Chapter 14

Filters and Filtration Technology

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1 Basics

Filters are devices which separate solid particles from fluids. The filters used to filter solid particles from fluids or to separate dust from gas are made out of fibre or granules.

The filtered fluid is known as the filtrate (this expression is not used in hydraulics).

The process is known as filtration. The size of particles present in fluids are shown in *table 1*.

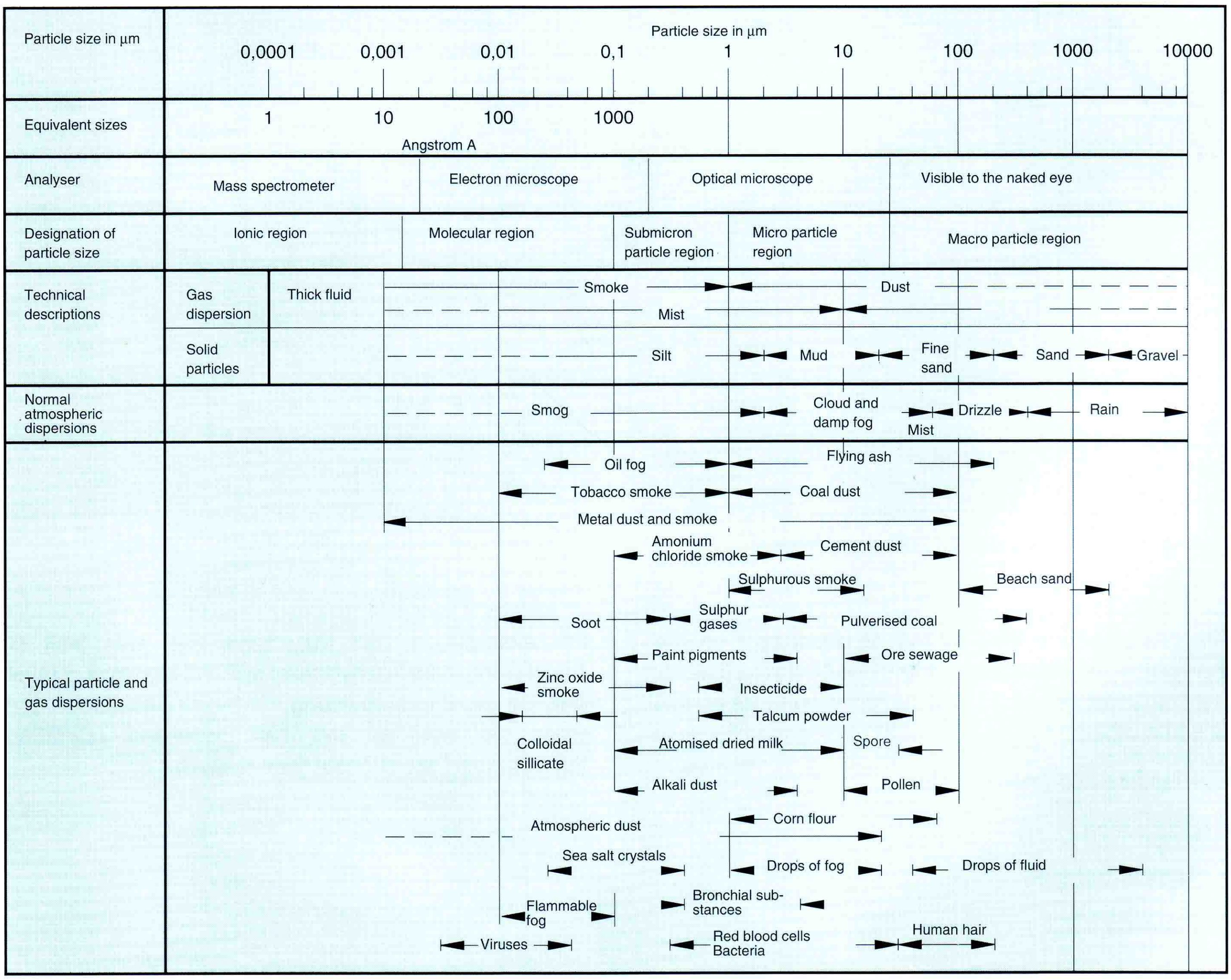


Table 1: *Sizes of particles for various substances*

Various filtration processes are used to filter particles. The choice of process is dependent on the required filter pore size.

The features of individual filtration processes are shown in *table 2*.

Medium to be filtered	**Fluid**				**Gas**	
Filtration process	**RO** Reverse osmosis	**UF** Ultra-filtration	**MF** Micro filtration Membrane filtration	**FF** to **GF** Fine filtration to rough filtration	**MFG** Micro filtration	**FFG** Fine filtration to rough filtration
Filterfeinheit	0 to 0.001 μm	0.001 to 0.1 μm	0.1 to 3.0 μm	3 to 1 000 μm	0.1 to 3.0 μm	3 to 1 000 μm
Molecular weight	up to approx. 1000	up to 1 000 000	—	—	—	—
Use	Removal of soluble substances (e.g. salt) from fluid.	Removal of smallest particles and colloids from fluids	Removal of particles from fluids.	Removal of particles from fluids.	Removal of particles from gases.	Removal of particles from gases.
Application	Desalination of salt water. Removal of heavy metals.	Environmental, separation of macro molecules and emulsions, e.g. oil-water separation	Semi-conductor technology, pharmaceutical industry, food industry	Water preparation, hydraulics, lubrication technology, split into safety and working filtration	Semi-conductor technology, pharmaceutical industry, sterile ventilation of chambers	Ventilation of chambers, ventilation of hydr. tanks, ventilation of computers, ventilation, vehicles
Filter medium	Membrane	Membrane	Membrane	Depth filter, surface filter	Membrane	Depth filter, surface filter
Types	Pipe membrane, flat membrane	Pipe membrane, flat membrane, capillary mem-brane	Pipe membrane, flat membrane	Elements with organic and innorganic fibre, wire mesh, split pipe, centrifuge, cyclone	Pipe membrane, flat membrane	Elements with organic and innorganic fibre, steel mesh, cyclone

Table 2: *Filtration processes for gases and fluids*

The design of the filter system is dependent on the characteristics and requirements of the fluid to be filtered. The fluid must be able to fulfil the following tasks as well as some others:

- Pressure and force transfer
- Lubrication
- Temper transfer
- Cleaning

However, it must be pointed out that the fluid must be capable of fulfilling several tasks at the same time.

For example, a fluid may have the main task of transferring force in a hydraulic system. However, it must also be capable of lowering the friction resistance and wear, as well as the high localised operating temperatures which occur (see *table 3*).

Medium to be filtered	**Fluid**					
Main task of medium	Transfer of forces		Reduction of frictional resistance		Temperature transfer	Cleaning of components
Type of medium	– Hydraulic oil – Fire resistant fluids – Water		– Hydraulic oil – Lubicating oil – Fat		– Thermal oil – Cooling machine oil – Water – Hydraulic oil	– Operating oils – Water-oil emulsions – Cold cleaner
Types of system	Hydraulic systems		Lubricating systems			
	Stationary systems	Mobile systems	Circulation lubrication	Losses lubrication	– Cooling systems – Heat transfer	– Cleaning systems
Examples	– Machine tools – Founderies – Heavy industry	– Construction machines – Communal devices – Ship-building	– Gear boxes – Sealers – Loaders	– Single line systems – Multi-line systems – Machine tools	– Plastic smelting – Calenders	– Test rigs – Cooling of workpieces – Cleaning of worked parts
Criteria for the filter	– Narrow clearances between moving parts – Large tank volume – Good filtration required	– Narrow clearances between moving parts – Small tank volume – Average filtration required	– High wear – Rough filtration usually sufficient	– Narrow clearances between moving parts – Average filtration required	– Removal of carbon residue – Good filtration required	– Prevent contamination of newly processed components – Rough filtration sufficient
Required filter pore size	3 to 20 µm	6 to 30 µm	10 to 100 µm	10 to 30 µm	3 to 20 µm	3 to 100 µm

Medium to be filtered	**Gas**	
Main task of medium	Processing	Ventilation
Type of medium	Air	Air
Types of systems	– Suction air – Systems to remove dust	– Clean room technology – Air-conditioning
Examples	– Suction air from int. combustion engs., sealers and hydr. systems – Exhaust air from power stations	– High quality manufacturing plants – Buildings
Criteria for the filter	– Protection of pistons in internal combustion engines – Environment protection – Good filtration necessary	– Sterile ventilation – High quality filtration required
Required filter pore size	1 to 10 µm	0.1 to 30 µm

Table 3: *Tasks of the medium to be filtered*

In hydraulic systems filtration is in the range of fine filtration to coarse filtration.

The following sections only deal with this filtration process.

2 Notes on design and servicing

In order for the hydraulic system to operate without problems, certain pre-requisites must be taken into account during design and operation of the system:

- Clear definition of task for the system and the components used in the system. So that no mistakes are made in the design phase for a system, a specification must be written.
- Determination of which components are to be used and their quality rating.
- Consideration of sensitivity to contamination of the components, ambient contamination and possibility of dirt ingress into the hydraulic system.
- Determination of realistic periods between servicing.
- Amount that system is used.
  Period of operation of the system per day (one or more shifts).

The factors which must be taken into account for disturbance free operation of a hydraulic system are shown in *table 4*.

One of the pre-requisites for disturbance free operation of a hydraulic system is the filtration of the fluid and the ambient air which comes into contact with the tank.

The contamination which is to be removed by filters comes from the environment into the hydraulic system via filler caps and seals.

This type of contamination is known as external contamination or contamination entering from outside the system.

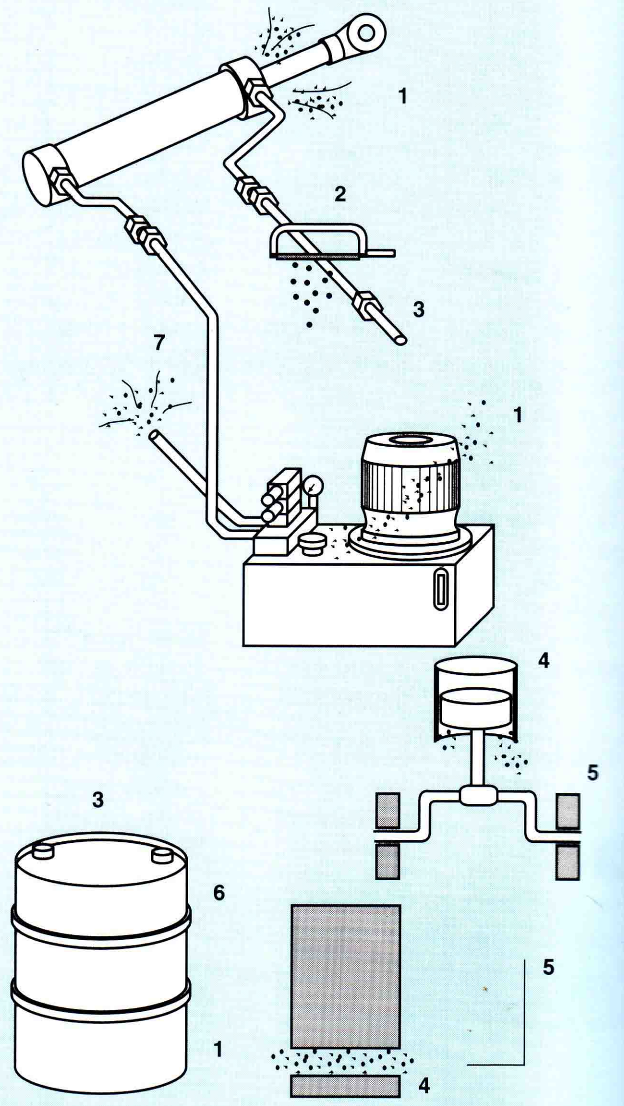
The expected rate of contamination ingress is only dependent on the ambient contamination and the system and component formation.

The moving parts in the hydraulic system, e.g pumps, pistons and valves also create particles (dust). This type of contamination creation is known as internal dirt production.

Above all, the danger exists, that due to solid particles entering the system whilst the system is being assembled, individual components may be damaged or destroyed on commissioning.

Many of the malfunctions occurring in hydraulic systems are due to heavily contaminated fluids. When a new fluid is filled into a hydraulic system, it is often contaminated to an impermissible high degree.

Fig. 1 shows some of the sources of contamination in hydraulic systems.



1 External contamination
2 Assembly
3 Start-up contamination
4 Internal contamination
5 Wear
6 New oil
7 Repairs

Fig. 1: *Sources of contamination*

Definition of task	System design	Contamination control
– Determination of task by user taking into account market requirements – Design of circuit by system manufacturer – Achieving advertised advantages whilst maintaining high technological standard – Disturbance free system model – Low servicing and energy costs – Economic cost/power ratio – Specification written for complete system	– Taking into account acceptance regulations – Design of switching logic – Selection of components e.g. pumps, cylinders, motors, valves and accessories – Matching components to each other – Determination of operating fluid – Determination of conditions for use for the complete system – Amount of use for the system – Determination of operating time for the system (one, two or three shift operation)	The functionality and hence the cost of the hydraulic system are effected by: – Installation contamination, – Fluid contamination on delivery, – Ambient contamination and dirt ingress, – Servicing of the system, – Ambient system conditions, – Production of wear in components, – Use of highly effective filters, – Determination of system specific filter power, – Correct filter arrangement and – Careful sealing of hydraulic system.
Responsibility System operator System manufacturer	*Responsibility* System operator System manufacturer Component supplier	*Responsibility* System operator Installation engineer Component supplier

Table 4: *Criteria for satisfactory operation of a hydraulic system*

2.1 Causes of contamination

2.1.1 Contamination in the manufacture of components (component contamination)

As a result of the extremely complex internal contours of housings and internal parts of components, these can often not be cleaned properly. When the hydraulic system is flushed, this contamination is passed into the fluid.

Components are usually preserved when they are stored. Preservatives fuse dirt and dust. This dirt also finds its way into the fluid when the system is commissioned.

Typical contamination is:
Swarf, sand, dust, fibres, paint, water or preservatives.

2.1.2 Contamination during assembly (assembly contamination)

As the individual components are put together, e.g. in the installation of screws, solid particles may be produced.

Typical contamination is
Sealing material, scale, weld spatter, pieces of rubber from hoses, residue of pickling and flushing fluid, separating and grinding dust.

2.1.3 Contamination during operation of the system (production contamination)

Due to abrasion in components, particles are produced. Particles smaller than 15 µm are particularly guilty of causing wear.

Ageing processes in fluids usually initiated at high operating temperatures, cause the lubricity of the fluid to change.

Contamination entering the hydraulic system from outside causes disturbances in operation and wear.

2.1.4 Critical clearances in hydraulic components

In order to ensure that the hydraulic components function correctly a clearance must be left between the moving parts.

Particles which become trapped in these clearances lead to malfunctions and also to wear. The critical clearances for various hydraulic components are shown in *table 5*.

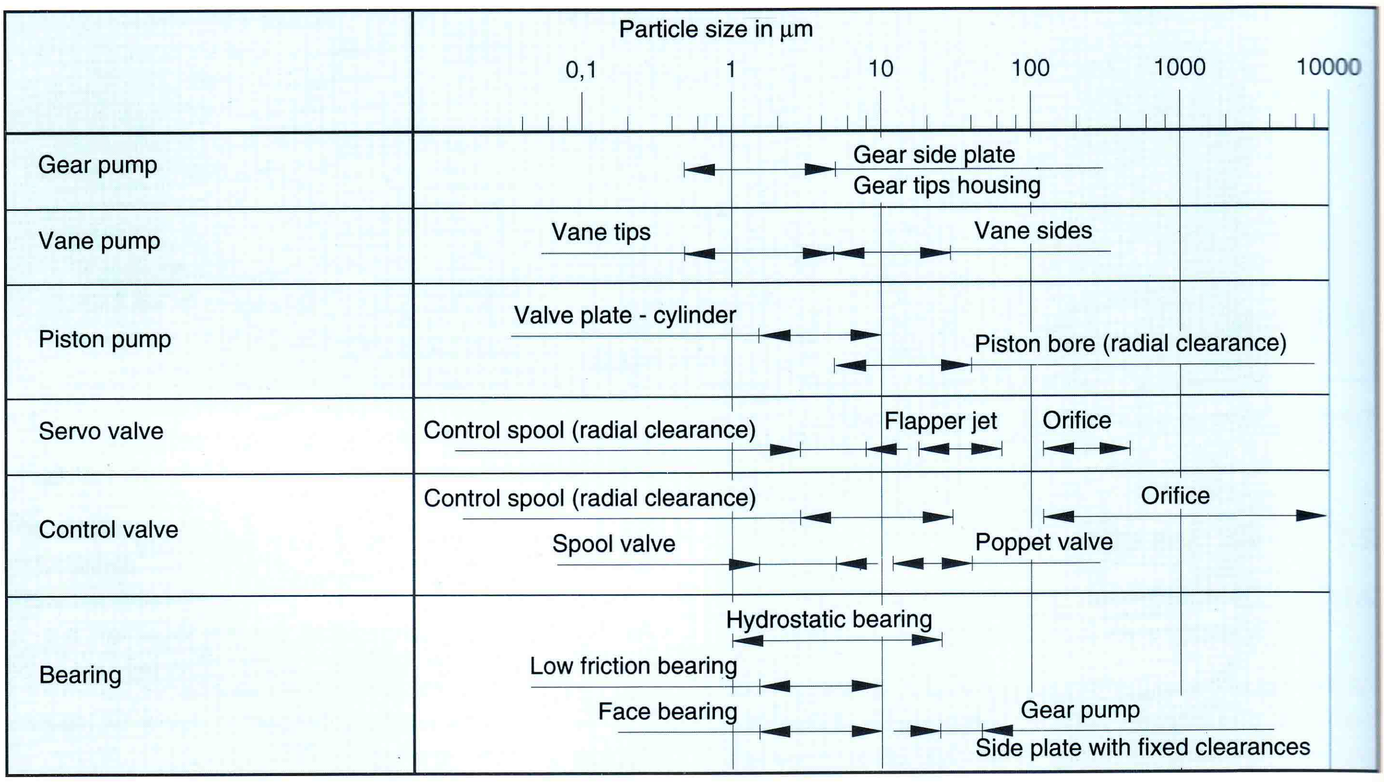
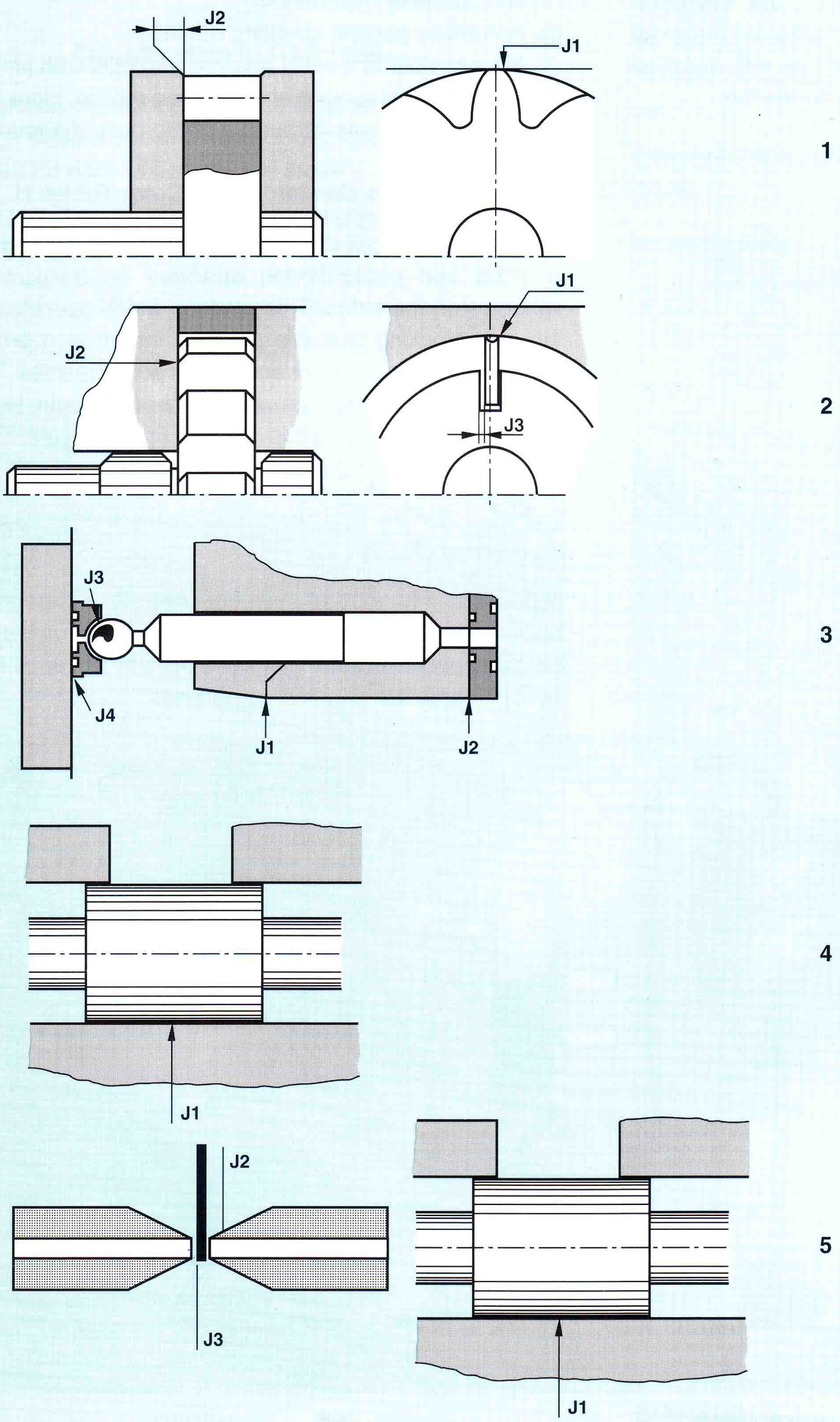


Table 5: *Clearance sizes for various hydraulic components to Cetop RP 92 H*

2.1.5 Points which are sensitive to contamination in hydraulic components

The critical tolerances (size of clearances) on parts of a gear pump, vane pump, piston pump, spool valve and servo valve are shown in *fig. 2*.



1 Gear pump

J1 from	0.5	to	5 micron
J2 from	0.5	to	5 micron

2 Vane pump

J1 from	0.5	to	5 micron
J2 from	5	to	20 micron
J3 from	30	to	40 micron

3 Piston pump

J1 from	5	to	40 micron
J2 from	0.5	to	1 micron
J3 from	20	to	40 micron
J4 from	1	to	25 micron

4 Valve

J1 from	5	to	25 micron

5 Servo valve

J1 from	5	to	8 micron
J2 from	100	to	450 micron
J3 from	20	to	80 micron

Fig. 2: *Critical tolerances in hydraulic components*

3 Analysis of solid particle contamination

In order to analyze solid particle contamination, fluid samples must be taken from the hydraulic system. The various ways of removing samples are standardised to ISO 4021, Cetop RP95H and DIN ISO 5884.

Test points should already be included in the design of a hydraulic system in accordance with the standard. However, care must be taken that samples are removed from turbulent flow. The individual bottles with samples must have labels with the following information:

Sample no.: ....

Source of sample: ....

Method of sampling: ....

....

Date and time of sampling: ....

Type of fluid: ....

Filters installed: ....

Remarks: ....

....

Particle analysis may be carried out by one of two methods:

a) Microscopic particle counting process
The fluid sample is filtered via a membrane and the residue is examined under a microscope for the size of and number of particles.
This method is standardised to ISO 4407 and 4408.
This method is very time-consuming and requires considerable experience.

b) Automatic particle counting process
It is possible to quickly analyze particles with an automatic measuring and counting device. Here the fluid sample flows through a photo-optic measuring cell.
This method is standardised to Cetop RP 94 H.

The measuring cell contains a flow channel with light sources and photo-diodes arranged on transparent windows on the sides. This process which operates on the light blocking principle provides information on the distribution of the number and size of solid particles. The particles flowing past cause the area of light being emitted to be reduced. As a result of this change in light, the size of particles may be determined.

Particles pass the light beam individually and hence may be counted (*fig. 3*).

Naturally, this optical system cannot differentiate between the types of particles and so apparent contamination such as gas bubbles and drops of fluid contaminants are counted as particles.

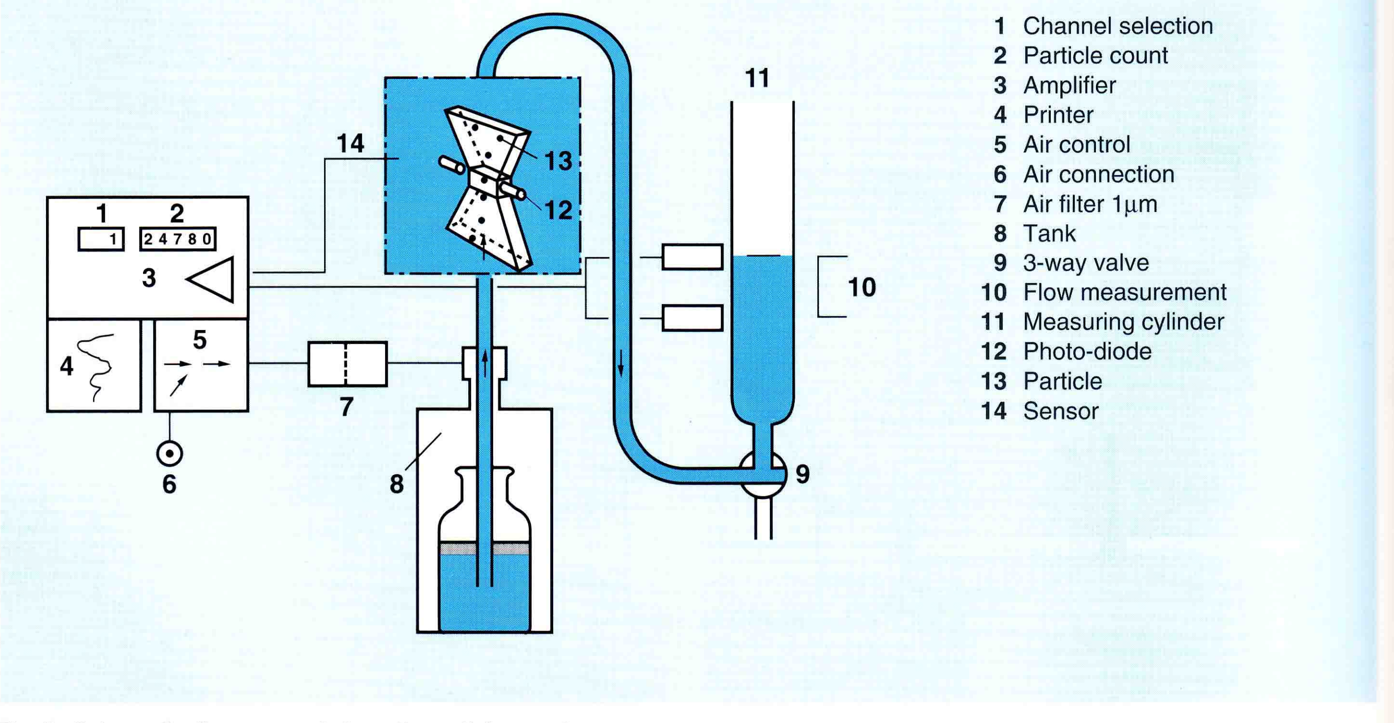


Fig. 3: *Schematic diagram — Automatic particle counter*

3.1 Classification systems for the degree of contamination in a fluid

Classification systems (standardised cleanliness classes) are used to help determine the amount of solid particles present in a fluid.

The most commonly used standards today are NAS 1638 and ISO DIS 4406.

3.1.1 Classification to NAS 1638

Fourteen cleanliness classes exist to classify fluids. In each class a specific number of particles (in 100 ml) is given for each of 5 ranges of sizes.

Table 6 shows how contamination classes are formed to NAS 1638.

Cleanliness class	Particle size in µm				
	5 – 15	15 – 25	25 – 50	50 – 100	> 100
00	125	22	4	1	0
0	250	44	8	2	0
1	500	89	16	3	1
2	1000	178	32	6	1
3	2000	356	63	11	2
4	4000	712	126	22	4
5	8000	1425	253	45	8
6	16000	2850	506	90	16
7	32000	5700	1012	180	32
8	64000	11400	2025	360	64
9	128000	22800	4050	720	128
10	256000	45600	8100	1440	256
11	512000	91200	16200	2880	512
12	1024000	182400	32400	5760	1024

Table 6: *Cleanliness classes to NAS 1638*
Maximum number of dirt particles found in 100 ml of fluid

3.1.2 Classification to ISO DIS 4406

Here the sizes larger than 5 µm and larger than 15 µm are cumulatively provided.

The cleanliness class of the fluid is determined on the basis of both particle counts.

Twenty-six ranges are available for classification. The designation of the cleanliness class comprises only two numbers. The first number indicates the range number for the particle size larger than 5 µm and the second number indicates that for the particle size larger than 15 µm.

Diagram 1 illustrates the contamination class to ISO DIS 4406.

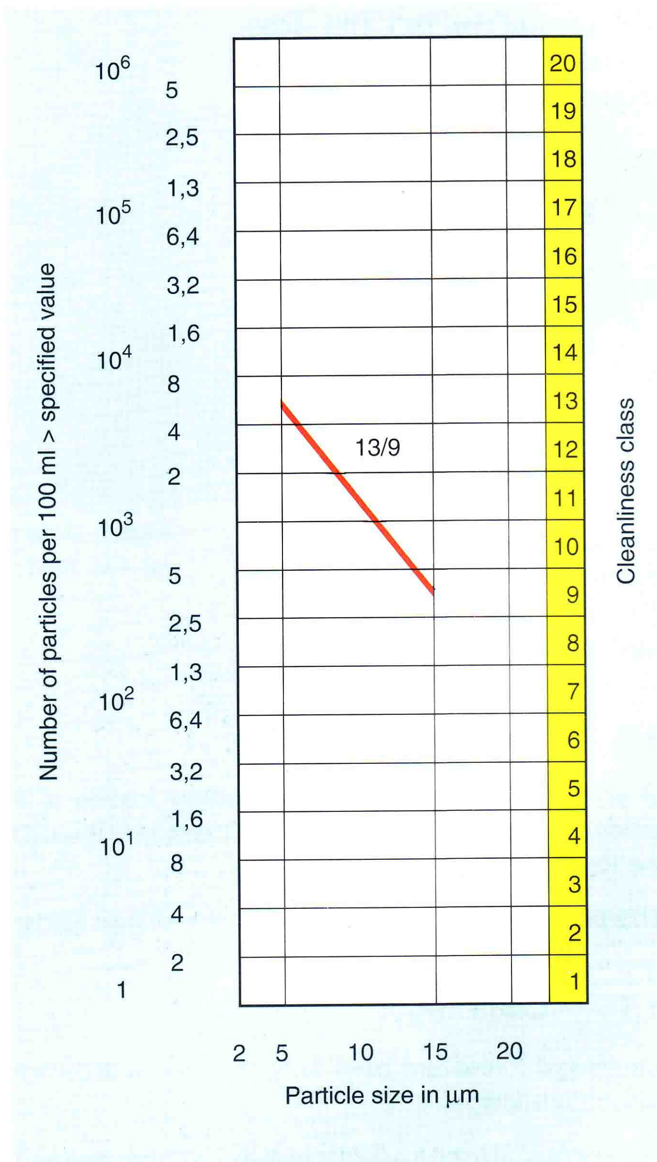


Diagram 1: *Cleanliness classes to ISO DIS 4406*

Both classification systems may be represented graphically.

It is obvious from diagram 2 that ISO DIS 4406 only deals with a small section of the complete analysis spectrum to NAS 1638 when determining contamination.

The number of particles determined by analysis cannot be matched to any one class with respect to the cleanliness classes to NAS 1638. This means that classes are usually determined for the smallest particles of 5 to 15 µm to NAS 1638.

As already mentioned, the cleanliness classes to NAS 1638 cover a larger particle spectrum than that covered by ISO DIS 4406. Hence NAS 1638 is to be used in preference to ISO DIS 4406.

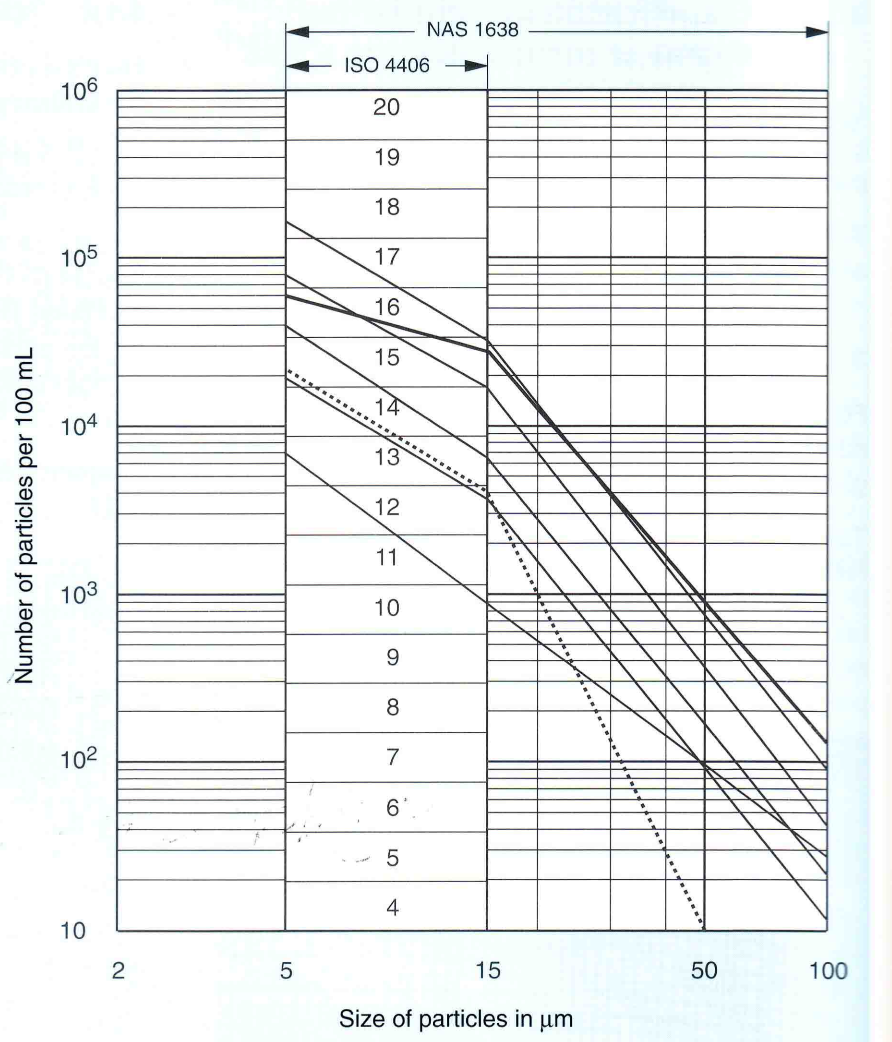


Diagram 2: *Graphical representation of a particle distribution to ISO DIS 4406 and NAS 1638*

4 Filtration processes

4.1 Gravity filters

In gravity filtration, the fluid flows through the filter as a result of its own weight.

This process is not used in hydraulics and lubrication technology. It is only used in the production of drinking water and in the preparation of operating fluids (rubble filter, paper filter).

4.2 Pressure line filter

In pressure filtration, fluid is pushed by means of a pressure drop between the dirty and clean side through the filter.

This process is used for the filtration of hydraulic fluids.

4.3 Centrifuges

Centrifugal forces are used in centrifuges to separate solids from liquids.

This process is used if a fluid is heavily contaminated and also to filter water.

4.4 Filter presses

In filter presses, fluid is pressed out of the solid particles by mechanical forces. The solid particles stay in the press and a filter cake is formed.

This process is not used in hydraulics. It is mainly the food industry which uses this process.

Each of these processes may also be used in the preparation of coolants.

5 Filter element material

In the filtration processes mentioned a variety of or combination of materials are used for the filter element.

5.2 Surface filtration (*fig. 4*)

In surface filters, particles are removed directly on the surface of the filter element. Particles, which due to their small diameter, enter the filter element can pass through it without any further resistance. The filter resistance however increases as the surface becomes clogged. The layer of particles formed on the surface of the filter may lead to a decrease in the filtration rating.

Either a membrane filter or filters made of wire mesh, metallic edges or woven metallic twist are used for surface filtration.

5.2 Depth filters (*fig. 5*)

The fluid to be cleaned passes through the filter structure. The dirt particles become trapped in the deep layers of the filter. As the level of trapped dirt increases, the resistance to flow increases, so that the filter element needs to be changed. In these filters, the element is made of

- impregnated cellulose material (organic filter material)
- glass fibre (inorganic filter material)
- sintered metal fibre or
- porous, sintered metal.

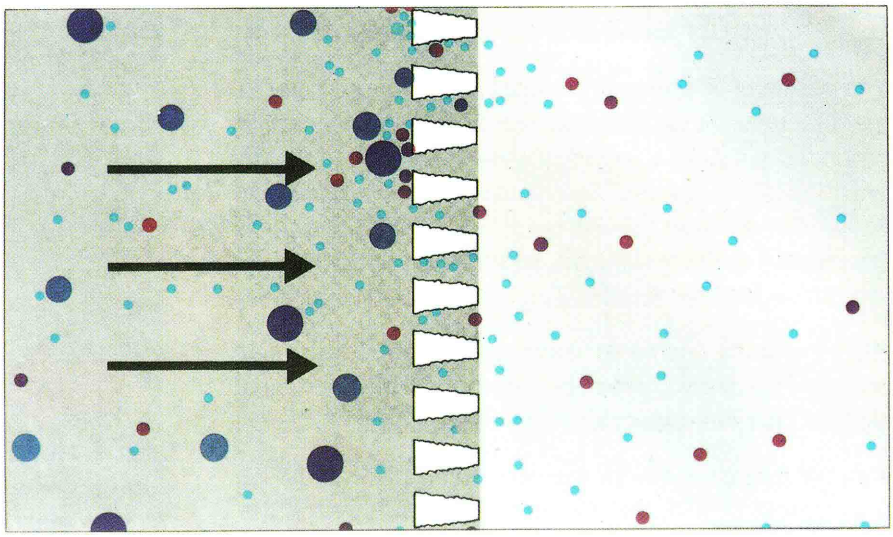


Fig. 4: *Representation of surface filter*

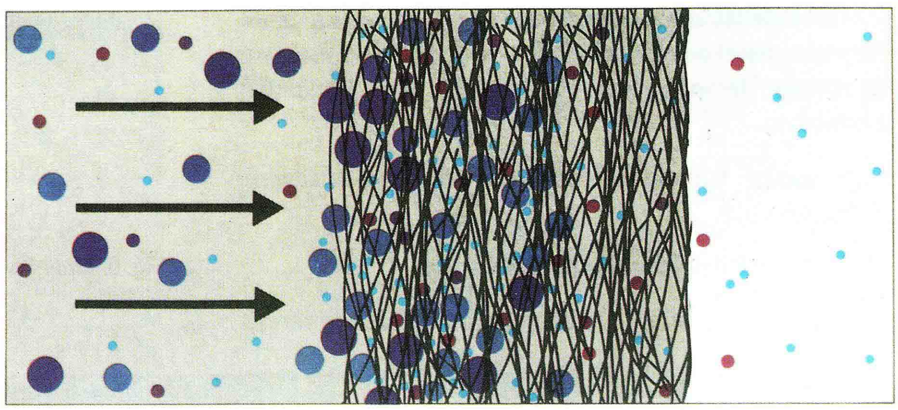


Fig. 5: *Representation of depth filter*

6 Filter element design (*Fig. 6*)

The design of filter elements varies from manufacturer to manufacturer. In simple paper elements, the filter matt is produced without a supporting wire mesh, so that at high pressure differences the filter pleats are pressed together at the filter element. Hence the possibility of drainage in the pleated matts is reduced, so that many of the layers remain unused for filtration purposes.

Higher quality elements have a multiple layer matt design. This design determines how robust the element is against pressure peaks and alternating flows.

A certain mesh width for the supporting mesh must be maintained, or else the filter dirt is pushed through the mesh and the filter becomes less effective.

The elements must be handled very carefully and according to instructions by the service engineers. If the element pleats are pushed against sharp edges when they are installed, this results in the matt construction becoming damaged and hence the filter becoming ineffective.

High quality filter elements must have the following characteristics:

- Good stability in pressure differences
- Beta stability over a wide pressure difference range
- Filtration ratings for all cleanliness classes
- Good dirt holding capacity
- Larger filtration areas and
- Long service lives.

The demands made on high quality filter elements may be determined from DIN 24550 part 2.

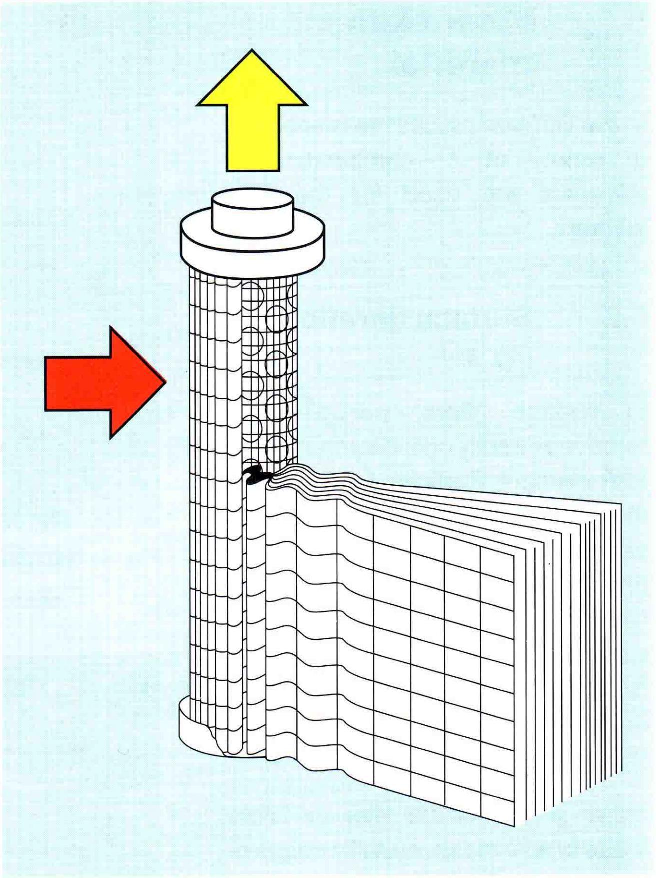


Fig. 6: *Multi-layer matt construction for Betamicron-2 elements*

7 Selection of filtration rating

The selection of a filtration rating is dependent on which main filtration group the filter is to be used in.

Table 7 describes the main filtration groups and their relevant filtrations.

In older technical documents on hydraulic components the required filtration rating is specified. However, as the safe functioning of components is dependent on the degree of cleanliness of a fluid, nearly all component manufacturers now state recommendations on the fluid cleanliness classes in their new technical documentation.

This is the correct specification in order to ensure that the components are protected, but makes the selection of a filtration rating a little harder, as the dirt load is dependent on the size of the particles as well as on the number of particles.

As a result of experiments and examinations of practical applications, filter manufacturers are able to specify the required filtration rating for a particular degree of fluid cleanliness. An example of this is shown in *table 8*.

However, the fluid cleanliness class required for a system is also dependent on the following parameters:

- Type of system
- Ambient contamination
- Excess operating pressure
- Operating period for the system
- Filter arrangement

Hence it may be very difficult to select a filtration rating for the fluid cleanliness class during the design phase. The filter size should be selected so that it is relatively simple to change the filter to a larger filter size at any time, so that during later operation of the system filter elements with a smaller filtration rating or a longer service life may be installed.

A typical cause of malfunctions in hydraulic components is the clogging of clearances and orifices. Especially sensitive to this are flow control valves, throttle valves and servo valves. If the relative movement is small, there is an increased danger of the clearances becoming blocked. Hence, considering clogging, the absolute filtration rating must be at least the same if not smaller than that of the clearances within a component.

Hydraulic components	Cleanliness class to NAS 1638	Cleanliness class to ISO DIS 4406	Recommended absolute filter pore size in µm
Gear pumps	10	19/16	20
Cylinders	10	19/16	20
Directional valves	10	19/16	20
Safety valves	10	19/16	20
Throttle valves	10	19/16	20
Piston pumps	9	18/15	10
Vane pumps	9	18/15	10
Pressure control valves	9	18/15	10
Proportional valves	9	18/15	10
Servo valves	7	16/13	5
Servo cylinders	7	16/13	5

Table 8: *Recommended absolute filter pore size for various hydraulic components (Rexroth)*

Finest contamination	Fine contamination	Coarse contamination:
Finest particles (3 to 5 µm) reduce functionality and power due to: – Effect of erosion by finest particles (often control land erosion) – Fine deposits in narrow gaps (due to gap filtration – danger of clogging) – Change in operating medium (oil ageing) as a result of chemical reaction at the particle surface.	Fine particles (5 to 20 µm) cause frictional wear especially in narrow passages. This causes: – Increase in clearance due to wear (increased internal leakages) – Periodic malfunctions (brief clogging effect at spool valves or leaks at valve pins – Total malfunction due to heavy wear	Coarse particles > 20 µm often cause a sudden total malfunction due to effects of clogging, blocking or direct disturbances. Typical effects are: – Blocking of orifices – Spool jamming or erosion – Material collapse if large forces present.
Finest filtration Effective separation of finest dispersed particles ($\beta_{3\text{ to }5} \geq 100$) High pressure difference stability, finest filters protect functionality – They minimise the creation of and development of erosion – They prevent clogging of narow gaps – They protect against oil ageing – They prevent disturbances from occuring in the system	**Fine filtration** Partial separation of fine contamination and complete separation of coarse contamination ($\beta_{5\text{ to }20} > 100$) Fine filters are used to reliably control the acceptable level of contamination in a system – They protect components to an optimum degree from contamination – They reduce frictional wear – They prevent components from suddenly malfunctioning.	**Coarse filtration** Separation of mainly coarse particles $\beta_X \geq 100$ *(see page 20)* X= µm particle size, which can cause a sudden mal-function of the components which are to be protected. Coarse filters protect system from coarse contamination They prevent the danger of sudden malfunctions or complete damage .

Table 7: *Effect of particles dependent on their size on components and the matching to main filtration groups*

8 Filter testing

8.1 Verification of production quality
(Bubble point test)

Using this test to ISO 29 42, it is possible to verify that production is perfect and also to verify the integrity of filter elements.

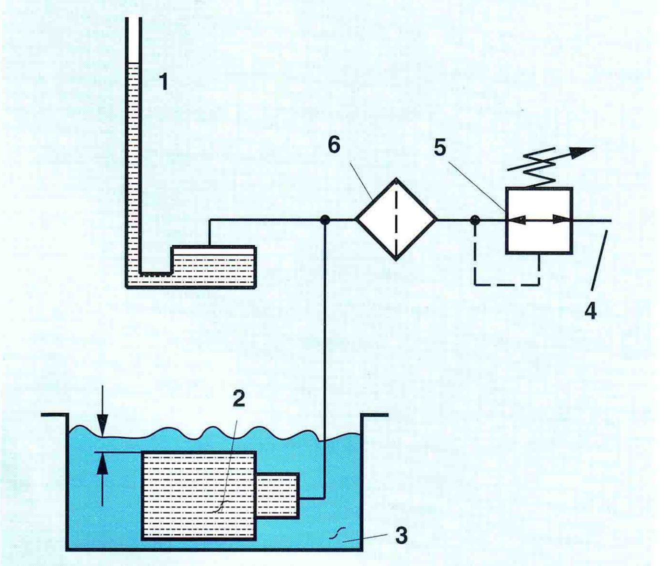
It is also used as the start of further tests (e.g. ISO 2941, ISO 2943, ISO 3723, ISO 3724, ISO 4572).

8.1.1 Test sequence (*fig. 7*)

The filter element is submerged in isopropanol and pressurised internally with pressurised air. Pressure is increased until the first bubble appears on the surface of the element. No bubbles should appear until the air pressure specified by the manufacturer has been reached. Taking into account the physical laws when the first bubble appears, the air pressure is a measure for the size of the largest pore. The creation of lots of bubbles is a measure of the average pore size.

The bubble point specified by the manufacturers is very dependent on the construction of the element. Hence it is not possible for the user to compare filter elements from various manufacturers.

In general this test may only be used to check the integrity of an element.



1	Pressure gauge	4	Air supply
2	Element to be tested	5	Low press. controller
3	Filtered Isopropanol	6	Air filter

Fig. 7: *Schematic diagram of bubble point test to ISO 2942*

Fig. 8: *Bubble point test*

8.2 Collapse and burst pressure test

In the standardised test to ISO 2942, the stability of pressure differences in the filter elements are tested.

The specification "permissible collapse and burst pressure" implies the max. pressure difference which may be present for the filter element not to be damaged in a specific direction of flow.

The expression collapse pressure is used, when flow through the filter element is from outside to inside. In the opposite direction the expression burst pressure is used.

8.2.1 Test sequence (*fig. 9*)

Tests on filter elements must be carried out at the nominal flow specified by the manufacturer.

Controlled test dirt ACFTD (Air Cleaner Fine Test Dust) is fed to the filter element. Due to the contaminant which then gathers on the element, the difference between the pressure upstream and downstream of the filter element increases.

The gradient of the curve must not decrease for values below the permissible collapse or burst pressure.

In addition, once the permissible collapse or burst pressure has been reached, a bubble point test must be carried out in order to verify the integrity of the element.

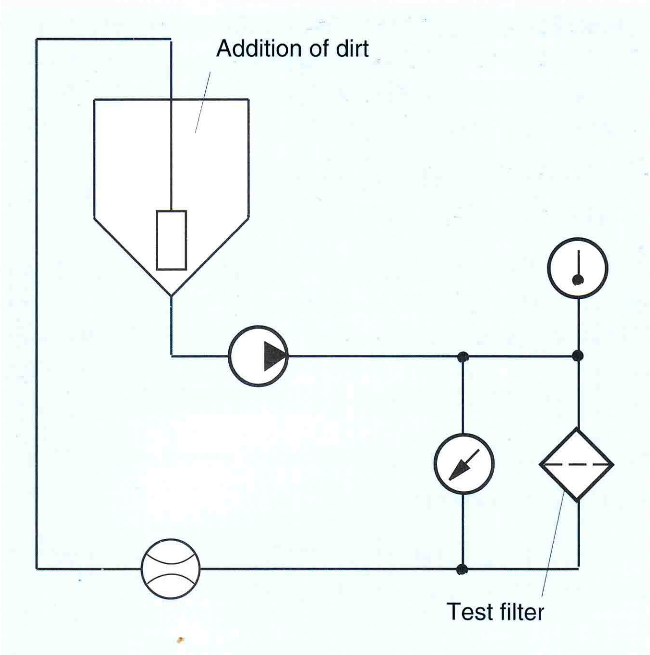


Fig. 9: *Schematic diagram of collapse and burst pressure test to ISO 2941 (δ_{test} = constant = 15 to 40 °C)*

8.3 Test of compatibility with fluid

The compatibility of the materials used in the filter element with the fluid are tested to ISO 29 43.

8.3.1 Test sequence (*fig. 10*)

The filter element is submerged in fluid for 72 hours at a test temperature of 15 °C above the max. operating temperature.

In this process the maximum safe temperature for the fluid must not be exceeded.

Once the test has been completed the filter element must not show any signs of damage or any reduction in its functionality. Afterwards a burst pressure test to ISO 2941 and a bubble point test to ISO 2942 must be carried out on the element.

The filter element has passed the test, if there are no visible signs of the element construction being damaged, no obvious decreases in functionality and if the collapse and burst pressure test is successfully passed.

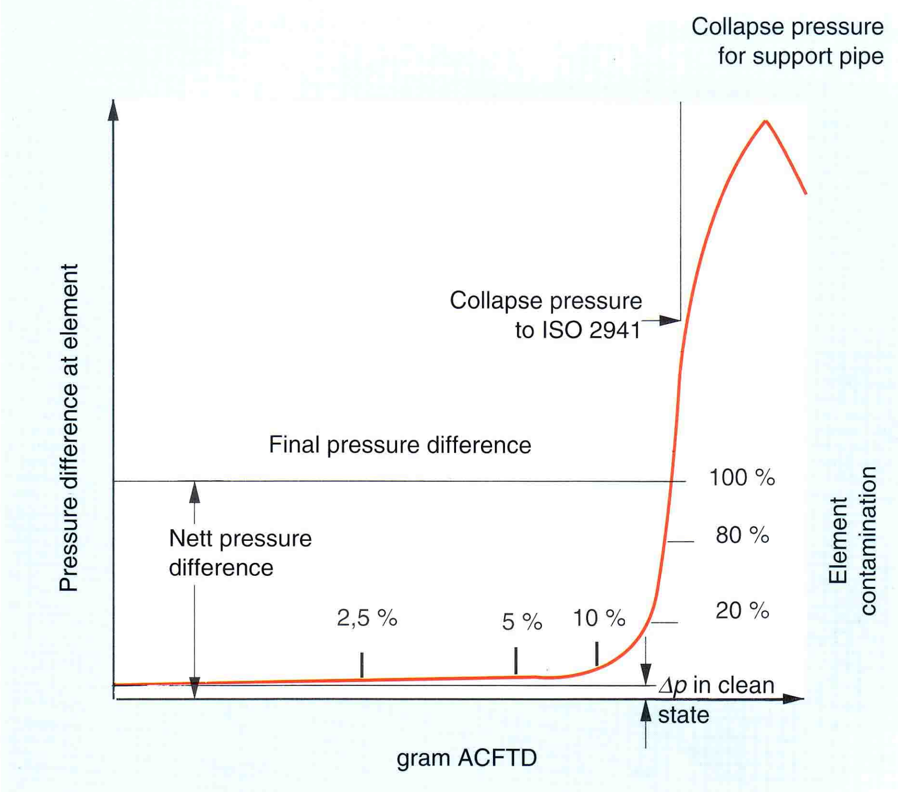


Diagram 3: *Pressure difference dependent on dirt addition*

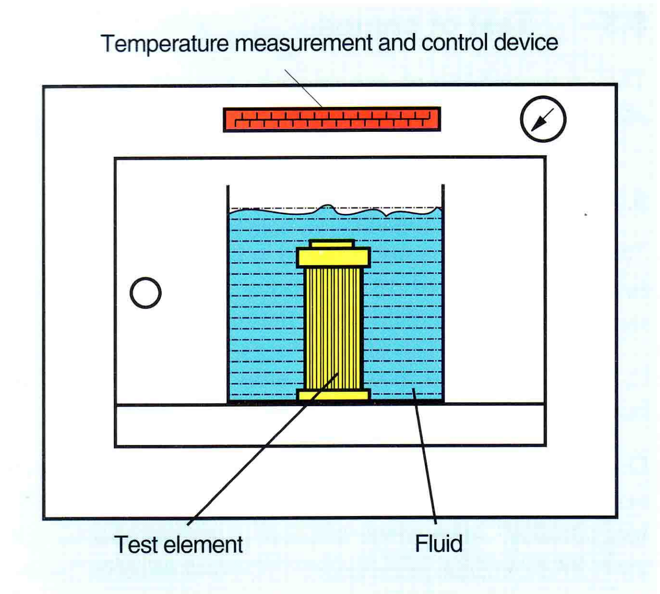


Fig. 10: *Schematic diagram of compatibility test to ISO 2943*

A specified number of pressure pulse cycles are sent to the filter element. Pressure pulse cycles are created due to changes in flow with a layer of dirt present on the element.

The pressure must be sinusoidal with a frequency of1 Hz or less.

The filter elements has passed this test, if the pressure pulse cycles (either prescribed or specified by the customer) do not produce any visible signs of damage on

- the complete element (filter construction)
- the seals or
- the filter material.

The operating curve for the collapse or burst pressure must not show any fall in the gradient.

8.4 Flow-fatigue characteristics of elements

The filter element is tested to ISO 37 24 to examine the ability of the element to resist structural damage, e.g. caused by deformation due to alternating directions of flow.

8.4.1 Test sequence (*fig. 11*)

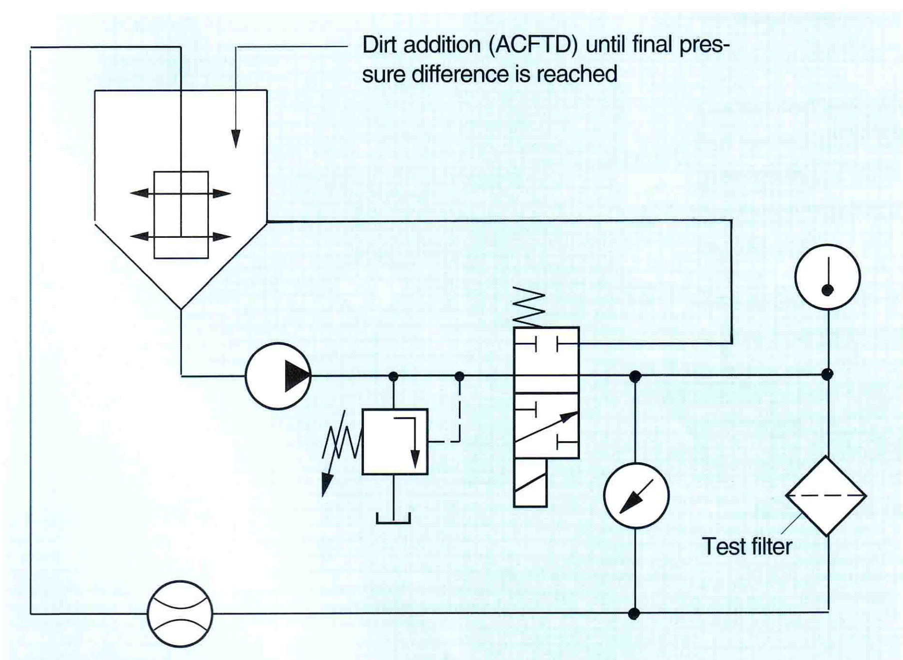


Fig. 11: *Schematic diagram of flow stability test to ISO 3742*
(δ_{test} = constant = 15 to 40 °C; $Q_{test} \leq Q_{nominal}$)

8.5 Determination of pressure losses dependent on flow

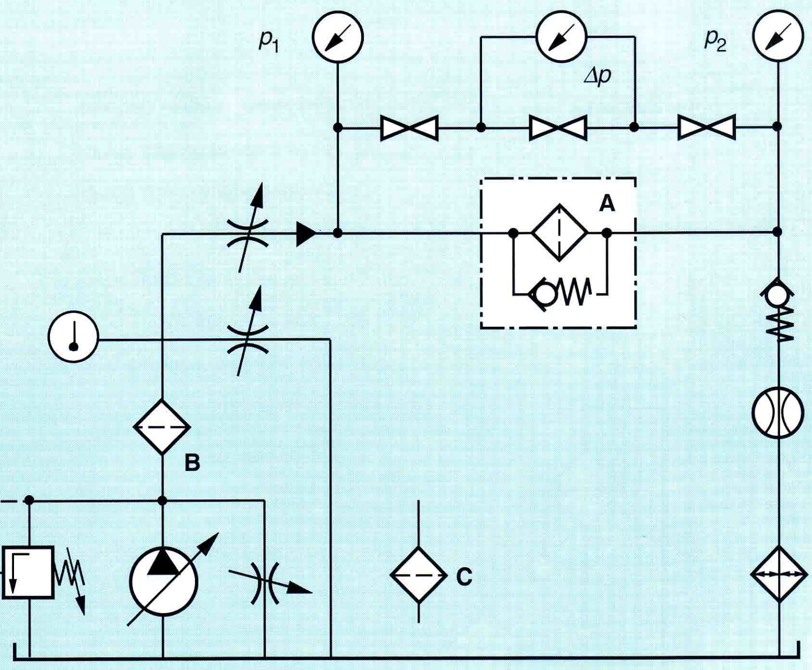
The pressure losses in the filter housing and element dependent on the flow and viscosity are determined the test to ISO 3968.

8.5.1 Test sequence (*fig. 12*)

The flow is shocklessly varied by a variable displacement pump installed in the test circuit. The test fluid used is usually a hydraulic oil from the viscosity class ISO VG 32.

The pressure losses in the housing and filter element are shown.

In this test the test points p_1 and p_2
upstream of the test filter: 5 x D_1
(D_1 = internal diameter of the pipe)
downstream of the test filter: 10 x D_1 must be arranged on a straight piece of pipe.



A Test filter
B Cleaning filter
C Breather

Fig. 12: *Schematic diagram for test to ISO 3968*

8.6 Multi-pass test

This test to ISO 4572 enables the filtration capacity and dirt holding capacity of filter elements to be determined.

The test is based on the principle of passing dirty fluid several times through the test filter.

This principle is justified in practice as some dirt particles which pass through the filter the first time around due to their size may be removed when they hit the filter on another pass.

8.6.1 Test sequence (*fig. 13*)

The "dirty" fluid from system 1 is injected into the circuit of system 2. Dirt is fed to the test filter by means of continuous circulation until the maximum pressure difference of the element or the test system has been reached.

During this time samples are taken from system 2 and evaluated in the automatic particle counting device. Hence it is possible to determine how the filtration power of the element changes with increasing pressure difference. The test temperature is also continually monitored.

Fig. 14: *Multi-pass test rig*

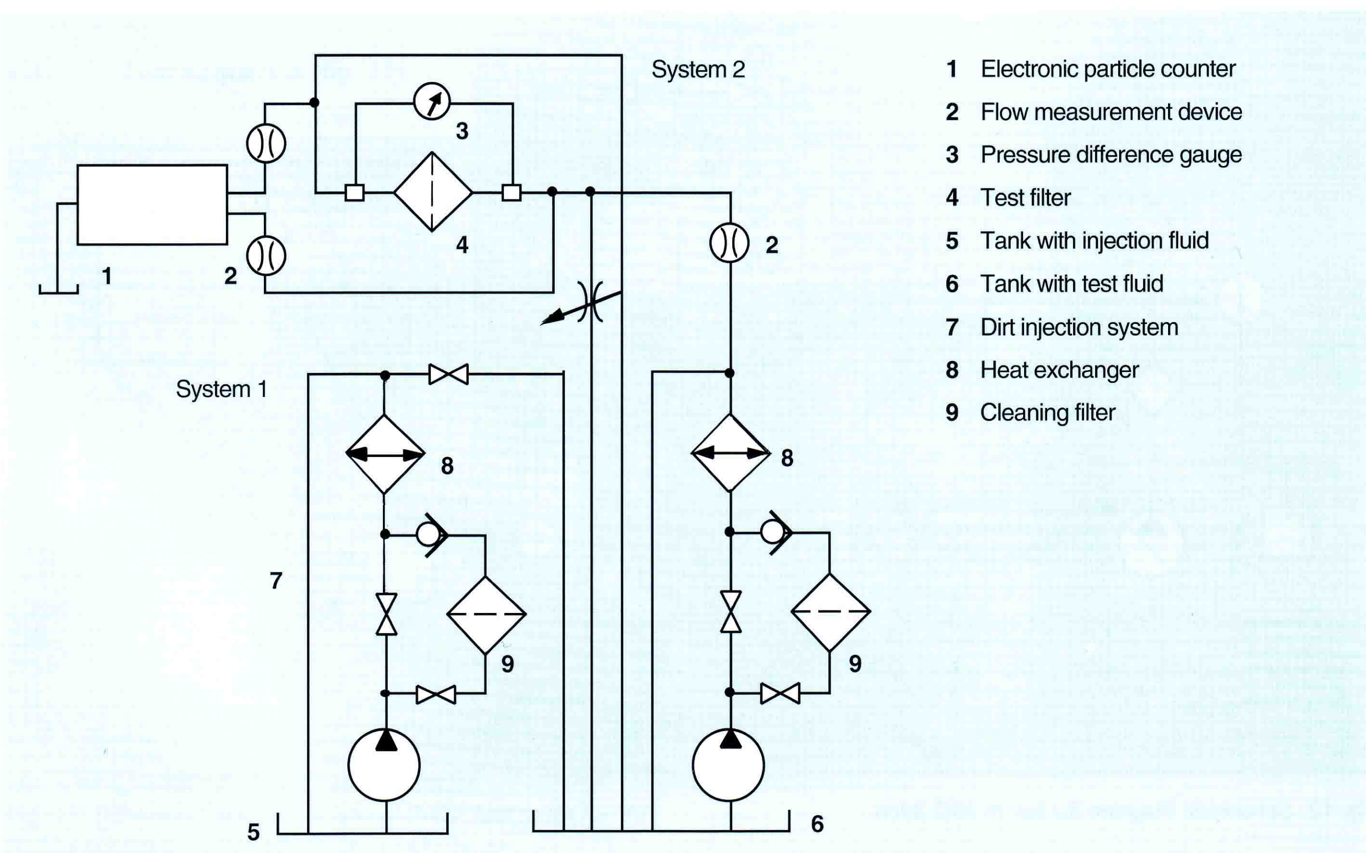
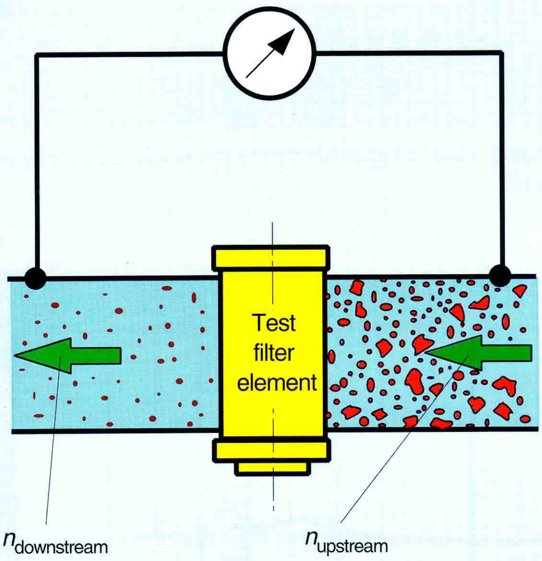


Fig. 13: *Simplified hydraulic circuit for multi-pass test rig*

The results of the test are printed out in the form of β_x values.

The filtration ratio β_x determined may also be given as a degree of separation in %.

$$\text{Degree of separation in \%} = \frac{\beta_x - 1}{\beta_x} \cdot 100$$



1000 particles
≥ 10 µm/100 mL
= 0.08 mg/L (ACFTD)

100 000 particles
≥ 10 µm/100 mL
= 10 mg/L (ACFTD)

$$\beta_x = \frac{n_{upstream} \geq X\ \mu m}{n_{downstream} \geq X\ \mu m}$$

Numerical example: $\beta_{10} = \frac{100\,000}{1000} = 100$

Particle size in µm

$\beta_x =$ 2 50 % degree of separation
$\beta_x =$ 20 95 % degree of separation
$\beta_x =$ 75 98,6 % degree of separation
$\beta_x =$ 100 99 % degree of separation
(absolute retention rate)

Fig. 15: *Determination of β_x*

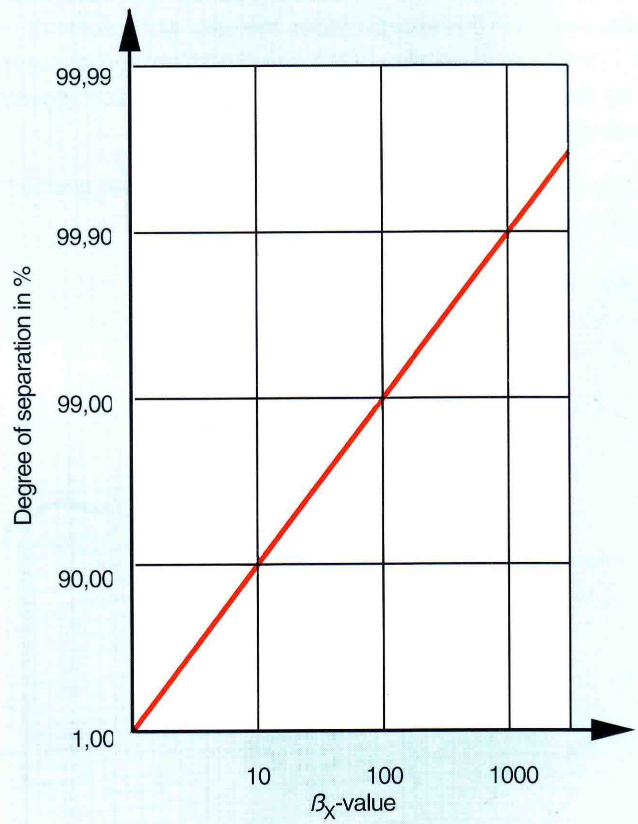


Diagram 4: *Degree of separation in % dependent on β_x value*

At $\beta_x = 1$, no separation occurs. The "ß" function may have a value less than 1 if the filter produces dirt. In practice this should not happen.

The evaluation of the test results provides information on the dirt holding capacity in grammes (gram per element) and on the effectiveness of the filter material (gram per cm^2, also known as the specific dirt holding capacity).

This test which is a close approximation of practice is very accurately repeatable given the same specified test conditions. Hence it is possible to compare various makes of filter. The effectiveness of the test filter determined in this way provides the user with information on the power capability of the selected filter and ensures that the decisions on application or on the cost/power ratio are known.

Diagrams 5 and 6 show the test results for filter element 0160 D010BH/HC-2.

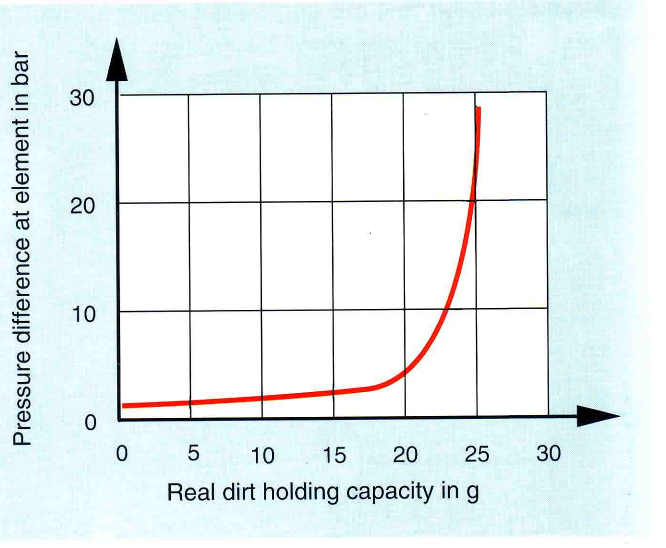


Diagram 6: *Operating curve for the dirt holding capacity of filte element*

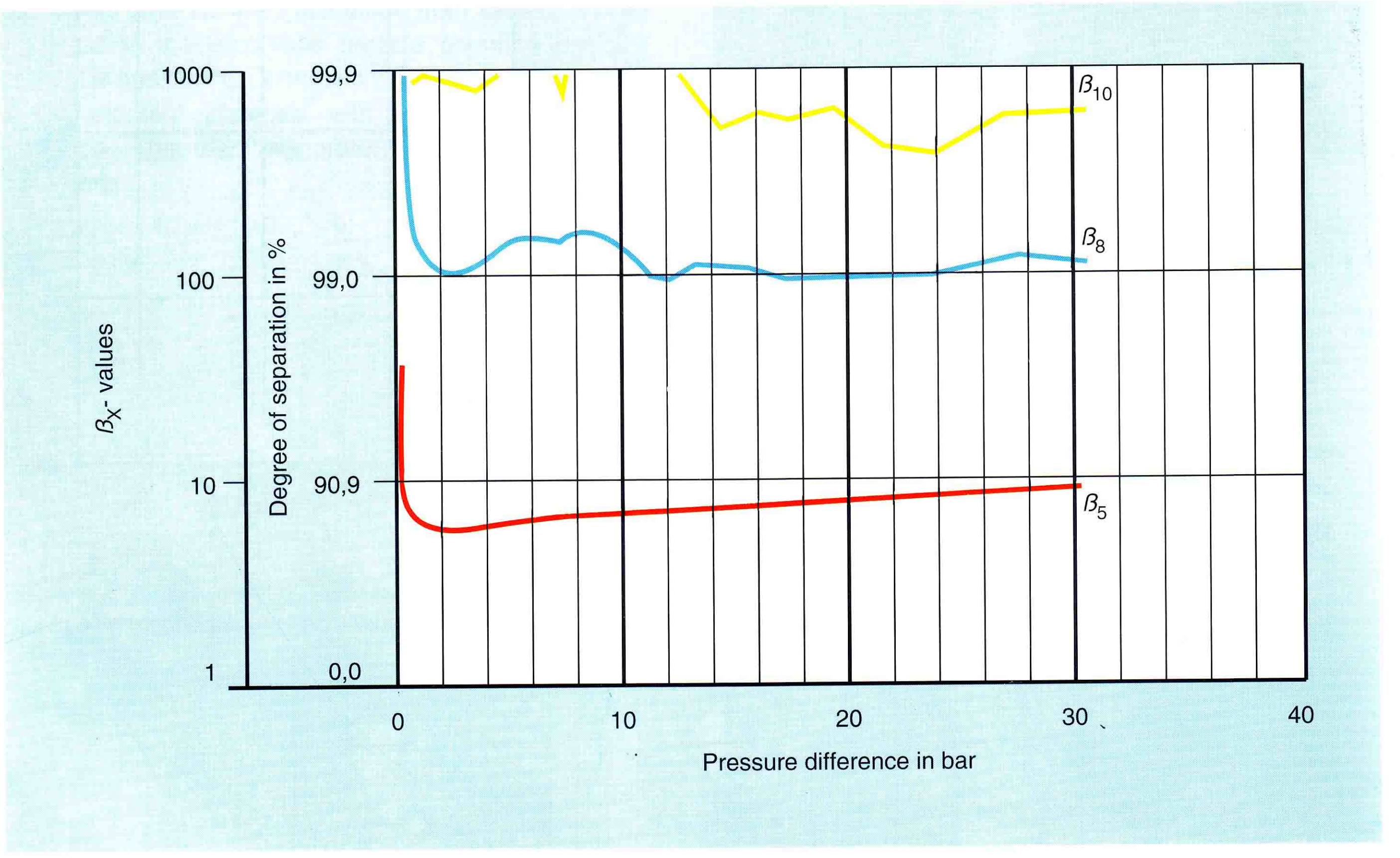


Diagram 5: *β_x values at various pressure differences at Betamicron-2 element (type ... D010BH/HC-2)*

8.7 Documentation on test results

The test parameters must be written down in a test protocol so that filter elements from various manufacturers may be compared.

This documentation must adhere to DIN 24550 and DIN 65385.

9 Types of filter housing

Various types of housing are available for the filtration of fluids.

These types are defined in DIN 24550.

Table 9 describes these types.

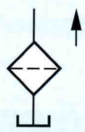
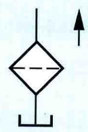
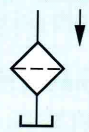
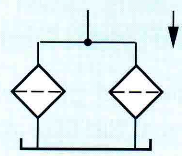
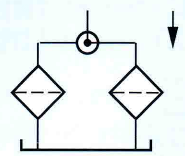
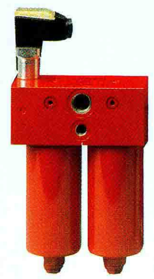
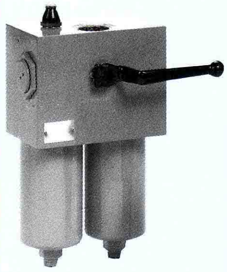
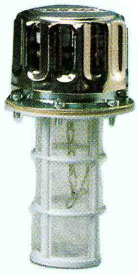
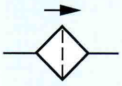
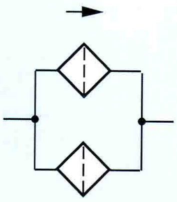
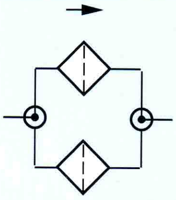
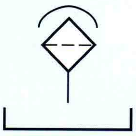
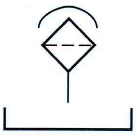
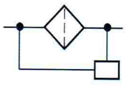
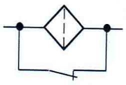
Type	**Suction line filter**		**Mounted return line filter**		
Model	Without housing	With housing	Simple	Double	Switchable
Place of installation	Tank, suction line	Tank, suction line	Tank	Tank	Tank
Diagram					
Symbol					
Max. operating pressure	1 bar	1 bar	25 bar	25 bar	25 bar
Filter pore size	20 to 200 µm	20 to 200 µm	3 to 100 µm	3 to 100 µm	3 to 100 µm
Typical applications	Pump protection, hydrostatic units, injection molding machines, construction machines	Pump protection, hydrostatic units, injection molding machines, construction machines	Working filter in hydraulic systems, construction machines	Working filter in hydraulic systems, construction machines	Systems dependent on manufacture
Remark	Usually only used to protect pump. Clogging indicator essential.	Usually only used to protect pump. Clogging indicator essential.	Standard model with bypass valve. With connection to fill system.	Standard model with bypass valve. With connection to fill system.	Standard model with bypass valve. With connection to fill system.

Table 9: *Summary of filter housing types*

Hydraulic filters

Line filter			**Breathers**		**Accessories**
Simple	Double	Switchable	With filling sieve	Without filling sieve	
Line	Line	Line	Tank	Tank	
					
					optical  electrical 
420 bar	420 bar	315 bar	1 bar	1 bar	420 bar
3 to 100 µm	3 to 100 µm	3 to 100 µm	3 to 40 µm	3 to 40 µm	—
Bypass filter, safety filter, working filter	Bypass filter, safety filter, working filter	Systems dependent on manufacture, working filters	Small Tank	Large tank; forced filling of system desired	In all filters which are used in hydraulic systems
Standard model without bypass valve.	Standard model without bypass valve.	Standard model without bypass valve.	Immense danger of very contaminated fluid entering tank	Filling of tank via filling power unit	Essential for filter servicing. Prevents elements from being damaged.

9.1 Suction filter

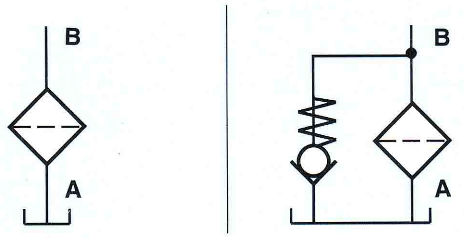


Fig. 16: *Symbol for suction line filter; (left) without and (right) with by-pass valve*

Hydraulic systems must include a suction filter, if there is likely danger of the pump being damaged due to large dirt particles.

This is especially the case when the following exists in a hydraulic circuit:

- Various hydraulic circuits operate with the same fluid supply
- Tanks cannot be cleaned due to their shape.

It is only possible to protect the functionality of the pump with a suction filter. Protection against wear must be ensured through filters which are installed in the pressure, return and bypass lines.

Due to the sensitivity of pumps to low pressure, the pressure difference at the filter must not be very large. Hence filters with large surfaces are usually installed. In addition, it is recommended that a bypass valve and a clogging indicator are installed.

In the suction region, filtration is limited to removing large particles, usually greater than 100 µm. A special model exists for the filtration in hydraulic drives. Here a suction filter is used with a filter pore size of 20 µm.

Two types of suction filter exist.

9.1.1 Suction filter without housing

Suction filters without housings are installed in the pump suction line.

Care must be taken that this suction filter is installed sufficiently below the minimum level of oil.

In order to protect the pump, a low pressure switch must be installed between the filter and pump.

Special suction filters without housings may be used as return flow distributors in the return line. They prevent foam from forming and settle the contents of the tank. Under certain conditions baffle walls may then not need to be used.

9.1.2 Suction filters with housing

These filters may also be installed below the level of fluid in the tank. So that the housing does not run empty when an element is changed, it must be fitted with a leakage barrier.

Advantages	Disadvantages
– Simple assembly – Price – It protects hydraulic components from coarse contamination	– Assembly is at the worse postion in the hydraulic system – Bypass is necessary – Bad service possiblities, as immersed in oil – Due to risk of cavitation only coarse filtration is possible – Clogging indicators may be mounted with difficulty

Table 10: *Advantages and disadvantages of suction line filters*

Fig. 17: *Suction line filter*

9.2 Pressure line filter

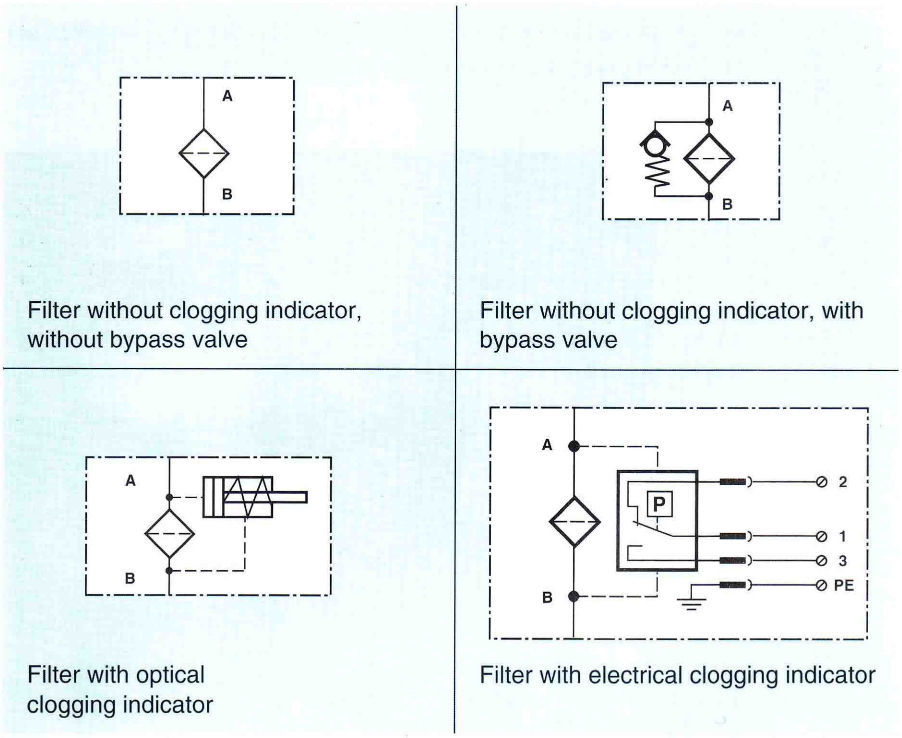


Fig. 18: *Symbols for pressure line filters*

This type of filter is used to ensure that the functionality of hydraulic components after the pump. Hence this type of filter must be fitted as close as possible to the components it is protecting.

The following points are important in deciding whether to use pressure line filters:

- Components are especially sensitive to dirt (e.g. servo valves or control valves) or are important for the functionality of the system
- Components are particularly expensive (e.g. large cylinders, servo valves, hydraulic motors) and are extremely important for the safety of the system.
- The idle time costs for the system are especially high.
- Pressure line filters may be used as safety filters and/or as working filters.

Hence these filters have the following tasks:

Working filters

- Protection against wear in components
- Maintenance of desired fluid cleanliness class.

Safety filters

- Protection of component functionality
  Safety filters are only used in combination with working filters.

pressure line filters should always be fitted with a clogging indicator. In front of especially critical components pressure line filters should only be used without bypass valves. This type of filter must comprise a filter element which can endure large pressure difference loads without sustaining any damage.

The filter housing must be able to be pressurised by the max. system pressure.

Advantages	Disadvantages
– May be mounted directly in front of sensitive components – May filter very finely – Simple servicing – May be supplied with clogging indicator – Long idle times – No pump cavitation	– Must be built robustly (weight) – Element must be designed for a high pressure difference – Depending on flow resistance power is converted into heat

Table 11: *Advantages and disadvantages of pressure line filters*

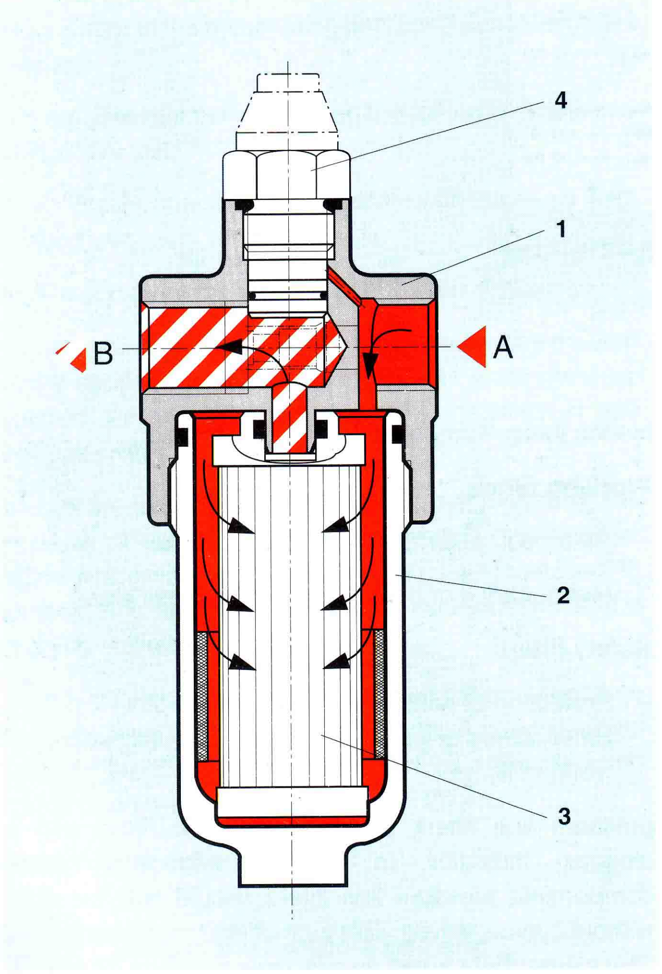
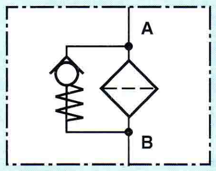


Fig. 19: *Sectional diagram of line filter*

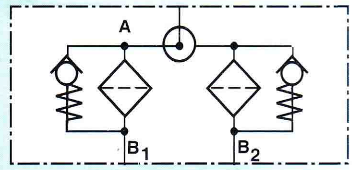
The filter (*fig. 19*) basically comprises filter head (1) with screwed in filter housing (2) and filter element (3). The standard model is without bypass valve and without pressure bleed screw. The port for a clogging indicator (4) is usually available.

Fig. 20: *Pressure line filter*

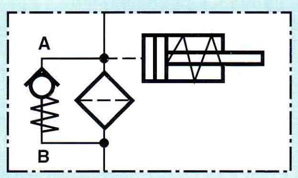
9.3 Tank mounted return line filter



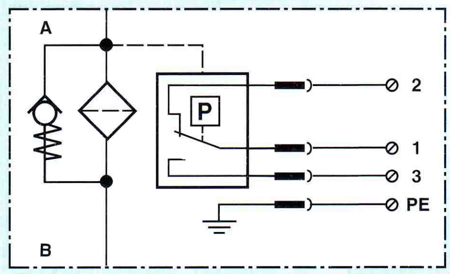
Filter without clogging indicator, with bypass valve



Filter without clogging indicator, with bypass valve, switchable



Filter with optical clogging indicator, with bypass valve



Filter with electrical clogging indicator, with bypass valve

Fig. 21: *Symbols for return line filters*

These filters are situated at the end of return lines and are designed to be mounted onto tanks. This means, that the fluid returned from the system flows back into the tank filtered. Hence all the dirt particles are removed from the fluid which are in the system or produced by the system, before they manage to reach the tank.

When selecting the size of filter the maximum possible flow must be taken into account.

In order to prevent the fluid from foaming in the tank, care must be taken that fluid is returned below the level of the fluid in the tank for all operating conditions. It might be necessary to install a pipe or flow distributor in the filter return line. Care must be taken that the distance between the bottom of the tank and the end of the pipe is not less than 2 or 3 times the size of the pipe diameter.

Advantages	Disadvantages
– Low costs – Simple servicing – May be fitted with clogging indicator – Fine filtraton is possible – No pump cavitation	– Bypass valve is necessary – Allows dirt particles to pass through the open bypass valve if pressure peaks occur or if a cold start takes place

Table 12: *Advantages and disadvantages of mounted return line filters*

The filter shown in *fig. 22* is mounted using a fixing flange (1) onto the tank cover. Housing (2) and filter port protrude into the tank. An advantage of this type of filter is the ease of access and hence the ease of servicing.

By removing the cover (3) the filter element (5) may be quickly and simply removed.

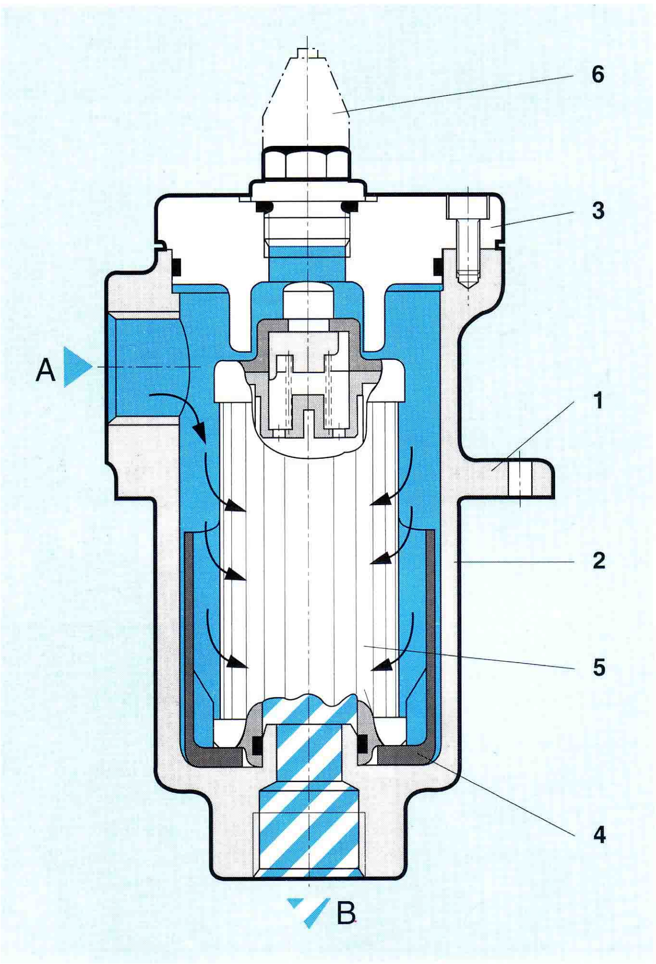


Fig. 22: *Sectional diagram of mounted return line filter for mounting in tank*

filter element (5). When the element is removed, the dirt collecting tray is also removed with it. This prevents the dirt which has been removed (collected) from flowing into the tank. A port for a clogging indicator (6) is usually present.

In order to avoid idle times due to the servicing of filters or changing of elements, double filters which may be connected in turn are used.

Here two filters are arranged in parallel. By switching to the second element, the first element may be changed without stopping the system.

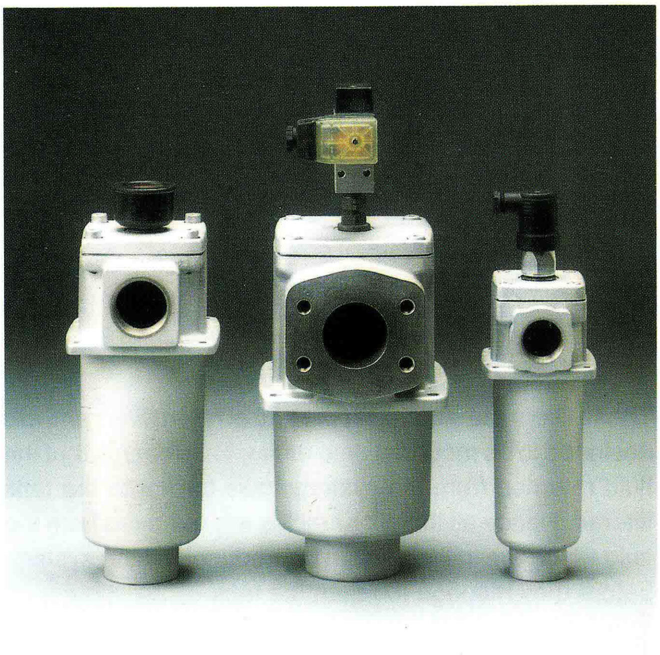


Fig. 23: *Mounted return line filter for mounting in tank*

A special type of return line filter may be fitted directly into a valve stacking assembly.

By using valves within blocks there is no need to pipe the return line.

The valve stacking assembly, type VAB comprises pressure relief valves, filter element and pressure gauge port with shut-off valve. On the bottom of the stacking assembly are the ports for the pump and tank. In type H on the top is the mounting pattern for hydraulic valves of sizes 6 or 10 to DIN 24 340. In type L a longitudinal stacking system for sizes 6 or 10 may be mounted by means of flanges on top.

The standard elements (1) from the RF series are used for the filter. A clogging indicator (2) may be mounted to monitor the degree of contamination.

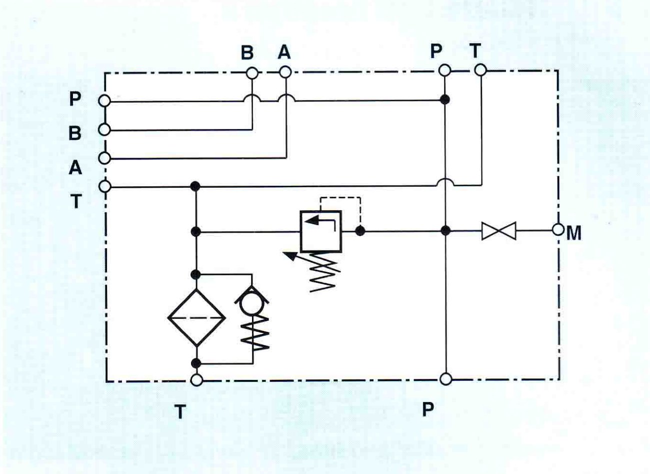


Fig. 25: *Symbol for valve connection block*

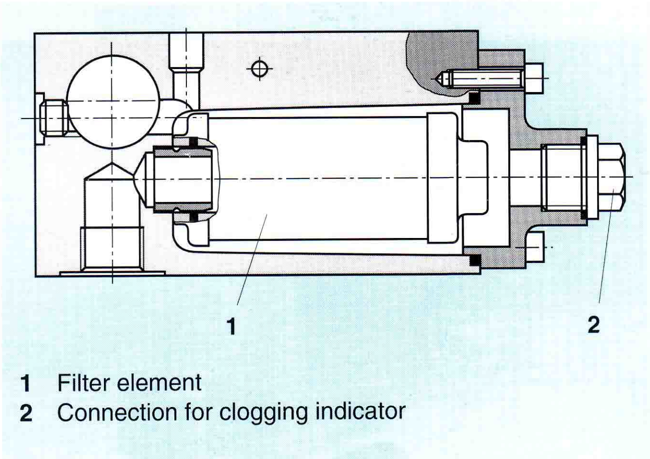


Fig. 26: *Sectional diagram for valve connection block*

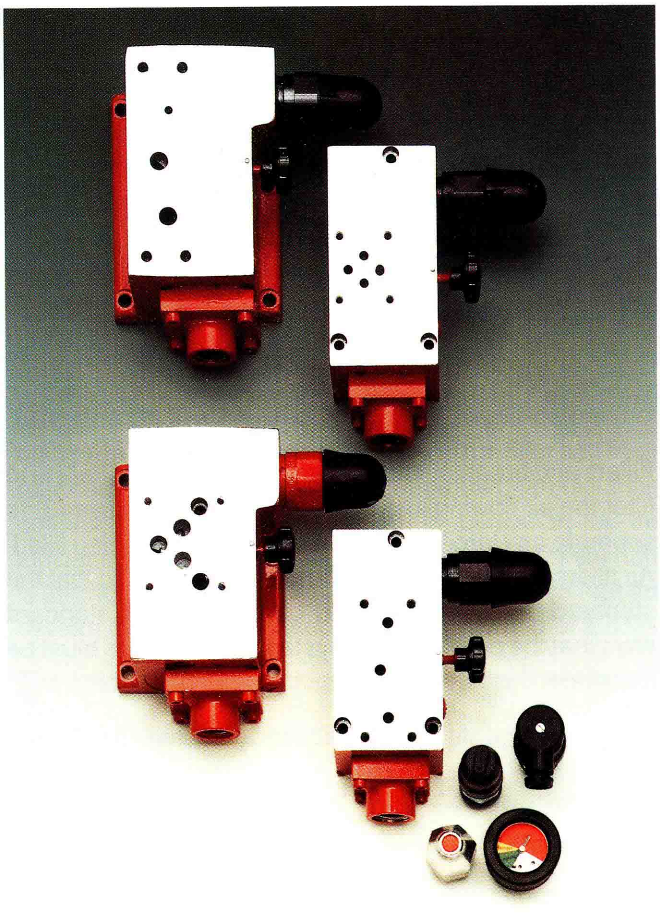


Fig. 24: *Valve connection block*

9.5 Fillers and breathers

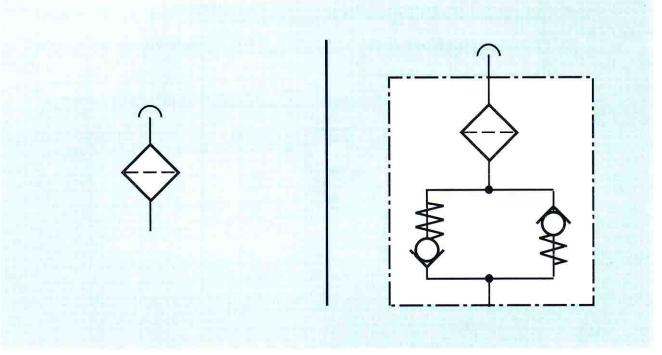


Fig. 27: *Symbol for filler and breather (left) without and (right) with bypass valve*

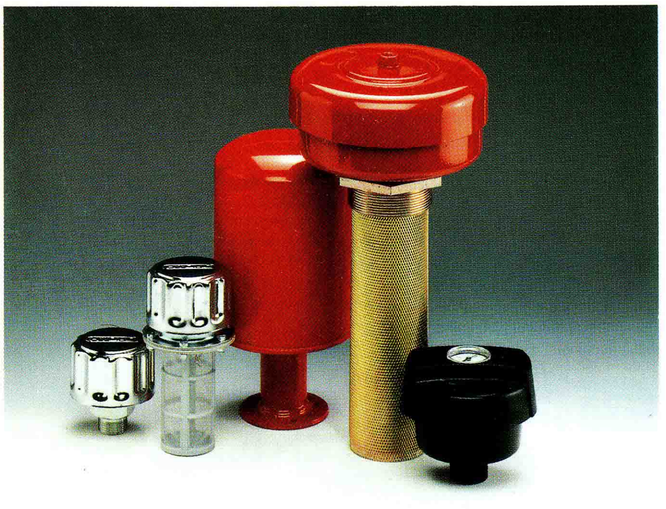


Fig. 28: *Filler and breather with and without filling sieve*

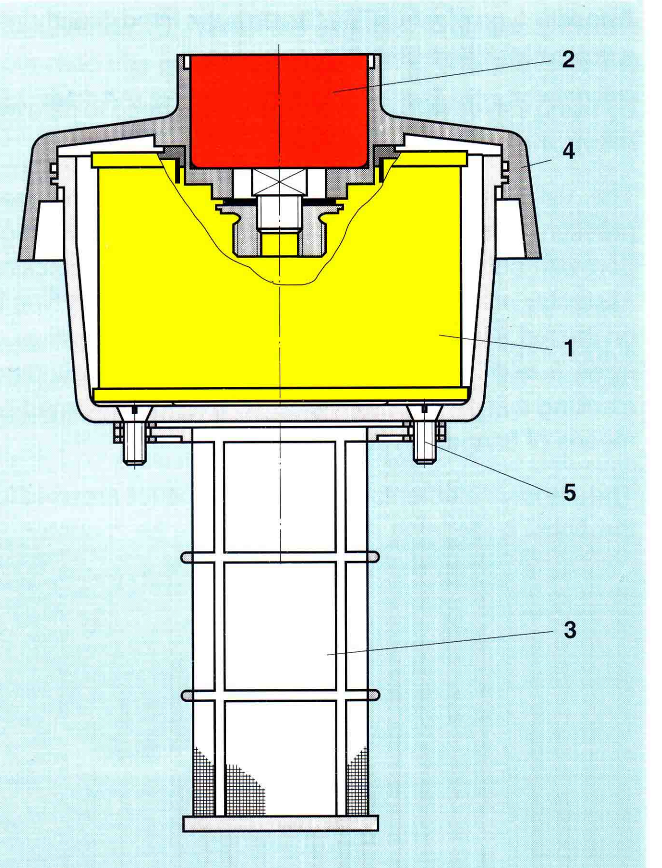


Fig. 29: *Filler and breather with filling sieve*

In the past little attention was paid to these filters in hydraulic systems. However, nowadays they are considered to be amongst the most important components for the filtration of fluid in a hydraulic system. A large amount of contamination enters hydraulic systems via unsuitable ventilation devices. Measures such as the pressurisation of oil tanks are usually uneconomic when viewed with respect to the highly effective breathers nowadays available.

Depending on the class of cleanliness required, breathers may be fitted with various interchangeable elements. These filters must be fitted with a port for a clogging indicator (2).

Fillers and breathers basically comprise an air filter (1) to filter the air flowing into the tank and a filling sieve (3) to separate any large particles when the tank is being filled. Air filters are available with various pore sizes so that the standard CETOP RP 70 may be fulfilled. This standard says that the pore sizes for system and air filters must be the same.

The requirements of this filter are laid out in DIN 24557.

9.6 Clogging indicators

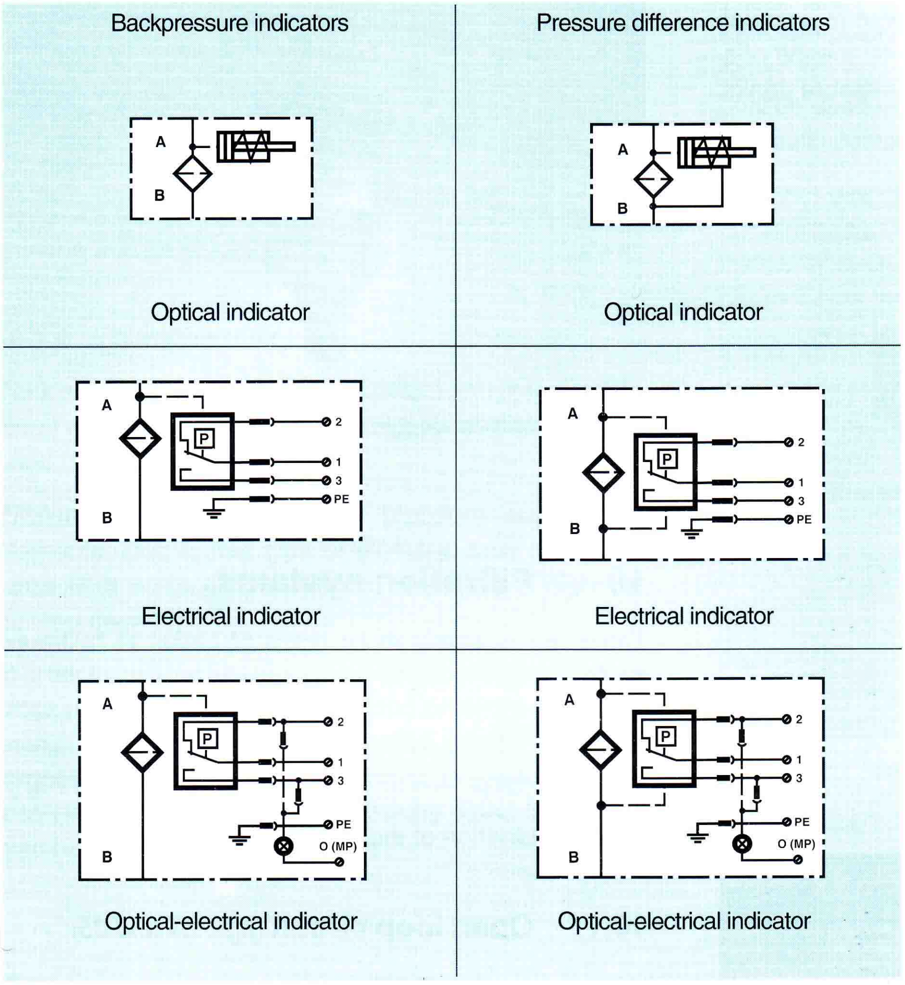


Fig. 30: *Symbols for clogging indicators*

Clogging indicators record when a pre-determined backpressure or pressure difference at the filter has been reached. Either an optical signal appears or an electrical contact is operated. The point of operation or the indicating point must be selected so that the filter element is still able to remove some more dirt. This is so that the system may continue to operate until the end of a shift.

The following types of clogging indicator are available:

- backpressure indicator
- pressure difference indicator and
- low pressure indicator

For pressure line filters the clogging indicators show the pressure drop between the filter input and output. In tank or block mounted return line filters the backpressure upstream of the element is measured. In suction filters the low pressure downstream of the filter element is measured. Clogging indicators must be able to be screwed into filters at any time as an afterthought without a lot of effort.

9.6.1 Function

In clogging indicators, each change in pressure is monitored by measuring spools or membranes as a change in stroke. Inside the clogging indicator is a spool connected to a solenoid which moves against the force of a spring. In an optical clogging indicator a solenoid with the same polarity is attached in the display head. The closer the poles come together, the greater the force with which the coils oppose each other, until the red display button jumps out.

In the electrical model a contact is closed.

Electronic clogging indicators were developed for the continuous display of element contamination. By using displays it is possible to calculate when servicing will be required.

In these completely electronic clogging indicators, the pressure difference existing in the filter as a result of element contamination is converted without movement into an analogue electrical output signal by means of a sensor. In addition a device to suppress pressure peaks and cold starts is installed.

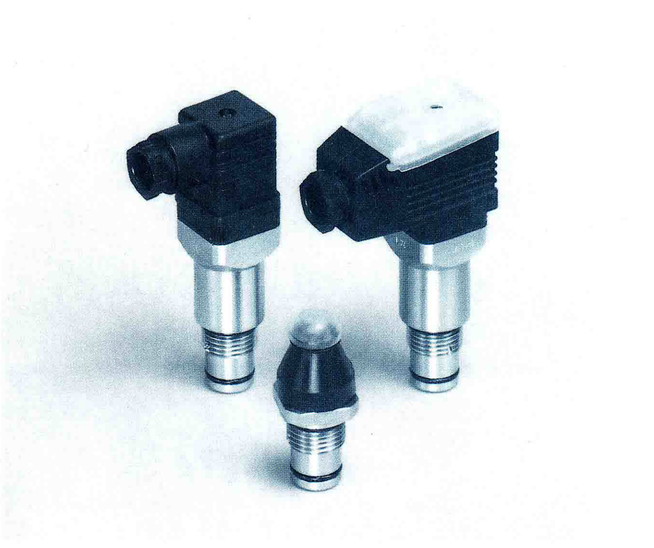


Fig. 31: Pressure difference clogging indicators

Fig. 32: *Backpressure clogging indicators*

Fig. 33: Electronic clogging indicator

10 Filtration systems

There are basically three types of circuit in hydraulic systems:

- open loop
- closed loop
- a combination of the above

10.1 Open loop circuit (*figs. 34 and 35*)

In open loop circuits the fluid is sucked out of the tank, pushed through the hydraulic system and led back to tank. The arrangement of filters in an open loop circuit depends on the tasks which the filters are expected to perform.

10.1.1 Main flow filter

Main flow filters are used to filter fluid which is found in the actual hydraulic circuit.

Suction, line and mounted return line filters may be used as main flow filters.

10.1.2 Bypass filters

These filters are used to filter the fluid found in the tank when it is circulating. Usually complete bypass filter units, comprising pump, filter and oil cooler are used.

The advantage of bypass filters is that the filters may operated independent of the operating cycles of the hydraulic system and the fluid flowing through the filter elements remains constant and without pulses.

The ageing process of the fluid is slowed down, so that the service life of the fluid is considerably increased.

10.1.3 Breathers

These filters are used to filter the air flowing in and out of the tank.

There are two types of filter dependent on their function: working and safety filters (*fig. 35*).

10.1.4 Working filters

Tank or block mounted return line filters and pressure line filters with bypass valves as well as bypass filters may be used here.

Working filters comprise low pressure stable filter elements. Due to this type of element, they may have large filter surfaces and hence they have a high dirt holding capacity.

In order to fulfil the filter task to an optimum degree tank or block mounted return line filters and pressure line filters being used as working filters must be placed where the largest flow in the hydraulic system occurs and they must also be sufficiently large. If necessary these filters may also be installed in leakage lines.

10.1.5 Safety filters

These filters are used to protect hydraulic components from suddenly malfunctioning due to a too high a level of solid particle contamination. This means that they should only be used to filter particles, which may suddenly clog hydraulic components.

A further use of safety filters is to protect a system from contamination when a pump or motor malfunctions. By installing such a filter high repair costs for damaged components may be avoided.

These filters must have a much larger pore size than the working filters used in the hydraulic system. The size of the filter may be smaller. The filter housing must not have a bypass valve. Hence these filters must be made of components which are highly pressure stable under pressure.

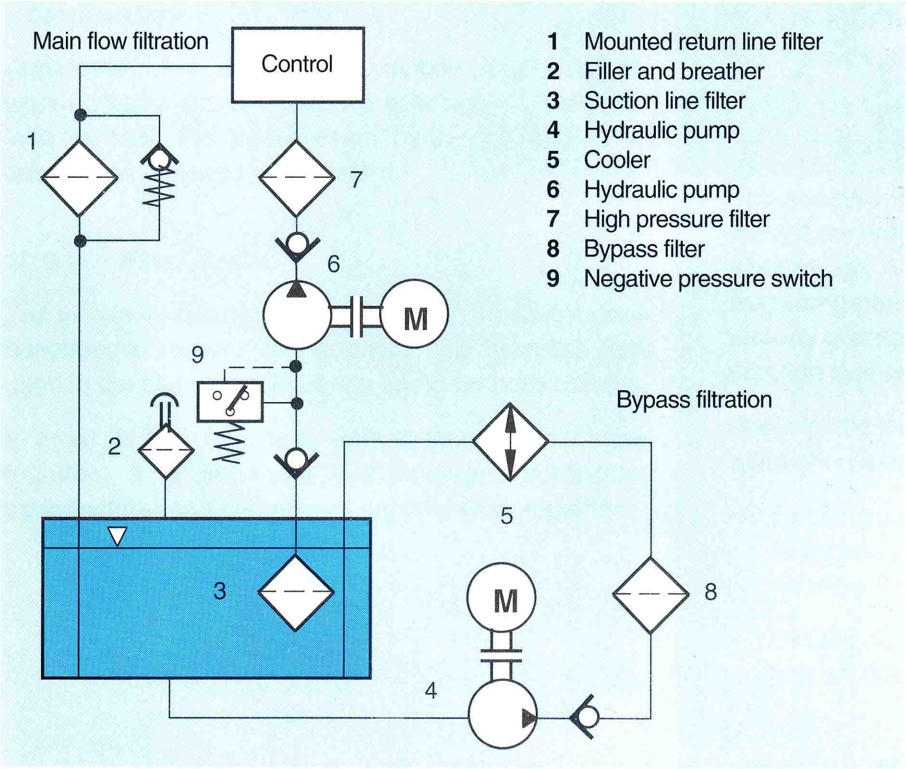


Fig. 34: *Filter arrangement in hydraulic systems*

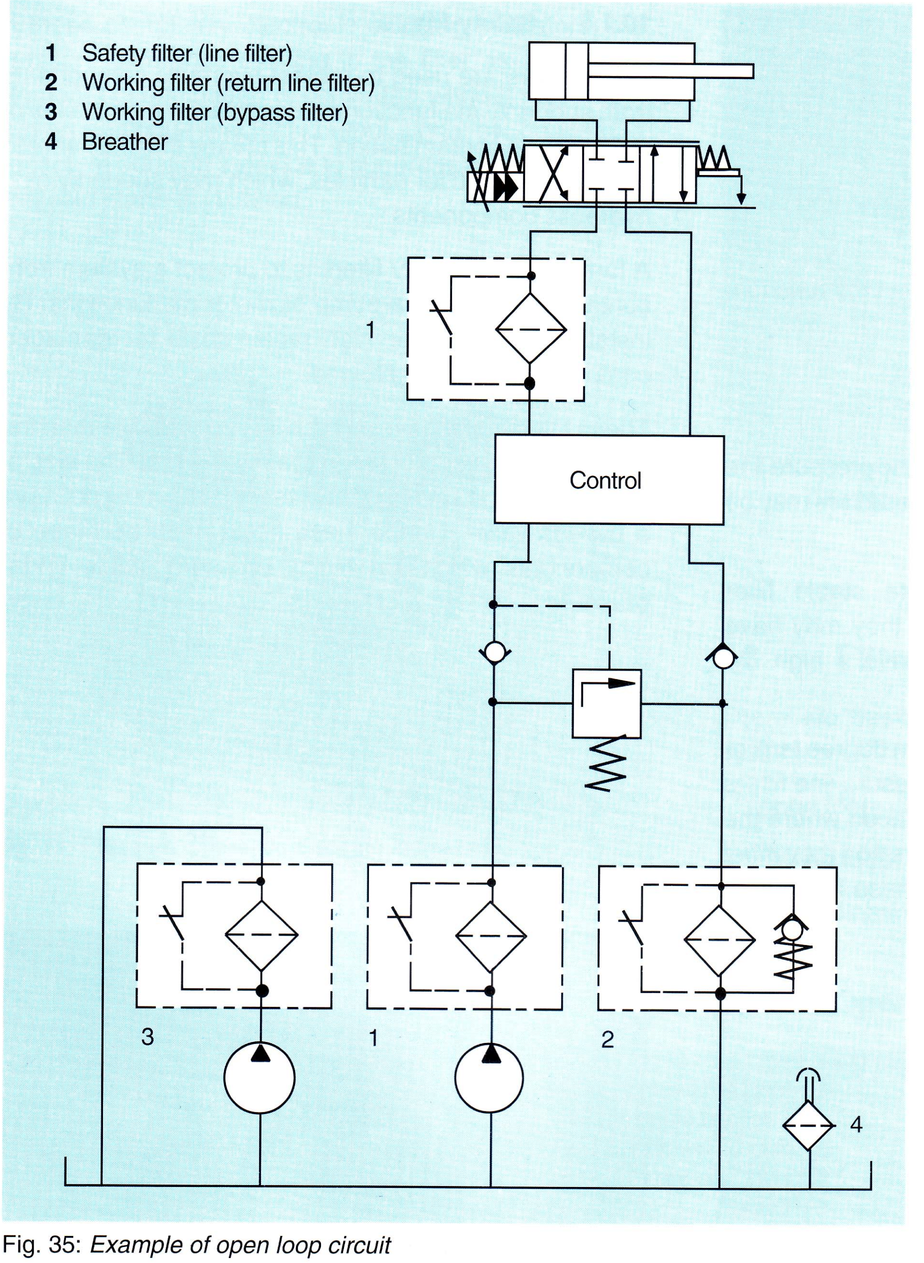


Fig. 35: *Example of open loop circuit*

10.2 Closed loop circuit

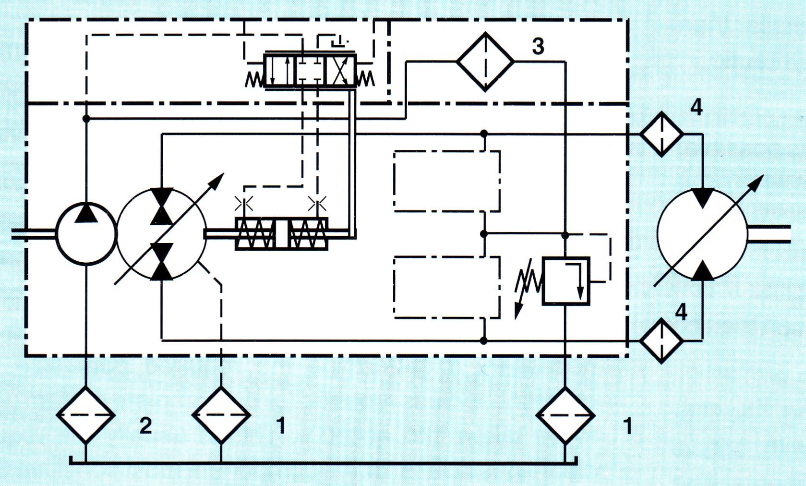
In closed loop circuits the fluid is continually pumped around the actual hydraulic circuit. Only the leakage oil flows back to the tank and is then fed back into the closed loop circuit by the boost pump.

Application: e.g. transmission hydraulics with hydraulic pump and hydraulic motor.

10.2.1 Filter model

The actual closed circuit is only filtered in the flushing stage. Once the system has been flushed the filters (4) are removed. The fluid is filtered either when the leakage oil flow is returned (1), in the suction line (2) or in the pressure line of the boost circuit (4).

By using pressure sensitive sealing systems in motors and pumps, it is only possible to filter the leakage oil flow in the return line using sieve filters with large pore sizes. These only produce a low pressure loss.



1 Mounted return line filter in leakage line
2 Suction line filter in boost line
3 Line filter in boost line
4 Flushing filter in closed loop circuit

Fig. 36: *Example of closed loop circuit*

10.3 Combination of both types of circuit

Where both types of circuit are combined the open and closed loop circuits installed in the system are supplied by a common tank.

Application: For example, in mobile machines, the working hydraulics and steering is designed as an open loop system, the transmission hydraulics and rotary actuator as a closed loop system.

10.3.1 Filter model

The individual circuits may be fitted with the filter models described in *sections 10.1 and 10.2*. The filter pore sizes used in the filters should be the same for both circuits.

In order for both circuits to work to an optimum degree together, it is important that operator, component manufacturer and component supplier work together.

11 Selection of filter

11.1 Filtration design

An effective filtration in hydraulic systems prevents disturbances and at the same time increases the service life of important and expensive components.

Hence: **Filtration is not a necessary evil, but a beneficial necessity**

The effectiveness of a filter is the most important factor but not the only factor which influences the evaluation of filter design. A filter may be ineffective if it is installed in the wrong place or if it designed for the wrong task. As already mentioned, one or more filters may be used for filtration purposes.

In designing the filtration for a system the following basic rules should be taken into account:

- By using suitable seals and installing highly effective fillers and breathers, dirt must be prevented from entering the system from outside.
- Dirt should be removed as quickly as possible after it has entered the system or after it has been created.

- Hydraulic filters should always be used to help reduce wear, i.e. the filter pore sizes should be smaller than the critical clearance tolerances for the hydraulic components.
- So that the filters can clean as much fluid as possible, they should always be installed in positions where the most flow is expected.
- A specification must be written.

Following on from these basic rules the filters can then be divided into working and safety filters.

The working filters carry out the task of cleaning. The filter pore size should be chosen to comply with critical clearance tolerances of the hydraulic components. The filters may have bypass valves and be fitted with low pressure difference stable filter elements. It is recommended that a pressure difference indicator is fitted.

The required protection against clogging is achieved by fitting a safety filter, i.e. these filters only remove particles which could lead to hydraulic components becoming suddenly clogged.

Safety filters prevent long-term wear and for this reason should have a larger pore size than the working filters. Safety filters should not have bypass valves and they must comprise high pressure difference stable filter elements.

11.2 Filter design criteria

In addition to the requirement for functional safety of and long service lives for hydraulic components, the operating and system costs and the cost of disposing of the fluid are important when designing a suitable hydraulic filter system.

The following criteria should be taken into account when designing a filter system:

- Sensitivity to dirt of the hydraulic components used
- Application for the complete system
- Determination of flow
- Permissible pressure difference or backpressure
- Compatibility of fluids with the filter materials
- Operating temperature
- Viscosity of fluid
- Design temperature
- Additional devices (e.g. clogging indicator)

11.3 Selection of filter elements

The recommended pressure losses in clean elements and at operating viscosity should not exceed the following values in the complete filter (housing and element):

Line filter without bypass: $\Delta p_A = 0.2 \times \Delta p_{Indicator}$

Line filter with bypass: $\Delta p_A = 0.15 \times \Delta p_{Indicator}$

Mounted return line filter: $\Delta p_A = 0.2 \times \Delta p_{Indicator}$

Before the size of the filter can be determined it is necessary to determine the required pore size. The cleanliness class required for the complete system needs to be taken into account. This is usually the required cleanliness class for the component most sensitive to dirt in the hydraulic system.

In order to attain a specific cleanliness class filter elements must be used with an absolute filter pore size ($\beta_x \geq 100$).

Tables 13 and 14 can be used to determine which pore size to use and hence which filter element.

Hydraulic system	Preferred absolute filter pore size ($\beta_x \geq 100$)	Attainable cleanliness class to NAS 1638 in particles > 5 µm	Attainable cleanliness class to ISO 4406
Systems with servo valves	X = 5	7	16/13
Systems with control valves	X = 5	7 to 8	16/13
Systems with proportional valves	X = 10	9	18/15
General hydraulic systems	X = 10 to 20	9 to 10	19/16

Table 13: *Determination of recommended filter pore size in hydraulic systems using Rexroth components*

Once the required filter pore size has been determined, it is then possible to determine the size of the filter. In determining the filter size the aim is to achieve a balance between the dirt entering the system and the dirt leaving the system via the filters. An economic time between element replacement also needs to be realised.

Hence when determining the size of a filter the degree of contamination in the machine environment, the care and service of the hydraulic system and the operating temperature of the fluid need to be taken into account.

The formulae required to determine the size of a filter are shown in *table 15*.

Application	Filter pore size µm	Element designation	Pressure difference stability	Remarks
Working filter, bypass filter, mounted return line filter, line filter with bypass valve	3	.R 003 BN/HC-2	30 bar	
	3	.D 003 BN/HC-2		
	5	.R 005 BN/HC-2		
	5	.D 005 BN/HC-2		
	10	.R 010 BN/HC-2		
	10	.D 010 BN/HC-2		
	20	.R 020 BN/HC-2		
	20	.D 020 BN/HC-2		
Safety filter, line filter without bypass valve	3	.R 003 BH/HC-2	210 bar	Further filter pore sizes on enquiry
	5	.D 003 BH/HC-2		
	10	.R 005 BH/HC-2		
	20	.D 005 BH/HC-2		
	25	.D 025 W	30 bar	
	25	.D 025 T	210 bar	
	50	.D 050 W	30 bar	
	50	.D 050 T	210 bar	
	100	.D 100 W	30 bar	
	100	.D 100 T	210 bar	

Table 14: *Selection of filter elements with respect to application and corresponging required filter pore size*

Filter arrangement in hydraulic system	Filter type	Total pressure difference in filter with new filter element	
		By using individual diagrams for filter housing and filter element	By using design diagrams
Working filter	Mounted return line filter, line filter with bypass valve	$f_2\ (\Delta p_{housing} + f_1 \times \Delta p_{element}) \leq$ 0,15 to 0,2 x $\Delta p_{indicator}$	$Q_{design} = Q_{system} \times f_1 \times f_2$
	Bypass filter, line filter; separate power units	—	—
Safety filter	Line filter without bypass valve	$f_2\ (\Delta p_{housing} + f_1 \times \Delta p_{element}) \leq$ 0,2 x $\Delta p_{indicator}$	$Q_{design} = Q_{system} \times f_1 \times f_2$
	Suction filter	$f_2\ (\Delta p_{housing} + f_1 \times \Delta p_{element}) \leq 0{,}01$	Q_{design} = 5 to 10 x $Q_{pump} \times f_2$

Table 15: *Determination of filter size*

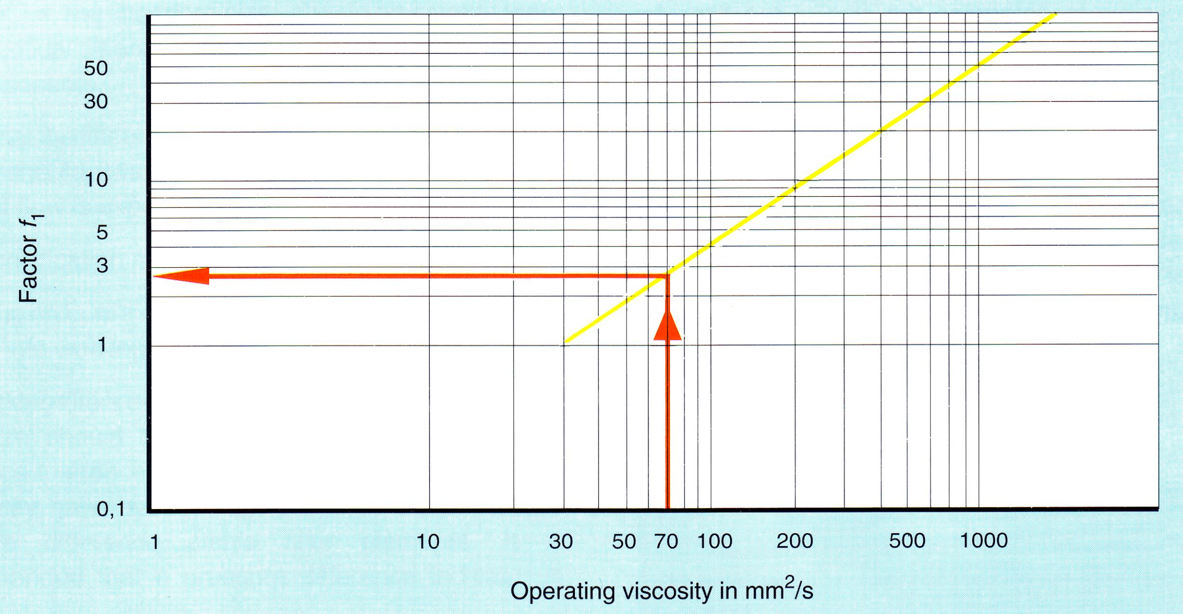


Diagram 7: *Graphical representation of viscosity conversion factor f_1*

Servicing and care of hydraulic systems	Degree of contamination in machine environment		
	[1] low	[2] average	[3] high
– Continuous control of filters – Immediate changing of filter element – Low dirt ingress – Good sealing of tank	1,0	1,0	1,3
– Sporadic checking of filter – Use of few cylinders	1,0	1,5	1,7
– Little or no control of filter – Many unprotected cylinders – High level of contamination entering system	1,3	2,0	2,3

Table 16: *Factor f_2 for ambient conditions*

Remarks to *table 16*
[1] low;
e.g. test machines in sealed climatised chambers
[2] average:
e.g. machine tools in heates halls
[3] high:
e.g. presses in founderies, machines for ceramic manufacture, machines in potash mines, agricultural machines and mobile devices, rolling mills, carpentry

In order to shorten and simplify the relatively complex process of determining the filter size, filter design diagrams were developed (see diagrams 8,9 and 10).

The diagrams are with respect to a viscosity of 30 mm²/s for the fluid. Higher operating viscosities and variations in ambient conditions are taken into account when determining the flow for the filter design.

The flow for the filter design using the diagrams is calculated from the following:

$$Q_A = Q_W \times f_1 \times f_2$$

Q_A = flow for filter design
Q_W = effective flow
f_1 = viscosity conversion factor
f_2 = factor for ambient conditions

The required filter size is determined from the point of intersection where the flow crosses the filter pore size.

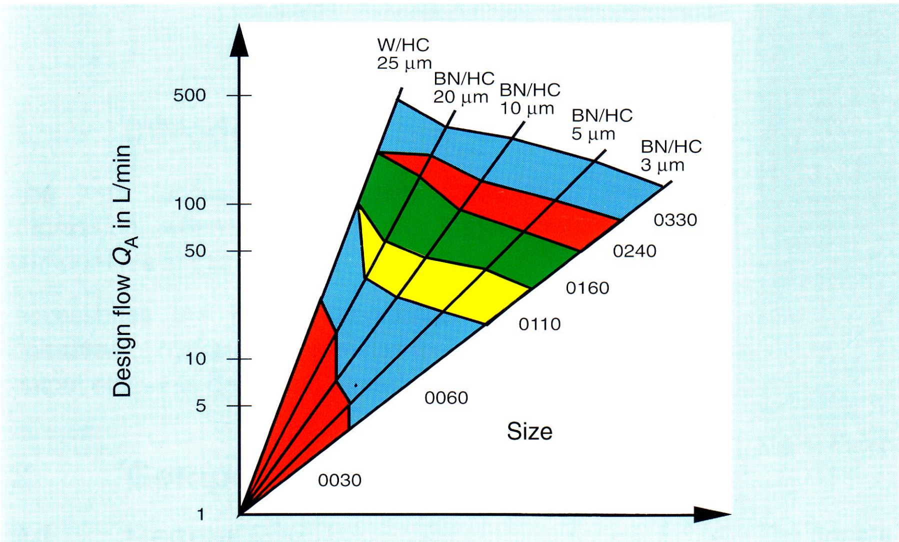


Diagram 8 :

Determination of filter size in mountec return line filters

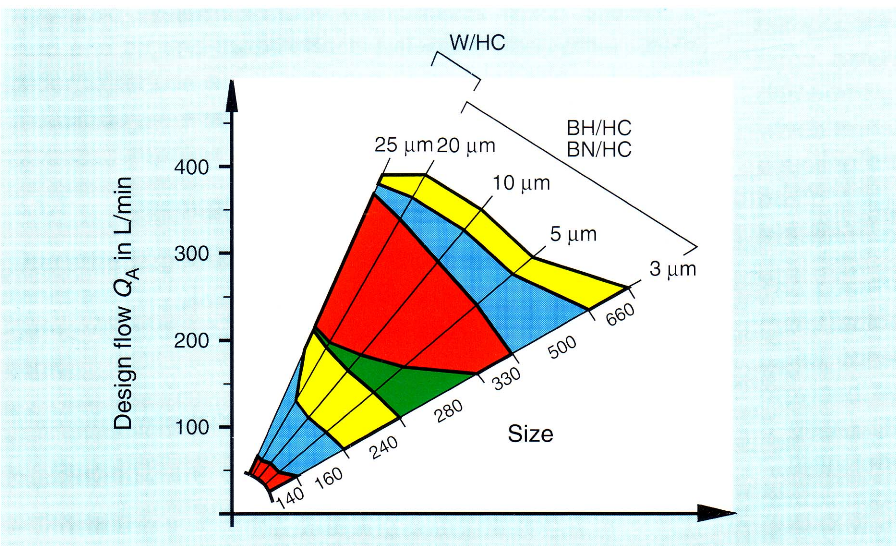


Diagram 9 :

Determination of filter size in powei filters

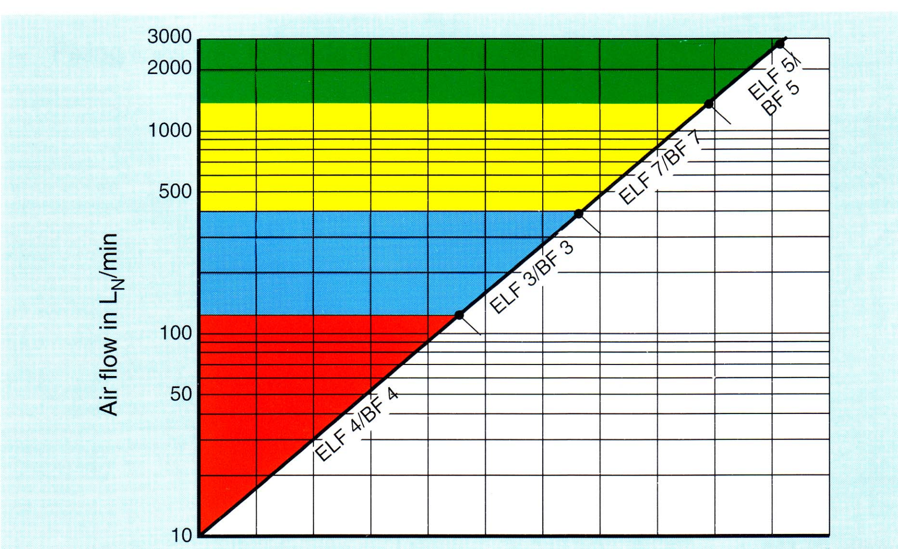


Diagram 10 :

Determination of filter size in breaters