigue test (ISO 3724)

The test is used to determine the ability of a filter element to withstand deformations due to changing differential pressures (flow volumes) without a change in its burst resistance. A test stand, as shown schematically at the bottom right, is used to perform the test.

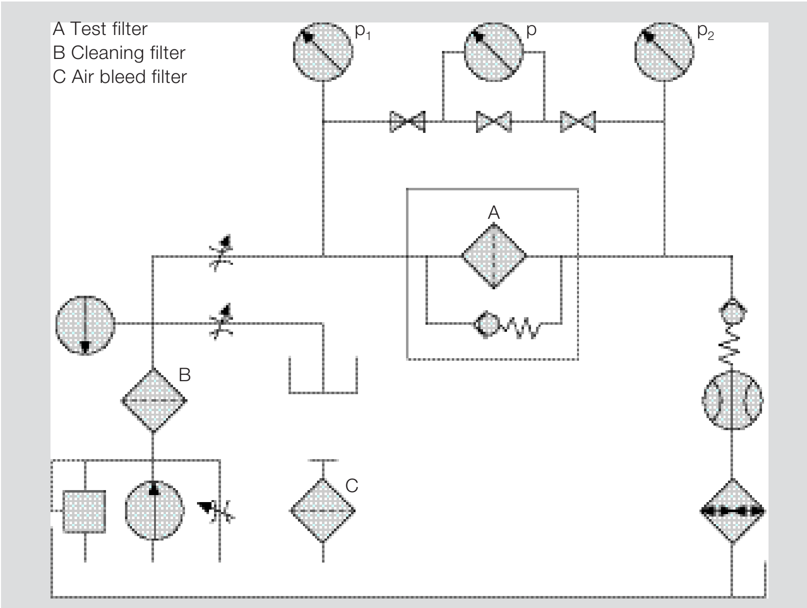


Diagram of a test standard suitable for Δp- and flow-rate measurements

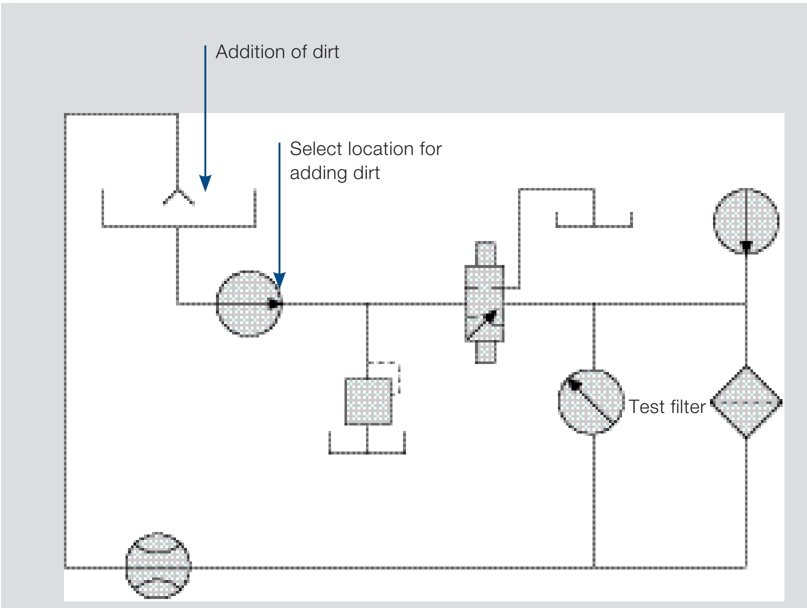


Diagram for typical flow-fatigue resistance test stand

Multipass test (ISO 16889)

The multipass test is the most important test for evaluating retention efficiency, dirt-holding capacity, and service life of a filter element. It is also known as the filter performance test, multipass test, or β_x test. A very complex test stand, divided into three parts, is required to perform a multipass test:

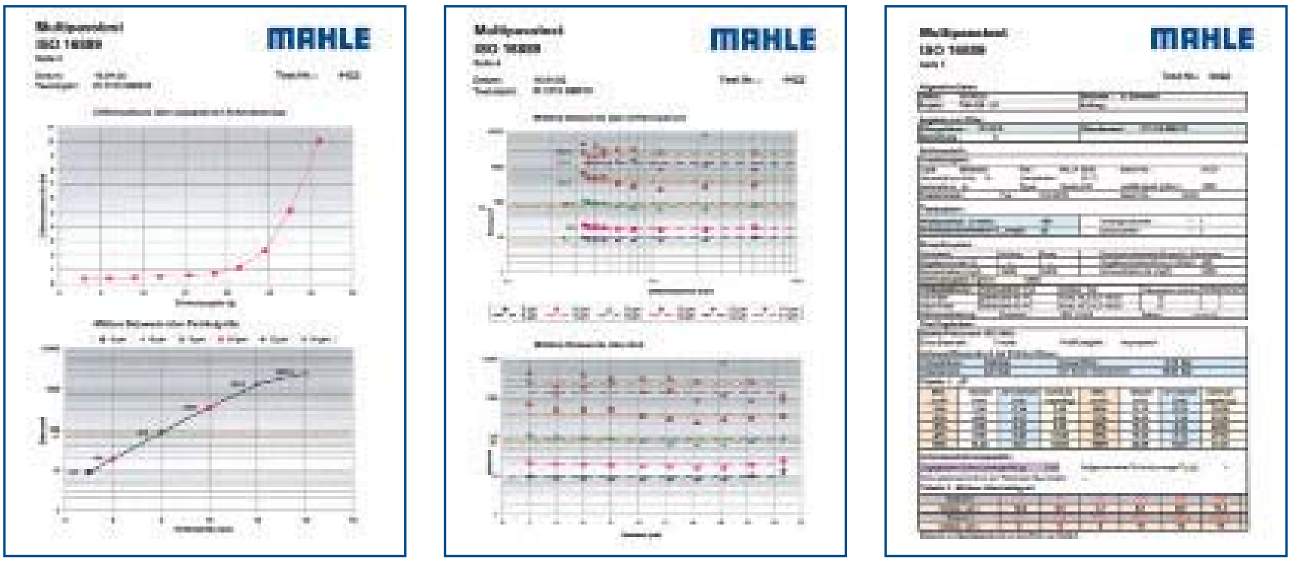
- In system 1, the test fluid (MIL-H-5606) is contaminated with test dust (ISO MTD) to a defined level.
- In system 2, the test filter is installed and the cleaned test fluid is circulated.
- In system 3, the fluid samples taken from system 2 are continuously counted in high-precision particle counters, and the information is displayed visually using a special PC program.

The multipass test is very close to the real-life contamination process. Differences include, however, the greater range of contaminants and thereby the very short test duration, relative to the filter service life.

Any changes to the filter element with increasing Δp, such as can occur during cold starts or other operating conditions, can be clearly demonstrated, however, with conclusions about the effectiveness and lifespan of the filter.

The test equipment and test procedure are very complex, and cannot be performed by an operator. This means that you are all the more dependent on the accuracy of the manufacturer's data.

Multipass test stand



Multipass test

Multipass test procedure

Contaminated fluid from system 1 is continuously injected into the circuit of system 2. The constant circulation causes dirt to be fed into the test filter until the maximum permissible differential pressure of the element or the test system has been reached. In the mean time, samples are continuously automatically tested in system 3, and the temperature and pressure curves are recorded. As the differential pressure increases, the progression of the element's retention efficiency can be determined. The test result is expressed in the form of the ß value, which represents the following ratio:

$$\beta_{x(c)} = \frac{\text{Number of particles >x(c) µm before filter}}{\text{Number of particles >x(c) µm after filter}}$$

The following values should always be presented:

- $\beta_{x(c)}$ value relative to the Dp, at which the value was measured
- $\beta_{x(c)}$ values at the switching level of the maintenance indicator and at the final Dp of the test stand, or the permissible Dp for the affected element
- The apparent dirt collection at the switching level of the maintenance indicator, and at the final Dp
- Actual bubble point of the test element, prior to start of test

Only these data, altogether, truly allow for a comparative evaluation of the performance of filters. In order to better evaluate the significance of the ß value, the comparison must be made with the separation rate in % on hand. The separation rate is calculated as follows:

$$e_{x(c)} = \frac{\beta_{x(c)} - 1}{\beta_{x(c)}}$$

A ß value of 200 thus corresponds to a separation rate of 99.5%.

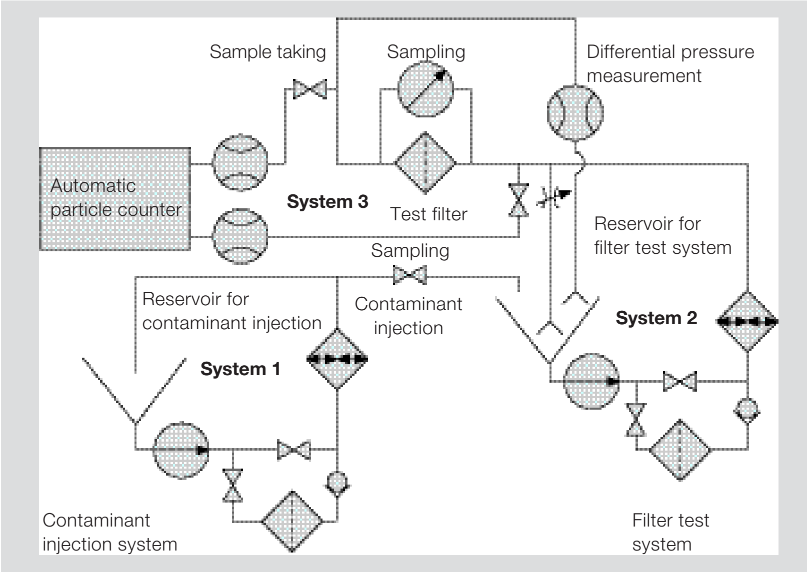
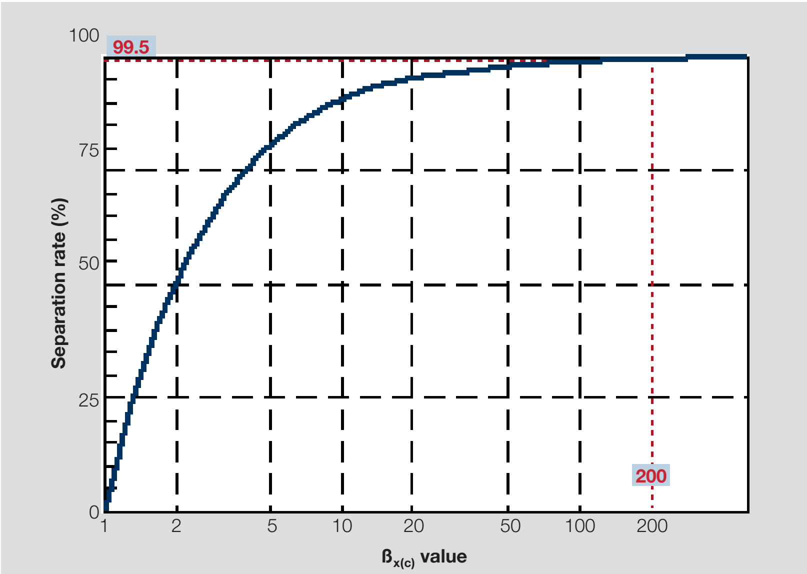


Diagram of the test stand



Relationship between $\beta_{x(c)}$ value and separation rate. Precise determination of the $\beta_{x(c)}$ by technical means is affected by severe variations between the individual measurement points, particularly for $\beta_{x(c)}$ > 200

LEAVING NOTHING TO CHANCE CAN SAVE EXPENSIVE PRODUCTION FAILURES

Filter elements are high-quality technical products. In order to fulfill their function reliably, they must be handled correctly and carefully. During operation, special attention should be paid to the serviceability of the filter and compliance with the required cleanliness class of the hydraulics. The intensity and frequency of maintenance work to be performed is then determined according to the loading resulting from environmental influences and the actual degree of loading. With suitable testing methods and equipment specially developed for this purpose, economical operation of filters and hydraulic systems can be controlled and monitored.

Short list but great effects

The most important rules for operating hydraulic systems equipped with filters can be summarized in six guidelines:

1. Hydraulic fluids should always be run through a fine filter when filling.
2. Filter elements should always be replaced after flushing a system.
3. Maintenance indicators should be checked every day after reaching operating temperature.
4. Analyses of system fluid samples or online measurements using particle counters should not be neglected. They provide indications of premature wear and failure of hydraulic components. An element investigation can yield important clues in case of problems.
5. A fine filter should also always be used when refilling hydraulic fluids.
6. When replacing filter elements, the instructions must be followed exactly.

Maintenance indicators of various series

Flushing and startup

Prior to commissioning a hydraulic system, the assembly dirt must be removed. The most convenient way is by flushing the entire system. The operating elements are removed from the installed filters and replaced with flushing elements for the duration of this process. They should be reinstalled or replaced with new elements only after flushing is complete.

When flushing, the oil flow can be cleaned with a portable bypass filter system. Mineral oil, or a different medium compatible with the hydraulic fluid to be used later, is pumped through the system, or individual parts of the system, at as high a flow rate as possible. Assembly dirt is separated out by the filter on the filter cart. Only smaller or less sensitive hydraulic systems can be flushed during the startup process using the installed filter. A prerequisite is that the system is run with no load, but with the flow volume gradually increasing to the maximum.

Refilling with hydraulic oil

In order to maintain the cleanliness class, a fine filter should also be used when refilling with hydraulic oil in case of leakage. A filling unit, or, with an appropriate setup, a return-line filter or line filter can be used for this purpose.

Continuous contamination monitoring

Each filter should be fitted with an optical or opto-electrical maintenance indicator. It continuously indicates whether there is any remaining dirt-holding capacity, or whether an element must be replaced. For optical indicators, a check should be performed daily after reaching the operating temperature.

For optical maintenance indicators, simply pressing in the red pin provides a clear result. If the pin remains pressed in, then the element is fully functional, but if it pops back out, then the element must be replaced no later than by the end of the shift. Electrical indicators also provide both an electrical and optical signal. The red pin and the electrical signal are independent of each other. Here again, evaluation of the level of contamination should be done at operating temperature, because the increased viscosity during a cold start can trigger a contamination signal. For this reason, systems that often start at low temperatures should have a cold start suppressor.

Element replacement

If the maintenance indicator signals a contaminated element, then the remaining dirt-holding capacity is generally enough for a few days. The filter element must be replaced soon. If the filter element is not replaced, then, in extreme cases, the element could collapse, with fatal results: dirt that has already been trapped will be dumped into the system through the torn filter matrix, often resulting in a complete system failure.

For filters without maintenance indicator, the following guidelines apply for filter inspections:

- 24 hours after commissioning the system
- After the run-in period (50–100 operating hours)
- Normal maintenance (300–500 operating hours)

In each case, the element should be replaced extremely carefully, following the operating instructions exactly.

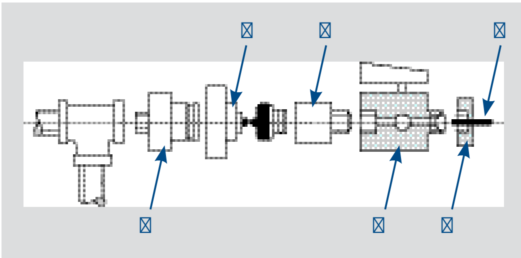
Cyclical contamination monitoring

When monitored regularly, filters can also act as good instruments for monitoring wear of components in the hydraulic system. If the operator regularly documents filter replacements, then a trend of shorter replacement intervals could indicate, for example, that component wear is increasing. A qualitative and quantitative analysis of the element and a fluid sample from the system would then allow the source of the dirt particles, and thus the cause of the increased wear, to be localized. By tracing back the installed materials, preventive repairs can be undertaken before a total failure and loss of production occur. In general, quantitative analysis of the contaminants in the hydraulic fluids, which should be done anyway, also serves to achieve this purpose. Samples taken from a draw-off point intended for this purpose, or captured during online particle measurement, ensure that the required cleanliness class is met and that the system therefore remains serviceable.

Oil sample evaluation in the lab

Sampling according to ISO 4021 from a system in operation

Sampling locations, located in turbulent main flow areas, should be planned already at the design stage of a hydraulic system. Samples can be taken there, as long as normal precautionary measures are taken to protect personnel and equipment. In order to prevent extraneous dirt from compromising the sample results, the fluids must be carefully placed in bottles specially prepared for this purpose.



Typical sampling device according to ISO 4021

Sampling device

A typical sampling device according to ISO 4021 consists of six elements:

☒ Dust cover
☒ Valve, without recoil device
☒ Capillary tube for fluid sampling
☒ Cover with capillary tube
☒ Ball valve
☒ Check valve and outer part for quick connection

A quick connection point (6) with a dust cover (1) is permanently installed in the opening through which the sample is to be drawn. The other parts of the device (2-5) are attached only when sampling.

Oil sampling bottle

Sampling procedure

The ball valve (5) is opened, in order to allow at least 200 ml of fluid to flow out. Only then is the sampling bottle for collecting the fluid brought into position. The sharp end of the capillary tube is used to puncture the foil over the bottle opening, and a sample is taken of no more than 90% and no less than 50% of the bottle volume. Before flow is cut off again by the ball valve, the bottle is removed and closed as soon as the capillary tube is pulled out.

If a quick connection point (6) is used, then the removable parts of the sampling device are dismantled and all traces of fluid are removed by rinsing with a suitable solvent. Do not forget: replace the dust cover (1) on the quick connection point immediately after dismantling.

Sampling from a tank—similar to CETOP RP 95 H

For a representative sample, the system must be run up to operating conditions, so that the fluid in the tank is well mixed. The outer surface of the tank should be carefully cleaned beforehand around the location where sampling will be performed.

Using a pipette or a cleaned single-use syringe, a sample of at least 150 ml can be drawn off easily. Insert the pipette to about half the depth of the fluid, taking care that it does not contact the side walls or come too close to the floor of the reservoir. Transfer the contents of the pipette into the sampling bottle and close it—done. Now, the tank just needs to be covered again or—if additional samples are required—closed off with a precleaned foil cover.

Suitable sampling bottles, according to the DIN 5884 standard, are precleaned, prepared, and supplied together with the associated questionnaire. Extensive instructions on handling the bottles are contained in the CETOP RP 95 H standard.

The sampling bottle must have a label containing data about the company, date, machine, and sample number. In addition, a questionnaire required for the analysis is to be filled out for each sampling bottle. It contains information about:

- Sample number
- Source of the sample
- Sampling method
- Date and time of the sampling
- Type of fluid
- Analysis method used
- Data on the machine and the installed filters
- Comments and notes, if required

Analysis set

Ideally suited for oil sampling according to ISO 4021 or CET OP RP 95 H: an oil analysis set that you can use to make a tendential statement about the contamination in the oil while still at the measurement location. Its measurement accuracy, however, is not comparable to that of a stationary laboratory.

Stationary laboratory

The analysis methods in the laboratory are more accurate and varied. The hydraulic fluid is assigned to a defined cleanliness class using particle analysis. The overall contamination level in mg/L can be determined using a filtration device. Using microscopic contaminant analysis, the type and amount of dirt can be determined. Additional tests can help identify and correct problems in the hydraulic system; they include analyses of water content, viscosity, filterability, and material compatibility.

Qualitative material analysis

Portable contamination measuring system PiC 9300

The portable, self-powered PiC 9300 contamination measuring system measures contaminants in hydraulic fluids and determines the cleanliness class.

The high-precision laser sensor uses the light blockade principle, which provides precise and reproducible particle counts. It measures sizes > 4 µm(c), > 6 µm(c), > 14 µm(c), > 21 µm(c), > 38 µm(c), > 70 µm(c), calibrated according to ISO 11171:1999.

Particle sizes > 5, > 15, > 25, > 50, > 100 µm can also be output for additional analysis according to the superseded standard NAS 1638.

Measurement values can be displayed on a touchscreen display and saved automatically according to ISO 4406:1999, SAE AS 4059, or also according to the withdrawn standard NAS 1638. The internal memory capacity is 2,600 measured values, which can be managed in up to 64 measurement series. Several machines can thus be measured, one after another, and analyzed individually at a later time.

Portable contamination measuring system and sampling case

The user can print out the measured data on the spot, using the integrated printer, or read them out for optional analysis using special software (Log and Show).

The measurements can also be copied to a USB memory stick, and displayed in Microsoft Excel. The touchscreen is used as a menu-driven user interface. Individual measurement points or continuous curves can be measured, with individually adjustable measurement cycles.

The device can be used with all typical hydraulic and lubricating oils. Measurements can be taken at pressures up to 315 bar and from sampling bottles.

Potential areas of application include:

- Regular checks of hydraulic circuits
- Determining cleanliness classes when commissioning new machines
- Checking component cleanliness when manufacturing components
- Controlling bypass filter units in order to achieve a target cleanliness class

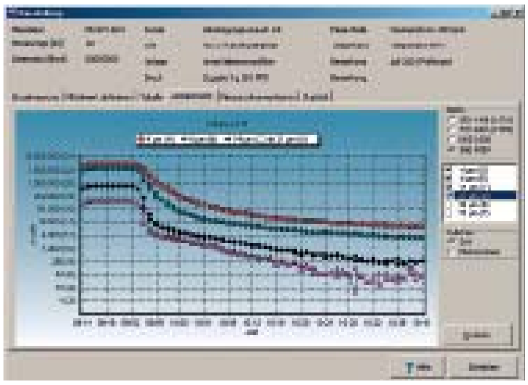
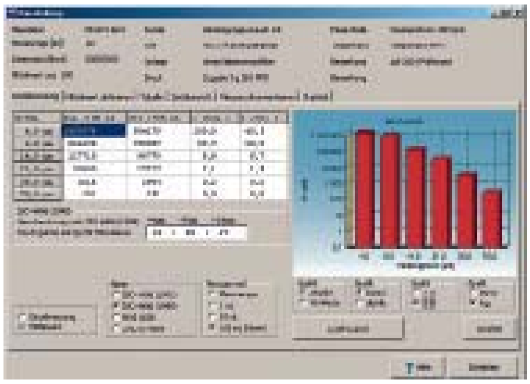


Table of values



Measurement record

No guarantee without maintenance

Faults and premature component wear in hydraulic systems are often a consequence of insufficient maintenance. Hoping to reduce operating costs by delaying filter replacement doesn't pay off. Usually this actually causes downtime incidents.

Many suppliers of complete systems therefore require documentation of regular maintenance and inspection, right in their maintenance and operation manuals, and limit guarantee coverage if this evidence is not provided. A typical guideline for systematic maintenance and inspection of hydraulic systems is DIN 2434.

MAHLE Industriefiltration—Service and consultation on site

Recommended for manufacturers and suppliers of hydraulic systems

With just a few targeted steps, service quality can be improved and the number of unjustified complaints can be reduced:

- With support from MAHLE, customer service technicians should also be trained on filter questions.
- In case of faults, check whether exclusively MAHLE original parts have been used.
- Maintenance documentation should be requested in order to evaluate the functionality and cost-effectiveness of hydraulic filters.
- Used filter elements or replacement filters that are coated with oil should be carefully allowed to drain and dry before proper disposal.

Oil sample analysis in clean room

Inspection of replacement elements and the oil tank

As a customer service technician, you should always check, prior to repairing damage, whether the filter has been serviced regularly and whether exclusively MAHLE replacement elements have been used. All too often, people try to clean the dirty Mic or PS elements instead, which will definitely destroy them. Only wire mesh elements—and only to a limited extent—can be made ready to use again in this way. In addition, check whether the oil tank is properly closed and the air breather is in good condition. When in doubt, take oil samples in order to ensure that the required cleanliness class has been maintained.

Replacement frequency of filter elements

Use caution if the filter elements have seldom or never needed to be changed because the installed maintenance indicator did not indicate a required replacement. If the maintenance indicator is not defective, this may be caused an installed bypass valve, which no longer closes correctly due to dirt particle deposits. In single-shift operations, filters with maintenance indicators should generally be replaced at least annually. Filters without maintenance indicators should be replaced twice a year. This is the only way to ensure that none of the elements are past their service life due to having been neglected in the daily inspection.

Original MAHLE replacement elements

Standards for obtaining, testing, and analyzing oil samples			
No.	**Edition**	**English title**	**Identical with/corresponds to**
ISO 3722	1976	Hydraulic fluid power; fluid sample containers; qualifying and controlling cleaning methods	E DIN ISO 3722-1988
ISO 3938	1986	Hydraulic fluid power; contamination analysis; method for reporting analysis data	
ISO 4021	1992	Hydraulic fluid power; extraction of fluid samples from lines of an operating system	
ISO 4406	1999	Method for coding the level of contamination by solid particles	
ISO 11171	1999	Calibration of automatic particle counters for liquids	
ISO 11943	1999	Online automatic particle-counting systems for liquids; methods of calibration and validation	
ISO 5884	1987	Aerospace; fluid systems and components; methods for system sampling and measuring the solid particle contamination of hydraulic fluids	DIN ISO 5884-1989
NAS 1638	1964	Cleanliness requirements for particles in hydraulic systems (standard withdrawn)	Replaced by SAE AS 4059
CETOP RP 94 H	1978	Determination of solid particles in hydraulic fluids using an automatic particle counter working on the basis of the light extinction system	
CETOP RP 95 H	1979	Recommended method for the bottle sampling of hydraulic fluids for particle counting	
CETOP RT 118 H	1988	Guideline for contaminant inspection of fluids in hydraulic systems	
CETOP RP 120 H	1990	Method for calibrating automatic particle counters using the principle of light masking using latex spheres of uniform size	
SAE AS 4059	2005	Aerospace; hydraulic fluid power; cleanliness classification for hydraulic fluids	

Standards for testing filter housings			
No.	**Edition**	**English title**	**Identical with/corresponds to**
DIN 50104	1983	Testing of hollow bodies by internal pressure	
ISO 4548-6	1985	Methods of test for full-flow lubricating oil filters for internal combustion engines; Part 6: static burst pressure test	
ISO 10771-1	2002	Hydraulic fluid power; fatigue pressure testing of metal pressure-containing envelopes—test method	

Design standards for hydraulic filters			
No.	**Edition**	**English title**	**Identical with/corresponds to**
ISO 7744	1986	Statement of requirements for filters in hydraulic systems	CETOP RP 92 H-1978
DIN 24550 Part 1	2006	Hydraulic fluid power; hydraulic filters; definitions, nominal pressures, nominal sizes, fitting dimensions	
DIN 24550 Part 2	2006	Hydraulic fluid power; hydraulic filters; characteristics, requirements; performance data	
DIN 24550 Part 3	1992	Hydraulic fluid power; hydraulic filters; hydraulic filter elements for inline filters; envelope dimensions	
DIN 24550 Part 4	1992	Hydraulic fluid power; hydraulic filters; hydraulic filter elements for tank top return-line filters; envelope dimensions	
DIN 24550 Part 5	1992	Hydraulic fluid power; hydraulic filters; tank top return-line filters; fitting dimensions	
DIN 24550 Part 6	1999	Hydraulic fluid power; hydraulic filters; test filter housings; dimensions	
DIN 24550 Part 7	2006	Hydraulic fluid power; hydraulic filters; spin-on filters; characteristics, requirements	
DIN 24557 Part 2	1990	Hydraulic fluid power; air breathers; fitting dimensions	
CETOP RP 98 H	1979	Guidelines for the specification, selection, and application of hydraulic reservoir air breather filters	

Standards for the classification and minimum requirements for hydraulic and lubricating oils			
No.	**Edition**	**English title**	**Identical with/corresponds to**
ISO 3448	1992	Lubricants; industrial liquid lubricants—ISO viscosity classification	DIN 51519-1976
ISO 6743 Part 0	1981	Lubricants; industrial oils and related products (class L); classification; general	DIN ISO 6743 Part 0-1991
ISO 6743 Part 4	1982	Lubricants; industrial oils and related products (class L); classification; family (hydraulic systems)	
DIN 24320	1986	Fire-resistant fluids; hydraulic fluids; category HFAE; characteristics and requirements	VDMA 24 320
DIN 51517 Part 1	2004	Lubricants; lubricating oils; C lubricating oils; minimum requirements	New draft standard 2008
DIN 51517 Part 2	2004	Lubricants; lubricating oils; CL lubricating oils; minimum requirements	
DIN 51517 Part 3	2004	Lubricants; lubricating oils; CLP lubricating oils; minimum requirements	New draft standard 2008
DIN 51524 Part 1	1985	Hydraulic fluids; hydraulic oils; HL hydraulic oils; minimum requirements	
DIN 51524 Part 2	1985	Hydraulic fluids; hydraulic oils; HLP hydraulic oils; minimum requirements	
DIN 51524 Part 3	1990	Hydraulic fluids; hydraulic oils; HVLP hydraulic oils; minimum requirements	
CETOP R 39 H	1987	Schedule of required data for hydraulic fluids	
CETOP RP 91 H	1977	Fluids for hydraulic oil transmission—mineral oils, specifications	
CETOP RP 97 H	1989	Fluids for hydraulic systems—fire-resistant fluids—specifications	
CETOP RP 100 H	1987	Fluids for hydraulic systems—fire-resistant fluids, group HFA—specifications	
VDMA 24317	1982	Hydraulic fluid power; hydraulic oils; fire-resistant fluids; guidelines	

Standard for filter element testing			
No.	**Edition**	**English title**	**Identical with/corresponds to**
ISO 2941	1974	Hydraulic fluid power; hydraulic oils; filter elements; collapse and burst pressure testing	DIN ISO 2941-1983
ISO 2942	2004	Hydraulic fluid power; hydraulic oils; filter elements; verification of fabrication integrity	
ISO 2943	1974	Hydraulic fluid power; hydraulic oils; filter elements; Verification of material compatibility with fluids	DIN ISO 2943-1990
ISO 3723	1976	Hydraulic fluid power; hydraulic oils; filter elements; method for end load tests	
ISO 3724	1976	Hydraulic fluid power; hydraulic oils; filter elements; determination of resistance to flow fatigue	
ISO 3968	1981	Hydraulic fluid power; hydraulic oils; filter elements; evaluation of differential pressure versus flow characteristics	
ISO 16889	1999	Hydraulic fluid power; hydraulic oils; filters; Multipass method for evaluating filtration performance of a filter element	
DIN 65385	1991	Aerospace; hydraulic fluid power; hydraulic oils; filter elements; reporting of test data	
CETOP RP109H	1983	Hydraulic fluid power; hydraulic oils; filter elements; low-temperature integrity test	

Institutions and industry associations	
AFNOR	Association Française de Normalisation
AGMA	American Gear Manufacturers
ANSI	American National Standards Institute
API	American Petroleum Institute
ARP	Aerospace Recommended Practice
ASTM	American Society for Testing and Materials
BCAS	British Compressed Air Society
BFPA	The British Fluid Power Association
BSI	British Standards Institution
CETOP	Comité Européen des Transmissions Oléohydrauliques et Pneumatiques
CNOMO	Comité Européen des Transmissions Oléohydrauliques et Machines Outils
DIN	Deutsches Institut für Normung e.V.
DIS	Draft International Standards (ISO, for which the opposition proceedings have not yet been closed)
FHP	Federatie Hydraulik en Pneumatiek
IFA	Institut für Arbeitsschutz der DGUV
ISO	International Organization for Standardization
MIL	Military Specification (L-Lubricating Oil)
NAS	National American Standard
NFPA	National Fluid Power Association
NLGI	National Lubricating Grease Institute
SAE	Society of Automotive Engineers
SEB	Stahl-Eisen-Betriebsblätter
UNITOP	Union Nationale des Industries de Transmissions Oléohydrauliques et Pneumatiques
VDI	Verein Deutscher Ingenieure
VDE	Verband Deutscher Elektrotechniker
VDMA	Verband Deutscher Maschinen- und Anlagenbau e.V.
VSM	Verein Schweizerischer Maschinen-Industrieller

ACFTD dust

(Air Cleaner Fine Test Dust)

Test dirt for performing the multipass test according to ISO 4572. Was replaced by ISO MTD.

Tank-top filter

Filter designed as a sandwich filter or a flange-mounted filter for installation on the tank or on control blocks.

Initial differential pressure Dp for filters

Pressure drop that occurs in a new, uncontaminated filter when a certain volume flow is sent through it. This value depends on the design of the filter element, the viscosity, the density, and the size of the volume flow.

Air breather

Filter fitted on the tank, which filters air flowing into the system when the pump is drawing. Its filter rating should correspond to that of the hydraulic filter.

Burst pressure

The permissible collapse/burst pressure according to ISO 2941 is defined as the pressure differential that a filter element can withstand in the prescribed flow direction.

$\beta_{x(c)}$ value

The $\beta_{x(c)}$ value is used as a measure of the effectiveness of a filter in the multipass test. It is a ratio, calculated from the particle count before and after passing through the filter.

Pressure filter

The pressure filter is installed in the pressure line for filtering the flow from the pump, and serves to protect the downstream components.

Filling filter

A filling filter should always be used when filling a system with hydraulic fluid.

Filter surface

The total surface area of the filter element exposed to the volume flow. In order to achieve as great a filter surface as possible for a given filter size, the filter materials are pleated in the form of a star.

Characteristic values of a filter

The most important characteristic values of a filter are:

- Filter rating
- Separation rate
- Apparent dirt-holding capacity
- Filter surface
- Initial differential pressure
- Burst pressure
- Nominal pressure
- Nominal size

Filter concept

Sensible selection and arrangement of various filters, with optimal installation locations.

Filter service life

The lifespan of a filter element depends on many parameters. It can only be estimated, even if the operating conditions are known. In order to optimally utilize the filter‘s dirt-holding capacity, the use of a maintenance indicator is recommended.

ISO MTD (ISO Medium Test Dust)

Test dust for performing the multipass test according to ISO 16889 and calibrating particle counters according to ISO 11171:1999.

Line filter

Filter installed directly in the pipeline using a threaded or flange connection.

Multipass test

Standardized test according to ISO 16889 for determining the separation rate of a filter, wherein a test fluid at a defined contamination level is sent multiple times through the hydraulic circuit and the filter to be tested.

Bypass filtration
Arrangement of the filter in a circuit that is separated from the main system and fitted with its own pump. Bypass filtration through a precisely specified filter can occur independently of the system's operating time, until the required cleanliness class is achieved.

Nominal pressure (PN)
Pressure for which the filter has been designed for long-term use.

Nominal size (NG)
Volume flow expressed in numbers, for which the filter has been designed. The nominal size is based on a viscosity of 32 mm^2/s and a filter rating of $\beta_{20(c)}$ p 200.

Surface filter
Filter used to separate contaminant particles only at the surface of the filter element (e.g., wire mesh elements, metal-edge filter). Surface filters are designed to have uniform pores (gaps). In comparison with depth filters, surface filters have a relatively small dirt-holding capacity.

Return-line filter
Filter installed in the return line of a system. Return-line filters must be selected for the largest possible volume flow—regardless of the pump's flow rate.

Suction filter
The suction filter is typically designed with a wide mesh (e.g., 100 µm) and is suitable for filtering the hydraulic fluid drawn in by the pump.

Partial-flow filtration
Arrangement of the return-line filter in parallel with a throttle, so that only part of the returning oil flow is filtered. An ideal solution for oil flows that increase greatly at periodic intervals.

Depth filter
Filter used to separate contaminant particles mainly in the interior of the filter material. In comparison to surface filters, their dirt-holding capacity is greater and the pressure drop is smaller.

Spin-on filter
In spin-on filters or spin-on cartridges, the filter element is encapsulated in a sheet-metal housing, which is replaced after use, complete with a new housing. Spin-on filters are threaded on to a corresponding filter head. Spin-on filters are used as low-pressure, return-line, or bypass filters, especially in mobile hydraulics. Their ratings are PS, Mic 10, or Mic 25, depending on the filter concept. Bypass valves and nominal sizes correspond to those of pressure, return-line, and bypass filters. The maximum possible nominal pressure is 10 or 25 bar. A maintenance indicator is fundamentally required.

MAHLE

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