Filtration in Hydraulic Systems with Servo and Proportional Valves

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1 *Filtration of Hydraulic Oils*

The demand for more efficiency, reduction in the number of faults, longer service life and easier servicing of servo and proportional valves has led to valve manufacturers and operators demanding improved filtration of the hydraulic fluid.

Due to a continual increase in the power consumption of hydraulic devices, stringent requirements are necessary for the switching accuracy of valves. One of the ways of achieving this, is to make the clearance between housing and control spool even smaller.

1.1 *Effect of Contamination by Solids*
(Fig. 253)

Dirt particles which are much larger than the clearance tolerance do not affect the valve. Particles which are smaller than the clearance tolerance pass through the clearance and also do not affect the valve.

Dirt particles which are the same size as the clearance tolerance are critical for the surfaces of valve and control spool. Due to the scouring effect of these dirt particles during operation new particles (from the valve material) are produced. Particles, which are larger than the clearance, are reduced in size by movement of the spool or by the speed of flow of the hydraulic fluid.

This results in increased leakage, spool jamming, changes in switching times, valve failure and changes in valve characteristics.

Without suitable filtration, a chain reaction occurs which results in the concentration of dirt being increased.

After long periods of continuous flow, these dirt particles may block the clearance in the pilot circuit.

1.2 *Effect of Erosion on Control Lands*

Dirt increases the load on the material of the sensitive control edges.

This results in increased erosion and leads to inaccurate operation and control of servo and proportional valves (wear increases steadily).

External contamination entering the system may trigger off or accelerate this development.

The chain reaction of particle development and of increases in the number of particles must be minimized or even prevented by using efficient system filters.

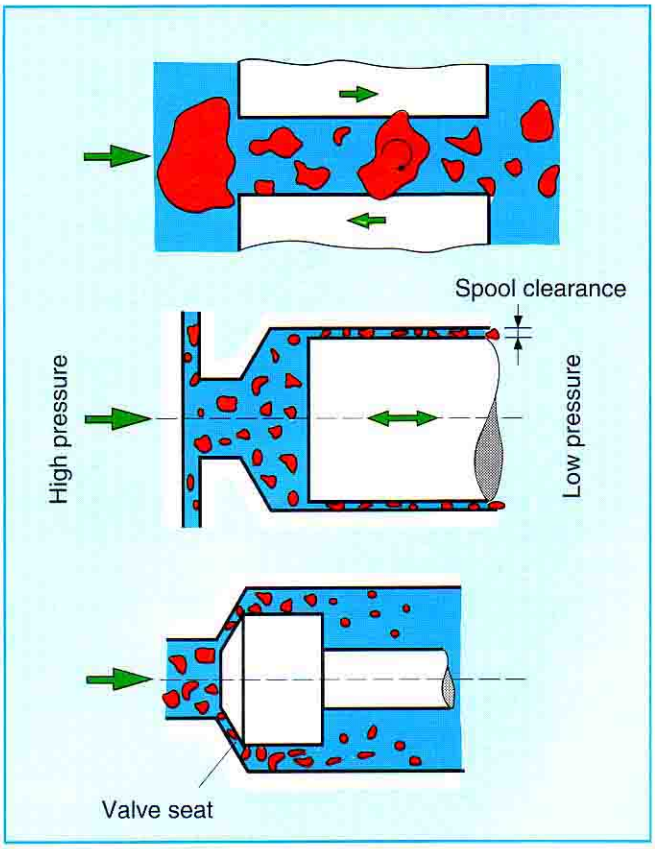


Fig. 253: *Wear process – influence of dirt particles on valve seat and spool clearance*

Correct filter design and selection leads to higher efficiency of the overall system (reduction of downtimes) and to less servicing.

The selected filter system must ensure that the following are maintained:

- Functionality and service life of the valves
- No sudden valve failures
- No continuous reduction in power due to increasing internal leakage
- No changes in valve set-up data during the period of operation
- No changes in valve characteristics, e.g. due to embedded dirt particles.

Hydraulic filters are often neglected or even forgotten in the planning of a hydraulic system. A filter is often then installed at the last minute during assembly of the system.

For reasons of cost or space, a filter is then selected which is often too small and too coarse. The system operator is then faced with the difficulty of the costs which result from the short service life of the filter elements (filter too small) or from the frequent servo and proportional valve failures (filter too coarse).

2 Creation of Contamination by Solid Particles in Hydraulic Systems

2.1 Initial Contamination

This type of contamination of the hydraulic oil takes place during installation and commissioning of hydraulic systems (dust, scale, metal shavings, welding spatter, fluff, rust, residual packing, paint particles etc.).

2.2 Contamination During Operation

Dirt may enter the hydraulic tank by means of inefficient tank ventilation, pipe ports, piston rod seals etc. The contamination rate is dependent on the application, e.g. quarries, road construction, cement works etc.

2.3 Contamination due to Fresh Oil

Fresh oil delivered by oil suppliers often has a contamination level which is not permissible for servo and proportional valves. This contamination must be removed by filters installed in the system.

However, in systems which only have one return line filter, the contamination in the oil (which is poured into the system) may result in serious damage to the installed components on flushing the system.

It is therefore necessary to fill, change, or add oil to the tank by means of an oil service power unit, via the return line filter installed in the hydraulic power unit *(Fig 254)*. It is recommended that a quick connection coupling on the oil service power unit and on or in the return line is installed.

The hydraulic filter used in the service unit must have the same filter element pore size as the filter in the hydraulic system.

Fig. 254: *Oil service power unit*

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.

3.1 Arrangement of the Multi-pass Test Rig *(Fig. 255)*

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 contamination particle count in the systems has been achieved.

3.2 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.

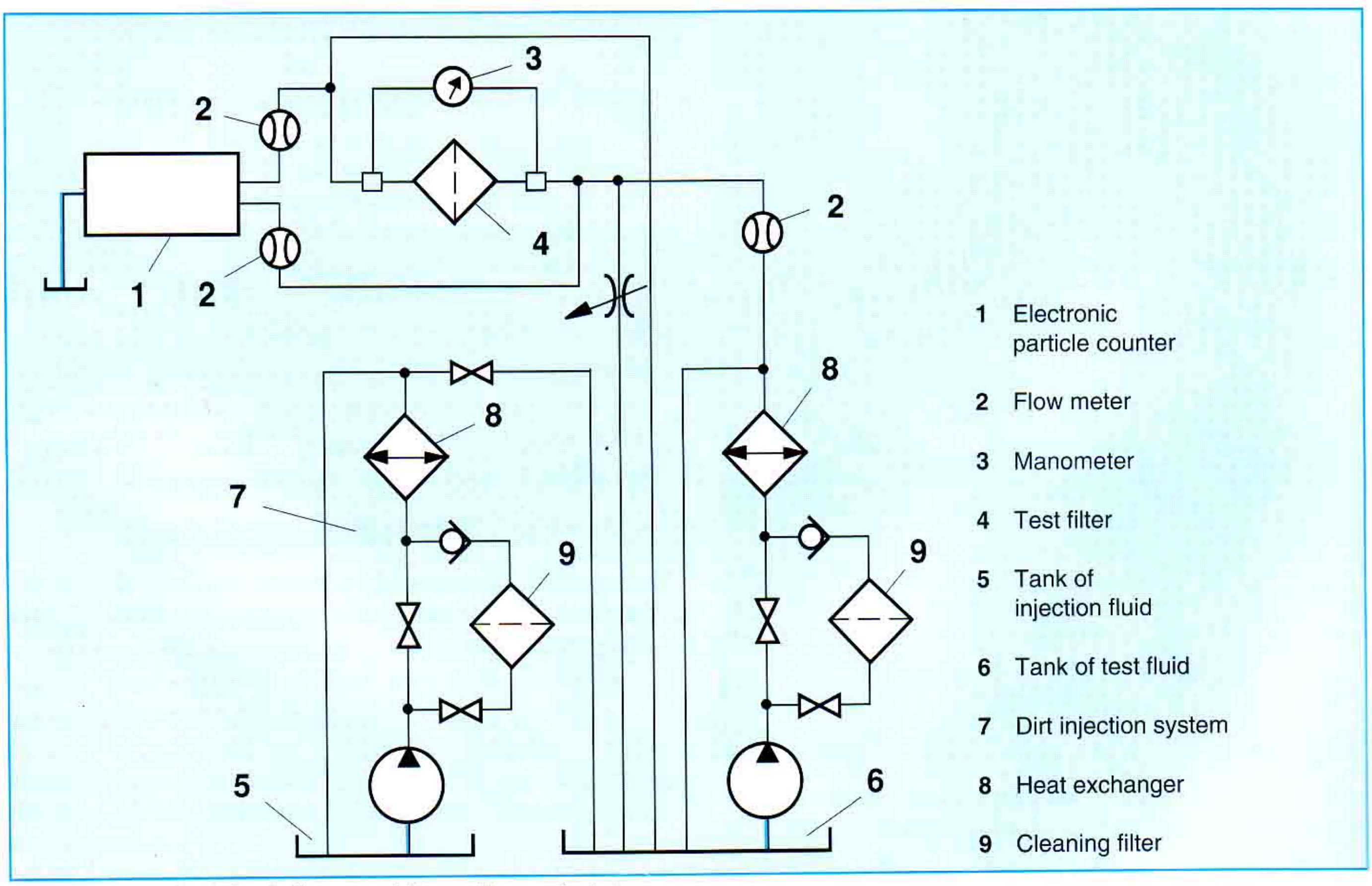
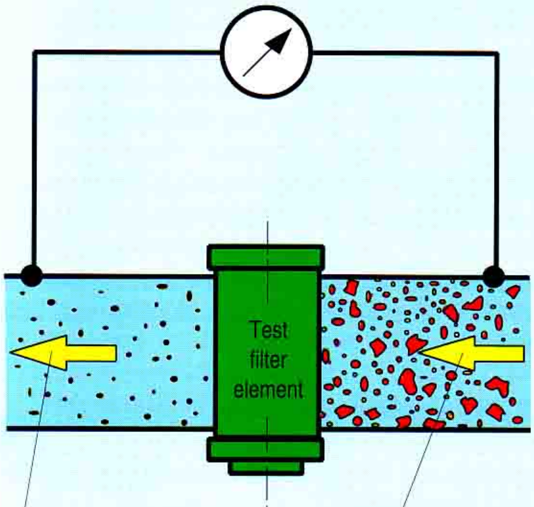


Fig. 255: *Simplified circuit diagram of the multi-pass test rig*

3.3 Determination of β_x Value *(Fig. 256)*

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.



$n_{Z\ Outlet}$ — 1000 particles $\geq$ 10 µm/100ml = 0,08 mg/l (ACFTD)

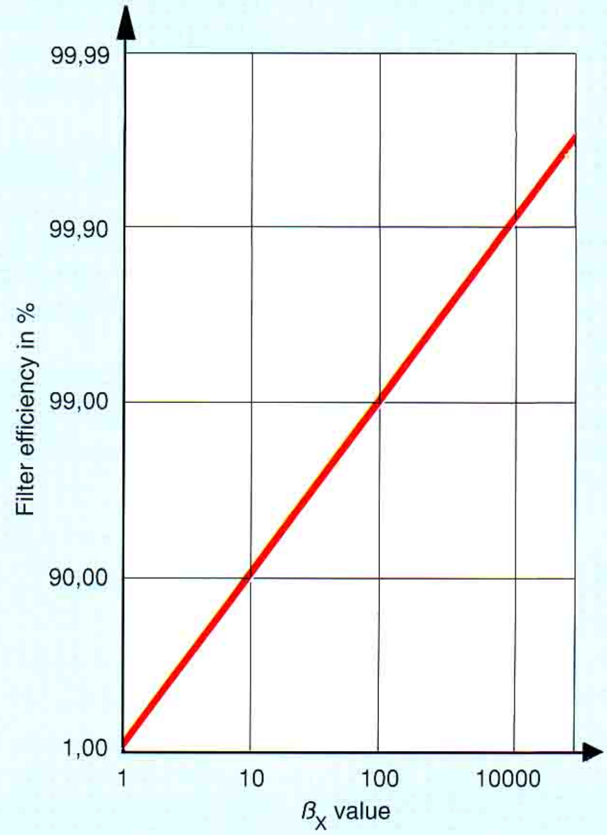
$n_{Z\ Inlet}$ — 100 000 particles $\geq$ 10 µm/100ml = 10 mg/l (ACFTD)

$$\beta_X = \frac{n_{Inlet} \geq X\ \mu m}{n_{Outlet} \geq X\ \mu m}$$

Numerical example: $\beta_{10} = \frac{100\,000}{1000} = 100$ (10 = Particle size in µm)

β_x = 2 — 50 % filter efficiency
β_x = 20 — 95 % filter efficiency
β_x = 75 — 98,6 % filter efficiency
β_x = 100 — 99 % filter efficiency (absolute retention rate)

Fig. 256: *Determination of β_x value*



Diag. 86: *Degree of separation (βx value) versus filter efficiency in %*

3.4 Definition of the 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.

3.4.1 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 .

3.4.2 Absolute filter element pore size

Above a β_x value of $\leq$100 or a filter efficiency of 99%, the filtration rating is called the absolute retention rate *(see Diag. 86)*.

3.5 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 β_x 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 Diag. 87).*

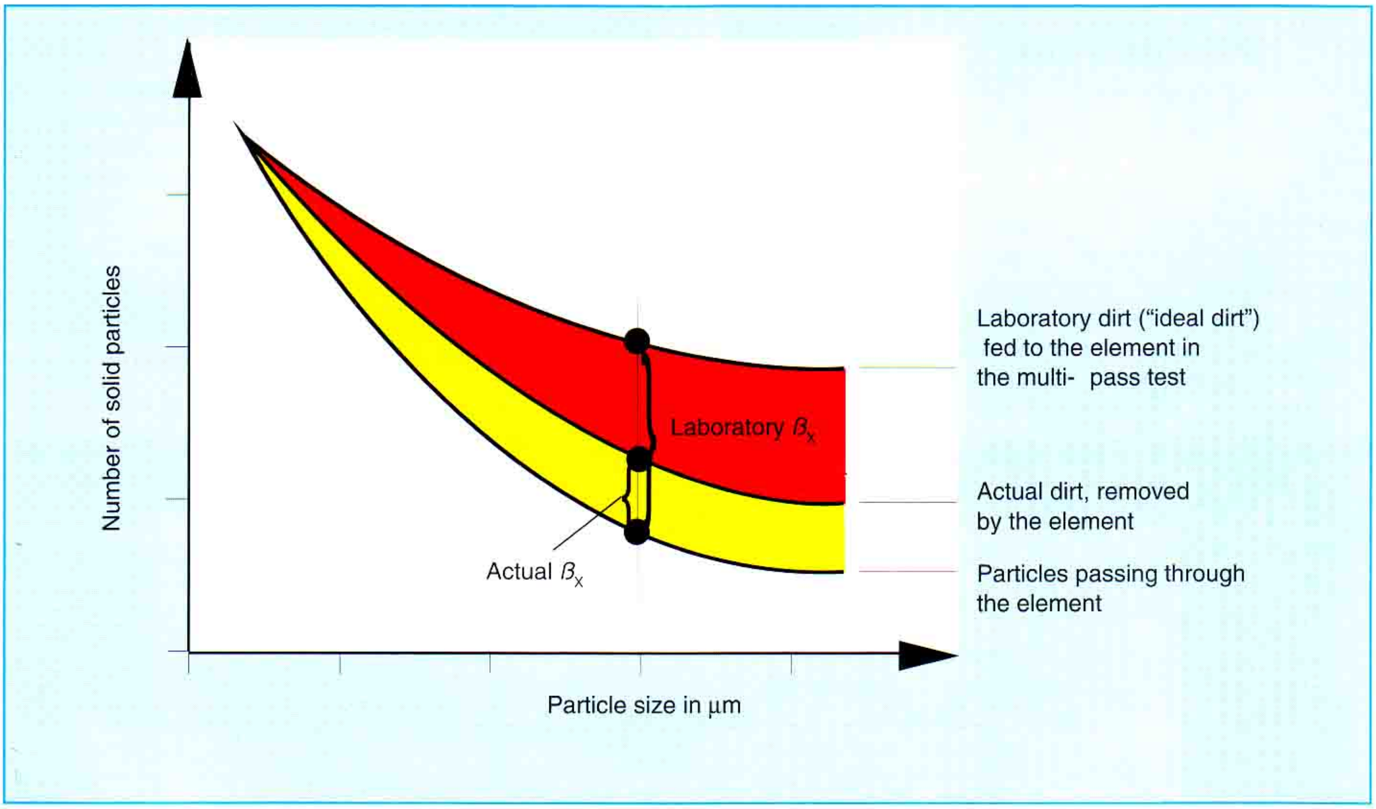


Fig. 87: *Variation in β_x values with laboratory dirt and real dirt*

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® and Betamicron® -2 - *(Fig. 257).*

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.

And 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 of over 120 °C.

Betamicron® -2 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 B_x values *(Diag. 88)*.
- high dirt holding capacity through a large specific capture area *(Diags. 89 and 90)*.
- good chemical resistance
- protection against element damage due to a high bursting strength, e.g. during cold starts and switching or differential pressure peaks
- water or water drops in the hydraulic fluid causes no reduction in filtration performance.

4.1 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.

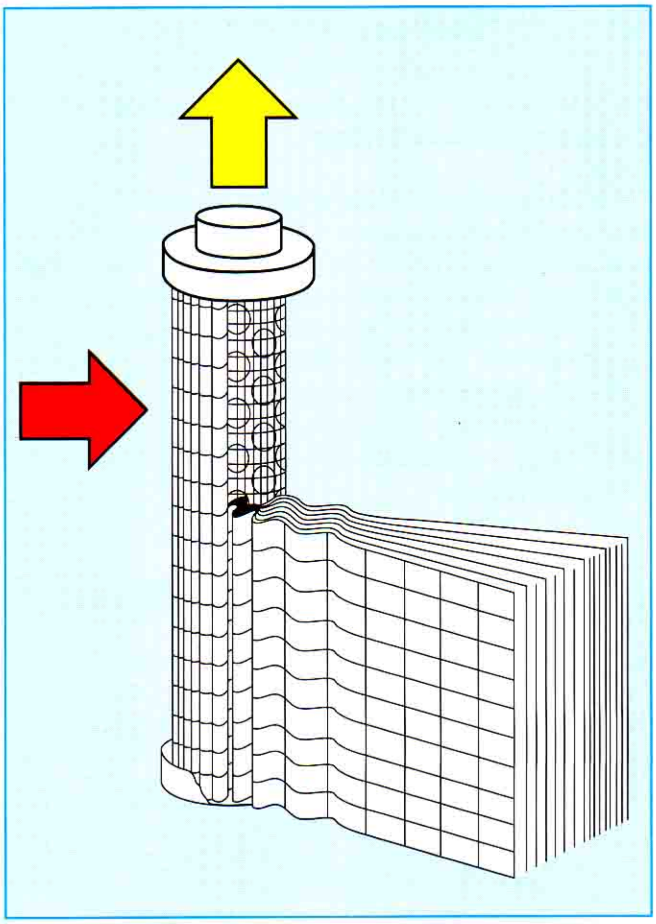
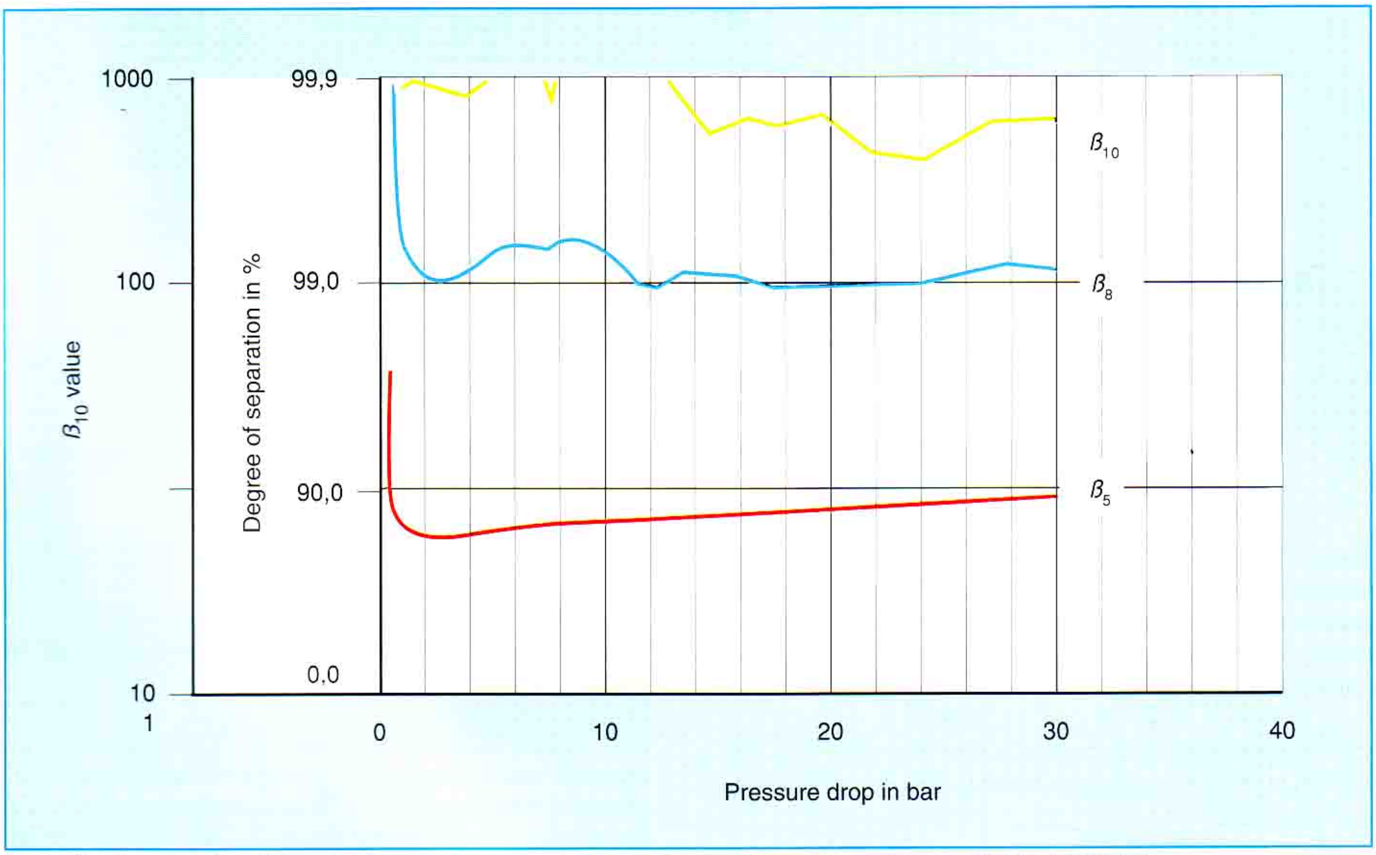


Fig. 257: *Betmicron® -2 element of multi-layer mat construction*



Diag. 88: *B_x values for different pressure drops across the Betamicron® -2 element (type ... D010 BH/HC-2)*

4.2 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.

4.3 Pressure drop at the Filter Element

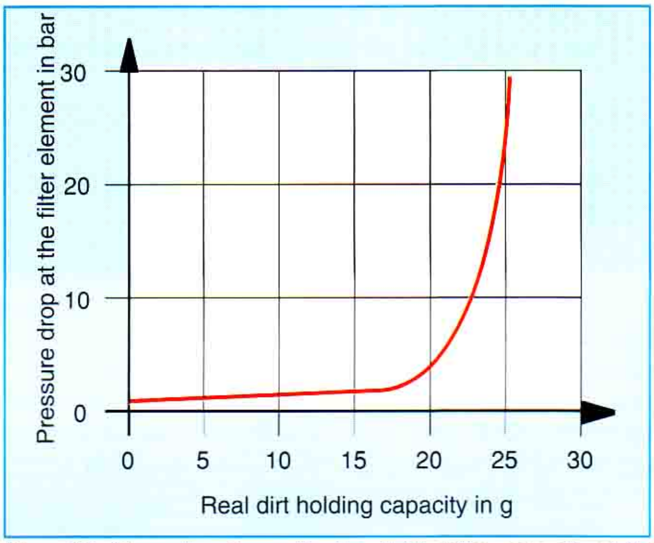
In order that the filter element's dirt holding capacity is fully utilised and that the energy loss in the hydraulic system is not increased much above the pressure loss at the clean filter element, care must be taken to ensure that a lower pressure drop is present when using clean filter elements.

The recommended pressure drop at clean filter elements is given in *paragraph 8.7.*

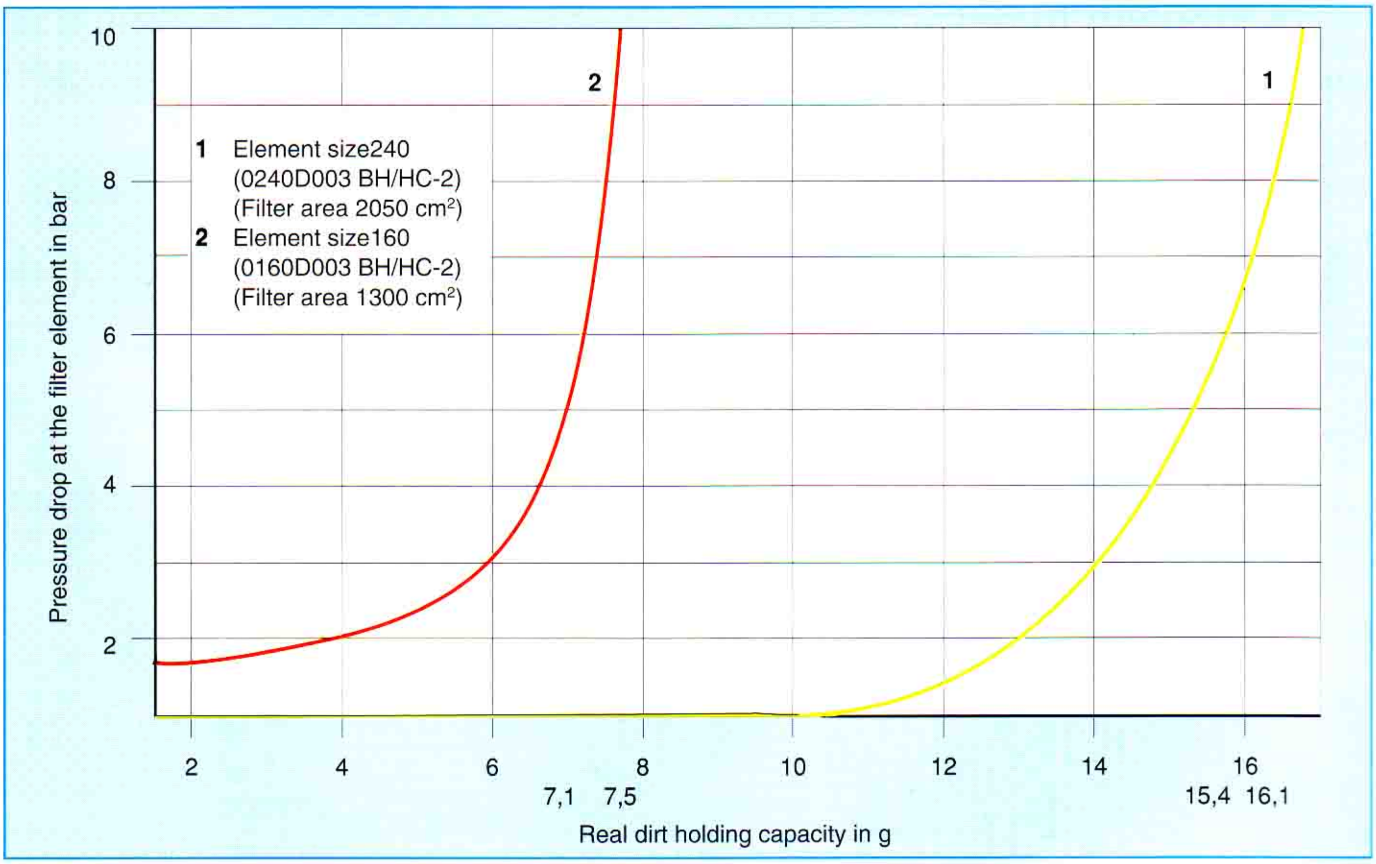
A lower pressure drop at a filter is not economical. The extra cost for a larger filter is greater than the savings made by lower energy and maintenance costs for elements with longer service lives.

In order to maintain the degree of separation (β_x value) at filter elements flow must not fall below the minimum flow quoted by the filter manufacturer.

Diag. 90 shows how the selection of a larger filter element, and hence a decrease in the pressure drop at the clean filter element, may substantially increase the dirt holding capacity and hence the service life of the filter



Diag. 89: *Operating Curve for the dirt holding capacity of the filter element*



Diag. 90: *Dirt holding capacity in different sizes of Betamicron® -2-elements with the same flow of 120 L/min*

element.

4.4 Dirt Holding Capacity

This term is defined as the maximum amount of solid particle contamination that a filter element may absorb.

Solid particle contamination is contained in the hydraulic fluid, so that an element's service life (operating hours) may be determined by the feed flow from the pump.

The task of the filter to ensure that the specified degree of cleanliness of the fluid is maintained, must be guaranteed for the entire period in which the element is installed.

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.

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 Diags. 89 and 90)*. The graphs show the pressure drop across the element with increasing clogging and service life. It is obvious that the low initial pressure drop Δp of a larger filter element provides more real dirt retention capacity than a smaller filter element with a higher initial pressure drop Δp. In both cases the by-pass valve, clogging indicator or element pressure-drop strength set the upper limit for element loading.

5 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:

5.1 Highly Stable β_x Values over a Wide Pressure Drop Range (β_x Stability)

In order for hydraulic systems to be operated without suffering damage due to solid particle contamination the type of filter element used must possess a constant filtration capacity 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 *Diag. 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.

5.2 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.

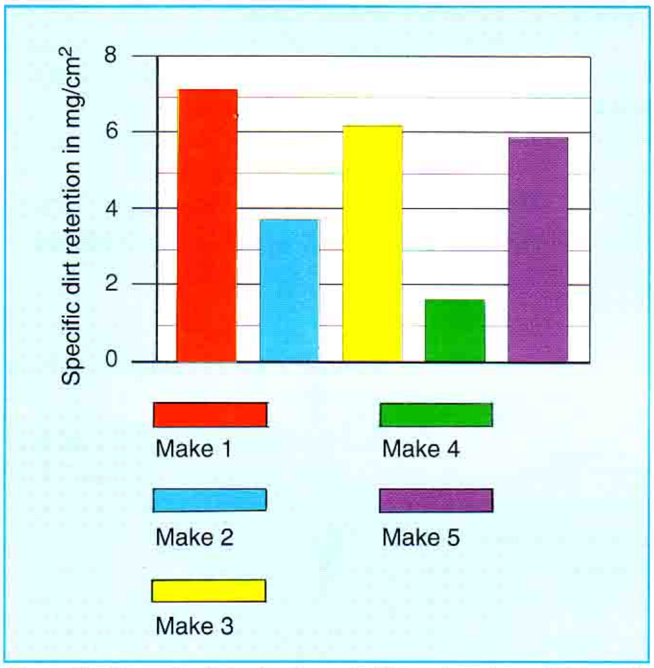
As *Diag. 92* shows, the filter element of Make 1 has the highest dirt holding capacity.

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.

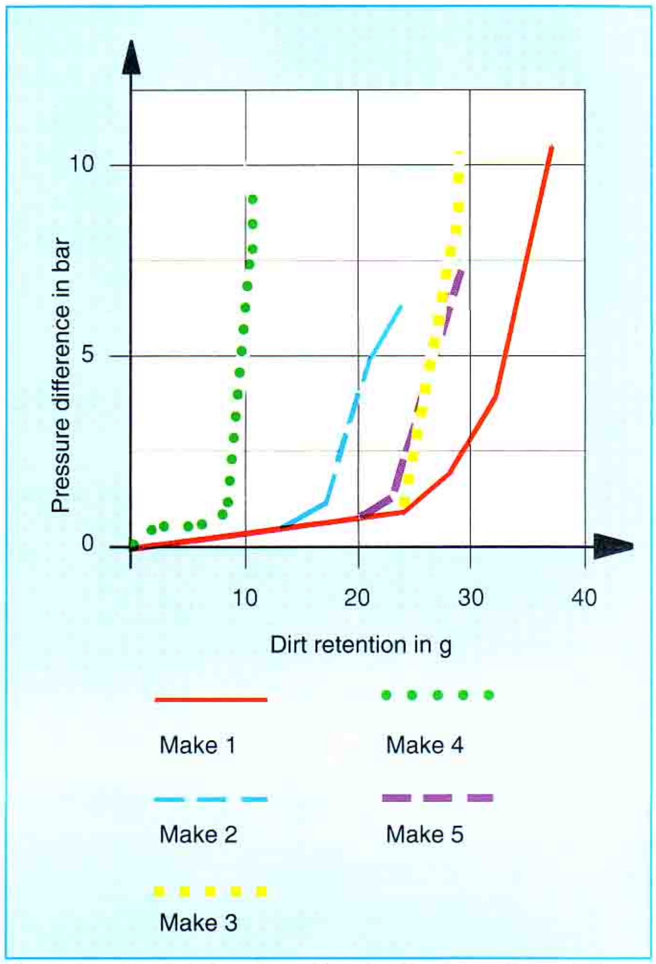
Obviously, a longer service life means lower service costs as well as longer maintenance intervals.

5.3 Specific Dirt Retention of Filter Elements

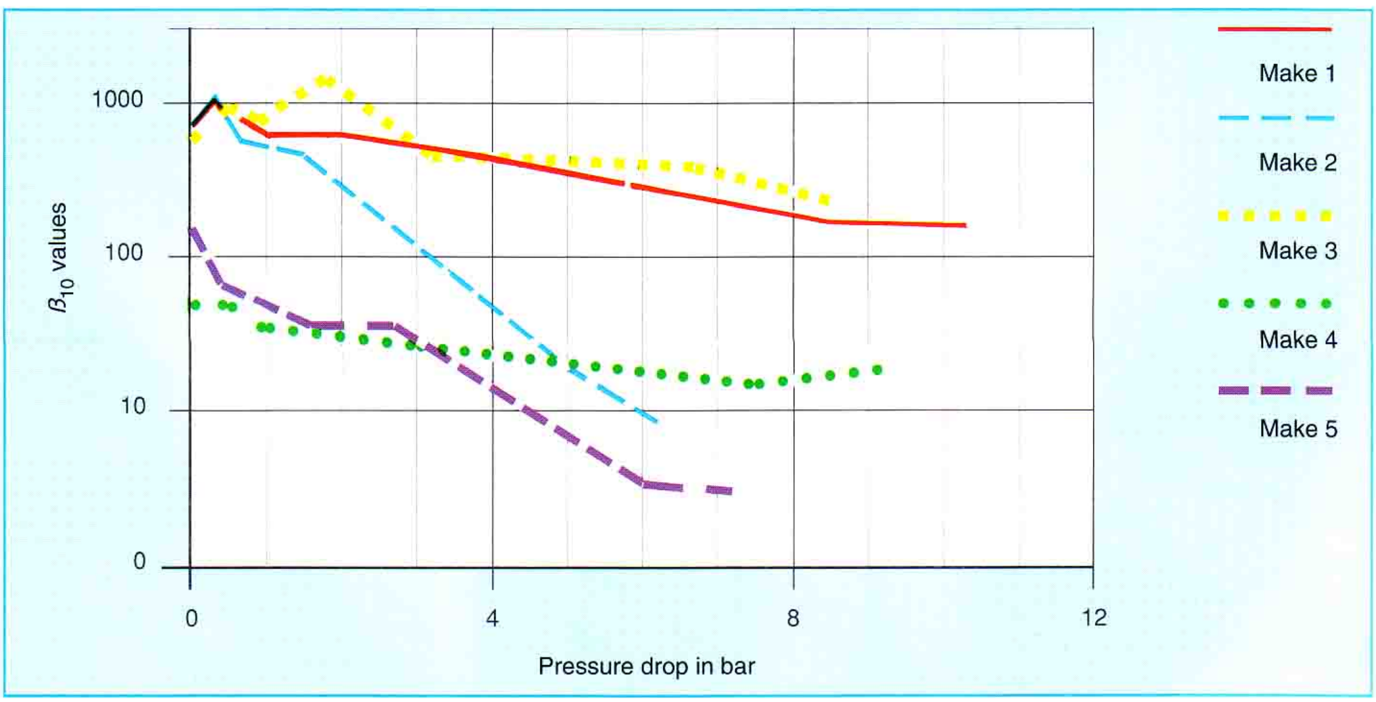
Investigation of the specific dirt retention provides an even clearer assessment of the price/performance ratio of filter elements. The figure is obtained by dividing the total dirt retention of a filter element at a certain pressure drop by the effective filtering area of the element, which gives a figure of dirt retention per cm² filter area *(see Diag. 91)*.



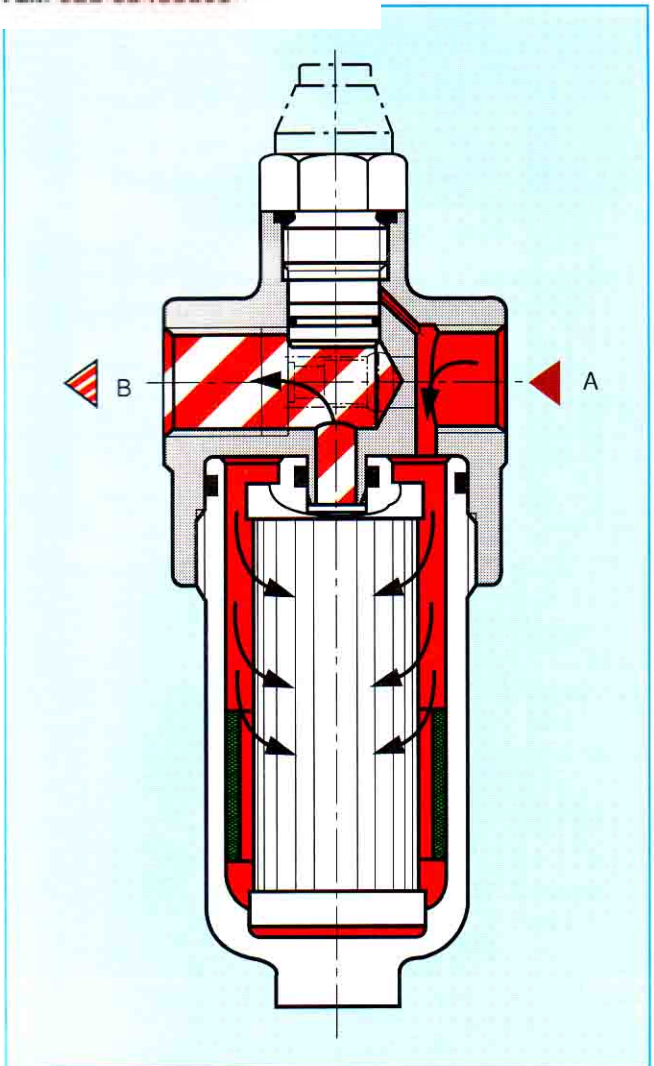
Diag. 91: *Specific dirt retention of different makes of filter at a pressure drop of 3.5 bar*



Diag. 92: *Dirt holding capacity of different makes of filter of comparable sizes*



Diag. 93: *Variation in ß10 value for different makes of filter of comparable sizes and identical performance data*



6 Assembly Notes on Hydraulic Filters

6.1 Pressure Filters (for installation in pressure lines)

(Fig. 258)

Pressure filters should be used without by-pass valves. Flow through the filter element must always be from the outside towards the inside (Note the direction of flow indicated by an arrow on filter cap).

Pressure filters should only be used with filter clogging indicator.

6.2 Pressure Filter to be Mounted Direct on Proportional and Servo Valves

(Fig. 259)

This filter arrangement ensures that contamination of the hydraulic fluid no longer occurs between the filter and valve. In addition the system may be flushed with help of the valve.

Fig. 258 : *Section of a pressure line filter*

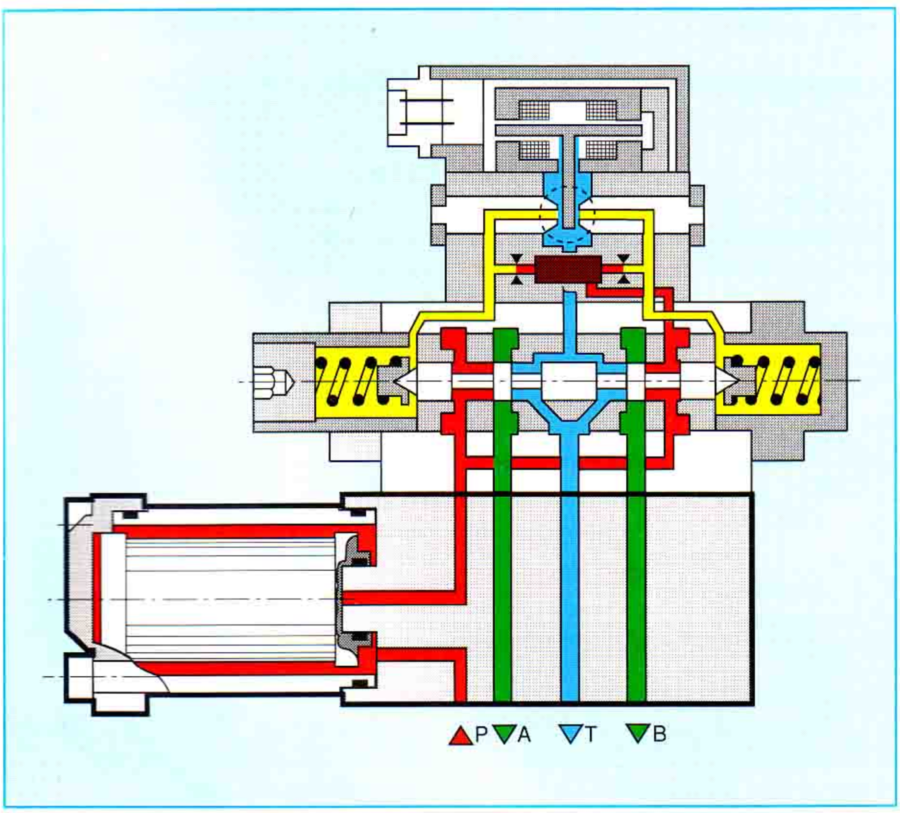


Fig. 259: *Pressure filter in sandwich plate construction*

6.3 Return Line Filter (for tank installation)

(Fig. 260)

To ensure that valves or other hydraulic devices cannot be operated incorrectly, return line filters are normally installed with by-pass valves.

The flow of fluid through the filter element normally takes place from outside towards the inside.

A filter clogging indicator must be used, or else the opening of the by-pass valve is not registered.

The built-in dirt collection tray prevents heavily contaminated fluid from flowing into the tank when the filter element is changed.

The specified excess operating pressure of 25 bar is with respect to the filter housing under dynamic load.

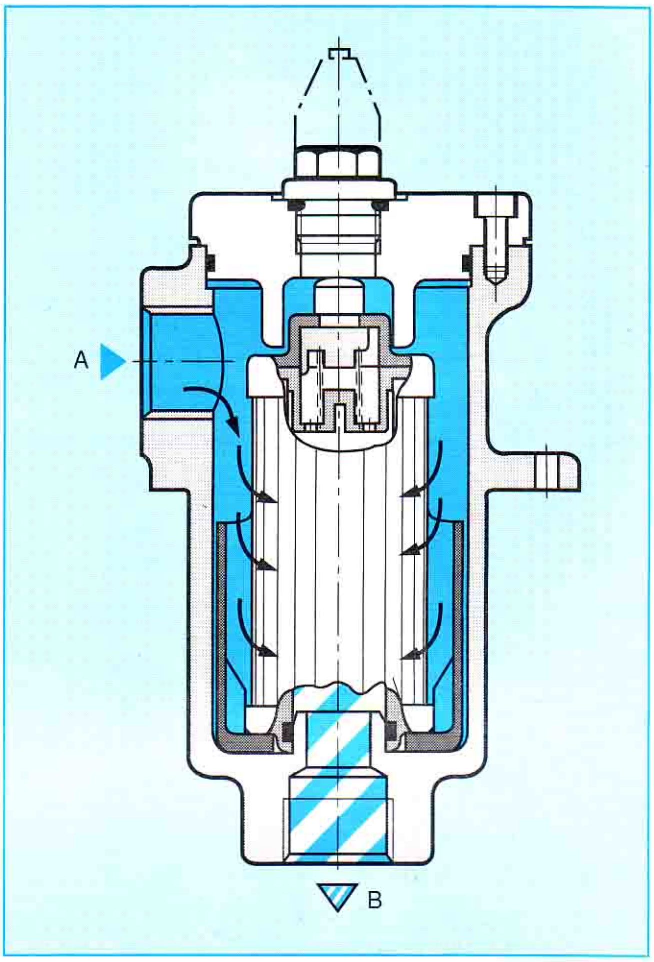


Fig. 260: *Section of a return line filter (tank installation)*

6.4 Clogging Indicator

Various types of clogging indicators are available to indicate and monitor the changing of and cleaning of filter elements. Care must be taken in the case of visual indicators *(Figs. 261 and 262)* to ensure that they are not concealed by part of the system covering, as they may then be ignored. Electrical indicators *(Fig. 263)* may also be installed at points which are difficult to access, as maintenance may be indicated by a multi-purpose electrical signal.

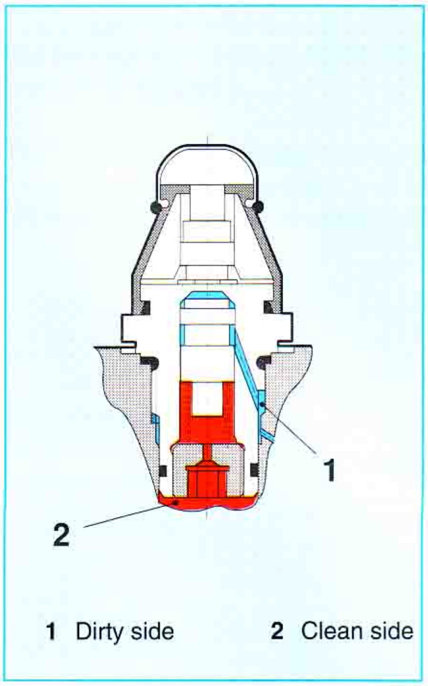


Fig. 261: *Visual pressure drop indicator*

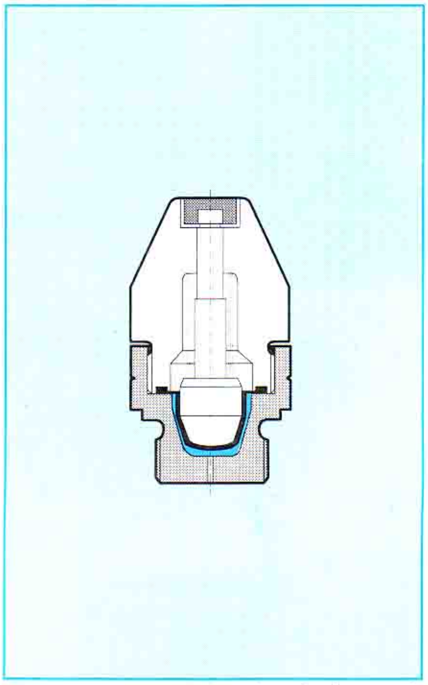


Fig. 262: *Visual clogging indicator for return line filter*

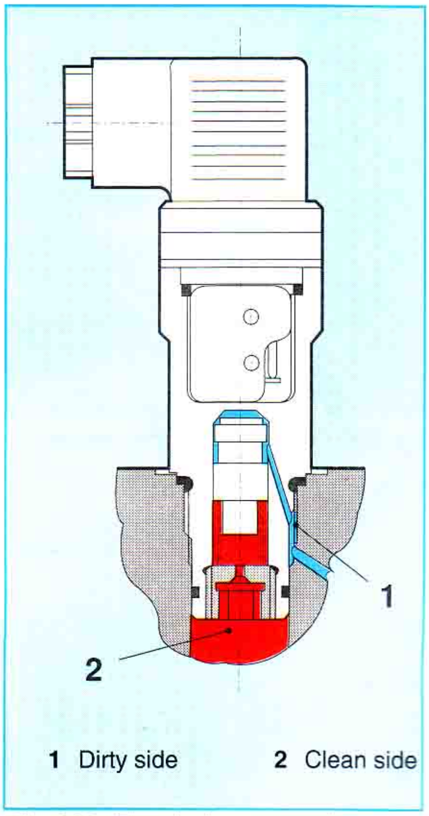


Fig. 263: *Electrical pressure drop indicator*

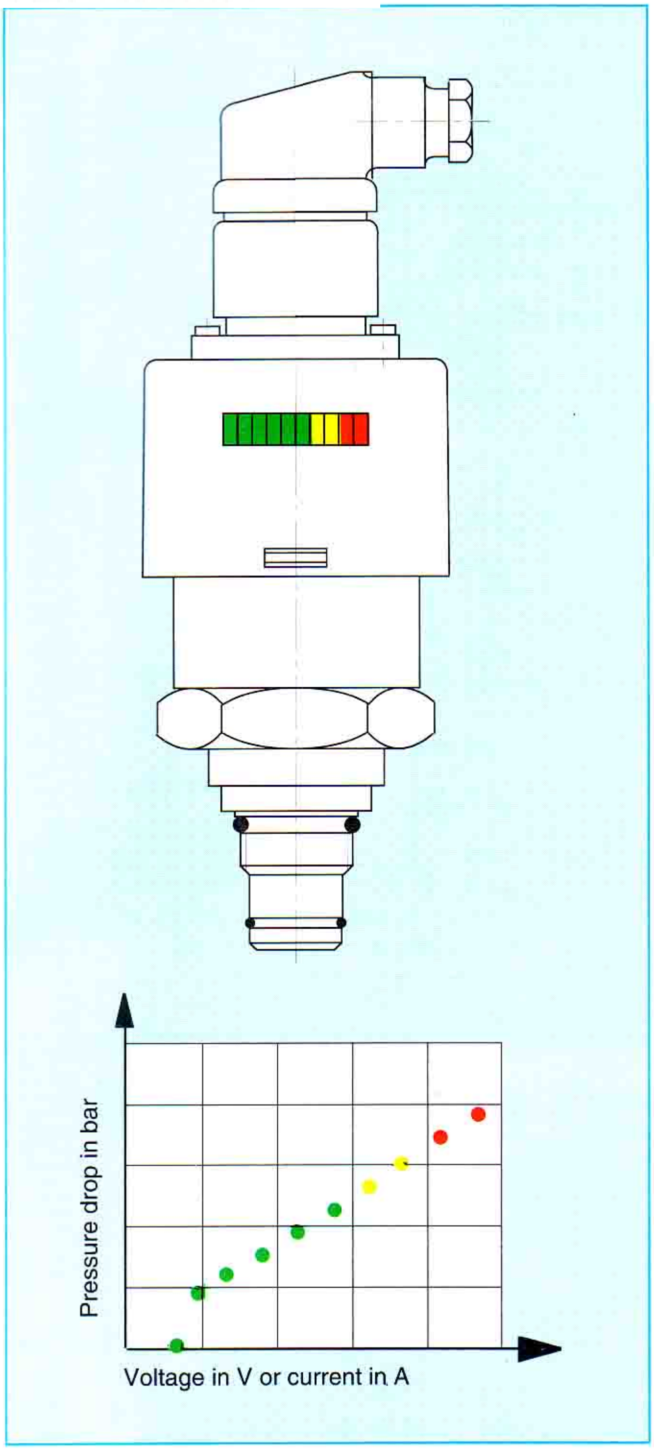


Fig. 264: *Electronic clogging indicator*

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. 264)*.

6.5 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 dirt which collects on top of the tank cannot 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.

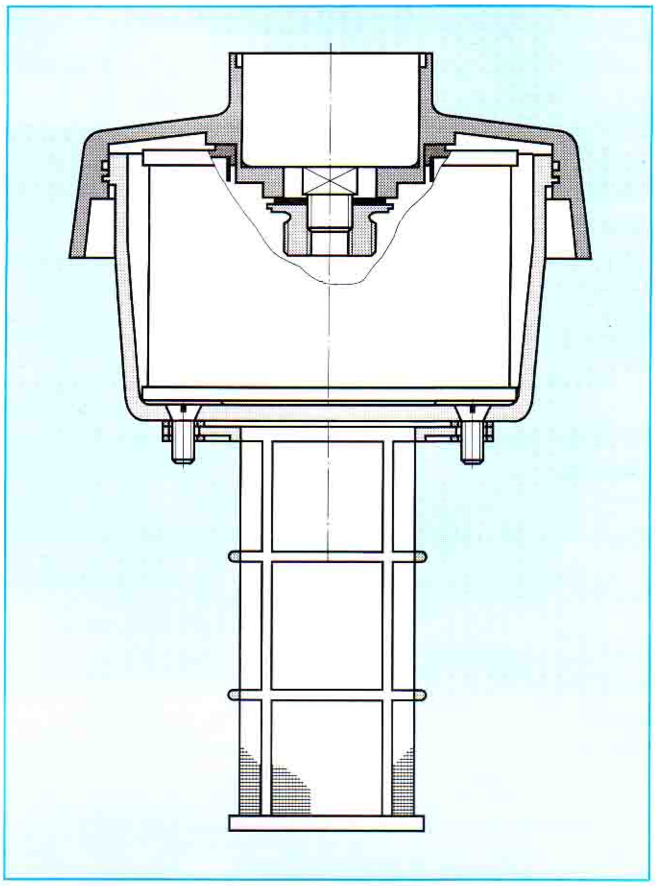


Fig.265: *Section of a breather*

7 Hydraulic fluids

7.1 General

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

The base fluids are:

- mineral oil
- vegetable oil
- synthetic oil, or
- water.

They may be used in hydraulic systems as:

- homogeneous fluids (solutions)

  or as:
- emulsions.

Due to the composition of fluids, fluids may have any of the following important characteristics:

- hydraulic oil with high VI-index (viscosity index)
- hydraulic oil for high pressures
- hydraulic oil that is water resistant
- hydraulic oil that is bio-degradable
- fire resistant fluids such as:
  - water-in-oil or oil-in-water emulsions (HFA, HFB)
  - water-glycol solution (HFC)
  - phosphate ester (HFD), or
  - ester oil.

The base oils used in hydraulic fluids do not incorporate all the characteristics which a high performance hydraulic fluid should have. Therefore additives must be completely or almost completely disolved in the base oils to form a solution.

The following improvements may be achieved:

- oxidation stability
- protection from corrosion
- anti-wear
- may be used at extreme pressures and
- viscosity temperature characteristic.

With respect to filtration of such hydraulic fluids, the following questions must be answered by the fluid manufacturer:

- filtration capability;
- filter medium, materials used for housing and elements, and seals must be compatible with the fluid;
- information on viscosity and density over the entire range of operating temperatures;
- what contamination is to be taken into account and which catalytic reactions may occur;
- compatibility of mixtures.

The most important requirements of a hydraulic fluid as far as the user is concerned are:

- oxidation stability
- thermal stability
- hydrolysis stability
- slow breakdown of material
- shear stability
- not sensitive to pressure
- good protection against corrosion
- low solid particle contamination
- good lubrication properties
- compatible with seals, hoses, paints and metals
- physiologically harmless
- low temperature/viscosity dependence
- low gas content
- lower vapour pressure and
- favourable energy properties.

From the point of view of fluid filtration, the following requirements are made:

- low solid particle contamination on delivery
- good filtration capacity
- favourable, i.e. flat viscosity/temperature curve and
- neutral reaction to materials.

Resident contamination in the fluid has a great influence on the deterioration of the oil. Therefore, good filtration, which decreases the amount of contamination resident, may extend the life of the oil in the hydraulic system.

When changing oil, all remains of the old oil must be removed, as the residue may contain deteriorating properties that can effect the deterioration stability of the new oil. It is, therefore, recommended that the system is flushed thoroughly before filling with new oil.

7.2 Types of Hydraulic Fluid

7.2.1 Hydraulic Fluid based on Mineral Oil

Most hydraulic systems use these fluids. Therefore, the design of hydraulic filters, described in *paragraph 8*, is based on filtration using HL and HLP oils. If other fluids are used for filtration, it may be necessary to undertake modifications to the filter housing, element and/or accessories and seals. The minimum requirements of these hydraulic fluids are shown in *Table 5*.

When filtering HLP-D and HV oils it is recommended that, the filter size should be considered on the following basis, as a low contamination level will eventually arise in the tank:

Filters with clogging indicators

$\Delta p_A = 0.1 \cdot \Delta p_{Indicator}$

Δp_A = Maximum pressure loss from filter housing and clean element at operating temperature and maximum flow.

$\Delta p_{Indicator}$ = Pressure drop which clogging indicator accesses

Filters without clogging indicators

Return line filters Δp_A = maximum 0.2 bar

Pressure filters Δp_A = maximum 0.5 bar

Moreover the pore size should be selected at least one size smaller than that shown in the diagrams.

7.2.2 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.

7.2.3 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 an 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.

7.2.4 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 6.*

Modifications must be made to the standard filters. Filter makers must therefore 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. (Installation of automatic breathing valves is recommended.)

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

Hydraulic oil quality class Class to DIN 51 502	ISO 6743	Additives for protection against wear	protection against corrosion	ageing stability	Sub-groups	Application	Note
H	HH	—	—	—	None	Simple hydraulic systems	Not important It is no longer described in the new version of DIN 52 524
HL	HL	—	+	+	None	In systems, where frequent water ingress is likely (condensation). Higher protection against wear is not required for pumps and motors.	Viscosity index (VI) (90 to 100)
HLP	HM	General +	+	+	3 sub-groups which greatly vary in their characteristics	In all hydraulic systems. Especially used for protection against wear in fields where various frictions are present.	Important groups Viscosity index (VI) (90 to 100)
					Sub-group 1 with good de-emulsificaiton properties	In systems where frequent water ingress is likely.	Water ingress is quicky removed. (May be removed from the tank) Most commonly used sub-group
HLP-D		+	+	+	Sub-group 2 with polarised additives (HLP-D)	Machine tool field. Same oil for hydraulics, bearings and gears.	Good surface coating and adhesive properties. Stick-slip is avoided.
		+	+	+	Sub-group 3 with dispersant/detergent properties (HLP-D)	Machine tools, in which water mixed coolants may enter the hydraulic circuit	Water ingress is dispersed, hence is kept low. Less than 2% water Improved corrosion protection More than 2% water Worse corrosion protection and quick ageing of the oil Warning Danger of control valve sticking
		+	+	+	None		
HV	HV	+	+	+		Hydraulic systems which are susceptible to large changes in ambient temperatures	Improvement of relationship between temperature and viscosity Viscosity index (VI) (170 to 180) Warning Improvement of VI by adding large long chain molecules

Table 5: *Minimum requirements of hydraulic fluids which are based on mineral oil*

Fluid designation to DIN 51 502 or ISO DIS 6071	**HFA**	**HFB**	**HFC**	**HFD**
Composition	Oil-in-water emulsion or synthetic polymer solution	Water-in-oil emulsion	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 (mm^2/s)	46 to 100 (mm^2/s)	22 to 68 (mm^2/s)	15 to 100 (mm^2/s)
Density	0,998 (kg/dm^3)	0,92 to 1,05 (kg/dm^3)	1,04 to 1,09 (kg/dm^3)	1,1 to 1,9 (kg/dm^3)
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 EPDM
Remarks	Susceptible to microbial attack, high mechanical wear due to low viscosity.	Widely used in mining applications in english speaking coiuntries.	Poor dirt separation capacity. Sensitive to mineral oil contamination.	May not be mixed with water. sensitive to moisture contamination.

Table 6: *Properties of fire-resistant fluids*

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.

7.2.5 Hydraulic Fluid from Pure Water

Pure water is seldom used as the fluid in hydraulic systems.

Standard filters cannot be used.

7.3 Viscosity and Density of Hydraulic Fluid

Both of these properties have an effect on pressure loss in hydraulic filters and so both values must be known.

7.3.1 Density

Density (mass per unit volume) is specified at 15 °C for hydraulic fluids. It is dependent on temperature but it is only necessary to correct it using the volume expansion coefficient when large fluctuations in temperature occur. The effect of compressibility in conjunction with pressure loss in hydraulic filters may be completely ignored.

If fluids with different densities are filtered, the change in density only has an effect when determining the pressure loss in the filter housing.

7.3.2 Viscosity

Types: Dynamic viscosity
Kinematic viscosity

The dynamic viscosity is a measure for the internal friction of a fluid. It is not taken into consideration when examining hydraulic filters.

The kinematic viscosity is a measure of the viscosity to density ratio. It is usually measured by a gravity viscosi-meter.

$$\delta = \frac{\eta}{d} \text{ in } \frac{mm^2}{s}$$

ν = kinematic viscosity
η = dynamic viscosity
d = density

Kinematic viscosity is necessary in filters.

Whenever viscosity is mentioned in information on filters, kinematic viscosity is implied.

This viscosity is very dependent on temperature (it decreases as temperature increases) and it is furthermore dependent on pressure. Viscosity increases as pressure increases. However, this dependence on pressure may be ignored for operating pressures of less than 200 bar. When determining the pressure drop across a filter element, the viscosity/temperature ratio must be taken into account.

When selecting the filter size, the viscosity at operating temperature is usually required.

7.3.3 Viscosity/temperature Ratio of Hydraulic Fluids

During design and operation of hydraulic filters, the viscosity/temperature ratio of the hydraulic fluid is an important factor, if the whole system is to operate smoothly. Therefore, the viscosity/temperature curve of the fluid used in the system must be known to the system operator. For this purpose the necessary specifications must be requested from the fluid manufacturer or DIN 51 519 must be referred to *(Diag. 95)*. The curve (gradient of the curve) is a measure of the viscosity index according to DIN ISO 2909.

The various ratios for individual fluid groups may be deduced from *Diag. 94*.

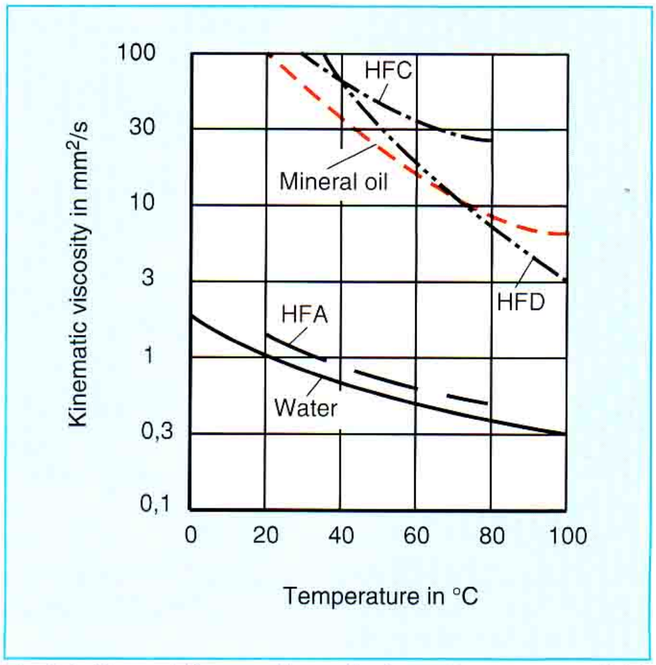


Fig. 94: *Viscosity/temperature ratio for various pressure fluids*

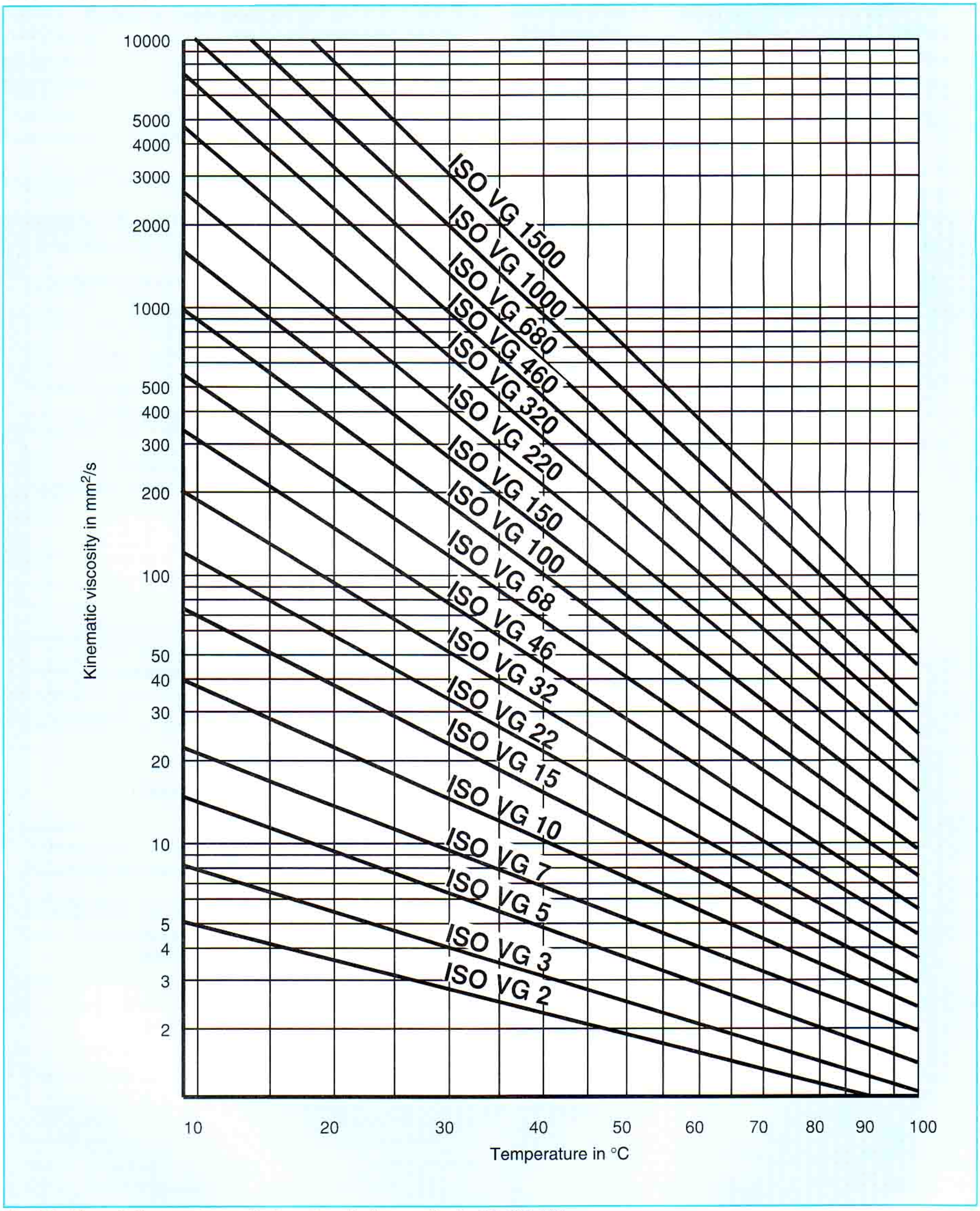


Fig. 95: *Viscosity/temperature ratio for mineral oil according to DIN 51 519*

In Diag. 96 the viscosity/temperature curves of hydraulic fluids from a lubricant manufacturer from various quality groups, but with the same class of viscosity are shown.

If the operating temperature deviates greatly from the reference temperature of the fluid (40 °C), it is recommended that the fluid manufacturer is asked as to what the viscosity is for the particular operating or filtration temperature.

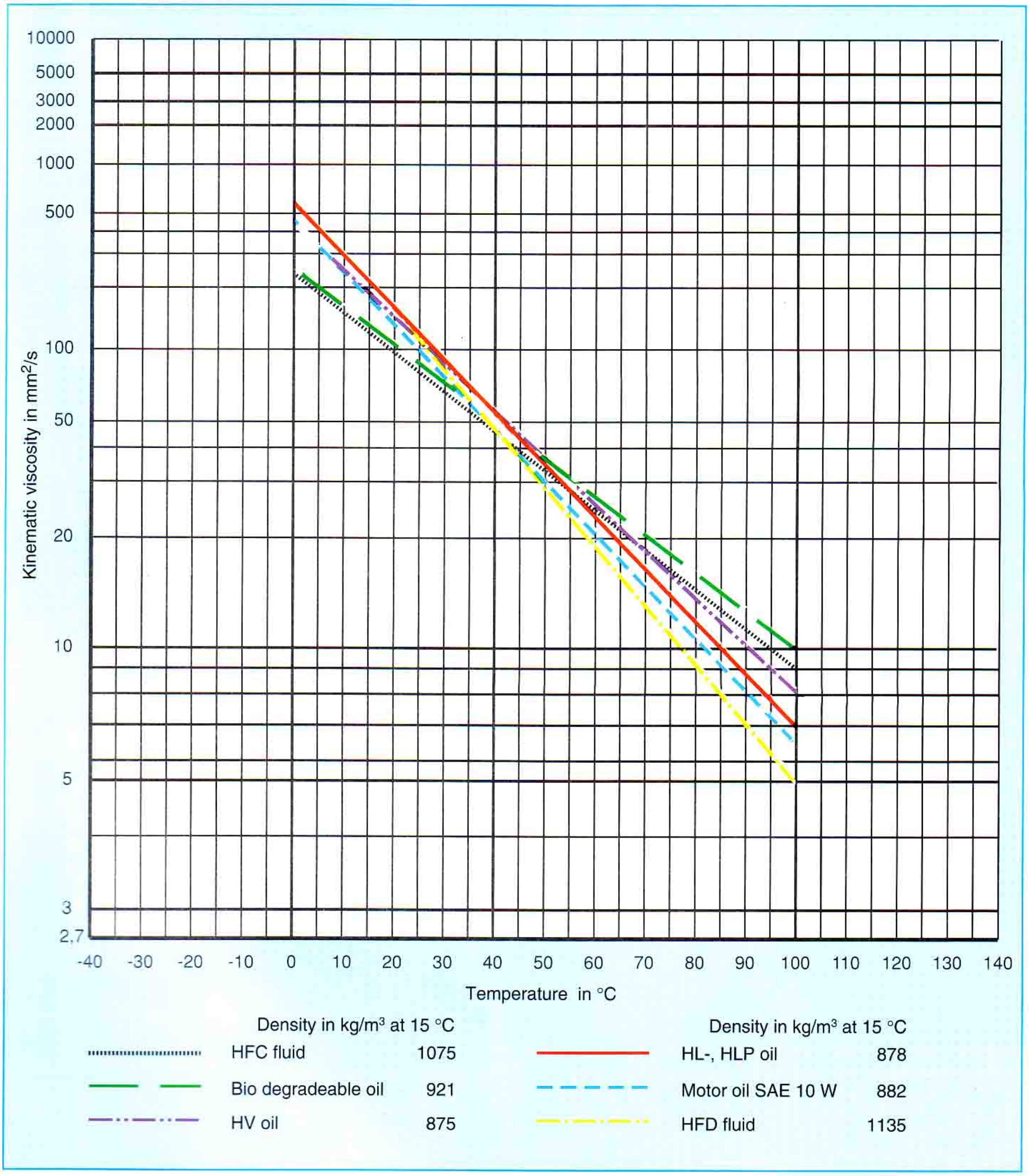


Fig. 96: *Viscosity/temperature curves for pressure fluids from standard group ISO VG 46*

7.4 Material Compatibility

Material compatibility must be guaranteed for all components which come into contact with each other. In particular in filters, they must be compatible with the hydraulic fluid in accordance with ISO 2943.

The following must be examined:

- housing material;
- protection of housing surface;
- seals for housing, element and indicator;
- material for indicator housing;
- filter element material;
- adhesive used when installing elements;
- impregnation of filter matt.

It must also be investigated whether contamination of the hydraulic fluid, or the addition of other fluids has an effect on material compatibility.

Numerous investigations have already been carried out by filter manufacturers on the most common fluids. Sufficient information on material compatibility for these fluids is therefore available.

However, investigations on compatibility need to be carried out on little used fluids, synthetically produced oils and mixtures.

7.5 Filtration Capability

Filtration capability of oil implies the ability of oil to flow continuously through the filter.

Fluid molecules are incredibly small: about 10^{16} molecules per mm^3 of hydraulic oil!

There is no need to worry that these oil molecules will not pass through the filter. This is also usually true of most additives. Only some so-called viscosity index (VI) enhancers are known to have some difficulty under certain circumstances in passing through very fine filters, e.g. 3µm absolute filters. VI enhancers are polymers, i.e. in comparison to base oils they have gigantic molecules. They enhance the velocity/temperature ratio in that these gigantic molecules are spheres at low temperatures and assume long, bulky shapes at high temperatures.

This may lead to the pores in the filter element being blocked.

As there are different types and concentrations the filtration capability of oil alloys (especially the high VI oils) is determined through practice. Ask your filter or oil manufacturer for further information! The same applies for polyglycols which are contained in all HFC fluids. They have a restricted filtration capability due to their inherent stickiness.

The explanation of the size of filter pores as opposed to that of the fluid molecules is an over-simplification. In addition, the properties of stability, networking or stickiness must be taken into account. Physically these are to do with features which may be described by interface tension, contact angle, dipolar moment etc. Fluids in capillaries, formation of menisci or control of gravitational pull via the use of smooth, vertical surfaces are examples of surface phenomena, which may also have a disturbing influence on filters. HLP-D-oils may be alloyed with fatty oils to prevent the unpleasant stick-slip phenomenon in, for example, large construction machine, telescopic cylinders. Such an additive obviously does not differentiate between filter surfaces and other surfaces. It also dampens and settles on filter material with very small pore sizes, with the result that the filter is soon clogged. If wire gauze is used this does not occur, i.e. the practical maximum filter pore size must be established. These difficulties must be recognised. Manufacturers of filters and fluids may also be addressed on these aspects.

Oxidation products found in used oil, under certain circumstances, act as pure adhesives to the filter material. The oil's own ageing products are partly more polar than the intact oil, in which they float. Resins, asphalts and oil-insoluble ageing scum do not appear until the ageing process is extremely advanced, but as their names indicate, they lead to filter problems. Filtration is no substitute for overdue oil changes!

In addition, emulsions must be considered. Emulsions comprise a water and an emulsion (fat) content. In stable emulsions, water and emulsion cannot be separated. The ratio of emulsion (fat) to water varies - emulsions may be either milky, opaque or transparent. Emulsions may be either macro or micro emulsions and this affects the filter pore size. If the filter pore size is too small, the fat is separated from the water. Emulsions are unstable at high and at low temperatures, i.e. the fat is separated from the water and once the fat has been separated, it may not be recombined with the water by centrifuge. The use of emulsions is very complex and must be matched to a particular application. If you are uncertain about emulsion filtration capability, ask the emulsion manufacturer for advice on type of emulsion to be used, filter pore size and filtration capability.

Due to these problems, a rapid blockage of the filter element may occur. Consequently, the pressure drop across the element rapidly increases, and hence shortens the service life of the element. The filtration capability of hydraulic fluids is determined, by using test filter plates. Short filtration times are advisable.

Recently filtration capability of a fluid has become increasingly significant. In the future, good filtration capability may be the most important property of hydraulic oils.

In general it may be ascertained, that hydraulic oils with fewer water particles, which contain zinc-di-alcyl-di-thio-phosphate (ZndTP), may not be as easily filtered as hydraulic oils, which contain ash-free phosphor-sulphate (P-S) additives.

7.6 Solid Contamination

The contamination of hydraulic fluids by solid particle 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 7 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 volumetric analysis.

However, with this method the individual dirt particles cannot be classified.

ISO 4406 or Cetop RP 70 H	Particles per ml > 10 µm	ACFTD Solid 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 7: *Comparison of cleanliness classes (source: SAE 31165)*

Note: Cleanliness classes may also be referred to as contamination classes by the filter manufacturers.

7.6.1 Using ISO DIS 4406/Cetop RP 70 H

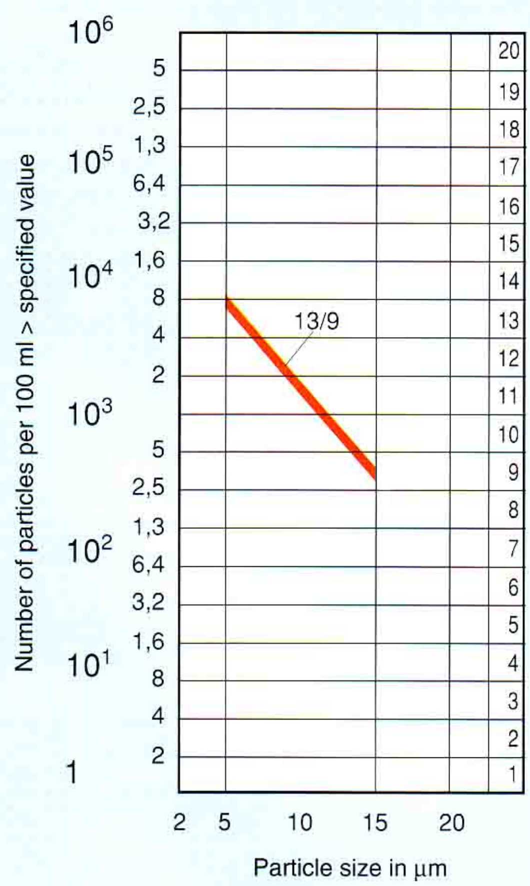
Diag. 97 shows how the particle size is plotted along the ordinate and the number of particles and classification code along the abscissa.

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 or Cetop RP 70 H, 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 *Diag. 97*).

These code numbers form the designation of the sample.

Table 4 lists the contamination figures and their coding.



Diag. 97: *Cleanliness classes to ISO 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 8: *Number of particles and their short form coding*

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 *(see Table 9).*

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

7.6.3 Contamination classification to SAE 749 D [1)]

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

[1)] (In 1971 was removed from SAE and NAS 1638 was recommended as the SAE standard).

7.6.4 Contamination classification to MIL STD 1246 A

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

7.7 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 may be deduced when regular checks are made on solid contamination.

7.7.1 Methods of taking samples *(Fig. 266)*

- 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.

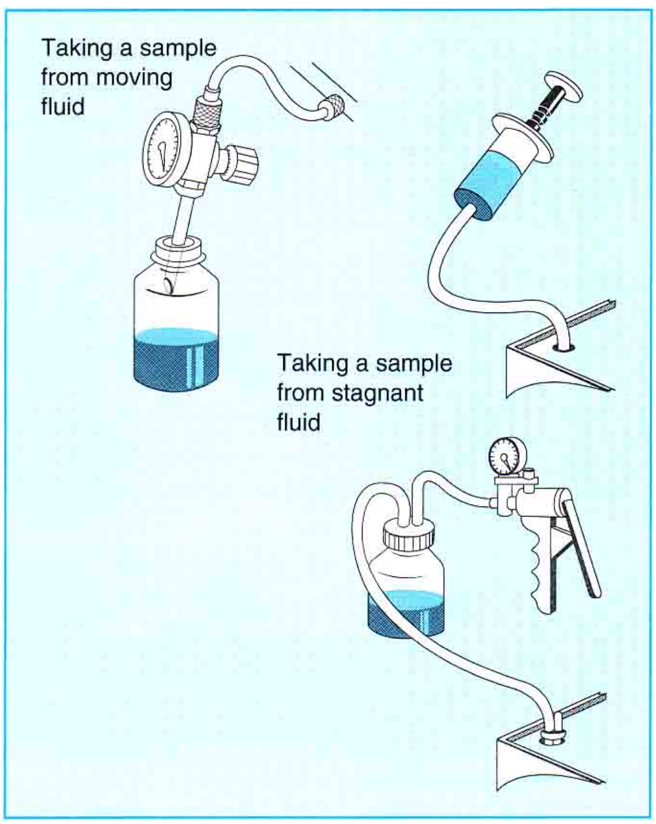


Fig. 266: *Methods of taking samples*

7.7.2 Fluid sampling procedure

- 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 thesampling 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.

7.7.3 Analyzing the samples

The samples are usually analyzed 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 and a direct check at the time of sampling is out of the question (Fig. 268).

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 *(Fig. 269).*

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. 267).*

Fig. 267: *Mobile laboratory for on-site analysis*

Fig. 268: *Fluid sample analysis in the laboratory*

Fig. 269: *Sampling kit*

8 Designing hydraulic filters

8.1 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, fewer spares replacements.

Table 10 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 10: *Types of hydraulic filter, their advantages and disadvantages*

8.2 Tasks of filters in hydraulic systems

8.2.1 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.

8.2.2 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.

8.2.3 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.

8.2.4 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.

8.2.5 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.

8.3 Positioning of filters in hydraulic systems

The position of a filter in a hydraulic circuit depends on the task which that filter is expected to perform *(Fig. 270).*

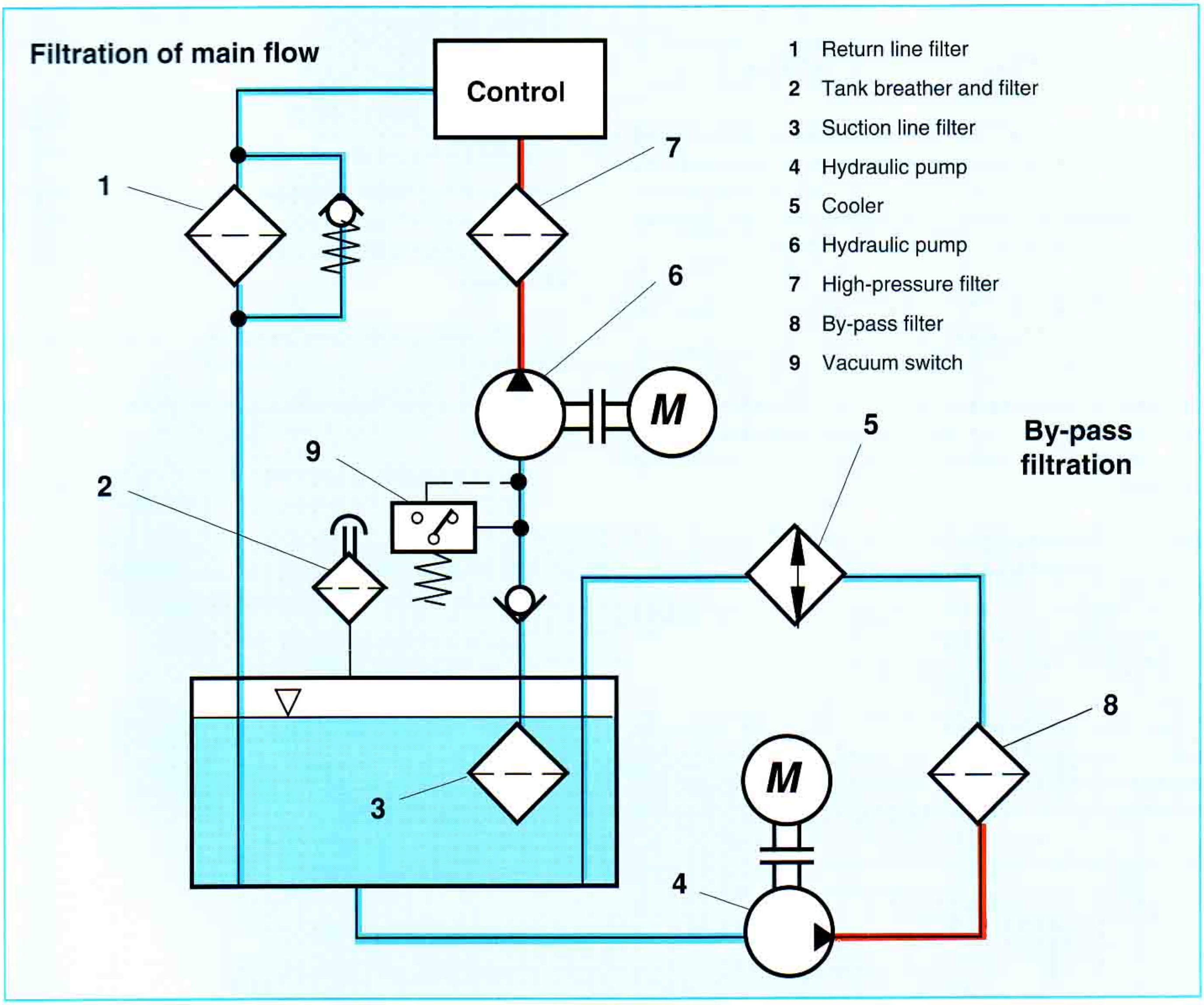


Fig. 270: *Diagram of filter positioning in hydraulic systems*

8.4 Main flow filters

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

The types of filter used are suction, pressure and return line filters and breathers.

8.4.1 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.

Hence suction filters are only used in systems, where the pump is only likely to be damaged by very coarse contamination. An example of this would be in mobile hydraulics, where the hydraulics, the lubrication of the gearbox and the transmission are all supplied with fluid from the same tank.

The individual components must be protected against wear, by finer filters in the hydraulic system.

8.4.2 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.

This means, that pressure-line filters must ensure that functions of the following hydraulic components are protected.

Pressure-line filters are in particular recommended when:

- Components are particularly sensitive to contamination (e.g. servo and proportional valves, flow controllers)
- Components are especially important for the function of the overall system
- Components are expensive (e.g. large cylinders)
- Components are responsible for the safety of the equipment.

8.4.3 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 flow of the pump.

8.4.4 Breathers

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

8.5 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.

8.5.1 Advantages of by-pass filtration

- *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 *Figs. 98 and 99.*

Note that the rubber press and pump test stand continue to operate during the filtering process.

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,
- when rapidly changing flows are present.

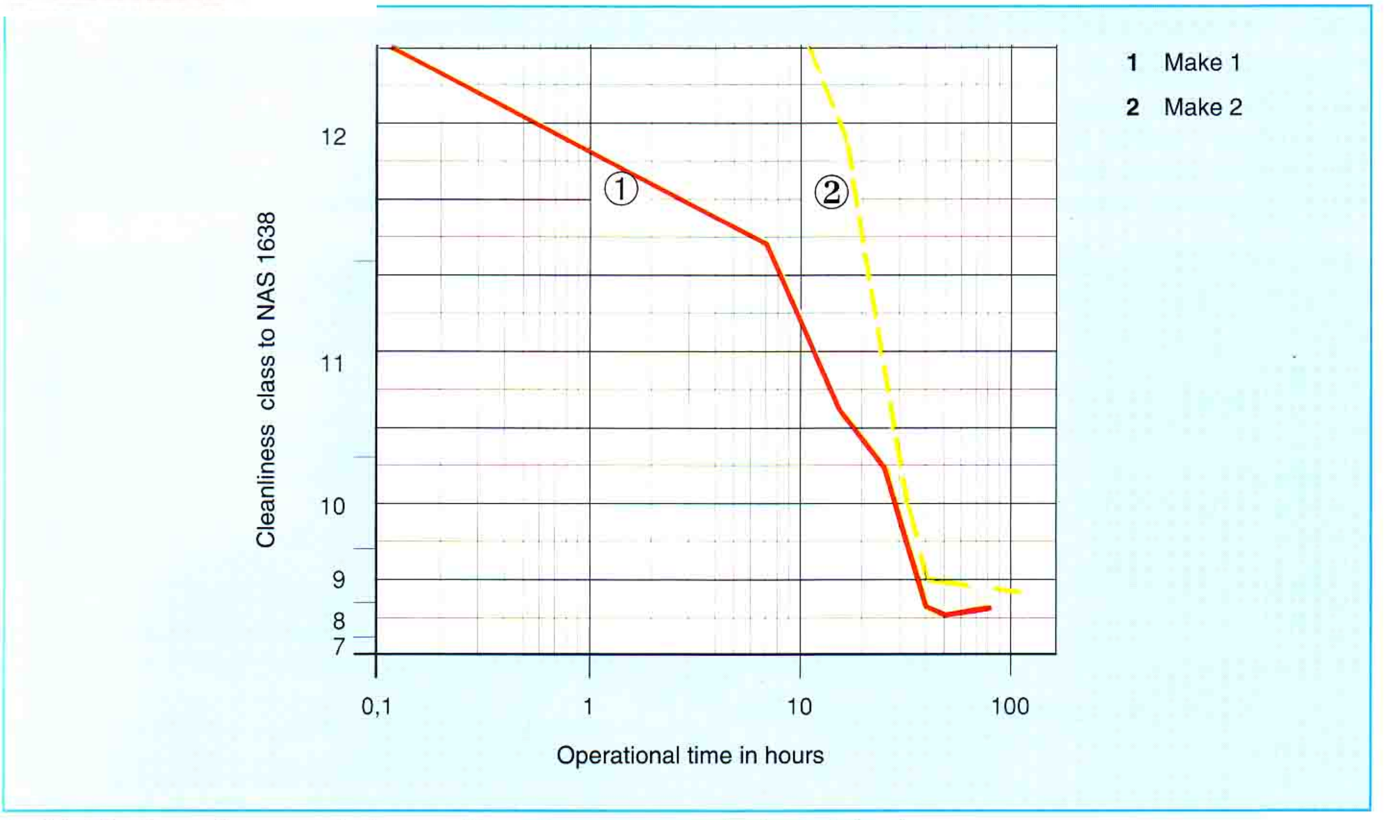


Fig. 98: *Filtration performance of a by-pass filter unit on a pump production test stand*

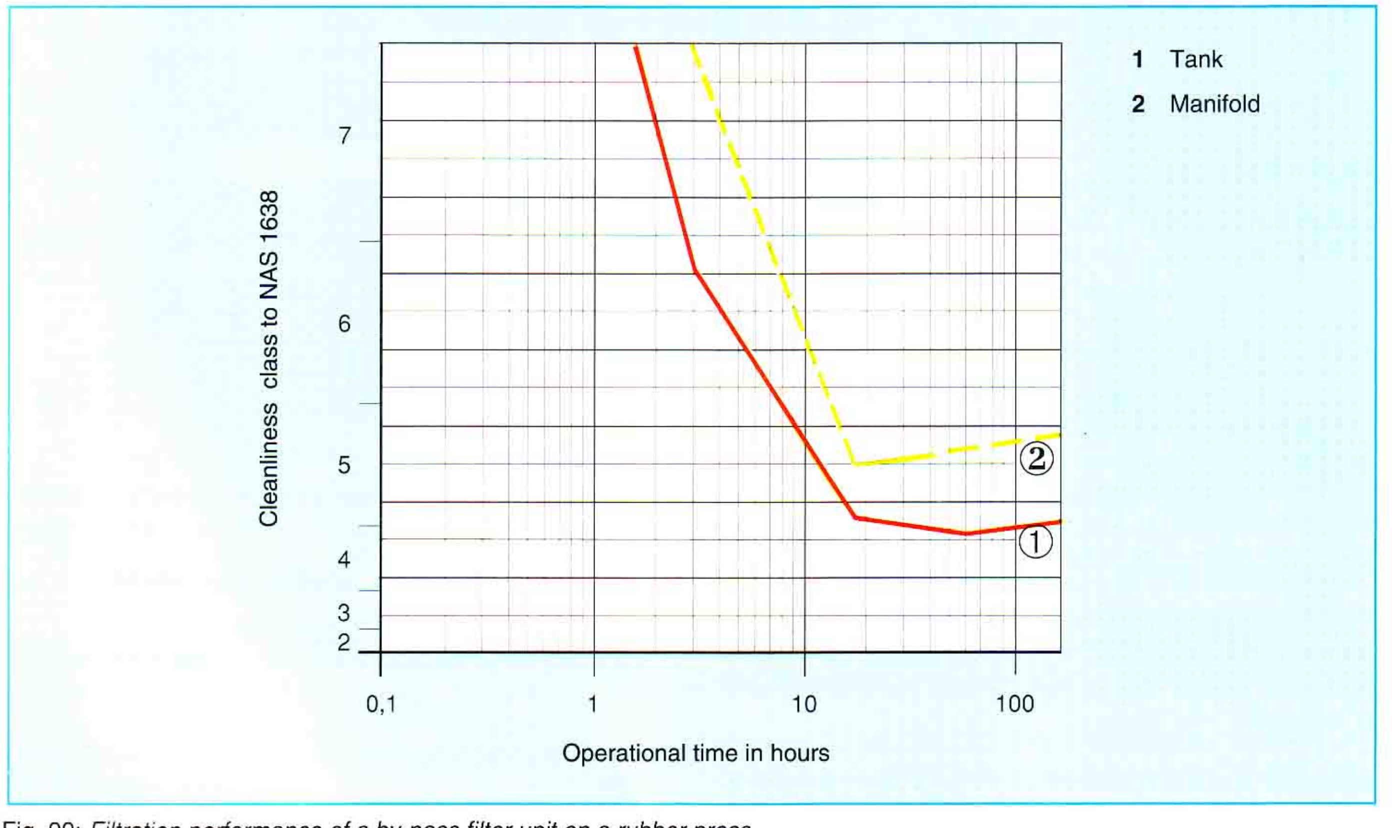


Fig. 99: *Filtration performance of a by-pass filter unit on a rubber press*

8.6 Task assignment of filters

For economy in hydraulic system design the filters are divided into two groups - working filters and protective filters *(Fig. 271)*.

8.6.1 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 flow of the system. If necessary, such filters can also be installed in the leakage fluid lines.

8.6.2 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 pump or motor 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.

The 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.

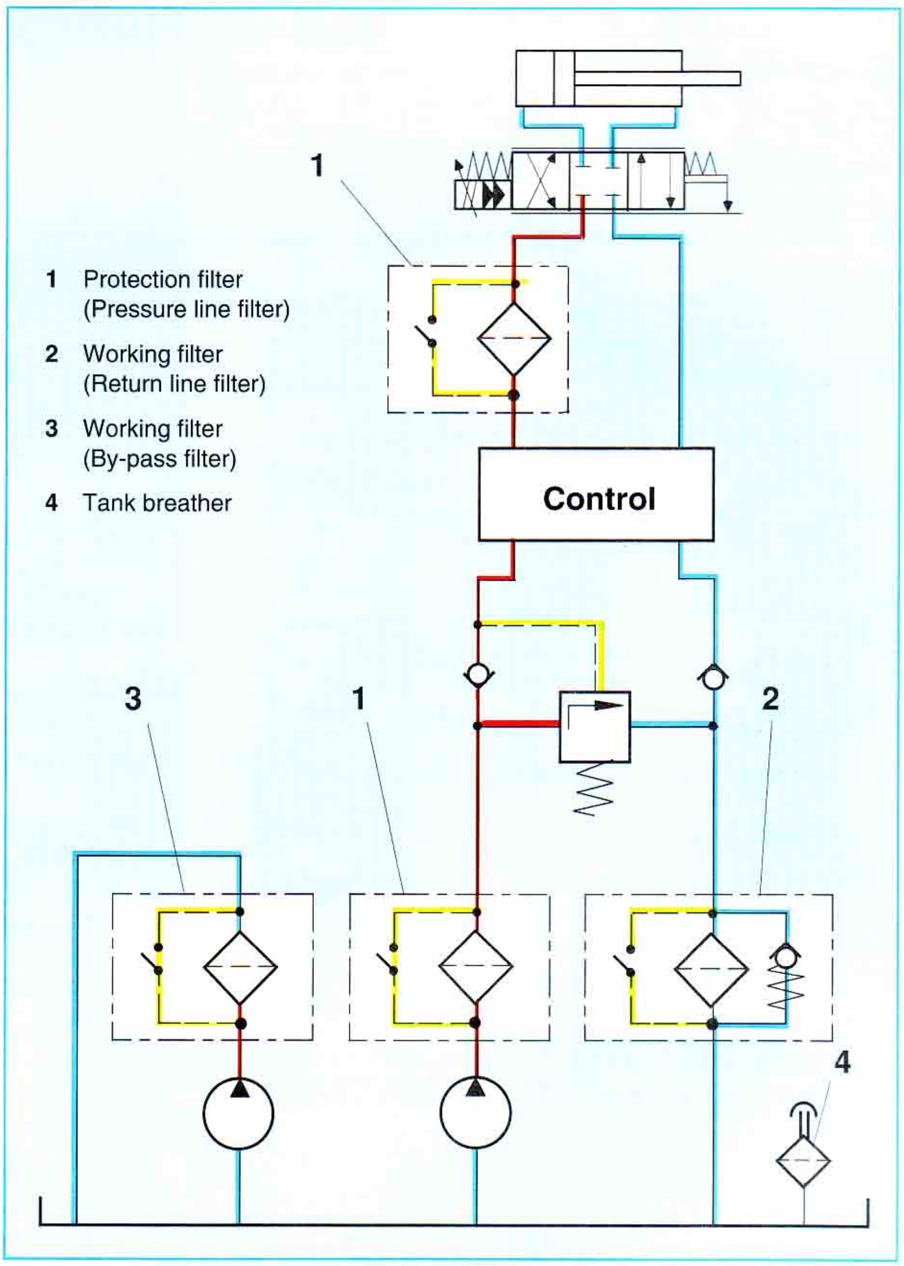
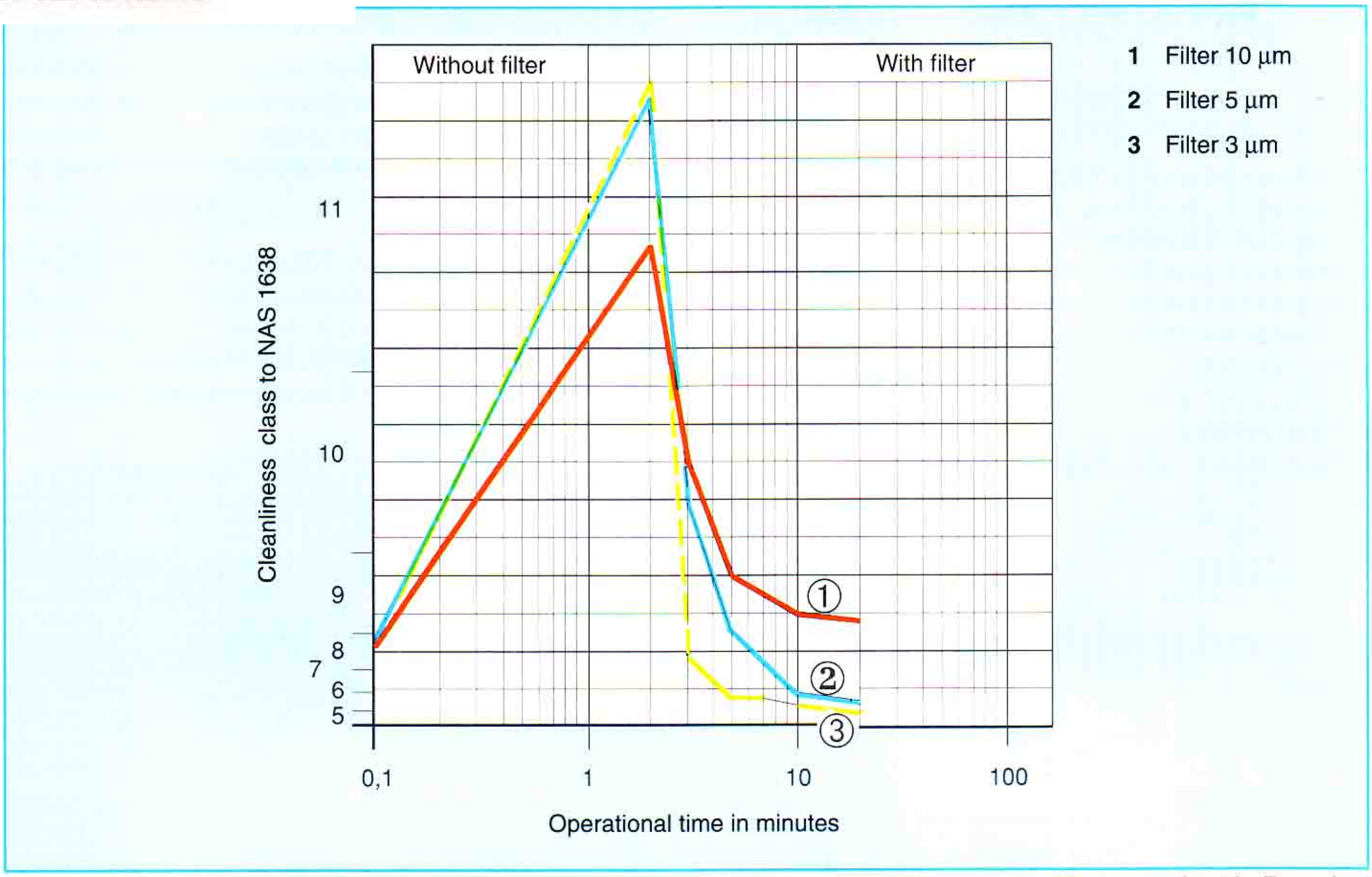


Fig. 271: *Simplified hydraulic circuit diagram showing working filters and protective filters*



Diag. 100: *Cleanliness classes that may be achieved using the recommended absolute filtration rating (Tank capacity: 4 L, Pump feed flow: 4 L/min)*

Hydraulic system	Recom-mendet absolute filtration rating ($\beta_x \geq 100$)	Available cleanliness class to NAS 1638 with parts > 5 µm	Available cleanliness class to ISO DIS 4406
Systems with servo valves	5	7	16/13
Systems with control valves	5	7 to 8	16/13
Systems with proportional valves	10	9	18/15
General hydraulic systems	10 to 20	9 to 10	19/16

Table 12: *Determining the recommended filtration rating for hydraulic systems with Rexroth components*

Application	Filtration rating µm	Hydac 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 filters without by-pass valve	3	... D 003 BH/HC	210 bar	Consult 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 13: *Selecting filter elements according to application and absolute filtration rating required*

8.9 How the fluid affects filter design

8.9.1 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 *(see Diag. 101)*.

8.9.2 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:

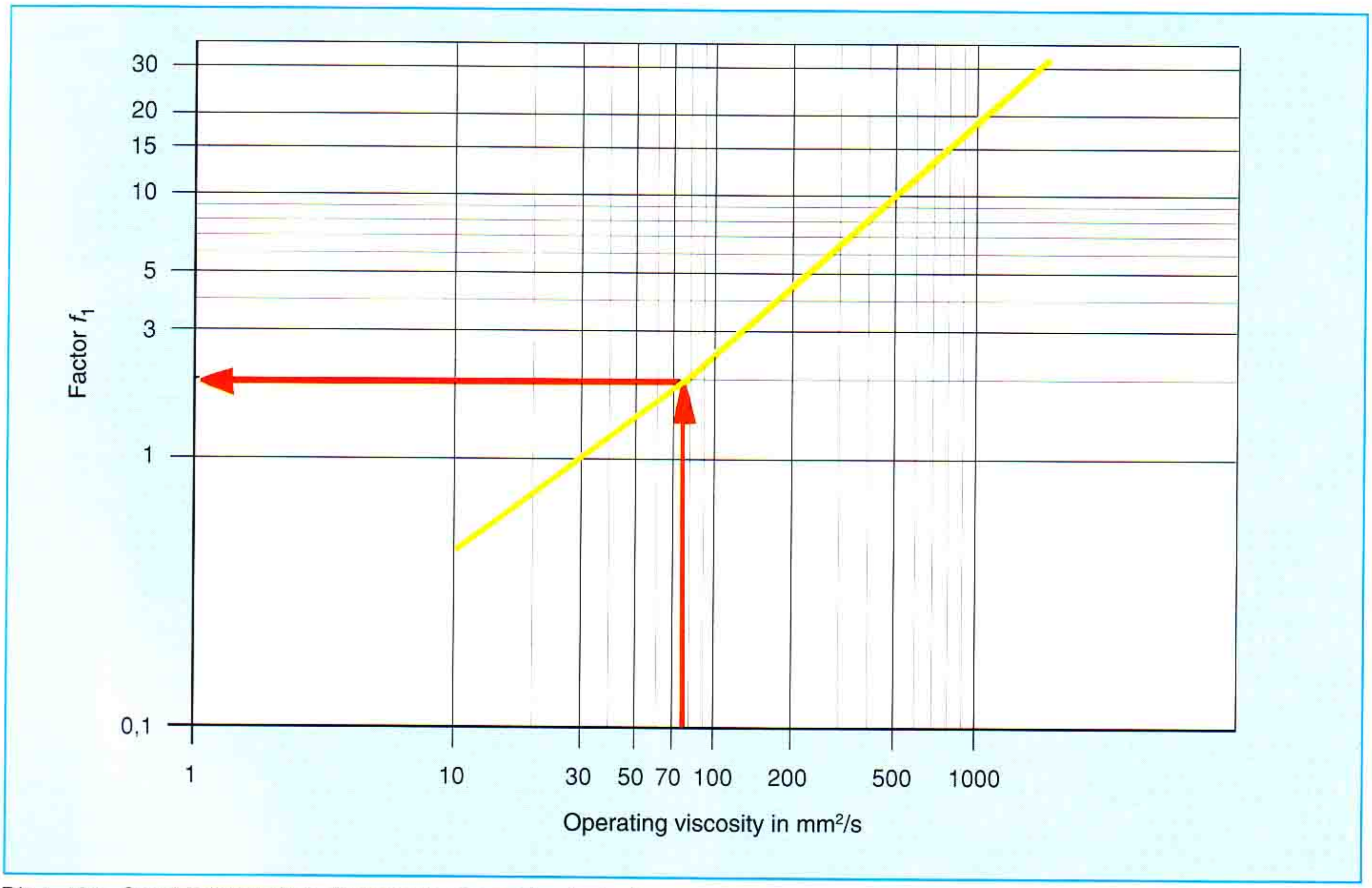
$$\Delta p_{GB} = \Delta p_{GP} \cdot \frac{\rho_B}{\rho_P}$$

Δp_{GB} = Housing pressure drop, operating fluid

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

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

ρ_B = Density of fluid, operating value



Diag. 101: *Graphic illustration of viscosity conversion factor f_1*

8.10 Determination of the filter size

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 may be taken from *Table 14.*

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
– irregukar 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 to the system	1,3	2,0	2,3

Table 12: *Environmental factor f_2*

Notes on Table 12

[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

The size of the filter may be determined from the following:

- pressure loss curves of the filter
- dirt retention rate of the filter element
- element life times required by the user

8.10.1.1 Determining the filter size, using pressure loss curves

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

The equation is:

$$Q_W = Q_P \cdot \ddot{U}$$

Q_w = Effective flow

Q_p = Flow of pump

$\ddot{U}$ = Increased pump flow due to accumulators or cylinders.

The maximum initial pressure drops given in Table 15 must not be exceeded in determining the size of filter required.

The data refers to a new filter element filtering hydraulic oil (HL, HLP).

Other design criteria are applicable when filtering fire-resistant fluids or engine oil (consult filter manufacturer if required).

Filter arrangement in hydraulic system	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	$f_2 (\Delta p_{Housing} + f_1 \cdot \Delta p_{Element}) \leq$ $\leq 0{,}15$ to $0{,}2 \cdot \Delta p_{Indicator}$	$Q_{Design} = Q_{System} \cdot f_1 \cdot f_2$
	By-pass filters, Line filters; Separate units	—	—
Protection filters	Pressure line filters without by-pass valve	$f_2 (\Delta p_{Housing} + f_1 \cdot \Delta p_{Element}) \leq$ $\leq 0{,}2 \cdot \Delta p_{Indicator}$	$Q_{Design} = Q_{System} \cdot f_1 \cdot f_2$
	Suction line filters	$f_2 (\Delta p_{Housing} + f_1 \cdot \Delta p_{Element}) \leq 0{,}01$	$Q_{Design} = 5$ bis $10 \cdot Q_{Pump} \cdot f_2$

Table 15: *Determining the size of the filter*

The total pressure drop across the filter can be determined:

- using the individual diagrams for filter housing and element,
- using the filter design diagrams, or
- using computer programmes.

Filter design using individual diagrams

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

$$\Delta p_{tot} = (\Delta p_{GB} + f_1 \bullet \Delta p_E) \bullet f_2$$

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

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

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

f_1 = Viscosity conversion factor

f_2 = Factor for ambient conditions

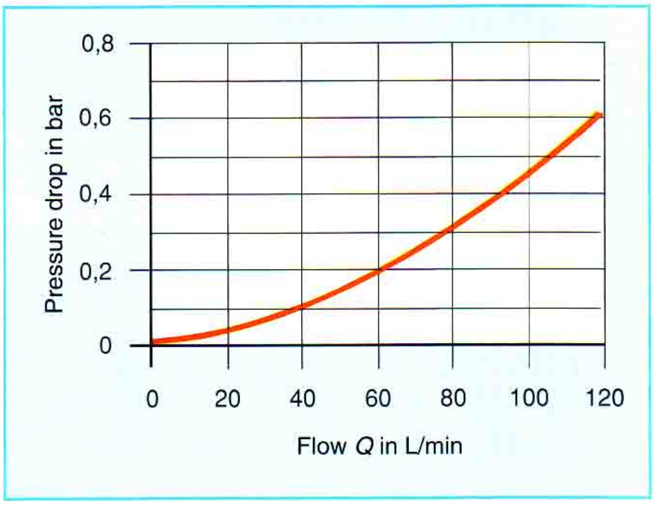
The individual pressure drops across the filter housing and element at the effective flow Q_w and operating viscosity must be hereby ascertained.

Diag. 102 shows the pressure drop across the filter housing when filtering hydraulic fluid. *Diag. 103* shows the pressure drop across the clean filter element with a fluid viscosity of 30 mm²/s.

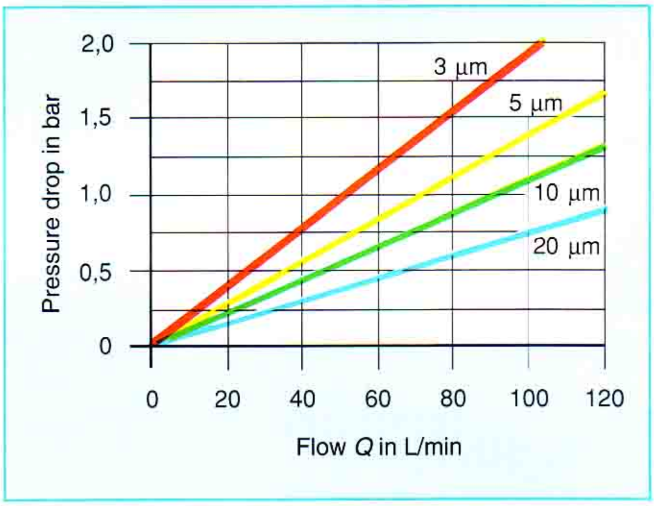
In calculating the required size of filter the total pressure drop must be multiplied by the factor f_2 in order to allow for the ambient conditions.

If the total pressure drop across the filter ascertained in this way is greater than the maximum value given in *Table 15* the whole calculation will have to be repeated for a larger size of filter.

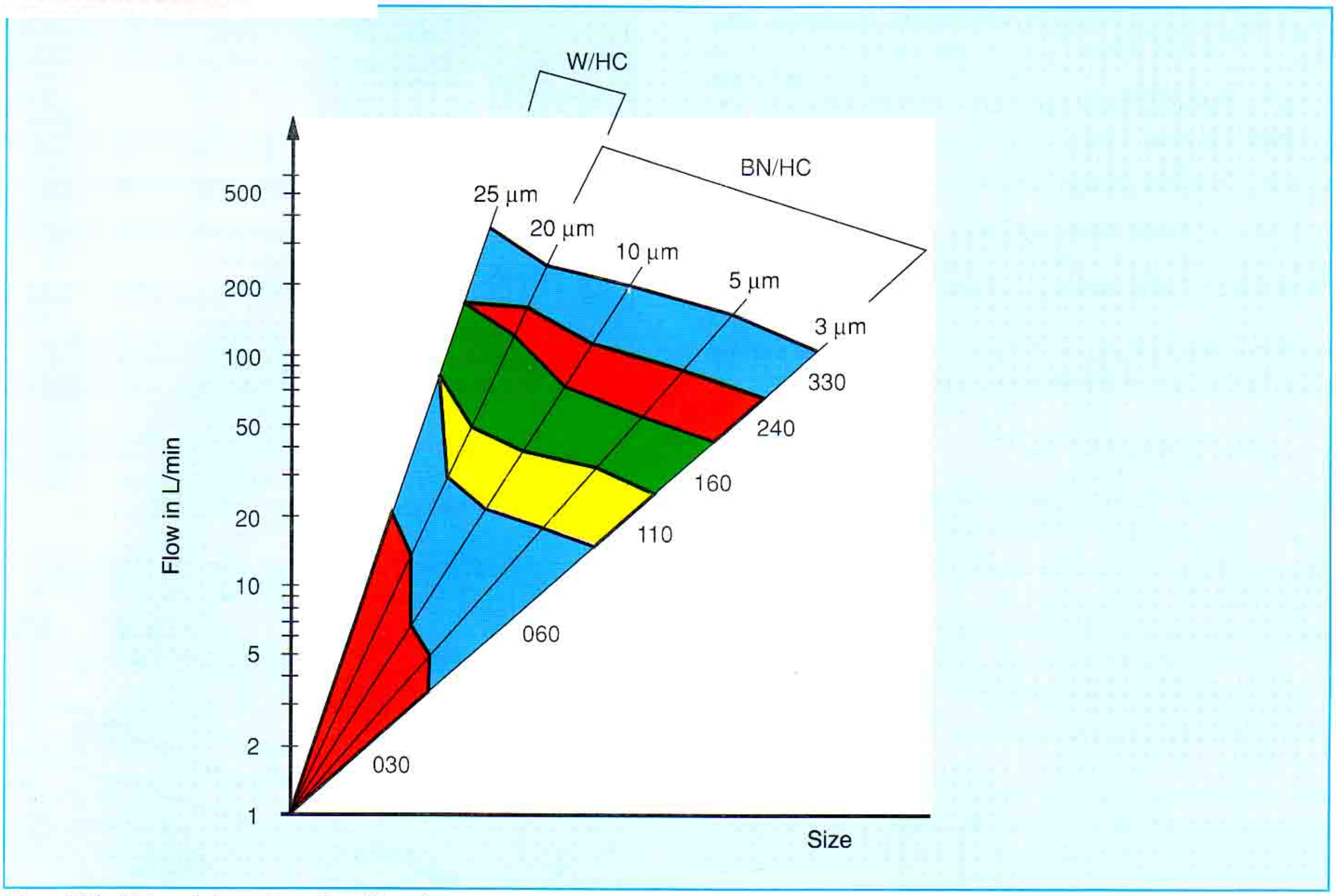
Only when the calculated total pressure drop of the filter is equal to or less than the maximum permitted total pressure drop has the filter been correctly sized.



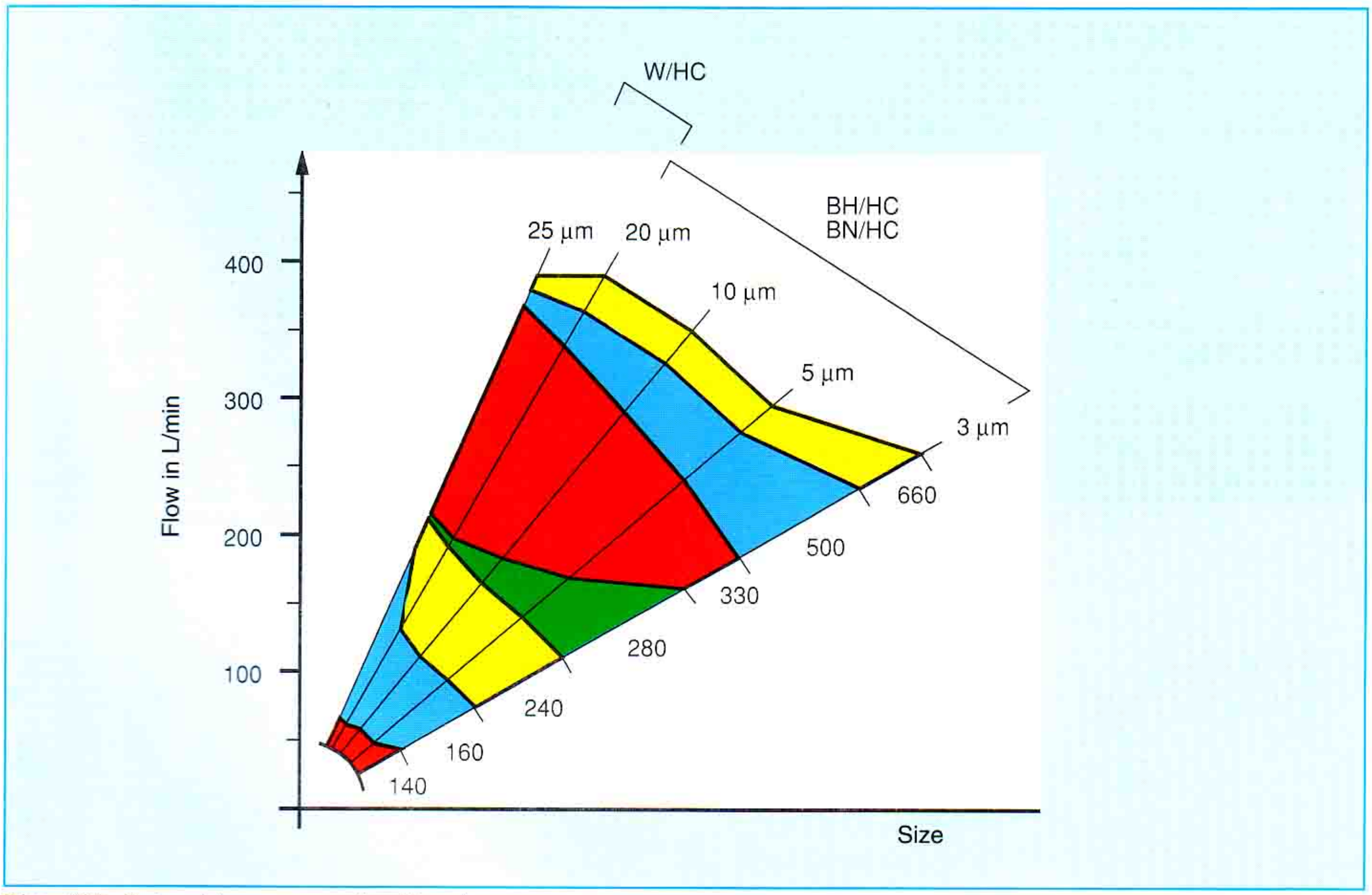
Diag. 102: *Pressure loss across a filter housing*



Diag. 103: *Pressure loss across a filter element*



Diag. 104: *Determining return line filter size*



Diag. 105: *Determining pressure line filter size*

...ign diagrams

In order to simplify and shorten the complicated process of determining the filter size, filter design diagrams were developed *(Diags. 104 and 105)*.

These diagrams are with respect to a hydraulic fluid viscosity of 30 mm²/s.

Higher operating viscosities and various ambient conditions are taken into account when determining the flow for the filter design.

Flow for the filter design is determined by

$$Q_A = Q_W \bullet f_1 \bullet f_2$$

Q_A = Flow for filter design

Q_W = Effective flow

f_1 =Viscosity conversion factor

f_2 = Environmental factor

The point on the curve at which flow Q_A crosses the filtration rating is the required filter size.

Filter design using computer programmes

By using computer programmes, it is possible to determine the filter size within a very short time.

The following computer operations are used at the moment:

- Determination of the filter size with respect to various installation conditions
- Determination of the filter size with respect to specific system properties

Determination of the filter size with respect to various installation conditions

All parameters which effect the filter design are taken into account.

These are:
Housing and element operating curves, viscosity and density of the hydraulic fluid, required filtration rating and filter material, effective flow and ambient conditions.

The correct filter size may be determined, on the basis of the pressure loss over the complete filter (with a clean filter element) determined by the computer.

In addition, it is quickly possible to control the set filter size at other operational temperatures, e.g. at cold start.

Filter design

Data input:

RM = 1,000		*DP* =	1,000 bar
Q = 120,000 L/min		*RHO* =	0,860 kg/L
		T =	50,000 °C
		FFH =	5,000 mic

Legend:

RM =	Computer model	*Q* =	Selected flow
DP =	Selected filter pressure loss		
RHO =	Density	*T* =	Fluid temperature
		FFH =	Filtration rating

Fluid	ISO VG 46
Type of housing	DF
Element material	BN/HC

result:

Filter type	DF	
Element material	BN/HC	
Size	240	
Filtration rating	5	mic
Number of filter elements	1	
design viscosity	28,89	mm²/s
Factor *f*	0,97	
Flow through filter	120	L/min
Filter area	2150,00	cm²
specific load on area	0,0558	L/min/cm²
$\Delta p_{Housing}$	0,2700	bar
$\Delta p_{Element}$	0,5347	bar
Δp_{Filter}	0,8047	bar
Dirt retention rate	20,3675	g

Fig. 272: *Filter design using a computer progamme*

Determination of filter size with respect to specific system properties

In this case the complete hydraulic system is simulated by the computer.

The filter size is fixed by considering the expected dirt ingress rate in the complete hydraulic sytem, as in the built-in hydraulic components. This design method may, however, only be carried out under certain conditions, as the actual amount of contamination which enters the system is only known in very few cases.

Hence this design method is only carried out to determine the position of the filter (pressure line filter, return line filter, by- pass filter) and to select the group of possible filter sizes.

8.10.1.2 Determination of filter size using element dirt retention rates or required minimum life times

So that the demand of the system operator for longer element life times may be met, it is necessary to determine the filter size with respect to the amount of dirt retained by the element. As this design method will increase in importance in the future, Betamicron-2 elements were developed. This type of element is characterised by a much higher dirt holding capacity, than that found in elements on the market with similar dimensions.

Size may be determined by the following methods:

- System operator specifies a minimum dirt holding capacity
- System operator specifies particular intervals between element changes

In carrying out a Multi-pass test on the filter element, the dirt holding capacity is determined. Hence it is very easy for the system operator to determine the filter size, by selecting the dirt holding capacity.

However, it is very difficult for the system operator to determine the filter size, by selecting particular intervals between element changes.

Usually, the actual dirt ingress rate is not known during the project phase of the system. Hence reference values are used for the dirt ingress rate for the calculation of the required element dirt retention rate.

These reference values were determined on the basis of many years of investigation on hydraulic systems and are available for the filter manufacturer, power unit manufacturer or operator. The determined filter size may only be considered to be a guide, as the actual amount of dirt entering the system is only discovered at a later stage, when the system is in use.

8.10.2 Design of 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, weekends, etc.

The sizing of a by-pass filter is based on

- the flow through the filter and
- the filter area.

8.10.2.1 Determination of flow through by-pass filter

In determining flow through the by-pass filter, the following data must be taken into consideration:

- required oil cleanliness
- operational time for the by-pass filter
- operational time for the hydraulic system
- ambient conditions
- hydraulic fluid
- tank size
- introduced flow in main flow
- flow to be introduced for the cooling circuit
- filter placed in main flow (protection filter, working filter)

Power units for system flushing

A large amount of dirt must be expected to be flushed out of the completed sytem, when flushing the sytem *(see Diag. 106)*. This means, that the hydraulic fluid, which flows back into the tank, is heavily contaminated with particles. The return line filter installed in most systems is not designed for this amount of contamination. Hence the elements do not last very long in return line filters. Therefore, the system must be flushed with the help of a stationary or mobile flushing unit *(Fig. 254)*.

Flow for these units is determined by the equation:

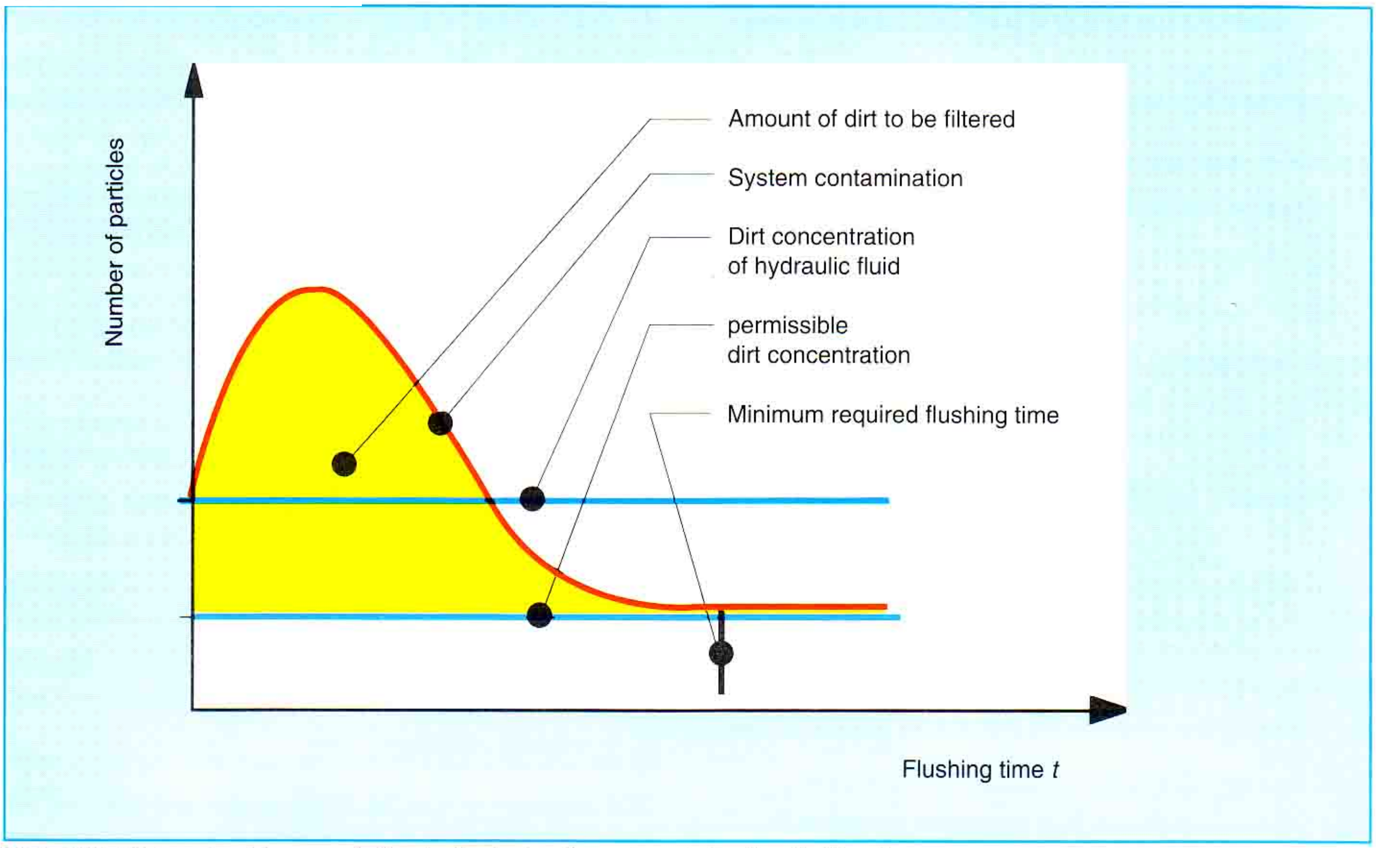
$$Q_N = Q_A \cdot f_4$$

Q_N = Flow for by-pass filter

Q_A = Overall introduced flow by pump in the hydraulic system

f_4 = Flow conversion factor

The factor f_4 is dependent on the ratio of tank size to the flow introduced by the pump.



Diag. 106: *Change in dirt concentration in the hydraulic system during the flushing time*

The appropriate factor may be determined from *table 17.*

Tank size / Installed pump power	Factor f_4
> 3 : 1	1,25
> 1 : 1	1,5
< 1 : 1	2

Table 16: *Factor f_4 flow conversion factor*

The effect of cleaning is dependent on the filtration rating used in the power unit.

Hence the filtration rating of these filters must be selected at least one size finer, than the filtration rating of the main flow filter in the hydraulic power unit.

Power units for the filling of a sytem

The determination of the flow through the filler is dependent on the tank size and the required filling time specified by the system operator.

$$Q_N = \frac{\text{Tank size}}{\text{Filling time}}$$

As the dirt particles are only presented to the filter once, the filtration rating again must be selected a size finer that the required filtration rating needed to achieve a particular oil cleanliness *(see table 12).*

8.7 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?

– Flow through the filter

This may 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 $\Delta p_A = 0.2 \bullet \Delta p_{indicator}$
with by-pass: $\Delta p_A = 0.15 \bullet \Delta p_{indicator}$
Return line filters: $\Delta p_A = 0.2 \bullet \Delta p_{indicator}$

Δp_A = maximum pressure loss of complete filter
$\Delta p_{indicator}$ = pressure drop which indicator refers to.

– 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 protective filters may not have by-pass valves.

– 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.

8.8 Determination of the filtration rating

The chosen filtration rating should be the same for all hydraulic filters (e.g. pressure-line, return line filters and breathers) in a particular hydraulic system.

Hydraulic components	Cleanliness class to NAS 1638	Cleanliness class to ISO DIS 4406	recommended absolute filtration rating in µm
Gear pumps	10	19/16	20
Cylinders	10	19/16	20
Directional valves	10	19/16	20
Relief valves	10	19/16	20
Throttle valves	10	19/16	20
Piston pumps	9	18/15	10
Vane pumps	9	18/15	10
Pressure valves	9	18/15	10
Proportional valves	9	18/15	10
Servo valves	7	16/13	5
Servo cylinders	7	16/13	5

Table 11: *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 may be selected from Tables 11, 12 or 13.

The filtering action in a hydraulic system is illustrated in *Diag. 100.* This diagram also shows very clearly the rapid rise in the contamination of the fluid that occurs when no filter is fitted.

8.10.3 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 combatting 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 *Diag. 107.*

8.10.4 Filter design for fire-resistant fluids

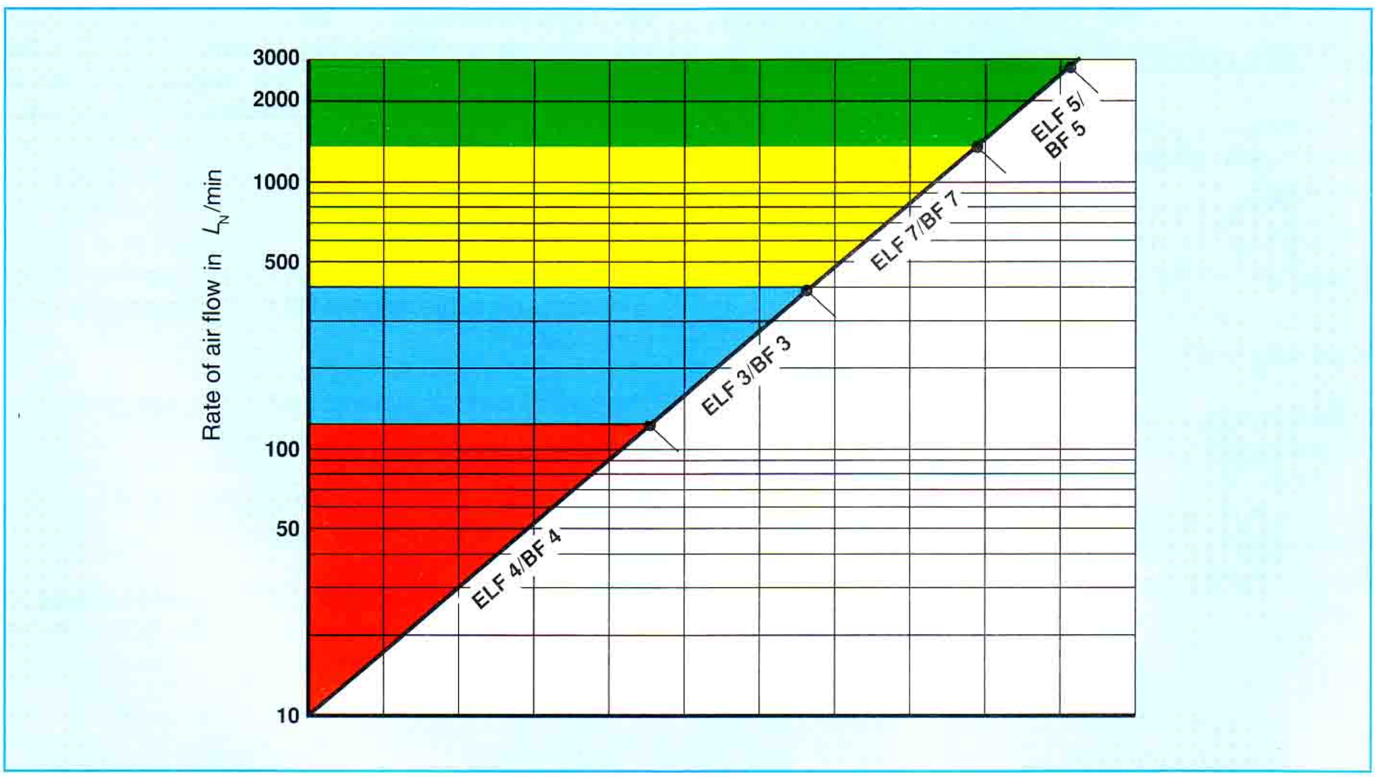
The filtering of these fluids requires special attention to compatibility with the materials of the filter elements and housings.

Past experience has shown the following materials to be suitable:

Filter material:	glassfibre non-woven, metal non-woven, stainless steel wire mesh
Filter housings:	steel, cast iron with surface protection, phosphated or electroless nikkel 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.



Diag. 107: *Determination of filter size in breathers*

The filter area may 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 *(Table 18)*
Q_W = Effective 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.

8.10.4.1 Determination of filter pore size

Fluid designation	Factor f_3
HFA	1,16
HFB	1,16
HFC	1,27
HFD	2,21

Table 18: *Factor f_3 for fluid density conversion*

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.

8.10.4.2 Design of by-pass filters

The procedure for the design of by-pass filters is the same as that described in *Section 8.10.2*.

8.10.4.3 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 foreign fluids 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 the traces of contaminating fluids from fire-resistant fluids.

9 Notes on Maintenance

9.1 Filling and Flushing the Hydraulic System

A further opportunity for dirt to enter the system from the outside is provided when filling the system with hydraulic oil. Due to its manufacture, filling, transport and storage, the new pressure medium can already at this stage be contaminated to a relatively high degree. In order to eliminate this possibility, it is advisable to fill the system via one of the filter units shown in *Fig. 254*. These types of filter units are also particularly suitable for flushing a system prior to commissioning. Flushing reduces the contamination incurred during installation to a degree necessary for reliable operation of the system without unnecessarily subjecting the filters of the system to additional load.

The size of the filler connection must be selected corresponding to the pump delivery.

The pore size of the filter element must be at least the same as that of the system filters.

To ensure quick replacement of the devices shown in *Fig. 254*, it is recommended to provide quick-release couplings at the hydraulic tank.

9.2 During Commissioning

Check whether the fluid, pressure and flow of the system agree with the specifications for the filter provided in the brochure and on the filter.

9.3 During Operation

Open the filter housing and clean when indicator indicates this. Renew seal if leaks are found at the housing.

Caution: Depressurize before opening filter.

9.4 Changing Filter Element

a) Generally, all filter elements should be changed after one year of operation.

b) The filter element must be changed when the signal “filter clogged” is indicated

c) When changing the filter element, no contaminated medium must enter the hydraulic system. Contaminated medium must be drained from the filter housing before changing the filter element.

10 Symbols, subscripts, and prefixes

Symbols

Symbol	Unit	Designation
Q	L/min, m³/s	Flow
A	m², cm², mm²	Area, Filter area
p	bar, N/m²	Pressure
α	g	Dirt retention
ρ	kg/dm³	Densitiy
τ	h	Operational time
q	L/min/cm²	Spec. area loading
n	min⁻¹	Speed
ν	mm²/s	Kinematic viscosity

Dimensionsless symbols

Symbol	Designation
f	Correction factor, conversion factor
%	Per cent
t	Time, flushing time
ß	Beta value, degree of separation
n	Number
M	Million
K	Thousand

Subscripts

Symbol	Designation
1, 2, 3, 4	Element number, factor number
X	Particle size
GB	Housing, with operating fluid
GP	Housing, reference data
P	Data sheet, pump
B	Operating conditions
W	effective
Ü	Mechanical ratio
Tot	Total
E	Element
G	Housing
A	design, area, system
N	Nominal flow, nominal
TA	Hydraulic system per day
WA	Hydraulic system per week
TN	By-pass filter per day
WN	By-pass filter per week

Prefixes

Symbol	Designation
Δ	Difference, drop

11 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 controllingcleaning 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
ISO 4572	Hydraulic fluid power - Filters - Multi-pass method for evaluation filtration performance
ISO 5598	Fluid power systems and components - Vocabulary
ISO 6162	Hydraulic fluid power - Flange connections
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
DIN ISO 3724	Hydraulic fluid power - Filter elements - Verification of flow fatigue characteristics
DIN ISO 3968	Hydraulic fluid power - Filters - Evaluation of pressure drop versus flow characteristics
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 51592	Testing of content of solid particles in lubricants
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 particle 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
CETOP RP 98 H	Guidelines for the specification, selection and application of breathers in hydraulic tanks
CETOP RP 118 H	Guidelines for the control of contamination in pressure fluids in hydraulic systems
NAS 1638	Cleanliness Requirements of Parts used in Hydraulic Systems
SAE 749 D	Society of Automotive Engineers, Inc.