Clean Oil Guide

3 micrometres:
Oil

25 micrometres:
Pollen

8 micrometres:
Coal dust

2 micrometres:
Bacteria

40 micrometres:
Naked eye visibility

100 micrometres:
Grain of salt

70 micrometres:
Human hair

Clean Oil Guide
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"Chemistry in electrical apparatuses"
Lars Arvidson
Västerås PetroleumKemi AB
C.C.JENSEN

Contents

Introduction

Maintenance is the largest single controllable expense in a manufacturing plant. With as many as 80% of all machine failures related to contamination in the oil, pro-active methods are saving industries considerable costs every year.

This booklet offers an introduction to the problems with insufficient oil cleanliness, the causes and the remedy of the problems. All the information presented is generally known and accepted. It was compiled and published by people within the company C.C. Jensen A/S. We invite you to take advantage of the experience we have gathered over the past 50 years with oil maintenance within various types of industrial and marine applications. The perfect oil cleaning system will control the level of all types of contamination. For further information, we recommend that you visit www.cjc.dk.

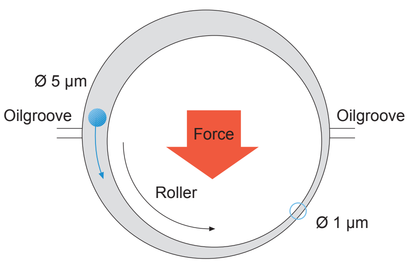
Wear and tear in oil systems

Any machine using oil for power transmission or lubrication will be affected by the condition of the oil. The oil comes into contact with all the other components in the system and should be considered the most important. Contamination in the oil is anything that should not be there, e.g. solids and water.

Mechanical Wear

Solid particles typically cause 50% of all failures and multiply by destroying the surface of even very hard metal. The most harmful particles are the ones trapped in the dynamic tolerance like in bearings (figure 1).

Fig. 1

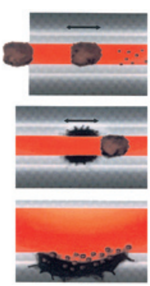


Source: Västeras PetroleumKemi AB

"Chemical" Weare!

Chemical contamination includes water and oil degradation products and certain metals (e.g. copper). Water typically accounts for 20% of mechanical failures. It reduces the lubricity of the oil and results in corrosion and erosion leading to spalding (figure 2). Furthermore, it acts as a catalyst in the oxidation of the oil, just as copper does. Oxidation products form a sticky layer on metal surfaces and is often referred to as varnish.
Hard particles of all sizes get caught in the sticky layer, creating a sandpaper like, grinding surface.

Fig. 2



Oil Degradation products

Oil Degradation products or soft contaminants are a widespread problem in all industries. They are the precursors of deposit (varnish) on components causing machine problems. The problems are most notable in close tolerances and sensitive control systems. If you whish to know more about this topic, then please ask for our 16-pagded Oil Degradation brochure.

Oil sampling

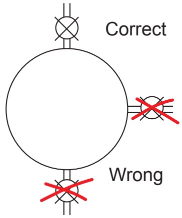
The purpose of oil sampling is to achieve the highest level of machine performance and reliability at the lowest possible cost. The initial samples serve to establish benchmarks and to identify the machines with critical levels. The routine sampling is done to document that goals are met and can also provide indication of abnormal wear that needs to be addressed.

The quality of analysis results depends first on correct sampling and handling of the sample, secondly on the quality of the laboratory performing the analysis. The importance of the knowledge about where and how to take a sample is paramount and requires special attention.

Where to take an oil sample

Referring to figure 3 derive the oil from a preferably upwards pointing pipe with continuous and ample flow to produce a representative sample. Sampling points fitted on the lower perimeter of a pipe tend to allow depositing of particles in the sampling valve.

Fig. 3: Pipe cross section with sampling valves



Source: Västeras PetroleumKemi AB

The best sampling point is the return line from the system before any filtration. A sample taken between the pump and the filter housing of an off-line filter is normally the worst contaminated part of the oil system. A satisfying result from such a sample is the best guarantee that the whole system is clean. If no off-line filter system is installed a vacuum type sampling pump is a valid option. In such case the sample should be drawn 10 cm (4 inches) off the lowest part of the tank (see page 7).

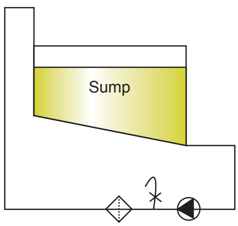
How to take an oil sample - between the pump and the filter

To take an oil sample, the following is required:

- a 200 mL particle free glass bottle
- a cloth
- a five litre (1 1/2 US gallon), open oil container

Please read the following instructions carefully before taking the oil sample.

Fig. 4: Oil sampling



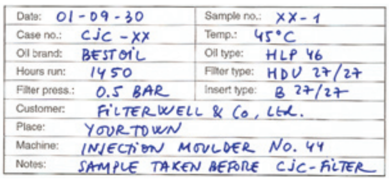
Steps 1-3

Steps 4-5

Step 6

1. Place the oil container beneath the sampling valve
2. Open and close the valve five times and leave it open.
3. Flush the pipe by draining one litre (one US quart) into the container.
4. Open the sample bottle.
5. Place the bottle under the oil flow without touching the sampling valve

6. Fill the bottle approximately 80% full.
7. Place the cap on the bottle immediately after taking the sample.
8. Close the sampling valve.
9. All samples must be clearly marked with number, place of sampling, date and oil type/make (see below example).



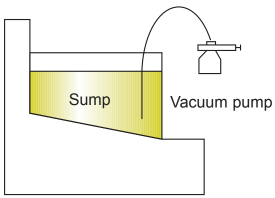
Date:	01-09-30	Sample no.:	XX-1
Case no.:	CJC-XX	Temp.:	45°C
Oil brand:	BEST OIL	Oil type:	HLP 46
Hours run:	1450	Filter type:	HDU 27/27
Filter press.:	0.5 BAR	Insert type:	B 27/27
Customer:	FILTERWELL & Co, Ltd.		
Place:	YOURTOWN		
Machine:	INJECTION MOULDER No. 44		
Notes:	SAMPLE TAKEN BEFORE CJC-FILTER		

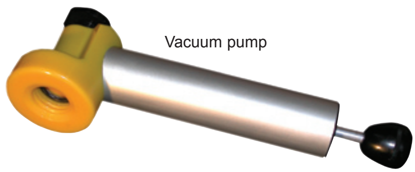
Samples should only be collected with the machine operating at normal working temperature. When sampling for particle counting the method is very important. Remember that you can never make a sample any better (cleaner) than the oil in the system, but it is easy to make it worse

– using a manual vacuum pump

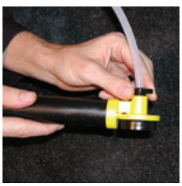
Follow the instructions that came with the pump kit.
The illustrations below show the CJC oil sampling kit.

Fig. 5: Oil sampling with a vacuum pump.





Steps 1



Step 2

Step 3

Try to lower the free end of the plastic tube to one third above the bottom of the tank in the center of the tank – or, if relevant, above the lowest point of the tank. Be careful not to touch the walls or the bottom of the reservoir with the tube. When you have sealed the bottle, make sure that the label is filled in with all the information as per example on page 6.

Used Oil analysis

As a minimum an oil analysis should include:

- a particle count
- viscosity
- water content in ppm
- acidity level (TAN)

If the oil additive content is of interest a spectral analysis should be included. This test is best carried out by the oil supplier as they have the detailed knowledge of the initial additivation of the oil.

It is recommended that the initial tests are performed by an independent laboratory with special knowledge on lubricants.

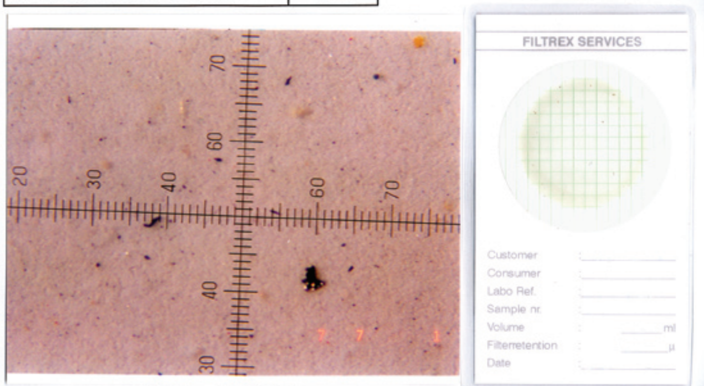
Fig. 6: Particle analysis

PARTICLE COUNTING.

NUMBER OF PARTICLES PER 100 ML	>2 MICRON	313650
	>5 MICRON	87221
	>15 MICRON	8137
COLOUR TEST FILTER DISC		l.grey
ISO CLASSIFICATION ACC. 4406		19/17/14

PARTICLES IDENTIFICATION.

Black metal	:	70 %
Weld. sparks	:	%
Bright metal	:	10 %
Rust	:	5 %
Sand	:	%
Fibres	:	5 %
Synthetics	:	5 %
Cupper	:	5 %



1 DIV. = 15 MICRON

Source: Filtrex Services BV, Holland

ISO Standards

The ISO 4406/2000 classification of particle contents was introduced to facilitate comparisons in particle counting.

Sudden break down in an oil system is often caused by large particles (>14 µm) in the oil while slower, progressive faults, e.g. wear and tear, are caused by the smaller particles (4-6 µm).

This is one of the explanations why the particle reference sizes were set to 4 µm, 6 µm and 14 µm in ISO 4406/2000. A typical sample from a wind turbine gearbox, for example, contains in every 100 mL of oil:

450,000 particles >4 micron
120,000 particles >6 micron
14,000 particles >14 micron

Introduced in the ISO classification table (on the right), this oil sample has a contamination class of 19/17/14.

Fig. 7: Contamination classes according to the new ISO 4406/2000 standard.

More than	Till	Class
8.000.000	16.000.000	24
4.000.000	8.000.000	23
2.000.000	4.000.000	22
1.000.000	2.000.000	21
500.000	1.000.000	20
250.000	500.000	19
130.000	250.000	18
64.000	130.000	17
32.000	64.000	16
16.000	32.000	15
8.000	16.000	14
4.000	8.000	13
2.000	4.000	12
1.000	2.000	11
500	1.000	10
250	500	9
130	250	8
64	130	7
32	64	6

Number of particles per 100 ml fluid after their size ranges

NAS Classes

NAS 1628 is a American standard that translates approximately into ISO Codes. The difference is that the NAS gives breakdown of the different particle sizes lager than 15 µm.

Fig. 8: NAS 1628

Size	*Classes NAS 1628*													
µ	*00*	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
5-15	125	250	500	1,000	2,000	4,000	8,000	16,000	32,000	64,000	128,000	256,000	512,000	1.024,000
15-25	22	44	89	178	356	712	1425	2,850	5,700	11,400	22,800	45,600	91,200	182,400
25-50	4	8	16	32	63	126	253	506	1,012	2,025	4,050	8,100	16,200	32,400
50-100	1	2	3	6	11	22	45	90	180	360	720	1,440	2,880	5,760
>100	0	0	1	1	2	4	8	16	32	64	128	256	512	1,024

Evaluation of particle count

The obtained ISO code is an indication of the cleanliness of the oil in the system and can be verified in the contamination charts shown below.

Fig. 9a: Contamination guide for hydraulic and lube oil systems

ISO Code	Description	Suitable for	*
ISO 14/12/10	Very clean oil	All oil systems	8.5 kg
ISO 16/14/11	Clean oil	Servo & high pressure hydraulics	17 kg
ISO 17/15/12	Light contaminated oil	Standard hydraulic and lube oil systems	34 kg
ISO 19/17/14	New oil	Medium to low pressure systems	140 kg
ISO 22/20/17	Very contaminated oil	Not suitable for oil systems	> 589 kg

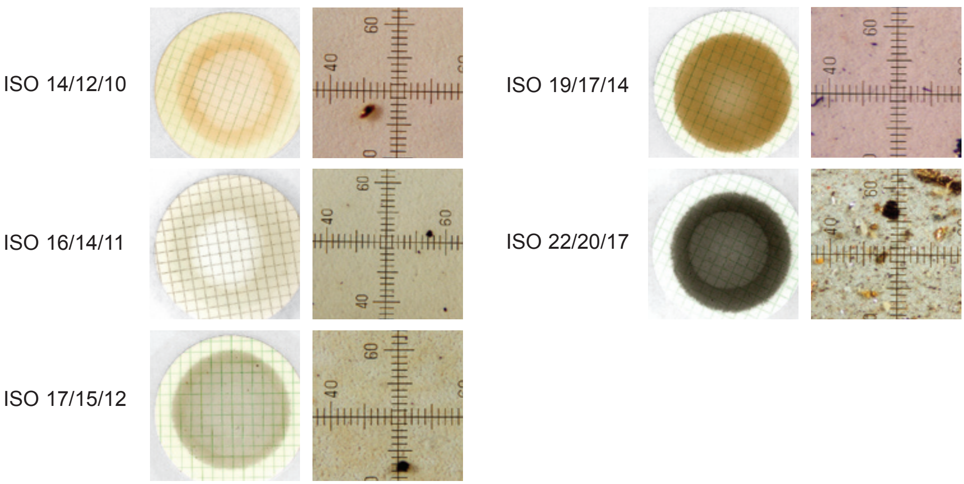
Fig. 9b: Contamination guide for gears

ISO Code	Description	Suitable for	Improvement Factor	*
ISO 14/12/10	Very clean oil	All systems	200%	8.5 kg
ISO 16/14/11	Clean oil	Critical gear system	150%	17 kg
ISO 17/15/12	Light contaminated oil	Standard gear systems	100%	34 kg
ISO 19/17/14	New oil	Non critical gear systems	75%	140 kg
ISO 22/20/17	Very contaminated oil	Not suitable for gear systems	50%	> 589 kg

* kg of solid particles passing the system pump yearly at the given ISO code.

For every oil-filled system, a cleanliness goal should be specified. This is the basic requirement to insure reliability at the lowest possible cost.
The millipore membranes show oil degradation if a 0,45 µm cellulose membrane is utilized.

Fig. 10: Test membranes together with microscopic photographs of various contamination levels



Frequency of analysis

In the implementation phase of a condition monitoring system, analyses must be made frequently – at least every six months – in order to establish a knowledge data base.

Every oil system should have a log where analysis results are registered, The logbook must also contain information about oil type, oil changes, break-downs, targeted ISO class code and oil analysis results.

Oil cleaning methods

Several oil cleaning methods are available:

Fig. 11: Oil cleaning methods

Method	Cleaning action
Conventional surface filter	Reduces the content of solid particles.
Cellulose-based depth filter	Reduces the content of solid particles, water and oil degradation products
Electrostatic filters	Reduces the content of polar contaminants
Centrifugal separator	Reduces the content of particles with a density higher than that of oil as well as water
Vacuum filter	Reduces the content of air and water

All the above technologies are commercially available. The surface filter and the depth filter however, are often preferred due to their superior effeciency and economy.

Both these cleaning techniques work best under constant conditions, i.e. steady flow and pressure. The depth filter is often placed in a separate off-line circuit and with such stable conditions, it retains the majority of contaminants in the oil. The surface filter could be installed in an oil cooling circuit or as a full-flow »emergency« filter in the pressure (upstream) line of the oil system.

Filter types

The Depth Filter is like a maze where the oil passes through several layers of cellulose. The largest particles are retained on the outside of the element whereas the smaller particles enter the element and are retained within the filter material,

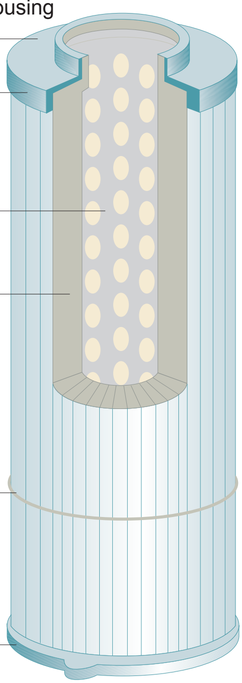
ensuring a high dirt holding capacity. Using a cellulose element also enables removal of water by absorption and oil degradation products (resins/varnish) by adsorption.
This type of filter can also be installed in a by-pass circuit, using the pressure of the system pump.
Off-line filters are designed to maintain a good oil cleanliness at the lowest cost.

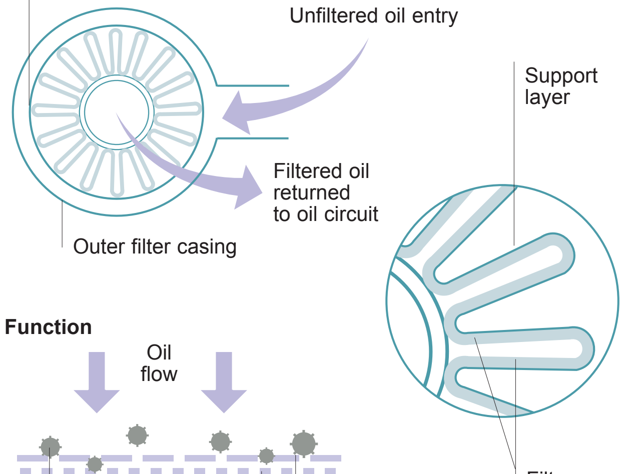
The Surface Filters of conventional designs have relatively thin layers of filter media, allowing high flows through the element. The filter element is pleated in order to increase the surface area and reduce the pressure drop. The filter is capable of removing solid particles only – and as it utilizes only the surface area, it has a restricted dirt holding capacity.

See illustrations on pages 14 & 15.

Modern oil systems often combine the two cleaning systems, where the depth filter removes the contamination and the surface filter serves as full flow security filter.

Surface Filter





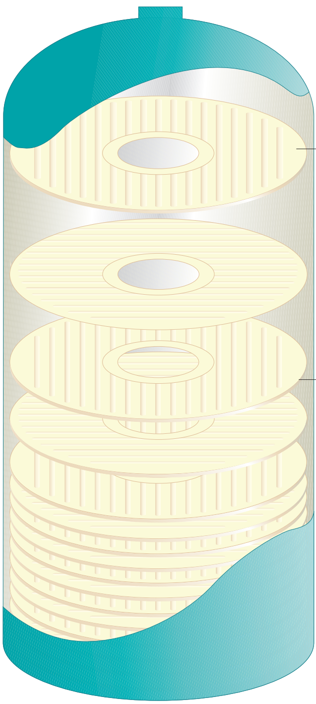
Surface filters have a limited contamination holding capacity, usually between 1 and 100 grams, which makes filter insert replacement at short intervals necessary in order to ensure efficient filtration.

Surface filters removing particles <20 µm ensure effective protection when installed before an important machine part.

Surface filters do not absorb water.

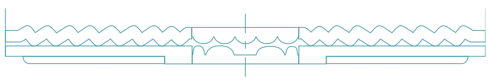
Surface filters do not remove oil degradation products (resins).

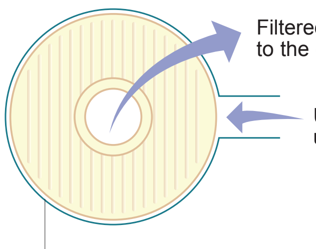
Depth Filter



Filter element:
Made as a sandwich of corrugated wood cellulose discs rotated at 90° to the next and bonded together. This gives a series of connected surfaces with corrugations running north-south and east-west.

Two-disc filter sandwich



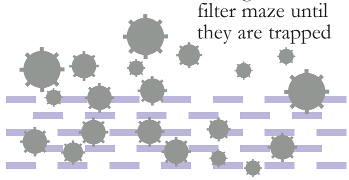


The CJC™ depth filter has a contamination holding capacity of approximately 2 L and only needs replacing every 12 months.

Depth filters filter effectively down to 3 µm absolute.

Depth filters absorb water and oil degradation products (resins).

Function



Particles pass through the filter maze until they are trapped

Basic filtration definitions

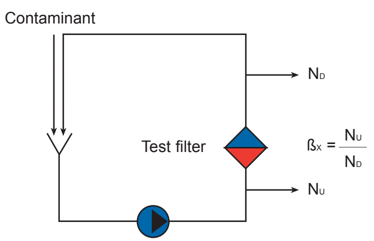
Nominal filtration ratings are estimated values, indicating a particulate size range at which the filter is claimed to remove a given percentage. There is no standard for this, so consequently, different products/makes cannot be comparred. Operating pressure and concentration of contaminants will affect the retention efficiency of nominal rated filters.

Absolute filtration ratings describe the pore size, indicating the largest size of particle which can pass through the filter. The filter need to apply to a standard test method intended for filter usage. The rating of depth filters if often 3 micron absolute or less. The rating og surface filters varies according to the requirements of the components to be protected.

Beta values are describing filter efficiencies at a given particle size. The value is written $ß_x$, where the ”x” represents the particle size in question and the ß is the efficiency, e.g. $ß_3 = 75$, which means that one out of 75 particles of 3 micron size will pass throygh the filter (1.3% passes though and 98.7% are retained in one pass). In order to find the Beta value, a stanardised ”Multipass test” is used, and the Beta value is calculated by the following formula:

$$ß_X = \frac{\text{number of particles upstream} > x\ (N_U)}{\text{number of particles downstream} > x\ (N_D)}$$

Fig. 12: Multipass test



Filter efficiency

$$E = \frac{ß_x - 1}{ß_x} \times 100$$

Source: ISO Standards

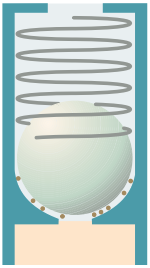
Dirt holding capacity

Dirt capacity is the quantity of contamination absorbed by the element when the saturation pressure is reached. This is measured in weight or volume.

Filter by-pass valve

The filter by-pass valve eliminates the filtration function by by-passing the full flow filter, i.e. a by-pass valve opens when the pressure drop over the filter is too high.
The oil flow then completely or partially passes by – and not through – the filter. A leaking by-pass vale has a devastating effect on the filter efficiency value. For off-line filters, the by-pass valve should be in the pump, connecting the pressure and suction ports.

Fig. 13: By-pass valve



Installation methods

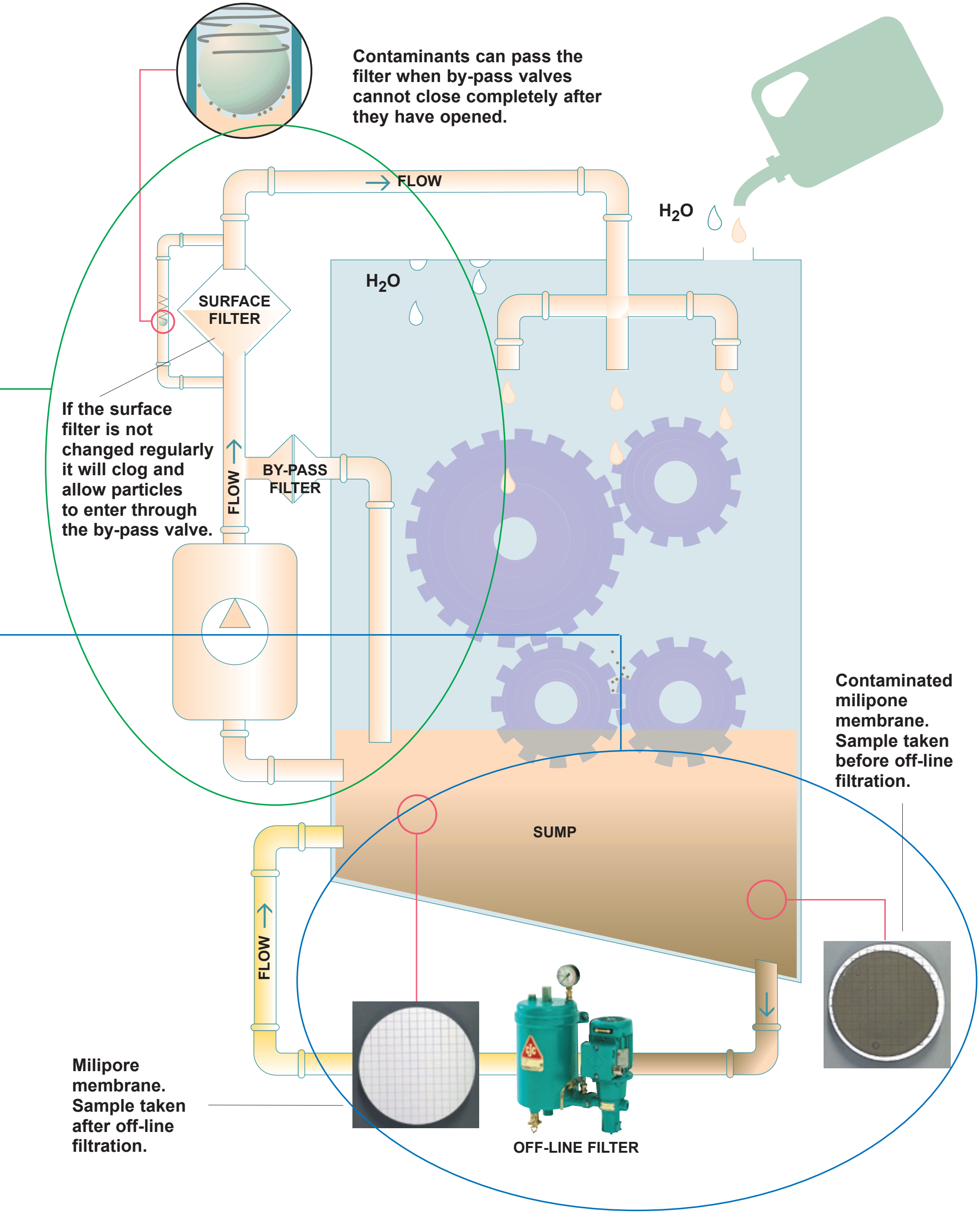
Oil system diagram

Full-flow filtration

The total system flow passes through the filter. Only surface filter elements are applicable here.

Off-line filtration

An installation method where the filtration unit operates in a separate cleaning circuit, enabling the use of depth filter elements.



Contaminants can pass the filter when by-pass valves cannot close completely after they have opened.
FLOW
H_2O
H_2O
SURFACE FILTER
If the surface filter is not changed regularly it will clog and allow particles to enter through the by-pass valve.
FLOW
BY-PASS FILTER
Contaminated milipone membrane. Sample taken before off-line filtration.
SUMP
FLOW
Milipore membrane. Sample taken after off-line filtration.
OFF-LINE FILTER

Economy

Before investing in a filtration system, a cost benefit study should be carried out. The involved costs can be divided into two groups:

- **Purchase costs:** costs directly related to the purchase of a filtration system, i.e. purchase price and installation costs.
- **Operational costs:** costs for keeping the filtration system unit in operation, i.e. replacement of filter inserts, energy consumption and repairs.

Purchase Costs + Operational Costs = Total Investment

The total investment has to be lower than the savings obtained through clean oil.

- **Savings:** the reductions in maintenance costs, the minimizing of lost production hours, prolonged service intervals, longer oil life time, extended component life, etc.

For a CJC off-line filter, for example on a wind turbine, the payback period is approximately three days of operation. This means that if the improved oil condition leads to just 3 x 24 hours of additional production, the filter unit has paid for itself.

Ordering a filtration system

When ordering a filtration system the following should be specified:

- Operational costs of the filter.
- Required fluid system cleanliness level
- Control procedure confirming that the cleanliness level has been achieved (oil sample).

Calculate the total cost for the life time of the system – or 10 years of operation.

Handling of oil and oil systems

New oil in containers

- New oil should be considered contaminated until a sample has been analyzed.
- Oils containing additives that are not necessary for the application are to be considered contaminated
- New oil should always be introduced to the system via a filter, preferably a 3 µm absolute filter.
- Do not mix oils without previously investigating compatibility.
- Keep lubricating products in closed containers to avoid ingress of contaminants.

Oil in the system

- Observe the oil regularly during operation in order to discover any sudden appearance of water, air, oil degradation products, or other contaminants. Using fresh oil as a reference may be helpful.
- Check the oil after machine malfunctions or other incidents which might affect the oil.
- Always observe maximum cleanliness and accuracy during sampling.
- Systems should be as sealed as possible. All permanent openings should be equipped with venting filters. All systems should be equipped with permanent filter installations.
- When changing the oil, the tank and the system should be emptied completely and the tank should be cleaned manually of settlings (sludge, etc.).
- When replacing seals, only oil-resistant materials should be used. Compatibility with the oil should be checked.
- Never apply new additives without consulting the oil supplier/consultant. Ask for written confirmation of the measures to be taken.
- Always use independent analysis resources with adequate quality control.

Recommendations for buying oil

When buying oil in bulk, buyers have a right to set special certified requirements to ensure the quality.

Below find some **examples of requirements** and test for the quality of the oil, emphasizing oil cleanliness.

Oil test certificates and test sampling

The results of an oil test of the batch should be presented to the buyer. A sample should be taken during the filling of the batch. Samples should be marked with the trademark, number and size of the consignment. The oil should be analyzed by an independent laboratory and the analysis should include the data described in the oil analysis section of this booklet.

Claims

If the oil supplied does not fulfill requirements, returning the consignment might be considered. If the problem can be corrected, new samples must be approved. The supplier must pay all costs, including machinery failure and downtime.

Sampling

Samples must be drawn from each manufactured batch. The analysed sample must be a representative sample of the manufactured batch. Test records must be available for the buyer for at least five years.

An analysis certificate must be delivered together with the ordered oil and include at least the following items:

– Visual inspection
– Viscosity @ 40°C
– Density
– **T**otal **A**cid **N**umber of finished product
– Air bubble separation time
– Contaminants, gravimetric.

For wind turbine oils, foaming at 50°C could be included.

The oil must be delivered by tanker trucks, epoxy-painted drums or 20-litre cans. The buyer must indicate the type of container for each individual case. The container must be of first class quality and the type generally used in the oil trade. The container must be marked with the buyer's trade description, the suppliers trade designation, net content and a continuous manufacturing batch number.

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