Contamination Control Fundamentals

Why Filter?

Over 90% of all hydraulic system failures are caused by contaminants in the fluid. Even when no immediate failures occur, high contamination levels can sharply decrease operating efficiency.

Contamination is defined as any substance which is foreign to a fluid system and damaging to its performance. Contamination can exist as a gas, liquid or solid. Solid contamination, generally referred to as *particulate contamination*, comes in all sizes and shapes and is normally abrasive.

High contaminant levels accelerate component wear and decrease service life. Worn components, in turn, contribute to inefficient system operation, seizure of parts, higher fluid temperatures, leakage, and loss of control. All of these phenomena are the result of direct mechanical action between the contaminants and the system components. Contamination can also act as a catalyst to accelerate oxidation of the fluid and spur the chemical breakdown of its constituents.

Filtering a system's fluid can remove many of these contaminants and extend the life of system components.

How a System Gets Contaminated

Contaminants come from two basic sources: they either enter the system from outside (ingestion) or are generated from within (ingression). New systems often have contaminants left behind from manufacturing and assembly operations. Unless they are filtered as they enter the circuit, both the original fluid and make-up fluid are likely to contain more contaminants than the system can tolerate. Most systems ingest contaminants through such components as inefficient air breathers and worn cylinder rod seals during normal operation. Airborne contaminants are likely to gain admittance during routine servicing or maintenance. Also, friction and heat can produce internally generated contamination.

Figure 1. Typical Examples of Wear Due to Contamination

Vanes for Vane Pump — Relief Valve Piston — Vane Pump Cam Ring

Size of Solid Contaminants

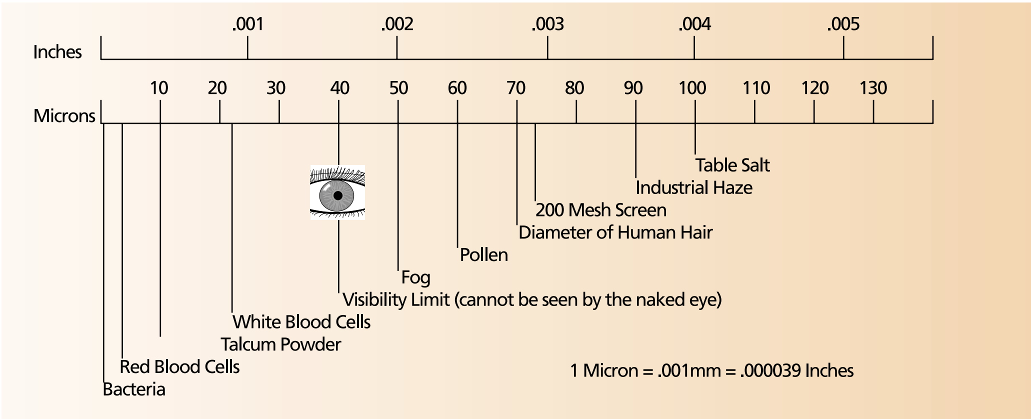
The size of solid particle contaminants is commonly measured in micrometers, μm, (usually referred to as microns, μ). A *micron* is a unit of length equal to one millionth of a meter or about .00004 inch. Particles that are less than 40 μ cannot be detected by the human eye.

Figure 2 shows the sizes of some common substances. To gain some perspective, consider the diameters of the following substances:

Substance	Microns	Inches
Grain of table salt	100 μ	.0039″
Human hair	70 μ	.0027″
Talcum powder	10 μ	.00039″
Bacteria (average)	2 μ	.000078″

A *micron rating* identifies the size of particles that a particular filtration media will remove. For instance, Schroeder Z3 filter media is absolute rated at $\beta_3 \geq 200$, meaning that it can remove particles of 3 μ and greater at 99.5% efficiency.

Figure 2. Sizes of Known Particles in Inches and Microns



How Contaminants are Measured and Reported– Changes in the Industry

In hydraulic fluid power systems, power is transmitted and contained through a liquid under pressure within an enclosed circuit. These fluids all contain a certain amount of solid particle contaminants. The amount of particulate contaminants present in a hydraulic or lubrication system's fluid is commonly referred to as its *cleanliness level*.

Recent changes in measuring and defining the cleanliness of fluid systems have created a shift in the way the size and amount of solid contaminants are reported. In 1999, the International Standards Organization (ISO) introduced a series of new fluid cleanliness standards that reflect these changes. These new standards are summarized in Table 1.

Table 1. Changes in Industry Standards

Old	New	Description
ISO 4402	ISO 11171	Automatic Particle Counter (APC) calibration procedures (ACFTD to ISO MTD)
ISO 4406	ISO 4406:1999	ISO Range Code
ISO 4572	ISO 16889	Multi-pass test reports

The change in calibration procedures (ISO 4402 to ISO 11171) occurred for two reasons. First, the industry developed a new standard test dust for calibration fluid. This new ISO Medium Test Dust (ISO MTD) replaced the previously used AC Fine Test Dust (ACFTD), which is no longer available. Secondly, there has been a change in how particle sizes are measured. By way of newer technologies, particles are now measured in two dimensions, whereas in the past they had been measured using the largest dimension (chord). Older technology was not as precise as it is today, and particle sizes reported were less than accurate. Table 2 shows that what used to be classified as a 2 μ particle is now classified as a 4.6 μ(c) particle. The (c) denotes that particle size measurements are certified using an Automatic Particle Counter (APC) which has been calibrated in accordance with ISO 11171.

ISO 11171 calls for the use of ISO MTD dust and changes the way we report the number of particles based on the new distribution of particles in the new standard reference material (SRM2806). Today, the ISO Medium Test Dust and the new calibration standard (11171) are used to synchronize all APC's. This change was made in an effort to reduce variability in tests conducted in different laboratories around the world.

How will these changes affect you?

In comparing the old standards to the new, **the following have not changed:**

- The amount and the size of solid contamination in your system is still the same!
- The filters still work the same way!

What has changed:

- The way particle size is specified has changed.

The new standards and reporting methods "move the measuring stick" to correct for the inaccurate calibration assumptions made over the past 40 years.

Particle Size Definitions– ISO 4402 vs. ISO 11171

This change in the way contaminants are measured had the net effect of changing the classification of the size of the particle.

Table 2. A Comparison of Particle Size Classification

ISO 4402 (ACFTD)	ISO 11171 (ISO MTD)
<1.0 µ	4.0 µ(c)
1.0 µ	4.2 µ(c)
2 µ	4.6 µ(c)
3 µ	5.1 µ(c)
5 µ	6.4 µ(c)
10 µ	9.8 µ(c)
15 µ	13.6 µ(c)
20 µ	17.5 µ(c)
25 µ	21.2 µ(c)
Old Size per ISO 4402	New Size per ISO 11171

Note that the size of the particles is reported differently; i.e., a particle 1.0 µ in size under ISO 4402 is now considered to be 4.2 µ(c) in size. **Keep in mind that the particles are actually the same size they have always been; we are just using a different ruler.**

ISO Scale Numbers– ISO 4406 vs. ISO 4406:1999

ISO 4406:1999 provides guidelines for defining the level of contamination present in a fluid sample in terms of an ISO rating. Due to the change in the specification of particle sizes shown in Table 2, the definition of the ISO scale (or range) numbers needed to be redefined. Tables 3(a) and 3(b) provide a comparison of ISO scale numbers under ISO 4406 and 4406:1999, respectively.

Another change involved the addition of a third scale number to define an ISO rating. Under the old ISO 4406, the ISO scale numbers represented the number of particles greater than or equal to 5 µ and 15 µ in size. The new ISO 4406:1999 uses three scale numbers, representing the number of particles greater than or equal to 4 µ(c), 6 µ(c), and 14 µ(c) in size.

Figure 3(a) shows the graph used to plot particle counts per ISO 4406. When the count of particles ≥5 µ and ≥15 µ in size are plotted, the corresponding ISO rating can be determined graphically. Two micron (2 µ) levels are optional, as they are not a required part of the old ISO 4406 standard.

Similarly, Figure 3(b) shows the graph used to plot particle counts per ISO 4406:1999. This figure shows how 4406:1999 is different from the old ISO 4406 in that it plots the cleanliness level based on the number of particles at the 4 µ(c)/6 µ(c)/14 µ(c) sizes per 1 mL of fluid.

Also, Schroeder previously measured the number of particles per 100 mL of sample fluid. Under ISO 4406:1999, we now report the number of particles per 1 mL of sample fluid.

It is important to note that net effect of all these changes keeps the ISO rating unchanged. In other words, a fluid that was determined to have an ISO rating of 18/15/13 under ISO 4406 will still have an ISO rating of 18/15/13 under ISO 4406:1999.

Figure 3(a). Graphing Particle Counts per ISO 4406

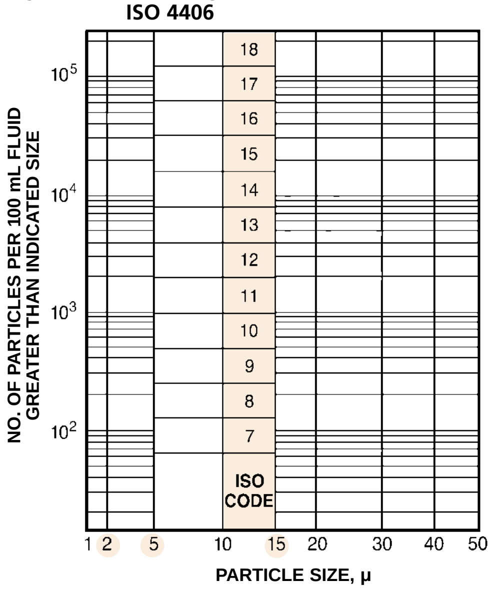


Figure 3(b). Graphing Particle Counts per ISO 4406:1999

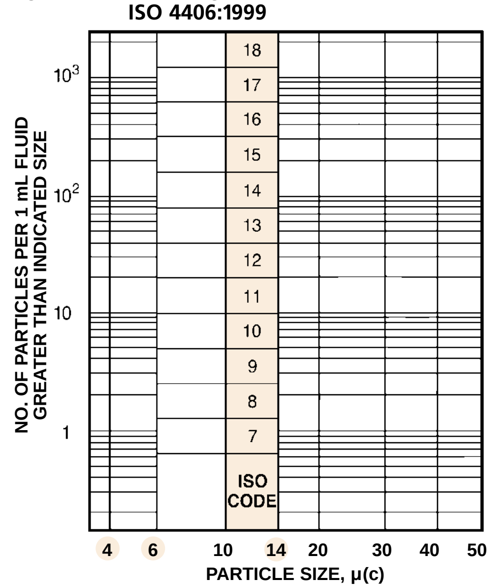


Table 3(a). ISO Code 4406 Hydraulic Fluid Power–Solid Contamination Code

Number of Particles per 100 mL of Fluid		Scale Number
More Than	Up to and Including	
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
16	32	5
8	16	4
4	8	3
2	4	2
1	2	1

Old ISO codes are commonly made up of 2 scale numbers representing the number of particles ≥5 μ and ≥15 μ. Showing a third scale number, ≥2 μ is optional. The left number will **always** be larger. The scale numbers are defined such that each successive scale is generally a doubling of the previous scale. *The particle count can be expressed as the number of particles per mL or per 100 mL,* but the ISO range numbers and the ISO codes do not change.

Table 3(b). ISO 4406:1999 Hydraulic Fluid Power – Solid Contamination Code (New)

Number of Particles per 1 mL of Fluid		Scale Number
More Than	Up to and Including	
1,300,000	2,500,000	28
640,000	1,300,000	27
320,000	640,000	26
160,000	320,000	25
80,000	160,000	24
40,000	80,000	23
20,000	40,000	22
10,000	20,000	21
5,000	10,000	20
2,500	5,000	19
1,300	2,500	18
640	1,300	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	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
0.00	0.01	0

- New ISO codes are made up of 3 numbers representing the number of particles ≥4 μ(c), ≥6 μ(c) and ≥14 μ(c). *The particle count is expressed as the number of particles per mL.*
- Reproducibility below scale number 8 is affected by the actual number of particles counted in the fluid sample. Raw counts should be more than 20 particles. If this is not possible, then refer to bullet below.
- When the raw data in one of the size ranges results in a particle count of fewer than 20 particles, the scale number for that size range shall be labeled with the symbol ≥.

EXAMPLE: A code of 14/12/≥7 signifies that there are more than 80 and up to and including 160 particles equal to or larger than 4 μ(c) per mL and more than 20 and up to and including 40 particles equal to or larger than 6 μ(c) per mL. The third part of the code, ≥7 indicates that there are more than 0.64 and up to and including 1.3 particles equal to or larger than 14 μ(c) per mL. The ≥ symbol indicates that less than 20 particles were counted, which lowers statistical confidence. Because of this lower confidence, the 14 μ(c) part of the code could actually be higher than 7, thus the presence of the ≥ symbol.

Cleanliness Levels– ISO 4406 vs. ISO 4406:1999

The following example shown in Figures 4(a) and 4(b) compares the cleanliness level, or ISO rating, of a typical petroleum-based fluid sample using both the old ISO Code 4406 and the new ISO Code 4406:1999 rating systems.

The fluid sample contains a certain amount of solid particle contaminants, in various shapes and sizes. Figure 4(a) shows a 100 mL sample that contains 300,000 particles greater than 2 µ in size, 20,000 particles greater than 5 µ in size, and 1,500 particles greater than 15 µ in size.

Since the particle count for contaminants size 2 µ and greater falls between 250,000 and 500,000, the first (optional) ISO range (or scale) number is 19 using Table 3(a). The particle count falls between 16,000 and 32,000 for particles greater than 5 µ, so the second ISO range number is 15. The particle count falls between 1,000 and 2,000 for particles greater than 15 µ, so the third ISO range number is 11. Thus, the cleanliness level for the fluid sample shown in Figure 4(a) per ISO 4406 is ISO 19/15/11.

In Figure 4(b), note that 1 mL of fluid (not per 100 mL) is measured per ISO 4406:1999. Also, the amount of particles at the 4 µ(c)/6 µ(c)/14 µ(c) levels are measured instead of at the 2 µ/5 µ/15 µ levels.

The number of 4 µ(c) particles falls between 2500 and 5000, so the first ISO range number is 19 using Table 3(b). The count for 6 µ(c) particles falls between 160 and 320 particles, so the second ISO range number is 15. The 14 µ(c) particle counts falls between 10 and 20, so the third range number is 11. Therefore, the cleanliness level for the fluid sample shown in Figure 4(b) per ISO 4406:1999 is 19/15/≥11.

Although the ranges for the scale numbers have changed, the resulting ISO Code has not changed.

Figure 4(a). Determining the ISO Rating of a Fluid Using ISO 4406 (Old)

Sample Fluid (100 mL)

Particle Size	Number of Particles
≥ 2 µ	300,000
≥ 5 µ	20,000
≥10 µ	4,000
≥15 µ	1,500
≥20 µ	1,000
≥30 µ	0.3

If Particle Count Falls Between	Scale Number is*
250,000-500,000	19
16,000-32,000	15
1,000-2,000	11

*Source: ISO/DIS 4406

The Sample Fluid is ISO 19/15/11.

optional

Figure 4(b). Determining the ISO Rating of a Fluid Using ISO 4406:1999 (New)

Sample Fluid (1 mL)

Particle Size	Number of Particles
≥ 4 µ(c)	**3,000**
≥ 5 µ(c)	700
≥ 6 µ(c)	**200**
≥10 µ(c)	
≥14 µ(c)	**15**
≥15 µ(c)	
≥20 µ(c)	10
≥30 µ(c)	3

If Particle Count Falls Between	Scale Number is*
2500-5000	19
160-320	**15**
10-20	**11**

*Source: ISO 4406:1999

The Sample Fluid is ISO 19/15/≥11.

*Note: When the raw data in one of the size ranges results in a particle count of fewer than 20 particles the range code for that number for that size range shall be preceded with a ≥ sign.

Required Cleanliness Levels

The pressure of a hydraulic system provides the starting point for determining the cleanliness level required for efficient operation. Table 4 provides guidelines for recommended cleanliness levels based on pressure. In general, Schroeder Industries LLC defines pressure as follows:

Low pressure: 0-500 psi (35 bar)
Medium pressure: 500-1500 psi (35-100 bar)
High pressure: 1500 psi (100 bar) and above

A second consideration is the type of components present in the hydraulic system. The amount of contamination that any given component can tolerate is a function of many factors, such as clearance between moving parts, frequency and speed of operation, operating pressure, and materials of construction. Tolerances for contamination range from that of low pressure gear pumps, which normally will give satisfactory performance with cleanliness levels typically found in new fluid (ISO 19/17/14), to the more stringent requirements for servo-control valves, which need oil that is eight times cleaner (ISO 16/14/11).

Today, many fluid power component manufacturers are providing cleanliness level (ISO code) recommendations for their components. They are often listed in the manufacturer's component product catalog or can be obtained by contacting the manufacturer directly. Their recommendations may be expressed in desired filter element ratings or in system cleanliness levels (ISO codes or other codes). Some typically recommended cleanliness levels for components are provided in Table 5.

Table 4. Cleanliness Level Guidelines Based on Pressure

System Type	Recommended Cleanliness Levels (ISO Code)
Low pressure – manual control	20/18/15 or better
Low to medium pressure – electro-hydraulic controls	19/17/14 or better
High pressure – servo controlled	16/14/11 or better

Table 5. Recommended Cleanliness Levels (ISO Codes) for Fluid Power Components

Components	Cleanliness Levels (ISO Code) 4 μ(c)/6 μ(c)/14 μ(c)
Gear Pump	19/17/14
Piston Pump/Motor	18/16/13
Vane Pump	19/17/14
Directional Control Valve	19/17/14
Proportional Control Valve	18/16/13
Servo Valve	16/14/11

The above is based on data shown in various hydraulic component manufacturers' catalogs. Contact Schroeder Industries LLC for recommendations for your specific system needs.

For your convenience, Table 6 provides a cross reference showing the approximate correlation between several different scales or levels used in the marketplace to quantify contamination. The table shows the code levels used for military standards 1638 and 1246A, as well as the new SAE AS4059 standard.

Table 6. ISO Cleanliness Level Correlation

ISO Code 4 μ(c)/6 μ(c)/ 14 μ(c)	Mil Std. 1638 (1967)	Mil Std. 1246A (1967)	ACFTD Gravimetric Level–mg/L	SAE AS4059 Standard
21/19/16	10			
20/18/15	9			
19/17/14	8	300		
18/16/13	7		1	
17/15/12	6			
16/14/12		200		
16/14/11	5			12
15/13/10	4		.1	11
14/12/9	3			10
13/11/8	2			9
12/10/8		100		8
12/10/7	1			7
12/10/6			.01	6
11/9/6				5