HYDAC FILTER SYSTEMS

Fluid Control
Contamination Handbook

EN 7.603.11/02.23

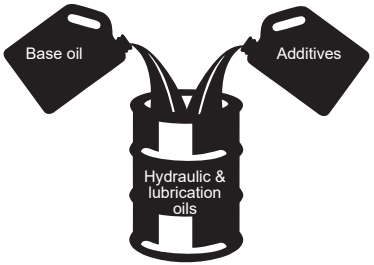
Classification of base oils according to API 1509*

	API* Group			
	I	II	III	IV
Oil type	Raffinate	Hydrated base oil	Synthetic oil	PAO
Amount of saturated hydrocarbons	<90 %	>90 %	>90 %	100 %
Viscosity index	80–120	80–120	>120	-
Polarity	High polarity	Less polar	Nearly non-polar	No details
Solubility of varnish	High	Medium	Weak	Weak
Electrical conductivity	Good	Bad	Very low	Low

* American Petroleum Institute (API)

Composition of hydraulic and lubrication oils

Hydraulic and lubrication oils = **Base oil** + **Additives***



*** Example additives:**
- VI-improving agent
- Pour-point lowering agent
- Oxidation inhibitor
- Corrosion inhibitor
- Antiwear
- Anti-foam

Classification of hydraulic oils according to DIN

Operating fluid	Code	Density at 15 °C (kg/m^3)
Mineral oil acc. to DIN 51524 or ISO 11158	H, HL, HLP, HV, HLPD	860
Fire resistant acc. to DIN 5150 or ISO 12922	HFA/HFB	1000
	HFC	1090
	HFDR, HFDS	1200
More rapidly biodegradable acc. to ISO 15380	HETG	930
	HEES	940
	HEPG	1100
	HEPR	890
Lubricating oils acc. to DIN 51517	CL, CLP, CG	860

Food-grade oils acc. to NSF International

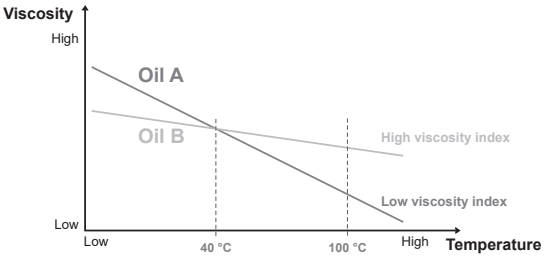
H1 lubricant	“Food-grade (FG) lubricants” “Food-grade oil” Occasional, technically unavoidable contact with foodstuffs not hazardous
H2 lubricant	Contact with food not permitted. Use only outside of the closed production process.
H3 lubricant	Soluble oils for cleaning or rust protection for machines

Viscosity – Comparison ISO/SAE

ISO VG (DIN 51519)	Medium point viscosity (40 °C) and approx. viscosities in mm²/s at				Approximate classification of the	
	0 °C	40 °C	50 °C	100 °C	Motor oils SAE	Automobile transmission fluids SAE
5	8 (1.7 E)	4.6	4	1.5		
7	12 (2 E)	6.8	5	2.0		
10	21 (3 E)	10	8	2.5		
15	34	15	11	3.5	5 W	
22	55	22	15	4.5	10 W	70 W
32	88	32	21	5.5		75 W
46	137	46	30	6.5	15 W	
68	219	68	43	8.5	20 W	80 W
100	345	100	61	11	30	
150	550	150	90	15	40	85 W
220	865	220	125	19	50	90
320	1340	320	180	24		
460	2060	460	250	30		140
680	3270	680	360	40		
1000	5170	1000	510	50		250
1500	8400	1500	740	65		

Viscosity index acc. to ISO 2909 – comparison of two mineral oils

The higher the viscosity index of an oil, the smaller the change in viscosity in relation to the temperature.



Contamination types

Solid contamination

– Corundum, tinder, rust particles
– Wear metals iron, copper, tin, zinc etc.
– Fibres, rubber particles, paint particles

Liquid contamination

– Cooling water
– Steam

Gel-like contamination

– Oil ageing/varnish
– Oil mixtures
– Additive separation (dropout)

Gaseous contamination

– Air
– Process gases

Causes of contamination in oil

	Cause
Solid	– Installation contamination – Ambient contamination – Refilling of operating fluid – Internal wear processes – Oil ageing
Liquid	– Moisture from the ambient air – Leakage of cooling systems – Process water/process steam – Leakage of seals – High-pressure cleaner – Chemical processes (incineration, oxidation, neutralisation)
Gel-like	– Oil ageing – Oil mixing
Gaseous	– Mixtures – Outgassing of oil

Consequences of contamination

	Consequences
Solid	– Abrasive wear – Increased leakage – Component failure – Control inaccuracies – Blockage of control pistons – Short fluid service life
Liquid	– Corrosion – Reduction in dynamic viscosity • Reduction in lubricating film thickness • Contact with surfaces • Wear – Change in the oil properties • Creation of acidic oil degradation products • Formation of sludge • Increase in speed of oil ageing – Cavitation damage
Gel-like	– Reduction in lubrication gaps caused by deposits • Increased friction and temperature • Increased bearing wear – Malfunctions in valves • Unstable control behaviour – Damage to dynamic seals • Leakage – Blockage of filter elements • Short filter life caused by sludge formation – Increased bearing temperature caused by caking
Gaseous	– Cavitation – Oxidation – Local overheating of oil • Increase in speed of oil ageing • Control inaccuracies

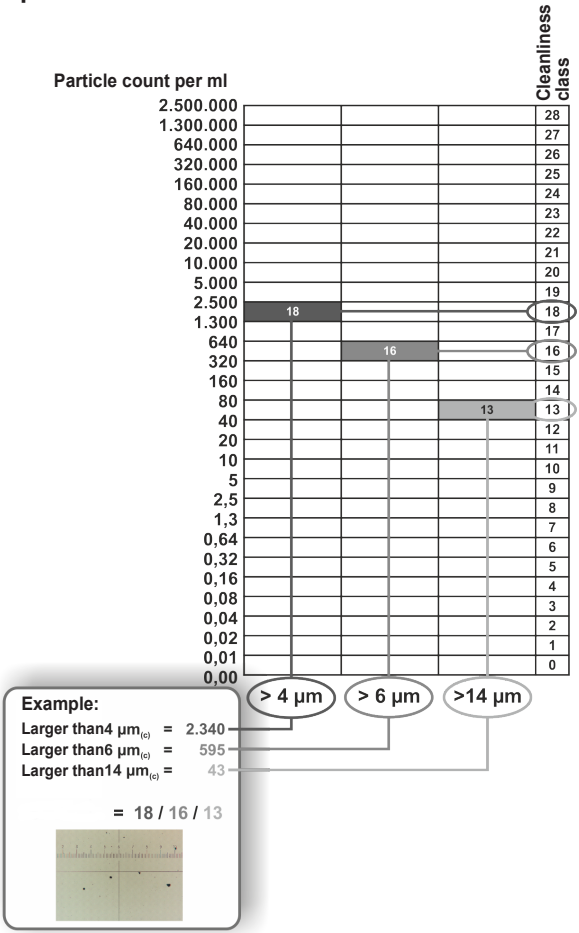
Cleanliness classes acc. to ISO 4406

Determining the ISO code

In ISO 4406 particle counts are determined cumulatively, i.e. >4 µm (c), > 6µm (c) and >14 µm (c) (manually by filtering the fluid through an analysis membrane or automatically using particle counters) and allocated to key figures.

ISO code	Particle count/100 ml		Contamination load (ACFTD)
	More than	Up to and incl.	[mg/l]
0	0.5	1	–
1	1	2	–
2	2	4	–
3	4	8	–
4	8	16	–
5	16	32	–
6	32	64	0.001
7	64	130	–
8	130	250	–
9	250	500	–
10	500	1,000	0.01
11	1,000	2,000	–
12	2,000	4,000	–
13	4,000	8,000	0.1
14	8,000	16,000	–
15	16,000	32,000	0.2
16	32,000	64,000	0.5
17	64,000	130,000	1
18	130,000	250,000	3
19	250,000	500,000	5
20	500,000	1,000,000	7/10
21	1,000,000	2,000,000	20
22	2,000,000	4,000,000	40
23	4,000,000	8,000,000	80
24	8,000,000	16,000,000	–
25	16,000,000	32,000,000	–
26	32,000,000	64,000,000	–
27	64,000,000	130,000,000	–
28	130,000,000	250,000,000	–
>28	250,000,000		

Example: ISO code 18/16/13



Cleanliness classes according to SAE AS 4059

Like ISO 4406, SAE AS 4059 describes particle concentrations in liquids. The analysis methods can be applied in the same manner as for ISO 4406 and NAS 1638.

Size ISO 4402 Calibration or optical counting*		> 1 µm	> 5 µm
Size ISO 11171, calibration or electron microscope**		> 4 $\mu m_{(c)}$	> 6 $\mu m_{(c)}$
Side code		**A**	**B**
Contamination classes	**000**	195	76
	00	390	152
	0	780	304
	1	1,560	609
	2	3,120	3,390
	3	6,250	3,390
	4	12,500	3,390
	5	25,900	3,390
	6	50,900	19,500
	7	100,000	38,900
	8	200,000	77,900
	9	400,000	156,000
	10	800,000	311,000
	11	1,600,000	623,000
	12	3,200,000	1,250,000

* Particle sizes determined on basis of longest dimension

** Particle sizes determined on basis of diameter of projected circle with same surface area

The SAE cleanliness classes are based on the particle size, the particle number and the particle size distribution. The particle size determined depends on the measurement process and calibration; consequently the particle sizes are labelled with letters (A–F).

Max. particle concentration (particle/100 ml)			
> 15 µm	> 25 µm	> 50 µm	> 100 µm
> 14 $\mu m_{(c)}$	> 21 $\mu m_{(c)}$	> 38 $\mu m_{(c)}$	> 70 $\mu m_{(c)}$
C	**D**	**E**	**F**
14	3	1	0
27	5	1	0
54	10	2	0
109	20	4	1
217	39	7	1
432	76	13	2
864	152	26	4
1,730	306	53	8
3,450	612	106	16
6,920	1,220	212	32
13,900	2,450	424	64
27,700	4,900	848	128
55,400	9,800	1,700	256
111,000	19,600	3,390	512
222,000	39,200	6,780	1,020

Cleanliness classes acc. to NAS 1638

Like ISO 4406 and SAE AS 4059, NAS 1638 describes particle concentrations in liquids. Although NAS 1638 is no longer a valid industrial standard, it is often used in practice because of its simplicity (just one key figure).

The analysis methods can be applied in the same manner as ISO 4406.

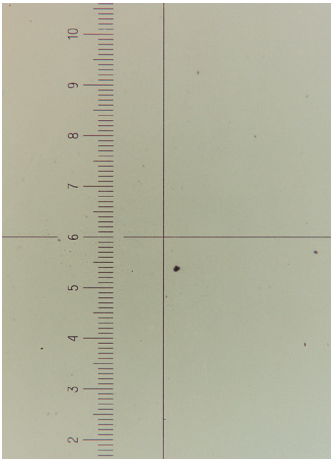
In contrast to ISO 4406, certain particle size ranges are counted in NAS 1638 and attributed to key figures.

No. of particles in 100 ml sample

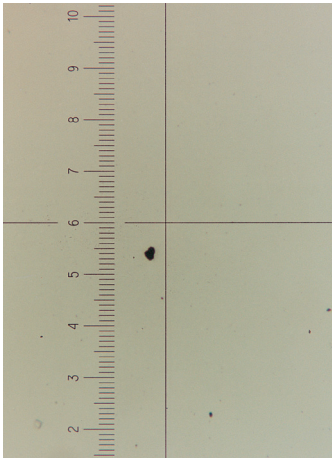
		Particle size (µm)				
		5–15	**15–25**	**25–50**	**50–100**	**>100**
Cleanliness classes	**00**	125	22	4	1	0
	0	250	44	8	2	0
	1	500	89	16	3	1
	2	1,000	178	32	6	1
	3	2,000	356	63	11	2
	4	4,000	712	126	22	4
	5	8,000	1425	253	45	8
	6	16,000	2,850	506	90	16
	7	32,000	5,700	1,012	180	32
	8	64,000	11,600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

Comparison photo for cleanliness classes

ISO 4406 **Class 14/12/9**
SAE AS 4059 **Class 4**
NAS 1638 **Class 3**

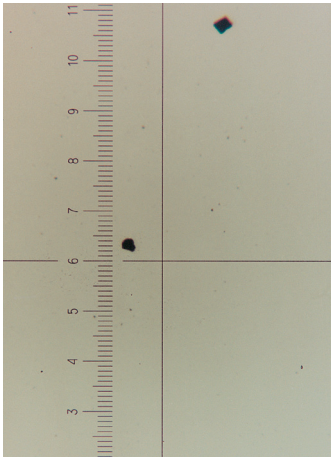


ISO 4406 **Class 15/13/10**
SAE AS 4059 **Class 5**
NAS 1638 **Class 4**

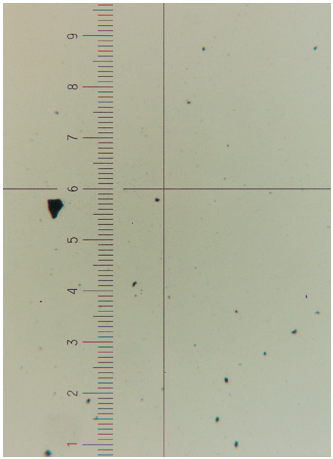


Magnification: x100
Oil volume: 100 ml
1 scale mark = 10 µm

ISO 4406 **Class 16/14/11**
SAE AS 4059 **Class 6**
NAS 1638 **Class 5**

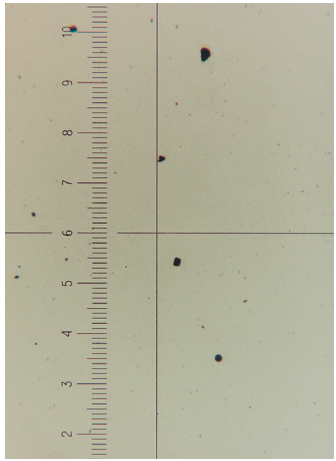


ISO 4406 **Class 17/15/12**
SAE AS 4059 **Class 7**
NAS 1638 **Class 6**

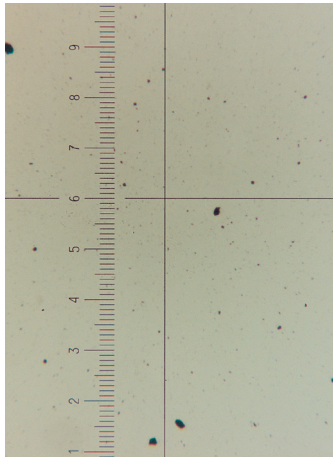


Magnification: x100
Oil volume: 100 ml
1 scale mark = 10 µm

ISO 4406 **Class 18/16/13**
SAE AS 4059 **Class 8**
NAS 1638 **Class 7**

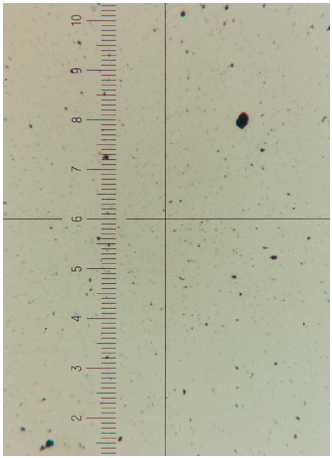


ISO 4406 **Class 19/17/14**
SAE AS 4059 **Class 9**
NAS 1638 **Class 8**

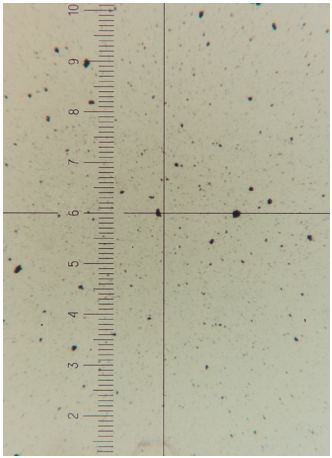


Magnification: x100
Oil volume: 100 ml
1 scale mark = 10 µm

ISO 4406 **Class 20/18/15**
SAE AS 4059 **Class 10**
NAS 1638 **Class 9**

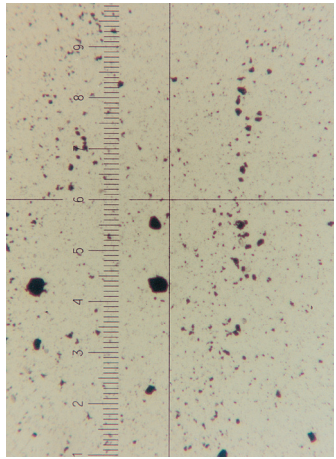


ISO 4406 **Class 21/19/16**
SAE AS 4059 **Class 11**
NAS 1638 **Class 10**

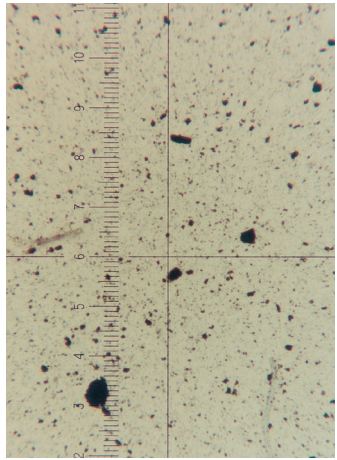


Magnification: x100
Oil volume: 100 ml
1 scale mark = 10 µm

ISO 4406 **Class 22/20/17**
SAE AS 4059 **Class 12**
NAS 1638 **Class 11**



ISO 4406 **Class 23/21/18**
SAE AS 4059 **Class 13**
NAS 1638 **Class 12**



Magnification: x100
Oil volume: 100 ml
1 scale mark = 10 µm

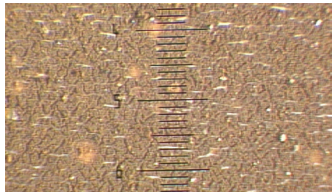
Examples of solid particle contamination

Predominantly rust, additives (white particles)

Effect:
– Strong oil ageing
– Malfunctions in pumps, valves
– Wear, mostly water in oil

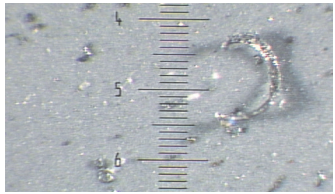
Oil degradation products

Effect:
– Filter blockage
– Sludge accumulating in the system



Metal chips (flow chips)

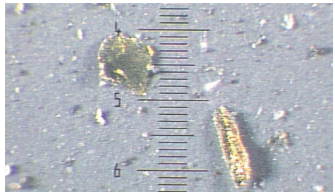
Effect:
– Malfunctions in pumps, valves
– Seal wear
– Leakage
– Oil ageing



Magnification: x48
1 scale mark = 45 µm

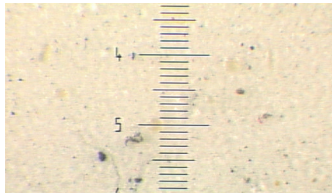
Particles/chips, bronze, brass or copper

Effect:
– Malfunctions in pumps, valves
– Oil ageing
– Leakage
– Seal wear



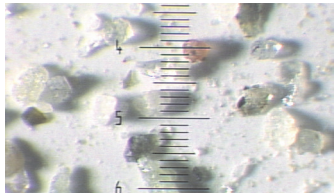
Gel-like residue

Effect:
– Filter blockage
– Sludge accumulating in the system



Silicates resulting from absent or insufficient breather filter

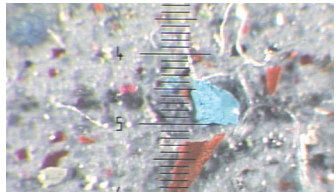
Effect:
– Strong wear on components
– Malfunctions in pumps, valves
– Seal wear



Magnification: x48
1 scale mark = 45 µm

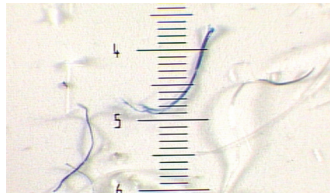
Paint particles (red/brown)
Plastic particles (blue)

Effect:
– Malfunctions in pumps, valves
– Seal wear



Fibres resulting from initial contamination, open tank, cleaning cloths etc.

Effect:
– Clogging of orifices
– Leakage of poppet valves



Magnification: x48
1 scale mark = 45 µm

Cleanliness requirements of hydraulic and lubricatio

	Low/medium pressure <140 bar (Moderate conditions)	
	ISO 4406 Target cleanliness class	Filtration rating µm
Pumps/motors		
Gear or vane	20/18/15	20
Piston	19/17/14	10
Variable vane	18/16/13	5
Variable piston	18/16/13	5
Drives		
Cylinder	20/18/15	20
Hydrostatic drives	16/15/12	3
Test benches	15/13/10	3 [2)]
Valves		
Non-return valve	20/18/15	20
Directional valve	20/18/15	20
Standard flow control valve	20/18/15	20
Poppet valve	19/17/14	10
Proportional valve	17/15/12	3
Servo valve	16/14/12	3 [2)]
Bearing		
Plain bearing [3)]	18/15/12	10
Gears [3)]	17/15/12	10
Ball bearing [3)]	15/13/10	3 [2)]
Roller bearing [3)]	16/14/11	5

Cleanliness requirements for diesel

	ISO 4406 target cleanliness cla
Tank	18/16/13
Injection system	12/10/8

1) Poor conditions can result from flow rate fluctuations, pressure spikes, frequent cold starts, extremely high ingress of contamination or the presence of water.
2) Two or more system filters of the recommended rating may be required to achieve and maintain the desired target cleanliness level.
3) Valid for the average diameter range

on oils

High pressure 140 to 200 bar (Low/medium under bad conditions[1])		Very high pressure >200 bar (High pressure under bad conditions[1])	
ISO 4406 Target cleanliness class	Filtration rating µm	ISO 4406 Target cleanliness class	Filtration rating µm
19/17/14	10	18/16/13	5
18/16/13	5	17/15/12	3
17/15/12	3	not required	not required
17/15/12	3	16/14/11	3 [2]
19/17/14	10	18/16/13	5
16/14/11	3 [2]	15/13/10	3 [2]
15/13/10	3 [2]	15/13/10	3 [2]
20/18/15	20	19/17/14	10
19/17/14	10	18/16/13	5
19/17/14	10	18/16/13	5
18/16/13	5	17/15/12	3
17/15/12	3	16/14/11	3 [2]
16/14/11	3 [2]	15/13/10	3 [2]
not required	not required	not required	not required
not required	not required	not required	not required
not required	not required	not required	not required
not required	not required	not required	not required

ss	Filtration rating µm
	5 µm (single pass elements)
	5 µm (single pass elements)

For system cleanliness, we recommend using one class better than the cleanliness required for the most easily damaged component. Filling/rinsing filtration at least one filtration rating finer than the system filter. According to DIN 51524 a cleanliness of ISO 21/19/16 must be provided for fresh hydraulic fluid.

Saturation point

Dissolved water

Below the saturation point

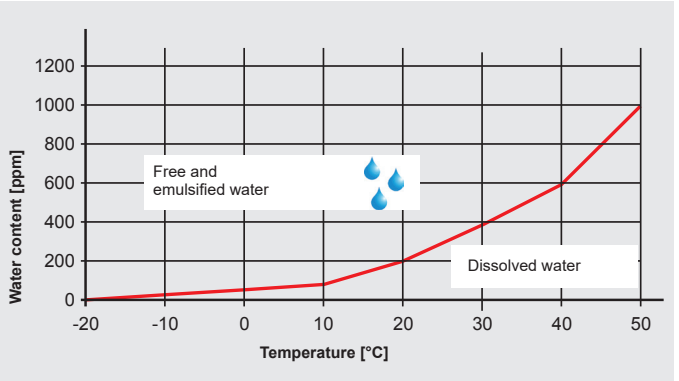
– Water is present in the oil in dissolved form – like the water that is present in humid air.
– All water molecules are deposited on polar oil components (e.g. additives, particles, oil degradation products)

Free water

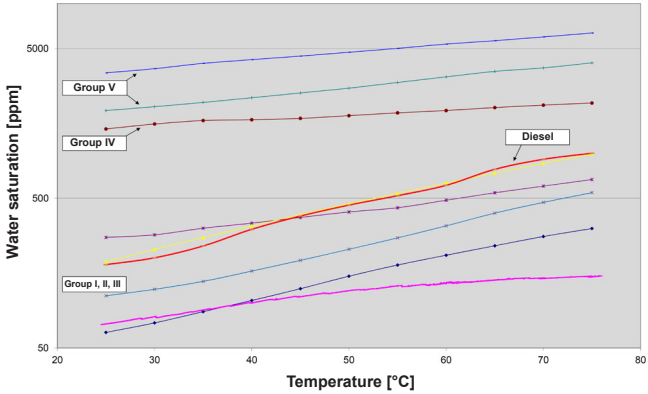
Above the saturation point

– Water is present as an emulsion (similar to fog), with ultra-fine water droplets distributed throughout the oil in a stable suspension. This causes clouding of the oil.
– Water is present in free form, normally settling on the base.

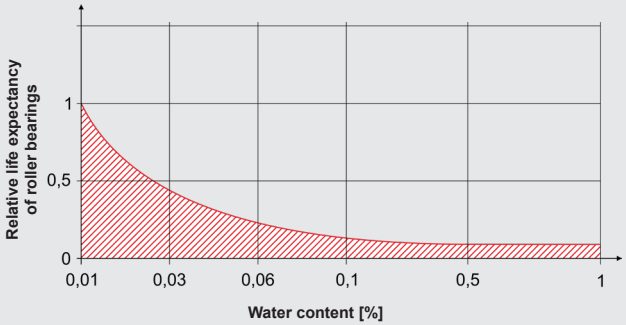
Saturation limit of water in oil



Water saturation curves



Life expectancy of bearings in relation to water content



Source: FAG/Schaeffler

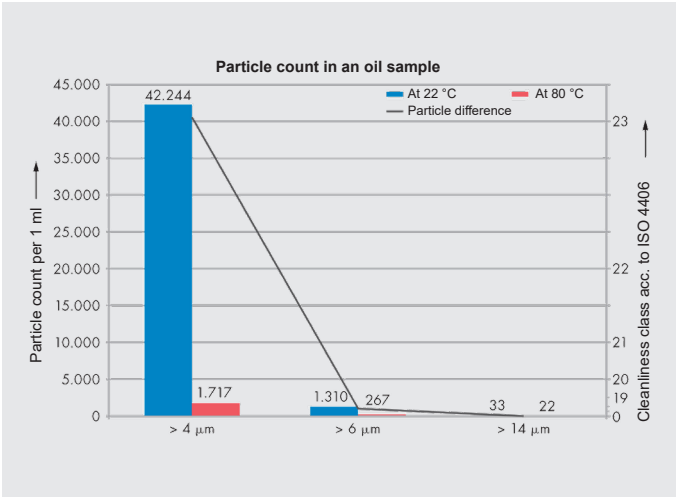
Varnish – analysis procedure

Laboratory analyses – varnish:

– **MPC (membrane patch colorimetry)**
based on ASTM D7843-12

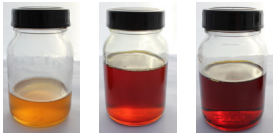
Laboratory analysis – specific:

– **Particle measurement at 20 °C and 80 °C**
based on ISO 11500

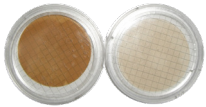


Example images

Valve piston with deposits



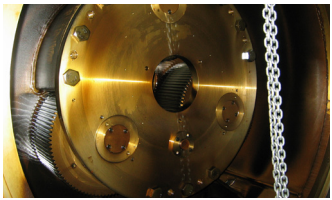
Oil samples at room temperature with slight clouding



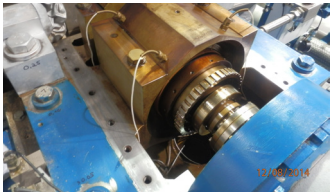
Filter membrane before and after varnish separation

Typical images of deposits in a steam turbine

Coupling sleeve

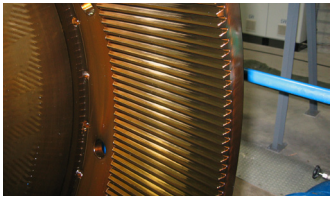


Gear, planetary stage

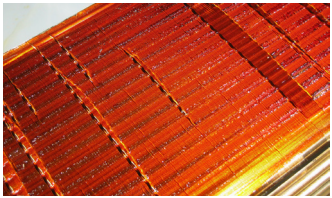


Turbine radial & axial bearing

Emergency oil pump



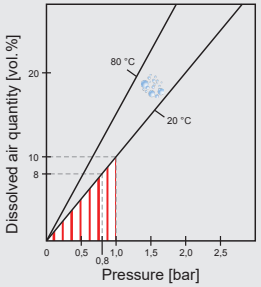
Gear teeth



Oil cooler fins (on oil side)

Solubility of air in oil

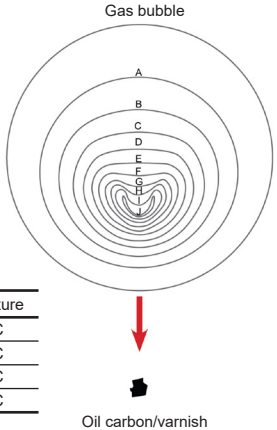
Relationship between pressure and temperature



At 20 °C and 1 bar
(atmospheric pressure)
Approx. 10 % dissolved air
→ in 100 litres oil,
approx. 10 litres air

With pressure reduction to
0.8 bar
Only 8 % of air soluble
→ in 100 litres oil,
2 litres of air released!

Fluid ageing caused by cavitation

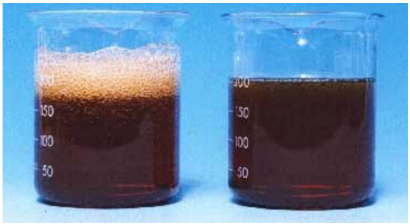


Range	Pressure	Temperature
A	1 bar	38 °C
F	69 bar	766 °C
H	138 bar	994 °C
I	207 bar	1140 °C

Air release capacity for fresh oils

Limit values of typical standard for fresh oil						
ISO VG/type	**32**	**46**	**68**	**100**	**(150)**	**(>320)**
Turbine oil DIN 51515, ISO 8068	5	5	6	x	x	x
Hydraulic fluid HLP/HM DIN 51524/2, ISO 11158	5	10	13	21	32	x

Example images



Product portfolio

Contamination type	Measurement devices (online/offline)	
Solid		
	ContaminationSensor **CS 1000**	Metallic ContaminationSensor **MCS 1000**
		
	ContaminationSensor Module Economy **CSM-E**	FluidControl Unit **FCU 1315**
Liquid		
	AquaSensor **AS 1000 & AS 3000**	
		
	ContaminationSensor Module Economy **CSM-E**	FluidControl Unit **FCU 1315**
Gel-like		
Gaseous		

Typical separation method/oil conditioning devices

Filter element

MobileFiltration Unit
MFU

OffLine Filter
OLF 5

OffLine Filter BiDirectional
OLFBD

Vacuum evaporation

FluidAqua Mobil
FAM

Coalescence

OffLine Separator
OLS

Superabsorber

MobileFiltration Unit
MFU

LowViscosity Housing
Coalescer Diesel **LVH-CD**

Aquamicron
AM

Cold filtration

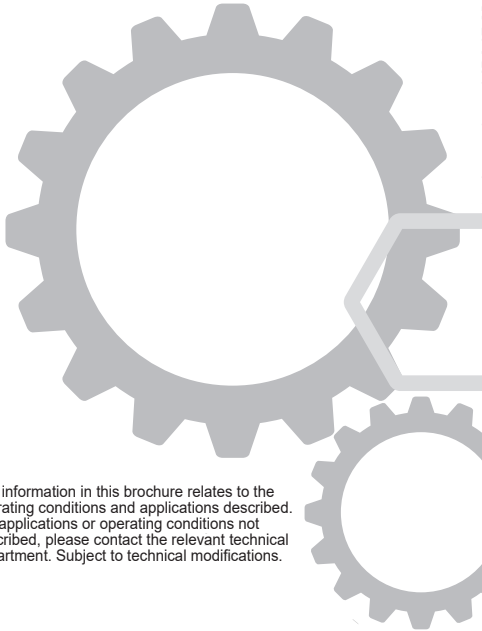
VarnishElimination Unit
VEU-F

Ion exchanger

Ion eXchange Unit
IXU

Vacuum drying

FluidAqua Mobil
FAM



The information in this brochure relates to the operating conditions and applications described. For applications or operating conditions not described, please contact the relevant technical department. Subject to technical modifications.

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