Filtration in Hydraulic Systems

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1 Introduction

Efficient and effective filtration in hydraulic systems is absolutely essential in order to prevent malfunctions and, at the same time, to increase the service life of important and expensive components.

Any analysis of the causes of hydraulic system failure will show that a majority of them are due to solid particles contaminating the fluid.

Such contamination is a result of inadequate filtration.

The repair costs of components can only be kept under control by preventive maintenance of the whole system. Constant checking of the fluid (*see Section 4.8*) provides a background for the condition of the fluid at any time. The necessary counter-measures can then be adopted as soon as deterioration sets in and any resulting damage can be minimized.

The constant clamour for better performance from hydraulic components means that fits and clearances are becoming ever tighter. Whereas in past years an absolute filtration rating of between 80 and 100 µm was usual for hydraulic systems, nowadays the minimum value is around 20 µm. When servo valves are used in a system the figure can be as low as 3 µm.

A correct choice of filter is essential as early as the project design stage of a system. However, the initial good intentions of project engineers are often overridden by price considerations once the contract is awarded. Changing the size of filter and the filtration rating is a simple method of reducing a quoted price without seeming to have any adverse effect on the functioning of the system. Retro-fitting of a more suitable filter, however, is complex and expensive. Also, the overall impression of the system suffers from the fact that the filters are less than the best. This often spoils the carefully nurtured image of the supplier.

It cannot, therefore, be emphasized strongly enough that there should be no "cutting of corners" as far as filters are concerned. Any extra costs incurred through the use of larger but optimum filters will definitely and quickly be recouped through less maintenance and downtime.

Using filters with more filtration surface area reduces the surface loading for the same throughput. This produces a disproportionate increase in filter life (*see Diagrams 32 and 40*).

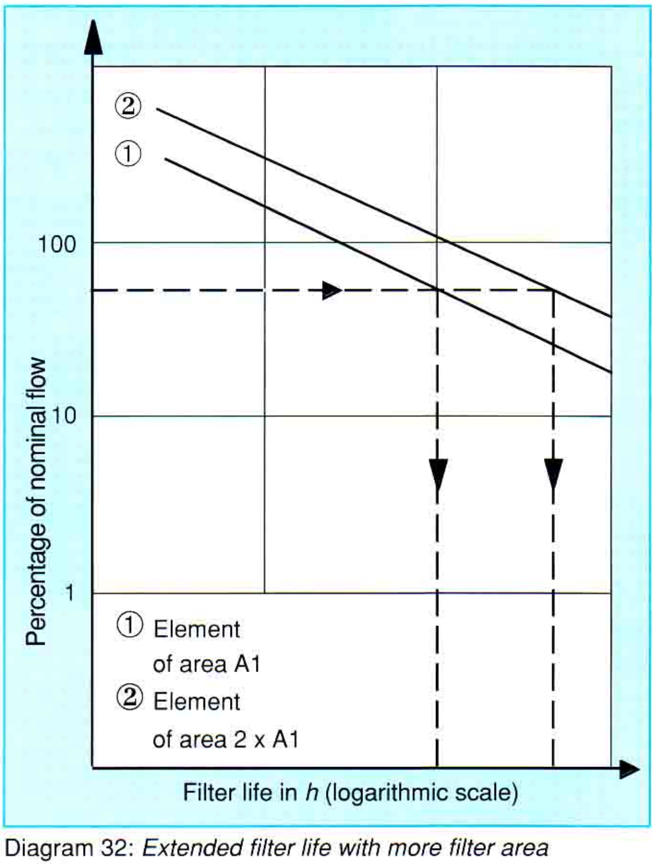


Diagram 32: *Extended filter life with more filter area*

When selecting the filtration rating

- remember that the component with the tightest clearances governs the rating figure for the whole system
- and filtration ratings must be selected for those components. Power units must not simply be equipped with the finest filter available from the manufacturer.

2 Functions of filters in hydraulic systems

2.1 The effect of solid particle contamination

General

Tests on hydraulic systems have shown that reducing the amount of solid particles in the hydraulic fluid makes an important contribution to longer component life and functional reliability.

Solid particles are often produced by high mechanical or hydraulic stresses and, when they are allowed to circulate unhindered in the system, cause severe wear. Quite naturally, this in turn produces more solid particles. Contamination entering the system from outside can sometimes initiate or accelerate the condition. The chain reaction of solid particle production and accumulation can be minimized by the use of a good filter. Effective filtering of the fluid put into the system, clean assembly and thorough flushing are all essential to give components the best start in life.

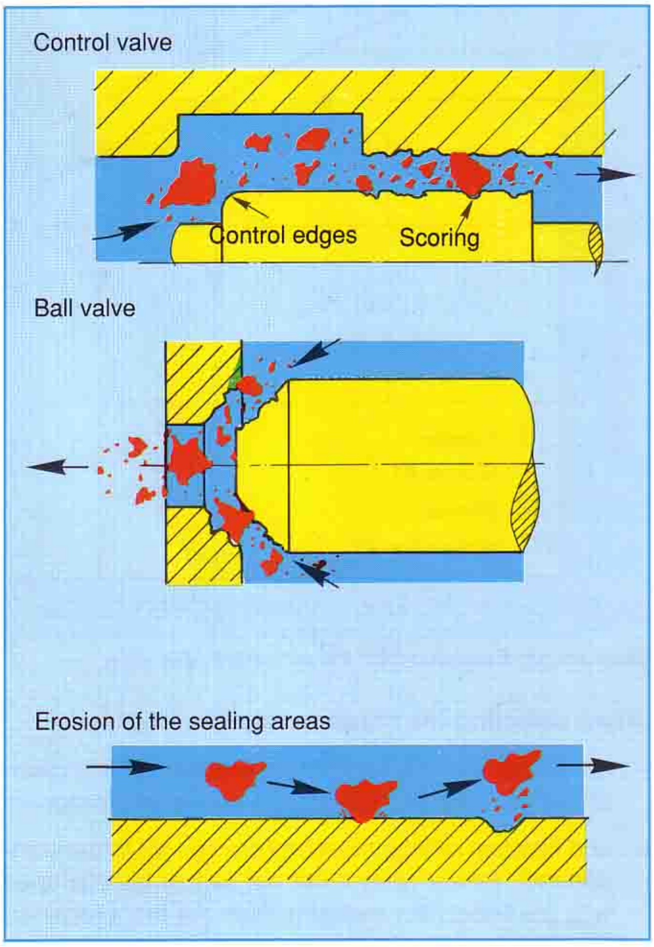


Fig. 83: *Surface damage due to solid particles*

Control valves and pumps

It will be clear from *Fig. 83* that solid particles substantially smaller than the clearance between two surfaces, e.g. an oscillating spool, cause no damage; they simply pass through the gap. If the relative motion is only occurs occasionally, however, there is a danger of the gap becoming silted up which can cause the valve to malfunction. Any solid particles larger than the gap build up in front of it and, to begin with, have no adverse effect on the valve. However, at high operating pressures or flow velocities there is a danger of the motion of the spool crushing the particles and forcing them into the gap.

Particles of about the same size as the gap itself are the most dangerous of all for the components because they cause scratches and therefore heavy wear. The cutting action of the original particles produces new particles and a chain reaction is initiated. Component failure is very often due to these solid particles.

Control lands frequently suffer from erosion due to the high flow velocities prevailing there. The erosion is made worse by any solid particles in the fluid. The end result is a change in the control characteristics of the component.

Seated valves (poppet valves)

Particles can become trapped between the valve and its seat, so causing it to leak.

Throttles and orifices

Particles of dirt in the hydraulic fluid become stuck in the orifices and the restriction interferes with the accuracy of flow control.

Bearings

With sintered bearings the particles of dirt get into the pores or, if they are hard particles, they can be pressed into the relatively soft sintered material. Severe scoring of the shaft is the result. The blocking of lubricating grooves is also a possibility, causing the bearing and shaft to run hot.

Erosion by solid particles

Due to the pressure gradient across a gap, solid particles are forced through the gap at approximately the same velocity as the flow within the gap. Due to its mass, each particle possesses certain energy which is given up when the particle strikes the surface. This causes other particles to be detached from the surface, so increasing the amount of solid particles in the fluid.

The effects of solid particles in a system

- Increased leakage
- Jamming of pistons and spools
- Component failure
- Changes in control characteristics

2.2 Types of contamination

The following are the different kinds of contamination encountered in hydraulic fluids (see Table 18).

Hard and sharp particles

These are mainly responsible for the wear of components. Their precise effect on the component depends on their shape and what they are made of.

Hard and sharp particles cause deep scratches and so are more dangerous than soft, spherical particles. They must be filtered out by means of filters in the systems which must be of a size and rating appropriate to the type of contamination anticipated.

Soft and gelatinous particles

These can cause blockages in working clearances and so lead to component failure. They also interfere with lubrication by gumming up lubricating channels.

Good system filters will take out these particles but they eventually block the filter element so a reduced filter life must be anticipated.

Dissolved substances in the fluid

These do not cause any wear of the components but they can lead to changes in the lubricating characteristics, faster ageing, carbonization and the deterioration of the filtration capacity of the fluid.

Material	Effect
Carborundum Scale, rust particles	Very severe damage
Steel Iron Brass Bronze Aluminium	Severe damage
Laminated fabric Fibres Seal residue Rubber particles from hoses Paint particles Oxydation products from fluid	Slight damage

Table 18: *Effects of solid particle contamination on working clearances*

Dissolved substances cannot be filtered with normal filter elements so all the fluid must be changed and the system thoroughly flushed out.

2.3 Effect of contamination on component wear

Generally speaking, all solid particles cause wear in hydraulic components. However, the actual amount of wear depends on the following parameters:

- The material of the solid particles
- The size of the solid particles
- The ratio of particle size to working clearance
- The shape of the particles
- The working pressure
- The flow velocity

Hard, mineral particles in even small quantities can cause serious damage. The frequency of damage depends on the operating pressure. The higher the pressure in the system, the more the particles are forced into the working clearances and the greater is the damage.

2.4 The origins of solid particle contamination

Before or during commissioning

In spite of thorough flushing of the equipment after assembly it is impossible to remove entirely every last particle of dirt from the components and pipework. Tests have shown the following substances to be present on many occasions:

core sand, weld spatter, swarf, scale, fluff,
rust, packaging residue, paint.

The hydraulic fluid itself with which the system is filled can be a major source of contamination so the following procedures should be adopted before the system is commissioned.

a New fluid should always be put into the system through the filter or a separate filter unit similar to that shown in Fig. 84. The filtration rating of the flushing filter or filling unit must be at least the same as the filtration rating for normal operation of the system.

b The existing hydraulic fluid in the system should be cleaned with a separate filter unit.

c Start the hydraulic pump. Keep the separate filter unit operating and this will ensure that the large amount of solid particle contamination to be expected in the fluid returning from the hydraulic power unit will also be filtered out.

d After a predetermined amount of flushing, take a fluid sample and determine the amount of contamination. Dependent upon the results, more flushing may be needed.

As *Diagram 33* shows that, the amount of flushing depends on the size of the tank, the cleanliness of the installation, the components being used, the required cleanliness of fluid and the cleanliness of the new fluid added.

The amount of flushing required can be gauged only very roughly before the actual flushing begins and it must be anticipated that high-precision components might be damaged during the flushing. Therefore, this type of component, e.g. servo valves and proportional valves, are best not installed until the flushing has been completed.

Of course, an installation should always be flushed again by the operator if any subsequent modifications are made to the piping, after repair work or if the equipment is moved to a new site.

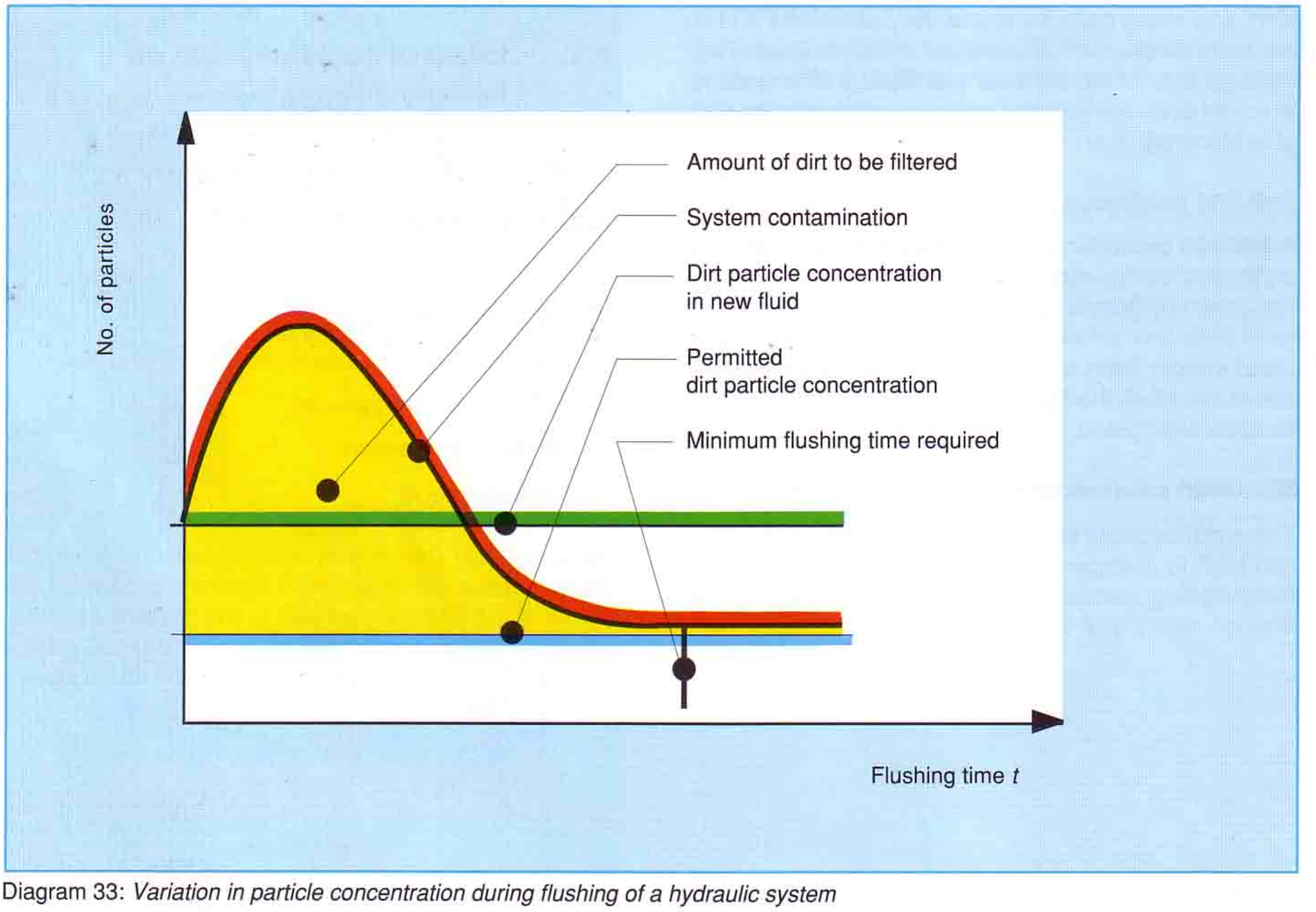


Diagram 33: *Variation in particle concentration during flushing of a hydraulic system*

Fig. 84: *Separate filter unit for cleaning hydraulic systems and filling them with fluid*

During operation of the system

This type of contamination can be divided into:

- internal contamination
- external contamination

Internal contamination means all the contamination originating from inside the system itself, e.g. due to wear at control lands, cylinders and pistons, particles of rubber from hoses and seals, particles of paint and the products of oxidation of the fluid.

External contamination is a result of dirt penetrating badly sealed tanks, unsuitable air filters and damaged seals on pistons and piston rods.

The task of the filters installed in the system is to filter out the internal and external contamination and so interrupt the chain reaction that produces contamination in the first place.

Tests have shown that, when using very fine filters in well-kept units with good external sealing, it is possible to achieve a much higher total number of service hours with less downtime.

2.5 The task of the hydraulic filter

The filters installed in hydraulic systems are of the same critical importance to its overall function as every other component with which it is associated. Correctly sized and installed filters ensure that the costs of maintenance, repair and downtime are kept to a minimum. Their use improves the efficiency of the hydraulic system and hence of the total installation of which it forms part. The filters also have a great effect on the operator's opinion of the availability and reliability of the system.

A correctly sized filter must perform the following tasks:

- Remove solid particle contamination from the hydraulic fluid
- Prevent functional disturbances due to solid particle contamination
- Prevent variations in switching times due to damaged control lands
- Reduce downtime between maintenance shutdowns
- Increase component life
- Permit preventive maintenance
- Prevent aging of the fluid due to chemical processes (resulting from solid particle contamination)
- Maintain the lubricity of the fluid
- Extend the life of the fluid
- Maintain high reliability between maintenance shutdowns
- Ensure long maintenance intervals for the filter
- Ensure continuous filtering of solid particle during service
- Have a high dirt holding capacity
- Ensure reliability and availability of the hydraulic system
- Ensure proper functioning of the filter under changing pressure and flow conditions in the system

3 Requirements for hydraulic filters

3.1 Testing standards

The filters used in hydraulic systems are subjected to a variety of tests on the elements and housings.

A filter element is assessed from criteria laid down in testing standards. These standards can either be applied individually or in combination depending on the requirements.

Testing standards are listed in the Appendix.

3.2 Filter elements

3.2.1 Materials for filter elements

The effectiveness of a filter element is governed by the type of mat employed. Filter mat is sometimes also called a matrix. The types of material used for filter mat allow filter elements to be divided into two broad groups:

- Surface filters
- Depth filters

Advantages and disadvantages of various materials

General

Surface filters and depth filters vary in terms of dirt holding capacity and filtration capacity according to their different construction (*see Diagrams 34 and 35*).

Surface filters

Fabrics in a variety of forms are used as the material in this case *(see Table 19).*

Due to their construction the filters possess a defined filtration rating referred to cubic particles which are about the same size as or larger than the mesh size of the filter. Under certain circumstances it is possible for long, thin particles such as fibres to pass through these filters.

The free filter area available for filtering is small depending on the filtration rating. ("Free filter area" means the area through which the fluid flows.) With surface filters the free filter area is approximately 30 to 40% of the total filter mat area. With a filtration rating below 25 µm the free filter area is even less.

Elements with a filtration rating of over 40 µm can be well cleaned quite simply. When the filtration rating is less than 40 µm it is advisable to supplement the cleaning process with an ultrasonic bath.

Due to the simple cleaning, low initial pressure drop and high differential pressure stability, especially with braided mesh, this type of filter element is chiefly used as safety filters in hydraulic systems, in lubrication systems and back flushing systems.

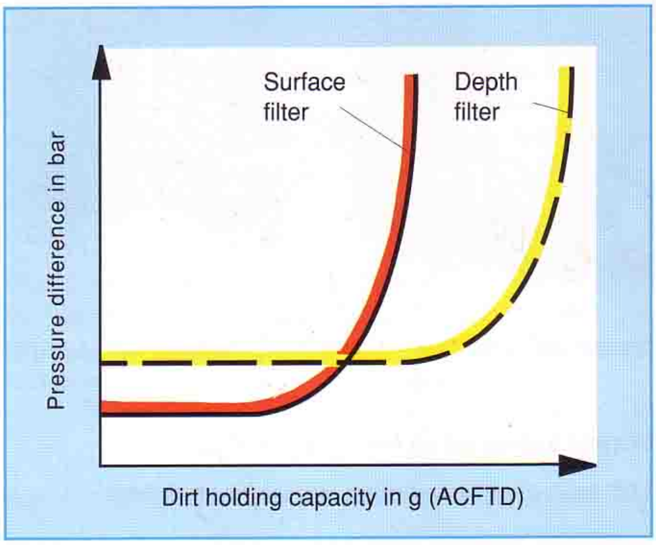


Diagram 34: *Dirt holding capacity of surface filters and depth filters*

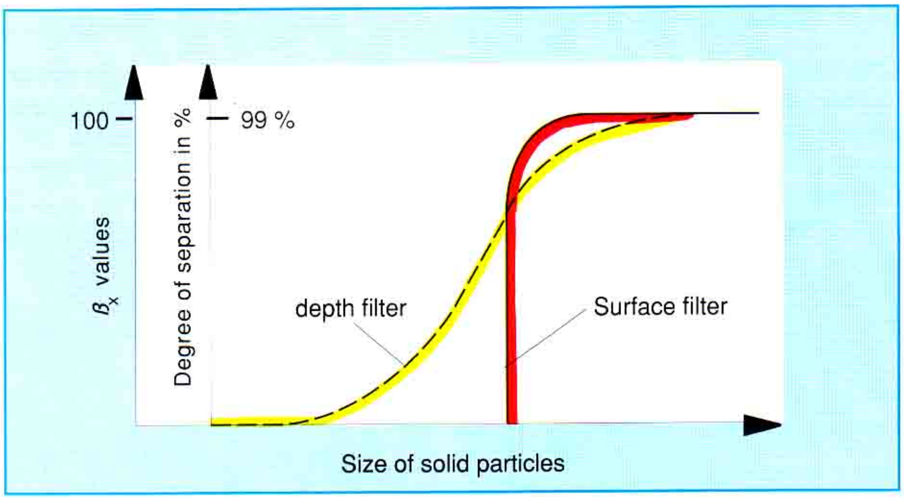


Diagram 35:
Filtration capacity of surface filters and depth filters

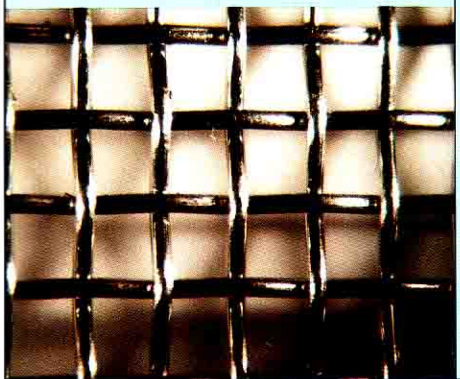
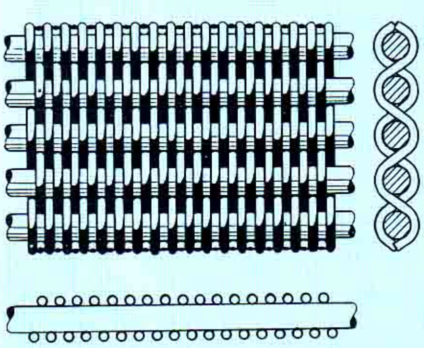
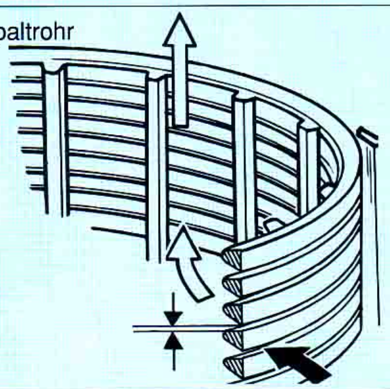
Construction		Application	Advantages	Disadvantages
Wire mesh 	Square mesh, stainless steel, galvanized iron or phosphor bronze	Lubricating oil filters, coarse filters, protection filters, suction filters For filtering water, fire-resistant fluids, at high operating temperatures, special fluids	Elements can be cleaned Low pressure drop	Filtration ratings below 10 µm impossible Multi-pass impossible *(see section 3.2.3)* Small free filter area (aprox. 30 to 40%)
Braided mesh 	Different wire gauges for warp and weft Stainless steel mesh	Coarse filters and protection filters	Elements can be cleaned Low pressure drop Very high pressure differences possible (up to Δp= 420 bar)	Multi-pass impossible *(see section 3.2.3)* Small free filter area
Spaltrohr 	Triangular-section wire wound on to a former at different pitch angles Stainless steel wire	Backflushing filters or coarse filters	Elements can be cleaned during operation Suitable for corrosive media, water, fire-resistant fluids	Filtration ratings below 50 µm impossible Small free filter area Multi-pass impossible *(see section 3.2.3)*

Table 19: *Materials for surface filters*

Depth filters

Cellulose, plastic, glass and metal are the materials used for this type of filter *(see Table 20)*. The pore structure is very closely related to the type of fibrous material used and the length and thickness of the fibres. There is no defined filtration rating from the construction. The resulting labyrinth effect causes particles of dirt of a wide variety of shapes and sizes to be trapped in the depth of the filter mat. It is possible to draw a "filtration profile" which must be determined by experiment.

With the exception of metal non-woven elements, depth filters cannot be cleaned and are regarded as disposable elements. Due to their excellent filtration performance and high dirt holding capacity they are chiefly used for the filtering of solid particles under 20 µm in size. This is usually necessary with systems that are particularly sensitive to dirt.

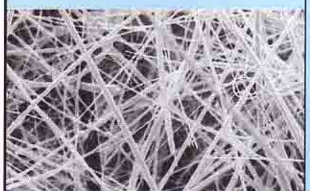
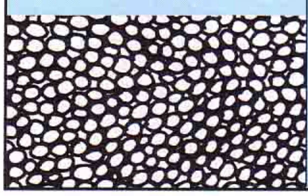
Filter material	Construction	Application	Advantages	Disadvantages
Paper non-woven 	Organic fibres, random layering with binding agent	Suction filters Return line filters Fine filters Disposable elements	Low cost Low pressure drop	Multi-pass restricted Medium dirt holding capacity Low pressure drop strength
Phenolic resin-impregnated Paper non-woven 	Organic fibres, random layering, impregnated with phenolic resin	Fuel filters Engine oil filters Fine filters Disposable elements	Low cost Simple element construction Large filter area	Multi-pass restricted, poor dirt holding capacity, not suitable for all fluids, low pressure drop strength
Glass fibre non-woven 	Glass fibre, random layering with binding agent	Very fine filters for precision components Disposable elements	Fine filtering possible with glass fibre, good dirt holding capacity, absorption of particles over wide pressure drop range, good chemical resistance, suitable for all hydraulic systems	High pressure drop Cannot be cleaned Low flow resistance
Metal non-woven 	Stainless steel wire random layering, sintered and calendered	Fine and very fine filtering, for high operating temperatures, high pressure drops, all fluids, limited cleaning of elements	Low pressure drop, good dirt holding capa-, city, Multi-pass possible with high-quality non-wovens, good fatigue properties, high temperature resistance, good compatibility with fluids	Very expensive Limited cleaning, depending on pressure drop and filtration rating
Sintered metal 	Metal granules sintered together. The diameter of the granules determines the filtration rating.	Protection filters	Low manufacturing costs	Only suitable for low flow rates, small free filter area, sensitive to pressure shock, high pressure drop

Table 20: *Materials for depth filters*

3.2.2 Constructive features of filter elements

The constructional features of filter elements are determined by the different conditions under which they are expected to function.

		Application	Advantages	Disadvantages
Pressure range	Low pressure	Low working pressure, filters with by-pass, working filters	Cheap elements	Damaged by severe, rapid pressure shocks
	High pressure	High working pressure, filters without by-pass, protection filters	Universal application	Expensive
Filtermat construction	Single layer	Automotive	Cheap	Poor pressure drop strength, poor filtration capacity
	Multiple layer	Hydraulic systems and lubricating systems	Good filtration capacity, high pressure drop strength	Expensive
	Star pleated	Hydraulics, Lubrication, Fuel	Large filter area in small space	Limited cleaning possible
	Shell strainer	Lubricating oil systems	Easily cleaned	Small filter area
	Basket strainer	Lubricating oil systems	All dirt removed when element is changed.	More complex construction
Flow direction	From inside to outside	For low pressure drops	All dirt removed when element is changed.	More complex construction
	From inside to outside	For high pressure drops	Can be cleaned, depending on material	Filtered dirt not trapped in element.
Bonding of filter mat to end caps.	Adhesive	For mineral oil up to 100 °C	Simple and cheap	Not suitable for high temperatures, not suitable for all fluids
	Soldered	For mineral oil 100 °C, over 100 °C, for corrosive media	For high operating temperatures and corrosive media	Expensive, complex
	Crimped	For mineral oil 100 °C, over 100 °C, for corrosive media	For high operating temperatures and corrosive media	Expensive, complex

Table 21: *Constructional features of filter elements*

3.2.3 Verifying the filtration performance to DIN ISO 4572 (Multi-pass Test)

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

It is an internationally standardized method and so allows a direct comparison to be made between elements with the same filtration rating produced by different manufacturers.

In order to make a comparison the conditions of the test must be recorded in the test log. Any modifications to the method of testing, as is common practice nowadays in all countries, must be stated.

Arrangement of the Multi-pass Test rig and the test procedure *(Fig. 85)*

The test rig incorporates two hydraulic circuits.

The test system with tank, test fluid, pump, cooler/heater, flowmeters, filter with test element and electronic particle counter.

The dirt injection system with tank, pump, cooler/heater, injection nozzle and injection fluid. In this tank the injection fluid is contaminated with the test dust (ACFTD).

Before the commencement of the test, both systems are cleaned with ultra-fine filters and the actual test is not begun until the prescribed figure of contamination particle count in the systems has been achieved.

Test sequence

The filter element is subjected to a constant circulating flow of hydraulic fluid into which a small quantity of fluid with a specific contamination is injected.

The now contaminated test fluid is fed to the element and fluid samples are taken upstream and downstream of the test filter and analyzed in the electronic particle counter. The pressure drop across the element caused by the contamination is also measured. The retention rate for filtration rating is defined by the degree of separation β_x, in which X denotes the particle size.

Any contamination not retained by the test filter element remains in the system and so simulates real operating conditions.

The β_x value always refers to particles either equal to or larger than the particle size X under consideration. A change in the pressure drop across the filter element also changes the β_x value.

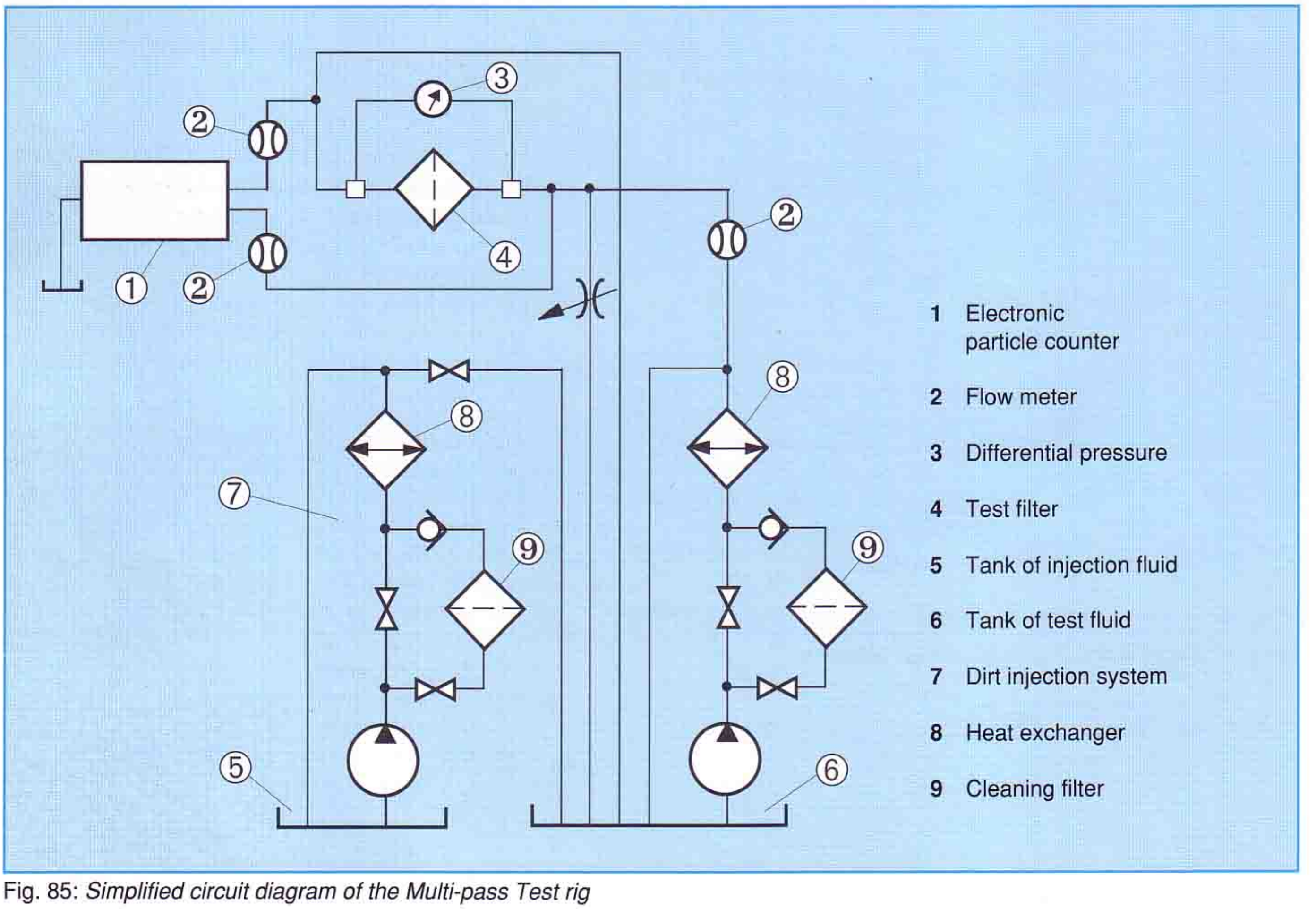
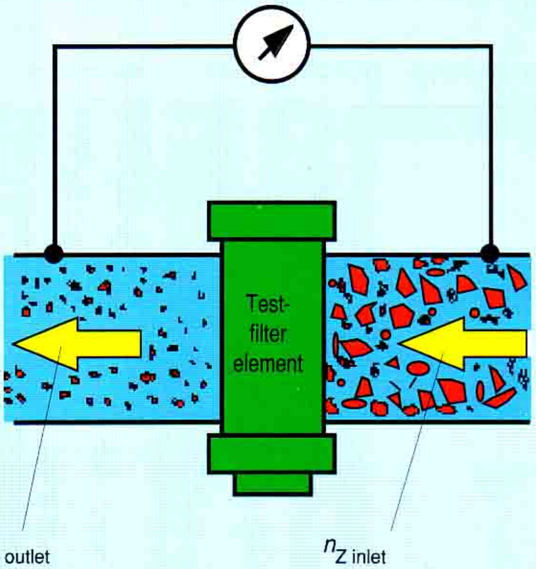


Fig. 85: *Simplified circuit diagram of the Multi-pass Test rig*

Determining the degree of separation ($\beta_{x\ value}$)

(Fig. 86)

The number of dirt particles larger than a specific particle size X counted upstream of the filter element is divided by the number of dirt particles counted downstream of the filter element (same particle size X, same pressure drop, at the same point in time). The resulting dimensionless number represents the degree of separation β_x



1000 particles
≥ 10 µm/100ml
= 0,08 mg/l (ACFTD)

100 000 particles
≥ 10 µm/100ml
= 10 mg/l (ACFTD)

$$\beta_X = \frac{n_{inlet} \geq X\ \mu m}{n_{outlet} \geq X\ \mu m}$$

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

Particle size in µm

β_X = 2 — 50 % filter efficiency
average pore size
= minimum particle capture size

β_X = 20 — 95 % filter efficiency
(nominal retention rate)

β_X = 75 — 98,6 % filter efficiency

β_X = 100 — 99 % filter efficiency
(absolute retention rate)

Fig. 86: *Determining the degree of separation ($\beta_{X\ value}$)*

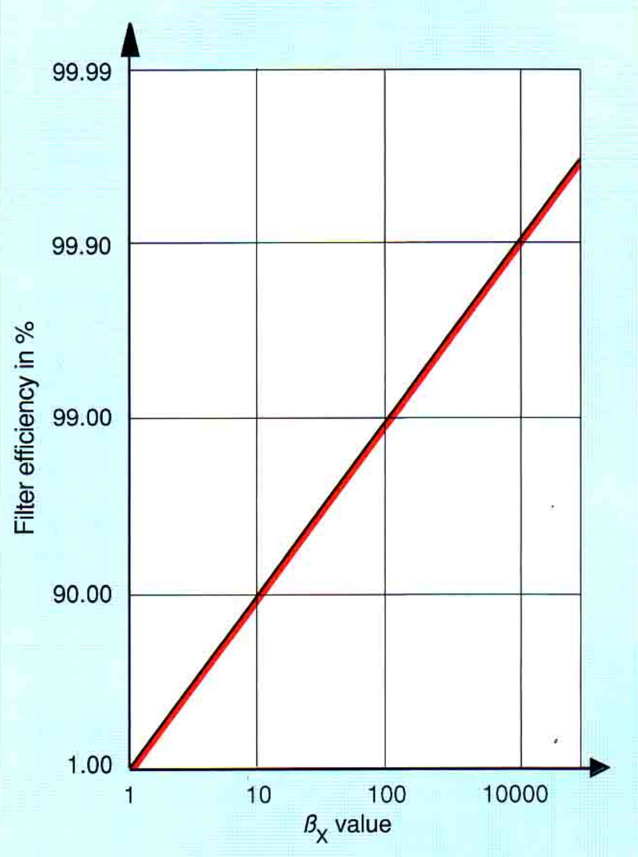


Diagram 36: *Degree of separation(βx value) versus filter efficiency in %*

Definition of filtration rating

Earlier data on filtration rating was based on a variety of in-house tests performed by different filter manufacturers. Only with the introduction of the degree of separation β_X, taking into account the resulting pressure drop, has it become possible to compare filtration rating data from different manufacturers.

Nominal filtration rating

There are no usable values of degree of separation laid down for this. For the user it means that only part of the dirt is actually filtered out which could be filtered out with an optimum filter.

Definition: $\beta_X \leq 20$
This corresponds to a filter efficiency of 95%.

Absolute filtration rating

Above a β_X value of ≤100 or a filter efficiency of 99%, the filtration rating is called the absolute retention rate *(see Diagram 36)*.

Notes on β_x values

In the Multi-pass Test the values of β_x are determined at a constant dirt concentration.

On account of the labyrinth effect of depth filters and the resulting porous structure a certain range of particles will be able to pass through the filter element. This means that the *βx values* change with different dirt concentrations, different kinds of dirt and different structures of dirt compared with the "ideal dirt" used for the Multi-pass Test. This circumstance is particularly important when the hydraulic fluids used in practice are to be employed for verifying the filtration performance of a filter element *(see Diagram 37)*.

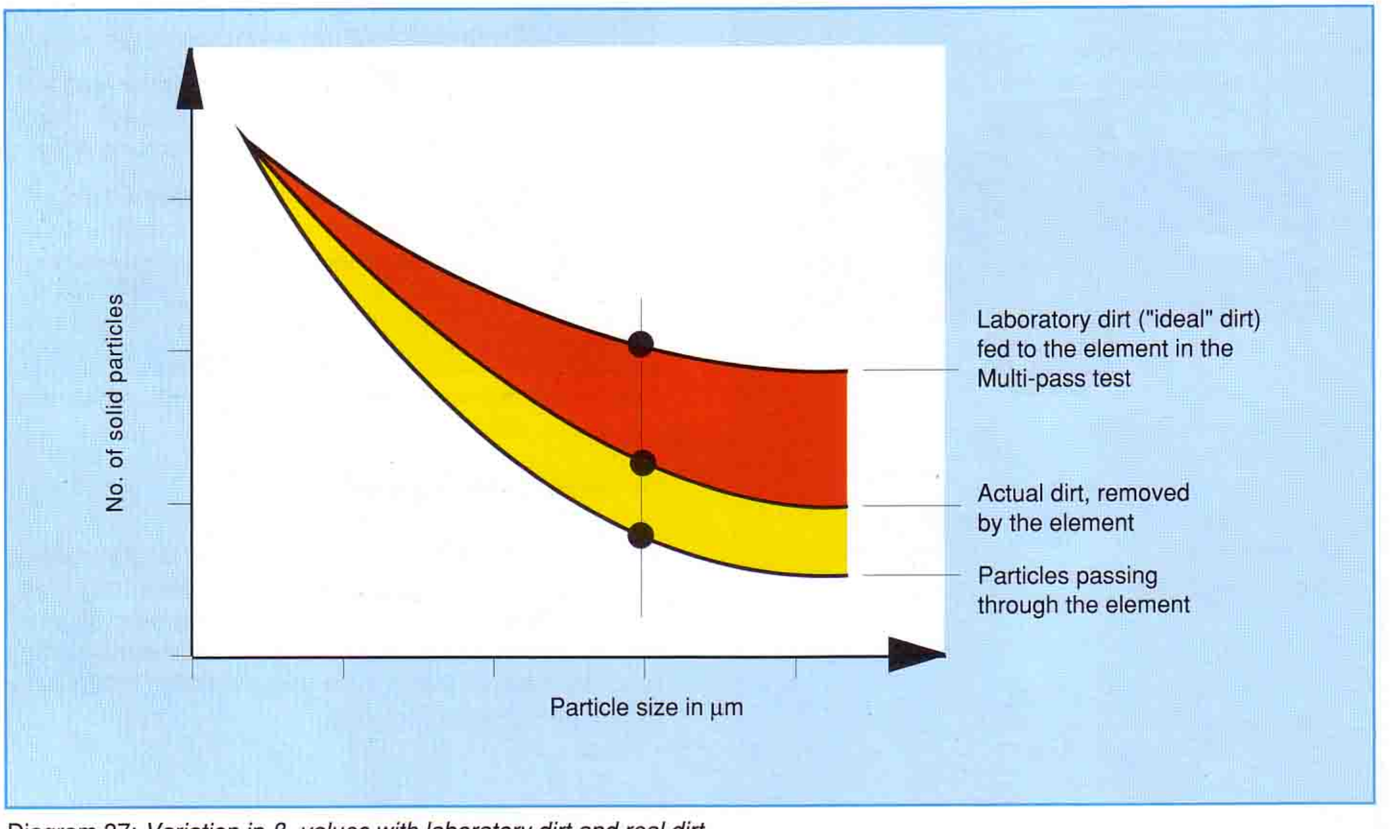


Diagram 37: *Variation in β_x values with laboratory dirt and real dirt*

3.2.4 Properties of filter elements of multi-layer mat construction

The experience that has been accumulated from actual practice and test rig experiments has led to the development of filter elements of multi-layer mat construction called Betamicron® *(Fig. 87)*.

Investigations have also shown that only with this mat construction is it possible to maintain the required levels of cleanliness.

The flow through the filter elements must always be from the outside to the inside.

So that as much filter area can be packed into a small volume, the filter mat should be pleated or corrugated to a star form. The actual construction of the filter mat depends on the permitted value of element pressure drop.

High-quality adhesives are used to attach the filter mat to the end caps of the element and to join the mat ends. The strength of these adhesives is temperature-sensitive and decreases sharply at high temperatures.

Betamicron® multi-layer elements possess a number of key features:

- a precise pore size
- excellent separation of very fine particles over a wide range of pressure drops, i.e. adherence to defined β_x values *(see Diagram 38)*
- high dirt holding capacity through a large specific capture area
- good chemical resistance
- protection against element damage due to a high bursting strength, e.g. during cold starts and pressure peaks
- water or water in the hydraulic fluid causes no reduction in filtration performance.

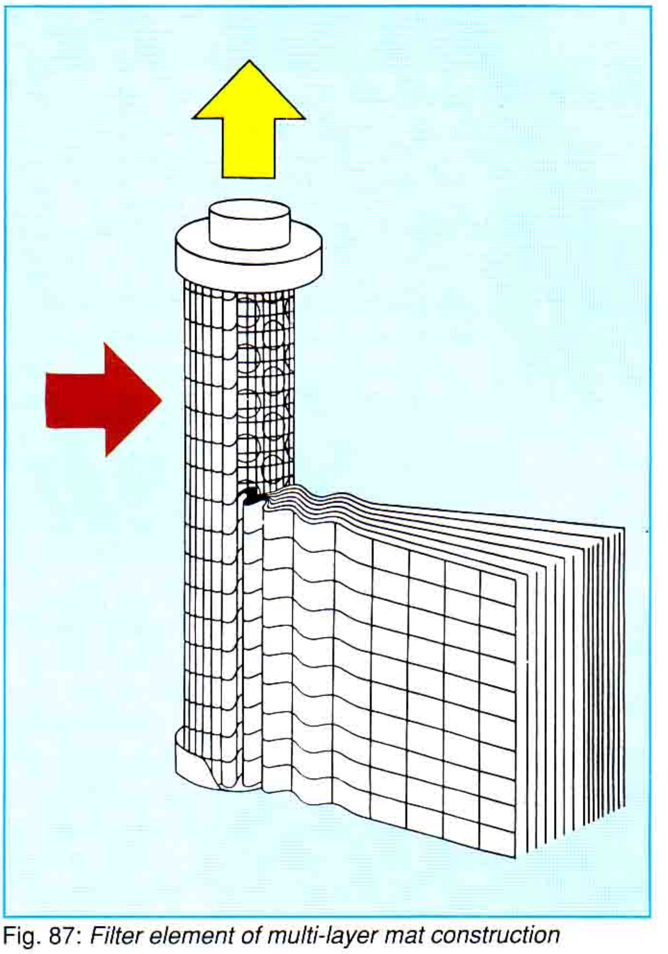


Fig. 87: *Filter element of multi-layer mat construction*

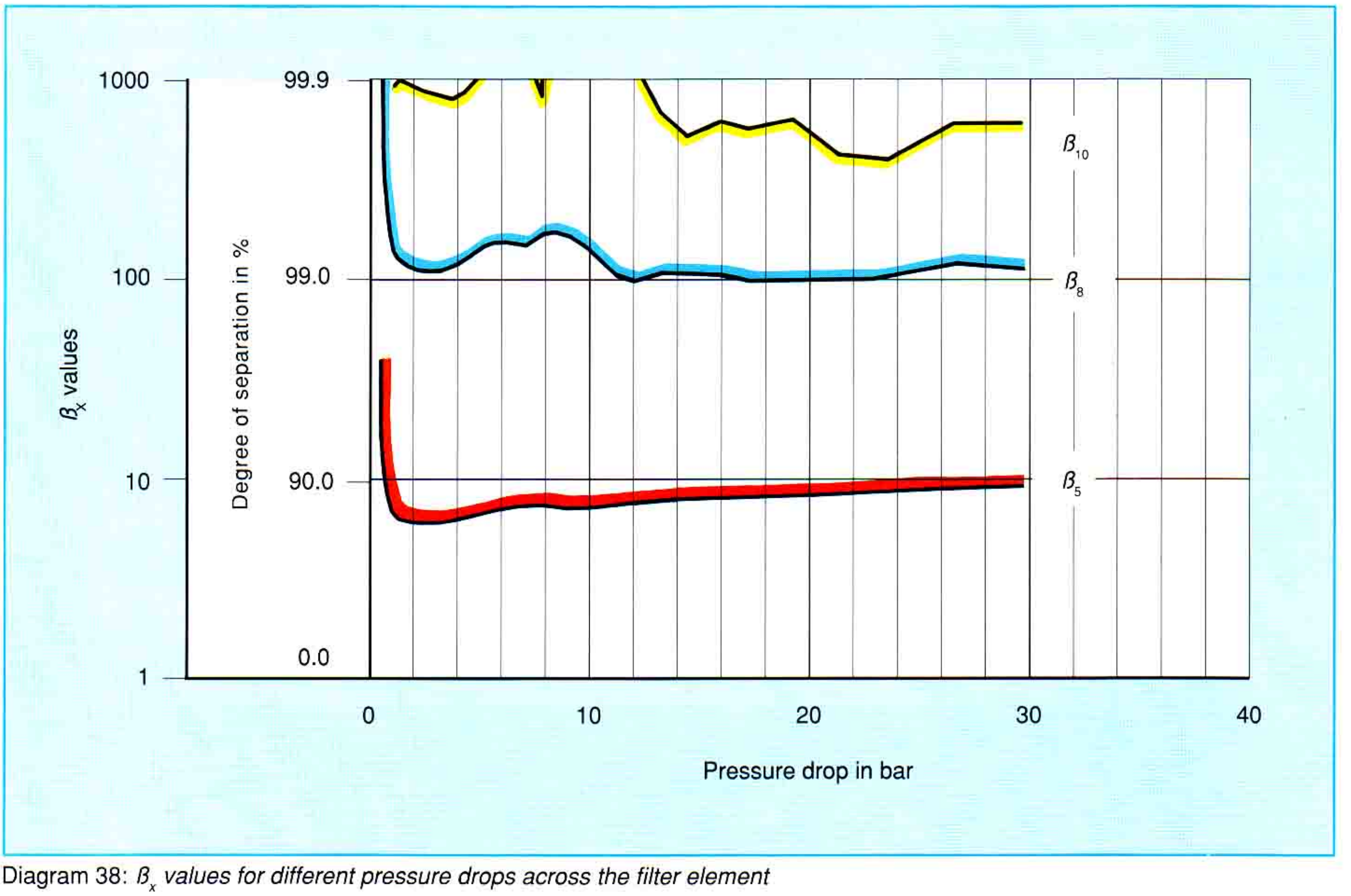


Diagram 38: β_x *values for different pressure drops across the filter element*

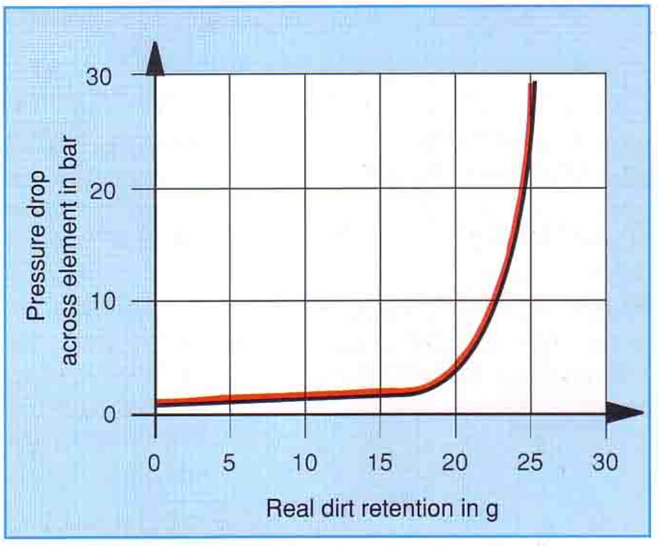


Diagram 39: Curve of dirt retention in a filter element

Constructional features of Betamicron® multi-layer elements

Direction of flow

With these filter elements the flow must be from the outside to the inside; flow in the opposite direction will damage them. If necessary, fast-acting check valves can be fitted downstream of the elements in order to prevent reverse flow. Filter bodies with integral check valves have proved ideal for such applications.

Star-shaped pleating

The filter mat of the elements is pleated into a star shape in order to compress as much filter area as possible into the element in order to achieve a long service life.

Filter element life

This means the number of hours for which a filter element can be used while delivering fluid of the required cleanliness.

The filter must be changed before the maximum permitted pressure drop across the element is reached and the clogging indicator is triggered with the fluid at operating viscosity.

Under certain unfavourable circumstances, such as when fluid temperatures are high or there are frequent and severe variations in the flow, it can be necessary to restrict the maximum service life of the element regardless of the clogging indicator signal. If the service life were unlimited in these circumstances there would be the possibility of fatigue failure in the filter material which would cause a deterioration in the filtering efficiency. In the worst case the clogging indicator would not operate at all.

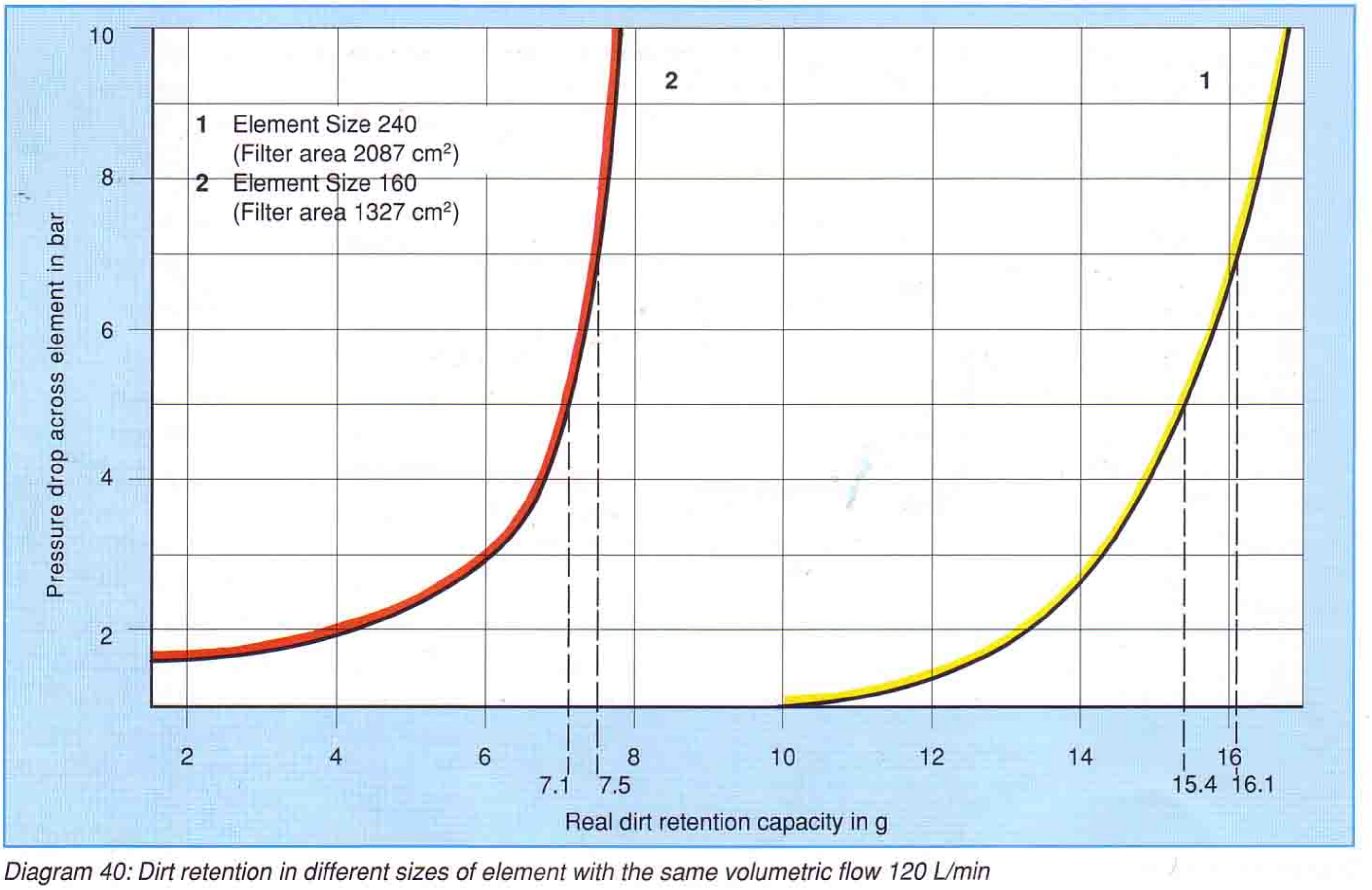


Diagram 40: Dirt retention in different sizes of element with the same volumetric flow 120 L/min

If there is no clogging indicator in the system, filter changing will have to be organized by time schedule, including adequate reserves of service life to ensure that the filtering is always satisfactory.

It is impossible to calculate filter element life theoretically in advance during the project design stage of a system.

In order to provide as large a useful range of pressure drop as possible for the dirt retention of a filter element, and therefore its life, it is advisable when determining its size to begin with the smallest possible pressure drop when the element is clean *(see Diagrams 39 and 40)*. The graphs show the pressure drop across the element with increasing clogging and service life. It is obvious that the low initial pressure drop of a larger filter element provides more real dirt retention capacity than a smaller filter element with a higher initial pressure drop. In both cases the by-pass valve, clogging indicator or element pressure-drop strength set the upper limit for element loading.

3.3 Selection criteria for filter elements

The selection of a suitable filter element for a hydraulic system with the best price/performance ratio should be based on the following factors:

Highly stable β_x values over a wide pressure drop range

In order that hydraulic systems may be operated without suffering damage due to solid particle contamination the type of filter element used must possess a constant filtration efficiency over a wide range of pressure drops. The range should extend to a multiple of the response pressure of the clogging indicator or the by-pass valve.

A graph of β_{10} values for filter elements of the same rating produced by different manufacturers is shown in *Diagram 41*.

It is clear to see how only filter elements 1 and 3 maintain a constant efficiency over the range of pressure drop up to 10 bar and therefore are suitable for the filtration of hydraulic fluid.

This stability of β_x value is of most importance to hydraulic filters having no by-pass valve and therefore having to function reliably at high pressure drops.

High values of pressure drop typically occur during cold starts or if the clogging indicator alarm is not heeded.

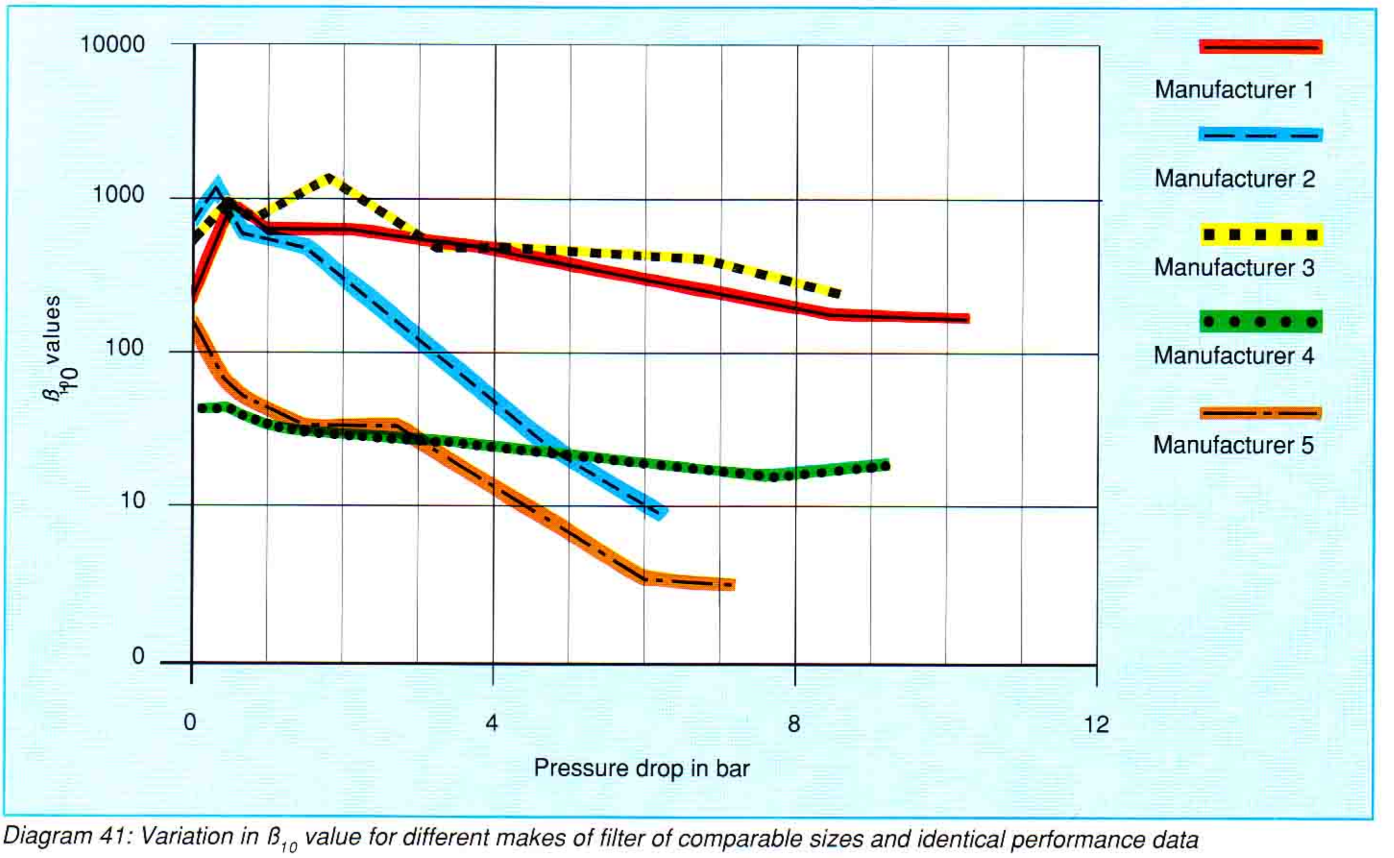


Diagram 41: Variation in β_{10} value for different makes of filter of comparable sizes and identical performance data

Dirt retention of filter elements

Another important criterion in assessing the price/performance ratio of filter elements is the dirt retention or dirt holding capacity.

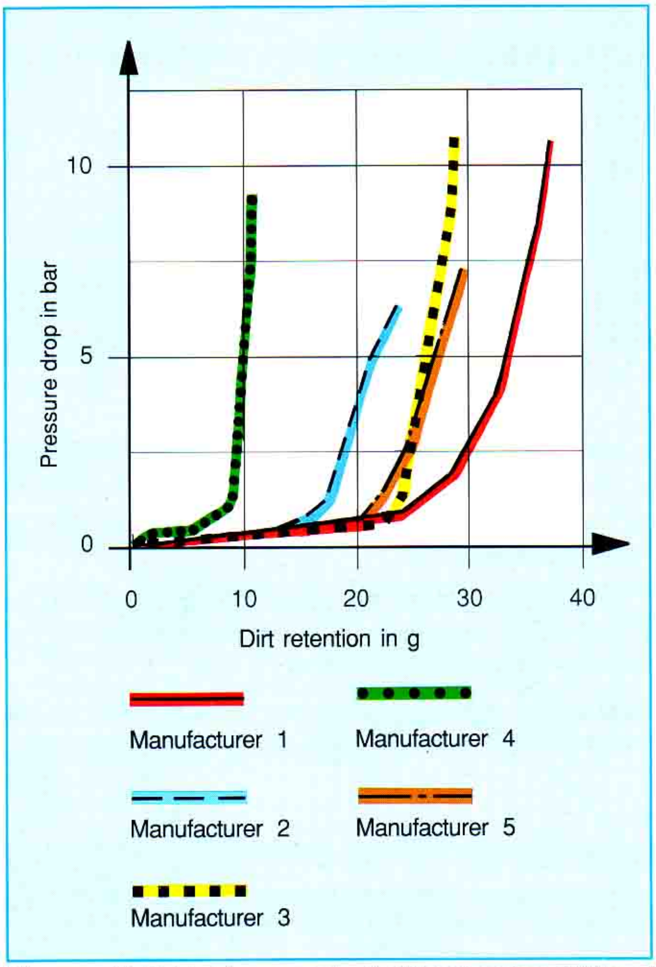


Diagram 42: Dirt holding capacity of different makes of filter of comparable sizes

As *Diagram 42* shows, the filter element of Make 1 has the highest dirt holding capacity. This factor, which also influences the service life, is a further important factor in addition to filtration rating and price in the overall assessment of the suitability of filter elements.

Obviously, a longer service life means lower service costs as well as longer maintenance intervals.

Specific dirt retention of filter elements

Investigation of the specific dirt retention provides an even clearer assessment of the price/performance ratio of filter elements. The figure is obtained by dividing the total dirt retention of a filter element at a certain pressure drop by the effective filtering area of the element, which gives a figure of dirt retention per cm² filter area *(see Diagram 43)*.

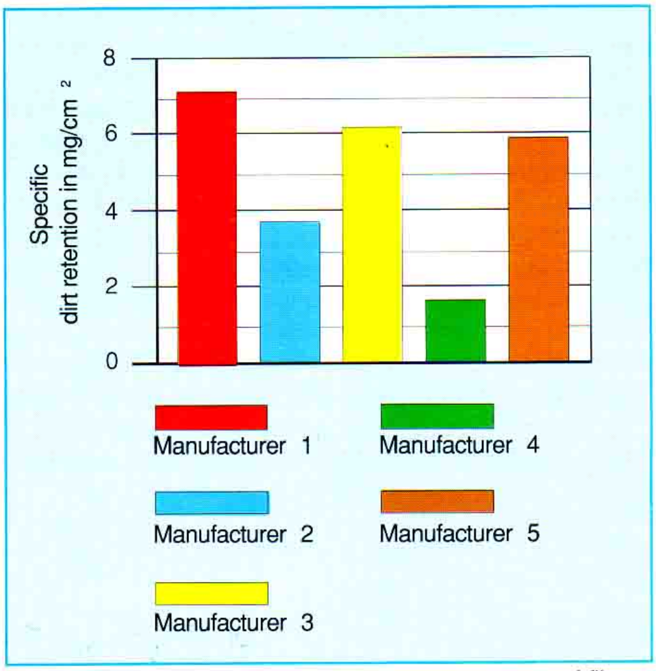


Diagram 43: Specific dirt retention of different makes of filter at a pressure drop of 3.5 bar

3.4 Filter housings

3.4.1 Requirements

Filter housings must satisfy the following requirements:

Low pressure drop across the housing

A low pressure drop across the housing must be achieved by means of a good flow shape inside the housing and primarily around the inlet and outlet ports.

Durable housing construction

Filter housings must be designed so that they have a long operating life at the given value of operating pressure. This means that they must successfully withstand a pulsation test.

Bursting pressure of the housing

In order to verify the maximum operating pressure for filter housings several licensing authorities specify that the burst pressure of the housing must be tested. The burst pressure is the pressure at which the housing ruptures.

Housing material

The materials used for the housings and seals must be suitable for the hydraulic fluid to be filtered.

3.4.2 Types of filter housing

The different types and designs of housings for pressure-line and return line filters are listed in *Table 22*.

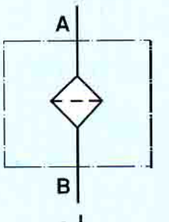
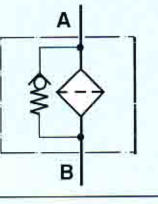
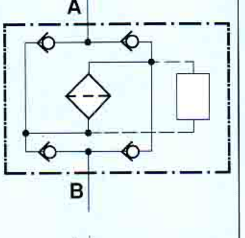
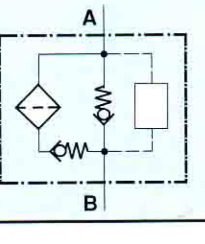
Type Pressure rating		Symbol	Application	Remarks
Low pressure, up to 100 bar Medium pressure, up to 210 bar High pressure, up to 420 bar			Pressure lines Control lines Safety filters	
For reversible fluid flow high pressure up to 420 bar			Safety filters for cylinders, proportional- or servo valves	

Table 22 *(Part 1)*

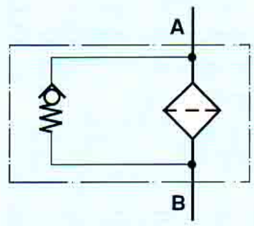
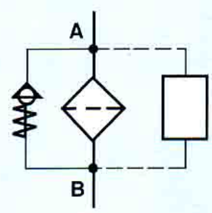
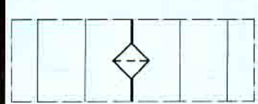
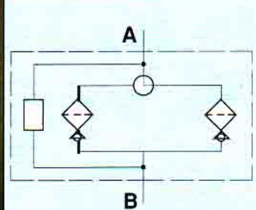
Type **Pressure rating**		**Symbol**	**Application**	**Remarks**
Low pressure, up to 25 bar			For large quantities of fluid	
Flange mounting, up to 315 bar			Manifold mounting	No filter piping required.
Sandwich plate model, up to 315 bar			Safety filters for precision valves, for vertical and horizontal stacking systems.	Can be fitted directly under the valve.
Pressure-line filter, duplex, up to 315 bar			For systems which cannot be shut down for element changing. Turbine control lines.	

Table 22 *(Part 2)*

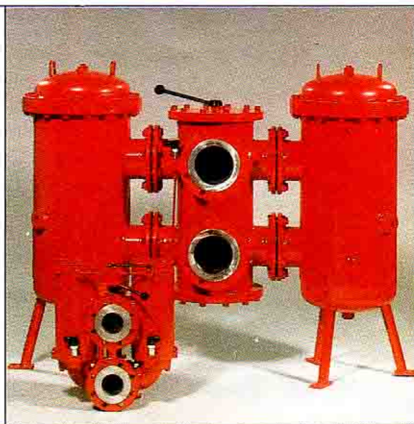
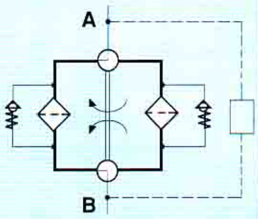
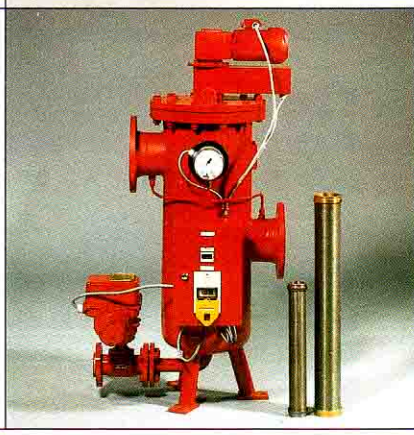
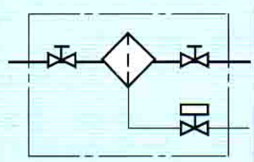
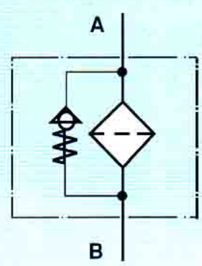
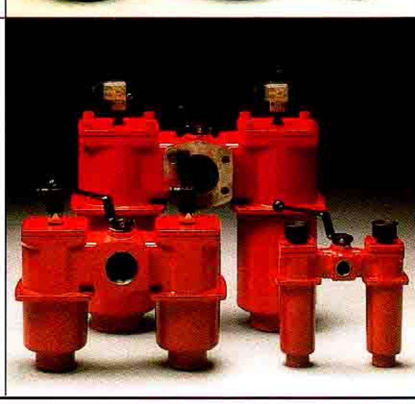
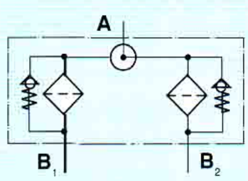
Type Pressure rating		Symbol	Application	Remarks
Pressure line filters				
Low pressure, duplex, up to 25 bar			Systems to API, oil supply systems. For systems which cannot be shut down for element changing.	
Automatic, up to 16 bar			Filtering of machining oils. For severe contamination.	No filtering below 20 µm
Return line filter				
Single, up to 25 bar			Mounted on the tank.	
Duplex, up to 25 bar			Mounted on the tank. For systems which cannot be shut down for element changing.	

Table 22 *(Part 3)*

3.5 Clogging indicators

Basically, hydraulic filters should always be fitted with a clogging indicator to monitor the state of clogging of the filter element.

3.5.1 Requirements

The body of the indicator must be designed for the maximum operating pressure of the filter housing. This means that the indicators must also be subjected to a pulsation test. The response setting must be reproducible.

3.5.2 Key features

Clogging indicators differ from each other in a number of key features:

Type of indication

Back pressure indicators (absolute pressure) *(Fig. 88)*

These indicators measure the difference between the pressure in the filter housing and the ambient atmospheric pressure. They are nearly always fitted to filters which discharge directly to the tank (return line filters).

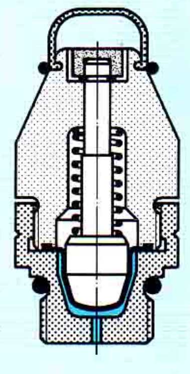
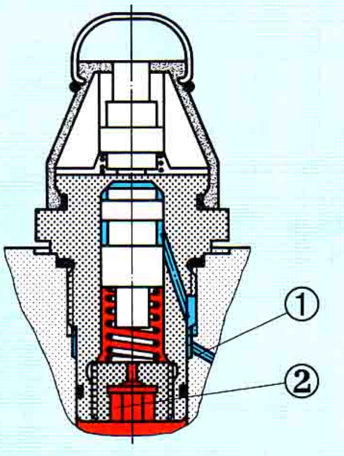


Fig. 88: *Visual pressure head indicator for return line filters*

Differential pressure indicators *(Fig. 89)*

These indicators measure the difference between the pressure on the dirty side and the pressure on the clean side. The ambient atmospheric pressure is not taken into account. The body of the indicator must be designed for the operating pressure of the filter housing.

The value of pressure drop indicated is independent of the instantaneous operating pressure in the filters. This type of indicator is used for pressure-line filters.



1 Dirty side 2 Clean side

Fig. 89: *Visual Differential pressure indicator*

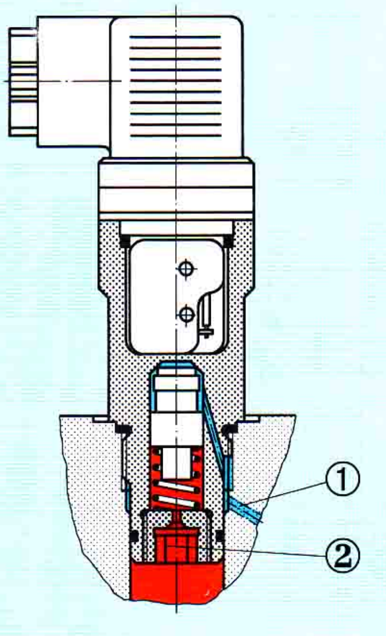
Processing the indicated signal

Visual

In this case the set pressure is indicated by means of a pressure gauge or a red pin which emerges from the indicator.

Electrical

Electric indicators are used when the signal is to be processed by machine control systems or transmitted to a control room. Such indicators can also be fitted in inaccessible places with the signal indicating the need to change the filter brought electrically to a convenient point *(Fig. 90)*.



1 Dirty side 2 Clean side

Fig. 90: *Electric pressure drop indicator*

Visual/electric

Electric indicators also have an electric light source to give a local signal for the operator or maintenance personnel in addition to the main electrical signal.

Electronic

There are electronic clogging indicators available for special applications. They are mainly employed for dynamic operating conditions. The electronic units suppress the indicator function up to an operating temperature of, say, 32 °C. Pressure peaks of up to 9 seconds are also suppressed so that they cannot trigger the indicator function. Electronic indicators are suitable for preventive maintenance because they indicate the instantaneous pressure drop across the element *(Fig. 91)*.

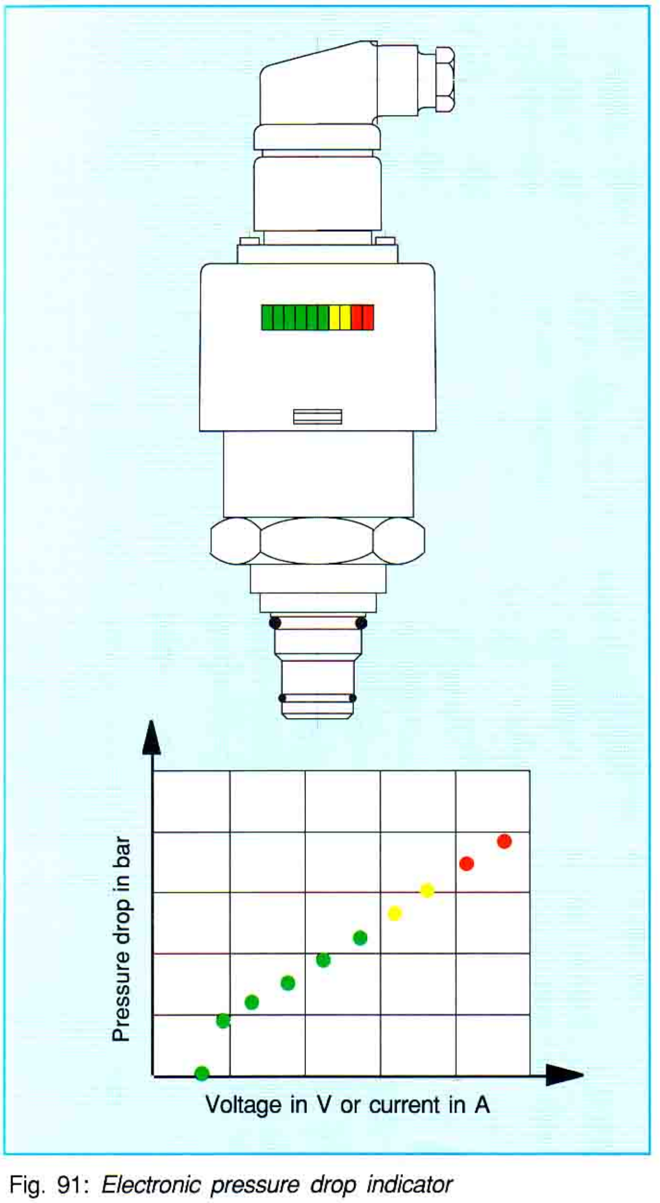


Fig. 91: *Electronic pressure drop indicator*

Contacts for electric clogging indicators

N/C contacts

With this type the circuit is broken when the clogging indicator is triggered. This contact arrangement is preferable because interference with the system is made more difficult and wiring faults can be detected immediately.

N/O contacts

In this case the circuit is closed when the contacts are operated.

Change-over contacts

The contacts can function in either the N/C mode or the N/O mode according to the terminal connections. This version is usually chosen by filter manufacturers so that either mode of display switching can be provided for the operator.

3.6 Breathers

The level of fluid in the hydraulic tank of a system fluctuates due to the supply and return of fluid and due to variations in temperature. This means that air is constantly being drawn into the tank and expelled from it. Depending on the surroundings this "breathing" can cause badly contaminated air to be drawn into the tank and particles find their way into the fluid.

A breather must be fitted to the tank in order to prevent the ingress of this contamination. The filtration rating of the breather must be matched to the filtration rating of the finest filter installed in the system.

Thus, if a system contains a filter with a filtration rating of 3 µm the breather fitted to the tank must also have a filtration rating of 3 µm for air. This is the specification recommended by the Cetop RP 98 H standard.

Smaller tanks are filled through a filling breather, although this arrangement should be avoided whenever possible. A better arrangement is for the system to be filled through a separate connection on the tank or upstream of the return line filter. The filling should be carried out with a mobile filter unit so that the fluid is of the prescribed quality as it enters the system.

Requirements for breathers

The filter element used in the breather must be renewable and have a large filter area.

The retention rate (or filtration rating) chosen for the element must be matched to the main filter.

The intake apertures must be as high as possible above the tank cover so that no dirt which collects on top of the tank can be sucked in.

Monitoring of the condition of the element by means of a clogging indicator is sensible and the cover fitted should offer adequate protection against splashing water.

Types of breather

Oil-wetted air breathers

These breathers contain oil-wetted knitted fabric for separating the particles of dirt from the flow of air. The filter can be cleaned by washing. The retention rate is over 40 µm and so is no longer adequate for the demands of modern fluids.

Oil-bath air breathers

With these breathers the incoming flow of air passes over a bath of oil and picks up minute droplets of oil in the process which bind the particles of dirt together. These dirt-laden droplets of oil are then trapped in knitted fabric and eventually drip back into the oil bath.

There must be a specific value of air flow velocity present in order for an oil-bath air breather to function properly. This is not the case with tank breathing so such breathers are basically unsuitable for hydraulic systems.

Breathers with oil-bath immersed elements

This type of breather is also known as the "pseudo oil-bath air breather". In fact, although the filter element dips into an oil bath, the bath itself plays no part in the function of the filter. Consequently, the combination of oil bath and paper or foam element brings no improvement in filtration capacity which is determined solely by the retention capacity of the paper or foam element.

The dipping of the filter element into the oil bath occupies some of the free area of the filter which shortens its service life.

As mentioned earlier, the filtration capacity of the element is the governing factor for the cleanliness of the air. The extra hydraulic fluid put into the filter only serves to shorten the service life of the element. They are unsuitable for use in hydraulic systems.

Special designs of breather

With back pressure valve

These breathers are used where the overflow of fluid is to be prevented or the inlet or outlet of air is only to take place at predetermined values of positive or negative pressure in order to improve the suction capacity of the hydraulic pump. The use of back pressure valves is intended to prevent the interchange of air in the tank with the atmosphere or to reduce it to a low value.

With dehydrating device

Hydraulic tanks are sometimes used in extremes of weather and climate with the attendant risk of air-borne water gaining ingress to the tank. Under some circumstances substantial quantities of water can get into the hydraulic system which the fluid cannot emulsify and so cause malfunctions. For this situation there are breathers incorporating a dehydrating chamber filled with silica gel.

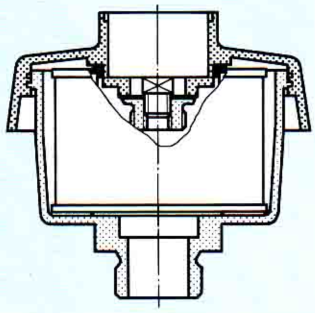
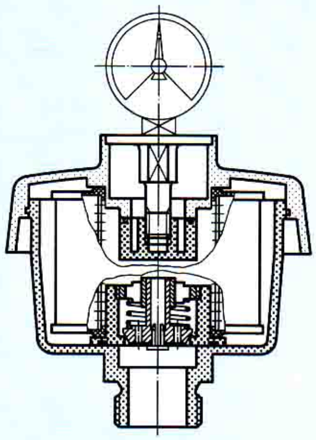
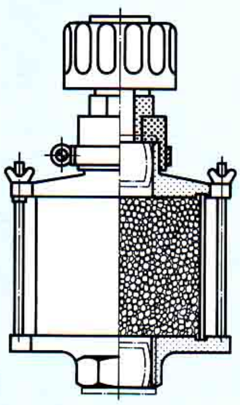
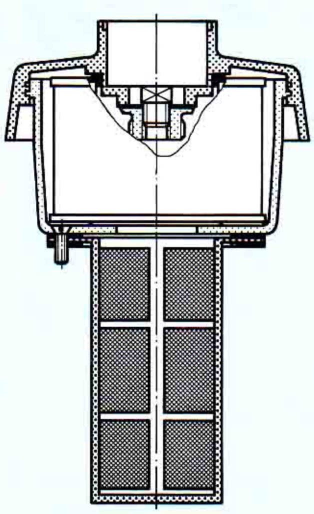
Type	Illustration	Filtration rating	Remarks
Tank breather		3 µm 5 µm 10 µm 20 µm	With replaceable filter element. Design to CETOP RP 98 H possible. Connection for clogging indicator.
Tank breather with check valve		3 µm 5 µm 10 µm 20 µm	With replaceable filter element. Design to CETOP RP 98 H possible Connection for clogging indicator. Fitted with check valve to minimize breathing. To improve pump suction.
Tank breather with dehydrating chamber		3 µm 5 µm 10 µm 20 µm	With replaceable filter element. Design to CETOP RP 98 H possible Connection for clogging indicator The moisture is removed from the incoming air.
Tank breather and filler		3 µm 5 µm 10 µm 20 µm	With replaceable filter element. Design to CETOP RP 98 H possible. Connection for clogging indicator Suitable for tank filling. Check valve fitted if required.

Table 23 (Part 1)

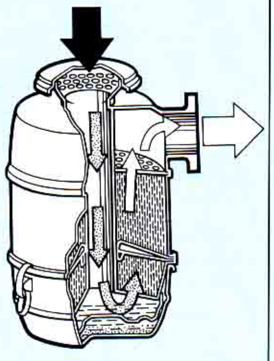
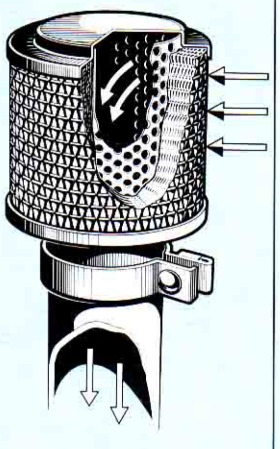
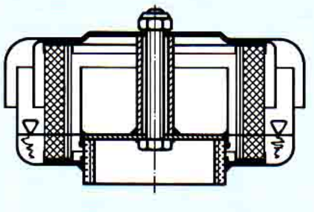
Type	Illustration	Filtration rating	Remarks
Oil-bath air breather		40 µm	For tank breathing, unsuitable for hydraulic systems.
Oil-wetted air breather		40 µm	Poor retention rate. Retention rate very dependent on. maintenance. Unsuitable for hydraulic systems.
Breather with oil-bath immersed element		3 µm 5 µm 10 µm 20 µm	No improvement in filter efficiency through oil bath. Reduced service life due to oil bath taking up filter area. Not suitable for hydraulic systems.

Table 23 (Part 2) *(top and centre illustrations by courtesy of Mann und Hummel of Ludwigsburg)*

4 The hydraulic fluid

4.1 General

Hydraulic power systems can be operated with fluids produced from a number of different base fluids.

The different classifications are as follows:

- Mineral oil-based hydraulic fluid
- Vegetable oil-based hydraulic fluid
- Fully-synthetic hydraulic fluid
- Fire-resistant hydraulic fluid
- Pure water.

From the filtration point of view a hydraulic fluid should satisfy the following requirements:

- low solid particle contamination in as-delivered state
- good filtration
- good viscosity/temperature characteristic, i.e. flat
- neutral behaviour towards materials.

Viscosity characteristic

In the design and operation of hydraulic filters the viscosity of the fluid is an important factor so that the whole installation can be operated trouble-free.

The method of determining the viscosity index is dealt with in DIN ISO 2909.

The viscosity/temperature characteristics for fluid lubricants needed for designing hydraulic filters will be found in DIN 51 519 and are reproduced in *Diagram 44.*

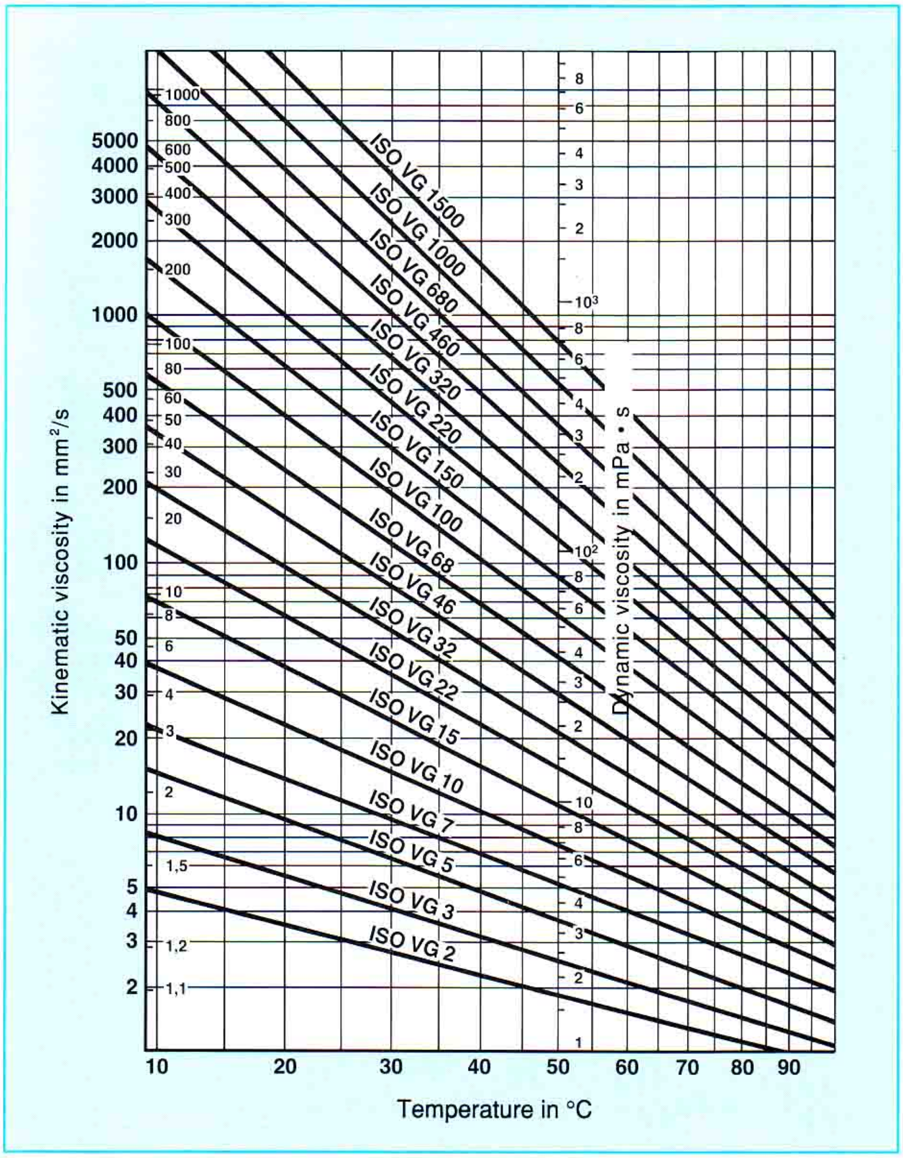


Diagram 44:
Viscosity/temperature characteristic for mineral oils to DIN 51 519

Filterability of hydraulic fluids

Additives in hydraulic fluids, or the adding of fluids other than that originally used in a system, can sometimes cause rapid clogging of filter elements. It results in the pressure drop across the element increasing quikkly and shortening the service life of the element.
The suitability of hydraulic fluids for filtration is ascertained by means of test filter discs. Short through-flow times are desirable.

4.2 Mineral oil-based hydraulic fluids

Most hydraulic power systems use this type of fluid. It is described in detail in *Section 3* of the chapter on *"Hydraulic Fluids"*.

Due to their frequent and widespread use in hydraulic systems the basic version of the hydraulic filter has been designed to filter HL, HLP and HV fluids. This means that when filtering other hydraulic fluids it might be necessary to modify the filter housing, filter element, accessories or seals.

The design of hydraulic filters described in *Section 5* refers to the filtration of HL, HLP and HV fluids.

The filters will have to be designed to different requirements if the properties of the fluid used differ from those of these mineral oils, e.g. dirt settling capacity, filtration, viscosity/temperature characteristic, etc.

For the filtering of HLP-D fluids it is advisable to calculate the size of the filter at approximately 0.2 bar for return line filters and approximately 0.5 bar for pressure-line filters because of their poorer dirt settling capacity in the tank. Also, the filtration rating ascertained from the diagrams must be selected at least one step finer.

4.3 Vegetable oil-based hydraulic fluids

These fluids are bio-degradable and so are being used more frequently in installations that are subject to strict anti-pollution regulations.

The filters are designed in the same way as for the HL, HLP and HV fluids. When operating a system with this type of fluid it is very important to ensure that no mineral oil gets into the fluid otherwise it will be more difficult to filter and the anti-pollution aspect will be compromised.

4.4 Fully-synthetic hydraulic fluids

These fluids are most commonly used in systems where there are special demands on the hydraulic fluid. It is impossible to make any general statement on the use of standard filters so filter makers must be approached as and when necessary. It is possible that a compatibility test to DIN ISO 2943 will be performed in order to check the compatibility of the materials used for the filter housings and elements and make any modifications found necessary.

4.5 Fire-resistant hydraulic fluids

These fluids are used when there is a fire or explosion hazard.

The most common applications are in:

- mining
- die-casting machines
- hydraulic presses for hot working
- governing systems on steam turbines and gas turbines
- various manufacturing processes in the automotive industry, e.g. upholstery
- installations in the chemical industry

The designations of the fluids and their properties are listed in *Table 24* and described in *Section 4* in the chapter on *"Hydraulic Fluids"*.

Modifications must be made to the standard filters so filter makers must be approached for advice on the filtering of these fluids.

Generally speaking, parts made of aluminium, zinc, cadmium and magnesium cannot be used in the filters.

Air carrying traces of these fluids can be very corrosive to steel parts and castings. The formation of a cushion of air in filters must be avoided.

The fitting of check valves downstream of the return line filter or to pressure line filters from which the filter outlet line runs to the hydraulic tank is to be recommended.

All filter housings which come into contact with air bearing traces of these fluids (e.g. return line filters) should be given suitable surface protection.

When determining the size of filter and filtration rating it is most important to consider the poor dirt settling characteristics and the soapy residue of these fluids.

The design of filters for fire-resistant fluids is dealt with in *Section 5.7.*

4.6 Pure water

Pure water is seldom used as the fluid in hydraulic systems due to the disadvantages described in the chapter on *"Hydraulic Fluids"*.

Standard filters cannot be used.

Fluid designation to DIN 51 502 and ISO DIS 6071	**HFA**	**HFB**	**HFC**	**HFD**
Composition	Oil-in-water emulsion or synthetic polymer solution	Water-in-oil emulsionn	Aqueous polyglycol solution	Synthetic anhydrous phosphate esters or chlorinated hydrocarbons
Water content	over 80%	over 40%	over 35%	under 0.1%
Operating temperature	+ 5 °C to + 55 °C	+ 5 °C to 60 °C	- 20 °C to + 60 °C	- 20 °C to + 150 °C
Kinematic viscosity	under 1.6	46 to 100	22 to 68	15 to 100
Density	0.998	0.92 to 1.05	1.04 to 1.09	1.1 to 1.9
pH value	7 to 10	7 to 10	7.5 to 10	7.5 to 10
Materials attacked	Zinc aluminium	Zinc aluminium	Zinc aluminium cadmium and magnesium alloys	
Seal materials	NBR	NBR	NBR EPDM SBR	FPM (Viton) EPDM
Remarks	Susceptible to microbial attack, high mechanical wear due to low viscosity.	Widely used in mining applications in English speaking countries.	Poor dirt separation capacity. Sensitive to mineral oil contamination.	May not be mixed with water. Sensitive to moisture contamination.

Table 24: *Properties of fire-resistant fluids*

4.7 Solid contamination

The contamination of hydraulic fluids by solid particles is dealt with by a number of different classification systems.

There are 5 in all at present:

- SAE 749 D
- ISO DIS 4406
- CETOP RP 70 H
- NAS 1638
- MIL STD 1246 A

Table 25 compares the classification systems with each other. The different classes of contamination define the quantity of particles of a certain size in a 100 ml sample of fluid.

A classification is determined by counting and sizing the contaminating solid particle. It is done either under a microscope or by means of an electronic particle counter. The electronic counter method is more objective than using the microscope. Above a dirt concentration of about 20 mg per litre, or if the fluid is very turbid, the contamination can only ascertained by weight, i.e. by gravimetric analysis. However, with this method the individual dirt particles cannot be classified.

ISO DIS 4406 or Cetop RP 70 H	Particles per ml > 10 µm	ACFTD solids content mg/L	MIL STD 1246 A (1967)	NAS 1638 (1964)	SAE 749 D (1963)
26/23	140000	1000			
25/23	85000		1000		
23/20	14000	100	700		
21/18	4500			12	
20/18	2400		500		
20/17	2300			11	
20/16	1400	10			
19/16	1200			10	
18/15	580			9	6
17/14	280		300	8	5
16/13	140	1		7	4
15/12	70			6	3
14/12	40		200		
14/11	35			5	2
13/10	14	0,1		4	1
12/9	9			3	0
18/8	5			2	
10/8	3		100		
10/7	2,3			1	
10/6	1,4	0,01			
9/6	1,2			0	
8/5	0,6			00	
7/5	0,3		50		
6/3	0,14	0,001			
5/2	0,04		25		

Table 25: *Comparison of contamination classifications*

Using ISO DIS 4406

Diagram 45 shows how the particle size is plotted along the ordinate and the number of particles and classification code along the abscissa.

In the case of ISO DIS 4406 the degree of contamination of the fluid is defined by a two-digit code. One is the number of solid particles over 5 µm in size and the other the number of particles over 15 µm in size in a 100 ml sample of fluid.

In order to determine the degree of contamination to ISO DIS 4406, first count all particles larger than 5 µm in the 100 ml sample and give it a code number. Then count all particles larger than 15 µm and give them another code number *(see example in Diagram 45).*

These code numbers form the designation of the sample. *Table 26* lists the contamination figures and their coding.

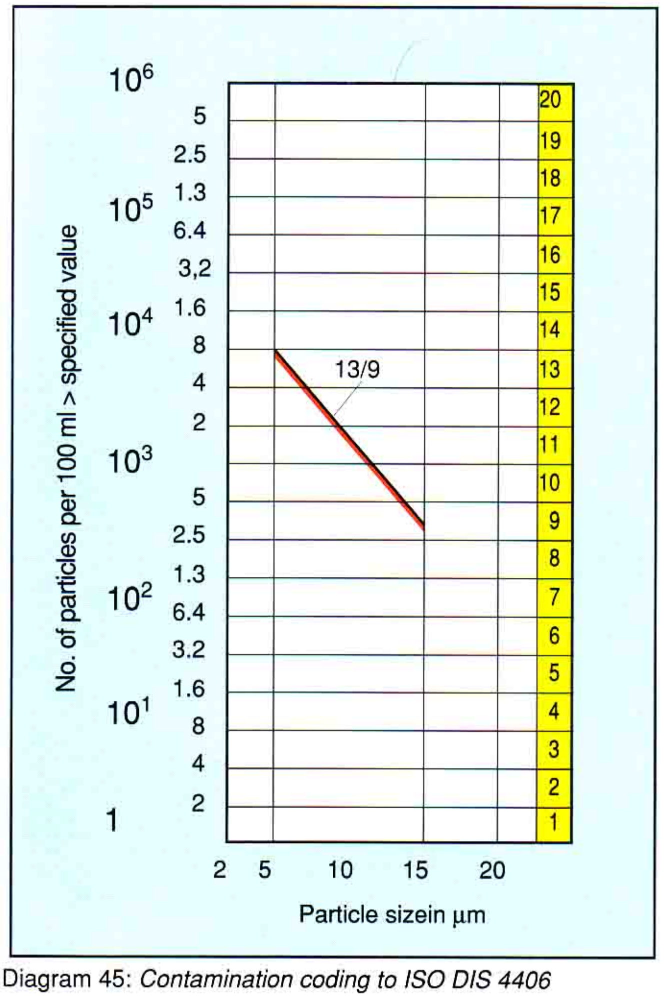


Diagram 45: *Contamination coding to ISO DIS 4406*

Code	No. of particles per 100 ml			
	over 5 µm		over 15 µm	
	more than	and up to	more than	and up to
20/17	500 k	1M	64 k	130 k
20/16	500 k	1M	32 k	64 k
20/15	500 k	1 M	16 k	32 k
20/14	500 k	1 M	8 k	16 k
19/16	250 k	500 k	32 k	64 k
19/15	250 k	500 k	16 k	32 k
19/14	250 k	500 k	8 k	16 k
19/13	250 k	500 k	4 k	8 k
18/15	130 k	250 k	16 k	32 k
18/14	130 k	250 k	8 k	16 k
18/13	130 k	250 k	4 k	8 k
18/12	130 k	250 k	2 k	4 k
17/14	64 k	130 k	8 k	16 k
17/13	64 k	130 k	4 k	8 k
17/12	64 k	130 k	2 k	4 k
17/11	64 k	130 k	1 k	2 k
16/13	32 k	64 k	4 k	8 k
16/12	32 k	64 k	2 k	4 k
16/11	32 k	64 k	1 k	2 k
16/10	32 k	64 k	500	1 k
15/12	16 k	32 k	2 k	4 k
15/11	16 k	32 k	1 k	2 k
15/10	16 k	32 k	500	1 k
15/9	16 k	32 k	250	500
14/11	8 k	16 k	1 k	2 k
14/10	8 k	16 k	500	1 k
14/9	8 k	16 k	250	500
14/8	8 k	16 k	130	250
13/10	4 k	8 k	500	1 k
13/9	4 k	8 k	250	500
13/8	4 k	8 k	130	250
12/9	2 k	4 k	250	500
12/8	2 k	4 k	130	250
11/8	1 k	2 k	130	250

Table 26: *Contamination data and short form coding*

Using NAS 1638

In this standard the individual particle sizes are divided into 5 ranges. A maximum number of particles is allowed for each range in each class.

Class	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	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 27: *Contamination classes to NAS 1638. Maximum number of dirt particles in 100 ml of fluid.*

Contamination classification to SAE 749 D

This classification system is hardly ever used due to the relatively small number of gradings (9 particles/ml to 580 particles/ml).

Contamination classification to MIL STD 1246 A

This standard is only used in special cases and is of practically of no importance in industry.

4.8 Measuring the contamination of a system

Solid particle contamination is measured by taking a sample of fluid from the hydraulic system and analyzing it.

The analysis can reveal:

- the solid particle contamination of fluid delivered by suppliers
- the effectiveness of the system filters
- the flushing time when commissioning a system
- the state of the system and any possible damage to components when regular checks are made.

Methods of taking samples *(Fig. 92)*

- Taking a sample from a moving fluid (dynamic sampling)

Sampling point:
Within a system which is operating (there must be turbulent flow). *See ISO 4021.*

- Taking a sample from a stagnant fluid (static sampling)

Sampling point:
From the hydraulic tank.
See CETOP RP 95 H, Section 3.

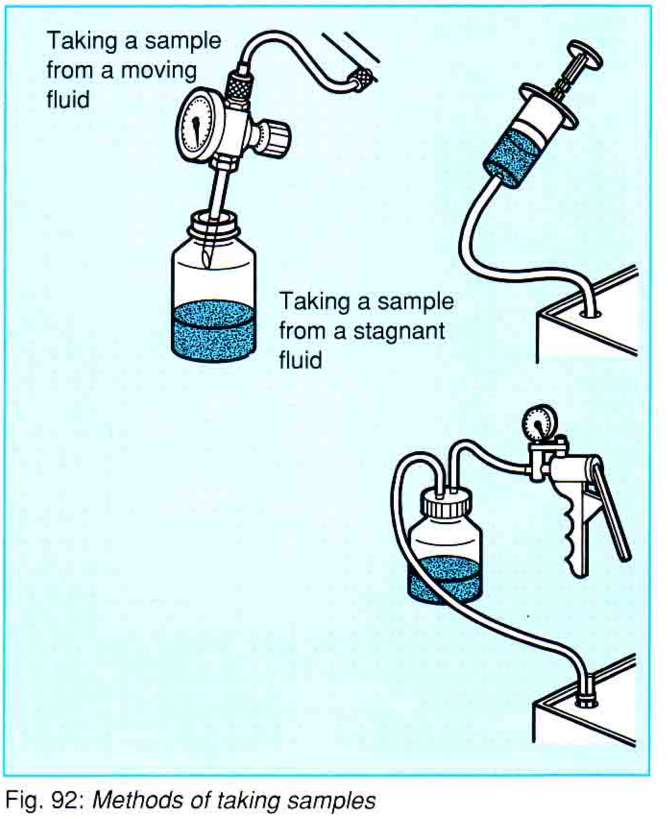


Fig. 92: *Methods of taking samples*

Fluid sampling procedure

General

- Before taking the sample the sampling device must be carefully flushed out with clean solvent
- Only use sample bottles that have been cleaned with fresh solvent
- Remove any remaining solvent before taking the sample
- Allow at least 2 litres of system fluid to flush through the sampling device before the actual sample is taken
- Take a zero sample. This is not used for the analysis because it is not representative of the system contamination
- Put the fluid to be analyzed into a new, clean sample bottle. The protective foil on the bottle should only be lifted.

Analysing the samples

The samples are usually analysed by means of an electronic particle counter.

Due to their high cost and constant attention needed, they will only be found in use by major users of hydraulics, the manufacturers of hydraulic filters and various institutes. This means that your fluid samples will probably have to be sent to one of these institutes. A direct check at the time of sampling is out of the question *(Fig. 94)*.

This is why a system of monitors or test charts has been produced in order to allow a rough but quick assessment of the fluid samples to be made on the spot. A microscope is employed to make an estimate of the solid particle contamination and from that it is possible to assess the state of the system.

What the fluid sample is able to tell depends very much on the person who took the sample. Therefore, only properly trained and experienced persons should be employed for the sampling.

Errors in sampling procedures can have a very great effect in the case of contamination classes below NAS 6 so it is advisable for particle counting to be carried out on site in order to eliminate any errors in sampling.

For such situations there is a mobile laboratory service available to perform the measurements for customers *(Fig. 93)*.

Fig. 93: *Mobile laboratory for on-site analysis*

Fig. 94: *Fluid sample analysis in the laboratory*

Fig. 95: *Sampling kit*

5 Designing hydraulic filters

5.1 General

Any filter used in a hydraulic system causes a pressure drop which increases steadily with time. The magnitude of this pressure drop is representative of the functional efficiency of the filter. Selecting a filter and positioning it properly in a system requires just as much care and experience as selecting any of the other components. Hydraulic filters should always be fitted with a clogging indicator to monitor the pressure drop across the filter element.

The following criteria govern the selection of a suitable hydraulic filter:

- Specific filtration rating
- Operating pressure
- Number of work cycles
- Filtration efficiency
- Dirt holding capacity of the element
- Place of installation of the filter.

The benefits of a correctly and generously sized filter are:

- greater reliability for the system
- longer service life for both machine and fluid
- less downtime and fewer spares replacements.

Table 28 lists the advantages and disadvantages of the different types of filter.

Type of filter	Advantages	Disadvantages
Pressure-line filters	Filtration takes place directly before the components requiring protection. Required cleanliness of fluid assured.	Expensive filter housings and elements. Complex element construction due to the pressure drop strength required. Pump is not protected. With single filters the system must be shut down to change the element.
Return line filters	The whole return flow of fluid is filtered. No contamination gets into the tank. Cheap filter housings and elements. Generous sizing of the filter possible.	A pressure-line filter must also be fitted when there are precision components such as servo valves installed. A by-pass valve must be fitted to the filter. Elements with low pressure drop strength can be damaged by flow pulsation. With single filters the system must be shut down to change the element.
By-pass filters	Uniform filtration independent of the work cycle. Optimum use of the dirt holding capacity of the filter element. Cheap filter housings and elements. System does not have to be shut down to change the element. Retro-fitting possible.	A pressure-line filter must also be fitted when there are precision components such as servo valves installed. Installing an extra pump increases the power consumption of the total system. Higher capital investment required in plant. More filtration required if contamination occurs regularly.
Suction filters	The fluid drawn in by the pump is filtered	Very fine filtering impossible. Poor cleaning facility. Pump must be protected against cavitation.

Table 28: *Types of hydraulic filter, their advantages and disadvantages*

5.2 Positioning of filters in hydraulic systems

The position of a filter in a fluid circuit depends on the task which that filter is expected to perform *(Fig. 96)*.

Protecting the fluid against contamination

This task is performed by return line filters or complete by-pass filter units in the hydraulic installation. The filter must be selected appropriately for the specified class of fluid cleanliness.

Protecting components sensitive to contamination

In order to offer as much protection as possible to the components in question, the filter must be positioned as close as possible to them. The filter must be selected for the appropriate operating pressure and the filtration rating specified by the component manufacturer.

Protecting the system against environmental contamination

The task of these filters or breathers is to prevent any environmental contamination from reaching the hydraulic fluid. Selection of the appropriate breathers must take into account the pulsating flow of air and the amount of contamination in it.

Protecting the system against component failure

These filters protect the system against major contamination in the event of component failure. They are intended to avoid high repair costs and knock-on costs.

When choosing the position for a filter in a hydraulic system the important points to watch are that the filter is easily accessible, the element can be changed easily and the clogging indicator can be clearly seen at all times. Badly positioned filters have an adverse effect on maintenance since they cannot perform the tasks allocated to them in the best possible manner.

Filters with by-pass valves

By-pass valves fitted to filters perform the following functions:

- They protect the filter element from damage due to excessive pressure drop across it.

A high pressure drop can arise due to the clogging of the element with contamination or high viscosity of the fluid during a cold start.

- They prevent the malfunctioning of components in the system.

With return line filters in particular, an excessive pressure drop across the filter element can result in malfunctioning of valves, uncontrolled operation of cylinders and damage to seals.

The following points must be noted when installing by-pass valves:

- The filtering action is reduced when the by-pass valve is open. When the valve is fully open there is no filtering at all and, therefore, no protection for the components in the system.
- Clogging indicators are absolutely essential so that filter maintenance can be carried out promptly.
- The filter element must be changed immediately when the clogging indicator is triggered.

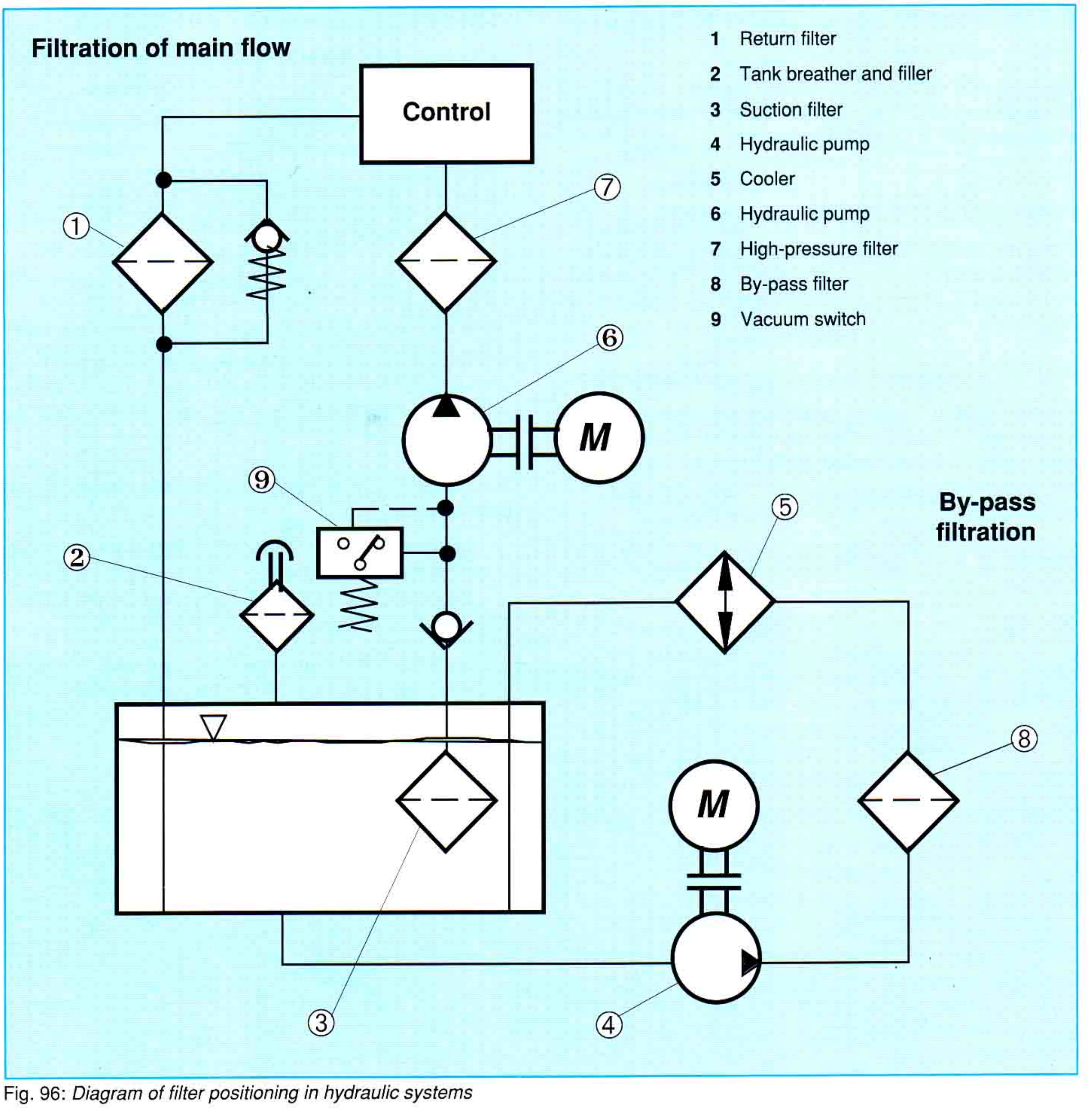


Fig. 96: *Diagram of filter positioning in hydraulic systems*

5.2.1 Main filters

These filter the fluid flowing in the actual main circuit of the system.

The following types of filter are used:

Suction filters

These are fitted between tank and pump and their task is to prevent any severe contamination from reaching the pump. In order to avoid cavitation damage to the pump such filters can only be fitted with coarse strainer elements. A vacuum switch must also be fitted between pump and filter in order to stop the pump if the vacuum falls below a certain figure. The low pressure drop means that fine filtration cannot be achieved with suction filters.

Pressure-line filters

These filters are fitted between the pump and the components of the system. In order to offer complete protection to the components they should not have a by-pass valve. Their task is to ensure the required cleanliness of the fluid fed to the hydraulic components such as servo valves.

Return line filters

The purpose of these filters is to filter the flow of fluid returning to the system tank. The filter must be capable of handling the total volumetric return flow which, when single-rod cylinders or accumulators are included, can be substantially higher than the installed volumetric flow of the pump.

Breathers

Their task is to filter the air drawn into the tank as the fluid volume "breathes".

The first law of filter design

The specified value of filtration rating must be applied to all the filters installed in a hydraulic system, e.g. pressure-line filters, return line filters and breathers.

Task assignment of filters

For the purpose of economy in hydraulic system design the filters are divided into two groups, working filters and protective filters *(Fig. 97)*.

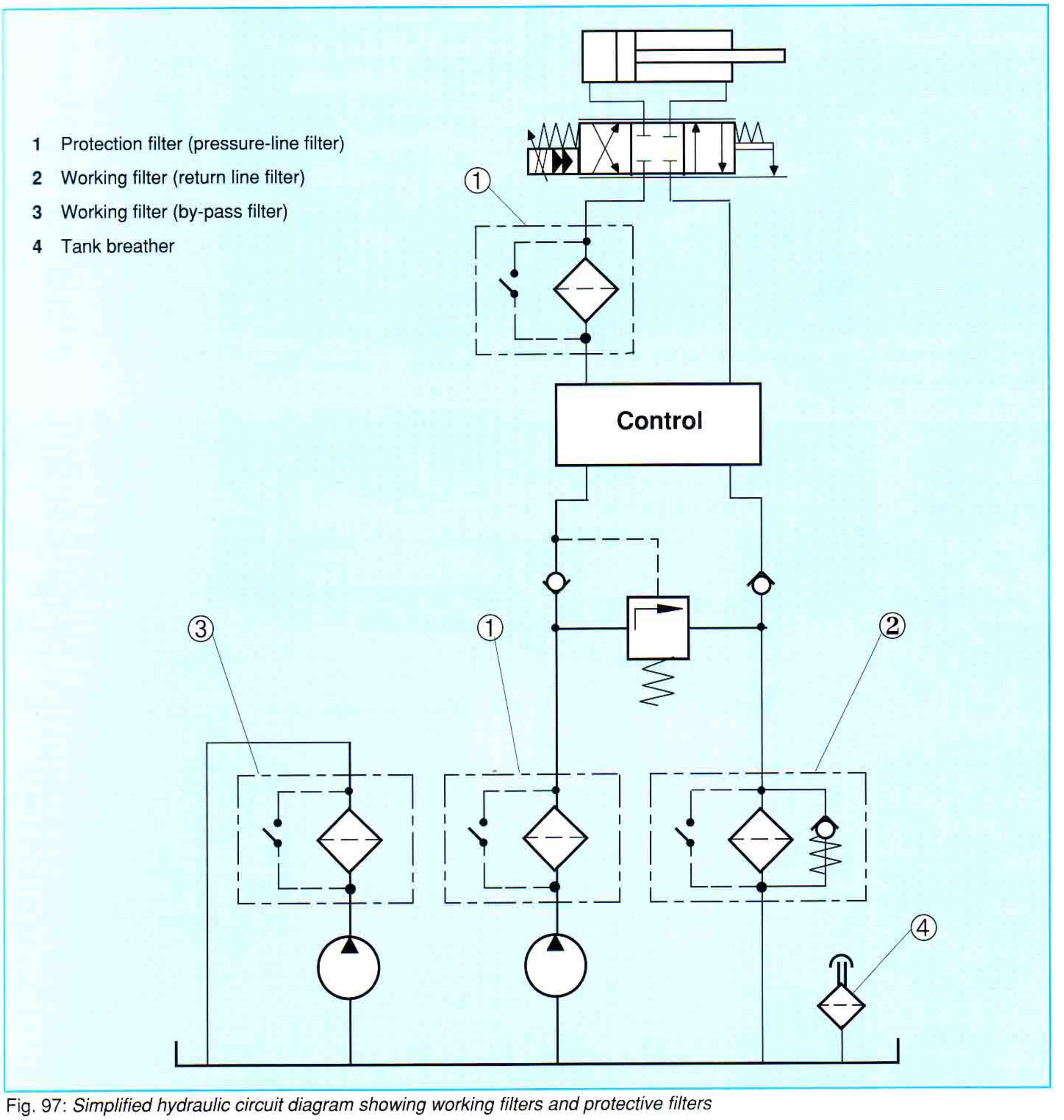


Fig. 97: *Simplified hydraulic circuit diagram showing working filters and protective filters*

Working filters

These include return line filters and pressure-line filters with by-pass valves and also by-pass filters.

Working filters are equipped with elements with good low pressure stability which allow them to have a large filter area and so a high dirt holding capacity.

In order to perform efficiently, return line filters and pressure-line filters used as working filters must be generously sized and positioned in the maximum volumetric flow of the system. If necessary, such filters can also be installed in the leakage fluid lines.

Protective filters

The purpose of these filters is to protect the components of the system against sudden failure due to high levels of solid particle contamination. It means that they only filter out those particles which could lead to sudden seizure of hydraulic components.

Another task for protective filters is extra protection against contamination in the event of hydraulic pump or motor failure. Installing such filters can help to reduce repair costs should pumps or motors suffer catastrophic failure.

When using these filters upstream of servo valves or proportional valves the position must be chosen so that, through the use of check valves, there are no negative pressure peaks on the filter element.

These filters must have a markedly coarser filtration rating than the other working filters installed in the system. They can be smaller in size and the filter housing may not have a by-pass valve.

Only filter elements stable under high pressure should be used.

5.2.2 By-pass filters

The purpose of these filters is to filter the tank fluid continuously in a by-pass circuit. The normal practice is to use a complete by-pass filter unit comprising pump, filter and cooler.

The advantage of by-pass filtering is that the filter can work independently of the operating cycles of the hydraulic system and the flow of fluid through the filter element is constant.

Ageing of the fluid is retarded and a clear improvement in the service life of the fluid is achieved.

The advantages of by-pass filtering are:

- filtering is independent of the system
- the elements achieve high dirt retention due to low, pulsation-free, constant flow
- elements can be changed without shutting down the main plant
- substantial cost savings through lower material costs
- less maintenance
- less downtime
- cheap filter elements
- suitable for system filling

The filtration capacity of a typical by-pass filter unit is shown in *Diagrams 46 and 47*. Note that the rubber press and pump test stand continue to operate during the filtering process.

The design of by-pass filters is described in *Section 5.6.2*.

In general, therefore, by-pass filters should be installed:

- when high dirt penetration rates are anticipated, e.g. on production test stands, machinery in dusty environments, cleaning installations
- when a separate cooling circuit is installed.

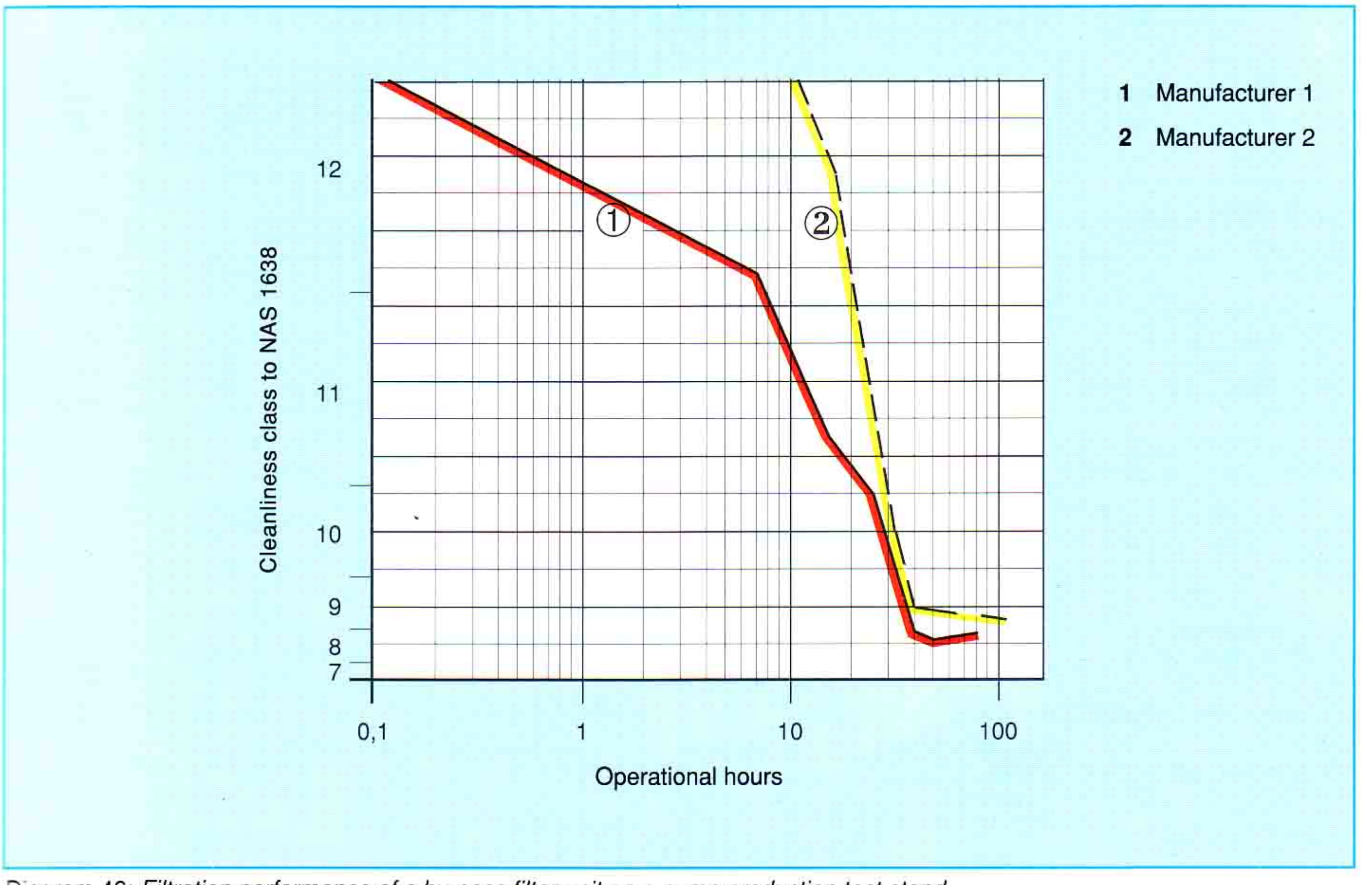


Diagram 46: *Filtration performance of a by-pass filter unit on a pump production test stand*

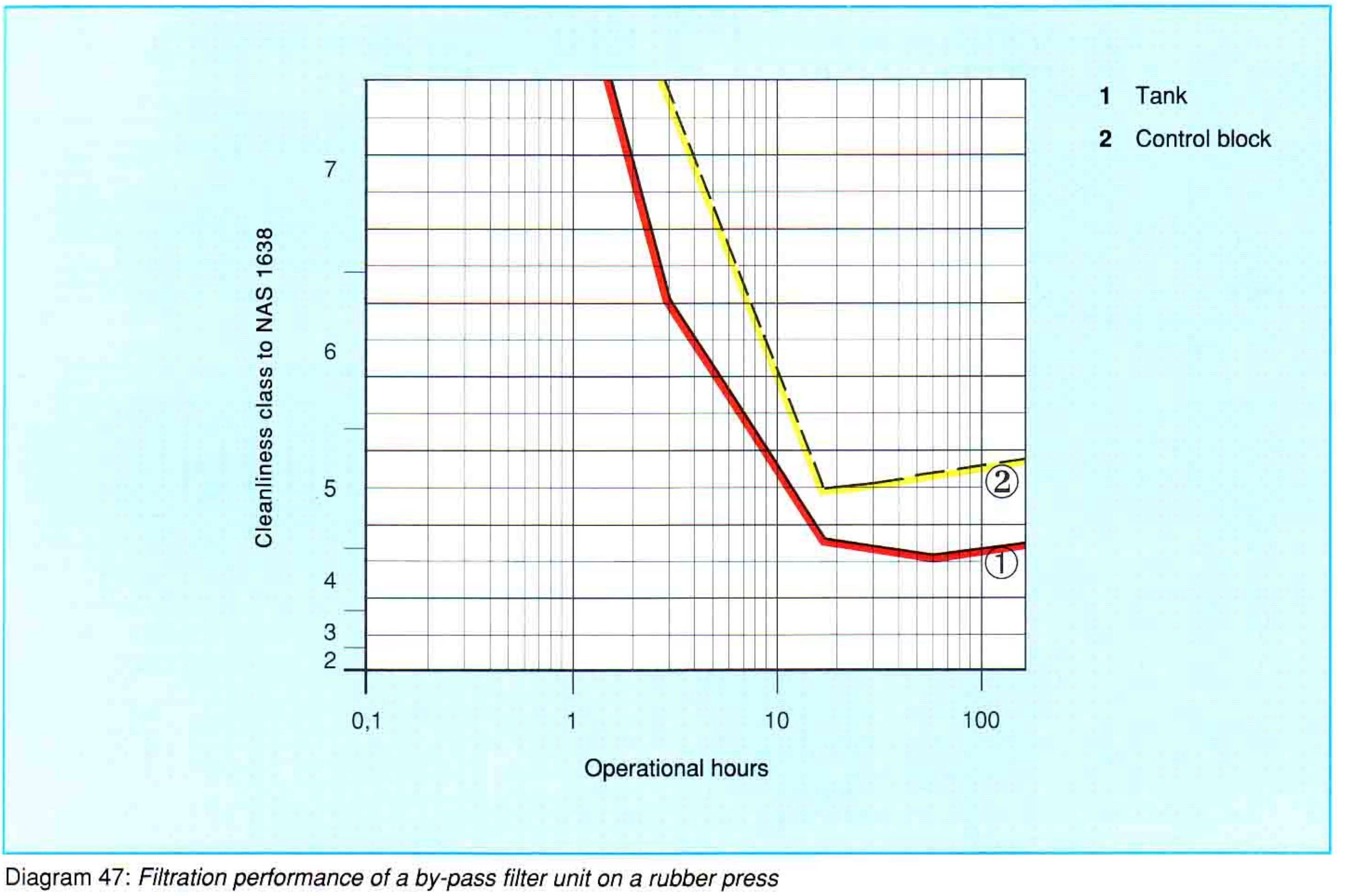


Diagram 47: *Filtration performance of a by-pass filter unit on a rubber press*

5.3 Criteria of filter design

The following criteria govern the selection of filter size, filtration rating and filter version:

Sensitivity to dirt
The filtration rating or specified cleanliness class must be appropriate for the hydraulic components.

Application area of the total system
This must take into account the possible contamination of the surroundings, i.e. is it a laboratory or on the steel-works floor?

Volumetric flow through the filter
This can sometimes be greater than the maximum delivery of the pump, e.g. in the case of single-rod cylinders or when there are return lines from several circuits.

Recommended pressure drop at normal viscosity with a clean element *(Housing and element)*

Pressure-line filters,	
without by-pass valve:	approx. 1.0 bar
with by-pass valve:	approx. 0.5 bar
Return line filters:	approx. 0.3 to 0.5 bar

Permissible maximum pressure drop
The maximum pressure drop across the filter element must be appropriate for the system conditions at the place of installation.

Compatibility of filter materials
They must be compatible with the hydraulic fluid.

Design pressure of the filter housing
The filter housing must have adequate fatigue strength.

Determining the filter model
Decide what type of clogging indicator is to be fitted, e.g. visual, electric or electronic. Pressure-line filters working as protection filters must have no by-pass valve.

Operating temperature or design temperature
The operating viscosity of the fluid calculated from these figures is an important factor in determining the size of the filter.

5.4 Determining the filtration rating

Hydraulic components	Cleanliness class to NAS 1638	Cleanliness class to ISO DIS 4406	recommended absolute filtration rating in µm
Gear pumps	10	19/15	20
Cylinders	10	19/15	20
Directional control valves	10	19/15	20
Relief valves	10	19/15	20
Throttle valves	10	19/15	20
Piston pumps	9	18/14	10
Vane pumps	9	18/14	10
Pressure valves	9	18/14	10
Proportional valves	9	18/14	10
Servo valves	7	17/13	5
Servo cylinders	7	17/13	5

Table 29: *Recommended values of absolute filtration rating for various hydraulic components*

The cleanliness class for the total system depends on the required classification for the system component that is most sensitive to dirt. This "most sensitive component" determines the filtration rating for the total system.

Filter elements with an appropriate absolute filtration rating ($\beta_x \geq 100$) must be used in order to achieve the required cleanliness class. Filtration ratings and the necessary elements can be selected from *Tables 29, 30 and 31.*

The filtering action in a hydraulic system is illustrated in *Diagram 48.* This diagram also shows very clearly the rapid rise in the contamination of the fluid that occurs when no filter is fitted.

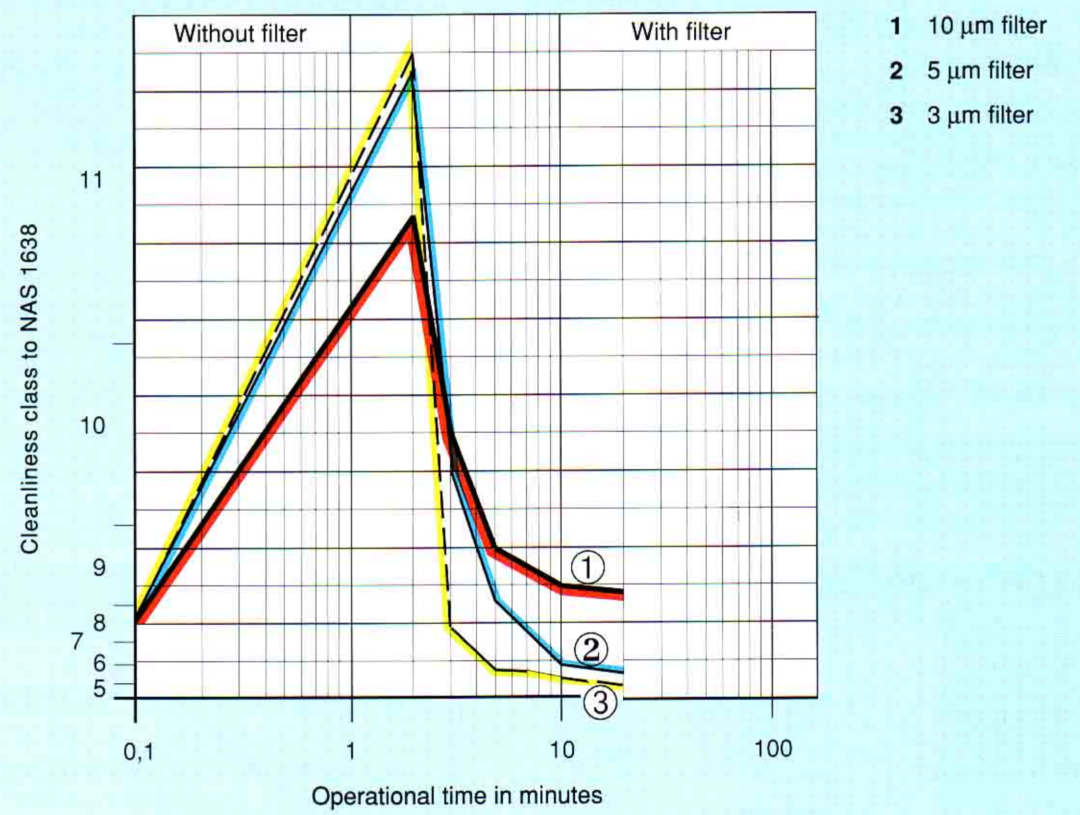


Diagram 48: *Cleanliness classes that can be achieved using the recommended absolute filtration rating*

Hydraulic system	Recommended absolute filtration rating ($\beta_x \geq 100$)	Attainable cleanliness class to NAS 1638 with particles > 5 µm	Attainable cleanliness class to ISO DIS 4406
Systems with servo valves	5	7	17/13
Systems with precision proportional valves	5	7 to 8	17/13
Systems with proportional valves	10	9	18/14
General hydraulic systems	10 to 20	9 to 10	18/14

Table 30: *Determining the recommended filtration rating for hydraulic systems with Rexroth components*

5.4.1 Selection of filter elements

Application	Filtration rating µm	Rexroth element designation	Pressure drop strength	Remarks
Working filters, by-pass filters, Return line filters, pressure line filters with by-pass valve	3	... R 003 BN/HC	30 bar	
	3	... D 003 BN/HC		
	5	... R 005 BN/HC		
	5	... D 005 BN/HC		
	10	... R 010 BN/HC		
	10	... D 010 BN/HC		
	20	... R 020 BN/HC		
	20	... D 020 BN/HC		
Protection filters, pressure line filter without by-pass valve	3	... D 003 BH/HC	210 bar	Enquire from manufacturer for other values of filtration
	5	... D 005 BH/HC		
	10	... D 010 BH/HC		
	20	... D 020 BH/HC		
	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 31: *Selecting filter elements according to application and absolute filtration rating required*

5.5 How the fluid affects filter design

5.5.1 Viscosity of the fluid

(kinematic viscosity)

The characteristics for filter housings and filter elements published in brochures refer to a fluid viscosity of 30 mm²/s. If the design viscosity (usually the operating viscosity) deviates from this reference value, the pressure drop across the filter element (taken from the diagram) will have to be converted to the appropriate value at operating viscosity. Conversion is performed by means of the viscosity conversion factor f_1.

The viscosity conversion factor f_1

This can be taken from *Diagram 49.*

5.5.2 Density of the fluid

The density of the fluid must be taken into account when determining the pressure drop across the filter housing. The filter housing pressure drop can be calculated with the following equation

$$\Delta p_{HF} = \Delta p_{HR} \cdot \frac{\rho_O}{\rho_R}$$

Δp_{HF} = Housing pressure drop, operating fluid

Δp_{HR} = Housing pressure drop, reference data (from catalogue)

ρ_R = Density of fluid, reference data (from catalogue)

ρ_O = Density of fluid, operating value

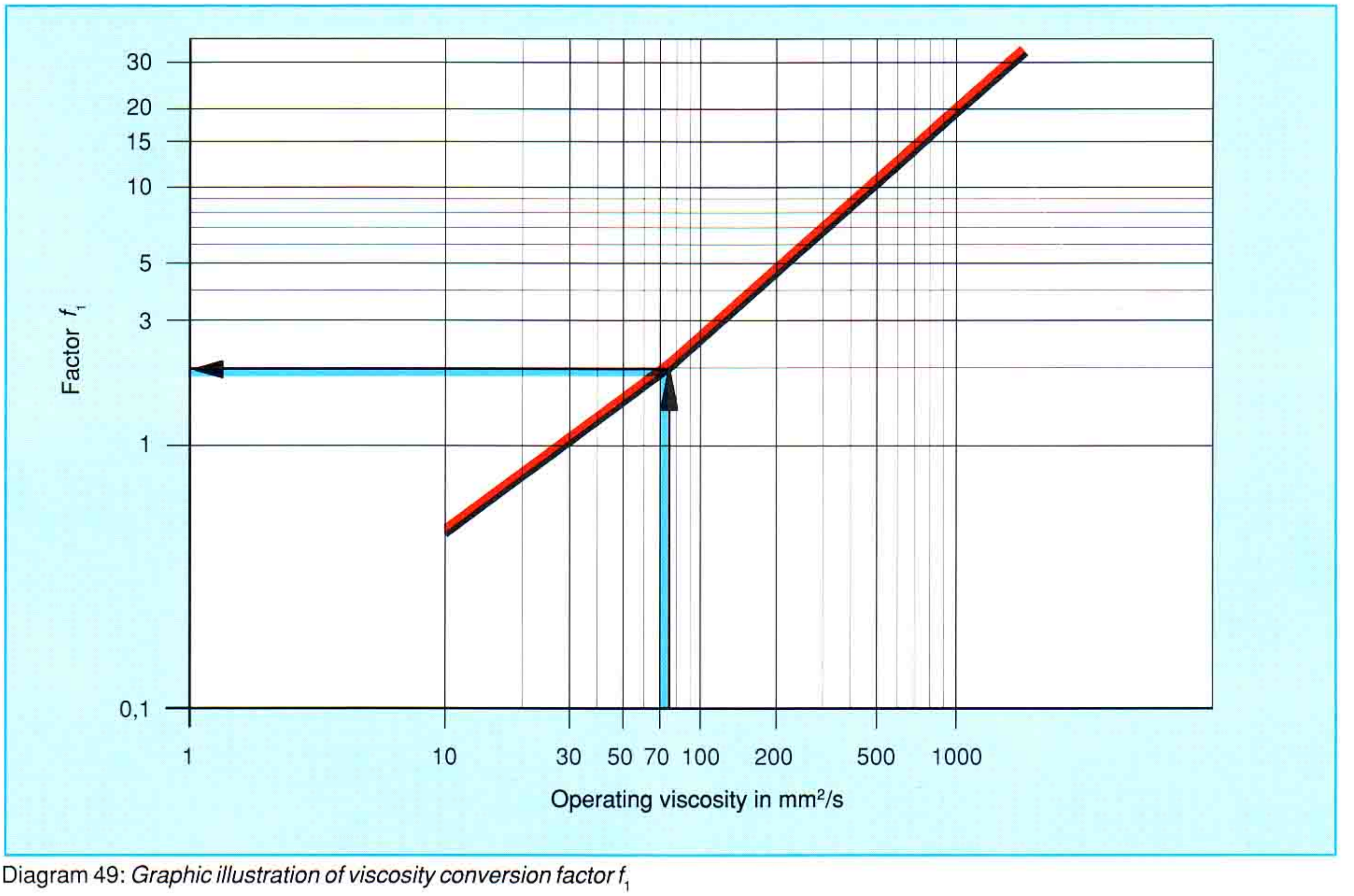


Diagram 49: *Graphic illustration of viscosity conversion factor f_1*

5.6 Determining the filter size

5.6.1 Main filters

The objective in determining the size of the filter is to establish a balance between the dirt gain of the system and the dirt loss through the filter. Filter service life must also be economical.

Therefore, the size of the filter must take into account the amount of dirt around the machine and the maintenance and care provided for the hydraulic systems. The environmental conditions are allowed for by factor f_2. Individual values of factor f_2 can be taken from *Table 32*.

The permitted pressure drop across the filter can be calculated from the following equation:

$$\Delta p_{tot} = (\Delta p_{HF} + f_1 \cdot \Delta p_E) \cdot f_2$$

Δp_{tot} = Total pressure drop across the filter at operating temperature with a clean element and effective volumetric flow

Δp_{HF} = Pressure drop across the filter housing with operating fluid

Δp_E = Pressure drop across the clean element with effective volumetric flow (catalogue data)

f_1 = Viscosity conversion factor

f_2 = Environmental factor

The pressure drop across the filter must be calculated for the effective volumetric flow passing through the filter.

The equation is:

$$Q_W = Q_R \cdot Ad$$

Q_W = Effective volumetric flow

Q_R = Flow of the pump

Ad = Additional flow due to accumulators or cylinders.

The maximum initial pressure drops given in *Table 33* must not be exceeded in determining the size of filter required.

The data refers to a new filter element filtering hydraulic oil. Other design criteria are applicable when filtering fire-resistant fluids or engine oil (enquire from the filter supplier as necessary).

Maintenance and care of hydraulic systems	Contamination of machine surroundings		
	1) low	2) average	3) high
– regular checking of filter – immediate changing of filter element – low dirt ingress – good sealing of tank	1,0	1,0	1,3
– irregular checking of filter – few cylinders used	1,0	1,5	1,7
– minimal or total absence of filter checking – numerous unprotected cylinders – high dirt ingress into the system	1,3	2,0	2,3

Table 32: *Environmental factor f_2*

Notes on *Table 32*

1) low: e.g. testing machines in closed, air-conditioned rooms

2) average: e.g. machine tools in heated workshops

3) high: e.g. presses in foundries, ceramics machinery, potash mining machinery, agricultural and mobile machinery, rolling mills, woodworking machinery

Size of filter required

The total pressure drop across the filter can be determined:

– using the individual diagrams for filter housing and element

Ascertain the individual pressure drops across the filter housing and element at the effective volumetric flow Q_E and operating viscosity. *Diagram 50* shows the pressure drop across the filter housing when filtering hydraulic fluid. *Diagram 51* shows the pressure drop across the clean filter element with a fluid viscosity of 30 mm²/s.

In calculating the required size of filter the total pressure drop must be multiplied by the factor f_2 in order to allow for the environmental conditions.

If the total pressure drop across the filter ascertained in this way is greater than the maximum value given in *Table 33* the whole calculation will have to be repeated for a larger size of filter.

Only when the calculated total pressure drop of the filter is equal to or less than the maximum permitted total pressure drop has the filter been correctly sized.

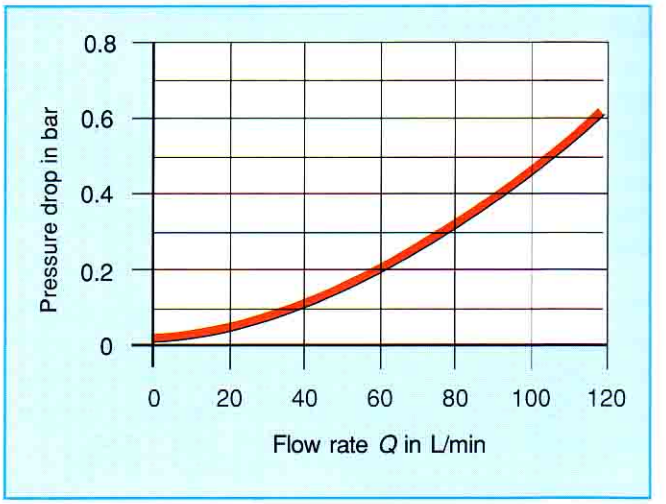


Diagram 50: *Pressure drop across a filter housing*

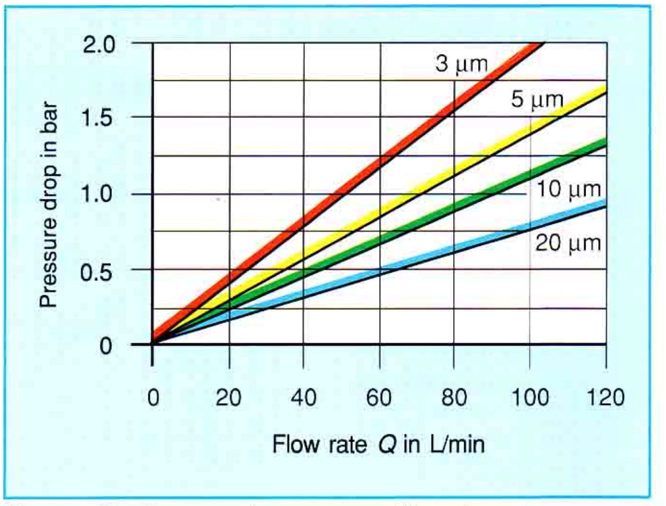


Diagram 51: *Pressure drop across a filter element*

Filter arrangement in Hydraulic systems	Type of filter	Total pressure drop across filter with new element: Using the individual diagrams for filter housing and filter element	Total pressure drop across filter with new element: Using the design diagrams
Working filters	Return line filters Pressure line filters with by-pass valve	$f_2\,(\Delta p_{housing} + f_1 \cdot \Delta p_{element}) \leq 0{,}5$	$Q_{design} = Q_{system} \cdot f_1 \cdot f_2$
Protection filters	Pressure line filters without by-pass valve	$f_2\,(\Delta p_{housing} + f_1 \cdot \Delta p_{element}) \leq 1{,}0$	$Q_{design} = Q_{system} \cdot f_1 \cdot f_2$
By-pass filters	Line filters separate unit	—	—
Suction filters		$f_2\,(\Delta p_{housing} + f_1 \cdot \Delta p_{element}) \leq 0{,}01$	$Q_{design} = 5 \text{ to } 10 \cdot Q_{pump} \cdot f_2$

Table 33: *Determining the size of filter*

– Using the filter design diagrams

The filter design diagrams *(Diagrams 52 and 53)* were originally developed in order to reduce and simplify the relatively complex procedure of filter sizing. The diagrams refer to a fluid viscosity of 30 mm²/s.

Higher operating viscosities and different environmental conditions are allowed for in determining the volumetric flow for the filter.

The volumetric flow can be calculated from the equation:

$$Q_D = Q_W \cdot f_1 \cdot f_2$$

Q_D = Volumetric flow for filter design

Q_W = Effective volumetric flow

f_1 = Viscosity conversion factor

f_2 = Environmental factor

The required size of filter can be read off from the point of intersection between the volumetric flow Q_D and the filtration rating.

5.6.2 By-pass filters

The cleaning of the fluid circulating in a hydraulic system can be greatly improved by installing a by-pass filter. Furthermore, the solid particle contamination of fluids in existing systems can be reduced at any time and without major modifications by using a by-pass filter.

The by-pass filter should work for longer than the hydraulic system itself so it is better for the filter to be independent of the system and filtration can then continue while the system is shut down, e.g. during meal breaks, tea breaks, weekends, etc.

The sizing of a by-pass filter is based on

– the volumetric flow through the filter

– the filter area.

Volumetric flow required in a by-pass filter

The maximum volumetric flow required can be calculated from the following equation:

$$Q_N = \frac{Q_D \cdot T_{TP} \cdot T_{PW} \cdot f_2}{T_{TB} \cdot T_{BW}}$$

Q_N = Volumetric flow for by-pass filter

Q_D = Total volumetric flow of pumps in power unit

T_{TP} = Operating time of power unit per day

T_{PW} = Operating time of power unit per week

T_{TB} = Operating time of by-pass filter per day

T_{BW} = Operating time of by-pass filter per week

f_1 = Environmental factor *(Table 32)*

When there are minor differences between the period of operation of the power unit and by-pass filter the flow rate through the by-pass filter will be similar to the installed pump delivery in the power unit.

However, this is uneconomical so it is advisable in such cases to design the by-pass filter as follows:

– Fix the flow rate through the by-pass filter so that the contents of a 1000 litre tank are circulated once at least every 30 minutes. With larger tanks the circulation cycle should be at least 120 minutes.

– The cleaning action must be increased so the by-pass filter should be selected one step finer than the filter in the power unit.

– The required filter area must be determined according to the specific area loading for the volumetric flow required.

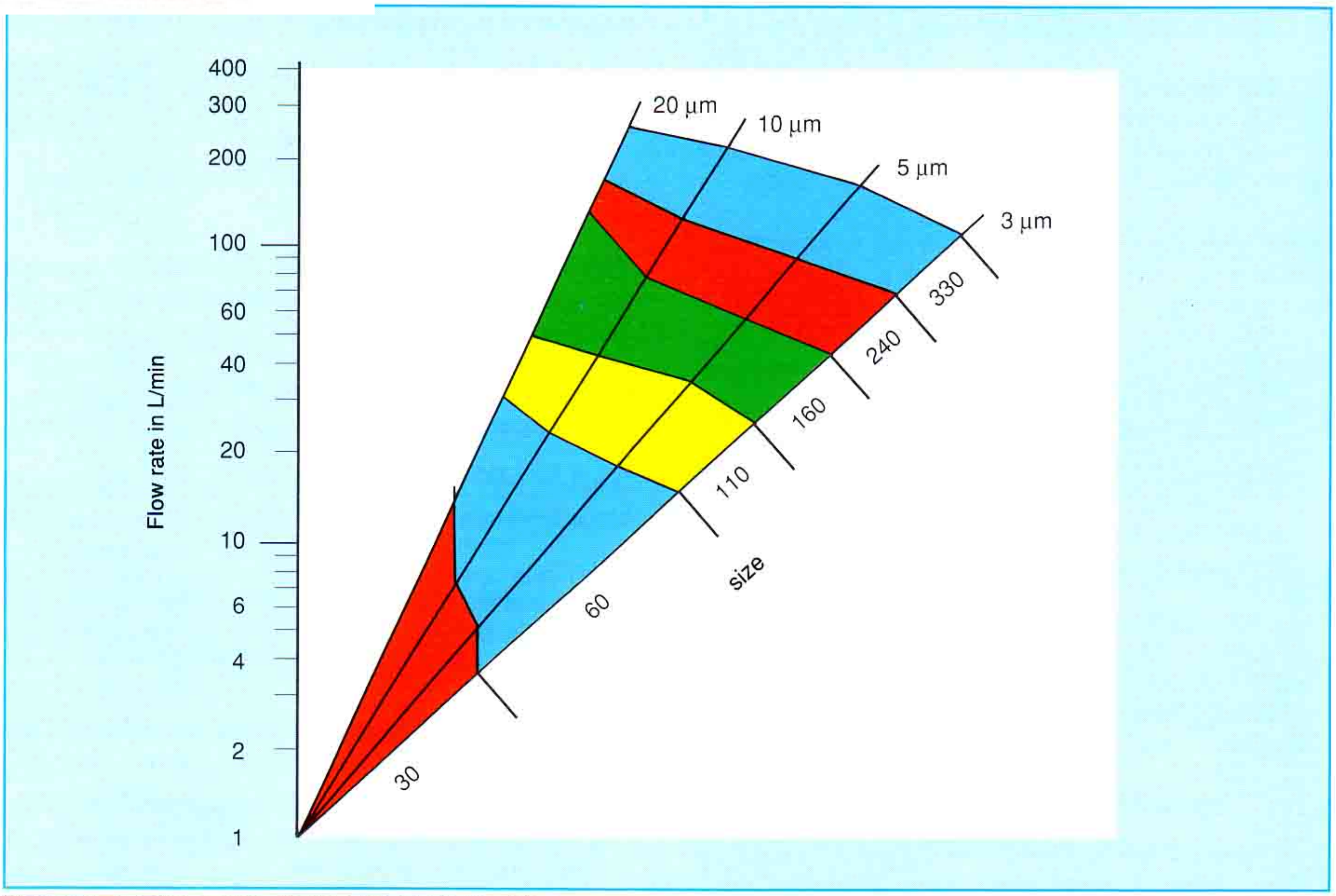


Diagram 52: *Filter design diagram for return line filters*

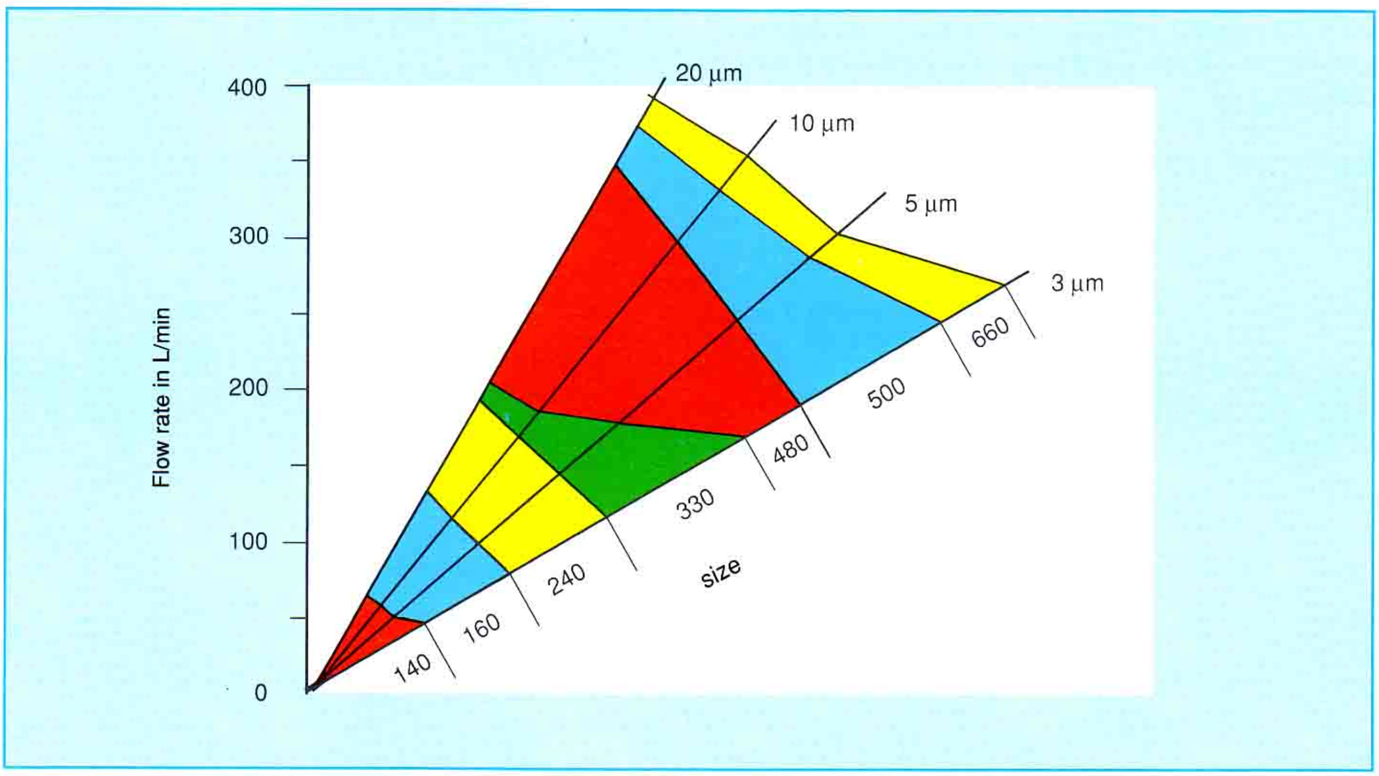


Diagram 53: *Filter design diagram for pressure filters*

Determining the filter area required

The filtration rating must be determined first before the required filter area can be calculated. If possible, it should be one step finer than the system filter.

The filtration rating depends on the hydraulic components used in the power unit. The procedure is described in *Section 5.4.*

The minimum required filter area can then be calculated taking into account the specific area loadings given in *Table 34.*

The maximum required filter area can be calculated with the following equation:

$$A = \frac{Q_N \cdot f_1}{q}$$

A = Required filter area
Q_N = Volumetric flow through by-pass filter
q = Specific area loading *(see Table 34)*
f_1 = Viscosity conversion factor

Filtration rating $\beta_x \geq 100$	Specific area loading L/min/cm²
3 µm	0.0025
5 µm	0.0035
10 µm	0.005
20 µm	0.005

Table 34: *Specific area loading for the design of by-pass filters with elements of glass fibre non-woven*

5.6.3 Tank breathers

The dirt penetration rate has a major effect on the contamination of the system and the tank breathing system is very important in combating the problem. The function of a tank breather is to prevent dirt from the environment penetrating the system while at the same time allowing the tank to "breathe" air. Wrongly or carelessly designed tank breathing can place a substantial extra load on the filter circuit and so shorten the service life of the elements. The performance data of the breathers should be matched to that of the system filters.

The design of breathers should take into account the following data:

Filtration rating $\beta_x \geq 100$
(must be matched to system filters).

Design flow rate for breather:
5 to 10 times the maximum pump capacity.

Design pressure drop 0.01 bar
(with clean element and at design flow rate).

The breather size can be determined with the aid of *Diagram 54.*

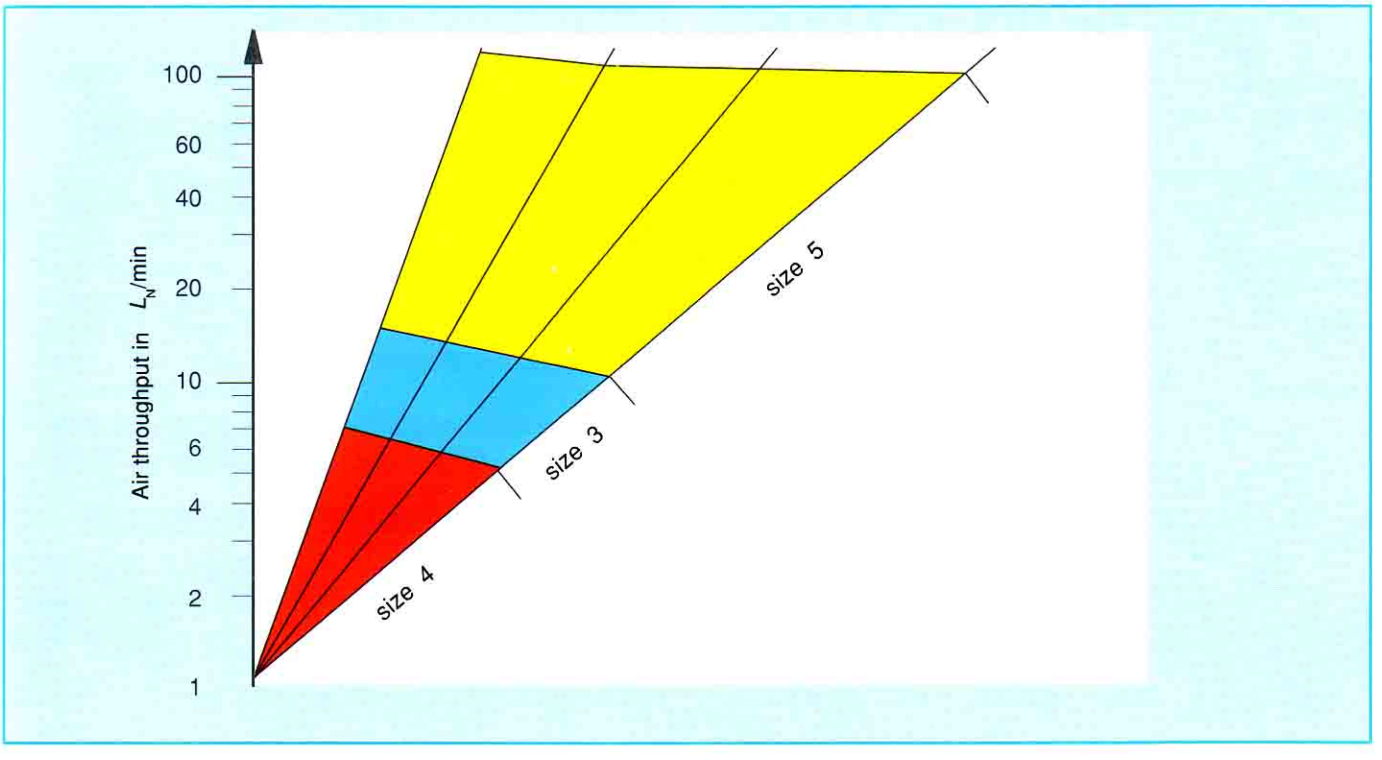


Diagram 54: *Determining the size of tank breathers*

5.7 Filter design for fire-resistant fluids

The filtering of these fluids requires special attention to compatibility with the materials of the filter elements and housings.
Past experience has shown the following materials to be suitable:

Filter elements: glass fibre non-woven, metal non-woven, stainless steel wire mesh

Filter housings: steel, cast iron with surface protection, phosphated or electro-less nickel plated.

Filter housings can also be protected with a suitable paint.

Filters for fire-resistant fluids must have a larger area than those for mineral oil-based fluids because of the greater wear of components, the soapy residue, the growth of micro-organisms and the different dirt settling characteristics.

The filter area can be calculated with the following equations:

For pressure-line filters: $A = 30 \cdot f_1 \cdot f_2 \cdot f_3 \cdot Q_W$

For return line filters: $A = 60 \cdot f_1 \cdot f_2 \cdot f_3 \cdot Q_W$

A = Required filter area

f_1 = Viscosity conversion factor (f_1 = 1 for HFA and HFB fluids)

f_2 = Environmental factor

f_3 = Fluid density conversion factor

Q_W = Effective volumetric flow

In determining the required size of filter, the area of the filter selected must be equal or greater than the area calculated above. In cases of doubt always take the next larger size of filter.

Suction filters and filter elements containing phenolic resin-impregnated paper must never be used.

Fluid density conversion factor f_3

Fluid designation	Factor f_3
HFA	1.16
HFB	1.16
HFC	1.27
HFD	2.21

Table 35

Determination of filter pore size

The filter pore for different types of hydraulic system are as follows:

General purpose systems:
10 or 20 μm absolute

Systems containing proportional valves:
10 μm absolute

Systems containing servo valves or control valves:
5 μm absolute

The filter size ascertained must be doubled in order to obtain economic operation of systems containing servo valves or control valves.

Design of by-pass filters

The procedure for the design of by-pass filters is the same as that described in *Section 5.6.2*.

General remarks on the filtering of fire-resistant fluids

The filtration of fire-resistant hydraulic fluids can be very badly affected by the presence of fluid contaminants such as mineral oil in HFC. Consequently, especially with filtration ratings of 10 μm absolute or 5 μm absolute, it is essential to ensure that the operating fluid is in a satisfactory state.

It may be necessary to use filters capable of removing any traces of foreign fluids from fire-resistant fluids.

6 Practical examples of filter design

The procedure for filter design will be explained by means of a number of examples.

Example 1

System data:

Pump: 1 PV2 V5-3X/16 RE 01 ML 70 A1

Max. operating pressure: 70 bar

Volumetric flow of pump Q_p = 27.5 L/min at a motor speed of 1450 rev/min

Hydraulic fluid: ISO VG 46

Operating temperature: 40 °C

Continuous monitoring of the filter is provided and the environmental contamination can be regarded as average.

A Type 4 WS 2 EM 10/4X/5B... servo valve is employed in the power unit control.

Volumetric flow through the servo valve: 5 L/min

According to the brochure for the servo valve, a fluid cleanliness of NAS 7 is specified.

The power unit also drives a hydraulic cylinder having a full bore/annulus area ratio of 2:1.

A working filter is to be installed in the hydraulic power unit and a protective filter upstream of the servo valve.

Procedure for filter selection

1. Determining the required filtration pore size

As the fluid cleanliness required is class of NAS 7, the filter must have a filtration rating of ß5 = 100 *(see Table 30.)*

2. Determining the viscosity conversion factor f_1

According to *Diagram 44* the operating viscosity of the fluid at 40°C is 46 mm²/s.
Diagram 49 then gives the viscosity conversion factor f_1 as 1.5.

3. Determining the environmental factor f_2

According to *Table 32* the factor f_2 for average environmental conditions and continuous monitoring of the filter is 1.0.

4. Determining the nominal filter size

In designing the hydraulic system it has been established that a return line filter will be the working filter and a pressure-line filter upstream of the servo valve the protective filter.

4.1 Determining the nominal size of return line filter (working filter)

First calculate the effective volumetric flow Q_W:

$$Q_W = Q_P \cdot Ad = 27.5 \text{ L/min} \cdot 2 = 55 \text{ L/min}$$

Determining the filter size from the individual diagrams for housing and element

First select a size from past experience. If the total pressure drop calculated for this size is greater than the figure of maximum pressure drop given in *Table 33* the whole calculation will have to be repeated for a larger size of filter. Only when the calculated figure of total pressure drop is less than the prescribed maximum total pressure drop has the filter size been correctly chosen and can be incorporated into the system.

In the case of this example a return line filter of Type RF BN/HC 110 G 005 C 1.X has been selected.

According to *Diagram 50* the pressure drop across the Type RF 110 filter housing at an effective volumetric flow rate of 55 L/min is 0.18 bar.

According to *Diagram 51* the pressure drop across the Type 0110 R 005 BN/HC clean filter element at an effective volumetric flow rate of 55 L/min is 0.7 bar.

Calculate the total pressure drop:

$$\Delta p_{tot} = (\Delta p_H + f_1 \cdot \Delta p_E) \cdot f_2 = (0.18 + 1.5 \cdot 0.7) \cdot 1.0 = 1.23 \text{ bar}$$

The calculated figure of total pressure drop is greater than the permitted figure of 0.5 bar which means that the selected filter is too small. The calculation will have to be repeated for a larger size of filter.

Determining the filter size using the filter design diagram

Calculate the volumetric flow for the filter:

$Q_P = Q_W \cdot f_1 \cdot f_2 = 55$ L/min • 1.5 • 1.0 = 82.5 L/min

The required size of filter can now be read from *Diagram 52*. The point of intersection between Q_P (82.5 L/min) and the 5 µm line is close to Size 240.

Therefore, a return line filter of Type RF BN/HC 240 G 005 C 1.X is used as the working filter.

4.2 Determining the size of protection filter

This filter is installed directly upstream of the servo valve and must have no by-pass valve. The filter is fitted with an electric clogging indicator for monitoring the state of the element. The filtration rating is to be $\beta_5 \geq 100$.

Determining the filter size using the filter design diagram

Calculate the volumetric flow for the filter:

$Q_P = Q_W \cdot f_1 \cdot f_2 = 5$ L/min • 1.5 • 1.0 = 7.5 L/min

In *Diagram 53* the point of intersection between Q_P (7.5 L/min) and the 5 µm line is close to Size 30.

Therefore, a Type LF BN 30 G 005 C 1.X filter must be fitted upstream of the servo valve as the protection filter.

Example 2

The procedure for by-pass filters is explained by the following example:

Power unit data

Tank capacity: approx. 1000 litres
Hydraulic fluid: ISO VG 46
Operating temperature: 50°C
The unit incorporates 2 pumps each with a delivery of 100 L/min
The system is equipped with proportional valves.
The environmental conditions are average.
Continuous monitoring of the filter is provided.
The unit is operated for 7 hours a day and 5 days a week.

By-pass filter data

The by-pass filter can be operated continuously 24 hours a day, 7 days a week.

Procedure for filter selection

1. Determining the volumetric flow

$$Q_N = \frac{Q_P \cdot T_{TP} \cdot T_{PW} \cdot f_2}{T_{TB} \cdot T_{BW}} = \frac{2 \cdot 100 \cdot 7 \cdot 5 \cdot 1}{24 \cdot 7} = 41.6 \text{ L/min}$$

Use: 40 L/min

2. Determining the filtration pore size

According to *Section 5.6.2* the filtration rating of the by-pass filter should be one step finer than that given in *Table 30*. This means that a rating of 5 µm absolute must be used.

3. Determining the filter area

$$A = \frac{Q_N \cdot f_1}{q} = \frac{40 \cdot 1}{0.0035} = 11428 \text{ cm}^2$$

Results

The by-pass filter must carry a flow of 40 L/min and its area must be at least 11,428 cm².

The filtration rating must be 5 µm absolute.

Example 3

For power unit data see Example 2

By-pass filter data

For safety reasons it will only be possible to operate the by-pass filter unit while the power unit is working.

Procedure for filter selection

The contents of the tank must be circulated at least once every 30 minutes. For a tank capacity of 1000 litres, this means that the flow rate through the by-pass filter must be:

$$Q = \frac{1000}{30} = 33.3 \text{ L/min}$$

Use 40 L/min

Filtration pore size required

A filtration rating one step finer means that the rating must be 3 µm absolute.

Determining the filter area

$$A = \frac{Q_N \cdot f_1}{q} = \frac{40 \cdot 1}{0.0025} = 16000 \text{ cm}^2$$

Results

Although the flow rate through the by-pass filter in this example is the same as that calculated in Example 2, the filter efficiency of the element is better and the filter area greater.

Example 4

The procedure for designing filters for filtering fire-resistant hydraulic fluids is explained by the following example:

Power unit data

Fluid: HFC 46

Hydraulic power unit for a die-casting machine

Environmental contamination around the machine: High

Intermittent monitoring of the filter

Tank capacity: approx. 1000 litres

Operating temperature: 50°C

Effective volumetric flow: 80 L/min

The system is equipped with proportional valves.

The power unit is to be fitted with return line filters.

Determining the filter pore size

The use of proportional valves means that a filtration rating of $\beta_{10} \geq 100$ is needed.

Determining the filter area

$$A = 60 \cdot f_1 \cdot f_2 \cdot f_3 \cdot Q_W$$

Viscosity conversion factor f_1

For 46 mm²/s the factor f_1 is 1.5 *(see Diagram 49)*

Environmental factor f_2

According to *Table 32* factor f_2 is 1.7

Fluid density conversion factor f_3

According to *Table 35* factor f_3 is 1.27

Required filter area

A = 60 • 1.5 • 1.7 • 1.27 • 80
A = 15.544 cm²

Results

Filter RF BN/HC 1300 F 010 A 1.1/SO105 must be used.

7 Instructions for operation and maintenance

7.1 Operation

Temperature limits for hydraulic filters

Most hydraulic filters may normally be used at operating temperatures between -10 and +100°C although temperatures up to 120°C for short periods will cause no harm. Higher operating temperatures can damage the filter elements and seals and proper filtering can no longer be assured. When temperatures are low the materials of the housings and seals must be checked for suitability. Filter elements can be stored at temperatures down to -50°C.

Fire-resistant fluids

A higher concentration of contaminants must be anticipated with these fluids. Also, galvanizing is not allowed. Consequently, the filters used for these fluids require special attention such as larger sizes and different kinds of surface protection. See also *Section 5.7.*

Changing of filtration rating or element materials in existing systems

In such cases it must be remembered that the filter elements will clog more quickly due to the particles of dirt already in the circuit. Therefore, a shorter element service life must be anticipated when using finer filters. The use of mobile by-pass units is recommended when carrying out such conversions.

Suggested intervals for element changing

The elements used in hydraulic filters should be changed at the following intervals:

- whenever the clogging indicator incorporated in the filter is triggered
- after 1000 hours of service or 1 year
- whenever the fluid in the whole system is changed.

7.2 Notes for the manufacturers of hydraulic power units

Satisfactory operation of hydraulic power units requires attention to the following points when installing the filters:

- Allow adequate space for changing the elements so that the work can be performed more easily, more quickly, and without damaging the elements.
- Run the pipes on the power unit so that they do not obstruct element changing
- Position the filters in easily accessible places on the unit. Correct positioning encourages proper maintenance. Allow adequate height for removal.
- Note the direction of flow marked on the filter housing.
- Use the N/C switching mode for the electric clogging indicator if possible. It makes interference with the system more difficult, e.g. removal of plugs, cutting of cables.
- Provide filling connections on the tank or upstream of the return line filter to make filling and topping-up of the tank easier.
- Provide Minimess connections for taking fluid samples. In order to protect the filter element, a pulsation damper is also advisable if there are high pressure peaks or fluctuations in flow .
- Avoid negative pressure peaks on the filters because they damage the elements. They can be prevented by fitting a check valve between filter and valve or accumulator.

7.3 Maintenance of hydraulic filters

Filter elements are protected in sealed plastic bags to prevent contamination during storage and handling. The plastic should not be removed until immediately before the element is to be inserted into the filter housing.

Only elements made of wire mesh, braided mesh or metal non-woven material can be cleaned. Filter elements made of non-woven paper or non-woven glass fibre cannot be cleaned.

Procedure for changing a filter element

- When the clogging indicator is triggered, depressurize the filter or the half of the filter containing the clogged element.
- Unscrew the filter housing or remove the cover, ensuring that the thread is not made dirty. Rotating the cover of a return line filter by about 45° makes lifting it off easier.
- Remove the clogged element and examine the residue on its surface. This might give a clue to any damage which has occurred to components. In the case of return line filters ensure that the element is removed together with the catchment basket.
- The fluid left in the housing must be removed into a suitable container. It is very contaminated and must never be allowed to get back into the system.
- Clean the filter housing with a clean, lint-free cloth.
- Examine the seal on the filter housing or cover and change it if necessary.
- Smear the thread and sealing surfaces of the filter and the seal of the element with clean hydraulic fluid.
- Insert the new element after first checking the filtration rating.
- Screw on the filter housing or cover.
- Switch on the system or fill the filter housing with fluid and examine it for leaks.

Maintenance instructions for tank breathers

It is advisable to change the breather element every time the fluid is changed. In some cases the whole breather has to be changed. Others are fitted with a renewable element or cartridge.

7.4 Flushing the whole system

Flushing of the system is recommended:

- when commissioning a new system
- after repair work
- after the system has been opened up in any way, e.g. for fitting a new pump or new valve.

Procedure for flushing a system

Fill the system with cleaned hydraulic fluid.

For this it is better to use a fluid service unit incorporating a filter. It allows both the tank to be filled and its contents to be filtered continuously in a by-pass operation.

High-precision valves such as servo valves or proportional valves must be replaced by flushing plates or flushing valves before flushing takes place.

The system filters should be fitted with elements of the filtration rating specified for operation of the system.

If necessary, use elements with the same filtration rating as the system filters but which will only withstand a lower pressure differential than the working filters.

After the total quantity of fluid has been circulated between 150 and 300 times, examine it for solid particle contamination and either stop or continue flushing.

Throughout flushing pay extra close attention to the clogging indicators on the filters. The elements must be changed immediately if the indicators are triggered so have sufficient spare elements to hand.

8 Symbols and subscripts

Symbols

Symbols	Units	Quantity
Q	L/min, m^3/s	Volumetric flow
A	m^2, cm^2, mm^2	Area, Filter area
p	bar, N/m^2	Pressure
α	g	Dirt retention
ρ	kg/dm^3	Densitiy
τ	n	Operational time
q	$L/min/cm^2$	Specific area loading
n	rpm	Speed
ν	mm^2/s	Kinematic viscosity

Dimensionless symbols

Symbols	Quantity
f	Correction factor, Conversion factor
%	Per cent
t	Time, Flushing time
ß	Beta value, Degree of separation
n	Number
M	Million
K	Thousand

Subscripts

Symbols	Quantity
1, 2, 3	Element number, Factor No.
X	Particle size
HF	Housing, with operating fluid
HR	Housing, reference data
R	Data sheet, Pump
O	Operating conditions
W	Effective (working)
Ad	Mechanical ratio
tot	Total
E	Element
H	Housing
D	Design, Area, System
N	Nominal flow, Nominal
TP	Hydraulic system per day
PW	Hydraulic system per week
TB	By-pass filter per day
BW	By-pass filter per week

Prefixes

Symbols	Quantity
Δ	Difference, drop

9 International standards

ISO 228	Pipe threads where pressure-tight joints are not made on the threads - Designation, dimensions and tolerances
ISO 1000	SI units and recommendations for the use of their multiples and of certain other units
ISO 3722	Hydraulic fluid power - Fluid sample containers - Qualifying and controlling cleaning methods
ISO 4021	Hydraulic fluid power - Particulate contamination analysis - Extraction of fluid samples from lines of an operating system
ISO 4402	Hydraulic fluid power - Calibration of liquid automatic particle-count instruments - Method using Air Cleaner Fine Test Dust contaminant
ISODIS 4405	Hydraulic fluid power - Fluid contamination - Determination of particulate contaminants by the gravimetric method
ISO 4406	Hydraulic fluid power - Fluids - Method for coding level of contamination by solid particles
ISODIS 6162	Hydraulic fluid power - Flange connections - Four-bolt split flanges rated for normal duty applications - PN 35 to PN 415 bar (PN 3,5 to PN 41,5 MPa) - Dimensions
DIN ISO 2941	Hydraulic fluid power; filter elements; verification of collapse/burst resistance
DIN ISO 2942	Hydraulic fluid power; filter elements; verification of fabrication integrity; identical with ISO 2942, edition 1985
DIN ISO 2943	Hydraulic fluid power; filter elements; verification of material compatibility with fluids
DIN ISO 3723	Hydraulic fluid power; filter elements; method for end load test; identical with ISO 3723, edition 1976
ISO 3724	Hydraulic fluid power - Filter elements - Verification of flow fatigue characteristics
ISO 3968	Hydraulic fluid power - Filters - Evaluation of pressure drop versus flow characteristics
ISO 4572	Hydraulic fluid power - Filters - Multi-pass method for evaluation filtration performance
ISO 5598	Fluid power systems and components - Vocabulary
DIN ISO 2909	Petroleum Products; Calculation of Viscosity Index from Kinematic Viscosity
DIN 24312	Fluid power systems and components; pressure; quantities, terms
DIN 24550	Fluid power; hydraulic filters; definitions, nominal pressures, nominal sizes, fitting dimensions
DIN 51519	Lubricants; ISO viscosity classification for industrial liquid lubricants
DIN 51562	Viscosimetry; measurement of kinematic viscosity by means of the Ubbelohde viscosimeter; micro Ubbelohde viscosimeter
DIN 51757	Testing of petroleum and related materials; determination of density
DIN 51777	Testing of mineral oil hydrocarbons and solvents; determination of water content according to Karl Fischer; direct method
CETOP RP 91 H	Fluids for Hydraulic Transmission - Mineral Oils Specifications
CETOP RP 92 H	Statement of requirements for filters in hydraulic systems
CETOP RP 94 H	Determination of particulate matter in hydraulic fluids using an automatic particle size analyser employing the light interruption principle
CETOP RP 95 H	Recommended method for the bottle sampling of hydraulic fluids for particle counting
NAS 1638	Cleanliness Requirements of Parts used in Hydraulic Systems