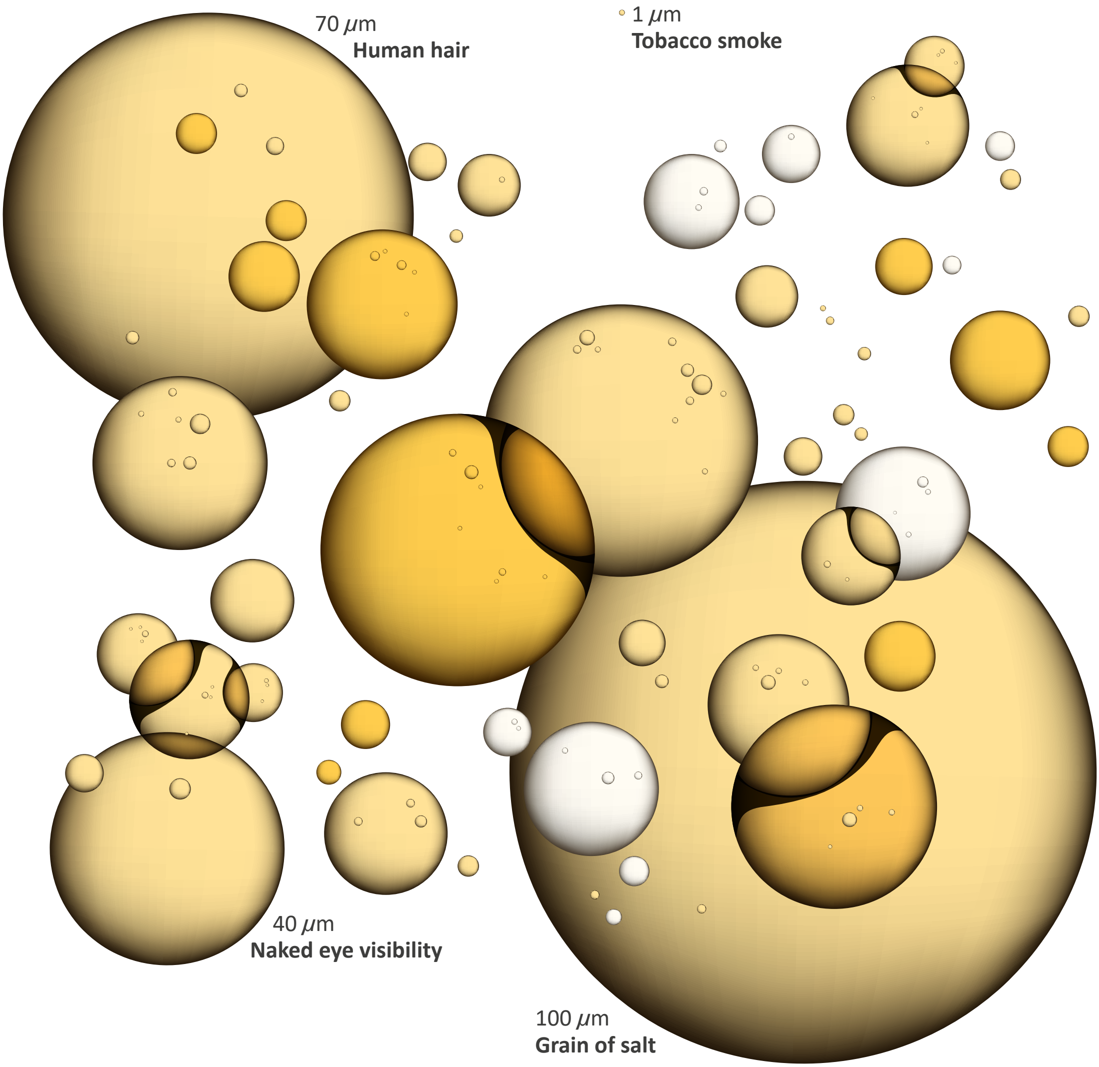
Clean Oil Guide

The importance of oil maintenance



Clean Oil Guide

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Noria Corporation Inc.
Lars Arvidsson, "Chemistry in electrical apparatuses"
Västeras PetroleumKemi AB
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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 65 years with oil maintenance within various types of 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.

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Oil Contamination Control

The best way to control the oil contamination is to stop the contaminants from entering the system in the first place. This entails making sure that all machine components are clean when installed and that the oil systems are thoroughly flushed before taken into operation. Furthermore the oil system should be as well sealed from the environment as possible with intact seals and gaskets as well as high quality tank breathers including fine particle and moisture retention (desiccant and/or bladder type breathers).

The oil should be pre-filtered before coming in contact with any machine component preferably by continuous filtration in the lube room / storage area or at least when transferred to the machines in operation.

Good oil contamination control also includes maintenance procedures for topping up with oil, replacing parts, taking oil samples etc.

Wear in oil systems

Any machine using oil for power transmission, lubrication or combustion will be affected by the condition of the oil. The oil comes into contact with all components in the system and should be considered very important – as blood is important in the human body.

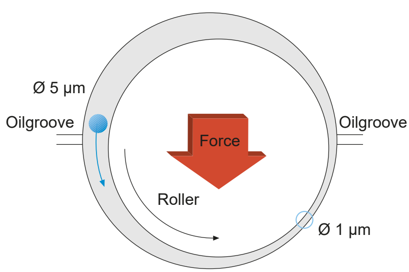


Figure 1: Lubricating a journal bearing
Source: Västeras PetroleumKemi AB

Particle Contamination

Solid particles account for the majority of all failures in an oil system.
The most harmful are clearance size particles of similar size or slightly bigger than the dynamic tolerance between the moving parts in the oil system *(figure 1, on page 7).*
Dynamic tolerances in an oil system are extremely fine.
Figure 2 indicates the finest tolerance found in different types of components.

Dynamic oil film

Component	Oil film thickness in micron (μm)
Journal, slide and sleeve bearings	0.5-100
Hydraulic cylinders	5-50
Engines, ring/cylinder	0.3-7
Servo and proportional valves	1-3
Gear pumps	0.5-5
Piston pumps	0.5-5
Rolling element bearings / ball bearings	0.1-3
Gears	0.1-1
Dynamic seals	0.05-0.5

Figure 2: Dynamic oil film
Source: Noria Corporation

1 µm = 1/1000 mm or same size as tobacco smoke.

When tiny abrasive particles such as sand and dust get into the oil system they flow with the oil into critical machine components and are wedged in the fine clearances. This leads to micro cracks being initiated in the surface of e.g. a ball bearing. The load and stress cycles will spread subsurface cracks resulting in degradation of the metal and releasing large spalls *(figure 3, on page 9).*

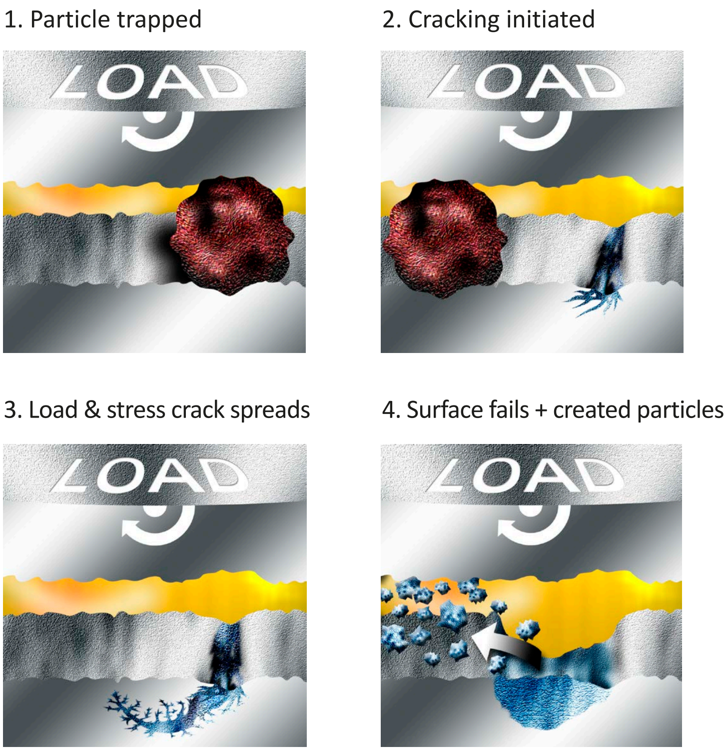


Figure 3: Fatigue Wear

Excessive amounts of particles stresses the additive package in the oil. The detergents and dispersants may get depleted if the particle contamination is not taken under control.

How clean the oil needs to be in terms of particle contamination depends on how sensitive the machine components are and how high the penalty for a failure is, i.e. involved costs for replacement parts, downtime cost, safety liability etc.

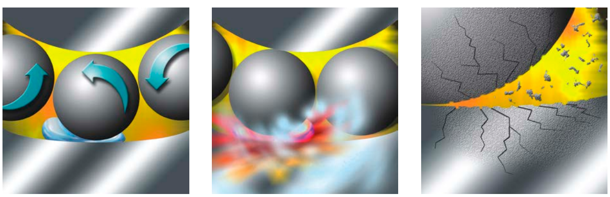
Recommendations for targeting the required oil cleanliness, see page 25.

Water Contamination

Water accounts for a major part of mechanical failures. In some heavily water contaminated oil systems e.g. in the paper industry, water is the predominant cause of failing components.
Water reduces the lubricity of the oil, due to the lower viscosity and poor load capacity of water. When water is exposed to the high pressures found in load zones in e.g. bearings and gears, the water droplets collapse (implode). The resulting micro-jets create micro-pitting in metal surfaces and can even result in metal-to-metal contact when water vapor pushes the oil away momentarily.
Free hydrogen ions in the water can further worsen the situation, since they migrate into machine components making steel brittle and prone to crack.
Water also results in corrosion and erosion leading to pitting damage.

Furthermore, water acts as a catalyst for oil degradation, speeding up the oils tendency to oxidize and form resins, sludge and varnish.

Figure 4: Cavitation and pitting



Cavitation & pitting
Occurs in areas where water is present and oil is compressed; the water implodes, causing the metal surfaces to crack and release more particles.

Water can be found in oil as:

- **Dissolved water:**
  water molecules dispersed one-by-one throughout the oil; like humidity in air.

- **Emulsified water:**
  microscopic globules of water dispersed in stable suspension in the oil; like fog in the air.

- **Free water:**
  water that readily settles to tank/sump bottom; like rain.

The states of water in oil changes depending on the base oil type, additives, pressure and temperature. When the state of water changes from emulsions to free water we have passed the **100 percent relative humidity (100% RH)**, which the oil is able to hold at a given temperature and pressure (depending on oil type down to 60% RH).

A mineral based hydraulic oil will typically have a saturation point (100% RH) around 150 ppm water in oil at 20°C. But this oil may dissolve up to 500 ppm of water at 60°C – still given at 100 percent relative humidity. Therefore 50% RH may correspond to around 250 ppm at 60°C.

Other oil types will have different saturation points, with SAE engine oils as the highest, holding up to a few thousands of ppm water in solution. Furthermore SAE engine oils will create mainly emulsions of water and rarely free any water.

Even water in solution can cause damage to the oil and machine components, so every reasonable effort should be made to keep water in oil levels as low as possible. It is recommended to maintain water below 60% of saturation levels in all machineries.

Removing water can extent life of bearings, pumps, valves, injectors, etc. *(see figure 29 in appendix, page 46).*

Unfortunately many oil analysis reports state water content very inaccurately as “<0.1%”, which means less than 1000 ppm. To know the total water content ask for a Karl Fisher Titration test, *see more on page 26.*

Water should not be found as emulsified or free water in oil

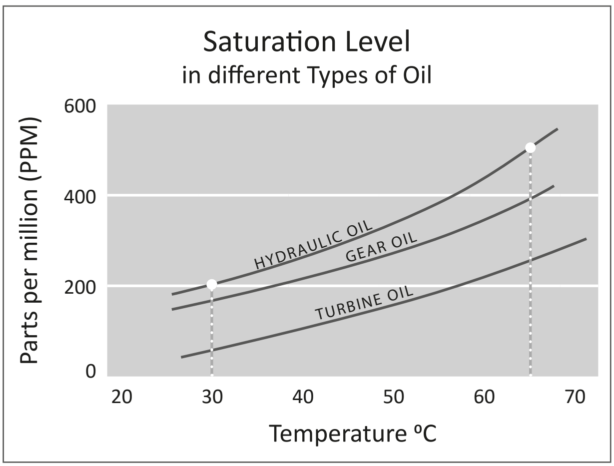


Figure 5:
Saturation levels in different oil types, Source: MP Filtri

Examples:
Hydraulic oil @ 30ºC = 200 PPM = 100% saturation
Hydraulic oil @ 65ºC = 500 PPM = 100% saturation

Oil Degradation

Oxidation
Sludge
Varnish

Oil degradation products or soft contaminants are a widespread problem in most industries. They are precursors of deposits often referred to as varnish which are known to cause problems in both hydraulic and lube oil systems.
When oil degrades due to elevated temperatures, water or chemical contamination e.g. copper, the composition and functional properties of the oil are changed, resulting in the following products being formed:

- Acidity in oil
- Polymerized compounds which are dissolved in warm oil (referred to as sludge or resins)
- Varnish precipitating out as deposits on colder machine components

Varnish products are forming a sticky layer on metal surfaces and will easily blog fine tolerances, making e.g. directional control valves seize. Hard particles of all sizes get caught in the sticky layer, creating a sandpaper like, grinding surface which radically speeds up machine wear.
Further consequences of varnish can be ineffective oil coolers, clogged oil passes or inline pressure filters, poor lubrication of bearings etc.

Figure 6: Varnish on valve plunger

Whether oil degradation products will cause problems in a specific oil system depends on how sensitive the machine components are.

Sludge and varnish can be removed from oil – *please see separate section "Cleaning methods for oil" at page 32.*

Acidity Contamination

Acidity can be found in oil as by-products of oil degradation, combustion of gas or fuel, hydrolysis of Ester-based fluids etc. The amount of acidity in oil should be limited, since acidity will cause chemical corrosion of machine components and shorten the lifetime of the oil, just to mention a few of the unwanted effects.

Acid number, also referred to as AN or TAN, is measured by titration with a strong base/alkaline and given in amount of potassium hydroxide in milligrams required to neutralize the acidity in one gram of oil (mg KOH/g). *See more on page 27.*

Acid numbers should not be allowed to increase more than +0.5 AN higher than that of new oil, and if +1 AN is spotted immediate action is required (i.e. if new oil has 0.5 AN, then 1.0 AN is alert and 1.5 AN is alarm value).

Acidity can be neutralized or removed from oil in different ways. The obvious is to use the alkalinity of the oil to neutralize incoming acidity. This is done in gas and diesel engine lube oil utilizing high base numbers (BN or TBN). The rule of thumb is to replace the lube oil if the BN falls below 30% of that of the new lube oil.

Acidity formed by hydrolysis in Ester-based fluids (HFD fluids) used in e.g. turbine control systems, can cause much harm. Acid numbers twenty times higher than that of new oil, which have been seen, result in severe acidity corrosion of system components. In such fluids the acid number can be lowered and maintained using a neutralizing catalyst such as Ion exchange resin, Fullers earth or Aluminum Oxides. C.C.JENSEN has such ion exchange medium in combination fine filters in the portfolio.

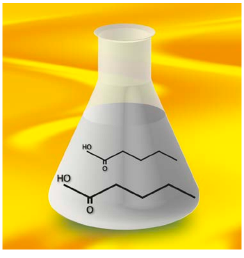


Figure 7:
Oil with high AN/TAN has poor lifetime

Oil Sampling

For representative samples: Sample during **operation conditions** (temperature, load, etc.)

The purpose of oil sampling is to utilize the oil as a messenger telling how the machine is doing. This can prompt pro-active actions in order 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 indications 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 8, preferably derive the oil from a upwards pointing pipe or bend with turbulent flow to produce a representative sample. Sampling points fitted on the lower perimetre of a pipe tend to allow depositing of particles in the sampling valve.

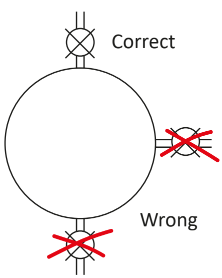


Figure 8: Pipe cross section with sampling valves
Source: Västeras PetroleumKemi AB

The best place to sample in order to see how machine components are doing, is downstream from the machine before any filtration and before the oil is returned to the system tank. This will show the undiluted result of any wear being created in the machine.
The best guarantee of clean oil in the system is to sample from the most contaminated part of the oil system – the bottom drain of the system tank.
This bottom drain is typically where the offline/kidney lube filtration system is connected, so a satisfying oil analysis result taken from between the pump and the filter housing of an offline filter, is the best guarantee that the oil and the system is clean.

2 Oil sampling

If no offline 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 18).*

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

<u>To take an oil sample, the following is required:</u>

- a certified particle free glass or hard plastic bottle (100-200 mL)
- a cloth
- an open oil container of approx. four litre (one US gallon)

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

Steps for oil sampling

Ensure the oil system is under stable operation condition

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 while keeping the cap in your hand to avoid contaminating it
5. Place the bottle under the oil flow **without touching the sampling valve or the drain pipe**
6. Fill the bottle to approximately 80% full.
7. Place the cap on the bottle immediately after taking the sample.
8. Close the sampling valve.
9. Fill in label and stick it onto the sampling bottle.
10. Pack the sampling bottle in plastic bag and cardboard container, and send via mail or courier.

All samples must be clearly marked with number, place of sampling, date and oil type/make *(see example at page 17)*

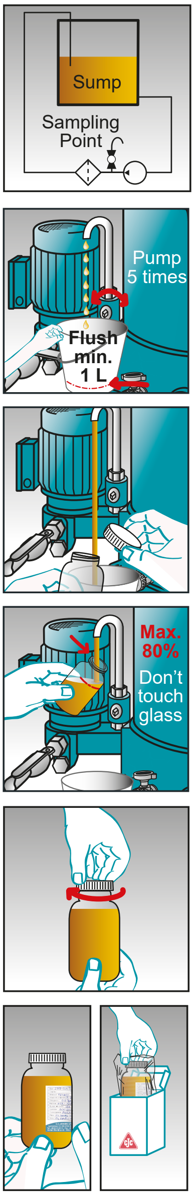
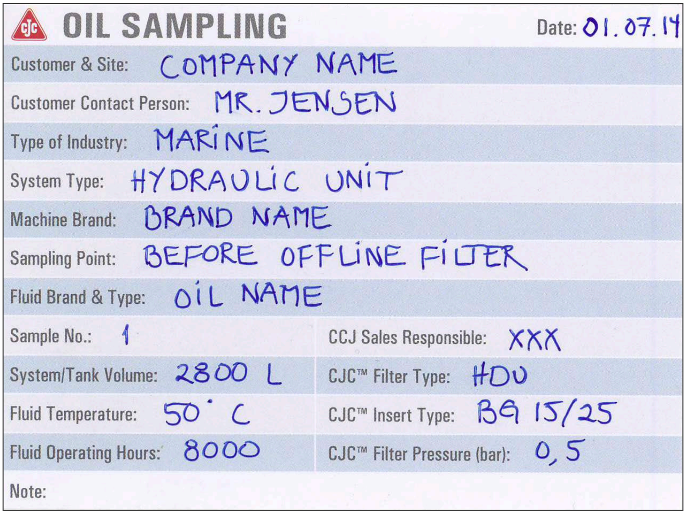


Figure 9:
Oil sampling between the pump and offline oil filter

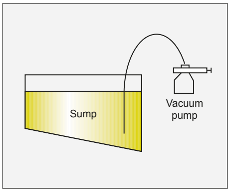


OIL SAMPLING		Date: 01.07.14	
Customer & Site:	COMPANY NAME		
Customer Contact Person:	MR. JENSEN		
Type of Industry:	MARINE		
System Type:	HYDRAULIC UNIT		
Machine Brand:	BRAND NAME		
Sampling Point:	BEFORE OFFLINE FILTER		
Fluid Brand & Type:	OIL NAME		
Sample No.:	1	CCJ Sales Responsible:	XXX
System/Tank Volume:	2800 L	CJC™ Filter Type:	HDU
Fluid Temperature:	50° C	CJC™ Insert Type:	BG 15/25
Fluid Operating Hours:	8000	CJC™ Filter Pressure (bar):	0,5
Note:			

Figure 10: CJC® Oil Sampling Label

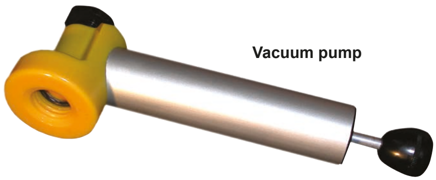
Remember that you can
never make a sample any better / cleaner,
than the oil in the system,
but it is easy to make it worse!

2 Oil sampling



How to take an oil sample - using a vacuum pump

Follow the instructions that came with the pump kit.
The illustrations below show the CJC® Oil Sampling Kit.



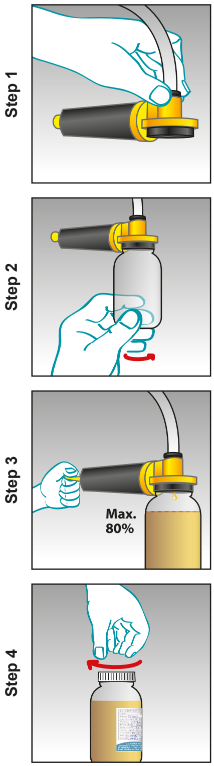


Figure 11: Oil sampling with a vacuum pump

Steps for oil sampling

1. Cut a suitable piece of tube off the roll. **Use new tube every time.** Push the tube into the pump head. Always flush tube with 2 L oil before taking the sample
2. Fit the bottle by screwing it unto the pump head
3. Create a vacuum in the bottle by a few pump strokes, and fill the bottle to approximately 80%
4. Close the lid

Lower the free end of the plastic tube to 10 cm (4 inches) above the lowest part of the tank, in the center of the tank.

Be careful not to let the tube touch the walls or the bottom of the reservoir.
Strapping the sample tube to a rod may help to position the tube. Utilizing a fixed pitot tube installed one third above the tank bottom can also be recommended.

When you have sealed the bottle, make sure that **the label is filled in with all the information** as *per example on page 17.*

Analysis Reports

How much 'life' remains in an oil can be seen by looking at the base oil and additive package during an oil analysis. As a rule of thumb, the additive level in used oil has to be at least 70% of the additive level of new oil (Ref. Noria Corporation). It is therefore vital to sample every incoming oil drum/batch to establish the base line. This will also help to prevent a faulty oil batch being used.
Determining whether to replace oil on the basis of time or operation hours is expensive and unnecessary. Basing oil changes on condition is best – and this is where oil analysis can help.

A good oil analysis report will answer key questions:

- Is the oil suitable for further use? That is, are base oil properties and additives still intact?
- What is the condition of the machine? Has a critical wear situation developed?
- What level of contaminants is evident? Are seals, breathers and filters operating effectively?
- Is oil degradation speeding up? Could a severe varnish problem occur soon?

Figure 12:
Degraded hydraulic oil compared to new oil
Source: C.C.JENSEN A/S

At a minimum, an oil analysis should include:

- Viscosity
- Particle counts
- Moisture/water content in ppm
- Acidity level
- Element analysis (wear and additive level)

It is recommended that the analyses are performed by an independent laboratory with expert knowledge of lubricants as well as the specific application the oil is used for.

Other analysis may also be important, depending on the application. In oil systems prone to varnish problems (e.g., gas turbines and hydraulic control systems), a varnish potential test is recommended.

Diesel engine lube oils require testing for fuel dilution, soot, base number (BN), and so on. Different applications will demand different types of oil analyses. This booklet will focus on the five analyses performed most frequently.

Analysis methods and frequencies

Before establishing a trend, it is important to have a baseline sample of the fresh new oil. This will be used as reference for later comparison e.g. verifying if the additive package is still intact.

In the implementation phase of a condition monitoring system, analyses must be made frequently, at least every three months, but even better once per month in order to establish a trend. A useful trend consists of minimum of five progressive samples taking from the same oil system under the same operating conditions.

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 cleanliness code and oil analysis results.

Viscosity

Viscosity is the single most important property of a lubricant. It separates machine surfaces under load, rotation and other stress factors. Changes in viscosity as small as 15% in either direction can cause malfunction and severe machine wear.

A viscosity measurement is performed at 40°C unless other requests have been made. Engine lube oils are often tested at 100°C. As viscosity varies with temperature, the temperature at which the viscosity is measured should always be reported.

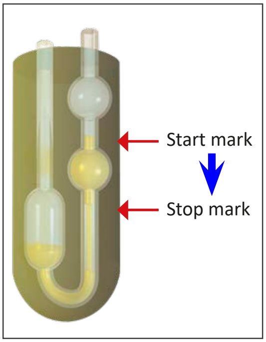


Figure 13: Viscometer measures kinematic viscosity (cSt)

Absolute/Dynamic viscosity (cP) is measured as the resistance measured when a spindle is stirred in the oil in a fluid container (heated to 40°C or 100°C). Absolute/Dynamic viscosity in cP is found after 5 minutes at the selected speed and temperature.

Kinematic viscosity (cSt) can be calculated by dividing dynamic viscosity with the density of the oil. Kinematic viscosity can also be measured by using a "U shaped" calibrated glass tube – a viscometer.

Note that, according to DIN 51519, the viscosity may deviate by 10%; that is, ISO VG 320 may be in the range 288-352 cSt.

For viscosity index, Kinematic viscosity at 40°C and 100°C is plotted into ASTM Standard Viscosity/Temperature Charts for Liquid Petroleum Products (ASTM D 341).

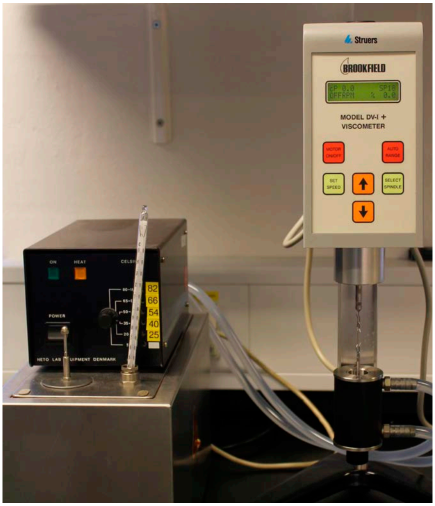


Figure 14: Equipment to test dynamic viscosity (cP)

Particle Counting

Since particle contamination of oil is one of the main reasons for a machine to break down, monitoring the level of hard contaminants is vital. The ISO 4406/2017 method for coding the level of contamination of solid particles is a classification system that converts a given particle count into an ISO class. It is not a test method.

The test methods used most frequently for counting particles are:

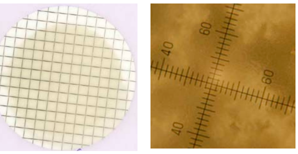
Automatic particle count (according to ISO 11500)
The contamination level of a liquid sample is determined by automatic particle counting, using the light extinction principle.

Automatic particle counters: **≥4, ≥6 and ≥14 µm**
(some types also larger micron sizes)

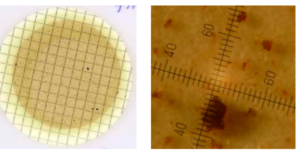
Manual particle count (according to ISO 4407)
Particles are counted manually with the use of membranes (pore size max 1,5 micron) and an optical microscope.

Particle sizes using manual counting: **≥2, ≥ 5 and ≥ 15 µm**

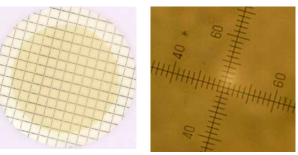
According to ISO 4407, counts at 5 and 15 µm are equivalent to 6 and 14 µm when using an automatic particle counter calibrated in accordance with ISO 11171.



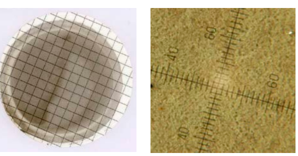
ISO 11/10/6



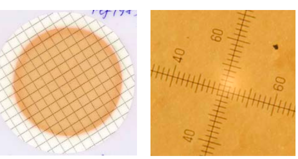
ISO 18/17/15



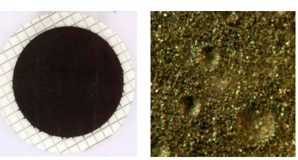
ISO 13/12/7



ISO 20/18/13



ISO 15/13/8



ISO 24/23/20

Figure 15: Test membranes and microscopic photographs of various contamination levels

ISO Classification Table

A typical sample from new bulk oil contains in every 100 mL of oil:

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

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

Some laboratories give the particle counting per millilitre in stead of per 100 millilitre (mostly USA).

Note: The ISO class is a logarithmic scale; that is, a double in particle counts leads the ISO class to increase by one.

Number of particles per 100 ml fluid after their size ranges		
More than	**Till**	**ISO 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

Figure 16: Contamination classes according to the ISO 4406/2017 standard

AS / NAS Classes

The American standard NAS 1638 has been changed to AS4059 (issue E) in 2001, which is considered to be a significant advance because it presents data in terms of cumulative counts (>X µm) rather than interval mode (X-Y µm), introduces a cleaner (Class 000,) and extends the size range to smaller sizes (>4 µm) for increased sensitivity.

Correlation table to compare ISO with AS/NAS

Size	Maximum contamination limits (Particles/100 mL)				
ISO 4402 *	>1 µm	>5 µm	>15 µm	>25 µm	>50 µm
ISO 11171 **	>4 µm(c)	>6 µm(c)	>14 µm(c)	>21 µm(c)	>38 µm(c)
SIze Code	A	B	C	D	E
Class 000	195	76	14	3	1
Class 00	390	152	27	5	1
Class 0	780	304	54	10	2
Class 1	1,560	609	109	20	4
Class 2	3,120	1,220	217	39	7
Class 3	6,520	2,430	432	76	13
Class 4	12,500	4,860	864	152	26
Class 5	25,000	9,730	1,730	306	53
Class 6	50,000	19,500	3,460	612	106
Class 7	100,000	38,900	6,920	1,220	212
Class 8	200,000	77,900	13,900	2,450	424
Class 9	400,000	156,000	27,700	4,900	848
Class 10	800,000	311,000	55,400	9,800	1,700
Class 11	1,600,000	623,000	111,000	19,600	3,390
Class 12	3,200,000	1,250,000	222,000	39,200	6,780

* *ISO 4402 or Optical Microscope.*
Particle size based on longest dimension
** *ISO 11171 or Electron Microscope.*
Particle size based on projected area equivalent diameter

Figure 17: AS4059 Cleanliness Coding System compared to ISO

Evaluation of particle count and machine lifetime

In figure 28, on page 46 you can find the Life Extension Table. The table describes the expected increase in lifetime when the oil cleanliness is improved. Each quadrant represents a machine type:

- top left quadrant is for hydraulic components and diesel engines
- top right quadrant is for rolling element bearings
- lower left quadrant is for machines incorporating journal bearings e.g. turbines and turbos
- lower right quadrant is for gear boxes and other components not covered by other quadrants

If, for example, the current oil cleanliness in a gear box is found to be ISO 22/20/17 and the oil is cleaned to an ISO cleanliness code of 16/14/11, it can be expected that the **lifetime of the gear is prolonged 2.5 times**. For every oil-filled system, a cleanliness goal should be specified. This is the basic requirement to ensure reliability at the lowest possible price.

Figure 18 show the recommended ISO cleanliness levels in oil and fuel systems. New oil is typical contaminated with particles to ISO 19/17/14.

ISO Code	NAS 1638	Description	Suitable for	Dirt/year
ISO 14/12/10	NAS 3	Very clean oil	All oil systems	7.5 kg *
ISO 16/14/11	NAS 5	Clean oil	Servo & high pressure hydraulics	17 kg *
ISO 17/15/12	NAS 6	Light contaminated oil	Standard hydraulic & lube oil systems	36 kg *
ISO 19/17/14	NAS 8	New oil	Medium to low pressure systems	144 kg *
ISO 22/20/17	NAS 11	Very contaminated oil	Not suitable for oil systems	> 589 kg *

*Figure 18: Contamination guide for **oil** and **fuel** systems*

*) The amount of dirt passing the pump per year, if the oil passes with a capacity of 200 ltr/min, 18 hours a day, 340 working days per year.

Moisture Level

Most laboratories start with a water screening test called the **crackle test.** Here, a drop of the tested lubricant is applied to a hot plate (160°C). The moisture in the oil will evaporate, causing it to crackle. This test is mainly an indication of water in oil, and no sign of crackles normally means less than 0.1 percent (1000 ppm) water in the tested oil. If the crackle test shows signs of moisture, then a more accurate test method is needed.

Karl Fisher (KF) titration is accurate to below 10 ppm moisture in oil (ASTM D 6304) and is based on a reaction of iodine with water in a Karl Fischer reagent. The iodine is generated electrolytically, at the anode, and reacts with water in the sample. Iodine is consumed as long as water is present, and excess iodine indicates the endpoint of titration. Based on this principle, water can be determined directly by the quantity of electricity required for electrolysis.

Water determination by KF may be volumentric or coulometric, direct or indirect. The result is given in ppm.

Direct KF titration of oils containing high additive levels is not recommended, as these might have side reactions with the KF reagent and thereby give a false indication of increased water content.

The indirect or oven KF method works by passing a stream of dry air through the heated sample. The released moisture is transferred from the oven to the titration chamber.

Figure 19: Equipment used for the indirect Karl Fisher method

Acid Number and Base Number

The **Acid Number (AN/TAN)** is a measurement of the acidic level in industrial lubricants; e.g., hydraulics and gear oils. The AN is determined by titration and is given as the amount of potassium hydroxide (KOH) used to neutralize the acidity in one gram of oil, according to ASTM D 664. The result is given in mg KOH/gram.

Increasing AN often indicates degradation of the oil (varnish). Certain additives like sulphur will give a high initial AN level in the fresh oil; e.g., 1 mg KOH/g. It is therefore important to know the fresh oil baseline to monitor increasing AN in the used oil.

Rule of thumb:
Caution: AN new + 0,5 mg KOH/g
Critical: AN new + 1,0 mg KOH/g

For engine lube oils the **Base Number (BN/TBN)** is measured, because these oils contain additives (detergent/dispersant package) used to neutralize the acidity generated as a by-product of the combustion process; e.g., sulphuric acid.

BN is monitored to ensure that the level of the acidity-neutralizing additives is acceptable. The titration with potassium hydroxide gives a result in mg KOH/gram.

Rule of thumb:
Caution: BN new minus 50 percent
Critical: BN new minus 70 percent

Figure 20:
Equipment for testing acidity

Element Analysis

Atomic Emission Spectroscopy (AES) is used to determine the level of additive elements, wear metals and contamination in lubricant. The trend is of highest importance, so it is vital to have a baseline showing the additive package in the new oil.

How it works:
Superheating the sample turns oil and its elements into 'light-bulbs' which emit atomic light. The light is analyzed to see which wavelengths are present and of which intensity. The wavelengths correspond to a specific element (for example, iron) and the intensity defines the concentration (given in ppm). The concentration of a given element/metal is the total of both very fine particles and chemically dissolved metals in the oil.

Two standard methods are used:

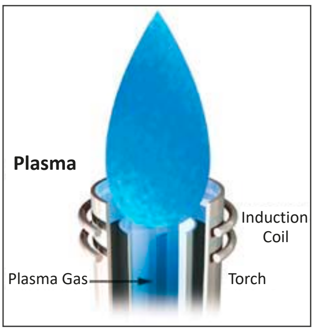


Figure 21: Illustrations show ICP. Source: Noria Corp

Inductively Coupled Plasma (ICP according to ASTM D 5185).

Here the sample is nebulized to form an aerosol. When the aerosol reaches the plasma, the droplets are very small, typically 3-5 microns. Consequently, wear particles larger than 5 microns cannot be detected by this method.

The Rotating Disc Electrode (RDE according to ASTM D 6595).

In this instrument the oil is vaporized and excited using a high-voltage discharge between an electrode and a rotating carbon disc. RDE detects and quantifies elements up to approx. 10 microns in size.

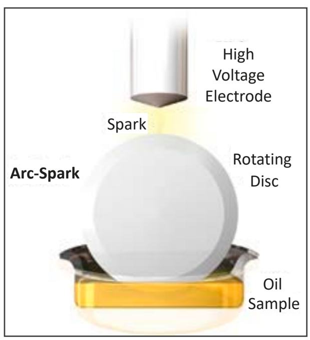


Figure 22: Illustrations show RDE, Source: Noria Corp

AES is one of the most frequently used oil analyses but, because the sample needs to be fully vaporized, the detection of particles larger than 5-10 microns is almost impossible. Wear spalls from heavily loaded gears (adhesive wear) will not be detected unless some other test is performed. Larger wear particles can be monitored by means of particle counts, ferrous density or magnetic indicators in the oil.

Analysis Log Book

Example of hydraulic oil analysis including new oil baseline, caution and critical levels

Oil analysis log book			
Parameter	Baseline	Caution	Critical
Particle count ISO 4406	15/13/10 (pre-filtered)	17/15/12	19/17/15
Viscosity (cSt)	32	low 29 high 35	low 25 high 38
Acid number (AN, mg KOH/g)	0.5	1.0 - 1.5	above 1.5
Moisture (KF in ppm)	100	200 - 300	above 300
Elements (in ppm) Fe	7	10 - 15	above 15
Al	2	20 - 30	above 30
Si	5	10 - 15	above 15
Cu	5	30 - 40	above 40
P	300	220	150 and less
Zn	200	150	100 and less
Oxidation (FTIR)	1	5	above 10
Ferrous Density (PQ, WPC, DR)	-	15	above 20

Figure 23: Example of analysis log book

Varnish Testing

Many types of analysis can indicate degradation of the oil – for example, acid number (AN) and viscosity increase – but at C.C.JENSEN, we have found the following give a very detailed picture of the varnish problem:

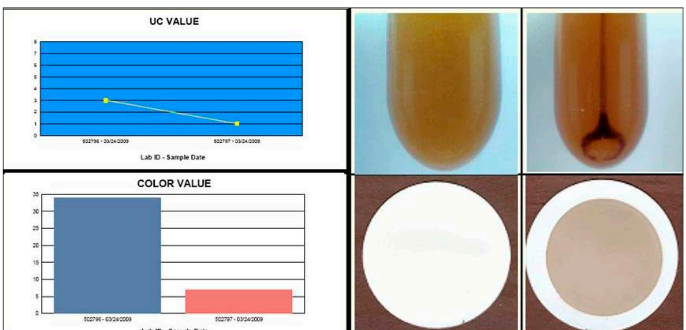
1. A Membrane Patch Colorimetric test (MPC according to ASTM D 7843) shows sludge/resin/varnish present in the oil by discolouration of the white cellulose patch (0.45 micron pore size). This indicates oil degradation products also dissolved in the oil, which may or may not result in varnish on machine components (depending on the oil temperature). The colour of the deposits on the membrane is measured by a spectrophotometer. The darker the colour and the higher the number (typically up to 100), the more the oil is prone to form varnish deposits.
Test MPC is developed for turbine oils, and is not recommended for oils with high particle contamination, as any particles will influence the colour of the membrane and thereby the colour, even though it may not be varnish.

2. Fourier Transform Infrared Spectroscopy (FTIR according to ASTM E 2412). The FTIR spectra is generated by measuring the degree of infrared absorption in the area 4000-500 cm-1 when passing infrared light through an oil sample. It is a cost-effective analysis that detects oil degradation/varnish, as well as other contaminants, such as glycol, fuel, soot, wrong oil type, etc.
Oil degradation products like aldehydes, ketones and carboxylic acidity all contain carbon-oxygen double bonds (carbonyl groups). These carbonyl groups absorb infrared light in the 1740 cm-1 region of the infrared spectra. As degradation increases, the absorbance peak will increase in this region. Deviations are seen between oil types, additives, type of degradation, etc. Thermal breakdown of base oil is not significant at 1740 cm-1; instead, a peak is seen at 1640-1600 cm -1 (nitration peak).

Like most other analyses, FTIR is most valuable if the trend is monitored.

3. Ultra Centrifuge test (UC) uses centrifugal force to extract the sludge and varnish precursors, driving them to the bottom of the test tube. The density/size of the concentrated material is then compared to a visual sediment-rating scale giving a number of 1 – 8 (8 being the worst).

The UC test shows the actual varnish and insoluble contaminants in the oil. Any oil degradation seen in this test will result in varnish as deposits on system components.
The UC test is not recommended for oil highly contaminated with particles, because it masks the result, nor for Ester or Glycol based fluids, since specific gravity plays a role in the UC test.
UC and MPC tests are very useful tools to trigger an action e.g. install a filter or change the oil.



SAMPLE DATE	03/24/2009	03/24/2009
LABID	502797	502796
ULTRA CENTRIFUGE TEST		
UC VALUE	1	3
MEMBRANE PATCH COLORIMETRY		
COLOR VALUE	7	34

Figure 24: UC Analysis and MPC Test Result

Cleaning Methods for Oil

Several oil cleaning methods are available:

Method	Cleaning action
Cellulose based offline filter	Reduces the content of solid particles, water and oil degradation products. Ion exchange medium can be added to reduce acidity
Glass fibre based pressure filter	Reduces the content of solid particles
Electrostatic filter	Reduces the content of solid particles, and oil degradation products
Centrifugal separator	Reduces the content of solid particles with a density higher than that of oil as well as water
Vacuum filter	Reduces the content of air and water

Figure 25: Oil cleaning methods

All the above technologies are commercially available. However the glass fibre based pressure filter and the cellulose based offline filter, are often preferred due to their superior efficiency and economy. Both of these oil filter techniques work best under constant conditions, i.e. steady flow and pressure.

The cellulose based depth filter is often placed in a separate offline circuit also called kidney loop filtration, and with such stable conditions, it retains the majority of contaminants found in the oil. The glass fibre based pressure filter could be installed in an oil cooling circuit or as a full-flow “last chance” filter upstream of the oil system.

Filter types

The best method for capturing and retaining fine particles as well as water and varnish is by installing an offline filter. An offline filter should operate continuously, circulating the oil volume in the system many times per day. With a low pressure and low flow rates a dense filter medium with very fine filtration can be selected (< 3 micron filtration).

The cellulose based offline filter is like a maze where the oil passes through several layers of cellulose. The largest particles are retained on the surface of the filter insert whereas the smaller particles enter the filter insert and are retained within the filter material, this ensures a high dirt holding capacity. This type of

filter can also be installed in a by-pass circuit, throttling the pressure of the system pump. Using a cellulose based offline filter also enables removal of water, by absorption or coalescing, and removal of oil degradation products such as sludge/varnish from the oil.
Varnish can be removed from oil systems through the detergent/dispersant additives in the oil, but the oil needs to be clean from particles, water and sludge before the additives are free to do the varnish cleaning job. Since sludge and varnish precipitate out of cold oil, typically between 10 - 40°C (50 - 100°F), cooling the oil in the offline filtration circuit combined with a cellulose based depth filter is highly effective.

The CJC® Offline Oil Filters removes oil degradation products such as sludge and varnish through polar attraction to the filter medium. A combination of adsorption and absorption fills each cellulose fibre with oil degradation products until the insert is completely saturated. The CJC® Filter Inserts can hold up to 4 kgs (8 lbs) of varnish depending on type.

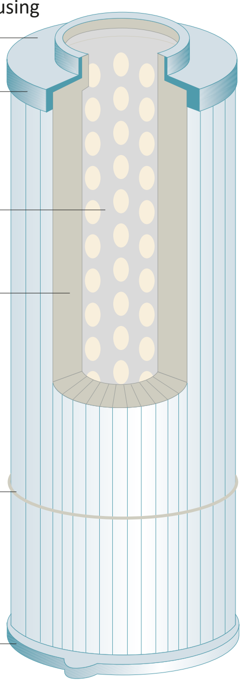
Conventional inline pressure filters are typically glass fibre based, because they need to operate under high pressure and high flow conditions, while creating as little restriction as possible. The filter element is pleated in order to increase the surface area and reduce the pressure drop.

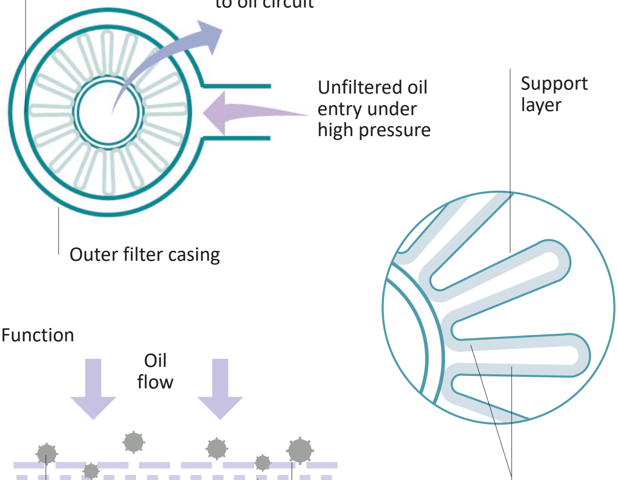
Since they are installed after the main system pump, they often live a tough life with cyclic flows and many stops and starts, which is very harmful for the efficiency of any filter. Capturing and retaining fine silt particles is therefore very difficult, which is why most of these inline filters have a rating of 10 – 30 micron. However, many already captured particles will be released again when the filter is exposed to pressure shocks at stop/start.
The glass fibre based pressure filter is capable of removing solid particles only – and due to the relatively small filter depth and volume, it has a restricted dirt holding capacity.

See illustrations on pages 34-35.

Modern oil systems often combine the two cleaning systems, where the offline filter removes the contamination and the inline pressure filter serves as security or “last chance” filter before critical components.

Glass Fibre Based Pressure Filter



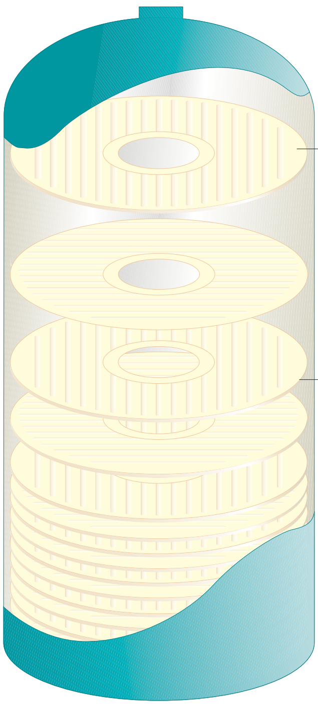


Pressure filters have a limited dirt holding capacity, usually between 1 and 100 grams, which results in filter element replacement at short intervals in order to ensure efficient filtration.

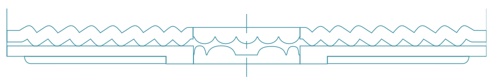
Typical filtration rating on inline pressure filters are 5 – 50 micron.

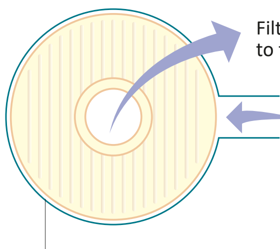
Conventional glass fibre based inline pressure filters do not absorb water, nor retain oil degradation products such as sludge and varnish.

Cellulose Based Offline Filter

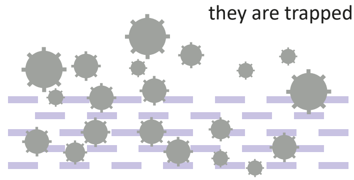


Filter Insert
Made of corrugated wood cellulose discs rotated at 90° to the next and bonded together. This gives a series of connected surfaces with corrugations running north-south and east-west.





Function



The CJC® Offline Oil Filter has a large dirt holding capacity of approximately 4 L solids, up to 2 L of water and 4 L oil degradation products (varnish). The CJC® Offline Oil Filters typically only need replacing every 12 months.

The CJC® Offline Oil Filter will filter effectively down to 3 µm absolute and remove water and oil degradation products (oxidation products, resin, sludge and varnish) from the oil, continuously cleaning machine components and the whole oil system.

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 compared. Operating pressure and concentration of contaminants will affect the retention efficiency of filters with nominal rating.

Absolute filtration ratings describe the pore size, indicating the largest size of particle which can pass through the filter. The filter needs to apply to a standard test method intended for filter usage. The rating of a cellulose based offline filter is often 3 μm absolute or less. The rating of a glass fibre based pressure filter varies according to the requirements of the system component(s) to be protected.

Beta values describe filter efficiencies at given particle sizes. The value is written ßx, where the ”x” represents the particle size in question and ß (”beta”) is the efficiency e.g. ß3 = 200, which means that one out of 200 particles of 3 micron in size will pass through the filter (0.5% passes through and 99.5% are retained in one pass).
In order to find the Beta value a standardized “Multipass test ISO 16889” is used, and the Beta value is calculated by the following formula.

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

This Multipass test is performed under controlled laboratory conditions and does not take into account some of the challenges an inline pressure filter will see in most oil systems, such as air bubbles, vibrations, pressure pulses from stop-start etc.

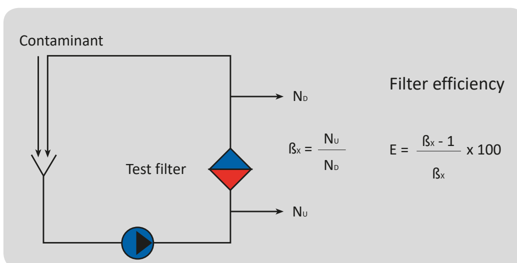


Figure 26: Multipass test
Source: ISO Standards

Dirt holding capacity is the quantity of contamination retained by the filter insert when the saturation pressure is reached. This is measured in weight or volume. How much oil contamination a filter insert is capable of retaining is of highest importance for the cost of operating over a period of time. While most conventional pleated pressure filter inserts can retain less than hundred grams of dirt (<0.2 lbs), they may be fairly inexpensive to replace. However, if the cost of removing 1 kg or pound of oil contamination is calculated, these conventional pressure filter inserts will suddenly appear quite expensive.
A good quality cellulose based offline filter insert can retain up to several kgs/lbs of dirt, so even though the purchase price is higher, the calculated cost for removing one kg or pound of contamination will be considerable lower than that of a pleated pressure filter insert, giving lower lifetime costs.

The cost of removing 1 kg or lbs of dirt

$$\frac{\text{Cost of filter insert in your currency}}{\text{Dirt holding capacity in kg or lbs}} = \text{cost for removing 1 kg or lbs of dirt}$$

	Example 1	Example 2
Filter type	Glass fiber based pressure filter insert	Cellulose based offline filter insert
Cost of element/insert	€ 35 / $ 50	€ 200 / $ 300
Dirt holding capacity	0.085 kg / 0.18 lbs	4 kg / 8 lbs
Cost per kg/lb removed dirt	**€ 412 / $ 278**	**€ 50 / $ 40**

The by-pass valve in filters is a safety device which reduces the pressure when the pressure drop over the filter gets too high. It eliminates the filtration function by by-passing the full flow filter which means the oil flow then completely or partially passes by - and not through - the filter. A leaking by-pass valve has a devastating effect on the filter efficiency value. *(Figure 27)*.

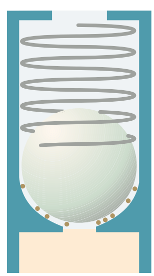


Figure 27: By-pass valve

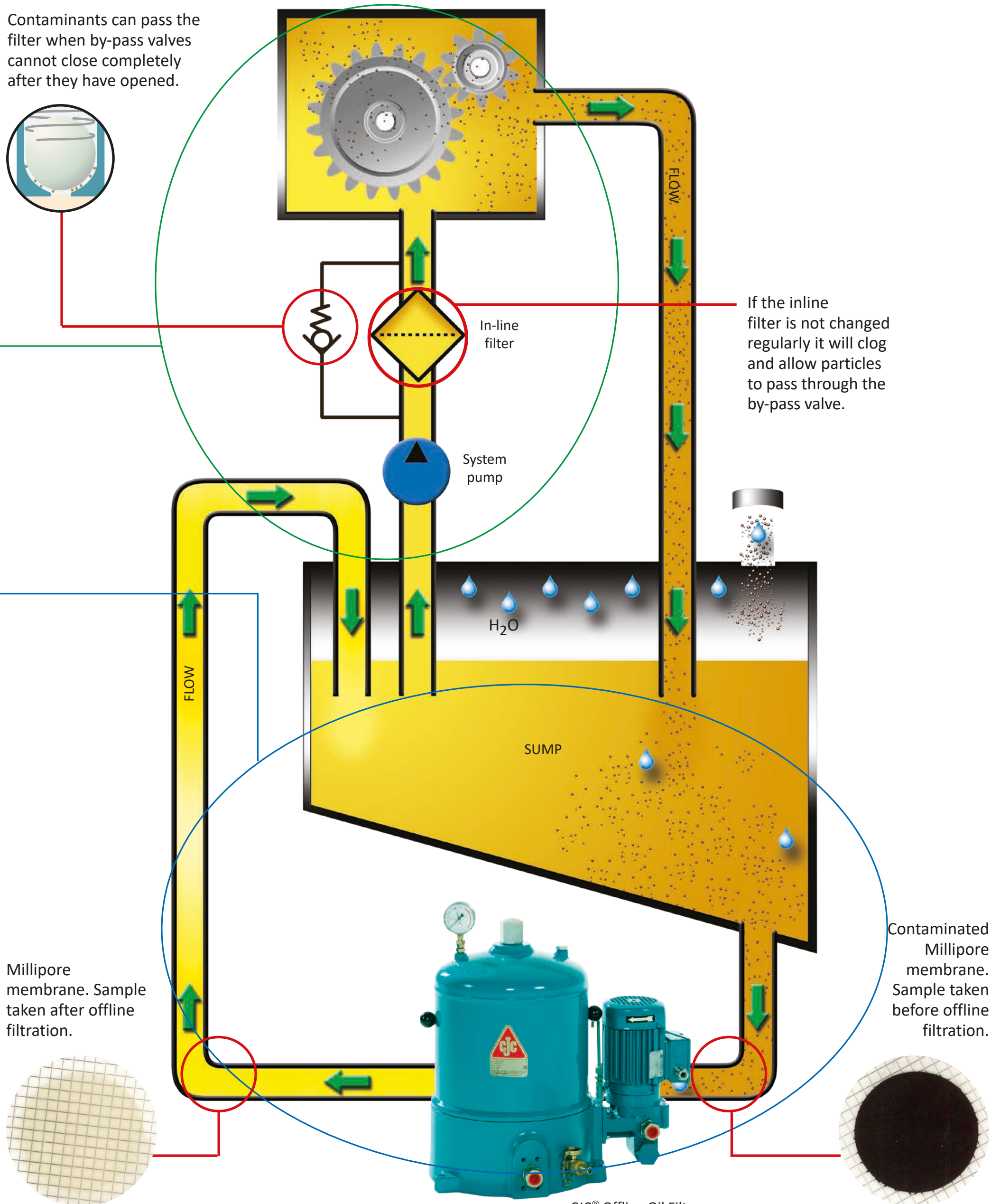
Installation Methods

Full-flow filtration (In-line)

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

Offline filtration

An installation method where the filtration unit operates in a separate kidney loop circuit, enabling the use of dense filter inserts.


Contaminants can pass the filter when by-pass valves cannot close completely after they have opened.
If the inline filter is not changed regularly it will clog and allow particles to pass through the by-pass valve.
In-line filter
System pump
FLOW
FLOW
H_2O
SUMP
Millipore membrane. Sample taken after offline filtration.
Contaminated Millipore membrane. Sample taken before offline filtration.
CJC® Offline Oil 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 lifetime, extended component life, etc.

In most applications the **payback period or the Return Of Investment** for a CJC® Offline Oil Filter is typically from a few weeks up to some month, but rarely more than one year.
In industries where any downtime is very costly e.g. steel production, the payback period can be a few hours. This means that if the improved oil condition leads to e.g. just 3 hours of additional production, the filtration system has paid for itself.
Because the operation cost of the filter solution also plays a role in the total investment, it is relevant to look at how much oil contamination the filter is capable of retaining – the so-called dirt holding capacity.
Most conventional pressure filters can retain less than hundred grams of dirt (less than 0.2 lbs), so they will need to be replaced more often than a good quality cellulose based offline filter capable of retaining several kg or lbs of dirt.
The cost of removing 1 kg (or pound) of dirt from the oil is a good factor for comparing different filter makes and help to find the lowest cost of ownership (the total investment).

See the calculation of the cost for removing 1 lbs dirt on page 37.

Ordering a Filtration System

In the quote for a filtration system from any supplier the following should be included:

- Operational costs of the filter over a period of min. 5 years (power, filter inserts, spares etc.)
- Obtainable fluid system cleanliness level (e.g. ISO 17/15/12 and 200 ppm water)
- Control procedure confirming that the cleanliness level has been achieved (e.g. oil samples)

Offline oil filter sizing

When sizing an offline oil filter the following basic information about the oil system should be specified:

- Oil volume in the system (tank volume)
- Oil type (ISO VG)
- Oil temperature: Normal operation and minimum temperatures (ambient)
- Oil contamination problem:
    - particles
    - oil degradation products, sludge and varnish
    - water (ingress or accumulated)
- Type of application (indoor/clean, outdoor/dirty, severe ingress etc.)
- Machine operating hours per day
- Available power supply

This information will help your local distributor to size the correct CJC® Oil Filter for your oil system.

Aside from continuous filtration of the oil in machines, drums or bulk tanks, the CJC® Offline Oil Filters can also be utilized for filling and topping up with oil, thus ensuring that only clean oil enters the system.

CJC® Oil Maintenance Systems

CJC® Fine Filter

- Dry oil with limited water content (accumulated over time)
- Hydraulic, lube and gear oils – also EAL, Glycols or Ester based fluids
- Retains particles and varnish
- Water removal by absorption (free, emulsified and some dissolved water)
- Reduce acidity level utilizing ion exchange inserts

CJC® Filter Separator

- Water contaminated oil and diesel
- Hydraulic, lube and gear oils – up to ISO VG 150
- Retains particles and varnish
- Free water is removed by separation (coalescing)
- Suitable for oil with good demulsibility (not engine oil, Ester based fluids etc.)

CJC® Desorbers

- Water contaminated oil – even with strong emulsions
- Hydraulic, lube and gear oils – up to ISO VG 1000 (depending on Desorber type)
- Removes both free, emulsified and dissolved water
- Suitable for most oils even engine oil, paper machine oil, EAL, etc.

CJC® Desorbers do not retain particles and varnish, thus a separate CJC® Fine Filter is recommended.

CJC® Varnish Removal Unit

- Dry oil with limited water content
- Retains varnish very effectively
- Suitable for systems with servere varnish production e.g. gas turbines

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 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 sealed as much as possible. All permanent openings should be equipped with venting filters (preferably desiccant breathers). 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. (this can be avoided by installing CJC® Offline Oil Filters)
- 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 high quality control and repeatability

Buying Oil Recommendations

When buying oil in bulk, buyers have a right to set specific certified requirements to ensure the quality.
Below find some examples of requirements and test for the quality of the oil, emphasizing oil cleanliness.

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 first batch. Samples should be marked with the trademark, batch 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 of new oil

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
- Total Acid Number of finished product
- Air bubble separation time
- Contaminants, gravimetric or ISO cleanliness code

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.

Appendix

Life Extension Table - Cleanliness Level, ISO Codes

	21/19/16		20/18/15		19/17/14		18/16/13		17/15/12		16/14/11		15/13/10		14/12/9		13/11/8		12/10/7	
24/22/19	2	1.6	3	2	4	2.5	6	3	7	3.5	8	4	>10	5	>10	6	>10	7	>10	>10
	1.8	1.3	2.3	1.7	3	2	3.5	2.5	4.5	3	5.5	3.5	7	4	8	5	10	5.5	>10	8.5
23/21/18	1.5	1.5	2	1.7	3	2	4	2.5	5	3	7	3.5	9	4	>10	5	>10	7	>10	10
	1.5	1.3	1.8	1.4	2.2	1.6	3	2	3.5	2.5	4.5	3	5	3.5	7	4	9	5.5	10	8
22/20/17	1.3	1.2	1.6	1.5	2	1.7	3	2	4	2.5	5	3	7	4	9	5	>10	7	>10	9
	1.2	1.05	1.5	1.3	1.8	1.4	2.3	1.7	3	2	3.5	2.5	5	3	6	4	8	5.5	10	7
21/19/16			1.3	1.2	1.6	1.5	2	1.7	3	2	4	2.5	5	3	7	4	9	6	>10	8
			1.2	1.1	1.5	1.3	1.8	1.5	2.2	1.7	3	2	3.5	2.5	5	3.5	7	4.5	9	6
20/18/15					1.3	1.2	1.6	1.5	2	1.7	3	2	4	2.5	5	3	7	4.6	>10	6
					1.2	1.1	1.5	1.3	1.8	1.5	2.3	1.7	3	2	3.5	2.5	5.5	3.7	8	5
19/17/14							1.3	1.2	1.6	1.5	2	1.7	3	2	4	2.5	6	3	8	5
							1.2	1.1	1.5	1.3	1.8	1.5	2.3	1.7	3	2	4	2.5	6	3.5
18/16/13									1.3	1.2	1.6	1.5	2	1.7	3	2	4	3.5	6	4
									1.2	1.1	1.5	1.3	1.8	1.5	2.3	1.8	3.7	3	4.5	3.5
17/15/12											1.3	1.2	1.6	1.5	2	1.7	3	2	4	2.5
											1.2	1.1	1.5	1.4	1.8	1.5	2.3	1.8	3	2.2
16/14/11													1.3	1.3	1.6	1.6	2	1.8	3	2
													1.3	1.2	1.6	1.4	1.9	1.5	2.3	1.8
15/13/10															1.4	1.2	1.8	1.5	2.5	1.8
															1.2	1.1	1.6	1.3	2	1.6

Hydraulics and Diesel Engines	Rolling Element Bearings
Journal Bearings and Turbo Machinery	**Gearboxes and others**

Figure 28: Life Extension Table, cleanliness level - See the example on page 25 *Source: Noria Corp.*

LEM - Moisture Level

Current moisture level, ppm	Life Extension Factor								
	2	3	4	5	6	7	8	9	10
50,000	12,500	6,500	4,500	3,125	2,500	2,000	1,500	1,000	782
25,000	6,250	3,250	2,250	1,563	1,250	1,000	750	500	391
10,000	2,500	1,300	900	625	500	400	300	200	156
5,000	1,250	650	450	313	250	200	150	100	78
2,500	625	325	225	156	125	100	75	50	39
1,000	250	130	90	63	50	40	30	20	16
500	125	65	45	31	25	20	15	10	8
260	63	33	23	16	13	10	8	5	4
100	25	13	9	6	5	4	3	2	2

1% water = 10,000 ppm. | Estimated life extension for mechanical systems utilizing mineral-based fluids

Example: By reducing average fluid moisture levels from 2,500 ppm to 156 ppm, machine life (MTBF) is extended by a factor of 5

Figure 29: Life Extension Method, moisture level *Source: Noria Corp.*

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