Process Bulletin

Hydraulic System Cleanliness

Executive Summary

Sun Hydraulics Quality Management System complies with the requirements of ISO 9001: 2015. Since 1993, Sun has met these requirements and is ISO 9001 certified through 2023.

Hydraulic system designers need to consider their specific operating conditions, types of hydraulic products used, expected life and reliability, and then implement effective filtration means to control both start-up and ongoing system cleanliness.

Overview

Hydraulic systems must be clean to operate properly and efficiently. At issue is how clean is clean enough? Cleaner is always better, and generally cleaner costs more.

It is not appropriate to have a single, tight specification for cleanliness applicable to all machines, all functions, and all operating conditions. Designers should define a cleanliness specification appropriate, attainable, and cost effective for the particular system considering operating conditions and expected life and reliability.

Schroeder Industries, for example, offers a helpful guide on their website, "Contamination Control Fundamentals" in their Hydraulic & Lube Filtration product catalog. The publication answers the question "What is the required cleanliness?" The section on contamination control is excerpted in Appendix B.

Other references are also instructive, including the Lightning Reference Handbook published by Penton Publishing and available for purchase on the "Hydraulics & Pneumatics" website.

Finally, hydraulic system builders and machine manufacturers gain experience, through both successes and failures, and collect their own intelligence over time about appropriate cleanliness levels for their own products and applications.

Sources of Contamination

Hydraulic system contamination comes from three sources:

- Built-in from the beginning
- Generated internally by moving part wear
- Ingested contamination once the machine begins to operate, typically resulting from atmospheric air exchange and contamination entering thru moving items such as cylinder rods and rotating shafts

Clean components at machine assembly help to control built-in contamination, but some level of contamination is expected in new systems at startup. It is likely the fluid will become cleaner after some operation if well-designed filtration systems are part of the design.

Figure 1 –Sun filter cartridges are part of an integrated hydraulic system cleanliness strategy.

Sun Standards

Sun keeps its cartridge valves, manifolds, and integrated packages clean throughout manufacturing, including packing and shipping. More detailed descriptions of the associated cleanliness practices in our Sarasota facilities are included in the following pages.

Sun’s Fluid Cleanliness Standards and Recommendations (specified in accordance with ISO 4406:1999; (4 µm/6 µm/14 µm) are
as follows:

- Non-Electro-Hydraulic cartridge valves: 19/17/14 (Standard)
- Electro-hydraulic cartridge valves: 15/13/11 (Recommended)

This recommendation from Sun and statements from other manufacturers are necessarily general in nature and serve as a starting point for determining a machine cleanliness specification. Critical high-cycle or high-performance hydraulic systems expected to operate over a long machine life may need cleaner fluid.

Sun Valve Manufacturing & Cleanliness

Clean assembled cartridge valves are the result of robust manufacturing processes, the highest quality machine tools, and a focus on cleanliness and contamination control throughout the complete cartridge manufacturing process. Sun tests cartridges with continuously filtered and monitored oil that meets our product cleanliness specifications.

Hydraulic oil samples are taken from every test stand, analyzed for contamination and reported out on a weekly basis in house. In addition, Sun Hydraulics sends these samples out to an accredited (ISO 4406 and Elemental Spectrum Analysis) third party lab for validation twice a year.

Cartridge Marking

All Sun cartridge bodies are marked by either laser engraving or stamping. After laser engraving, we clean any residue from the cartridges. The stamping process is only done on a relatively small number of valves and does not produce any significant contamination.

Machine Coolant/Lubricant

Sun uses various machine coolants and lubricants during its machining processes. The machine coolant serves to remove debris from the machine processes and is filtered to remove metal filings and contaminants. The machine lubricants and coolants are either aqueous based or oil based and are maintained on a preventative maintenance schedule for replacement at specific intervals. In addition, every machining operator is tasked with cleaning parts after each machining operation.

Figure 2 – A MAFAC parts cleaning system solution.

Washing Systems

Sun uses several types of power jet and MAFAC washing systems (Figure 2) to clean parts prior to assembly. Before washing, we demagnetize the parts to prevent any iron or steel debris from clinging to the parts. In addition to washing the parts, we apply a rust preventative to inhibit rust from forming prior to assembly and test.

Assembly Process

During cartridge assembly, operators additionally inspect the parts for any defects and to ensure our products are free from contamination prior to shipping.

Many of Sun's assembly processes are either fully or semi-automated. These processes contain automated inspection cameras and sensors to insure correct assembly. Tooling and devices used to assemble valves are kept separated from the machining areas and stored in containers designated for specific assembly areas, minimizing the chance of contamination.

Test Stand Filtration

Sun uses industry-standard filtration and monitoring systems to ensure we maintain the specified ISO cleanliness codes outlined in Appendix A.

To maintain specified fluid cleanliness, we change filters on a specified maintenance schedule or if monitors indicate the need. We perform hydraulic functional testing, and clean, filtered hydraulic fluid flushes the valve to aid in removal of any contaminants and to ensure we ship a clean product.

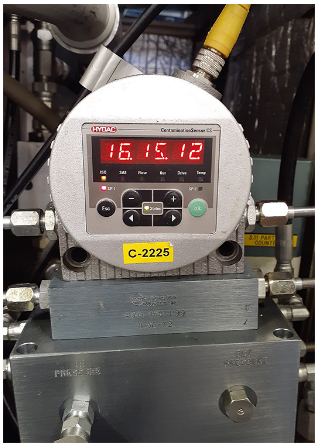


Figure 3 – Particle counter on test stand.

Packing

After testing, we wrap each cartridge in a plastic bag or place in a pocketed bulk-packaged, blow-molded plastic tray. Each cartridge has a very light coating of residual test stand oil, preventing any rusting while in the shipping packages. We then place them in individual cartridge boxes or, if bulk packaged, into corrugated boxes for shipping.

Manifold Manufacturing & Cleanliness

It is Sun Hydraulics' goal to deliver accurately machined, compact, and clean hydraulic manifolds ready for integration into customer systems.

Manifold cleanliness is accomplished by rigorous multi-step processes in the manifold manufacturing. Cleanliness begins at the machining centers with machining sequences staged to minimize burrs and dead spots.

Tooling

Sun is focused on continual improvement in all processes, including tooling, with the following goals:

- Improve finishes
- Increase tool life
- Reduce cycle time
- Improve machining chip removal

Many of our larger cutting tools are high-pressure, coolant-fed tools that help flush out chips and debris (Fig 4). All machine tool coolant systems use 5-µm filters which are on a regular maintenance schedule to ensure machining fluid cleanliness.

In some instances, the machining center sequences include secondary tool insertion and brushing of the passages to insure debris removal. Machine operators manually remove any larger chips at the machining centers during inspection, then blow out the manifolds with compressed air to remove any smaller chips.

Figure 4 – Coolant-fed tools help flush out chips and debris.

Aluminum Manifold Processing

After machining, operators palm sand aluminum manifolds on all gasket surfaces (except where these are brushed on the machine). For all other surfaces, they use wet or dry-belt sanding to break any sharp corners, improve appearance, and remove any residual fine burrs.

Manifolds go through an initial wash after machining prior to deburring. The deburr process includes manually reaming all cavities and drilled holes, and manually "cutting" the edges of intersecting holes to eliminate sharp edges that might damage rings and seals, and to remove residual burrs.

Sun marks manifolds using machine engraving, laser engraving or pin stamping. Machine engraving occurs during the machining process. Any residual residue from laser engraving is removed during the final wash process. The impact of pin stamping produces a very minimal amount of fine debris that, if at all present, will be removed later in the washing process.

Final Aluminum Manifold Wash

In the final wash process, manifolds pass through a multi-jet spray washer with an acidic detergent. The manifolds are placed in wire baskets with a very wide mesh allowing the jet spray to pass through them easily.

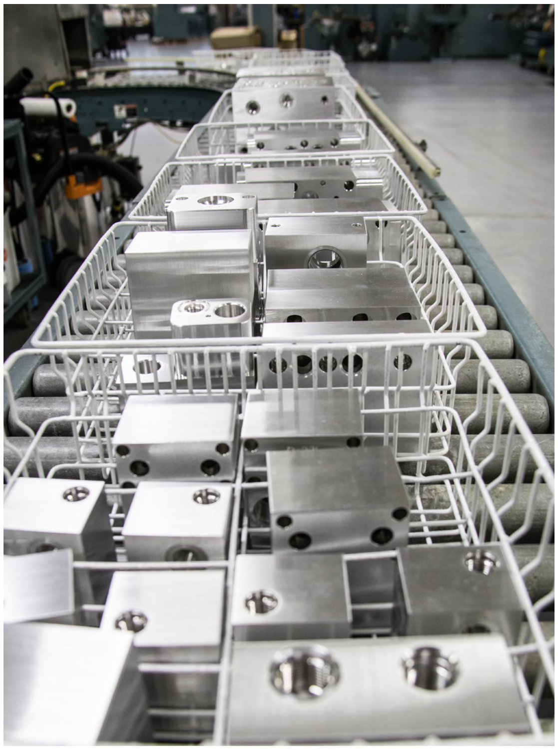


Figure 5 – Aluminum wash process

The aluminum wash process consistently produces blocks with a contamination level of no more than 44mg/m^2, regardless of the size of the block. Random samples are tested for cleanliness on a weekly basis and as needed. See Figure 5.

After wash, we use compressed air to blow out all parts to aid in drying, then place them on carts and cover them with plastic to protect them from any airborne debris.

Iron Manifold Processing

After machining iron manifolds, operators use compressed air to blow out all passages and then grind all gasket surfaces to insure proper flatness and surface finish. Non-gasket surfaces are palm sanded to break edges, remove any residual fine burrs and improve appearance. They then receive an initial wash after machining prior to deburring. The deburr process includes manually reaming all cavities and drilled holes, using deburring tools to cut sharp edges and rotary abrasive tools to clean off burrs.

Similar to the aluminum manifolds, iron manifolds are either machine engraved, laser engraved or pin stamped, all which create minimal debris which is removed during final wash.

Final Iron Manifold Wash

Sun washes iron manifolds in a dip-style, jet-agitated washer using ultrasonics and an alkaline cleaner, again using wire trays with a very wide mesh allowing spray to access the manifold passages easily. Then parts are checked for any burrs and chips.

Similar to the aluminum wash process, the iron wash process consistently produces blocks with a contamination level of no more than 44mg/m^2, regardless of the size of the block. Random samples are tested for cleanliness on a quarterly basis and as needed.

All standard iron manifolds go through a blackening process (Figure 6). Custom iron manifolds are usually cleaned, then dipped in de-watering oil and placed on a holding area to drain. After draining, we put them in transport carts and cover them with plastic to protect from airborne debris.

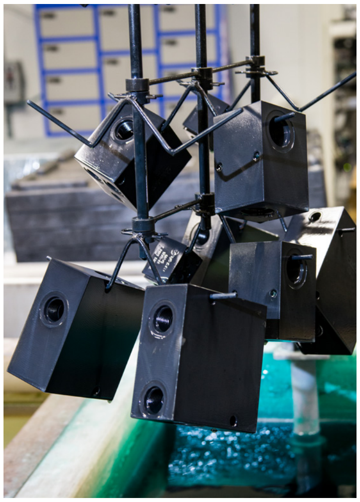


Figure 6 – Blackening process for standard iron manifolds

Figure 7 – Thermal deburring delivers reliable results

Thermal Deburring: All Manifolds

Both iron and aluminum manifolds are thermal deburred.

Thermal deburring is a highly effective process that can be applied to parts of all shapes and sizes. It not only removes burrs from external part surfaces, but also internal burrs and burrs in difficult or impossible-to-access areas, such as inside tapped holes or other cavities. During the process, metallic particles are eliminated and converted to microscopic oxides.

Assembly & Shipping: All Manifolds

All manifolds are kept covered to protect them until they enter the assembly and shipping process. During assembly of integrated packages, assemblers again check for burrs and chips before installing cartridges. Prior to shipping, we put all manifolds or integrated packages into clean plastic bags to protect them from contamination.

Regardless of cleanliness processes employed by Sun, it is good engineering practice to flush all hydraulic systems prior to initial system start up.

Summary: Achieving System Cleanliness

As a leading manufacturer of high-performance hydraulic cartridges, manifolds and integrated packages, Sun Hydraulics adheres to rigorous documented processes to ensure our customers receive products that meet or exceed applicable cleanliness specifications.

Sun Hydraulics operates an in-house Cleanliness Lab, staffed with a dedicated, full-time lab tech. Our Cleanliness Lab is capable of gravimetric particle analysis and liquid fluid analysis.

Hydraulic system designers should always consider machine operating conditions, expected life, and reliability requirements when creating cleanliness specifications, keeping in mind initial individual cleanliness is only one component of maintaining system cleanliness. Cleaner is better, but generally more expensive as well.

Systems using quality products from reputable manufacturers and designing in filtration components and systems to control contamination at appropriate levels will ensure optimized system performance and long hydraulic component life.

APPENDIX A

Hydraulic Fluids

- Chevron Rando HD ISO 32
- Skydrol 500-B4
- Test Temperature: 100-110 °F (38-43 °C)

Hydraulic Oil Cleanliness Specifications

- Maximum contamination level 19/17/14

Wash Machines - Cartridge Manufacturing

- MAFAC parts cleaning system solution. See Figure 8.
- Rotary aqueous cleaning machine. See Figure 9.

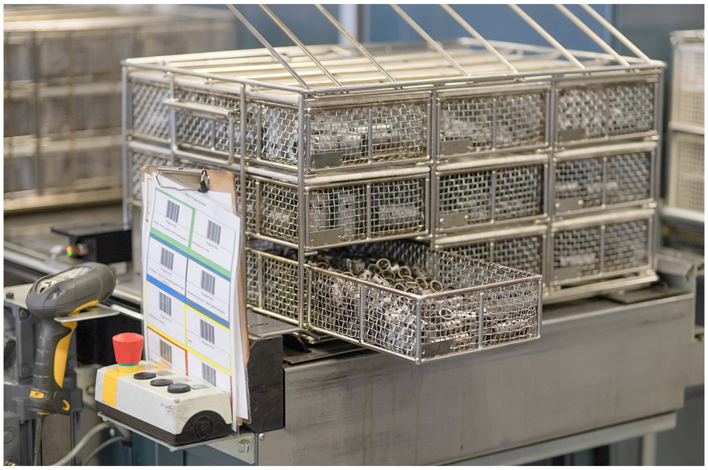


Figure 8 – MAFAC parts cleaning system solution

Figure 9 – Rotary aqueous cleaning machine

APPENDIX B

The following pages are excerpted and reprinted with permission from Schroeder Industries.

A complete download of their Hydraulic & Lube Filtration products catalog is available on their website.

www.schroederindustries.com

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.

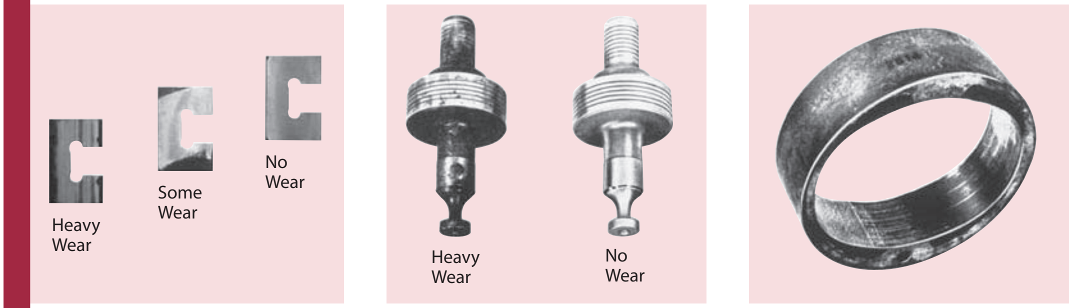
High contaminant levels accelerate component wear and decrease service life. Worn components, in turn, contribute to inefficient system operation, seizure of parts, higher fluid temperatures, leakage, and loss of control. All of these phenomena are the result of direct mechanical action between the contaminants 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

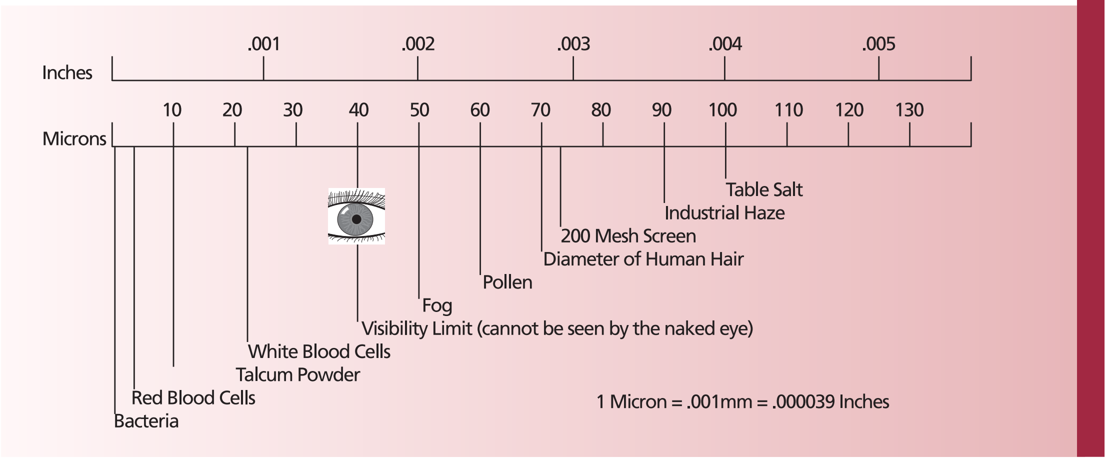
The size of solid particle contaminants is commonly measured in micrometers, µm, (usually referred to as microns, µ). A micron is a unit of length equal to one millionth of a meter or about .00004 inch. Particles that are less than 40 µ cannot be detected by the human eye.

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"

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

A micron rating identifies the size of particles that a particular filtration media will remove. For instance, Schroeder Z10 filter media is rated at ß10 ≥1000, meaning that it can remove particles of 10 µ and greater at 99.9% efficiency.

Figure 2. Sizes of Known Particles in Inches and Microns



How Contaminants are Measured and Reported

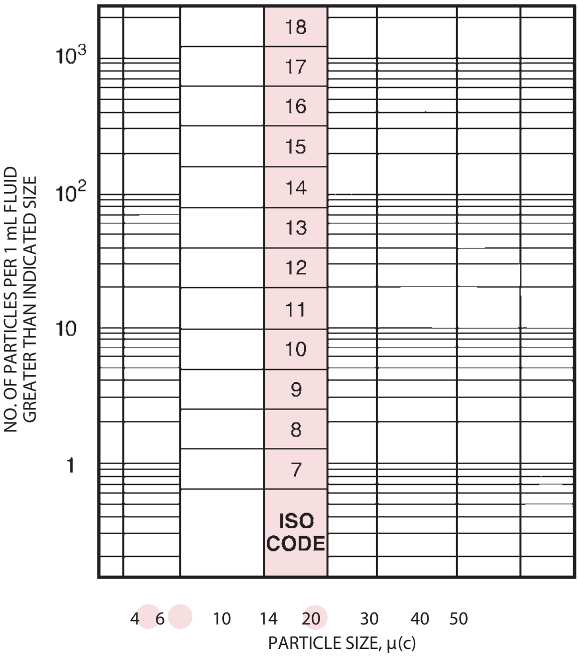
In hydraulic fluid power systems, power is transmitted and contained through a liquid under pressure within an enclosed circuit. These fluids all contain a certain amount of solid particle contaminants. The amount of particulate contaminants present in a hydraulic or lubrication system's fluid is commonly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

ISO Scale Numbers– 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. It 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 per 1 mL of sample fluid.

Figure 3 shows the graph used to plot particle counts per ISO 4406:1999.

Figure 3. Graphing Particle Counts per ISO 4406:1999



ISO Scale Numbers– ISO 4406:1999

(continued)

Table 1. ISO 4406:1999 Hydraulic Fluid Power– Solid Contamination Code

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

- 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.

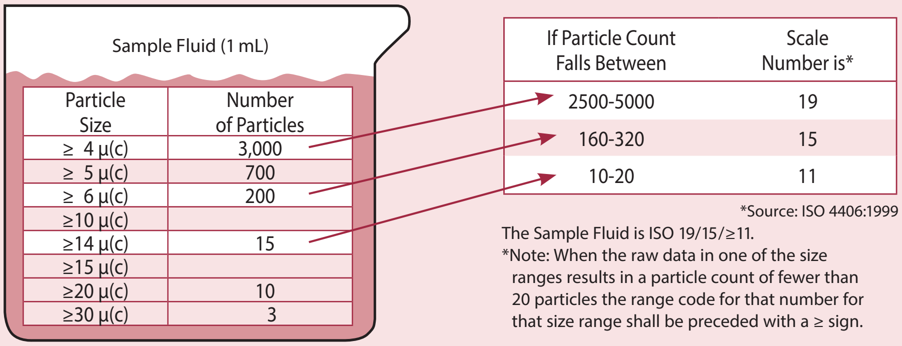
Cleanliness Levels– ISO 4406:1999

The following example shown in Figure 4 illustrates the cleanliness level, or ISO rating, of a typical petroleum-based fluid sample using the ISO Code 4406:1999 rating system.

The fluid sample contains a certain amount of solid particle contaminants, in various shapes and sizes.

Since the number of 4 μ(c) particles falls between 2500 and 5000, the first ISO range number is 19 using Table 1. The number of 6 μ(c) particles falls between 160 and 320 particles, so the second ISO range number is 15. The number of 14 μ(c) particles falls between 10 and 20, making the third range number 11. Therefore, the cleanliness level for the fluid sample shown in Figure 4 per ISO 4406:1999 is 19/15/≥11.

Figure 4. Determining the ISO Rating of a Fluid Using ISO 4406:1999



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 2 provides guidelines for recommended cleanliness levels based on pressure. In general, Schroeder defines pressure as follows:

Low pressure:	0-500 psi (0-35 bar)
Medium pressure:	500-2999 psi (35-206 bar)
High pressure:	3000 psi (206 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 3.

Table 2. Cleanliness Level Guidelines Based on Pressure

System Type	Recommended Cleanliness Levels (ISO Code)
Low pressure – manual control (0 - 500 psi)	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 3. 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 for recommendations for your specific system needs.

For your convenience, Table 4 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 SAE AS4059 standard.

Table 4. Cleanliness Class Comaprisons

ISO 4409:1999	SAE AS 4059:E	NAS 1638-01/196	MIL-STD 1246A 1967	ACFTD Gravimetric Level-mg/L
24				
23/20/18		12		
22/19/17	12	11		
21/18/16	11	10		
20/17/15	10	9	300	
19/16/14	9	8		
18/15/13	8	7	200	1
17/14/12	7	6		
16/13/11	6	5		
15/12/10	5	4		0.1
14/11/9	4	3	100	
13/10/8	3	2		
12/9/7	2	1		0.01
11/8/6	1	0		
10/7/5	0	00		
8/7/4	00		50	
5/3/01			25	
2/0/0			5	

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