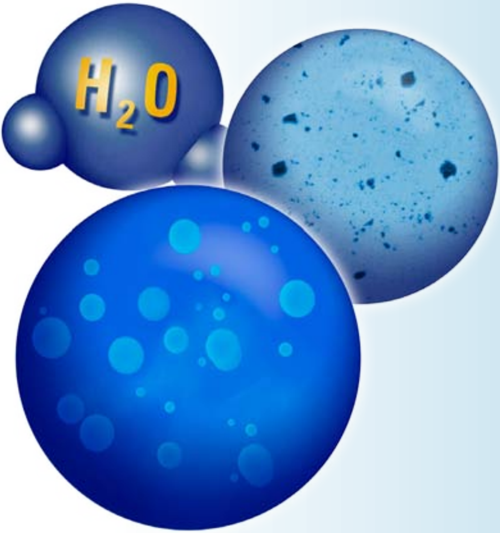
Fluid Condition Handbook



Manual of analysis and comparison photographs

MPFILTRI®

www.mpfiltri.com www.hydraulicparticlecounter.com

Index

Introduction

In hydraulic fluid power systems, power is transmitted and controlled through a liquid under pressure within an enclosed circuit. The liquid is both a lubricant and a power-transmitting medium.

The presence of solid contaminant particles in the liquid interferes with the ability of the hydraulic fluid to lubricate and causes wear to the components. The extent of contamination in the fluid has a direct bearing on the performance and reliability of the system and it is necessary to control solid contaminant particles to levels that are considered appropriate for the system concerned.

A quantitative determination of particulate contamination requires precision in obtaining the sample and in determining the extent of contamination. Liquid Automatic Particle Counters (APC) (MP Filtri Products), work on the light-extinction principle. This has become an accepted means of determining the extent of contamination. The accuracy of particle count data can be affected by the techniques used to obtain such data.

General Information

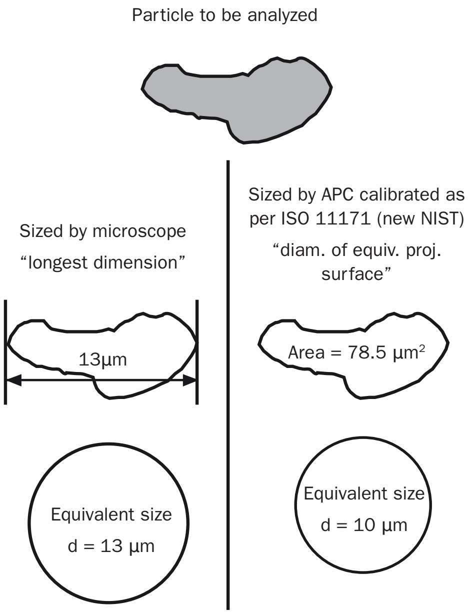
The NAS 1638 reporting format was developed for use where the principle means of counting particles was the optical microscope, with particles sized by the longest dimension per ARP598. When APC's came in to use this provided a method of analysing a sample much faster than the ARP598 method. A method of calibrating APC's was developed, although they measured area and not length, such that comparable results to that of ARP598 could be obtained from the same sample. Now, APC's are the primary method used to count particles and the projected area of a particle determines size. Because of the way particles are sized with the two methods, APC's and optical microscopes do not always provide the same results. ***NAS 1638 has now been made inactive for new design and has been revised to indicate it does not apply to use of APC's.***

Prior to ISO 11171, the previous APC calibration method most widely utilised was ISO 4402, which used Air Cleaner Fine Test Dust (ACFTD) as the reference calibration material. ACFTD is no longer manufactured and the ISO 4402 method using this dust has been made obsolete. The industry developed the method ISO 11171, which supersedes ISO 4402, with a calibration standard based on NIST-certified samples of ISO 12103-1 A3 medium test dust suspended in hydraulic oil. There is a difference between the particle measurements by ISO 4402 and ISO 11171. To retain the same cleanliness measure, calibrations using ISO 11171 are conducted to a corrected particle count scale. For example, particles reported as 5 um with the ISO 4402 method are reported as 6 um (c) by the ISO 11171 method. In fact 5 um corresponds to 6.4 um (c), and some round off was conducted for simplification.

Particle size analysis

Several methods and instruments based on different physical principles are used to determine the size distribution of the particles suspended in aeronautical fluids. The numbers of particles found in the different size ranges characterize this distribution. A single particle therefore has as many equivalent diameters as the number of counting methods used.

Figure 1 shows the size given to the particle being analysed (shading) by a microscope as its longest chord and an APC calibrated in accordance with ISO 11171 using the Standard Reference Material NIST SRM 2806 sized by the equivalent projected area.



Differences between NAS 1638 and AS4059E.

AS4059E was developed as a replacement/equivalent to the obsolete NAS 1638 format, where table 2 relates to the old AS4059D standard and table 1 is the equivalent NAS1638 standard. However, there are differences. Particularly in Table 2, (Cumulative Particle Counts).

Counting of Smaller Particles.

AS4059E allows the analysis and reporting of smaller particle sizes than NAS 1638.

Counting Large Particles and Fibres.

In some samples, it has been observed that many of the particles larger than 100 micrometers are fibres. However, APC's size particles based on projected area rather than longest dimension and do not differentiate between fibres and particles. Therefore, fibres will be reported as particles with dimensions considerably less than the length of the fibres. A problem with fibres is that they may not be present in fluid in the system but rather have been introduced as the result of poor sampling techniques or poor handling during analysis.

Determining AS4059E Class Using Differential Particle Counts:

This method is applicable to those currently using NAS 1638 classes and desiring to maintain the methods/format, and results equivalent to those specified in NAS 1638.

Table 1 applies to acceptance criteria based on differential particle counts, and provides a definition of particulate limits for Classes 00 through 12. A class shall be determined for each particle size range. The reported class of the sample is the highest class in any given particle range size.

NOTE: The classes and particle count limits in Table 1 are identical to NAS 1638. Measurements of particle counts are allowed by use of an automatic particle counter (calibrated per ISO 11171 or ISO 4402:1991), or an optical or electron microscope. The size ranges measured and reported should be determined from Table 1 based on the measurement method.

Determing AS4059E Class Using Cumulative Particle Counts:

This method is applicable to those using the methods of previous revisions of ÅS4059 and/or cumulative particle counts. The cleanliness levels for this method shall be specified by the appropriate class from Table 2. To provide versatility, the applicable cleanliness class can be identified in the following ways:

a. Basing the class on the highest class of multiple size ranges .

b. Total number of particles larger than a specific size.

c. Designating a class for each size range.

Designating a Class for Each Size Range:

APC's can count the number of particles in several size ranges. Today, a different class of cleanliness is often desired for each of several size ranges. Requirements can be stated and cleanliness can easily be reported for a number of size ranges. A class may be designated for each size from A through F*. An example is provided below:

7B/6C/5D is a numeric-alpha representation in which the number designates the cleanliness class and the alphabetical letter designates the particle size range to which the class applies. It also indicates that the number of particles for each size range do not exceed the following maximum number of particles:

Size B: 38,924 per 100 ml

Size C: 3462 per 100 ml

Size D: 306 per 100 ml

*Please check standard for definition of size/classes

Methods of taking samples from hydraulic applications using appropriate recepticles

ENSURE THAT ALL DANGERS ARE ASSESSED AND THE NECESSARY PRECAUTIONS TAKEN DURING THE SAMPLING PROCESS.

DISPOSAL OF FLUID SAMPLES MUST FOLLOW PROCEDURES RELATING TO COSHH.

Sampling procedures are defined in ISO4021. Extraction of fluid samples from lines of an operating system.

Receptacles should be cleaned in accordance with DIN/1505884.

The degree of cleanliness should be verified to ISO3722.

Methods of taking sample from hydraulic applications, using appropriate recepticles

Methods One & Two

Method One – Preferred method
(Using a suitable sampling valve with PTFE seating method)

1. Install sampling valve in pressure or return line (in closed condition) at an appropriate point under constant flow or turbulent conditions
2. Operate system for at least 30 minutes before taking a sample
3. Clean outside of sampling valve
4. Open the sampling valve to give appropriate flow rate and flush at least one litre of fluid through the valve

   Do Not Close Valve After Flushing
5. Remove cap from sampling bottle. Ensure cap is retained in hand face downwards
6. Place bottle under sampling valve. Fill bottle to neck. Cap bottle & wipe.
7. Close the sampling valve
8. Label the bottle with the necessary information for analysis e.g. Oil type, running hours, system description etc.

Method Two – Preferred method
(Using an unspecified sampling valve)

1. Install valve in return line or an appropriate point where flow is constant and does not exceed 14 bar
2. Operate system for at least 30 minutes before taking a sample
3. Flush sampling valve by passing at least 45 litres through valve back to reservoir
4. Disconnect line from valve to reservoir with valve open and fluid flowing

Methods of taking sample from hydraulic applications, using appropriate recepticles

Methods Three & Four

Method Three - Reservoir sampling

(Use only if methods One & Two cannot be used)

- Operate system for at least one hour before taking a sample
- Thoroughly clean area around the point of entry to the reservoir
- Attach sample bottle to the sampling device
- Carefully insert sampling hose into the midway point of the reservoir. Try not to touch sides or baffles within the reservoir
- Extract sample using the vacuum pump and fill to approx 75% volume
- Release vacuum, disconnect bottle and discard fluid
- **Repeat the above three steps three times to ensure flushing of the equipment**
- Attach ultra cleaned sample bottle to sampling device – collect final fluid sample
- Remove bottle from sampling device & cap - label with appropriate information

Method Four – Bottle Dipping

(Least preferred method due to possible high ingression of contamination

- Operate system for at least one hour before taking a sample
- Thoroughly clean area around the point of entry to the reservoir where sample bottle is to be inserted
- Clean outside of ultra clean sample bottle using filtered solvent, allow to evaporate dry
- Dip sample bottle into reservoir, cap and wipe
- Re-seal reservoir access
- Label the bottle with the necessary information for analysis e.g. Oil type, running hours, system description etc.

Cleanliness Reporting Formats

ISO 4406:1999 Cleanliness Code System

The International Standards Organisation standard ISO 4406:1999 is the preferred method of quoting the number of solid contaminant particles in a sample.

The code is constructed from the combination of three scale numbers selected from the following table.

The ***first*** scale number represents the number of particles in a millilitre sample of the fluid that are larger than 4 μm(c).

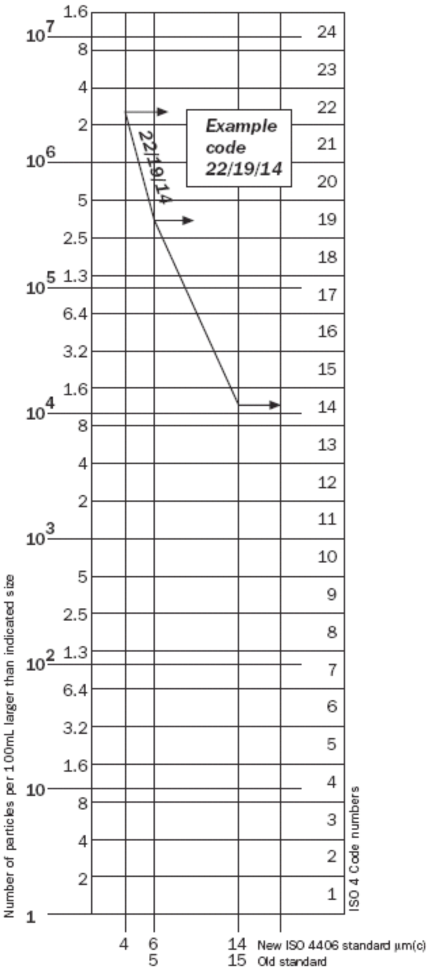
The ***second*** number represents the number of particles larger than 6 μm(c).

The ***third*** number represents the number of particles that are larger than 14 μm(c).

Number of Particles per mL		*Scale No.*
More than	*Up to and including*	
2.5M	-	> 28
1.3M	2.5M	28
640k	1.3M	27
320k	640k	26
160k	320k	25
80k	160k	24
40k	80k	23
20k	40k	22
10k	20k	21
5000	10k	20
2500	5000	19
1300	2500	18
640	1300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5.0	9
1.3	2.5	8
0.64	1.3	7
0.32	0.64	6
0.16	0.32	5
0.08	0.16	4
0.04	0.08	3
0.02	0.04	2
0.01	0.02	1
0.0	0.01	0

Table 5 - ISO 4406 Allocation of Scale Numbers

Microscope counting examines the particles differently to APCs and the code is given with two scale numbers only. These are at 5 μm and 15 μm equivalent to the 6 μm(c) and 14 μm(c) of the APCs.



ISO 4406
Cleanliness Code Chart
(with 100mL sample volume)

Classes of Contamination According to NAS 1638

The NAS system was originally developed in 1964 to define contamination classes for the contamination contained within aircraft components. The application of this standard was extended to industrial hydraulic systems simply because nothing else existed at the time.

The coding system defines the maximum numbers permitted of 100ml volume at various size intervals (differential counts) rather than using cumulative counts as in ISO 4406:1999.

Although there is no guidance given in the standard on how to quote the levels, most industrial users quote a single code which is the highest recorded in all sizes and this convention is used on MP Filtri's APC's.

CONTAMINATION LEVEL CLASSES according to NAS 1638 (January 1964)
The contamination classes are defined by a number (from 00 to 12) which indicates the maximum number of particles per 100 ml, counted on a differential basis, in a given size bracket.

Classes of Contamination According to NAS 1638

MAXIMUM CONTAMINATION LIMITS (PER 100 mL)

Size Range Classes (in microns)

	00	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
5-15	125	250	500	1000	2000	4000	8000	16000	32000	64000	128000	256000	512000	1024000
15-25	22	44	89	178	356	712	1425	2850	5700	11400	22800	45600	91200	182400
25-50	4	8	16	32	63	126	253	506	1012	2025	4050	8100	16200	32400
50-100	1	2	3	6	11	22	45	90	180	360	720	1440	2880	5760
Over 100	0	0	1	1	2	4	8	16	32	64	128	256	512	1024

SAE AS 4059 REV.E**

Cleanliness Classification for Hydraulic Fluids (SAE Aerospace Standard)

This SAE Aerospace Standard (AS) defines cleanliness levels for particulate contamination of hydraulic fluids and includes methods of reporting data relating to the contamination levels.

Tables 1 and 2 below provide differential and cumulative particle counts respectively for counts obtained by an automatic particle counter, e.g. LPA2.

TABLE 1 - Cleanliness Classes for Differential Particle Counts

MAXIMUM CONTAMINATION LIMITS (PARTICLES/100ml)

	Size	6 to 14 µm (c)	14 to 21 µm (c)	21 tp 38 µm (c)	38 to 70 µm (c)	> 70 µm (c)
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	1,425	253	45	8
	6	16,000	2,850	506	90	16
	7	32,000	5.700	1,012	180	32
	8	64,000	11,400	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

SAE AS 4059 REV.E**

Cleanliness Classification for Hydraulic Fluids (SAE Aerospace Standard)

TABLE 2 - Cleanliness Classes for Cumulative Particle Counts

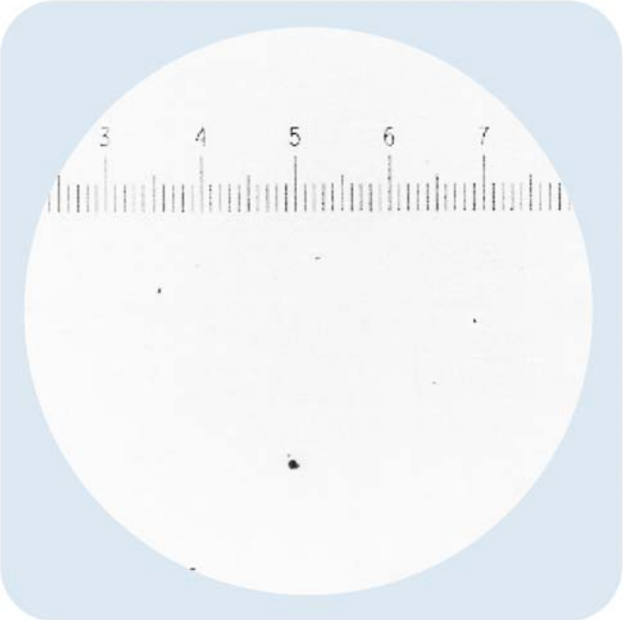
MAXIMUM CONTAMINATION LIMITS (PARTICLES/100ml)

	Size	>4 µm (c)	>6 µm (c)	>14 µm (c)	>21 µm (c)	>38 µm (c)	>70 µm (c)
	Size Code	A	B	C	D	E	F
CLASSES	000	195	76	14	3	1	0
	00	390	152	27	5	1	0
	0	780	304	54	10	2	0
	1	1,560	609	109	20	4	1
	2	3,120	1,217	217	39	7	1
	3	6,250	2,432	432	76	13	2
	4	12,500	4,864	864	152	26	4
	5	25,000	9,731	1,731	306	53	8
	6	50,000	19,462	3,462	612	106	16
	7	100,000	38,924	6,924	1,224	212	32
	8	200,000	77,849	13,849	2,449	424	64
	9	400,000	155,698	27,698	4,898	848	128
	10	800,000	311,396	55,396	9,796	1,696	256
	11	1,600,000	622,792	110,792	19,592	3,392	512
	12	3,200,000	1,245,584	221,584	39,184	6,784	1,024

*** The information reproduced on this and the previous page is a brief extract from SAE AS4059 Rev.E, revised in May 2005. For further details and explanations refer to the full Standard.*

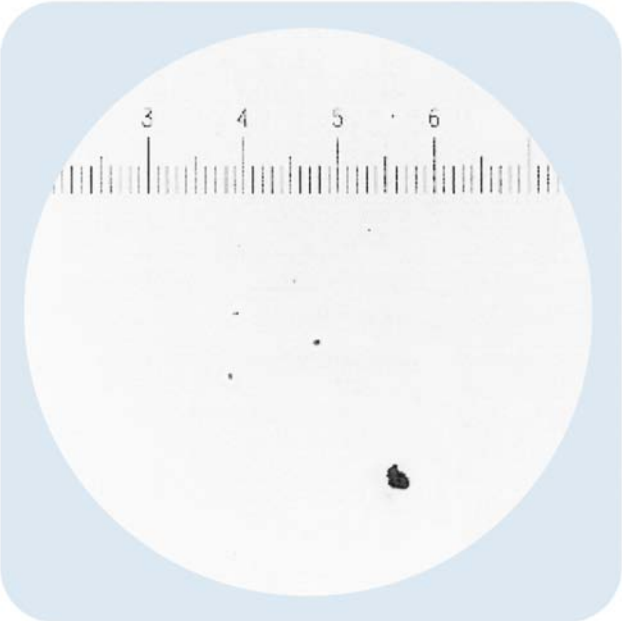
ISO 4406:1999	**Class 14/12/9**
SAE AS4059E Table 1	**Class 3**
NAS 1638	**Class 3**
SAE AS4059E Table 2	**Class 4A/3B/3C**

1 graduation= 10 µm



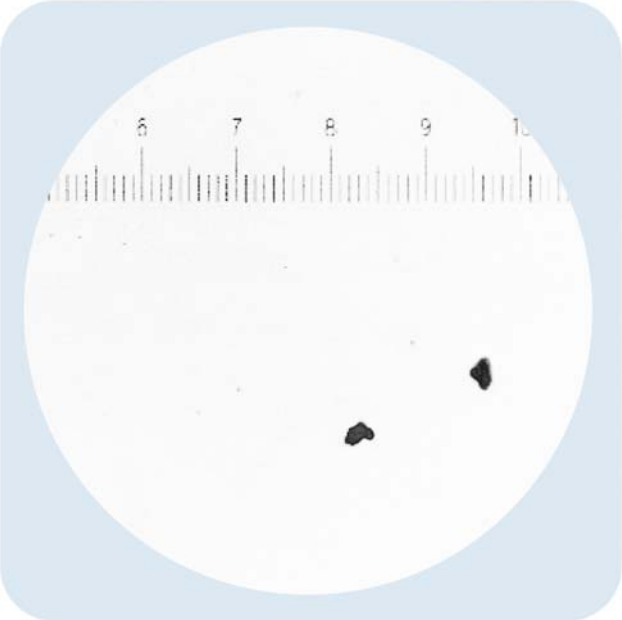
ISO 4406:1999 Class 15/13/10
SAE AS4059E Table 1 Class 4
NAS 1638 Class 4
SAE AS4059E Table 2 Class 5A/4B/4C

1 graduation= 10 µm



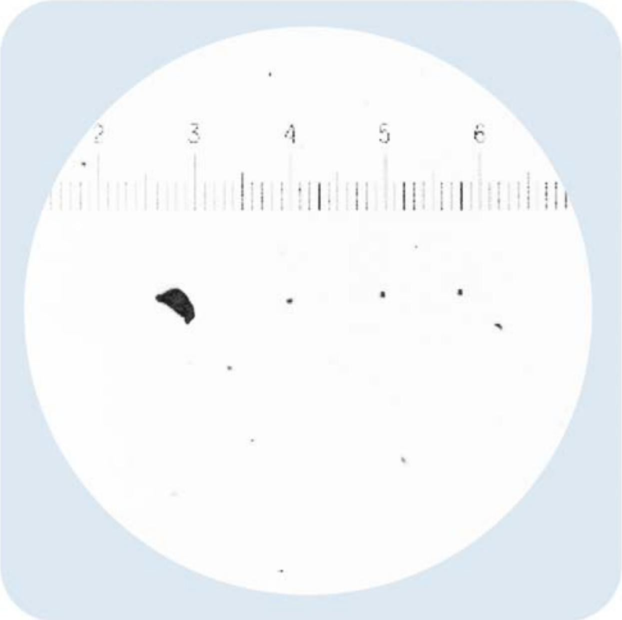
ISO 4406:1999	**Class 16/14/11**
SAE AS4059E Table 1	**Class 5**
NAS 1638	**Class 5**
SAE AS4059E Table 2	**Class 6A/5B/5C**

1 graduation= 10 μm



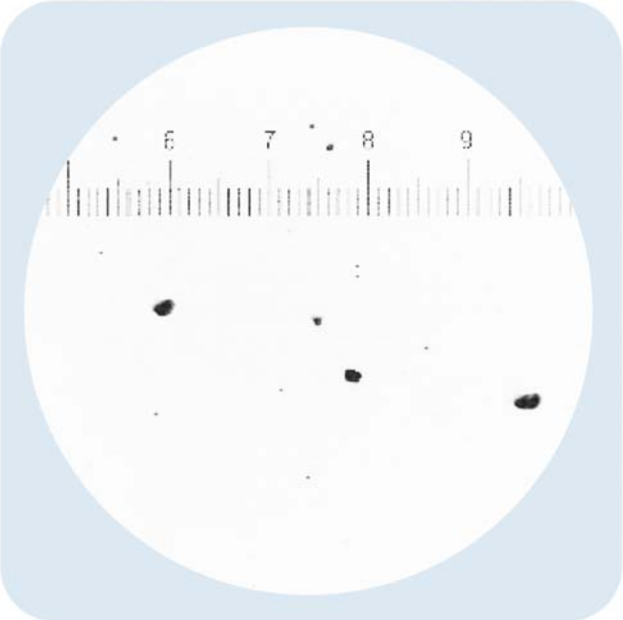
ISO 4406:1999	**Class 17/15/12**
SAE AS4059E Table 1	**Class 6**
NAS 1638	**Class 6**
SAE AS4059E Table 2	**Class 7A/6B/6C**

1 graduation= 10 µm



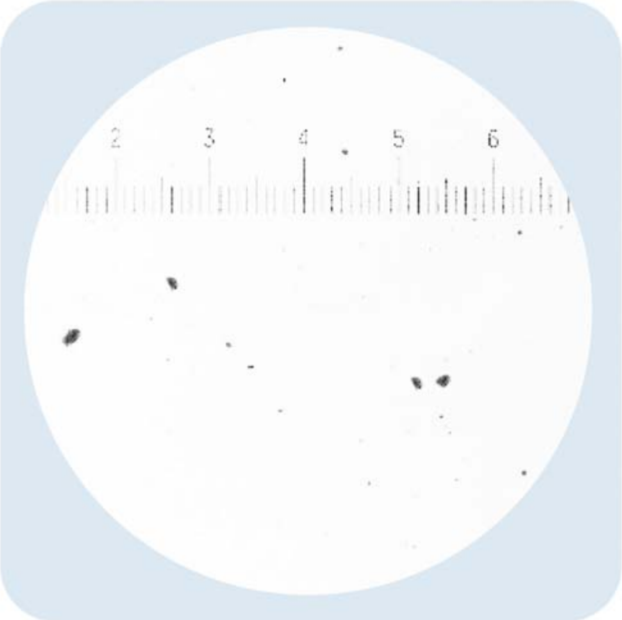
ISO 4406:1999	Class 18/16/13
SAE AS4059E Table 1	Class 7
NAS 1638	Class 7
SAE AS4059E Table 2	Class 8A/7B/7C

1 graduation= 10 µm



ISO 4406:1999	**Class 19/17/14**
SAE AS4059E Table 1	**Class 8**
NAS 1638	**Class 8**
SAE AS4059E Table 2	**Class 9A/8B/8C**

1 graduation= 10 µm

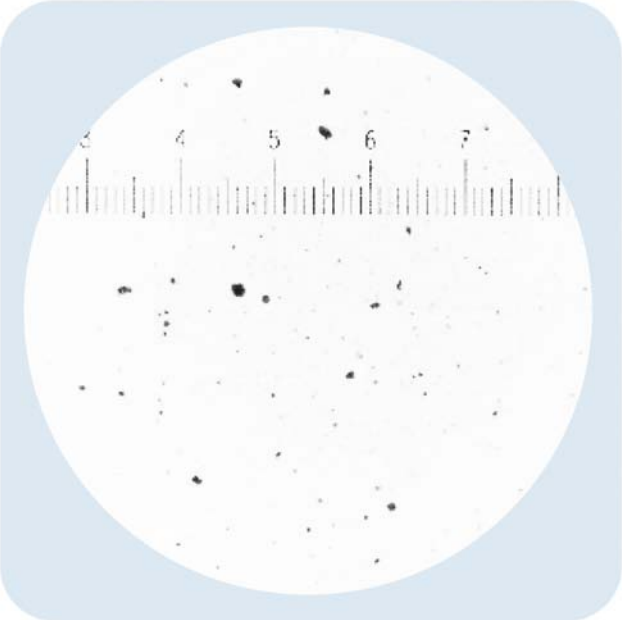


ISO 4406:1999	**Class 20/18/15**
SAE AS4059E Table 1	**Class 9**
NAS 1638	**Class 9**
SAE AS4059E Table 2	**Class 10A/9B/9C**

1 graduation= 10 µm

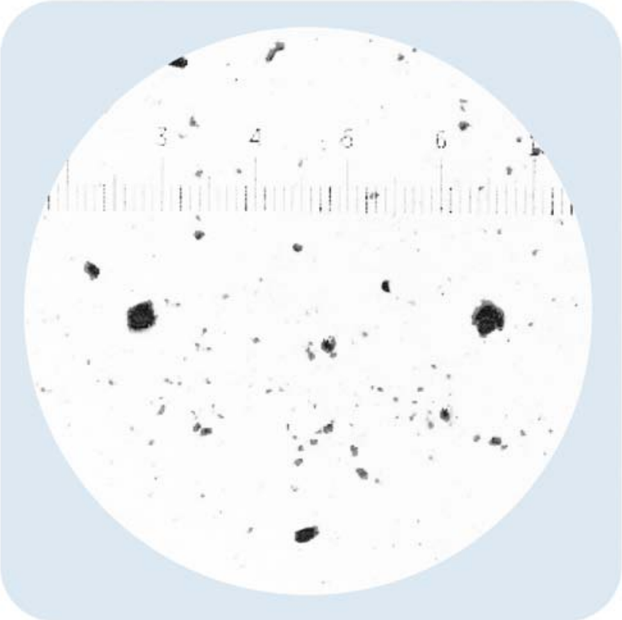
ISO 4406:1999	**Class 21/19/16**
SAE AS4059E Table 1	**Class 10**
NAS 1638	**Class 10**
SAE AS4059E Table 2	**Class 11A/10B/10C**

1 graduation= 10 µm



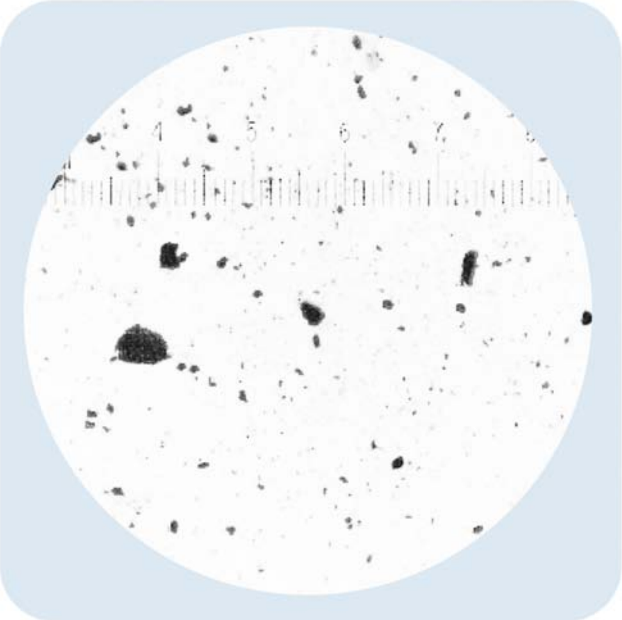
ISO 4406:1999 Class 22/20/17
SAE AS4059E Table 1 Class 11
NAS 1638 Class 11
SAE AS4059E Table 2 Class 12A/11B/11C

1 graduation= 10 µm



ISO 4406:1999	**Class 23/21/18**
SAE AS4059E Table 1	**Class 12**
NAS 1638	**Class 12**
SAE AS4059E Table 2	**Class 13A/12B/12C**

1 graduation= 10 µm



Hydraulic Component Manufacturer's*** Recommendations

Most component manufacturers know the proportionate effect that increased dirt level has on the performance of their components and issue maximum permissible contamination levels. They state that operating components on fluids which are cleaner than those stated will increase life.

However, the diversity of hydraulic systems in terms of pressure, duty cycles, environments, lubrication required, contaminant types, etc, makes it almost impossible to predict the components service life over and above that which can be reasonably expected.

Furthermore, without the benefits of significant research material and the existence of standard contaminant sensitivity tests, manufacturers who publish recommendations that are cleaner than competitors may be viewed as having a more sensitive product.

Hence there may be a possible source of conflicting information when comparing cleanliness levels recommended from different sources.

The table opposite gives a selection of maximum contamination levels that are typically issued by component manufacturers. These relate to the use of the correct viscosity mineral fluid. An even cleaner level may be needed if the operation is severe, such as high frequency fluctuations in loading, high temperature or high failure risk.

Hydraulic Component Manufacturer's*** Recommendations

Unit	*Type*	*ISO 4406 Code*
PUMP	Piston (slow speed, in-line)	22/20/16
	Piston (high speed, variable)	17/15/13
	Gear	19/17/15
	Vane	18/16/14
MOTOR	Axial piston	18/16/13
	Radial piston	19/17/13
	Gear	20/18/15
	Vane	19/17/14
VALVE	Directional (solenoid)	20/18/15
	Pressure control (modulating)	19/17/14
	Flow control	19/17/14
	Check valve	20/18/15
	Cartridge valve	20/18/15
	Proportional	18/16/13
	Servovalve	16/14/11
ACTUATOR		20/18/15

Typical Manufacturer's Recommendations for Component Cleanliness (ISO 4406)

*** It should be noted that the recommendations made in this table should be viewed as starting levels and may have to be modified in light of operational experiences or user requirements.

Hydraulic System Target Cleanliness Levels****

Where a hydraulic system user has been able to check cleanliness levels over a considerable period, the acceptability, or otherwise, of those levels can be verified. Thus if no failures have occurred, the average level measured may well be one which could be made a bench mark. However, such a level may have to be modified if the conditions change, or if specific contaminant-sensitive components are added to the system. The demand for greater reliability may also necessitate an improved cleanliness level.

The level of acceptability depends on three features

- the contamination sensitivity of the components
- the operational conditions of the system
- the required reliability and life expectancy

Contamination codes ISO 4406			*Correspondent codes NAS 1638*	*Recommended filtration degree*	*Typical applications*
4μm(c)	*6μm(c)*	*14μm(c)*		*B x ≥200*	
14	12	9	3	3	High precision and laboratory servo-systems
17	15	11	6	3-6	Robotic and servo-systems
18	16	13	7	10-12	Very sensitive - high reliability systems
20	18	14	9	12-15	Sensitive - reliable systems
21	19	16	10	15-25	General equipment of limited reliability
23	21	18	12	25-40	Low - pressure equipment not in continuous service

Cleanliness Code Comparison

ISO 4406 >4µm(c)/>6µm(c)/14µm(c)	SAE ASA059 Table 2 >4µm(c)/>6µm(c)/14µm(c)	SAE ASA059 Table 1 4-6, 6-14, 14-21, 21-38, 38-70, >70	NAS 1638 5-15, 15-25, 25-50, 50-100, >100
23/21/18	13A/12B/12C	12	12
22/20/17	12A/11B/11C	11	11
21/19/16	11A/10B/10C	10	10
20/18/15	10A/9B/9C	9	9
19/17/14	9A/8B/8C	8	8
18/16/13	8A/7B/7C	7	7
17/15/12	7A/6B/6C	6	6
16/14/11	6A/5B/5C	5	5
15/13/10	5A/4B/4C	4	4
14/12/09	4A/3B/3C	3	3

Standards

**** Although ISO 4406 standard is being used extensively within the hydraulics industry other standards are occasionally required and a comparison may be requested. The table above gives a very general comparison but often no direct comparison is possible due to the different classes and sizes involved.

Measuring WATER in hydraulic and lubricating fluids

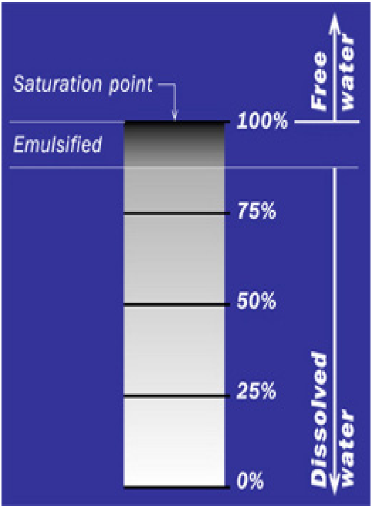
In mineral oils and non-aqueous fire resistant fluids water is undesirable. Mineral oil usually has a water content of 50-300ppm which it can support without adverse consequences. Once the water content exceeds about 500ppm the oil starts to appear hazy.

Above this level there is a danger of free water accumulating in the system in areas of low flow. This can lead to corrosion and accelerated wear. Similarly, fire resistant fluids have a natural water content which may be different to mineral oil. (From North Notts Fluid Power Centre)

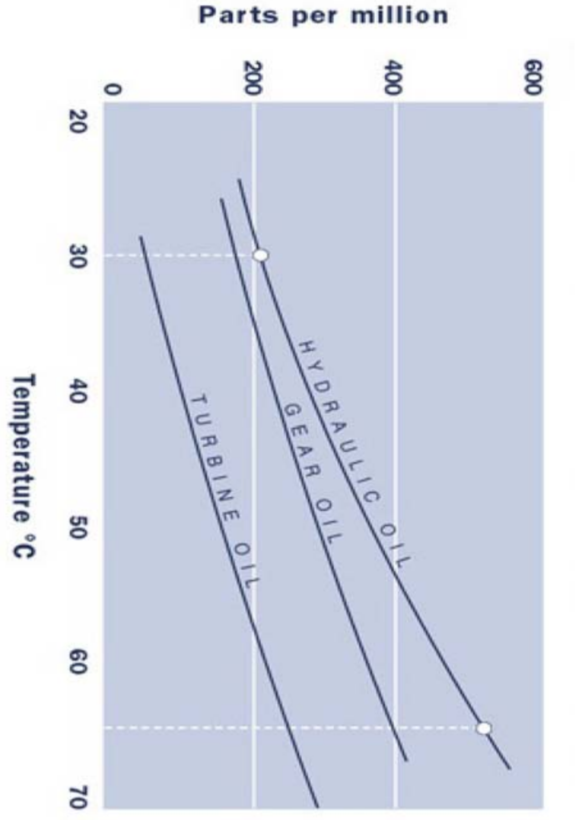
Saturation Levels

Since the effects of free (also emulsified) water is more harmful than those of dissolved water, water levels should remain well below the saturation point. However, even water in solution can cause damage and therefore every reasonable effort should be made to keep saturation levels as low as possible.

There is no such thing as too little water. As a guideline, we recommend maintaining saturation levels below 50% in all equipment.



Typical Water Saturation Levels - For new oils



Examples: Hydraulic oil @ 30°C = 200ppm = 100% saturation
Hydraulic oil @ 65°C = 500ppm = 100% saturation

Contamination Monitoring Products

VPAF – 100

A simple way to check the fluid used in hydraulic applications is to verify the contamination of solid particles ; the KIT “VPAF – 100” is suitable for checking these contaminants.

LPA2 – Twin Laser Particle Analyser

The **LPA2** is a highly precise, lightweight & fully portable instrument suitable for on-site and laboratory applications. It can automatically measure and display particulate contamination, moisture and temperature levels in various hydraulic fluids.

CML2 – Compact Laser Particle Analyser

The CML2 is a compact, super lightweight mains operated unit for on-site and laboratory applications. It can automatically measure and display particulate contamination, moisture and temperature levels in various hydraulic fluids.

Contamination Monitoring Products

BS110 & BS250 – Bottle Samplers

The BS110 & BS250 bottle samplers are suitable for off line and laboratory applications where fluid sampling at point of use is inaccessible or impractical. A fluid de-aeration facility comes as standard.

PML2 – Permanently Mounted Laser Particle Analyser

The PML2 is a pressure dependant in-line product intended for on-site and industrial applications. It can automatically measure and display particulate contamination, moisture and temperature levels in various hydraulic fluids.

ICM - Inline Contamination Monitor

The ICM automatically measures and displays particulate contamination, moisture and temperature levels in various hydraulic fluids. It is designed specifically to be mounted directly to systems, where ongoing measurement or analysis is required, and where space and costs are limited.

The complete range of Contamination Monitoring Products

When contamination is
the problem,
we have the solution.

MPFILTRI®

Fluid Condition Handbook

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