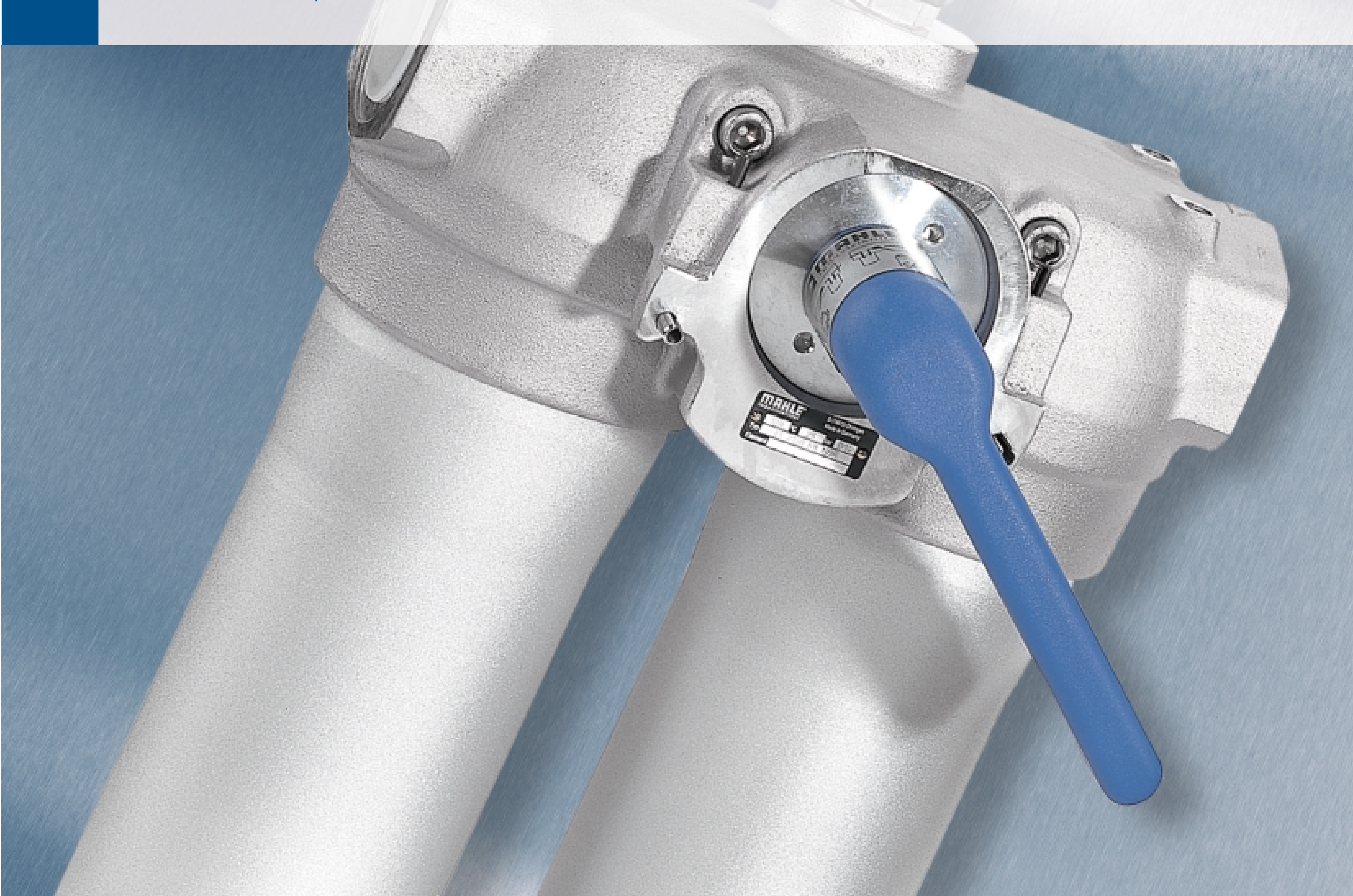
MAHLE

MAHLE Industrial Filters

Know-how for more efficiency and profitability

Filtration in hydraulic and lubrication circuits



Hydraulic equipment needs innovative filter solutions

It is impossible to conceive modern hydraulic and lubrication equipment without high-performance filter systems. They protect highly sensitive components, ensure compliance with the required purity of fluid media, and ensure the necessary reliability and profitability of the equipment.

With this manual we would like to provide current comprehensive information concerning filtration in hydraulic and lubricating circuits to those interested in hydraulics, as well as to seasoned specialists: from the fundamentals to equipment operation and service.

This manual provides all-important theoretical and practical details in a compact and understandable format. We would be pleased to respond to you personally if you have any questions. Simply contact our engineers and technicians.

We hope you enjoy this brochure.

Pioneering systems, modules and components of the highest precision and quality for engines and vehicles, as well as for industrial applications – this is what approximately 38,000 employees at MAHLE are working on at 70 manufacturing locations worldwide. Research and development, production, and worldwide marketing for the product groups, fluid technology, dedusting, and automatic filters are concentrated in the Öhringen plant, where industrial filters have been developed and manufactured since 1962.

Always a clean solution

MAHLE Industrial Filters

The Öhringen plant employs about 800 highly qualified people. Our manufacturing range in the Industrial Filters division includes filters and filter equipment, devices and accessories for fluid technology, dust filter equipment, as well as automatic filter systems for coarse and superfine filtration of liquids and pastes as well as for homogenization of foodstuffs. Continuous development of materials and manufacturing technologies guarantee the highest quality for economical and technically optimal products. Our production is certified in accordance with DIN EN ISO 9001 and our environmental management is certified in accordance with ISO 14001, as well as EMAS. We thus design our future and success as well as that of our customers.

MAHLE Industrial Filters, Öhringen plant

Perfection in all filter applications

Thanks to highly effective filters and filter equipment, devices and accessories for keeping hydraulic fluids clean, MAHLE is the competent partner for machine manufacturers, as well as users of mobile and stationary hydraulic equipment worldwide.

For applications involving air, MAHLE air filters and air oil separators ensure economic generation of compressed air.

MAHLE dedusting devices and equipment help protect the environment and improve work safety, and they are used successfully to reclaim product.

Through the advantage of rational non-stop, around-the-clock operation with automatic cleaning and disposal processes, MAHLE automatic filters, which are used for the entire range from rough to superfine filtration, or for homogenization, have broad areas of application ranging from cooling lubricant filtration, to foodstuffs technology, to ship operation technology.

MAHLE hydraulic fluid and lubricating oil filters

MAHLE has been involved with filtration of hydraulic fluids and lubricating fluids since the early 60s. Today this product group is the core of the Industrial filter manufacturing range. The superior technical know-how and the outstanding quality of our products have made MAHLE into one of the world's leading manufacturers of filter systems, devices, and accessories for fluid technology.

The product range includes pressure filters, double filter systems with diversion switches, bypass filters, suction filters, return line filters, vent filters, coalescer filters, highly efficient filter elements in standard designs, and in accordance with DIN 24550, as well as accessories, filter and service devices for maintaining hydraulic fluids and lubricating fluids. Proven in thousands of plants, our high-performance filter elements protect highly sensitive hydraulic systems and ensure the required class of purity for a wide variety of fluid media.

Still one of the main causes of malfunctions and operating failures of hydraulic equipment: Contamination that results in premature component wear. The most effective means of prevention: Filters that reduce solids contamination in the system to a tolerable measure, prevent penetration of contamination from the environment, and maintain the characteristics of the hydraulic fluid over the longest possible period. MAHLE fluid filters are also characterized by long service life, and economical operation, and thus increase the efficiency and profitability of equipment.

Fail-safe security provided by systems with a constant low contamination level

Sources of contamination

Hydraulic equipment is exposed to a variety of contaminants over its entire service life. Contamination already takes places during production processes of the hydraulic components and during their installation. In addition, there is the basic contamination of the hydraulic fluid. And during operation, abrasion and wear jeopardize the system. Contaminants can even penetrate from outside via defective seals and inadequate venting of the tank.

Essentially there are three sources of contamination:

- Contamination associated with installation (primary contamination)
- Contamination, which occurs in the system (operating contamination)
- Contamination from the environment and through the hydraulic fluid (contamination ingress)

If you are familiar with these sources of contamination, then you can use MAHLE fluid filters for specific remedies.

Primary contamination

In manufacturing hydraulic components and production of equipment, various types of contamination accrue, such as shavings, mold sand, core residue, fibers, burr residue, dust, paint residue, or welding residue, depending on the process.

Most of these coarse contaminants must be removed from the entire system by washing out and flushing prior to commissioning. After flushing, there should be a run-in phase of the load-free equipment to loosen firmly bonded contaminants and to remove them through the filter.

For complex equipment in addition to the already installed operating filters, it is recommended to

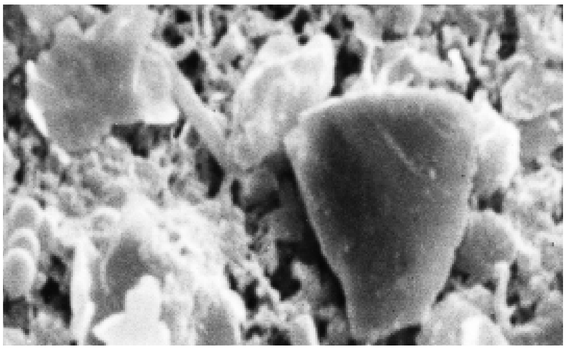


Fig. 1: Primary contamination at 170x magnification

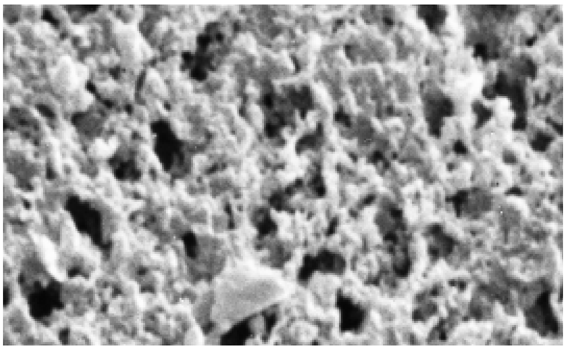


Fig. 2: Tolerated residual contamination at 170x magnification

Contamination Balance

Primary contamination

Pollutants already present in the system:

- On components
- In the hydraulic fluid

Operating contamination

Pollutants generated in the system:

- Through abrasion
- Through wear

Contamination ingress

Contaminants that penetrate from outside the system:

- Through topping off hydraulic fluid
- Through cylinders and seals
- Through venting the tank

MAHLE Industrial filters
Filter Concept

System with constant low contamination level install flush filters at strategic points in order to thus break down primary contamination as quickly as possible.

Complete removal of the primary contamination and production contamination is seldom successful. Vibrations and temperature changes in flow conditions can loosen residual contamination that is still firmly bonded long after the equipment has been commissioned. Consequently it is important that the installed filters capture this contamination, and this measure thus protects highly sensitive components.

Operating contamination

From the contaminants in the components and in the equipment, the hydraulic system generates new contamination through mechanical and thermal influences. In addition there is abrasion of the hydraulic components. These processes produce a self-accelerating contaminant avalanche that must be caught by the filters and brought to a level that is appropriate for the equipment.

Contaminants from the environment

A frequently underestimated source of contaminants are unsuitable vent filters or a lack of vent filters, service caps on hydraulic fluid tanks that are not closed after service, or defective seals on flanges and cylinders, through which dust and contaminant penetrates from the environment and thus constantly aggravates the contaminant avalanche. Also the dust content of the ambient air

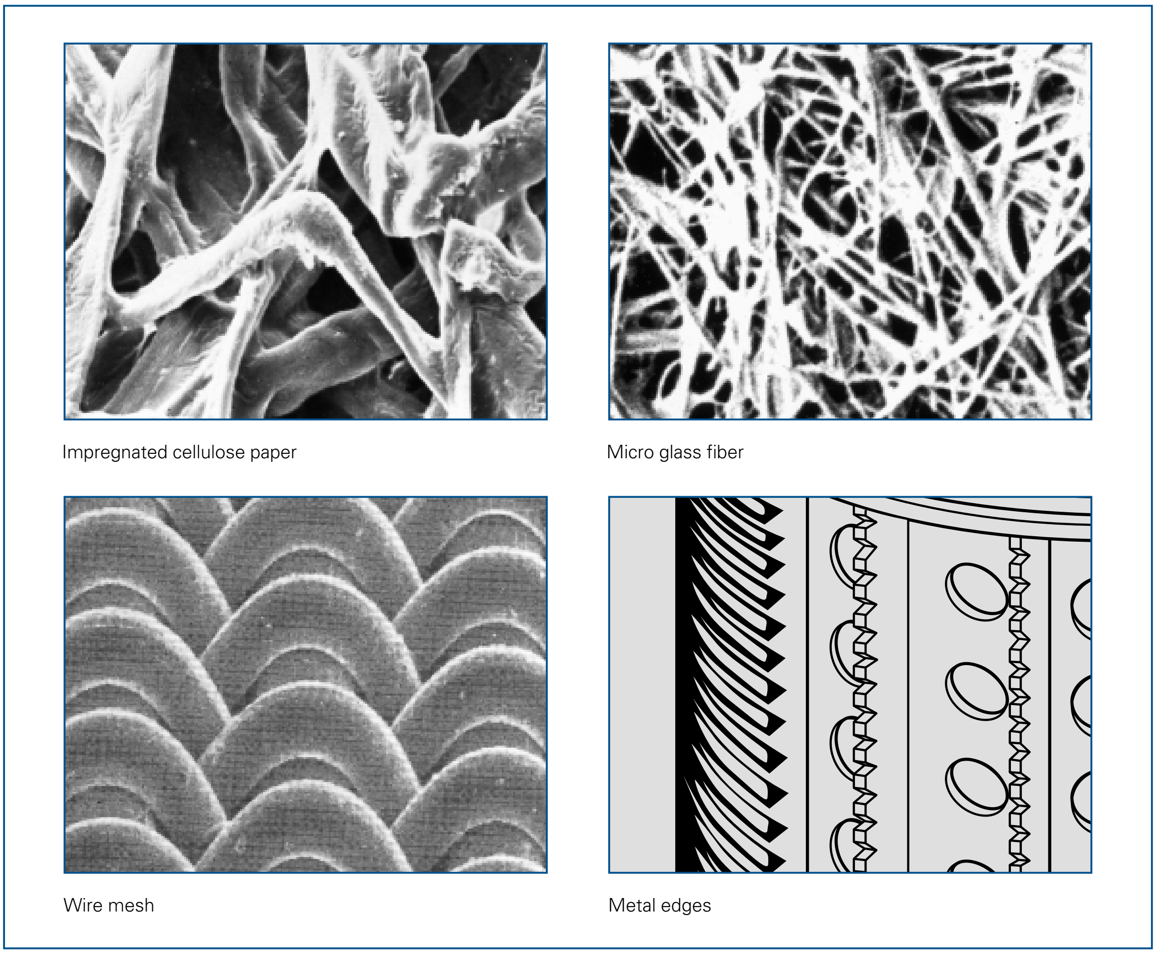


Fig. 3: Filter media for hydraulic fluid and lubricant filtration are used individually, however they are used most often in combination

Fig. 4: MAHLE Industrial Filters - the complete filtration range

where hydraulic equipment is located is usually underestimated. The air that penetrates into the tank for level compensation must at least be filtered with the same fineness as that provided by the fluid-filter. Also component and seal leaks must be resolved as quickly as possible, for service and repair work the openings provided on the tank must be covered, and must always remain closed when the equipment is in operation.

Contaminants through hydraulic fluids

Hydraulic fluid can become significantly contaminated in production, filling, transport, and storage. Particularly storage in tanks and vats, results in problems, as such containers are not adequately protected against corrosion, contamination, water condensation, and dust from the environment.

Online measurements of hydraulic fluid at first filling, and when servicing (topping off) often reveal classes of purity that are far below the fluid purity class required by the equipment. To improve this situation fluid must always be filtered through suitable filters, for the initial filling as well as when topping off. When filling, the filter effect must be achieved in a single passage, this means that the requirements placed on special filling filters are quite high.

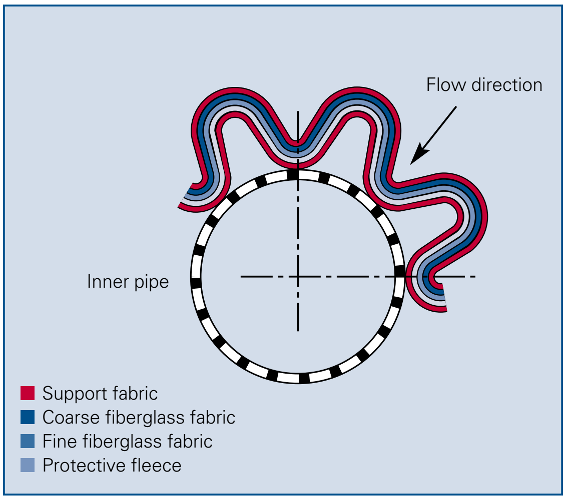


Fig. 5: Structure of a Sm-x star pleat

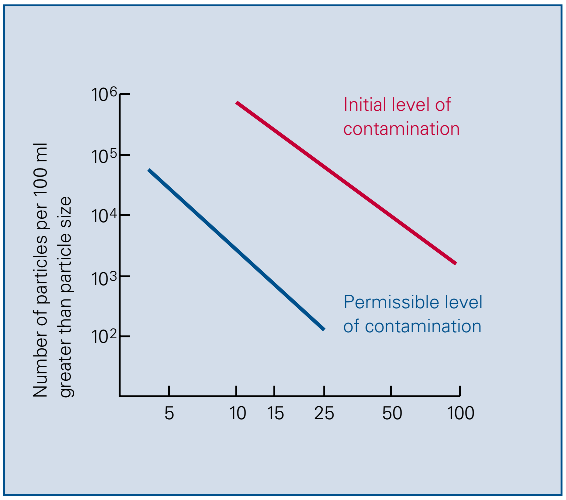


Fig. 6: Typical relationship between the design-specified, permissible level of contamination and the actual level, prior to commissioning

Hydraulic fluids are used primarily to transfer the energy from the pump to work cylinders, hydro motors and other components. In this process they should also protect the system from corrosion, dissipate heat and lubricate parts that have glide contact. The same applies for lubricating circuits. However all of these requirements can only be satisfied if the hydraulic and lubricating fluids do not age prematurely and if their characteristics remain unchanged over a long period.

Purity is the main thing for the hydraulic and lubricating circuit

The filterability of hydraulic and lubricating fluids primarily depends on their viscosity; hydraulic fluids and lubricants are grouped in viscosity classes (Table 1) in accordance with DIN 51519. In addition to mineral oils, flame-retardant, biologically degradable fluids and special fluids are used in the foodstuffs industry as lubricating and hydraulic fluids, for example.

Mineral oils

In hydraulic and lubricating equipment, mineral oils are used predominantly because their characteristics relative to aging, corrosion protection, temperature influence on their viscosity, lubricating behavior and water bearing capacity can be improved by introducing additives to a base oil. Mineral hydraulic fluids are classified in different quality groups in accordance with DIN 51524 (Table 2) depending on the requirement.

Native oils

Rapeseed oil is primarily used from the group of plant and animals oils, although it would also be possible to use olive oil, sunflower oil, and castor oil in agriculture, forestry or mobile hydraulics.

Flame-retardant fluids

Flame-retardant fluids are used in mining, for die-casting machines, foundries, and other applications where fire hazard is present with mineral oils due to the high heat build-up. The various fluids are described below.

Viscosity class ISO	Mid-point 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

Table 1: Standard ISO viscosity classes in accordance with DIN 51519 (excerpt)

Hydraulic fluid type	Requirement standard	International designation	Characteristics	Application
Hydraulic fluid HL	DIN 51224 Part 1	HL, ISO 6743	Oxidation inhibiting, rust preventing	For moderately stressed equipment
Hydraulic fluid HLP	DIN 51524 Teil 2 Part 2	HM, ISO 6743	Oxidation inhibiting, rust preventing, wear reducing	For high-pressure equipment
Hydraulic fluid HVLP	DIN 51524 Part 3	HV, ISO 6743	Like HLP, especially favorable viscosity/temperature ratio	For low or widely fluctuating temperatures
Hydraulic fluid HLPD	–	–	Like HLP, in addition contamination bearing and to a limited extent hydrophilic	For equipment with water flow at oil opening
Hydraulic fluid HVLPD	–	–	Like HVLP, in addition contamination bearing and to a limited extent hydrophilic	For equipment with water flow and low or widely fluctuating temperatures
HD motor oil	–	–	Oxidation inhibiting rust preventing, wear reducing, contamination bearing, hydrophilic	For drivable oil-hydraulic equipment

Table 2: Types of mineral oil-based hydraulic fluids

HFA fluids

Many HFA fluids have virtual water viscosity and consequently they are primarily used in areas where fire is a hazard, such as in mining applications or in welding equipment. Usable in a temperature range from + 5 °C to + 55 °C, these oil-in-water emulsions resemble the bore oil emulsions used for metal processing. The consumer himself produces them by mixing an HFA concentrate with the necessary amount of water. Generally the maximum proportion of oil in this process is only 20 %. A distinction is made between HFA E emulsions that contain mineral oil, and HFA S emulsions that do not contain mineral oil.

HFB fluids

HFB fluids with a nominal viscosity similar to that of hydraulic fluids are not widely used in Germany, because they are not recognized as flame-retardant. HFB fluids are used in Great Britain and Commonwealth countries. They can be used from + 5 °C to + 60 °C, the mineral oil proportion is < 60 %.

HFC fluids

The most frequent representative of these aqueous polymer solutions are polyglycol water solutions. They are shipped ready-to-use and can be used – depending on the viscosity requirement – for fluid temperatures between – 20 °C to + 60 °C. In order to keep reduction of water content through evaporation to a minimum, operating temperature should not exceed + 50 °C. In any case, water content (< 35 %) and the rust protection reserve of HFC fluid should be monitored during operation and be maintained at the target value by adding demineralized water or a rust inhibitor.

HFD fluids

For water-free synthetic HFD fluids, a distinction is made on the basis of phosphoracetic acid (HFDR) and other water-free synthetic fluids like polyolester or organic ester (HFDU). Their temperature range (max. from – 20 °C to +150 °C) is determined by the viscosity temperature behavior and the viscosity requirements of the drive. It is generally less than for mineral oils and must be verified on a case-by-case basis.

Lubricating oils

Mineral oil based lubricating oils can be filtered with star pleat filter elements. The most frequently used Newtonian fluids are lubricating oils for circulating oil lubrication, turbine oils and air compressor oils. Usually, and depending on the components that will be lubricated, filter fineness from 10 to 25 µm is used. Here the possible flow capacity depends on the viscosity of the lubricating oil (Table 4).

Biologically degradable hydraulic fluids

These environmentally friendly plant-based, animal-based, or synthetic-based fluids with low biotoxicity are used as alternatives to mineral hydraulic fluids in agriculture and forestry, as well as in mobile hydraulics.

- HETG: Natural ester based on plant oils (rape seed oil, sunflower oils etc.), water insoluble
- HEES: synthetic ester, water insoluble
- HEPG: Polyalkaline glycols, polyglycols or polyethylene glycols, water insoluble

Requirements and use are specified in the VDMA standard sheets 24568 and 24569.

Synthetic hydraulic fluids

Synthetic hydraulic fluids are used most often for special applications (e.g. aerospace and military). In their filter behavior, they resemble mineral oils, yet they have specific advantages over mineral oils. However, often they are extremely aggressive to metals and sealing materials.

Filterability of hydraulic fluids and lubricating fluids

All necessary characteristics can only be safely assured with the use of additives. These are often in particulate form, and their size range is under 1 µm.

Hydraulic fuid type	Requirement standard	Composition	Application
Hydraulic fluid HFA	DIN 24320	Oil-in-water-emulsion	pressing water, e.g. for hydraulic pressure
Hydraulic fluid HFB	VDMA-standard sheet 24317	Oil-in-water-emulsion	Not used in Germany
Hydraulic fluid HFC	VDMA-standard sheet 24317	Aqueous polymer solutions	For equipment that poses a fire hazard
Hydraulic fluid HFD	VDMA-standard sheet 24317	Water-free syntetic fluids	For equipment that poses a fire hazard at high temperatures and high-pressures

Table 3: Types of flame-retardant hydraulic fluids

AN	DIN 51501	Lubricating oil primarily for circulating oil lubrication	Without higher requirements, permanent temperature max. +50 °C
C	DIN 51517 Part 1		Non-ageing mineral oil
CL	DIN 51517 Part 2		Mineral oil with active indegrients to increase non-aging characteristics and corrosion protection
CLP	DIN 51517 Part 3		Like CL, additional agents for reducing wear in the area of mixed friction
TD	DIN 51515 Part 1	Turbine oil	Mineral oils with agents to increase corrosion protection and the non-aging characteristics
VB	DIN 51506	Air compressor oils	Compression temperatures max. +140 °C
VBL	DIN 51506	Air compressor oils	Compression temperatures max. +140 °C
VC	DIN 51506	Air compressor oils	Compression temperatures max. +180 °C
VCL	DIN 51506	Air compressor oils	Like VC, preferred for screw compressors and multi-cell compressors
VDL	DIN 51506	Air compressor oils	Particulary high compressor temperature (+220 °C), extremely low residue formation

Table 4: Lubricants and their areas of implementation

This results in a clearly defined requirement or limit for filtration of hydraulic fluid: There must be a capability to filter out contaminant particles in the range under 3 µm, and at the same time there must be absolute assurance that the additives will remain in the hydraulic fluid. The manufacturer of the hydraulic fluid must warrant filterability down to approx. 1 µm in this regard.

The filterability, and thus the capacity of the hydraulic fluid to flow continuously through a fine filter, depends not only on viscosity, but to a large extent also depends on the oil components in the colloidal area, where the additives are present. Contaminations can lead to significant changes of the fluid's colloidal structure and thus to plugging the filter.

Contamination 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

Table 5: Contamination classes according to NAS 1638 (NAS 1638 is currently being reworked)

Contamination classes

So-called contamination classes have been defined for hydraulic fluids because it is economically impractical to remove all contaminants from hydraulic systems through superfine filters. These classes specify the permissible quantity of particles – rated according to the operating requirements and sensitivity of components used.

Classification systems

NAS 1638 and ISO 4406 are the most prevalent contamination classifications for contaminant quantity. Both classification systems are oriented on the fact that depth filters with a balanced ratio of filtration quality and service life are the filters most frequently used today. Their filter media does not have uniform pore sizes, but refers to a pore spectrum. For instance, for a filter element, which separates 99 % of all particles >10 µm note that: Not all particles >10 µm are retained, and under some circumstances even significantly larger particles will pass through.

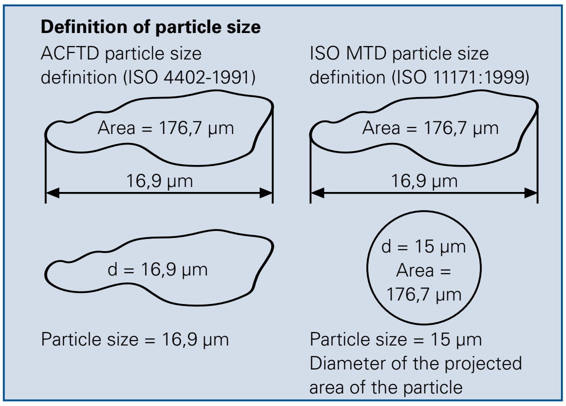


Fig. 7: Particle size as longest particle measurement and as projected surface with allocated equivalent diameter

For industrial hydraulic systems, particle counts are coded in accordance with ISO 4406. With replacement of the ACFTD test dust through ISO MTD, the particle sizes have also been redefined.

According to ISO 11171:1999, now the diameter of the circle with the same projected area for particle

Number of particles per 100 ml		Ordinal number (Code)
More than	Up to & including	
$8*10^6$	$1,6*10^7$	24
$4*10^6$	$8*10^6$	23
$2*10^6$	$4*10^6$	22
10^6	$2*10^6$	21
$5*10^6$	10^6	20
$2,5*10^6$	$5*10^6$	19
$1,3*10^5$	$2,5*10^5$	18
64.000	$1,3*10^5$	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

Table 6: Contamination classes in accordance with ISO 4406

sizes is the determining factor (Fig. 7). With the new definition of test dust and particle size, the standard ISO 4406 has also been updated. This new issue ISO 4406/1999 now uses a three digit code for particles >4 $\mu m_{(c)}$, >6 µm(c) and >14 $\mu m_{(c)}$.

Sizes >6 $\mu m_{(c)}$ and >14 µm(c) for the most part correspond to the previously used particle sizes >5 and >15 µm according to the ACFTD calibration. The newly included range in the classification for particles >4 $\mu m_{(c)}$ approximately corresponds to 0.9 µm of the old standard.

In order to distinguish the new standard from the old standard, specifications relative to filter fineness in accordance with the new standard are given a supplemental „c".

Classification example

The following particle sizes are measured when examining the contaminants in 100 ml of hydraulic fluid:

- 210,000 Particles >4 µm (ordinal number 18),
- 42,000 Particles >6 µm (ordinal number 16) and
- 1,800 Particles >14 µm (ordinal number 11).

Thus the key for identifying solid contamination in accordance with ISO 4406/1999 is as follows: 18/16/11.

Selecting filter fineness and filter elements

State of the art hydraulic equipment is fitted with very sensitive controls. A certain work medium contamination class that is as low as possible is necessary to ensure problem-free operation of these units. Consequently, selection of filter fineness represents one of the most important, and also one of the most difficult, parameters of a filter. Normally the contamination classes required by the component manufacturer must be considered.

The current contamination class of fluid in a hydraulic system can also be determined by an oil test. However, in general the following applies: At higher pressure levels, always select the lower contamination class and higher filter fineness. Our know-how, gained over years of experience in designing filter concepts makes it possible to define guide values. Frequently, much lower contamination classes are achieved with many of the recommended filter finenesses and filter elements.

Specification of contamination class in accordance with ISO 4406/1999			Corresponds approx. to contamination class in accordance with NAS 1638		Type of hydraulic system	Recommended filter fineness in acc. with ISO 16889	Recommended element
>4 µm(c)	**>6 µm(c)**	**>14 µm(c)**	**5–15 µm**	**5–25 µm**			
13	11	8	3	2	Control system against silting with very high reliability	$ß_{4(c)} \geq 200$	Sm–N2
14 16	12 13	9 10	6 7	5 6	High-performance servo systems and high-pessure systems with long service life, e.g. aerospace, machine tools	$ß_{5(c)} \geq 200$ $ß_{7(c)} \geq 200$	Sm–x3 Sm–x6
17	15	11	8	7	High-quality, reliable systems general machine tools	$ß_{10(c)} \geq 200$	Sm–x10
20	17	12	10	8	General machine tools and vehicles, medium capacity	$ß_{15(c)} \geq 200$	Sm–x16
23	19	13	11	9	General machine tools and vehicles, low-pessure systems in heavy machine tools	$ß_{20(c)} \geq 200$	Sm–x25 Mic 10

Table 7: Reference values for determining filter fineness x (µm) and Contamination class present in the hydraulic fluid

Fig. 8: Heavy load transport platform (Scheuerle) with MAHLE hydraulic filters

Definition of the $ß_x$ value

The $ß_x$ value is the measure for the effectiveness of a filter. It expresses the ratio of the particle count before and after filter passage. The formula for this is:

$$ß_x = \frac{\text{Number of particles greater than } x\ \mu m \text{ upstream from the filter}}{\text{Number of particles grater than } x\ \mu m \text{ downstream from the filter}}$$

In hydraulics, reference is made to filter fineness x (in µm), if the filter element corresponds to the requirements of the multipass test in accordance with ISO 16899. For the sake of completeness, it is also necessary to mention the specification of the beta value, e.g. $ß_{10(c)} \geq 200$. The terms „nominal" and „absolute" are not defined and should not be used. For filter finenesses ≥40 µm, when specifying filter fineness, the mesh width or the average pore size of a filter material are also listed.

Fig. 9: Filter for ship operating technology

Fig. 10: Hydraulic power pack with duplex filter for the machine industry

Efficiency criteria

In addition to the filter finenesses required by the contamination class, further peripheral conditions determine filter selection:

- Intended install point
- Intended temperature range
- Type of pressure medium with viscosity and density
- Maximum volume flow
- Maximum pressure
- Environmental conditions

Often the install point in particular leaves few options. Nevertheless, in order to achieve the largest possible filter surface for the specified filter dimension, the filter materials are pleated in a star shape.

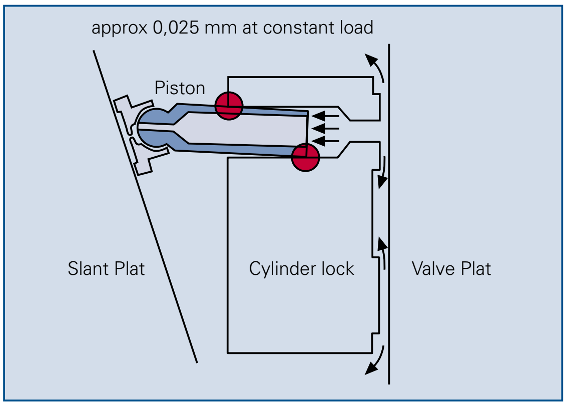


Fig. 11: Critical points in an axial piston pump; with a specified piston play, eccentricity changes as a consequence of load and viscosity

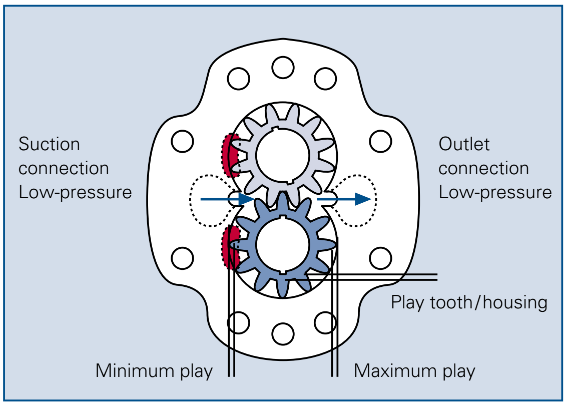


Fig. 12: Critical points in a gear pump; The play between tooth and housing changes depending on the angular position so that fluid can flow in from the pressure side.

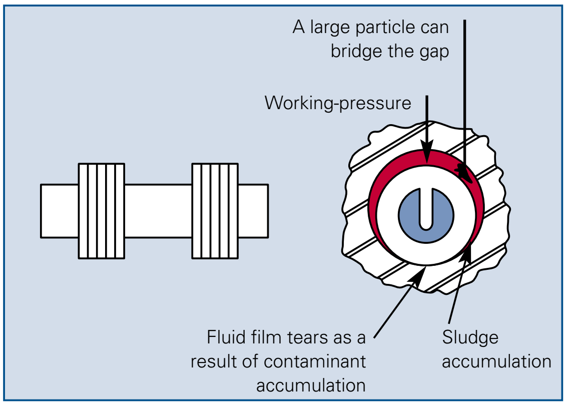


Fig. 13: Critical tolerances for a valve piston – usually working with a certain eccentricity

Component dependent filter fineness

Also selection of filter fineness always depends on the components that will be protected. Thus, the largest permissible particle diameter e.g. for proportional, servo, directional, and pressure control valve systems should always be less than the smallest gap width occurring there.

The filter is only economical if the filter element has the longest possible service life at adequate filtration quality. In addition, it may allow particles that are greater than the gap width to pass through accordingly. Finally, contaminant particles have a three-dimensional character and to some extent can be easily deformed. Moreover, the work gap is pressure dependent: The lower the system pressure, the greater the work gap.

Filter concept

Filters must be selected in such a manner that the hydraulic system components are adequately protected in accordance with the required contamination class. Consequently, in order to specify filter fineness, the entire system must be taken into consideration, starting with the contamination sources. Then the install point of the filter or filters must be planned upstream of each component that will be protected.

Fig. 14: Application example – turbine system

Hydraulic components	Gap width in µm
Wing pumps	
Wing head stroke ring	0,5 to 5
Wing sides	5 to 15
Gear pump	
Side plate	1 or 2 to 100
Tooth tip housing	2 to 100
Piston pump	
Piston in bore	5 to 40
Control disk	0,5 to 2
Servo valves	
Baffle	130 to 450
Deflector-Wall	18 to 63
Control piston in bore	1 or 2 to 20
Control edge	>1
Control valve	
Nozzle	130 to 10,000
Control piston (radial play)	2,5 to 23
Disk valve	1,5 to 5
Plug valve	13 to 40
Activations	50 to 250
Hydrostatic bearing	1 to 25
Friction free bearing	1,5 to 10
Side bearing	1,5 to 10

Table 8: Typical gap widths for hydraulic components

Due to the variety of information that must be taken into consideration (i.e. data, facts, and system parameters), a filter design that is both technically and economically optimal is a difficult task, which in its complexity, can only be mastered by experienced specialists. As an innovative development partner and reliable supply partner of the leading manufacturers of hydraulic equipment and devices, we are the competent system partner in all areas of filtration and hydraulic fluids. Our line of filters offers a broad application spectrum and enables compliance with the prescribed purity classes under all conceivable implementation conditions.

Highly effective filtration with a plus on performance and system competence

Filter design
Filter design is basically determined by the following system data:

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

The multi-layer structure of our filter inserts generally enables a broad application spectrum and high-level contamination absorption capacity. Even at increasing differential pressures, element filtration remains constant and offers the highest level of protection, even with pulsing stress. Long filter service life at low flow resistance guarantees economically optimal operation; in this regard our experience gained from similar types of applications is a benefit to you. Nevertheless, if preliminary tests are required in a particular case, then simply contact our engineers for advice. Together we always find the best solution.

Hydraulic filter structure
MAHLE hydraulic filters are structured uniformly. They consist of the filter element, a housing, and additional fittings depending on the type of implemen-

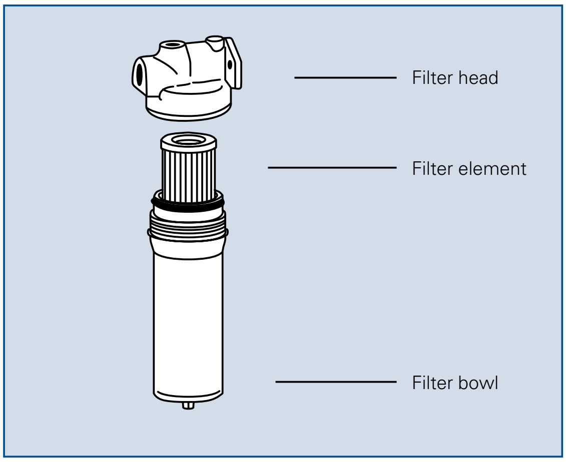


Fig. 15: Structure of a filter

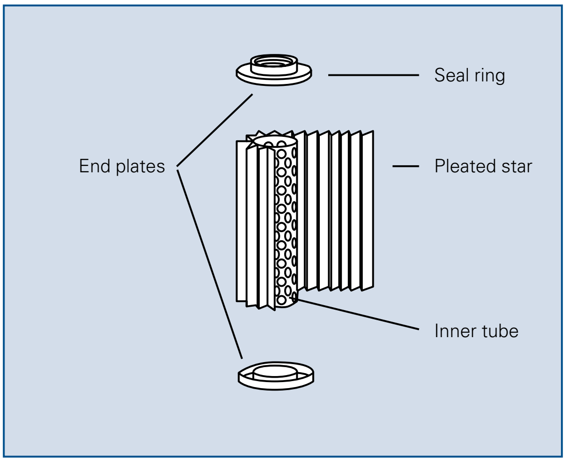


Fig. 16: Structure of a filter element

tation (e.g. bypass valve, contamination indicator, reversing valve). The housing comprises head and bowl. The inner tube, the pleated star and the end plates form the filter element itself. With few exceptions, filter flow is from outside to inside.

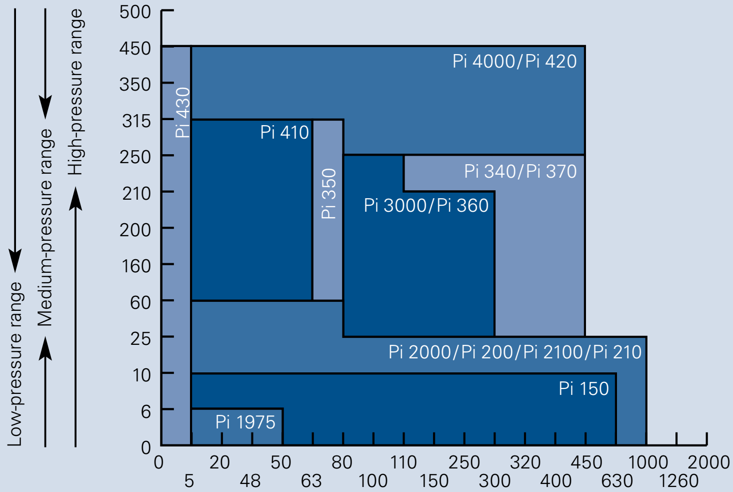
Contamination indicator

Filters can only be implemented in a manner that ensures maximum economy if their dirt holding capacity is fully exploited. Consequently, all filters should be fitted with a contamination indicator. Its mechanical or electronic sensors react to changes in pressure conditions on the filter element. With suction filters negative pressure is registered, with pressure filters the differential pressure is registered, and for return line filters the backpressure is registered. Depending on the version of the filter, results are signaled via manometer or via visual and visual-electrical switches. Here the switch point must be selected in such a manner that reserve capacity is ensured in the filter, at least until the end of the shift.

Bypass valve

Impermissibly high flow resistance, or collapse of the filter element are prevented via a bypass valve built into the head of the filter. It opens as the contamination level of the filter element increases, or if the fluid viscosity increases, in these cases only a partial flow is filtered. Three important conditions must be defined for this: opening pressure, closing pressure and the maximum permissible pressure drop in the nominal volume flow.

On the other hand, if the entire volume flow will always be filtered so that critical components do not fail prematurely, then a bypass valve is not practical. A bypass valve attached to the bottom of



Hydraulic pressure filters can be used starting at 0 bar and nominal size 0 l/min.
The filters Pi 210 and Pi 370 are duplex filters. Pi 410 is a sandwich filter.

Fig. 18: Nominal pressures and nominal sizes of hydraulic pressure filters

the filter housing is not suitable as it washes sediment contamination into the valve.

Reverse flow valves

A reverse flow valve enables flow through the filter housing in the opposite direction, without pressurizing the filter element in the process. Only necessary for equipment in which the flow direction changes. The reversing valve can also be combined with a bypass valve.

Cold start valve

In contrast to the bypass valve the volume flow that flows via this valve, is not channeled to the consumer, but rather is channeled back to the tank. Consequently, only filtered fluid is supplied to the consumer. Moreover, the fluid is quickly warmed through the pressure drop from filter to tank. Thus cold start valves are primarily used in mobile machines.

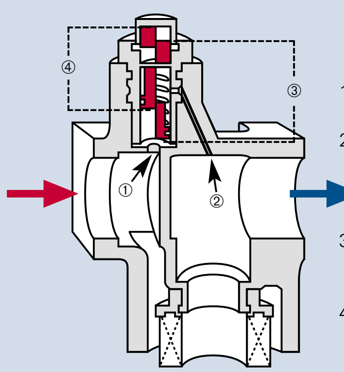


Fig. 17: Functional diagram – diff. pressure indicator

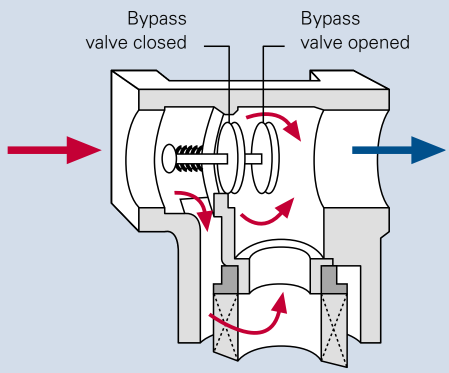


Fig. 19: Functional diagram – bypass valve

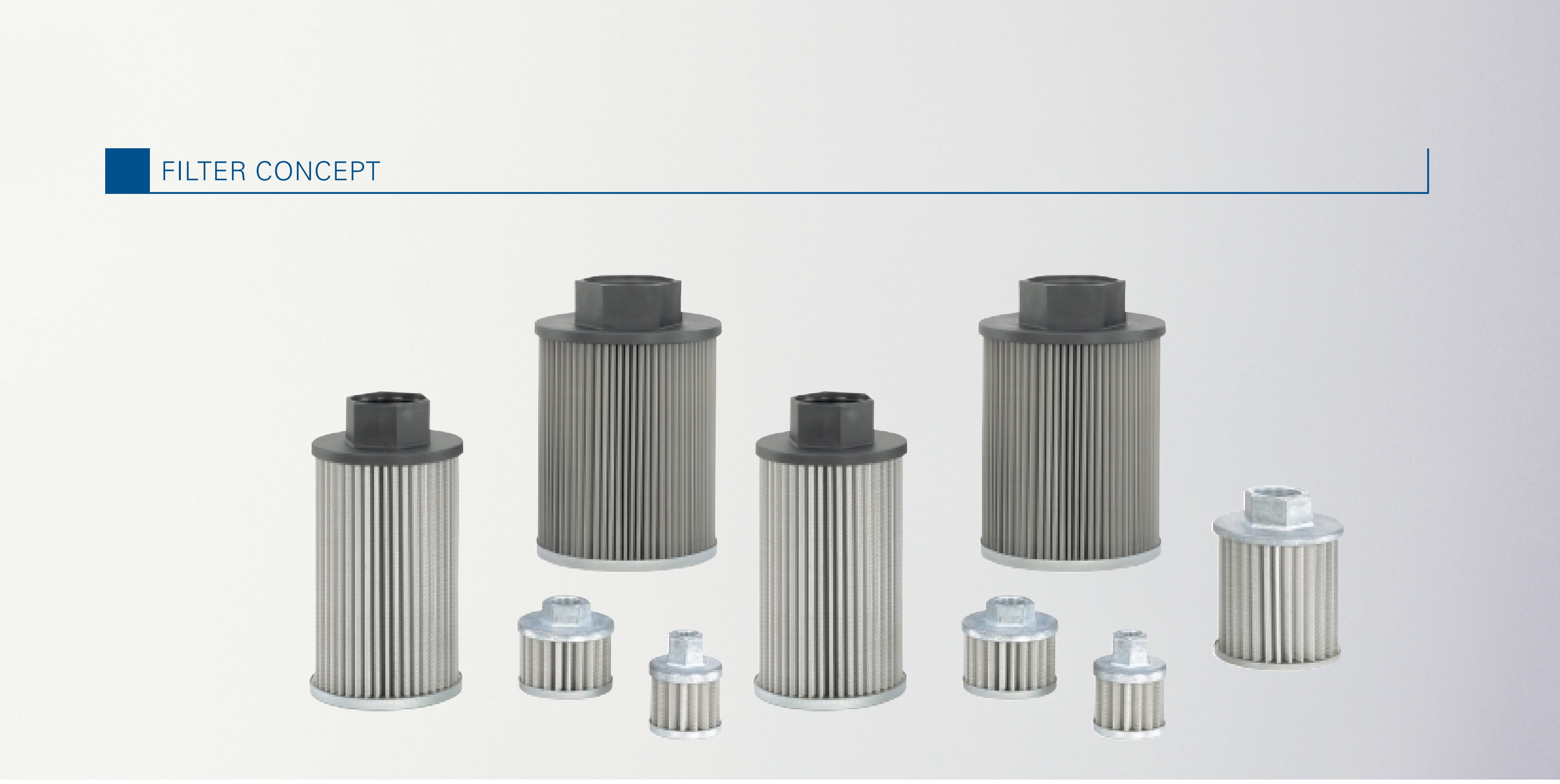


Fig. 20: Sieve star suction filter elements in different sizes

Suction filter

If formerly suction filters were limited to retention of coarse particles and other filters did fine filtration, then today filter fineness through filter material with low flow resistance extends to the range $ß_{20} \geq 200$. Installed directly upstream from the pump, suction filters are nevertheless subject to physical limitations. In order to filter even finer, they had to be designed larger and cavitation damages would occur due to the growing differential pressure on the added filter.

Their advantages in the area of mobile applications are undisputed, for instance for hydrostatic drives. In the case of hydrostatic drives, they filter almost exclusively in the suction area, as the frequently occurring reverse operation there would otherwise require pressure filters with reversing valves that are too complex. When using a suction filter as sole system filter, a contamination indicator in addition to a sufficiently dimensioned filter surface are strict requirements.

Suction filters are available as in-tank filters, also with closing valve for installation below the oil level, and they are available as line filters installation in the suction line. For the most part, suction filters implemented as line filters correspond to low-pressure filters up to 25 bar.

Install point:
Directly upstream from the pump

Fineness:
100–20 $\mu m_{(c)}$

Bypass:
Depending on the application

Contamination indicator:
Recommended; if not realizable, clean the wire mesh according to the operating instructions, or ensure replacement every 500 hours

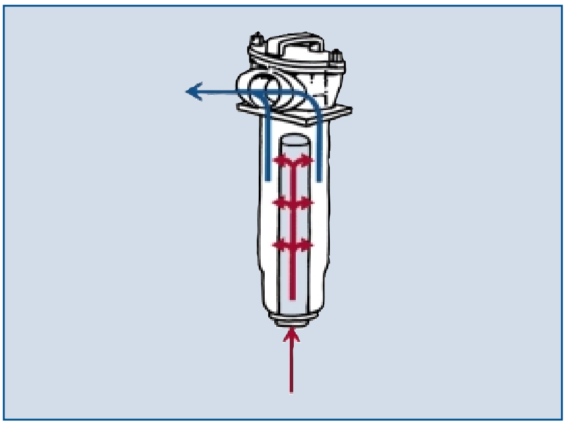


Fig. 21: Suction filter structure

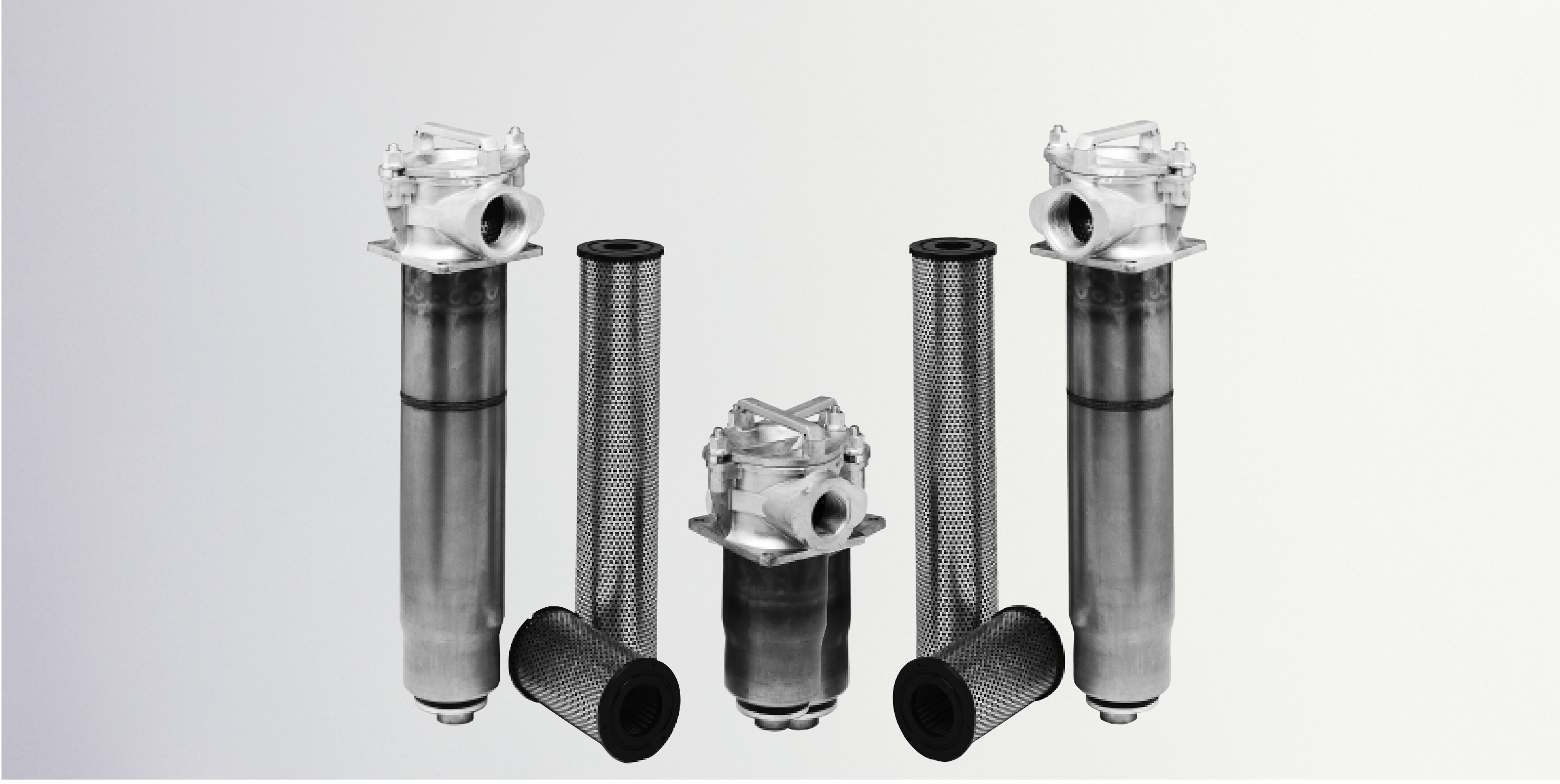


Fig. 22: Suction filter as in-tank filter

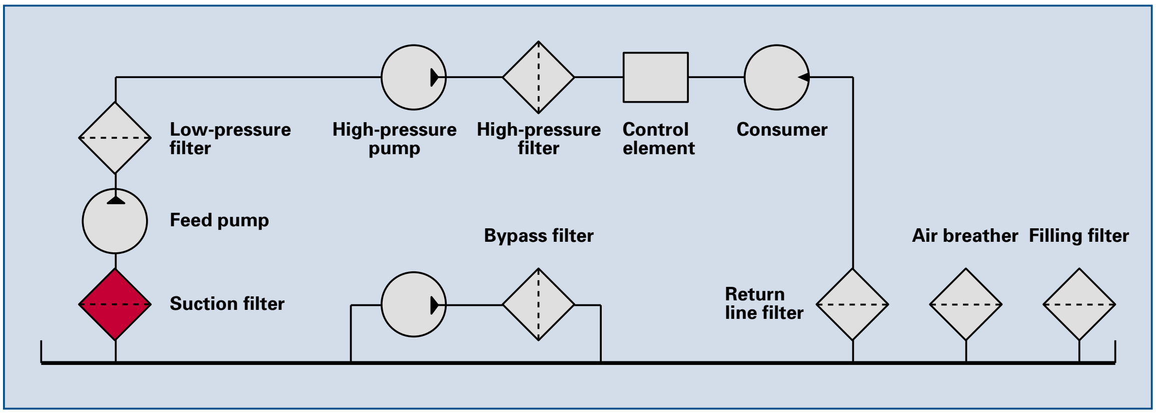


Fig. 23: Filtration in the suction line

Fig. 24: Low-pressure, medium-pressure and high-pressure filters of various filter series

Pressure filters

Pressure filters are designed for use as full flow or partial flow filters, and for the ranges low-pressure to 25 (60) bar, medium-pressure to 210 bar, as well as high-pressure to 450 bar. They are installed downstream from the pump and the pressure-limiting valve upstream from the components that must be protected. Pressure filters are available as different models, as line filters, flange-mounted filter, replacement filters (spin-on cartridges), and filters in sandwich design.

If there are no other possible contamination sources, such as cylinders in the circuit downstream from pressure filters, then additional system filters are usually not required for smaller equipment.

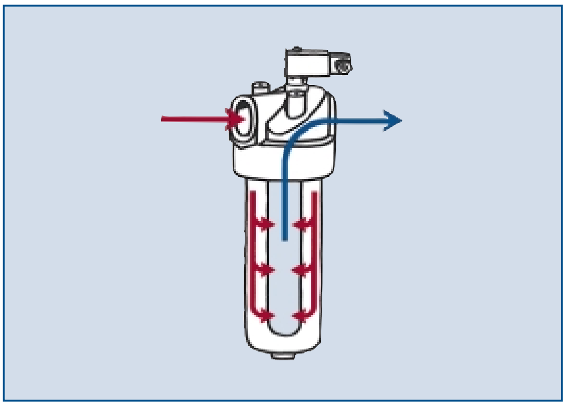


Fig. 25: Structure of a pressure filter

10	16	**25**	40	**63**	100
160	200	**250**	315	**400**	500

Nominal pressure in bar (excess pressure)
Values in bold typeface are preferred.

Pressure levels in accordance with DIN 24550, Part 1

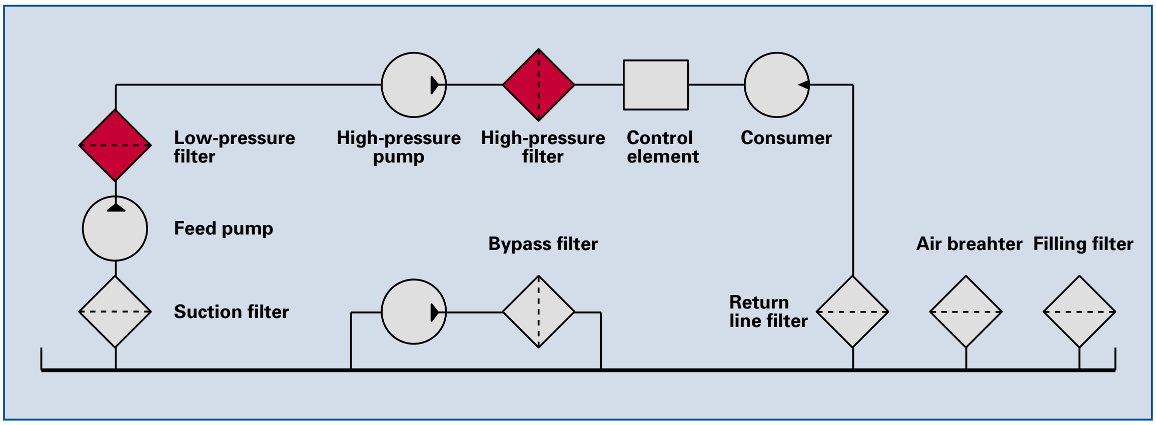


Fig. 26: Filtration in the pressure line

Fig. 27: Pressure filter as duplex filter

Pressure filter as duplex filter

The duplex filter with one-hand operation and loss-free switching of fluid flow offers the greatest economy in the low-pressure and medium-pressure range. It can be used around-the-clock without operational interruption. With duplex filters, the element can be changed while the equipment is in operation.

Nominal size of the filter:

Depending on environmental conditions and equipment sizes, the nominal size of the elements should be greater than the maximum pump capacity. Thus the filter offers sufficient service life, even under unforeseen operating influences. Partial flow filtration can be effective in large devices. A protection filter must be provided for sensitive components (servo valves).

Fig. 28: Duplex filters Pi 231

Nominal pressure:

The nominal pressure must be greater than the device's maximum operating pressure.

Contamination indicator:

Always required

Install point:

Downstream from the pump, downstream from the pressure regulating valve, upstream from the component that must be protected

Fineness:

Depends on the required contamination class

Bypass:

Suitable for equipment with frequent cold start, no bypass for protection filters

At nominal pressures up to 16 bar it is not necessary to use a bypass valve in conjunction with low-pressure elements if a pressure limiting valve with max. 16 bar is installed upstream from the filter. At higher pressures, if you dispense with a bypass valve, then elements that are resistant to high-pressure are always necessary.

Fig. 29: Return line filters in different sizes

Return line filter

If contaminants have not been previously retained via pressure filters, then return line filters capture all the contamination generated in the system and washed out of the hydraulic equipment and thus prevent the occurrence of a disastrous contamination circuit via tank and pump. Return line filters are mainly designed as in-tank filters. Their filter head is permanently connected to the tank and the discharge opening of the filter projects into the tank. With supplemental fittings, return line filters can also be used as filling filters.

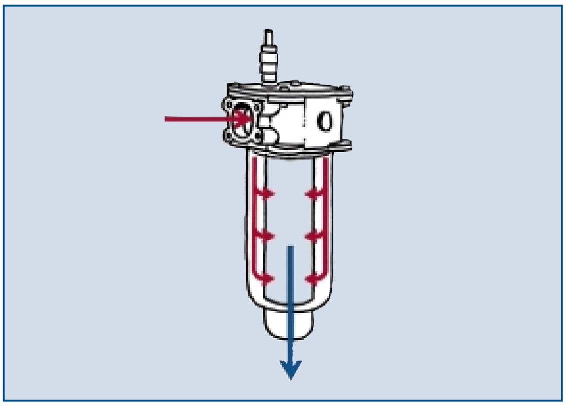


Fig. 30: Structure of a return line filter

Return line filter as duplex filter

Return line filters as duplex filters with one-hand operation and loss-free switching of fluid flow can be implemented around the clock without interrupting operation. This design is particularly economical because service work (changing elements) can be performed during operation when contamination absorption capacity has been completely used up.

Return line filters as line filters

In-tank filters may not be practical for very large devices and very large return quantities. In these cases, line filters in the low-pressure range (up to 16 bar) represent an economical alternative.

Nominal pressure:

The nominal pressure must be greater than the set pressure of the bypass valve, and it must be able to accommodate the additional pressure increase at cold start conditions.

Contaminant indicator:

Always required

Install location:

Directly upstream from the inlet of the return line to the tank, for line filters or as in-tank filter

Fineness:

Adapted to the filter concept

Fig. 31: Duplex return line filter

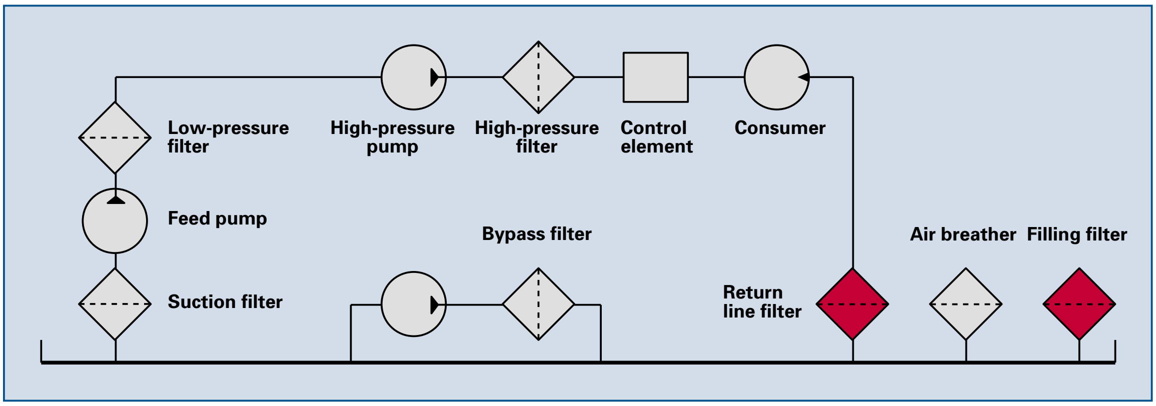


Fig. 32: Filtration in the return line and via filling filter

Bypass:

Always necessary to prevent the switch time changes caused by backflow in the equipment

Nominal size of the filter:

The nominal size should be configured based on the return line and the size of the equipment. In addition to maximum pump output quantity, the increased return quantity for differential cylinders must also be taken into consideration when determining nominal flow. Thus, the filter has sufficient service life even under unforeseen operating influences.

Fig. 33: Return line filter for mobile applications

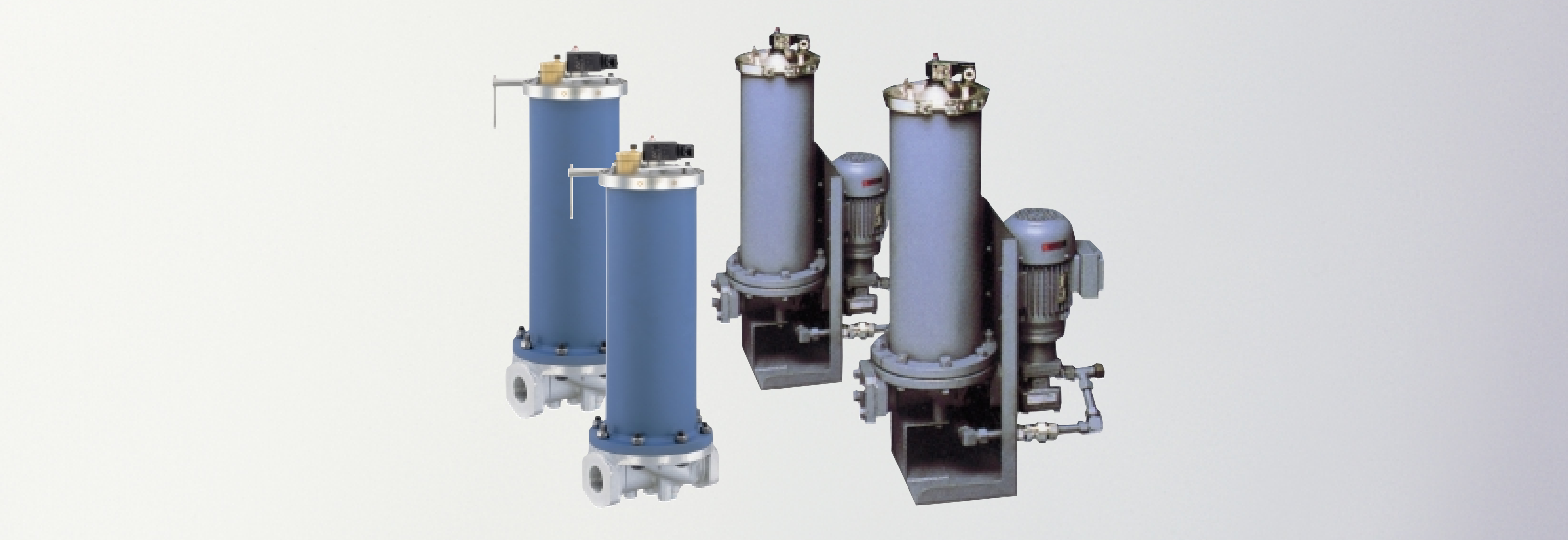


Fig. 34: Bypass aggregates and filters for bypass filter systems

Bypass filter

Bypass filters in stationary design, function as work filters for existing pressure filters, or return line filters in widely branched hydraulic systems with large tank volumes and fluctuating return flows. Bypass filters represent the optimal solution for filtration of large quantities of oil that either cannot be sufficiently cleaned, or can only be cleaned uneconomically with full flow filters. In addition, there are many combination possibilities e.g. with coolers.

In mobile design, bypass filters can be used with a lot of flexibility as flushing, filling, or filter aggregates.

Recommended filtration or pump capacity:

System conditions	Filtration capacity [l / min] As procentage of the system oil quantity [l]
Good	5 %
Medium	10 %
Poor	20 %

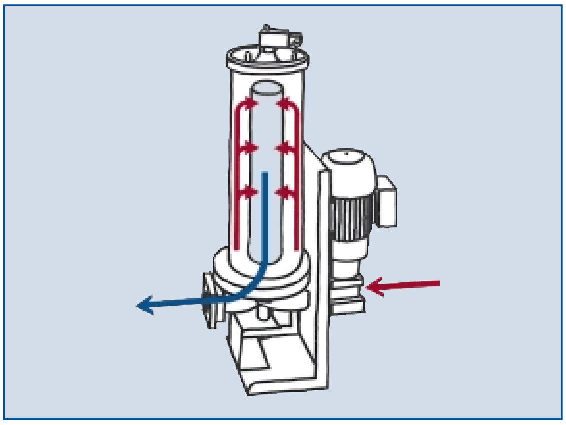


Fig. 35: Structure of a bypass filter

Fig. 36: Mobile bypass aggregates

Nominal pressure:
6/10 bar

Contamination indicator:
Always necessary for mobile devices, ideally as mechanical/electrical indicator, so that when the contaminant absorption capacity is exhausted, not only is the pump switched off, but an optical signal also indicates the situation at the same time.

Install location:
Usually in the vicinity of the hydraulic fluid tank

Fineness:
According to the recommended contamination class; fill filters require a special design

Bypass:
Reliable; also required when the pump is switched off through the contaminant indicator

Nominal size of the filter:
Filter capacity should always stand in sufficient ratio to the occurring volume flows. On the other hand, the housing connections are only based on the pump capacity installed in the bypass filter.

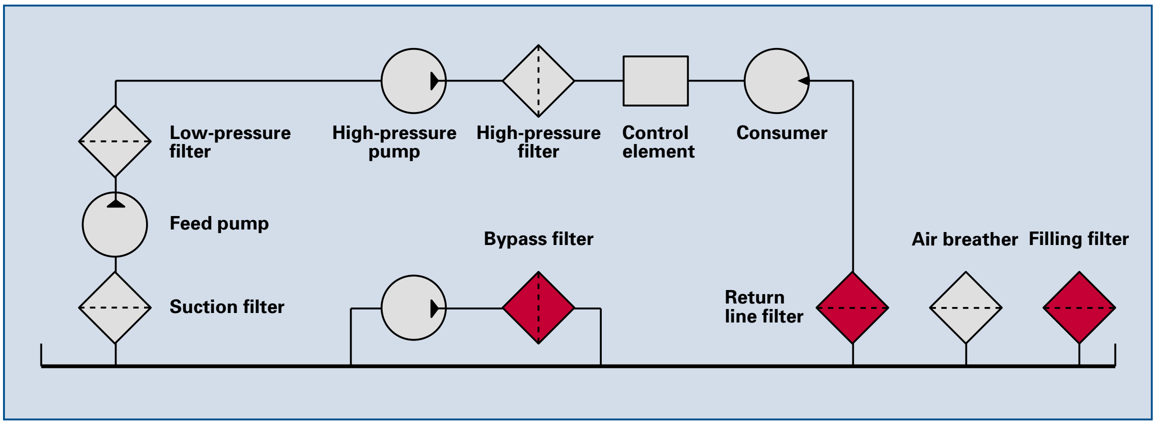


Fig. 37: Filtration in the bypass

Pressure loss at hydraulic filters

The pressure loss at hydraulic filters increases with increased filter service life. This means that correctly determining the initial Δp becomes even more important.

Determining the initial Δp

This is determined via appropriate diagrams in the data sheets. For oil with a viscosity of 33 mm²/s or 190 mm²/s it can be read directly, for other viscosities it must be calculated according to the formula

$$\Delta p = \frac{\Delta p1\ (\upsilon 3 - \upsilon 2) + \Delta p2\ (\upsilon 1 - \upsilon 3)}{(\upsilon 1 - \upsilon 2)}$$

(Δp in bar/υ in mm²/s).

Sample calculation

Determining the Δp for the MAHLE pi 3430 filter $\upsilon 1$ = 190 mm²/s, $\upsilon 2$ = 33 mm²/s, with element Sm-x 3 at a flow rate of 90 l/min and a viscosity of $\upsilon 3$ = 100 mm²/s:

$$\Delta p3 = \frac{2{,}8\ (100-33) + 0{,}51\ (190-100)}{(190-33)} = 1{,}48 \text{ bar}$$

Recommended initial differential pressure Δp	
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

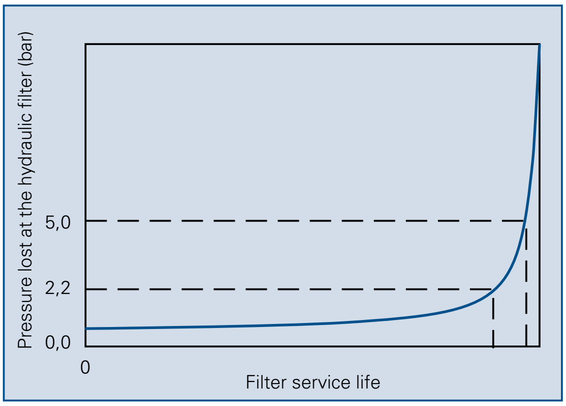


Fig. 38: Pressure loss at hydraulic filters depending on filter service life

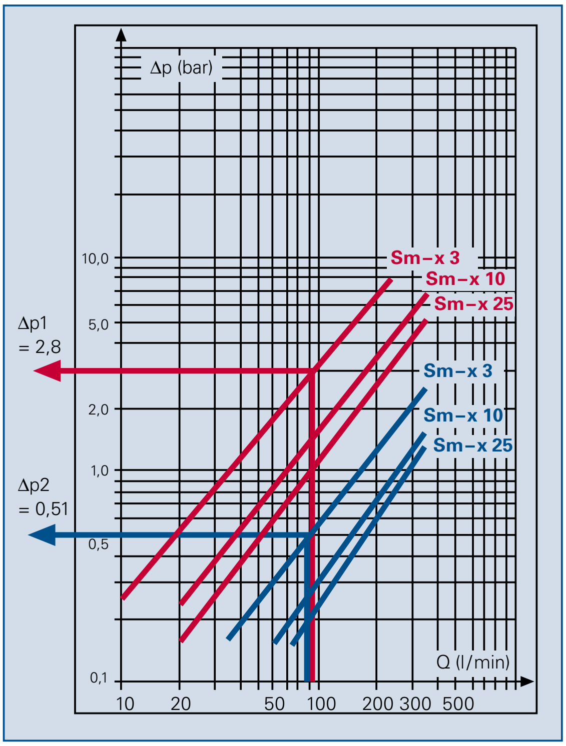


Fig. 39: Diagram for determination of the Δp for the MAHLE Pi 3430 filter

Fig. 40: Air breathers in different sizes

Air breathers

Air breathers are among the most important components of a filtering concept. Fitted with the appropriate change elements depending on the required contamination class, you ensure contaminant-free air supply for tanks. This filter is absolutely necessary in light of the considerable level of contaminants that can enter the system through venting fixtures. Filter fineness must be selected in accordance with the system filters. Ventilation integrated in the return line filter is only sufficient for small tanks and oil quantities up to a max. of 100 l/min.

Fig. 41: Air breather combined with fill sieve

Install location:

Directly at the highest point of the hydraulic tank; for mobile equipment take swash room into consideration, so that no oil can be forced out

Nominal dimension:

Based on the maximum occurring volume fluctuation, which causes an equal volume air exchange

Fineness:

	Filter fineness
Air breather	**Hydraulic filter**
Sm–L	Sm–x 3 Sm–x 6 Sm–x 10
Mic–L	Sm–x 16 Sm–x 25 Mic 10

Bypass:

No

Contamination indicator:

With self retaining function starting at $Q \geq 1{,}000$ l/min recommended

Water in hydraulic and lubrication systems not only reduces service life of the hydraulic fluid, but also reduces service life of machine components and of the entire system. Common damages are corrosion of metallic system parts, hydrolysis of hydraulic fluid, bearing wear, premature plugged filters, and chemical decomposition of additives. In order to prevent this type of damage, MAHLE has developed a new concept for water detection and removal, consisting of turbidity sensor and coalescer filter.

Spontaneous detection, immediate removal of free water in hydraulic fluids

Reliable and cost-effective

The consequences of water ingress that is identified too late range from extensive repairs to complete production failure. Formerly this hazard could only be countered with high-costs and calibration efforts with the usual methods and systems. For instance, the ensuing damage resolution was very expensive: All the hydraulic fluid had to be replaced, or dried via vacuum evaporation (absorption for smaller devices). The newly developed turbidity sensor is an inexpensive device that was been developed for rapid detection of water breakthroughs above the saturation limit. And in conjunction with the new coalescing filter, water that has penetrated can be mechanically removed, quickly and cost-effectively. The system is suitable for all fluid technical applications that are jeopardized by water breakthrough and offers a variety of implementation possibilities, e.g. in hydraulic equipment with water coolers, in mobile applications such as construction machines, in power plants, paper machines, wind energy plants, or in ship operating technology.

Water detection

The MAHLE turbidity sensor works with a clocked light beam, which divides into two different lengths, penetrates the hydraulic fluid and finally hits two receivers. Ideally it should be integrated in the return line or directly in the tank near the return. If water enters the circuit, the light beam weakens through turbidity of the hydraulic fluid, the electronic circuit recognizes this based on the target values that have been stored, and emits a signal or switches on an aggregate for water separation. Combined with the MAHLE Coalescer filter, water removal can be triggered immediately.

Fig. 42: MAHLE PIT 400 turbidity sensor and MAHLE PIW 1975 coalescer filter

Water removal

The MAHLE coalescer filter, consisting of multiple different layers, enables mechanical separation of the super-fine water droplets in the hydraulic fluid. In the first work step, these droplets are collected and brought together to form larger units. The resulting drops, which are several millimeters in size, leave the coalescer layer and hit a fabric treated with a special hydrophobic agent. This is where the water is separated from the hydraulic fluid. The water then exits the circuit through sedimentation. The important aspect of the process is that a certain differential pressure may not be exceeded in the coalescer, and the respective viscosity must be taken into consideration. The coalescer can be operated completely automatically. In addition there are different control possibilities, e.g. volume flow control by differential pressures via a pump, or also volume flow control via a pressure-limiting valve. In general, the following applies: The lower the quantity of emulsifying additives present in the hydraulic fluid, the better the coalescer will function. Conversely, inexpensive hydraulic fluids can replace expensive special oils.

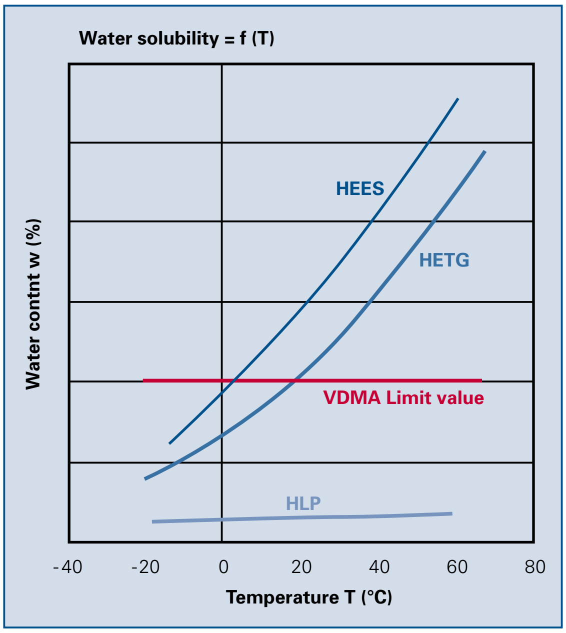


Fig. 43: Because only free water causes turbidity, water solubility should be considered depending on temperature. In accordance with VDMA standard sheet 24568 water content less than 1,000 ppm (0.1 %) must be maintained for hydraulic fluids of the HE group. Free water should not be present in the HLP group.

Prerequisite for filter elements with the best filtration characteristics: materials that conform to the quality requirements and high production quality. Standardized tests for the inspection provide important indications in this regard. Only those manufacturers who regularly perform this test can guarantee sustainable unchanging standards and ensure the requirement $ß_x \geq 200$ in every case. Combined with other important international test standards, such as the multipass test, this guarantees the security that is simply required for problem-free operation in practice.

Measurable high quality in accordance with all relevant norms and standards

Bubble-point test (ISO 2942)
Since a minimum pressure value can be allocated to each element type, with the bubble-point test, uniformity of the filter element production quality can be excellently monitored.

The filter element is immersed with the main axis parallel to the main axis of the test fluid (isopropanol) and after 5 minutes it is subjected to the specified minimum pressure at 360° rotation. If no continuous bubble flow is present then the element satisfies the test conditions. However, the test is not relevant for measuring filter capacity or degree of separation.

Collapse pressure / burst pressure test (ISO 2941)
Permissible collapse pressure is understood as the pressure differential to be withstood by the filter element in flow direction.

For this test any chemically neutral, particle-forming contaminant is added to the test circuit, until the pressure differential above the filter element corresponds to the permissible collapse pressure or burst pressure. The pressure differential curve is recorded and the filter element is only released if there is no indication of failure, i.e. there is no drop in the slope of the pressure differential curve to be recorded.

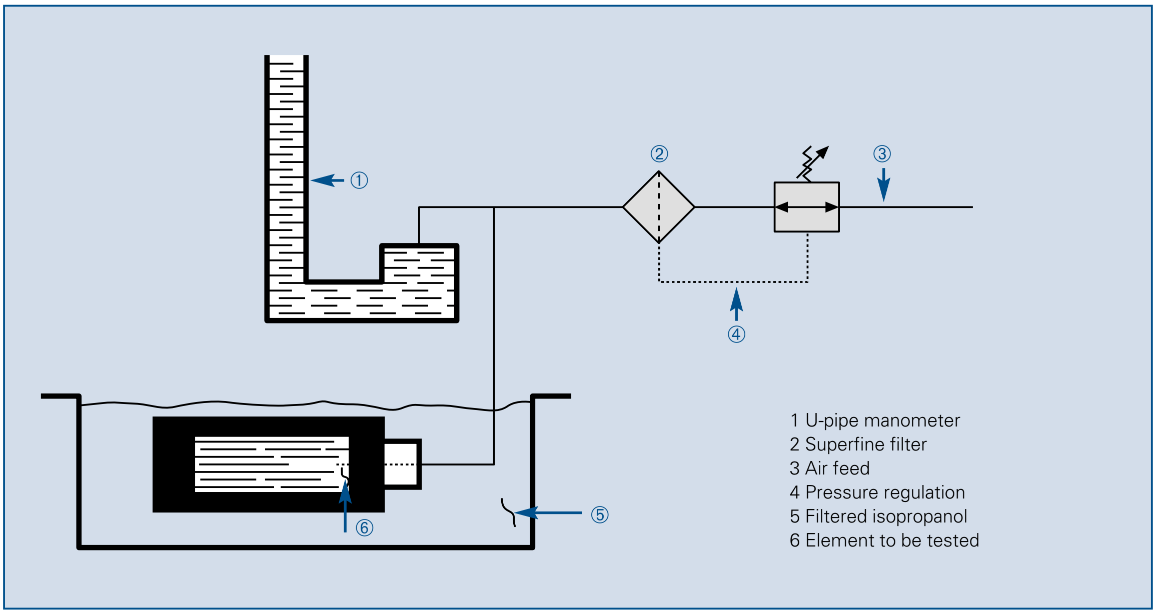


Fig. 44: Test assembly for bubble-point test

Determining initial differential pressure (ISO 3968)

Differential pressure (also referred to as flow resistance) is one important aspect in configuring hydraulic filters. It is determined by the entire pressure drop from housing inlet to outlet and is composed of housing and filter insert losses.

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

A test rig, consisting of pump, tank, heat exchanger, and measuring devices for pressure, temperature, and volume flow (as shown in the diagram in Fig. 42) is used to determine flow resistance. p_1 is the pressure at the filter inlet, p_2 is the pressure at the filter outlet, and Δp is the flow resistance of the filter. A test rig with high system pressure is not necessary when executing Δp volume flow measurements on a filter. It suffices to keep p_2 at a positive pressure value.

Flow fatigue test (ISO 3724)

The test is used to determine the capacities of a filter element to withstand the deformations caused by changing differential pressures (flow quantities) without changing the bursting strength. A test rig as shown in the diagram in Fig. 46 is used perform the test.

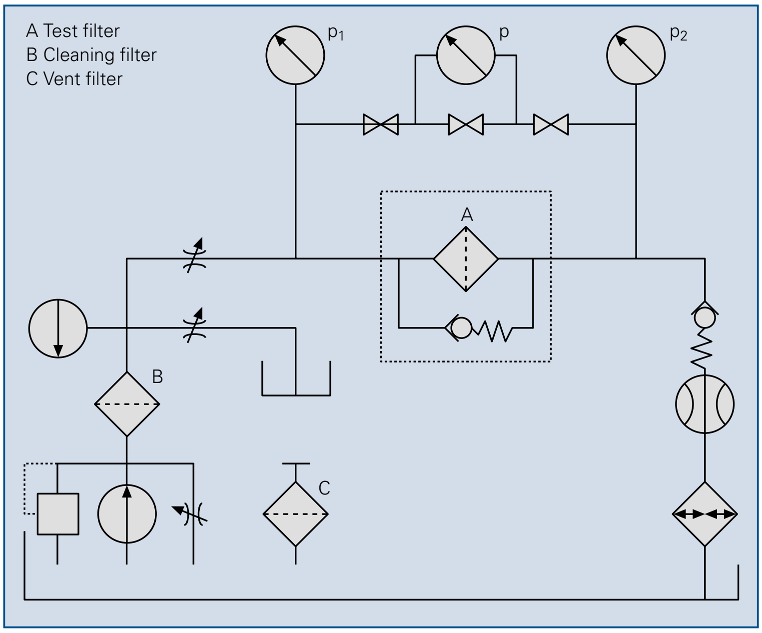


Fig. 45: Diagram of a test standard suitable for Δp and flow measurements

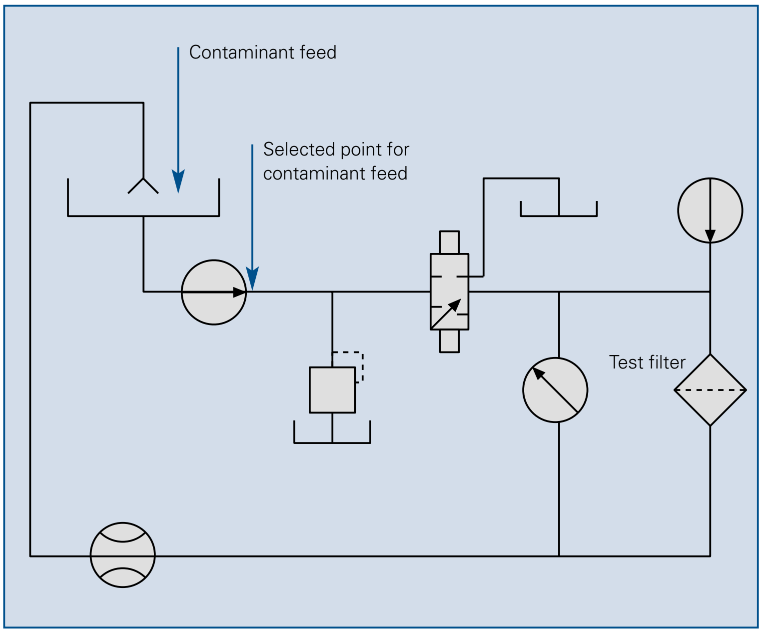


Fig. 46: Diagram for a typical flow fatigue test rig

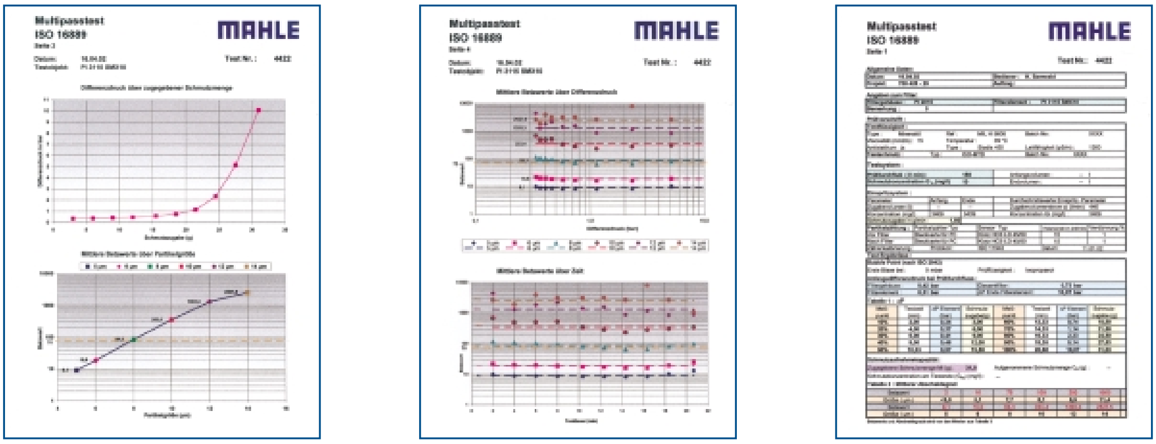


Fig. 47: Multipass test

Multipass test (ISO 16889)

The multipass test is the most important test for evaluating separation performance, contaminant absorption capacity and filter element service life, and it is also referred to as filter capacity test, or $ß_x$-test. An extremely complex test rig, divided into three main groups, is required in order to perform a multipass test:

- In system 1 the test fluid (MIL-H-5606) defined with test dust (ISO MTD) is contaminated.
- In system 2 the test filter is installed and the cleaned test fluid is recirculated.
- In system 3 the fluid samples removed from system 2 are continually counted out in highly precise particle counters, and the results are entered into a computer.

The multipass test closely approximates the progression of contamination in practical application. The differences are at the most the greater contaminant offering and consequently the thus made possible, significantly reduced test period compared to filter service life.

However, possible changes to the filter element at increasing Δp, as they might occur through cold starts and other operating influences, can be clearly verified and conclusions can be drawn relative to the effectiveness and service life of the filter.

The test fixtures and the text sequence are very complex and cannot be performed by the user himself. Consequently, you are even more dependent on the veracity of the manufacturer's information.

Fig. 48: Return lines on the multipass test rig

Multipass test procedure

Contaminated fluid from system 1 is continuously injected into the system 2 circuit. Contaminant is fed to the test filter through constant recirculation until maximum permissible differential pressure of the element, or the test system is achieved. During this period, samples are continuously analyzed and the temperature and pressure course is recorded in system 3. Thus you can determine the course of the element's separation performance at increasing differential pressure. The test result is expressed in the form of the ß value, which reflects the following relationship:

$$ß_x = \frac{\text{Number of particles} > x\ \mu m \text{ upstream from the filter}}{\text{Number of particles} > x\ \mu m \text{ downstream from the filter}}$$

The following values should always be supplied:

- $ß_x$ value based on the Δp with which the value was measured
- $ß_x$ value at the switch point of the contamination display and at the end Δp of the test rig or the permissible Δp for the affected element
- Apparent contaminant absorption at the switch point of the contamination indicator and at the end Δp
- Actual bubble point of the test element prior to test start

Only this information in total allows real comparative evaluation of the capacity of filters. This is best achieved when the filters are run on the same test rig. In order to better evaluate the significance of the ß value, you must keep the comparison with the degree of separation in % in mind. Degree of separation is the result of:

$$\varepsilon_x = \frac{ß_x - 1}{ß_x}$$

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

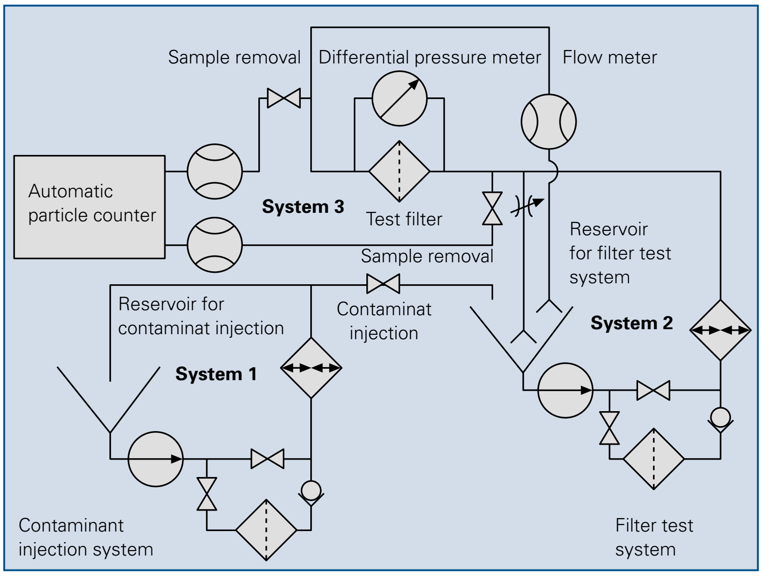


Fig. 49: Diagram of the test rig

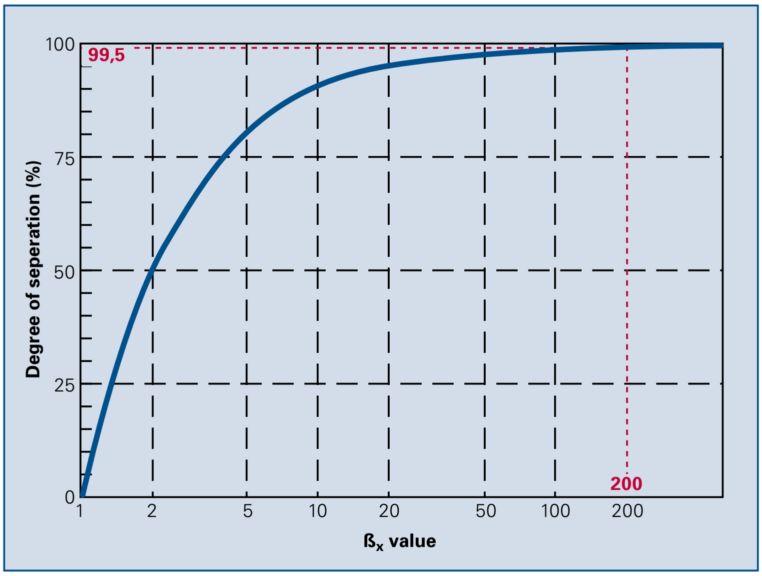


Fig. 50: Relationship between $ß_x$ value and degree of separation. Precise determination of the $ß_x$ value is particularly influenced by significant fluctuations between the individual measurement points at $ß_x$ >> 200.

Filter elements are high-quality technical products. To ensure that they reliably fulfill their function, they must be handled professionally and carefully. In operation, particular attention must always be directed to proper function of the filter and compliance with the required contamination class of the hydraulic system. Intensity and frequency of the required service work is based on the stress caused by environmental influences and the level of stress. Economic operation of filters and hydraulic equipment can be controlled and monitored with suitable test methods and devices that have been specially developed for this purpose.

Leave nothing to chance, and avoid expensive production failures

Short list, significant effect

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

- Hydraulic fluids should always be filled through a fine filter.
- Filter elements must always be replaced after flushing a device.
- The contaminant level indicator should be checked daily after the equipment has reached operating temperature.
- Do not neglect the analysis of liquid samples from the system or online measurements through particle counters, as they provide indications of premature wear or hydraulic component failure. An examination of elements can provide important indications of problem cases.
- Also topping off hydraulic fluids through a fine filter at all times.
- When replacing filter elements, the operating instructions should be followed with care.

Flushing and running-in

Prior to commissioning a hydraulic system, the assembly contamination must be removed - ideally by flushing the entire device. For the duration of this process, the operating elements must be removed from the installed filters and replaced with flush elements. They should only be reinstalled or replaced after the flushing process.

For the flushing process itself, the oil flow can be cleaned by a transportable bypass filter system. Here, at maximum flow speed, mineral oil or a different oil that is compatible with the hydraulic fluid that will be used later is pumped through the system, or is pumped through individual sections of the system. The assembly contamination is separated in the filter of the filter trolley. Only smaller or less sensitive hydraulic systems can be flushed during the running-in process via installed filters. The prerequisite: You must ensure that the equipment is operated without load, however with displacement volume which gradually reaches the maximum level.

Topping off hydraulic fluid

To maintain the contamination class, if there is a leak, always top-off hydraulic fluid through a fine filter. A filling aggregate can be used, or with an appropriate device, a return line filter or line filter can also be used.

Permanent monitoring of contamination

Each filter should be fitted with a visual or visual/electrical contaminant indicator. It allows you to determine at anytime whether contaminant absorption capacity is still present or whether it is necessary to change the elements. Check visual displays daily after reaching the operating temperature.

With visual contamination, displays simply press in the red pin and you will get a clear result. If the pin

Fig. 51: Contamination indicators for different filter series

stays in, then the element is fully functional, however if it does not stay in, then the element must be changed, at the latest after the shift ends.

Electrical displays also provide an electrical signal in addition to the visual display. The red pin and the signal are independent of each other. Here as well, the level of contamination should be evaluated when the equipment is warmed up, because a cold start can trigger a contamination signal due to the increased viscosity. Consequently, a cold start suppression device can be useful for equipment that frequently starts at lower temperatures.

Changing elements

If the contaminant display shows a contaminated element, then usually there is at least 8 hours of reserve capacity, i.e. there is reserve capacity for the duration of a shift. Thereafter the filter element must be replaced. If the filter element is not changed, then in extreme cases the element could collapse with fatal consequences: Contaminants that have already been retained are abruptly washed into the system through the torn filter matrix – this often results in a total failure.

The following filter control guide values apply for filters without contamination indicators:

- 24 hours after commissioning the equipment
- After the run-in phase (50–100 operating hours)
- Normal service (300–500 operating hours)

Elements must always be changed with the utmost caution and in strict compliance with the operating instructions.

Cyclical monitoring of the contamination

With focused monitoring, filters are also suitable as wear control instruments for hydraulic system components. For instance, if the operator regularly documents filter replacement, then increasingly shorter replacement intervals are an indication that component wear is increasing. Qualititative and quantitative analysis of the element and a fluid sample from the system make it possible to locate the origin of the contaminant particles and thus localize the cause of the increased wear. Hence, inferences are possible relative to the installed materials and thus preventative repair intervention can be executed before total failure and production downtime occur. Generally, quantitative contaminant determination of hydraulic fluids that is carried out anyway serves this objective. Samples taken at one of the specially designed removal points, or captured via online particle measurement, ensure that the required contamination class is maintained and that the system thus remains functional.

Sampling in accordance with ISO 4021 from equipment that is in operation

When designing hydraulic equipment, removal points should be provided in the turbulent main flow. Samples can be taken at these points in compliance with normal safety measures for protecting personnel and equipment. To prevent external contaminants from skewing the sample result, you must carefully draw the fluid in bottles that have been specially prepared for this purpose.

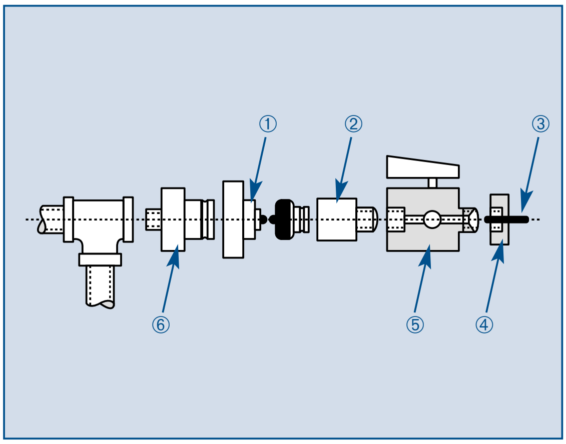


Fig. 52: Typical sampling arrangement in accordance with ISO 4021

Sampling arrangement

A typical sample removal arrangement in accordance with ISO 4021 consists of six elements:

1 Dust cap
2 Valve without check fixture
3 Capillary tube for fluid sampling
4 Cover cap with capillary tube
5 Ball valve
6 Check valve and outer part for fast mounting

A quick-mount coupling (6) with dust cap (1) is permanently attached to the opening through which the sample will be removed. The other parts of the arrangement (2 – 5) should only be anchored for the sampling process.

The inner diameter and length of the capillary tube depend on the sample quantity desired. Do not use capillary tubes with an inner diameter < 1.25 mm, other tubes such as those with rectangular cross sections may be used – with the prerequisite that the smallest inner measurement is not less than 1 mm. One end of the capillary tube is sharpened and deburred to facilitate subsequent piercing of the film that covers the sampling bottle. If turbulence is not guaranteed in the flow, then a fixture for generating turbulence must be implemented.

Sampling process

Open the ball valve (5) in order to first allow at least 200 ml of fluid to flow off. Only then bring the sample bottle into position to collect liquid, after the initial drain-off. Break the film on the bottle opening with the sharp end of the capillary tube and remove a sample that is not more than 90 % and not less than 50 % of the bottle volume. Before shutting off the flow with the ball valve, remove the bottle and seal it immediately after withdrawing the capillary tube.

If a quick-mount coupling (6) is used, then the removable parts of the sampling fixture must be dismantled after the bottle is sealed, and all traces of liquid must be removed by flushing with a suitable solvent. Do not forget: The dust cap (1) must be replaced on the quick-mount coupling immediately after dismantling the fixture.

Fig. 53: Oil sample bottle

Fig. 54: Oil sample evaluation in the lab

Sampling from a tank similar to CETOP RP 95 H
To obtain a representative sample, the equipment must be started up under operating conditions, in order for the fluid in the container to be well mixed. Carefully clean the exterior surface of the tank around the area where the sample will be taken.

Using a pipette or cleaned disposable syringe, it is easy to remove a sample of at least 150 ml. Introduce the pipette to at least half of the fluid depth and ensure that it does not come near the side walls or the floor of the reservoir, fill the content of the pipette into the sample bottle and then close the bottle – done. Now the tank must be reclosed or – if other samples are required, then it must be sealed with precleaned foil.

Suitable sample bottles are already pre-cleaned in accordance with standard DIN ISO 5884 and are supplied with the associated forms. Detailed instructions for handling the bottles are included in norm CETOP RP 95 H.

The sample bottle must be identified with a label that includes information on company, date, machine, and sample number. Moreover, the questionnaire required for the test must be filled out for each sample bottle. It includes information on:

- Sample number
- Source of the sample
- Sampling method
- Date and time of the sampling
- Fluid type
- Applied test methods
- Information on the machine and the installed filters
- Comments and notes, if required

Analysis set

Ideally suited for oil sampling in accordance with ISO 4021 or CETOP RP 95 H: An analysis set that can be used at the point of measurement to obtain a tendential statement about the contamination of the oil. However, the measuring precision of the set is not comparable to that of a stationary lab.

Stationary lab

The test methods in the lab are more precise and more varied. The hydraulic fluid is assigned to a contamination class through particle analysis. The total level of contamination can be detected gravimetrically in mg/l via a filtration device. In addition to contaminant quantity, the contaminant type is also determined with the microscopic pollution analysis. Additional tests that help in detecting and resolving faults in the hydraulic system, are for example determination of water content, viscosity, filterability, or material compatibility.

Portable particle counter

The Pic 9100 mobile contaminant measuring device is excellently suited for measuring mineral oil based hydraulic fluids. Possible areas of use include:

- Regular inspection of hydraulic circuits
- Confirmation of required low contaminant levels (ISO class) of hydraulic circuits as part of the machine acceptance process
- In-house production inspections for manufacturing machines and equipment with hydraulic circuits
- Monitoring a dedusting process with the option of switching an aggregate (e.g. a mobile bypass filter aggregate) when reaching a desired contamination class

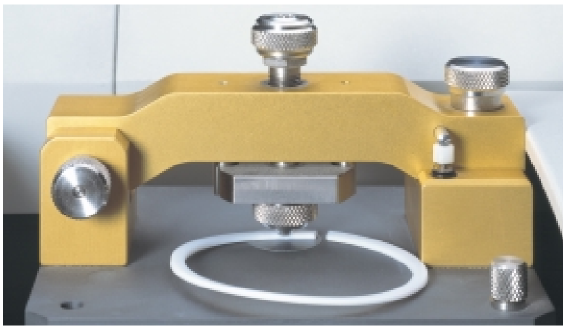


Fig. 55: Qualitative material analysis

Fig. 56: Oil sampling in the clean room

Fig. 57: Pic 9100 mobile particle counter

Analysis with the particle counter

The portable, Pic 9100 self-powered contamination measurement device makes it possible to measure the solid contaminants of liquids. The high precision laser sensor works in accordance with the principle of light extinction, and thus enables an exact count of individual particles. The sensor has twelve channels (six channels for ISO 4406/1987 and NAS 1638 from >2 to >100 µm, and six channels for ISO 4406/1999 from >4 to >100 µm).

The device can be used for all usual hydraulic fluids and lubricating fluids. The measured values are shown in a display, either in accordance with ISO 4406/1987 (extended by the range >2 µm), or NAS 1638, and are saved automatically.

Memory capacity suffices for 1,400 measured values that can also be managed in measurement series (up to 99), for example, in order to evaluate multiple machines in sequence and to later evaluate them individually. The measurement data can be printed out later with an integrated printer and read and processed with special software.

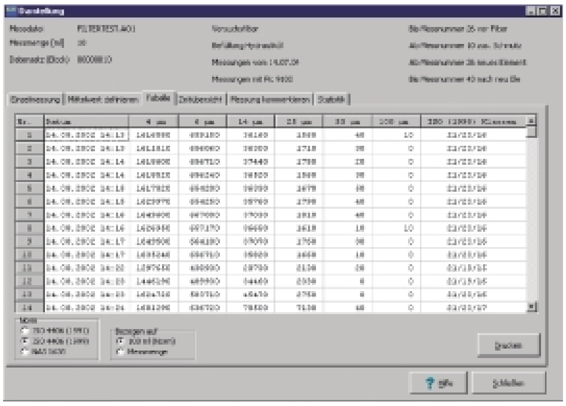


Fig. 58: Value table

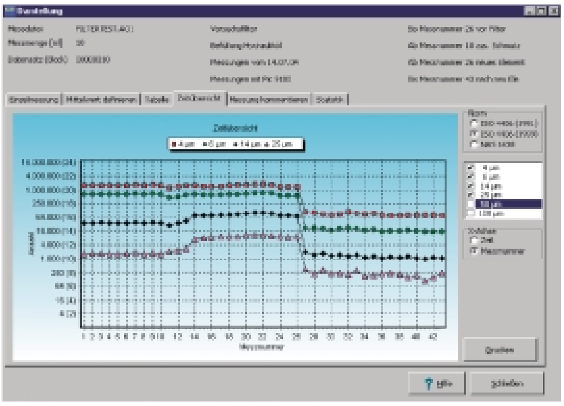


Fig. 59: Measurement log

Fig. 60: MAHLE Industrial Filters – on-site service and consulting

No guarantee without service

Malfunctions and premature component wear in hydraulic equipment is often a result of inadequate service. The hope of lowering operating costs by delaying filter replacement is misleading. Usually this measure provokes expensive equipment failure.

Consequently, many total system suppliers require keeping logs of regular service and inspections in their service and operating instructions, and they limit their guarantee performances without this verification process. Usually, DIN 2434 is used as a handbook for systematic service and inspection of hydraulic equipment.

Recommendations for manufacturers and suppliers of hydraulic equipment

Service quality can be improved, and just employing a few specific measures can reduce the number of unjustified complaints:

- Customer service technicians, supported by MAHLE, should also be trained in filter questions.
- In case of malfunctions, service technicians should check whether MAHLE original parts have been used exclusively.
- Service documentation should be requested in order to evaluate the function and economy of hydraulic filters.
- Before proper disposal, carefully wipe off oil-covered, used filter elements or filters that have been replaced, and let the fluid drain out.

Checking replacement elements and fluid tank

As customer service technician, prior to resolving a fault, always check first whether the filter has been serviced regularly, and whether MAHLE replacement elements have been used exclusively. All too often instead of replacing elements, the attempt is made to clean contaminated Mic or Sm-x elements, which will certainly destroy them. Only wire mesh elements – and these only under certain conditions – can be restored to functionality through cleaning. Also check whether the oil tank is properly sealed, and that the vent filters are in proper condition. If in doubt: Take oil samples to ensure that the required contamination class has been complied with.

Fig. 61: Original MAHLE replacement elements

Replacement frequency of filter elements

Caution; if filter elements have rarely been replaced, or have never yet had to be replaced because the built in contaminant indicator has never indicated a need for replacement. If the contaminant indicator is not defective, then the cause may be that an installed bypass valve is no longer closing correctly due to contaminant particles that have entered the system. In single-shift operation, filters with contaminant indicator are generally changed once a year, filters without contaminant indicator are generally changed twice a year. This is the only way to prevent worn elements from being used by overlooking them in the daily inspection.

Institutions and associations

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

Standards for removal, examination and evaluation of oil samples No.	Issue	English title	Identical with / corresponds to
ISO 3722	1976	Hydraulic fluid power – Determination of particulate contamination by automatic counting using the light extinction principle	E DIN ISO 3722-1988
ISO 3938	1986	Hydraulic fluid; contamination analysis; method of reporting the measured values	
ISO 4021	1977	Hydraulic fluid power – Particulate contamination analysis – Extraction of fluid samples from lines of an operating system	
ISO 4406	1999	Hydraulic fluid power. Fluids. Method for coding the level of contamination by solid particles	
ISO 11171	1999	Hydraulic fluid power. Calibration of automatic particle counters for liquids	
ISO 11943	1999	Hydraulic fluid power. On-line 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 5884-1987
NAS 1638	1964	Purity requirements for particles in hydraulic systems	
CETOP RP 94 H	1978	Determination of solid particles in hydraulic fluids using an automatic particle counter that works on the basis of the light extinction system	
CETOP RP 95 H	1979	Suggested method for the sample withdrawal of hydraulic fluids using bottles for the particle count	
CETOP RT 118 H	1988	Guideline for contaminant inspection of hydraulic fluids in hydraulic equipment	
CETOP RP 120 H	1990	Calibration process for automatic particle counters in accordance with the light extinction principle using latex spheres with uniform dimensions	

Standards for filter test

No.	Issue	English title	Identical with / corresponds to
ISO 2941	1974	Hydraulic fluid power – Filter elements – Verification of collapse/burst resistance	DIN ISO 2941-1983
ISO 2942	1988	Hydraulic fluid power – filter elements, verification of fabrication integrity and determination of the first bubble-point	DIN ISO 2942-1988
ISO 2943	1974	Hydraulic fluid power – filter elements – Verification of material compatibility	DIN ISO 2943-1990
ISO 16889	1999	Hydraulic fluid power filters – multipass method for evaluating filtration performance of a filter element	

Design standards for hydraulic filters

No.	Issue	English title	Identical with / corresponds to
ISO 7744	1986	Hydraulic fluid power – statement of requirements	CETOP RP 92 H-1978
DIN 24550 Part 1	1988	Hydraulic filters – concepts, nominal pressures, sizes and connecting dimensions	
DIN 24550 Part 2	1990	Hydraulic fluid power – hydraulic filters, evaluation criteria, performance data	
DIN 24550 Part 3	1990	Hydraulic fluid power – hydraulic filters, filter elements for filters, hull dimensions	
DIN 24550 Part 4	1990	Hydraulic fluid power – hydraulic filters, filter elements for add-on return line filters, hull dimensions	
DIN 24550 Part 5	1990	Hydraulic fluid power – hydraulic filters; add-on return line filters, connecting dimensions	
DIN 24557 Part 2	1990	Hydraulic fluid power – vent filters, connecting dimensions	
CETOP RP 98 H	1979	Guidelines for specification, selection/use of vent filters for hydraulic tanks	

Standards for classification and minimum requirements for hydraulic fluids and lubricating oil			
No.	**Issue**	**English title**	**Identical with / corresponds to**
ISO 3448	1975	Lubricants, ISO viscosity classification for liquid industrial lubricants	DIN 51519-1976
ISO 6743 Part 0	1981	Lubricants, industrial oils and related-products (class L) classification, general	DIN ISO 6743 Part 0-1985
ISO 6743 Part 4	1982	Lubricants, industrial oils and related products (class L) classification, family (hydraulic systems)	
ISO/DIS 6071	1978	Hydraulic fluid power, flame-retardant liquids; classification and designation	
ISO/DIS 6074	1978	Hydraulic fluid power, mineral oils, classification and designation	
DIN 24320	1986	Flame-retardant hydraulic fluids, Group HFAE; characteristics requirements	VDMA 24 320
DIN 51501	1979	Lubricants, lubricating oils, L-AN, minimum requirements	
DIN 51517 Part 1	1989	Lubricants, lubricating oils, lubricating oils C, minimum requirements	
DIN 51517 Part 2	1989	Lubricants, lubricating oils, lubricating oils CL, minimum requirements	
DIN 51517 Part 3	1989	Lubricants, lubricating oils, lubricating oils CLP, minimum requirements	
DIN 51524 Part 1	1985	Hydraulic liquids, hydraulic oils, hydraulic oils HL, minimum requirements	
DIN 51524 Part 2	1985	Hydraulic liquids, hydraulic oils, hydraulic oils HLP, minimum requirements	
DIN 51524 Part 3	1990	Hydraulic liquids, hydraulic oils, hydraulic oils HVLP, minimum requirements	
CETOP R 39 H	1987	Table of required information for hydraulic fluids	
CETOP RP 91 H	1977	Hydraulic fluids for oil-hydraulic equipment – mineral oils, requirements	
CETOP RP 97 H	1989	Hydraulic fluids for oil-hydraulic equipment – flame-retardant liquids – requirements	
CETOP RP 100 H	1987	Hydraulic fluids for oil-hydraulic equipment – flame-retardant liquids, Group HFA – require ments	
VDMA 24317	1982	Hydraulic fluid power – flame-retardant hydraulic liquids; guidelines	

Standards for filter element testing			
No.	**Issue**	**English title**	**Identical with / corresponds to**
ISO 3723	1976	Hydraulic fluid power – Filter elements – Method for end load test	DIN ISO 3723-1987
ISO 3724	1976	Hydraulic fluid power – Filter elements – Verification of flow fatigue characteristics	DIN ISO 3724-1990
ISO 3968	1981	Hydraulic fluid power – Filter elements – filter elements – filters, evaluation of differential pressure versus flow characteristics	
ISO 16889	1999	Hydraulic fluid power – filters, multipass method for evaluating filtration performance of a filter element	
E DIN 65385	1988	Aerospace, hydraulic fluid power; filter elements, hydraulics; filter elements; test verifications	
CETOP RP109H	1983	Hydraulic fluid power, hydraulics, filter elements, integrity test of a filter element at low temperature	

ACFTD dust

(Air Cleaner Fine Test Dust)
Test dust for execution of the multipass test in accordance with ISO 4572. Has now been replaced by test dust ISO MTD.

Add-on filter

Filters that has been designed as intermediate plate filter or as flange on filter for attaching to the tank or on control blocks.

Initial differential pressure Δp for filters

Pressure drop that occurs in a new, non-contaminated filter if a certain volume flow is passed through the filter. It depends on the structure of the filter element, on the viscosity, the density and the size of the passing volume flow.

Air breather

Filter on the tank that filters the inflowing air produced by the suction process of the pump. Its filter fineness should correspond to that of the hydraulic fluid filter.

Burst pressure

Collapse pressure/burst pressure in accordance with ISO 2941 is understood to be the pressure differential, which a filter element withstands at prescribed flow direction.

$ß_x$ value

The $ß_x$ value is determined as the measure of the effectiveness of a filter in the multipass test. It is a ratio that is calculated from the particle count before and after filter passage.

Pressure filter

The pressure filter is installed in the pressure line for filtration of the pump displacement flow and is used to protect downstream components.

Filling filter

A filling filter should always be used to fill equipment with hydraulic fluid.

Filter area

The total area of the filter element that is exposed to the volume flow. However, the filter materials are pleated in a star shape in order to obtain the largest possible filter surface within the specified filter dimensions.

Filter indicator values

The most important indicator values for filters are:

- Filter fineness
- Degree of separation
- Apparent contamination absorption capacity
- Filter surface
- Initial differential pressure
- Burst pressure
- Nominal pressure
- Nominal size

Filter concept

Effective selection and arrangement of different filters with optimal install points.

Filter service life

The service life of a filter element depends on numerous parameters and can be estimated – even if the operating conditions are unknown. Fitting the filter with a contaminant indicator is recommended for optimal exploitation of contaminant absorption capacity.

ISO-MTD (ISL Medium Test Dust)

Test dust for execution of the multipass tests in accordance with ISO 16889, and calibration of particle counters in accordance with 11171, 1999.

Line filter

Filters that are directly installed in the pipeline via threads or flange.

Multipass test

Standardized test in accordance with ISO 16899 for determining the separation rate of a filter in which a defined contaminated test liquid is sent multiple times through the hydraulic circuit and through the filter to be tested.

Bypass filtration

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

Nominal pressure (NP)

Pressure for which the filter has been designed.

Nominal size (NS)

Numeric volume flow for which the filter has been designed. The nominal size is based on the viscosity 32 mm²/s, and the filter fineness $ß_{20(c)} \geq 200$.

Surface filter

Filters that separate contamination particles only on the surface of the filter element (e.g. wire mesh elements, edge gap filters). Surface filters are designed so that they have uniform pores (gaps). Compared to depth filters, surface filters have only a low contamination absorption capacity.

Return line filter

Filters for installation in the return line of a device. Return line filters must be selected based on the greatest occurring volume flow – depending on the pump output flow.

Suction filter

Suction filters are usually designed with a wide mesh (e.g. 100 µm) and are suitable for filtration of the hydraulic fluid that is suctioned by the pump.

Partial flow filters

Arrangement of the return line filter parallel to a choke so that only a portion of the returning oil flow is filtered. An ideal solution for oil flows that significantly increase in periodic intervals.

Depth filter

Filters that mainly separate contaminant particles in the interior of the filtering material. Compared to surface filters, their contaminant absorption capacity is greater and their pressure loss is less.

Replacement filter

With replacement filters or screw-on cartridges the filter element is encapsulated in a metal housing and is replaced completely, along with the housing, after use. Replacement filters are screwed onto an appropriate filter head. Replacement filters are used as low-pressure filters, return line filters, or bypass filters, particularly in mobile hydraulics. Their fineness depends on filter concept Sm-x, Mic 10, or Mic 25. Bypass valve and nominal size correspond to those of the pressure filter, return line filter, or bypass filters. The maximum possible nominal pressure is 10 or 25 bar. A contaminant indicator is generally required.

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