FRIESS GmbH

Maintenance of hydraulic oil

Contents

1. Oil quality and oil maintenance

The hydraulic oil has many different tasks:

1. transmission of force
2. lubrication
3. corrosion protection
4. heat transfer

Depending on the application, hydraulic liquids are based on mineral oils, synthetic ester, water and oil emulsions or biologic degradable liquids. For standard applications like injection moulding machines, turning lathes, presses or production lines, hydraulic liquids based on mineral oil are used. Mineral oils offer perfect lubrication, high efficiency for power transmission and a very good protection against corrosion. In addition mineral oil has a long lifetime and is available at acceptable prices. The main disadvantage is, that mineral oil is not biologic degradable and it is harmful to water.

1.1. Important properties of hydraulic oil

The quality of the hydraulic oil is very important for the perfect function of a hydraulic system. There are many parameters, that have to be watched when you want to check a hydraulic oil.
Some of them are:

1. Viscosity
2. Base number
3. Additives
4. Air release property
5. Dirt particles

These are only some of the most important parameters that have to be checked when judging a hydraulic oil. In addition there are many other criteria that have to be checked. For example: demulsification, forming of foam, aggressivity against seals, protection against wear.

Here are short descriptions of the 5 most important parameters:

1.1.1 Viscosity

The viscosity is a dimension for the inner friction of a liquid. When testing hydraulic oils normally the kinematic viscosity will be tested.

In most injections moulding machines, hydraulic oils ISO VG 46 or ISO VG 68 are used. In case that the temperature in the hydraulic system does not change, a change of viscosity has many impacts.

In case that the viscosity is lower than it should be, it may happen that the lubrication film will be destroyed. This may cause serious damage at the hydraulic components. In addition it will cause inner and outer leaks.

In case that the viscosity is too high (for example because of forming of oxydation products) control valves may work slower or slip stick will happen. For these reasons the viscosity is a very important parameter in order to judge hydraulic oil.

1.1.2 Base number (TBN = Total base number)

The base number means the amount of KOH (potassium hydroxide [mg]) which is necessary in order to neutralize the acids which are in one g of oil. The higher the base number is the higher is the amount of acids. Acids in the oil will reduce the corrosion protection and are an indicator for oxydation process in the oil. In case that the base number is too high, chemical decomposition of the oil has started. In order to judge the base number of an used oil, you have to know the base number of the new oil. It's important to know the difference between the base number of the used oil compared to the base number of the new oil. The base number of a new oil may change between 0,1 mg and 1,5 mg KOH/g oil. The base number of the new oil is not important for the quality of the new oil.

1.1.3 Additives

Additives are chemicals which are added to the hydraulic oil in order to optimize the properties of the new oil for special applications. Hydraulic oils have additives, that improve the lubrication, the corrosion protection and reduce the building of foam and will improve the stability against oxidation.

Normal hydraulic systems use hydraulic oil type HLP which contains additives in order to improve corrosion protection, this stability against oxidation and the better lubrication.

In order to protect the hydraulic components against corrosion, hydraulic oil contain corrosion protection additives, which prevent against rust by building a film on a surface of the metal. In addition neutralizers are used in order to neutralize acids. (4)

In order to protect the oil against oxydation process, anti oxydation additives are added. In order to prevent against wear, the manufacturers add high pressure additives, in example organic phosphate (cls or N(3))

1.1.4 Air release properties

The DIN standard 51524 and 51525 define the minimum air release properties of the hydraulic oil. In case that the oil has a bad air release property, the air will remain in the oil. This may cause hydraulic failure as follows.

1. The oil will become compressible
2. Cavitation will happen in pumps and valves
3. The aging stability of the oil will be reduced and the lifetime of the oil will be reduced. Foam will be produced (5)

Air release properties of typical hydraulic oils
(Time [min] for air release down to 0,2 Vo% in min 50 °C)

ISO-VG class	HLP	HLPD
32	3	6
46	5	9
68	7-9	12-15

1.1.5 Dirt particles in the oil and analyse techniques

Dirt particles in the oil and different methods for analysis. The pollution in hydraulic oil maybe particles like metal chips or liquids like water. There are different standards for example ISO 4406 or NAS1638 which define pollution classes. Particles less than 4 µ are not mentioned in most standards. A typical liquid pollution is water that comes into the hydraulic systems. There is free water (droplet) or emulsified water in the oil.
In order to judge a hydraulic oil correctly, it's necessary to make a complete analysis. The cost for these analysis maybe between 100,00 € and 150,00 €.

1.1.5.1 Particle analysis according to NAS 1638 or ISO 4406

With an automatic particle counter, it is possible to count the amount of particles in an oil sample. Very much simplified said the particle counter is a light source and a photocell. When oil with dirt particles pass between light source and photocell, the particles will cause a shade on the photocell. This will cause a change in the voltage at the photocell. This change in the voltage allows to calculate the number and the size of the particles in the oil. The particle count can be done in an oil laboratory or with a portable particle counter. The costs for a particle counter are approx. 8.000,00 €-10.000,00 €.
The following table shows the number of particles per 100 ml of oils and the NAS code. In order to find the correct NAS code particles are counted in different sizes. For each size class the correct code according to the table has to be identified. The highest code is the total code for this oil sample.

Particles per 100 ml (µm)

NAS Code	5-15µm	15-25µm	25-50µm	50-100µm	>100µm
00 0	125 250	22 44	4 8	1 2	0 1
1 2	500 1.000	89 178	16 32	3 6	1 1
3 4	2.000 4.000	356 712	63 126	11 22	2 4
5 6	8.000 16.000	1.425 2.850	253 508	45 90	8 16
7 8	32.000 64.000	5.700 11.400	1.012 2.052	180 360	32 64
9 10	128.000 256.000	22.800 45.600	4.050 8.100	720 1.140	128 256
11 12	512.000 1.024.000	91.200 182.000	16.200 32.400	2.880 5.760	512 1.024

<u>How to identify the correct NAS code:</u>

A sample of oil contains 4100 particles, size between 5-15 µ. The table shows the NAS code 5 (number of particles between 4000 and 8000)

In the next step you identify the NAS code according to the results of the other size classes. The highest NAS code is the total result. The sample below shows NAS code 5.

Particle per 100 ml (µm)					
Size range	5 – 15	15 – 25	25 – 50	50 – 100	> 100
Particle number	4100	320	114	3	1
NAS Code	5	3	4	1	0
Total NAS 5					

Degree of purity according ISO 4406

Quantity Particle *More than*	**per 100 ml up to**	**ISO Code**
250.000.000		> 28
130.000.000	250.000.000	28
64.000.000	130.000.000	27
32.000.000	64.000.000	26
16.000.000	32.000.000	25
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
350.000	500.000	19
130.000	350.000	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
16	32	5
8	16	4
4	8	3
2	4	2
1	2	1
0	1	0

fachefr Reinheitsklassen ISO

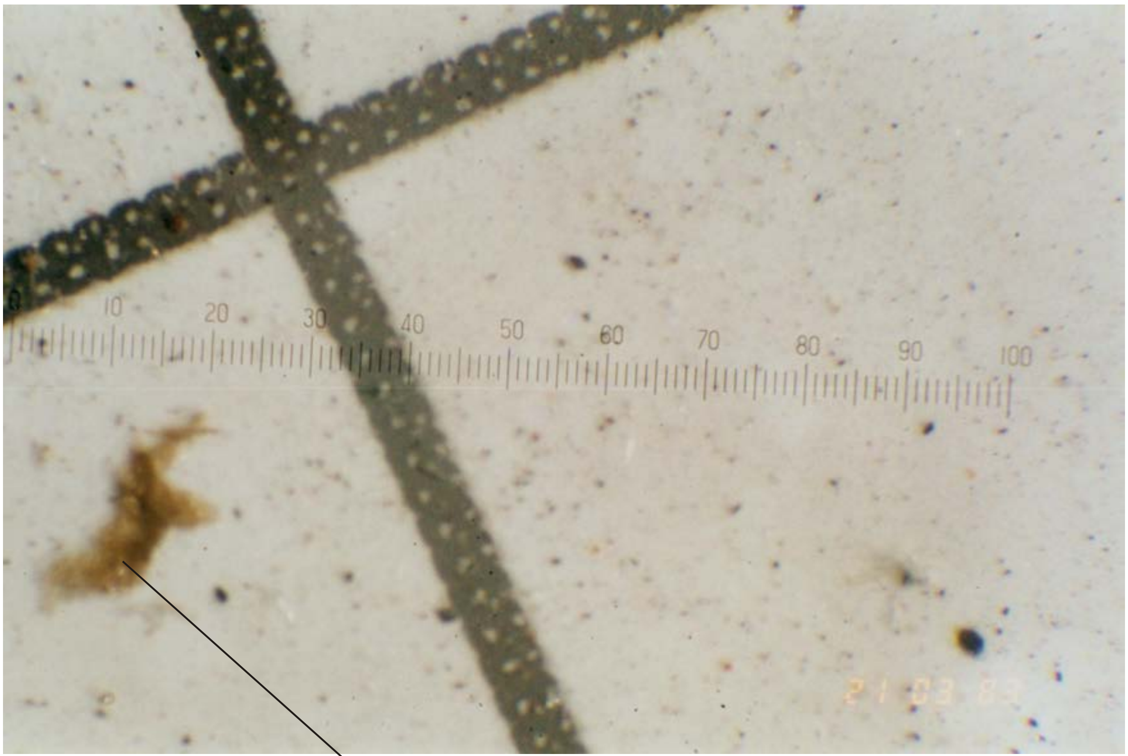
Example for the identification of the ISO code: A sample contains 9230 particles size more than 5 µm and 2221 particles size higher than 15 µm. The table shows NAS code 14 (amount of particles between 8000-16000.) The amount of particles between 2000-4000 is ISO code 12. The total result is ISO code 4406 14/12.

	Particle number	**ISO code**
Particle > 5 µm in 100 ml	9230	14
Particle > 15 µm in 100ml	2221	12
Total ISO 4406 14/12		

1.1.5.2 Membrane analyses

In order to find out the amount of dirt in the hydraulic oil a certain amount of oil has to be drawn through a membrane filter by vacuum. The pore size of the membrane is 0,8 µm, for example:

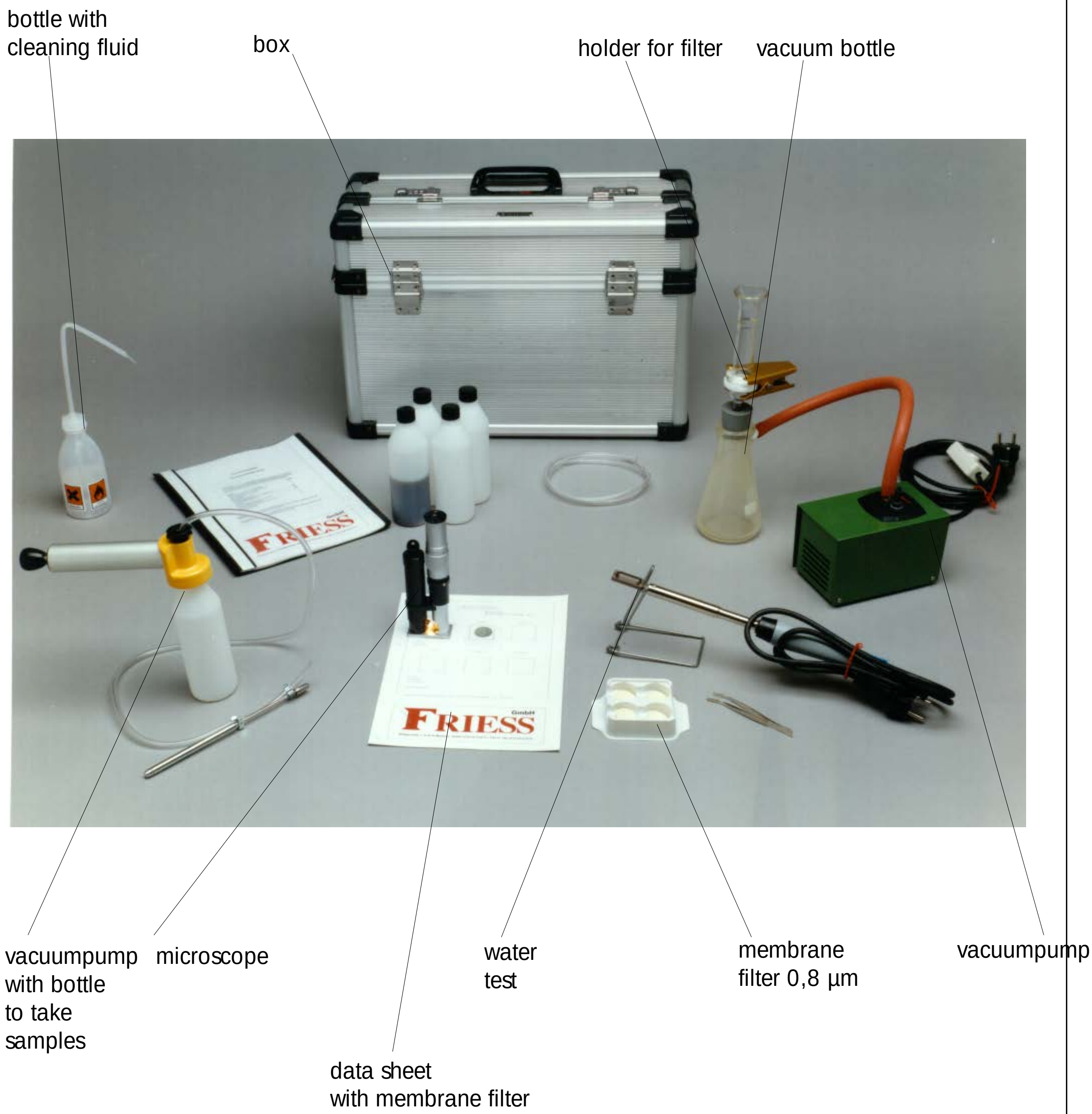
Oxydation products in hydraulic oil



Dirt particle included in resin particles

- membrane filter pore size 0,8 µm.

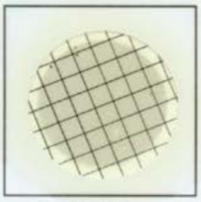
If you take a sample of oil before and after cleaning you can compare both membranes and see how the pollution has been reduced. The disadvantage compared to the particle counting is, that it's not possible to see the exact number of particles. It's only possible to compare the samples. When looking on the membrane with a microscope, you can see the form of the particles and the type of pollution. This gives the first hints to possible damage in the hydraulic system (metal parts or rubber parts from seals). When comparing new oil and used oil, the membrane analysis allows a pretty good judgement of the pollution of the oil. The price for a membrane analysis set is around 2.200,00 €.



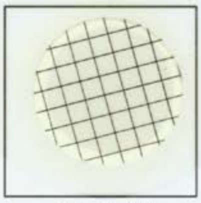
Ölprobenauswertung

Öltyp:	HLP 46	Ölreiniger:	D16
Einsatzdauer:		Ölreiniger im Betrieb seit:	03.11.99
Ölvolumen:	ca. 5000 l		
Maschinentyp:	Spritzgußmaschine F9		

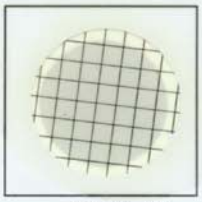
Probe 1



Probe 2

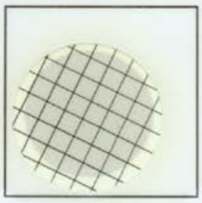


Probe 3

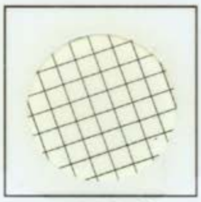


	Probe 1	Probe 2	Probe 3
Datum:	03.11.99	20.11.99	29.11.99
Volumen:	6 ml	30 ml	30 ml
Entnahme:	Tank	vor D16	vor D16

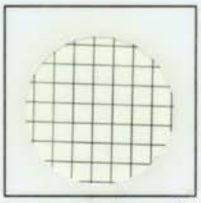
Probe 4



Probe 5



Probe 6



	Probe 4	Probe 5	Probe 6
Datum:	06.12.99	13.12.99	14.[illegible]00
Volumen:	30 ml	30 ml	30 ml
Entnahme:	vor D16	vor D16	vor D16

Bemerkungen: Gesamtlaufzeit 1316 Stunden
Aufgrund des hohen Feinschmutzanteils war die Membran bei Probe 1 bereits nach 6 ml blockiert. Bei allen anderen Proben konnten 30 ml durch die Membran gezogen werden.

Membranfilterplättchen mit einer Porengröße von 0,8 µm

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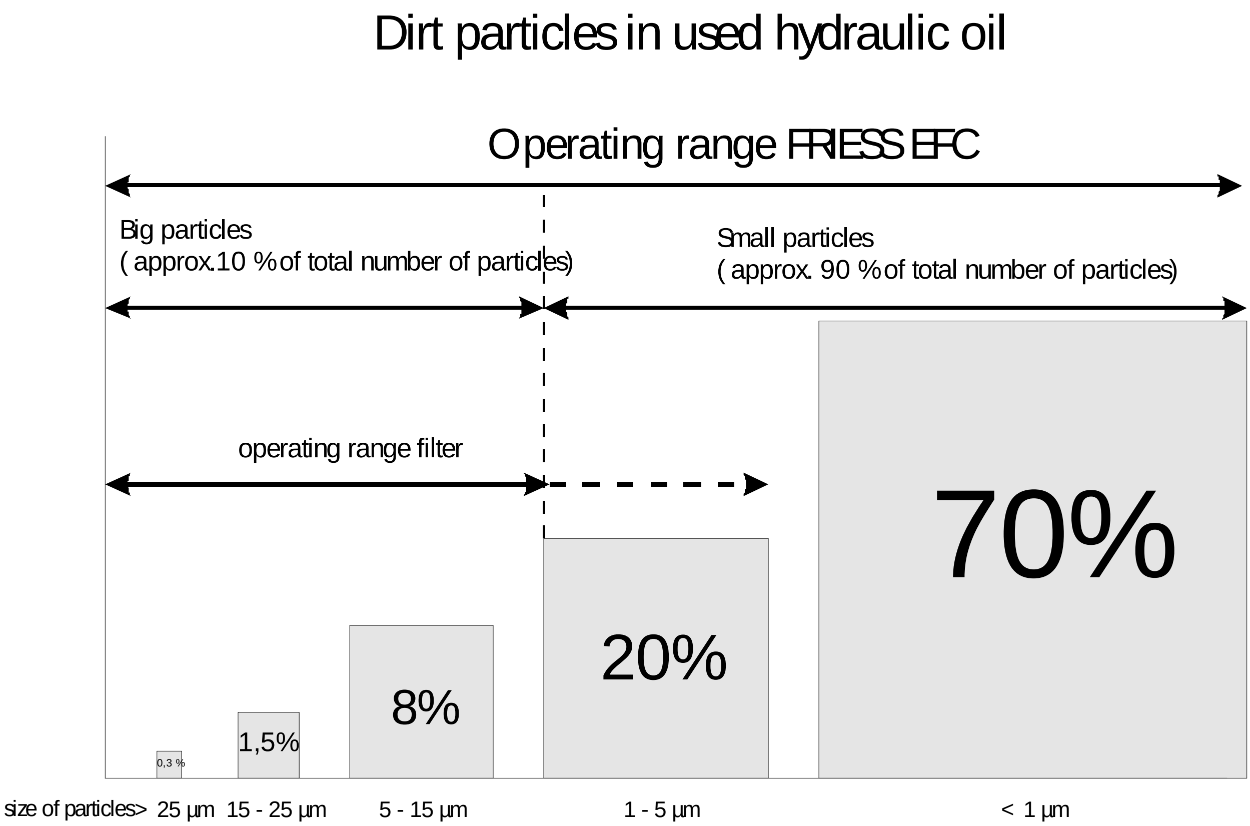
1.2 Impact of impurities to hydraulic oils

There are many pollutions in hydraulic systems caused by manufacturing. When mounting a new hydraulic system small metal particles and dirt particles will remain in pipelines, tanks and so on. Even new oil will contain lots of particles.

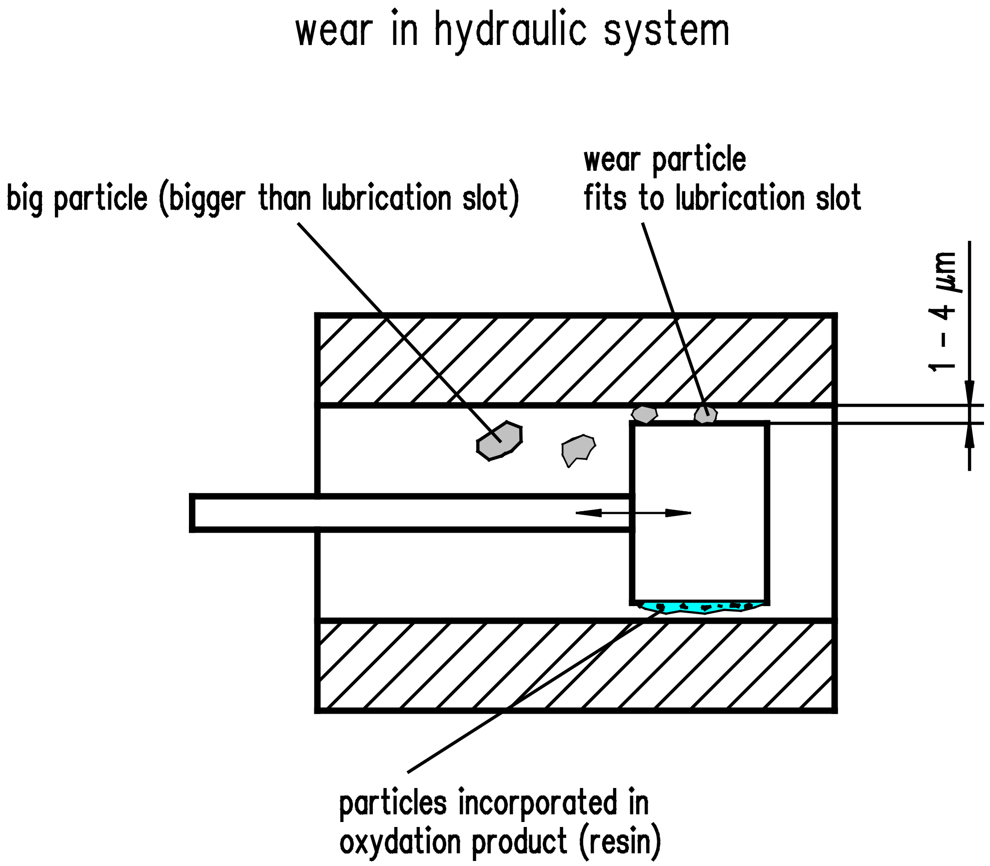
During operation the level of the hydraulic tank will change. Because of the changing level air with dust and dirt particles will come into the hydraulic oil tank. Some of these particles will come into the oil. Because of wear and abrasive particles, the hydraulic system itself will produce new dirt particles.



All these particles will cause wear and malfunction in the machine. In addition to this the particles are dangerous to the the oil itself. The oil works at a temperature of 45 °C – 55 °C and is in contact with oxygene. Together with a catalyst some molecules of the oil will react with the oxygene of the air. This chemical reaction will produce bigger molecules. These bigger oil molecules may polymerize. That means, that the longer than normal oil molecules will polymerize to small sticky resins (oxydation products). Finally these resins or oxydation products will form a thin layer of sludge in the hydraulic system. Small dirt particles act as a catalyst in this reaction. Each particle in the oil has a very small surface. Because of the big amount of particles the catalytic active surface is very big. The high number of particles improve the reaction between oxygene and oil. This means, that a higher impound of impurities will cause a faster reaction of the oil and faster oxydation of the oil.

2. Hydraulic system

Impurities in the hydraulic oil and oxydation product in the hydraulic oil of course will effect the function of the hydraulic system. Particles are very harmful to pumps, valves and so on. Especially when these particles have the same size as the slot between piston and cylinder. In this case the particle will be pressed with the oil between piston and cylinder. The particle will touch both surfaces at the same time. Because the piston moves in the cylinder hard solids will create abrasion or scratches. Because of the abrasion the particle will create new particles. In modern hydraulic systems the slot between piston and cylinder has a size of 0.5 µm – 4.0 µm (servo valves). For proper operation of the hydraulic system particles in this size have to be removed from the oil.



The hydraulic oil has to lube the parts in the hydraulic system. If the oil is contaminated with particles and resins the dirty oil will cause wear. Compared to hard particles oxydation product will cause other malfunction.

In the beginning of the oxydation process sticky oxydation products and resin will fall out only at lower temperatures. As soon as the oil has reached the operation temperature, the sludge and resin will be solved and the machine will work properly. After some time the sticky resins will settle at the hydraulic parts. The resin can be seen as brown layer on pistons and valves.

Especially in servo- and proportional valves, the resins will settle because of electrostatic field force caused by the electromagnetic coils.
Additional trouble is caused by very small metal particles, which will settle in the sticky sludge. This will cause additional friction between piston and cylinder. In the first step the valve will not work properly. For example it will open only 50% instead of 70% or 80%. Because of slip-stick effects the piston is not moved smoothly but step by step. Finally the piston will be totally blocked and machine will stop.

The formation of resines disturb the precision of the hydraulic system. Reports have shown, that caused by resins and oxydation products the repeating precision is changed up to 0.3 sec. After cleaning the repeating precision was less than 0.1 sec.
In case that the system does not work properly manufacturer parts have poor quality. Many reports show, that up to 80% of the hydraulic are caused by pollution hydraulic oil. This means, that 80% of the hydraulic malfunction is caused by pollution and sludge in the hydraulic oil. With correct cleaning of the hydraulic oil you can avoid 80% of hydraulic trouble and malfunction.

3. Mineral oils according to German industrial standard (DIN)

There are different type of hydraulic oil on the market. The German standard DIN 51524 describes minimum standards for hydraulic oil. Depending on the manufacturer and the price of the hydraulic oil you can buy oils that are much better than the minimum standard. Some manufacturers of hydraulic components demand oil with higher standards.

3.1 HL Hydraulic oil standard DIN 51524

These oils do not contain anti-wear additives and are not very common in industrial hydraulics.

3.2 HLP Hydraulic oil according to DIN 51524, part 2

These oils have anti-wear, anti-oxydation and anti-corrosion additives. HLP hydraulic oils are the typical standard oil in industrial hydraulics.

3.3 Hydraulic oil HLP VP according to DIN 51524, part 3

These oils contain an additional VI-improver in order to use the oil at different temperatures.

3.4 Hydraulic oil HLPD

These are hydraulic oils according to DIN 51524, part 2 typ HLP with additional detergents and dispersions. Compared to oil type HLP oils type HLP D are able to emulsify small amounts of water. The following table shows the advantages and disadvantages of hydraulic oils HLP against hydraulic oil HLPD.

Oil type HLP	Oil type HLPD

Advantages	Disadvantages	Advantages	Disadvantages
cheap			expensive
	Low cleaning capacity	High cleaning capacity	
Can be used in all types of hydraulic systems			Wetting capacity depending on manufacturer different may cause slip stick effects
Will separate water		Will emulsify water	
Good air release property			Poor air release property

A leading German manufacturer of hydraulic pumps recommend for industrial hydraulic systems like presses or injection molding machines oil type HLP. HLP D oils should be used only in case, that the hydraulic oil comes in contact with coolants. When using standard HLP oils together with coolants, they may form sticky products. In mobile hydraulic systems like trucks or loaders, that are used outdoors, they recommend HLP D oil because of forming of condensation water. In all other cases they suggest HLP oil, because HLP oil does not emulsify water. It is very easy to separate small amounts of water from the oil. Water, that is emulsified with the HLP D, oil cannot be separated any more. In case that the amount of water in the oil is higher than 0.1% the oil will oxydate soon. In addition corrosion in the hydraulic system will be produced. The filtrability of the oil is reduced. HLP D oils that contain fat-acid or fat-acid-ester may not be used in hydraulic system because they may destroy lead (1).

When using HLP oil be aware, that the DIN standard is only a minimum standard. Most of the high quality HLP oils have much better values than the DIN standard describes.

Hydraulic oils with or without zinc

Both types, HLP and HLP D oils, are available with or without zinc additives. HLP oils can be used in hydraulic system with zinc or without zinc additives. There are no special advantages or disadvantages.

It is very important to know that oils, that contain zinc additive and oils without zinc additive may not be mixed. When changing a hydraulic system from an oil that contained zinc additives to an oil that is without zinc additives it may happen, that small amounts of oil with zinc additives will be mixed with the oil without zinc additive. This may cause formation of sludge and resin and will block filter elements.

When adding new oil because of leaks or repairing make sure, that you do not mix oil with zinc additives with oils that do not contain zinc additives (2).

4. Different technologies for maintenance of hydraulic oil

The following technologies offer

1. longer lifetime of the hydraulic oil
2. less downtime of hydraulic components
3. reduction of the operation costs for hydraulic system

In hydraulic systems we use different cleaning methods.

1. separation of water with vacuum systems
2. filtration
3. electrostatic oil cleaning

In addition there are other methods to separate oil and dirt. The lubrication oil of big diesel engines is cleaned with centrifuges. For hydraulic oils this method is not very common. Another possibility to maintain the oil is an oil change every few thousand hours of operation. When changing the oil dirt particles will remain in the system. The new oil contains much more particles than allowed for modern hydraulic components. When changing the oil it is absolutely necessary to clean the hydraulic tank. New oil is able to solve particles that have been settled in the system. After few weeks of operation the new oil has solved settled particles and it contains the same amount of particles as the old oil. When chaning the oil it is not possible to change the total amount of oil. 20% of the old oil will remain in the tubes, cylinders, pumps and so on. In order to clean the system completely with new oil it is necessary to flush the system. If this is not done 20% of the old particles remain in the hydraulic system. As soon as the new oil starts to solve settled particles the oil is in short time as dirty as it has been before.

4.1 Removing of water with vacuum

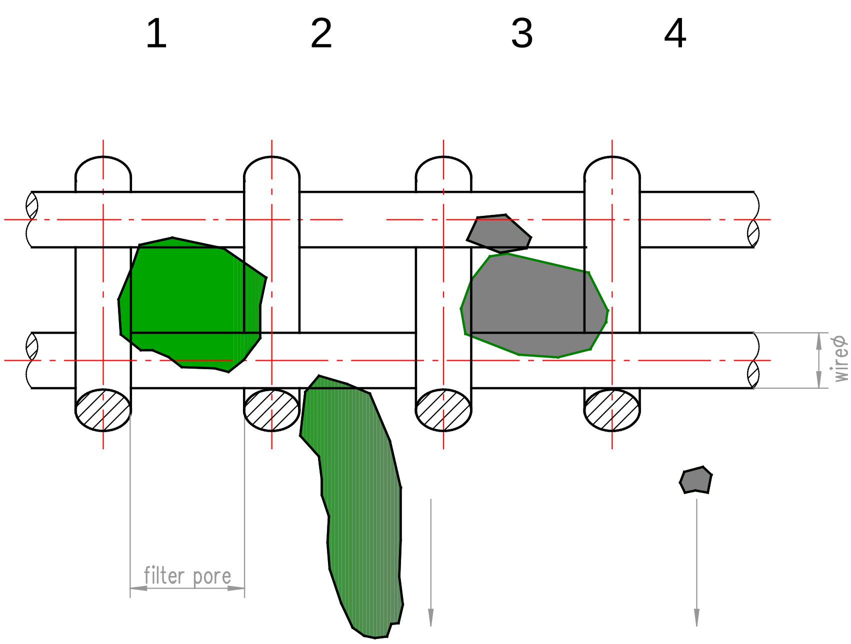
In order to remove the water from the hydraulic oil vacuum filtration system is a very simple method. The oil is pumped into a vacuum chamber. Because of the low pressure the water will vaporize at low temperature. The vaporized water will be sucked off with a vacuum pump. The oil will be pumped back into the hydraulic system. Vacuum filter systems are offline systems.

In case that a heat exchanger is broken big amounts of water will come into the hydraulic oil. When changing the oil some percent of water will remain in the hydraulic system, so that you have to change the oil several times. When using a vacuum filter you can remove the water in order to avoid the change of hydraulic oil.

4.2 Filtration

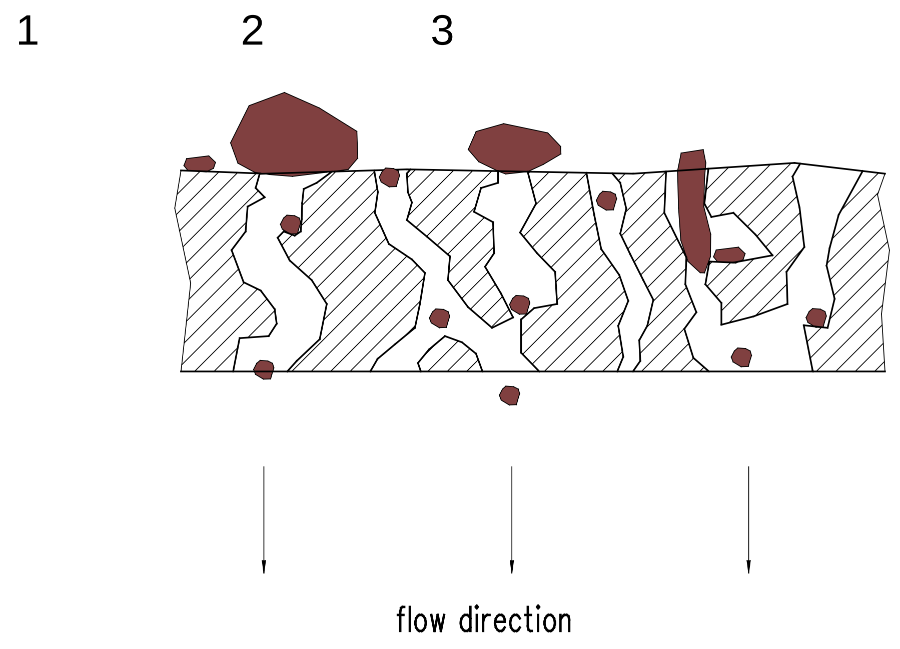
Hydraulic filters are very important parts of the hydraulic system. They are able to remove bigger dirt particles and are able to protect special components like servo valves in the system.

Fleece filter



1. particles bigger than pore will block the filter pore
2. long particles may pass the filter .
3. particles smaller than pore size may be old back by blocked filter pores
4. small particles will pass filter pore

Filters are used as inline filters or offline filters. The oil is pumped through the filter membrane. Particles, which are bigger than the pore size of the membrane, will remain on the surface of the membrane while the oil is pumped into the hydraulic system. Particles that are smaller than the pore size are normally not filtered. Depending on type of the membrane and structure of the membrane modern hydraulic filters will remove particles down to 2µm.



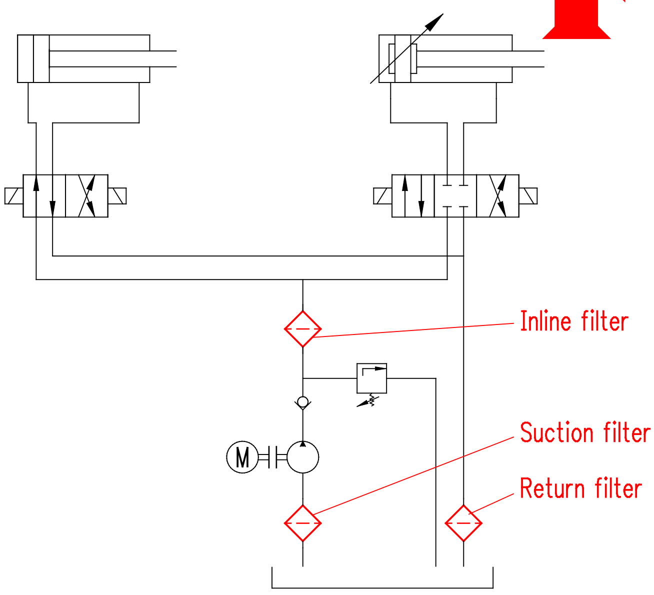
1. particles bigger than filter pore will block a part of the pore.
   Smaller particles may be pressed into slot between big particle and filter material.
2. smaller particles may be kept inside the filter media.
3. long particles will be hold back by filter media.

4.2.1 Inline filtration

The inline filter is very important to protect the system. Particles that are in the hydraulic oil will be removed by the inline filter before these particles will come to critical to valves.

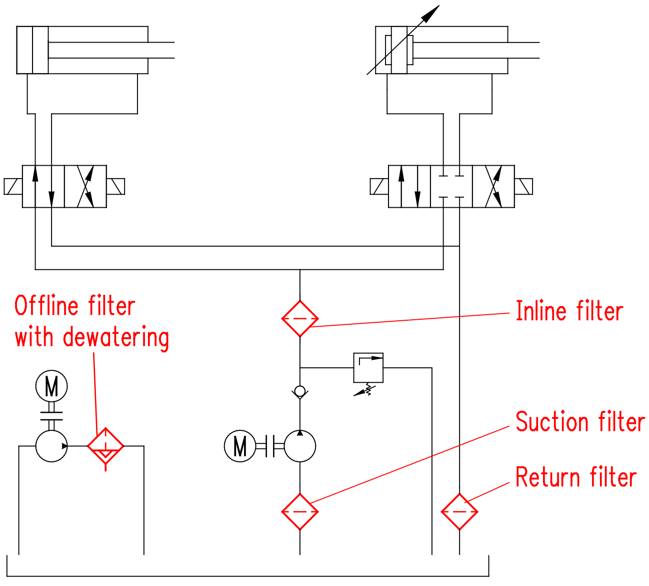
The disadvantage of the inline filter is, that the filter element has to withstand high pressure, changing pressure and changing volume. Inline filter elements have to be tough and resistant against high pressure. In order to reach a high volume and low pressure loss the pore size of the inline filter is very often not according to the needs of a hydraulic system.

Inline filters are not able to provide the necessary cleanliness of the hydraulic oil. Inline filter are good to protect the hydraulic systems against particles that have not been removed by other cleaning systems. Modern hydraulic system need an offline cleaning system in addition to the inline filter.



4.2.2 Offline filtration

In addition to the inline filter the offline filter system has many advantages. The environment for the filter element is perfect. The volume of oil is very low. The pressure of the oil is very low. It is possible to realize small pore sizes down to 3 – 5 µm. The mechanical stress is very low compared to inline filters. The offline filtration will provide much cleaner oil, specially particles between 2µ and 10µ can be reduced dramaticly. The disadvantage of all filter systems is the size of the smallest particles. Filter systems cannot reduce particles which are smaller than approx. 2µ – 5µ. Sludge, oxydation products and small particles will not be removed by filter systems.

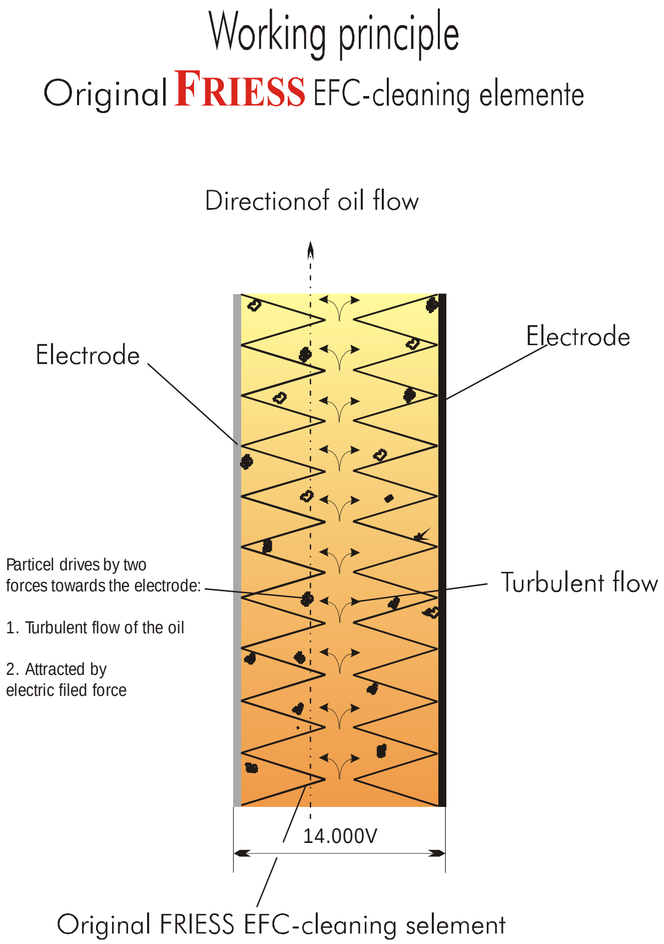


4.3 Electrostatic oil cleaning

Because of the unique working principle, electrostatic oil cleaning systems are able to remove particles down to 0.05 µm. It is no problem to clean the hydraulic oil better than new oil. In addition to the bigger particles, electrostatic oil cleaning is able to remove oxydation products and micro particles, which act as a catalyst and which are responsible for the oxydation in the oil. Because of removing the small particles, electrostatic oil cleaning prevents the oil from oxydation, so that the oil can be used much longer than with conventional filtration.

The dirty oil is pumped through an electric field, which is produced in the cleaning chamber. The dirt particles are attracted by the electric field force. All particles which have an electric charge are attracted by the electrode with the opposite electric charge. The particles move towards the electrode. The particles will be collected on a special formed cleaning element. The electric field force is able to attract solids like metal, plastic, glass, sand, fibres and so on. Liquid additives in the oil will not be attracted. The special design of the cleaning elements is able to deform the electric field compared to the electric field between the electrodes only. The electric force attracting on the particles is higher when using the cleaning elements. The special slots in the cleaning elements cause a turbulent flow, so that dirt particles are driven towards the cleaning elements. That means two forces drive the particles out of the main flow of the oil.

1. electric field force
2. the flow of the oil



The size of the particles has no influence on the cleaning effect. The particles are not attracted because of their size but because of their electric charge. Independent from the size they have an electric charge because of friction or other effects. For this reason electrostatic oil cleaners are able to remove all kind and all sizes of particles.
It is very important that additives and other liquids are not influenced by the electric field. Liquids are made of single molecules. Molecules which are stable have no charge and can not be attracted by the electric field. That means that the oil and the liquid additives will pass the electric field without being attracted. Hard and soft particles are set together from different molecules. Because a few molecules are set together, they may have an electric charge and can be attracted by electrostatic. In extreme cases it is possible to remove a hard particle which has an electric charge and which is smaller than the molecules of the liquid.

5. Summary

When cleaning hydraulic oils continuously, the operation cost of the hydraulic system can be reduced dramaticly. In addition the downtime and malfunction of the hydraulic system will be reduced by up to 60%. The important point is that the cleaning of the oil has to be done regulary. In addition to the cleaning, the analysis of the oil will give important hints about the condition of the oil. The consequent use of the best cleaning technology will guarantee the desired success. A condition monitoring will show malfunction of the system before the system will stop and can safe down time.

Many well known companies with injection moulding machines have reduced the down time of the hydraulic systems by 70 to 80 %. In addition, the lifetime of the hydraulic oil was extended to more than 100.000 hours. In nearly all companies the investment for electrostatic oil cleaning has been paid back within less than one year by the reduced operating cost for the hydraulic systems.

Legende

(1) Druckschrift RD07 075/07.98 Rexroth-Hydraulik
(2) Vortrag: Dirk Liese Castrol Industrie GmbH
(3) Mineralölfibel der Firma DEA
(4) Druckschrift Hydrauliköle der Firma BP
(5) Druckschrift Hinweise über Druckflüssigkeiten für Konstrukteure
Verfasser: Herr M. Frauenstein, Herausgeber Mobiloil AG