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Overview of Schroeder's Approach to Advanced Fluid Conditioning Solutions®

Contamination and degraded fluid quality cause inefficient operation, component wear, and eventually failures in all hydraulic and lubrication systems. The products in this catalog are the tools that are needed to prevent such occurrences. Schroeder recommends a three step approach to controlling contamination in any system:

Assess the Fluid System's Health

Assess the fluid system's health

Start by gathering complete information on the system.

This includes:

- A list of the most critical components
- The manufacturer's recommended ISO class for each component
- The type of oil being used
- Flow rate & operating pressure
- Fluid temperature & ambient temperature
- System's operational characteristics
- Details on all current filters in the system
- Solid contamination levels (ISO class)
- Water content levels

AMFS

Recommend and implement Advanced Fluid Conditioning Solutions®

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Next, specify your recommendations for upgrading the current filtration, and adding supplementary filtration:

- Pressure filters
- Return line filters
- Manifold cartridge/circuit protector filters
- Element micron rating
- Reservoir breathers or filler breathers
- Strainer baskets
- Addition of offline filtration loop
- Use of portable filters for filling/temporary offline loops
- Sufficient water removal protection
- Proper fluid monitoring devices

X-Skids

Monitor, Maintain, and Extend the Service Life

Monitor, maintain, and extend the service life

Finally, use reliable methods for continuous monitoring of the fluid conditions including:

- Solid contamination
- Water content
- Additive depletion
- Element clogging
- Periodic detailed analysis of actual fluid samples
- Portable filters for correcting unacceptable levels

Fluid Care Center: Multi-Pass Test Stand

Overview of Schroeder's Approach to Advanced Fluid Conditioning Solutions®

Savings Realized by Proper Contamination Control

The money invested in contamination control can easily be justified when the resulting machine availability increases significantly. The graph below illustrates that there is a range in which this investment really pays off.

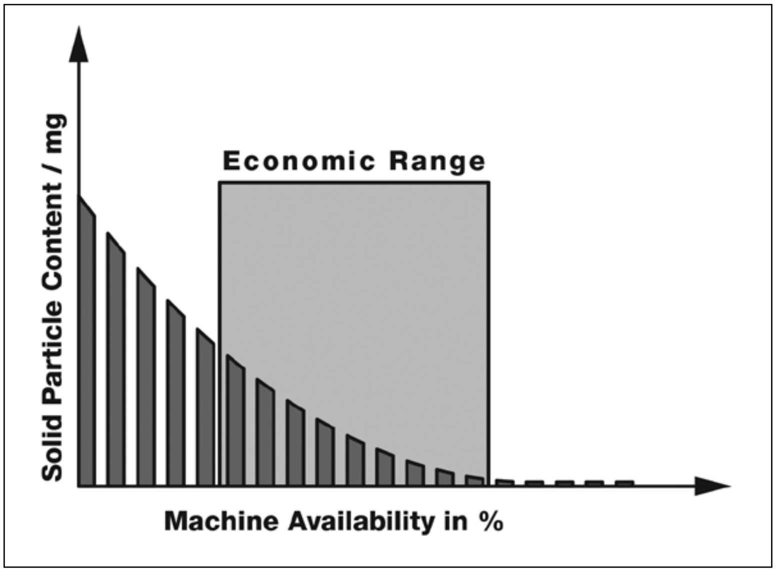


Figure 1. Savings Optimization

Savings Calculation Example

This example demonstrates how to calculate the potential savings that will be realized by implementing a proper fluid service program.

	Example	Your Data
Number of Machines	50	**a**
Operating Hours per year	5,000	**b**
Current Availability	92%	**c**
Downtime Costs per hour	$60	**d**
Total Downtime Costs	$1,200,000	$e = \frac{[a \times b \times (100-c) \times d]}{100}$
Downtime costs due to:		
Mechanical/electrical failures (65%)	$780,000	**f (e x .65)**
Hydraulic failures (35%) of which:	$420,000	**g (e x .35)**
70% is due to the fluid	$294,000	**h (g x .70)**
30% is caused by other faults	$126,000	**i (g x .30)**
Total	$264,600	**j (h x .90)**

Schroeder Fluid Service can return 90% of the fluid related downtime costs

Overview of Schroeder's Approach to Advanced Fluid Conditioning Solutions®

ISO 4406 Code

Cleanliness levels are defined by three numbers divided by slashes (/.) These numbers correspond to 4, 6, and 14 micron, in that order. Each number refers to an ISO Range Code, which is determined by the number of particles for that size (4,6, & 14µm) and larger present in 1 ml of fluid. Each range is double the range below. Refer to Figure 2 to see the actual ranges.

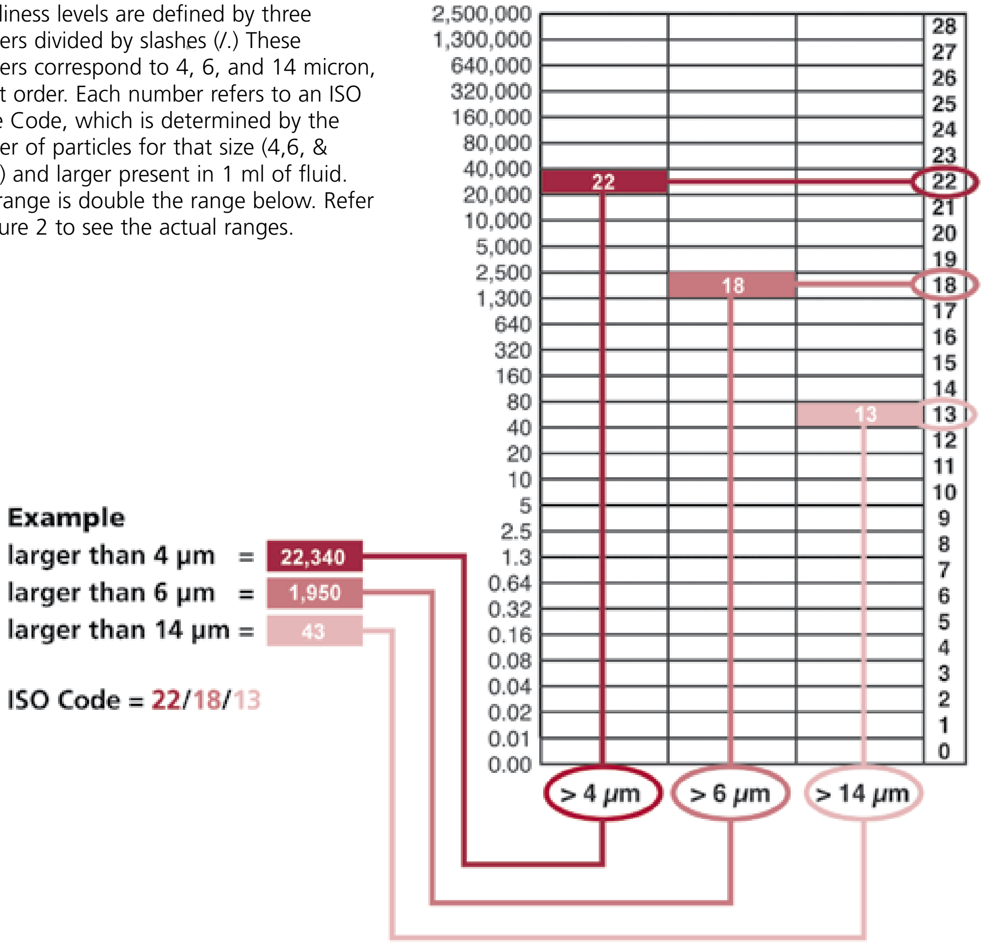


Figure 2. ISO 4406 Codes

Achieving the Appropriate Cleanliness Level in a System

The only way to achieve and maintain the appropriate cleanliness level in a hydraulic or lubrication system is to implement a comprehensive filtration program. Schroeder offers all of the products that are needed to do just that! They include:

Solid Contamination

- Pressure filters
- Return line filters
- Offline filtration loops
- Oil transfer units for pre-cleaning of new oil
- Portable and online contamination monitors
- Reservoir breathers and filler/breathers

Water Content

- Water content sensors
- Reservoir breathers with silica gel desiccant
- Vacuum dehydration water removal units
- Water removal elements

Fluid Analysis

- Bottle sampling kits
- Complete analysis kits

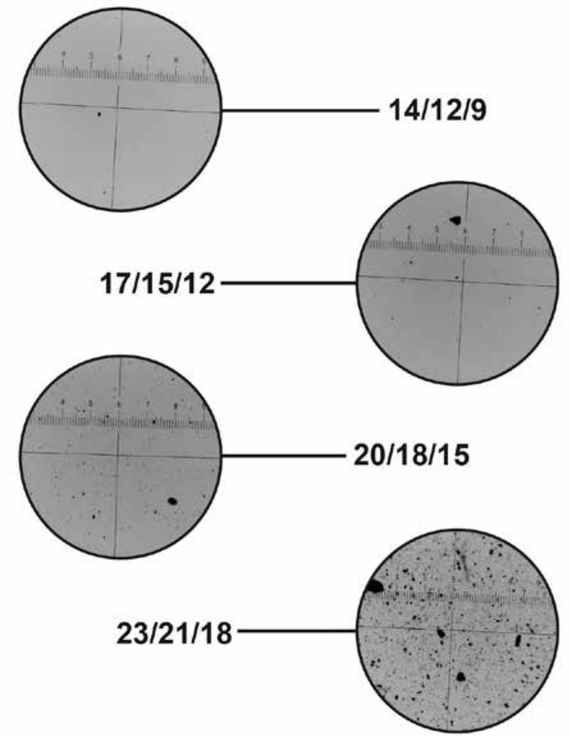


Figure 3. Microscopic Particulate Comparison

Overview of Schroeder's Approach to Advanced Fluid Conditioning Solutions®

1. Starting at the left hand column, select the most sensitive component used in the system.
2. Move right to the column that describes the system pressure and conditions.
3. Here you will find the recommended ISO class level, and recommended element micron rating.

	Low/Medium Pressure Under 2000 psi (moderate conditions)		High Pressure 2000 to 2999 psi (low/medium with severe conditions[1])		Very High Pressure 3000 psi and over (high pressure with severe conditions[1])	
	ISO Target Levels	Micron Ratings	ISO Target Levels	Micron Ratings	ISO Target Levels	Micron Ratings
Pumps						
Fixed Gear or Fixed Vane	20/18/15	20	19/17/14	10	18/16/13	5
Fixed Piston	19/17/14	10	18/16/13	5	17/15/12	3
Variable Vane	18/16/13	5	17/15/12	3	N/A	N/A
Variable Piston	18/16/13	5	17/15/12	3	16/14/11	3
Valves						
Check Valve	20/18/15	20	20/18/5	20	19/17/14	10
Directional (solenoid)	20/18/15	20	19/17/14	10	18/16/13	5
Standard Flow Control	20/18/15	20	19/17/14	10	18/16/13	5
Cartridge Valve	19/17/14	10	18/16/13	5	17/15/12	3
Proportional Valve	17/15/12	3	17/15/12	3	16/14/11	3[2]
Servo Valve	16/14/11	3[2]	16/14/11	3[2]	15/13/10	3[2]
Actuators						
Cylinders, Vane Motors, Gear Motors	20/18/15	20	19/17/14	10	18/16/13	5
Piston Motors, Swash Plate Motors	19/17/14	10	18/16/13	5	17/15/12	3
Hydrostatic Drives	16/15/12	3	16/14/11	3[2]	15/13/10	3[2]
Test Stands	15/13/10	3	15/13/10	3[2]	15/13/10	3[2]
Bearings						
Journal Bearings	17/15/12	3	N/A	N/A	N/A	N/A
Industrial Gearboxes	17/15/12	3	N/A	N/A	N/A	N/A
Ball Bearings	15/13/10	3[2]	N/A	N/A	N/A	N/A
Roller Bearings	16/14/11	3[2]	N/A	N/A	N/A	N/A

1. Severe conditions may include high flow surges, pressure spikes, frequent cold starts, extremely heavy duty use, 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.

Fluid Contamination Types

Various types of contamination occur in fluid power systems: gaseous (e.g. air), liquid (e.g. water) and solid contaminants. An overview of the various contamination types is shown in the following diagram (Figure 4).

Solid contamination is subdivided into three groups: extremely hard, hard and soft particles (see Figure 4). Extremely hard particles can cause substantial damage in fluid power systems if they are not removed as quickly as possible. Preventive measures can reduce the ingress of contaminants in systems.

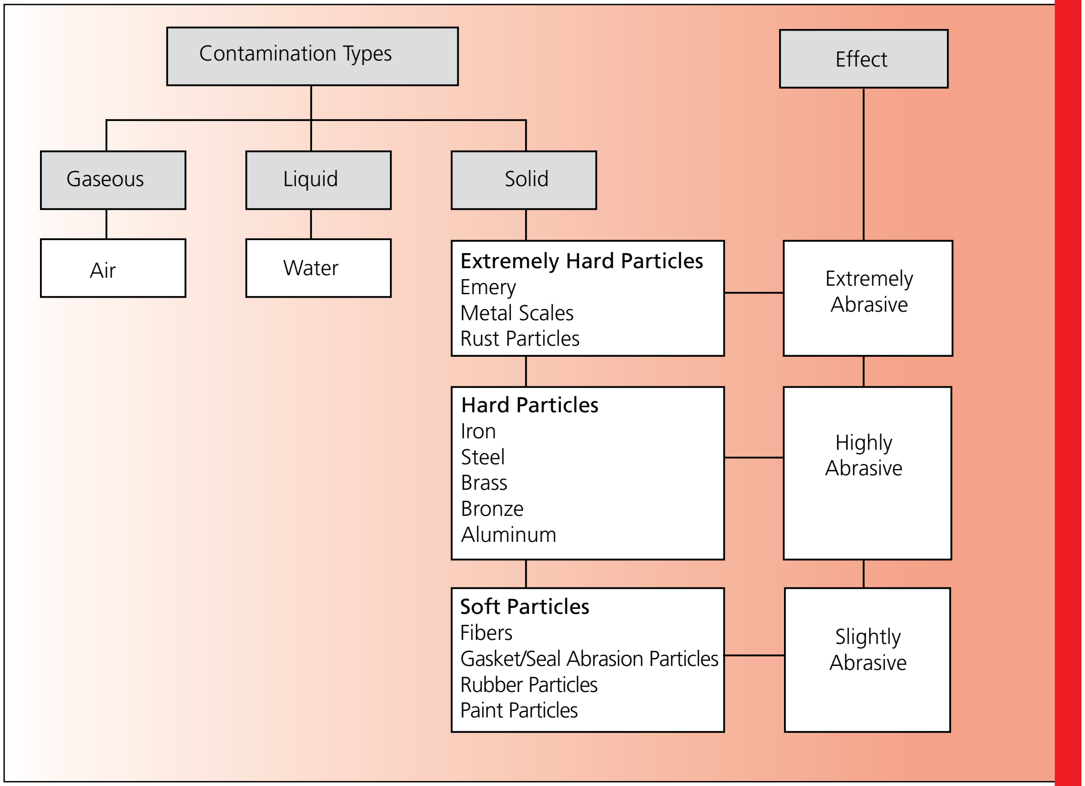


Figure 4. Types of Contamination

Hard particles are frequently listed separately in specifications. Maximum values are specified for the longest dimension these hard particles may have, e.g. largest abrasive particle: max. 200 µm or 200 x 90 µm or number of particles > 200 µm.

Not only do the hardness of contamination particles play a role but also their number and size distribution do as well.

The particle size distribution in new systems is different from that of systems that have been in operation for a number of hours. In new systems, there is an accumulation of coarse contaminants up to several millimeters long, which are then increasingly reduced in size in the course of operation or eliminated by filtration. After several hours of operation most particles are so small that they are no longer visible to the naked eye.

When commissioning fluid power systems there is additional particulate contamination by virtue of abrasive wear in which rough edges are worn away through running-in. Contamination management can’t prevent this ingress of contaminants; however, if basic contamination is lower, there is less abrasion during system startup.

Definition of Fluid Contamination Management and the Technical Cleanliness Process

Definitions

Fluid Power System
A power transmission system that uses fluids to transmit power

Basic Contamination
Quantity of contamination present subsequent to assembly

Ingress Contamination
Particulate ingressed during operation of a fluid power system

Initial Damage | "Start-Up"
Damage to component surfaces caused during function testing/commissioning/assembly of systems

Fluid Contamination Monitoring
Analysis of a fluid power system measures ingressed particulate levels

Online Measurement (Real Time Monitoring)
Measurement process which the sample to be analyzed is process fed to a measurement device directly from the system

Offline Measurement
Measurement process in which the sample is taken from the process system and analyzed elsewhere, e.g. taking an oil sample and sending it in to a laboratory

Contamination Management and Technical Cleanliness
Monitoring and optimization of cleanliness, from component design to the component assembly, to the assembly and operation of the system

Technical Cleanliness

As Figure 5 shows, the level of contamination without using the Technical Cleanliness Process is higher throughout system operation as compared to a system in which the Technical Cleanliness Process is employed, the result being that more initial damage may be caused to surfaces.

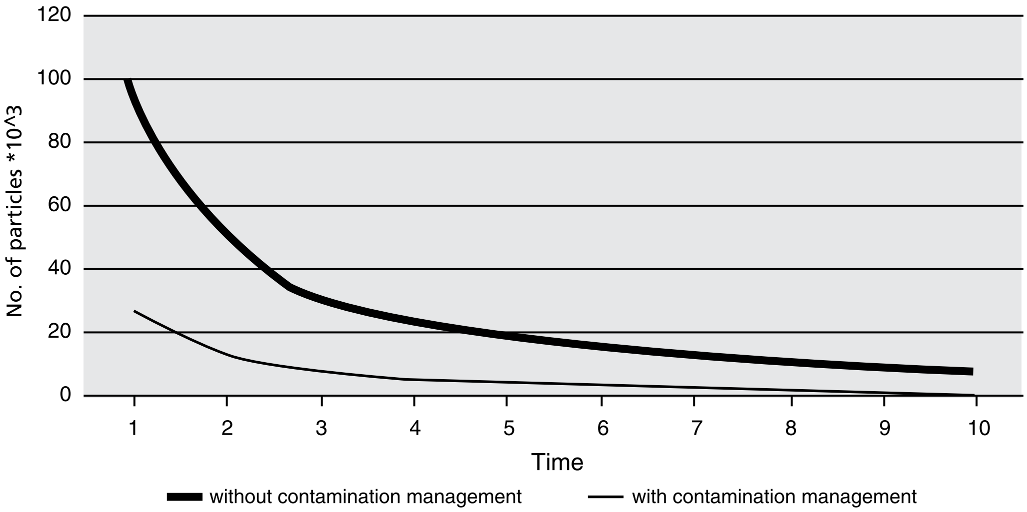


Figure 5. Cleaning of a Fluid Power System With and Without Contamination Management

Microscope images show typical particle samples, containing fine particles, as they occur in fluid power systems. (Figure 6)

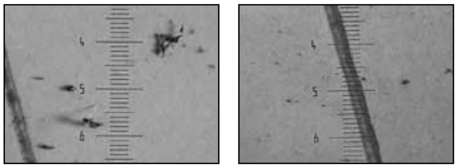


Figure 6. Typical Particle Samples

An average healthy human eye can see items down to approximately 40 µm in size. Particle analyses are conducted using a microscope or particle counters in fluid power systems employing the light extinction principle. (Figure 7)

Technical Cleanliness and Contamination Management Basics

Consequences of Particulate Contamination in Fluid Power Systems

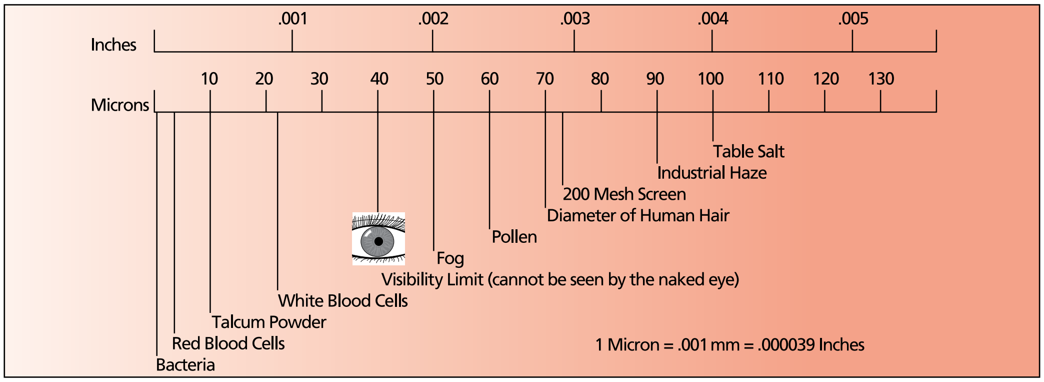


Figure 7. Sizes of Known Particles in Inches and Microns

Particulate contaminants circulating in fluid power systems cause surface degradation through general mechanical wear (abrasion, erosion, and surface fatigue).

This wear causes increasing numbers of particles to be formed, the result being that wear increases if the "chain reaction of wear" is not properly contained (by reducing contamination).

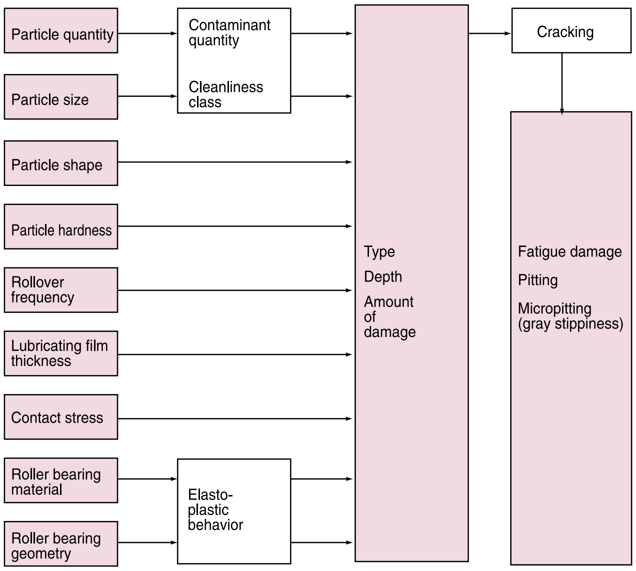


Figure 8. Factors Affecting Roller Bearing Life

Gaps grow larger, leakage oil flows increase in size, and operating efficiency (e.g. of pumps) decreases. Metering edges are worn away, thus resulting in control inaccuracies. In some cases, blockage of control ducts or nozzle bores occurs.

The chain reaction of wear during the everyday operation of hydraulic systems has to be interrupted by properly designed and dimensioned filter systems. However, the measure of security afforded the user is deceptive as highly damaging contaminants seep in during component and system assembly and system installation. This ingress of contaminants not only can cause preliminary damage to system components but also premature failure as well.

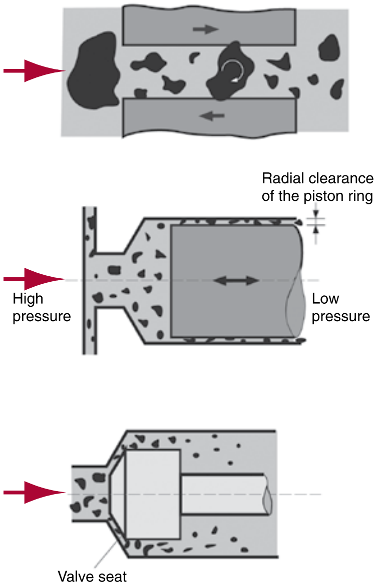


Figure 9. Examples of Wear to Movable Surfaces

Generally speaking, integrated system filtration concepts are not designed to adequately deal with large quantities of dirt as incurred with these operations:

- Component machining
- Commissioning
- System assembly
- System repair work
- System filling

A study conducted by the University of Hanover describes the factors impacting the fatigue life of roller bearings as follows: *"The quantity of contamination in the lubricant is described by the particle quantity and size. Combining this with particle hardness and geometry results in the type and extent of damage to raceways, with the extent also being affected by the elasto-plastic behavior of the material. The amount of damage is determined by the quantity of particles in the lubrication gap and the rollover frequency. Continued rollover leads to cracking, which in the form of fatigue damage (pitting) leads to roller bearing damage (bearing failure)."*

In practice ball bearings with their punctiform contact are shown in most cases to be less sensitive to particulate contamination than roller bearings with their linear contact. Friction bearings with their larger lubrication gaps are the least sensitive to particulate contamination.

Technical Cleanliness and Contamination Management Basics

Figure 10 provides an overview of the most common gap sizes illustrated in Figure 11. Comprehensive studies of particle distributions on components and in hydraulic systems have shown that at the beginning of a system's life, i.e. during assembly and commissioning, the particles are larger than during subsequent operation.

These large particles – up to several millimeters in size – can cause spontaneous outages, valve blockages, substantial preliminary damage to pumps, and destruction of seals and gaskets followed by leakage.

Active contamination management enables this rate of damage to be reduced and subsequent costs accordingly cut, i.e.:

- Costs caused by production stops
- Costs caused by delays in commissioning systems
- Warranty costs
- Reworking costs
- Costs incurred by longer testing periods since a flushing cycle is required to remove integral contamination

Contamination management counters the situation as follows: In new systems the individual components are brought to a uniform cleanliness level, the filling fluid is kept at a defined cleanliness level, as is the fluid during system operation.

Component	Typical Critical Clearance (μm)
1. Gear Pump (J1, J2)	0.5 - 5
2. Vane-cell Pump (J1)	0.5 - 5
3. Piston Pump (J2)	0.5 - 1
4. Control Valve (J1)	5 - 25
5. Servo Valve (J1)	5 - 8

Figure 10. Common Gap Sizes

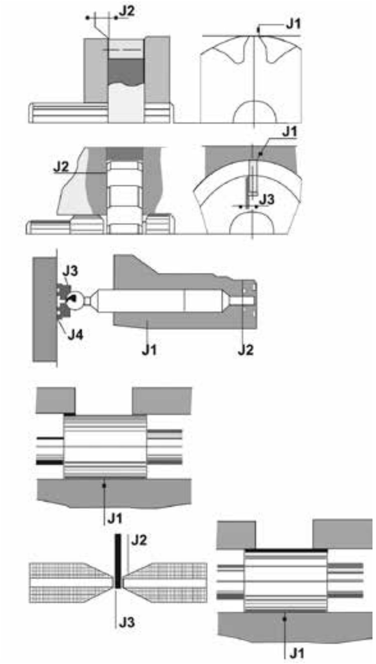


Figure 11. Common Gaps Illustrated

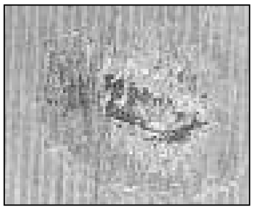


Figure 12. Destroyed raceway of a ball bearing caused by particulate contamination

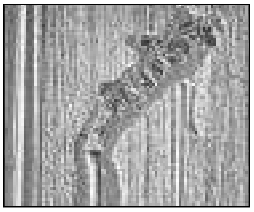


Figure 13. Contaminate embedded in the surface of a friction bearing

Classification of Particulate Contamination in Fluids and Parts Cleanliness Measurement Using Gravimetric Analysis

The objective of the procedures described below is to enable a reproducible classification of particulate contaminants in fluids.

Currently there are four procedures for classifying particulate contaminants in fluids: ISO 4405, ISO 4406:1999, NAS 1638, SAE AS 4059(D) (see chart below)

Standard	ISO 4405	ISO 4406:1999	NAS 1638	SAE AS 4059(D)
Application	Highly contaminated media, e.g. washing media, machining fluids	Hydraulic fluids Lubrication oils	Hydraulic fluids Lubrication oils	Hydraulic fluids Lubrication oils
Parameters	(mg/liters of fluid)	Number of particles > 4 µm(c) > 6 µm(c) > 14 µm(c)	Number of particles 5 - 15 µm 5 - 25 µm 25 - 50 µm 50 - 100 µm > 100 µm	Number of particles > 4 µm(c) > 6 µm(c) > 14 µm(c) > 21 µm(c) > 38 µm(c) > 70 µm(c)
Analysis Methods	In this lab method, a known volume of the fluid undergoing analysis is filtered through a prepared membrane,which is then weighed	1. *Manual evaluation:* The fluid undergoing analysis is filtered through a prepared membrane and the cleanliness class (contamination rating) estimated or counted by hand using a microscope. 2. *Automated particle counting:* The fluid undergoing analysis is conducted through a particle counter, which tallies the particle fractions.		
Remarks	Very time-consuming method	1. *Manual evaluation:* Very time-consuming, not very exact. 2. *Automated particle counting:* Result available almost immediately.		

ISO 4405

"Hydraulic Fluid Power – Fluid Contamination – Determining Particulate Contamination Employing Gravimetric Analysis Methods"

Gravimetric Analysis Methods

This international standard describes the gravimetric method for determining the particulate contamination of hydraulic fluids.

Basic Principle

A known volume of fluid is filtered through one or two filter disks using vacuum action and the weight differential of the filter disks (upstream and downstream of filtration) measured. The second membrane is used for evaluating accuracy.

In order to determine the gravimetric contamination of the fluid, a representative sample has to be taken from the system. ISO 4405 describes the cleaning procedure for the equipment being used. It also describes the preparatory procedures for the analysis membranes.

The membranes are flushed with isopropanol prior to use, dried in a drying oven until they achieve a constant weight, and then cooled in a defined dry environment. It is important that cooling takes place in a defined dry environment, otherwise the membrane absorbs moisture from the surroundings, thus skewing the final result.

Afterwards the membrane is weighed and this value recorded as m(T).

The membranes are then fixed in the membrane retainer and the fluid undergoing analysis is filtered. This is followed by flushing off the contaminant on the membrane using filtered solvent to completely remove the contaminant. When analyzing oil-laden fluids it is important that the remaining oil is completely flushed off the membrane.

This is followed by drying the membrane, cooling, and weighing it (as described above). The measured value is now recorded as m(E).

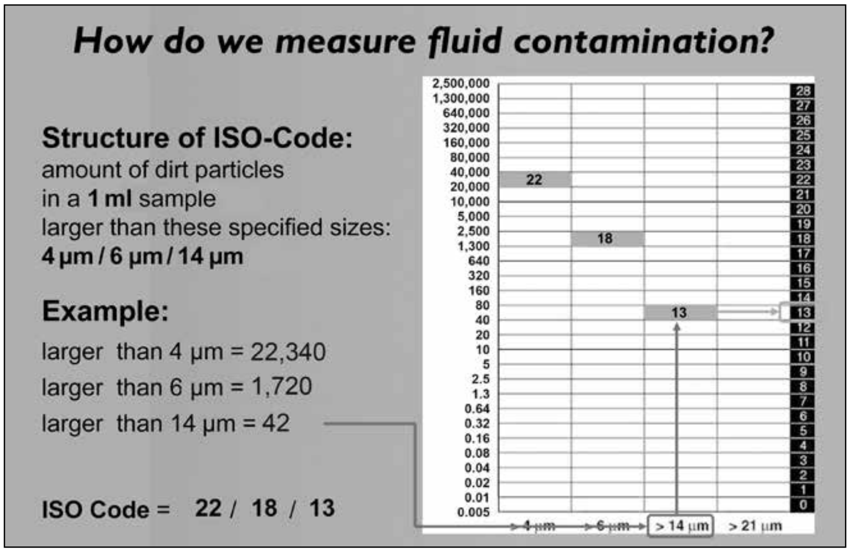
Gravimetric contamination is calculated as follows: $M(G) = m(E) – m(T)$

ISO 4406 Particle Counting in Fluid Systems

ISO 4406:1999

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

The goal of allocating particle counts to references is to facilitate the assessment of fluid cleanliness ratings.



How do we measure fluid contamination?

Structure of ISO-Code:
amount of dirt particles
in a **1 ml** sample
larger than these specified sizes:
4 µm / 6 µm / 14 µm

Example:
larger than 4 µm = 22,340
larger than 6 µm = 1,720
larger than 14 µm = 42

ISO Code = 22 / 18 / 13

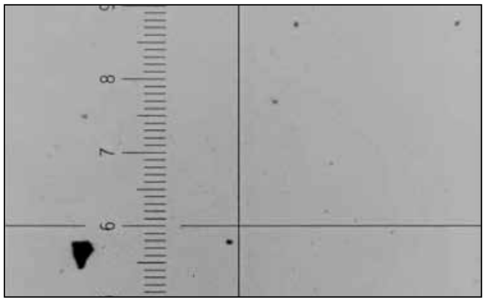


Figure 14. Microscopic Examination of an Oil Sample Magnification 100x (ISO 18/15/11)

Note: increasing the measurement reference by 1 causes the particle count to double.

Example: ISO class 18 / 15 / 11 says that the following are found in 1 ml of analyzed sample:

1,300 - 2,500 particles	> 4 µm(c)
160 - 320 particles	> 6 µm(c)
10 - 20 particles	>14 µm(c)

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.

Allocation of Particle Counts to Cleanliness Classes

No. of Particles/ml		Cleanliness Class
Over	Up to	
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

NAS 1638 Particle Counting in Fluid Systems

Like ISO 4406, NAS 1638 describes particle concentrations in liquids. The analysis methods can be applied in the same manner as ISO 4406:1987.

In contrast to ISO 4406, certain particle ranges are counted in NAS 1638 and attributed to measurement references.

The following table shows the cleanliness classes in relation to the particle concentration analyzed.

Cleanliness Class	**Particle Size (µm)**				
	5-15	15-25	25-50	50-100	>100
	No. of Particles in 100 ml Sample				
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	1,850	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

Increasing the class by 1 causes the particle count to double on average.

The particle counts of class 10 are bold-faced in the above table.

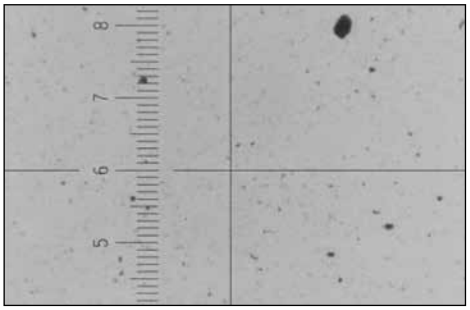


Figure 15. Microscopic Examination of an Oil Sample Magnification 100x (NAS 10)

SAE AS 4059(D) Particle Counting in Fluid Systems

SAE AS 4059(D)

Like ISO 4406 and NAS 1638, SAE AS 4059(D) describes particle concentrations in liquids. The analysis methods can be applied in the same manner as ISO 4406:1999 and NAS 1638.

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

The SAE cleanliness classes can be represented as follows:

1. Absolute particle count larger than a defined particle size
   Example: **Cleanliness class according to AS 4059:6**
   The maximum permissible particle count in the individual size ranges is shown in the table in boldface.
   Cleanliness class according to AS 4059:6 B
   Size B particles may not exceed the maximum number indicated for class 6.
   6 B = max. 19,500 particles of a size of 5 µm or 6 µm (c)

2. Specifying a cleanliness class for each particle size
   Example: **Cleanliness class according to AS 4059: 7 B / 6 C / 5 D**
   Size B (5 µm or 6 µm(c)): 38,900 particles / 100 ml
   Size C (15 µm or 14 µm(c)): 3,460 particles / 100 ml
   Size D (25 µm or 21 µm(c)): 306 particles / 100 ml

3. Specifying the highest cleanliness class measured
   Example: **Cleanliness class according to AS 4059:6 B – F**
   The 6 B – F specification requires a particle count in size ranges B – F. The respective particle concentration of cleanliness class 6 may not be exceeded in any of these ranges.

Maximum Particle Concentration* (particles / 100 ml)

Size ISO 4402 Calibration or Visual Counting	> 1 µm	> 5 µm	> 15 µm	> 25 µm	> 50 µm	> 100 µm
Size ISO 11171, Calibration or Electron Microscope**	> 4 µm$_{(c)}$	> 6 µm$_{(c)}$	> 14 µm$_{(c)}$	> 21 µm$_{(c)}$	> 38 µm$_{(c)}$	> 70 µm$_{(c)}$
Size Coding	A	B	C	D	E	F
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	1,220	217	39	7	1
3	6,250	2,430	432	76	13	2
4	12,500	4,860	864	152	26	4
5	25,000	9,730	1,730	306	53	8
6	**50,000**	**19,500**	**3,460**	**612**	**106**	**16**
7	100,000	38,900	6,920	1,220	212	32
8	200,000	77,900	13,900	2,450	424	64
9	400,000	156,000	27,700	4,900	848	128
10	800,000	311,000	55,400	9,800	1,700	256
11	1,600,000	623,000	111,000	19,600	3,390	1,020
12	3,200,000	1,250,000	222,000	39,200	6,780	

Table shows the cleanliness classes in relation to the particle concentration determined.
*Particle sizes measured according to the longest dimension.
**Particle sizes determined according to the diameter of the projected area-equivalent circle.

Fluid Condition Field Analysis Tools

Procedure in Evaluating Fluid Samples

According to
ISO 4406:1999,
NAS 1638 and
SAE AS 4059(D)

A representative sample is taken of the fluid and analyzed as follows:

1. **Manual procedure according to ISO 4407** (Hydraulic fluid power – Fluid contamination – Determination of particulate contamination by the counting method using a microscope).

   ISO 4407 contains a description of a microscopic counting method for membranes. 100 ml of the sample undergoing analysis is filtered through an analysis membrane featuring an average pore size of < 1 µm and square markings.

   The standard also describes the cleaning procedure and maximum particle count of the negative control.

   After the analysis membranes are dried, 10, 20 or 50 squares are counted depending on the size of the particles, followed by adding the values and extrapolating to the membrane diameter. See figure 16.

   The manual count of the particles is done in the "old" levels of > 5 µm and > 15 µm since the longest dimension of a particle is counted in ISO 4407 yet the diameter of the area-equivalent circle is counted in the "new" ISO 4406:1999. As described above, the reference values obtained for this count correspond to the reference values of the "new" evaluation.

   This counting method can only be used for very clean samples. Generally speaking, the cleanliness classes are estimated on the basis of reference photographs or the samples are automatically counted.

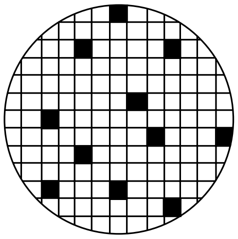


Figure 16.

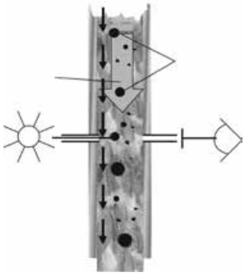


Figure 17.

2. **Automated particle counting**

   Below follows a description of how common particle counters employing the light extinction principle function.

   Figure 17 shows a simplified rendering of the measurement principle employed in the light extinction principle.

   The light source transmits the light (monochromatic light for the most part) onto an optical sensor, which emits a specific electrical signal.

   A shadow is created on the photodiode if a particle (black) comes between the light source and the photodetector. This shadow causes the electric signal emitted by the sensor to change. This change can be used to determine the size of the shadow cast by this particle and thus the particle size.

   This procedure enables the cleanliness classes according to ISO 4406:1987, ISO 4406:1999, NAS 1638 and SAE AS 4059(D) to be accurately determined.

   The "noise" involved in this measurement principle is extraneous liquids and gases which cause the light beam to be interrupted and thus be counted as particles.

   The particle counter should be calibrated according to ISO 11943 (for ISO 4406:1999).

Figure 18. Schroeder Industries offers seven products (see Figure 18) that include particle monitoring services: TPM TestMate® Particle Counter, TIM TestMate® In-Line Counter, TCM TestMate® Contamination Monitor, TMU TestMate® Monitoring Unit, CTU TestMate® Contamination Test Unit, the FS Filtration Station® and Asset Management Filtration System®. Product information for all of these is included in this catalog.

Determining the Residual Dirt Quantity of Components and Technical Cleanliness

Determining the residual dirt quantities present on components can be done by employing quantitative and qualitative factors.

Quantitative:

- mg/component
- mg/surface unit (oil-wetted surface)
- mg/kg component weight no. of particles > x µm/component
- no. of particles > x µm/surface unit (oil-wetted surface)

Qualitative:

- Length of largest particle (subdivision into hard/soft)

Components with easily accessible surfaces are components in which only the outer surface is of interest for the most part when performing residual dirt analyses. *There are exceptions e.g. transmission and pump housings, as the internal surface is of interest. These components belong to group 1 and their surfaces are not easily accessible in most cases.*

Components in which the inner surfaces are examined or *pre-assembled assemblies* belong to group 2.

There are two methods that can be used to determine the residual dirt of group 1 components.

Ultrasonic Method

The ultrasound method involves submitting the components to an ultrasonic bath, exposing them for a defined period of time at a defined ultrasonic setting and bath temperature. The particulate contamination is loosened by the exposure and then flushed off the component using a suitable liquid.

The particle dispersion in the flushing liquid obtained in this manner is analyzed according to specified evaluation methods.

The ultrasonic energy setting and the duration of exposure have to be indicated in reporting the result. The ultrasonic procedure is particularly suitable for small components in which all surfaces have to be examined. *Cast components and elastomers should not be subjected to ultrasonic washing if possible. A risk is posed here by the carbon inclusions in the cast piece being dissolved, thus skewing the results.* These effects have to be evaluated prior to performing an ultrasonic analysis.

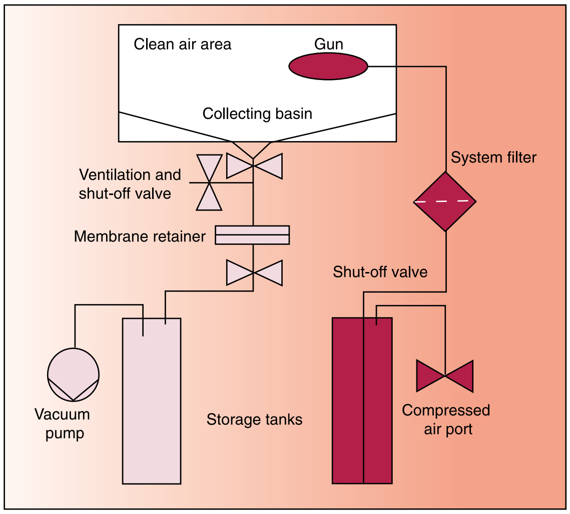


Figure 19

Flushing Method

Components with easily accessible surfaces or components in which only surface parts have to be examined are analyzed using the flushing method. This method involves flushing the surface undergoing analysis in a defined clean environment using an analysis fluid, which also has a defined cleanliness. A "negative control" or basic contamination control is performed prior to analysis in which all the surfaces of the environment, e.g. the collecting basin, are flushed and the value obtained reported as the basic contamination of the analysis equipment. The flushing fluid is then analyzed using the specified evaluation methods.

The darker areas in Figure 19 are the flushing areas; those to the left and lighter are the designated analysis area. In reality these two circuits are configured using suitable valves in such a manner that switchover can be done between the two storage tanks. The figure represents a simplified circuit diagram. The analysis fluid is subjected to a pressure of *approximately 58 – 87 psi (4 – 6 bar)* and conveyed through the system filter and the spray gun into the analysis chamber. The system filter ensures that the analysis fluid sprayed on the surface being examined has a defined cleanliness. The particle-loaded fluid *collects in the collecting basin* and is filtered through the analysis membrane via vacuum action. The membrane is then evaluated according to the analysis methods described on the following pages.

Shaking Method

The shaking method is very rarely used, as it is very difficult to reproduce manually. However, results are reproducible when automatic shakers such as those used in chemical laboratories are employed. The analyzed components are components subject to wear whose inner surfaces are to be analyzed (e.g. pipes, tanks). The important thing is that the particles are flushed out of the inside of the components after being shaken.

The table on the following page shows a comparison of the various methods for analyzing components and assemblies.

Testing Methods Comparison

Method Comparison

	Flushing Method	Ultrasonic Method
How Performed	Components are flushed with the analysis fluid in a defined clean environment.	Components are exposed to an ultrasonic bath and are then flushed with the analysis fluid.
Applications	Components in which only surface parts have to be examined and components in which ultrasound may damage the surfaces. Components with a simple design and with easily accessible surfaces.	Small components and components in which all surfaces are to be analyzed (the component size depends on the ultrasonic bath).
Pros	Analysis can be performed quickly	Reproducibility
Cons	Reproducibility Standards are not yet available (currently in preparation)	Analysis takes a long time The energy acts on the surface undergoing analysis The surface has to be flushed No valid standards

Evaluation Methods

Evaluating particle-laden flushing fluids can be done according to various criteria. Gravimetric analysis is useful for heavily contaminated components, whereas particle counts in various size ranges are useful for very clean components.

The following table provides an overview of the individual evaluation methods.

	Manual Methods		Automated Methods	
	Gravimetric method [mg/m^2]	Counting of particles on the analysis membrane [no. of particles > x μm/m^2]*	Counting of particles on the analysis membrane [no. of particles > x μm/m^2]*	Counting of particles on the analysis membrane [no. of particles > x μm/m^2]*
How Performed	The particle-laden fluid is filtered through a prepared analysis membrane			The particles on the particle-laden fluid are counted using an automatic particle counter
	The analysis membrane is weighed before and after analysis and the gravimetry computed on the basis of the difference between the measured values	The number of particles in the individual size ranges are estimated or counted < 100 μm estimated > 100 μm counted	The analysis membrane is placed under a microscope and evaluated using a software tool. This software records the light-dark contrasts on the membrane and interrupts them as particles.	
Applications	Samples exhibiting contamination >10 mg	Samples featuring high a content of coarse contamination. Often combined with gravimetric evaluation.	Samples featuring a low contamination content < 5 mg	Preferred for very clean components. When high dirt content is involved, the sample has to be diluted in order to perform counting.
Standard	ISO 4405	ISO 4407		ISO 11500
Advantages	Material types can also be analyzed. An overview can be quickly obtained of the largest particles. Air and extraneous liquids do not pose a problem (as long as no deposits form on the membrane). Can be used for large particle quantities			Analysis can be performed quickly, can be integrated in process chain as on-line method, detection of small quantities of particles possible, measurement range selectable (2-400μm). Accurate measurement method
Disadvantages	Takes a long time (min. 1 h) Lab Method	Takes a long time No. of particles <100 μm estimated Lab Method	Depending on the analysis accuracy this method can take a very long time. Light particles are not interrupted. Light-Dark contrast is manually selected in cases. The diameter of the area-equivalent circle is measured (=> result is not identical to visual appearance)	The sample has to be prepared (e.g. the sample might have to be diluted). Generally speaking, this is a statistical method providing for sufficient accuracy.
Application	Lab Method Used as a control for indirect measurement techniques (e.g. off-line process control in test stations)		Lab Method	On-line process control in manufacturing and assembly. Can also be used in labs

Evaluation Methods

The following table provides an overview of applications of the analysis and evaluation methods.

Evaluation		Gravimetry		Particle Counting		
Analysis Method		Flushing	Ultrasonic Method	Flushing	Ultrasonic Method	Function Testing
Simple Components	easy-to-access surfaces; gears	U	U	U	U	NU
Components	internal surfaces pipes, tanks	U	NU	U	NU	CU*
Complex Components	components featuring various bore holes or ducts; control plates	CU*	NU	CU*	NU	U
Simple Systems	surface is to be analyzed immersed sensors	U	U	U	U	NU
Systems	internal surfaces rails of common rail systems	CU*	NU	CU*	NU	U
Complex Systems	valves, pumps	CU*	NU	CU*	NU	U

* Must be ensured that the particles dislodged from the component can be flushed away.

U = Usable
CU = Conditionally usable
NU = Not usable

Patch Test Kit

Schroeder's EPK Patch Test Kit (shown to the right) provides the tools needed to pull contaminated fluid through a patch and compare the resulting patch under a microscope to representative photos of various contamination levels to determine the fluid's ISO level.

Advanced Technology

The Asset Management Filtration Station® (AMFS) is a complete fluid management system designed to manage fluid cleanliness, so that the greatest return of that asset is achieved. The AMFS is an all-in one system that monitors your fluid condition, filters out contaminants and tracks all the necessary data needed for trend analysis and record keeping by asset number or name.

Contamination Monitoring

The reliability of hydraulic systems can be impacted heavily by particulate contamination during the running-in phase. The risk of outages during the first minutes or hours of operation is particularly high as the foreign particles introduced or created during the assembly process are still relatively large and can thus cause sudden outages. During continued operation, these large particles are ground into smaller ones, the result being that damage can be caused to the surfaces of system components during this crushing process. The consequences are leakage, degraded output and efficiency, or a shortening of the component's service life. In many cases, microfiltering is used to quickly clean the system fluid during commissioning.

This is where contamination monitoring is key in the manufacture and assembly of these systems. By implementing contamination management a major portion of particulate contamination introduced during manufacture and assembly can be removed. The result is cost savings by virtue of smaller performance deviations on test stands caused by the sudden clogging of particles in sensitive system components plus lower costs associated with warranty and non-warranty courtesy work. *For more information, refer to page 31.*

Below follows a description of the goal, design and performance of a process audit.

Contamination monitoring extends to checking the cleanliness status of all manufacturing and assembly processes considered relevant in this connection. Proper preparation and informing all those involved are key in contamination monitoring.

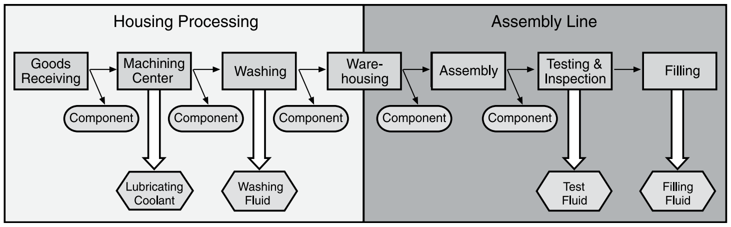


Figure 20. Schematic Excerpt of a Manufacturing Line

Planning and Design

First, the objective of contamination monitoring is specified, e.g.

- Determining the current situation
- Checking fluctuations between batches
- Checking washing processes
- Comparing the target with the actual situation
- Determining the sampling point

During the planning and design phase, the sampling points for components and taking liquid samples are determined using a production plan or operation sheet. The employees to be involved in contamination monitoring are informed of the objectives and procedures.

NOTE:

Manufacturing has to continue in the same manner, meaning that no additional cleanliness levels, etc. are to be integrated. The purpose of contamination monitoring is not to check the quality produced by the employees but rather determining the causes and sources of contamination.

Figure 20 above shows the manufacturing processes and the corresponding sampling points. However, in actuality sampling is more comprehensive, i.e. the description includes the number of the Minimess fittings at which sampling is done, for example.

How Sampling is Done

A representative sampling is taken of the fluids and components; the samples are stored so as to prevent any further contamination. Special sampling bottles are used for the fluid samples; the components are stored in defined clean packaging.

The analysis is performed in accordance with the methods specified on page 18 and the findings recorded.

Inspection of the Manufacturing and Assembly Line

Properly trained or experienced individuals while inspecting the manufacturing and assembly line can detect some sources of contamination. That is why such an inspection is conducted during the audit. The findings made during inspection are then compared with the results on hand.

Analyzing the Data

Results

The contamination monitoring results describe the condition at the time the sampling is done. The findings might look like this:

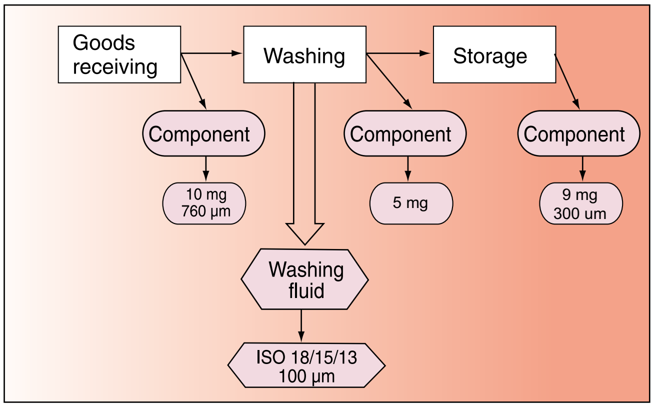
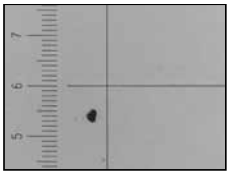


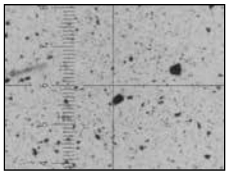
Figure 21. Housing Processing



Micro-photograph analysis membrane

Particulate contamination of a component prior to storage

Figure 22.



Micro-photograph analysis membrane

Particulate contamination of a component *after* being in storage for 2 weeks

Figure 23.

This chart shows an excerpt of the housing manufacturing process. The component samples are taken upstream and downstream of the washing station. The findings show that the washing station performs well and that it is well positioned. Subsequent storage is not being done properly as the particulate contamination is almost double.

Drafting a Cleanliness Specification

By applying a cleanliness specification to components and the system it can be ensured that as-supplied quality is constant.

The following should be kept in mind when drafting a cleanliness specification:

- State of the art
- Benchmarking – what do others do?
- Inclusion of previous experience – if available
- Defining and implementing contamination management as an “official project”
- Inclusion of all hierarchy levels
- Accurate documentation of how the specification was developed
- Developing clear-cut definitions

Next, it has to be determined which components in the system are the most sensitive. Frequently, it is not possible to achieve the same level of cleanliness throughout the system during assembly.

If suitable, filtration takes place upstream of the sensitive components. An area of low-contamination-sensitive components can be defined upstream of this filtration and an area of highly contamination-sensitive components downstream of the filter.

These individual components or system areas should be subdivided into sensitivity areas.

Category	Designation	Description
A	Low particle-sensitivity	For the most part low-pressure systems with large gap tolerances
B	Particle-sensitive	Low-pressure systems with small gap tolerances
C	High particle sensitivity	High-pressure systems with small gap tolerances and with exacting demands made of safety and security systems

A maximum particulate contamination value is specified for each of these cleanliness categories.

A car motor illustrates this subdivision below:

Category	Motor Area
A	Air / Coolant water circuit
B	Low-pressure oil circuit
C	Diesel direct injection / High-pressure oil circuit

In addition, the fluid cleanliness ratings of the individual system and process fluids are defined.

Analyzing the Data

Establishing Cleanliness Specifications

The following parameters are defined in the cleanliness specifications for the components:

1. Goal of the cleanliness specification
2. Applicability (system designation)
3. Extent of inspection and testing; inspection and testing cycles
4. Sampling
5. Analysis method
6. Evaluation method
7. Accuracy
8. Analysis fluids to be used
9. Documentation
10. Limit values

This specification has to be made for each individual system; consequently a few things are discussed which have to be borne in mind.

Work instructions concerning sampling, analysis and evaluation methods should be described in detail so as to ensure that sampling is always done in a uniform manner. In addition, the analysis results depend on the analysis fluid and method, particularly when it comes to component analysis. Documentation should be done using forms so that all the results are readily accessible.

Contamination Management			
System	Power Steering	Analysis date	Jan. 31, 2001
Component analysis			
Component	Rack	Sampling point	After washing 1
Part No.	Xx1235	Sample taken by	Joe Smith
Batch size	1	Sampling date	Jan. 30, 2001
Analysis method	Ultrasonic	Lot designation	01-2001
Analysis fluid	COLD-02	Analysis fluid vol.	1,500 ml
Negative value	.02 mg	Membrane filter rating	7 µm
Evaluation method			
In-line particle counting	Automated particle counting of the analysis fluid	Automated particle counting of the membrane	Manual particle counting
			x
	x		
Gravimetry	8	mg/component	
Largest abrasive particle	350	µm	
	No. of particles / component		
	> 50 µm	> 100 µm	> 200 µm
Actual value	100	10	3
Limit			0
System Fluid			
System	Washing 1		
Sampling point	Flushing bath		
Sample taken by	Joe Smith		
Sampling date	Jan. 30, 2001		
Measurement method			
In-line particle counting	Automated particle counting of the analysis fluid	Automated particle counting of the membrane	Manual particle counting
			x
ISO 4406	22/20/18	NAS 1638	
Largest abrasive particle	300 µm		
Signature:		Date:	

Example of a form for entering findings

Example of a Cleanliness Specification

1. Goal of the cleanliness specification
The goal in implementing this cleanliness specification is to achieve a constant level of cleanliness for system X.

2. Applicability (system designation)
This specification applies to system X including its series A, B, and C. It extends to all components whether sourced or manufactured in house. It also specifies the system fluids of system X with regard to their cleanliness.

3. Extent of inspection & testing; inspection & testing cycles
5 samples a month of each component are to be taken and analyzed. If the supplier parts achieve a constant cleanliness value after 6 months, the sampling cycle can be extended to every 2 or 3 months. An analysis of the entire (assembled) system is to be done at least once a week prior to delivery. Checking of the fluid cleanliness should be done on a continuous basis.

4. Sampling
Sampling of components is to be done at receiving and is to be representative. Samples should be packed in a dust-tight manner and sent into the laboratory. The fluid samples are to be taken at the sampling points indicated in the inspection and testing plan.

Analyzing the Data

Example of a Cleanliness Specification *continued*

5. Analysis method

The flushing method should be used for component analysis. The surfaces of the component are flushed in a clean environment using x ml of the test fluid (XY) which has a cleanliness of xx, under a pressure of z psi as specified by the inspection and testing plan. The flushed-off particulate contamination is collected on an analysis membrane and subjected to gravimetric analysis. Representative samples are taken of the system fluids at the specified sampling points. All testing parameters are specified; the duration of testing, what is tested, the pressures, and speeds. When conducting static inspection and testing make sure that a flushing effect is present so that the cleanliness of these components can be determined, (the static pressure test has to be followed by a dynamic flushing process in order to analyze the actual quantity of particles which is flushed out of the component.)

6. Evaluation method

In the component analyses the analysis membrane is dried until it achieves a constant weight, and then cooled in a defined dry environment and weighed. This procedure is repeated subsequent to filtration. The weight differential indicates the "gravimetric contamination" of the component. This is followed by visually examining the analysis membranes through a microscope and measuring the longest particles. Evaluation of the fluid samples is done in accordance with ISO 4405, ISO 4407, ISO 4406:1999 or NAS 1638.

7. Accuracy

The analysis equipment has to be brought to a residual dirt content of 0.2 mg prior to conducting the analysis so that the measurements taken of the component samples are sufficiently accurate. This is determined by performing a negative control, i.e. flushing the equipment without testing. When the result of the analysis drops below 0.5 mg, the batch size is to be increased and thus a mean value of the results computed.

8. Analysis fluids to be used

The following analysis fluid should be used for the component analyses: ABC-XX, with a cleanliness class of 14 / 12 / 9 and no particles > 40 µm.

9. Documentation

The documentation of the results is done using a result sheet.

10. Limit values

The components are subdivided into 3 cleanliness classes:

Category	Designation	Description
A	Low particle-sensitivity	For the most part low-pressure systems with large gap tolerances
B	Particle-sensitive	Low-pressure systems with small gap tolerances
C	High particle sensitivity	High-pressure systems with small gap tolerances and exacting demands

The following cleanliness specifications apply to each of these classes (fictitious example).

Category	Gravimetry	Particle Sizes
A	20 mg / component	Max. 4 particles > 500 µm Max. size: 400 µm No fiber bundles
B	10 mg / component	Max. 4 particles > 400 µm Max. size: 800 µm Fibers up to 4 mm
C	5 mg / component	Max. 4 particles > 200 µm Max. size: 1,000 µm Fibers up to 2 mm

The transmission components are subdivided into the individual categories.
Group A: crankcase sump.
Group B: intermediate housing, transmission housing, coupling flange
Group C: valve plate, valve housing, centering plate

Fluid samples:
At the end of the test run, the transmission fluid may not fall short a cleanliness rating of 17 / 15 / 13 (c) according to ISO 4406:1999. The system is to be operated using a cleanliness rating of 18 / 16 / 14 (c) according to ISO 4406:1999.

11. Procedure to be followed in the event that the specification is not adhered to

The supplier components are to be returned to the supplier in the event that the specification is not adhered to. If this procedure results in production delays, the components will be cleaned and analyzed by us at the supplier's expense.

Sources of Contamination in the Manufacturing and Assembly of Hydraulic Systems

Particulate contamination can enter a fluid power system in various ways. The main sources of ingression are shown in the following diagram. Some of these sources of contamination can be eliminated in a simple, cost-effective manner.

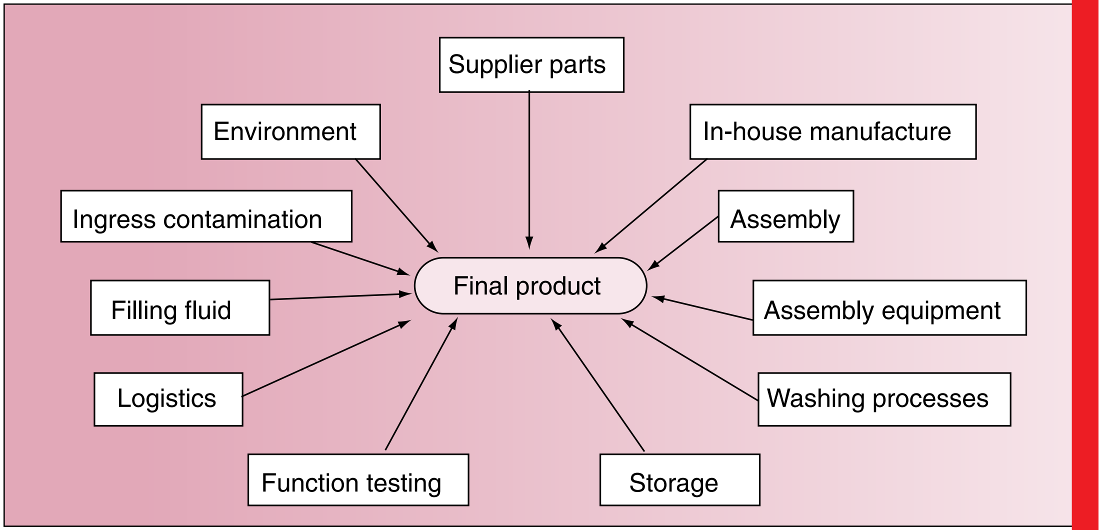


Figure 24. Sources of Contamination in the Manufacturing of Hydraulic Systems

Preventing the Ingression of Contamination in the Manufacturing and Assembly of Hydraulic Systems

The ingression of contamination in the manufacturing and assembly of hydraulic systems can be eliminated in a cost-effective manner in various process steps.

Storage and Logistics

When storing and transporting the components and systems care has to be exercised to make sure that they are properly sealed shut or well packed. Transportation and storage packing has to be in keeping with the cleanliness status of the individual components.

Assembly of Systems and Subassemblies

The assembly of these systems is to be done in accordance with system requirements. This means that the assembly and mechanical fabrication areas have to be separated if necessary in order to prevent the ingress of contamination. The assembly stations have to be kept clean to a defined cleanliness and those working in these areas have to wear special, lint-free clothing. The assembly equipment has to be properly cleaned so as to prevent the ingress of dirt here, too.

Raising the Awareness of Employees

In order to achieve the objective of “defined cleanliness of components and systems” it is important that employees at all levels be involved in this process. Frequently, a considerable savings potential is contained in the employees’ wealth of ideas and experience — particularly those working at assembly lines and in fabrication.

Experience has shown that when employees are able to identify with the objective being striven for, they are more able to help in implementing it quickly and effectively.

Environment — Air Cleanliness

In some cases it will be necessary to set up a clean room for the final assembly of very contamination-sensitive systems, e.g. fuel systems, brakes shock absorbers, etc. This has to be decided on a case-by-case basis. However, in many cases performing the measures described here suffices.

Removal of Particulate Contamination from Hydraulic Systems

(Practical Experience and Components)

Generally speaking, particulate contamination is removed from a hydraulic system via filtration. Various types of filters are used depending on the amount and type of contamination.

Belt filter systems or bag filters are used when large quantities of contaminants are involved. These filters have the job of removing the major portion of contaminants from the system. These filter types are also used for pre-filtration purposes.

In most cases, these coarse filters do their job of *“removing a lot of dirt from the system”* very well. However, microfiltering also has to be done if a constant defined high level of cleanliness of the system fluid is to be ensured.

Whereas microfiltration ensures quality, the job of coarse filtration is to control the quantity of contamination.

Removal of Particulate Contamination

Cleaning System

Individual components are freed of clinging contamination in cleaning systems (particles, remainder of machining or corrosion protection fluids, etc.). Cleaning can be done by employing various mechanical methods (e.g. spraying, flooding, ultrasonic methods) using various cleaning fluids (aqueous solutions or organic solvents). The temperature and duration of cleaning also have a decisive effect on the cleaning effect. These factors have to be carefully matched and optimally tuned in order for a favorable cleaning effect to be achieved in an economical amount of time.

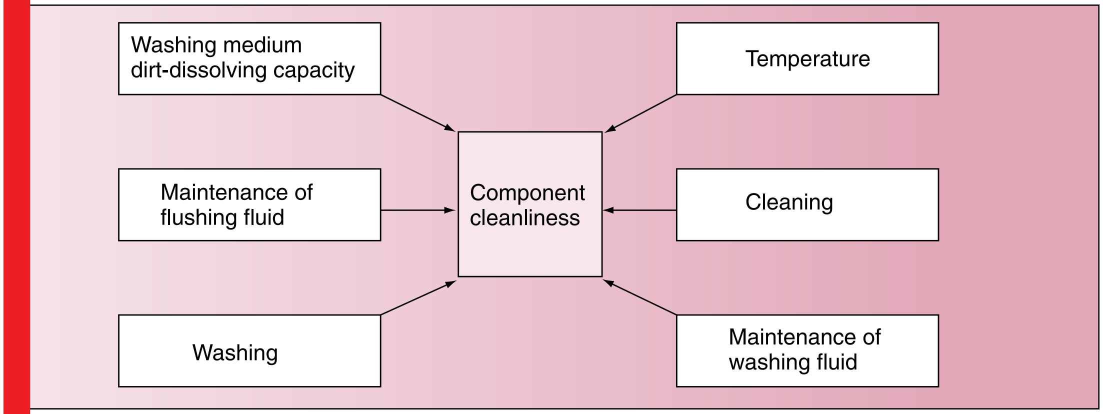


Figure 25. Cleaning Techniques

Various studies of washing processes have shown that some of these for the most part cost-intensive processes aren't worthy of the name. Some people refer to washing processes as "particle distribution processes". This "property" was detected in examinations of components sampled upstream and downstream of a washing process.

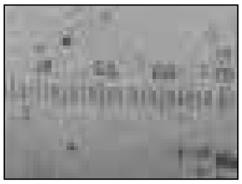


Figure 26. Micro-photograph Analysis Membrane: Pipe has been washed and sawed

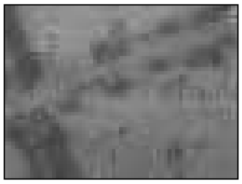


Figure 27. Micro-photograph Analysis Membrane: After sawing and washing, the pipe is bent and flushed

There are two possible responses in a case like this:

1. Discontinue the washing process when component cleanliness becomes worse after washing than before.

Advantage: temporary cost savings

The best alternative:

2. Optimize the process. The following should particularly be borne in mind when optimizing washing processes: cleanliness of the washing, flushing and corrosion protection fluid, mechanical aspects, suitability of the washing process for the components undergoing washing and filtration of the washing and flushing fluid.

When purchasing washing systems, make sure to specify the component cleanliness to be achieved and the maximum contamination load of the washing fluid in terms of *mg/l* or a cleanliness class.

Washing systems used to be subdivided into micro and micronic washing. This was a very imprecise definition of the cleaning performance to be achieved. Nowadays the permissible residual dirt quantity of the cleaned components is defined.

Specifying these residual dirt quantities is done as follows: mg/component, mg/kg component, mg/surface units or particle concentrations in various size ranges. In addition, the maximum sizes of the particles are defined which can be on the washed component, e.g. max. 3 particles > 200 µm, no particles > 400 µm.

These values cannot be achieved unless the factors indicated above are matched and fine-tuned. The following factors additionally have to be borne in mind: environmental protection and labor safety, local situation relating to space and power available, and the target throughput rate.

The cleanliness of the washing and flushing fluids also has a decisive impact on the cleaning performance of the washing machine. However, we are concerned here only with the maintenance of the washing and flushing fluids.

Removal of Particulate Contamination

Cleaning System *continued*

Cleaning Method	Solid Contamination	Liquid, Non-Dissolved Contamination (emulsion)	Liquid, Dissolved Contamination (emulsion)
Filtration			
Belt-type Filter	X		
Bag/Backflush Filter	X		
Micronic Filter (tube/disk filters)	X		
Ultrafiltration	X	X	
Distillation	X	X (for high boiling point differences)	X
Separator	X	X (density difference)	
Oil Separator		X	
Coalescer		X	

The type and composition of the cleaning medium is to be taken into account in selecting the fluid maintenance options indicated above. When using ultrafiltration, it has to be known that separating out the cleaning substances cannot be avoided in certain cases. In addition, ultrafiltration can only be used for pre-cleaned washing media since the performance of the separating membranes is degraded when they are loaded with particulate contamination.

Using Filtration as Fluid Maintenance for Separating out Particulate Contamination

Bag and backflush filters in various microfilter ratings are the standard equipment used in the maintenance of the fluid of washing systems. Although these filters are suitable for removing large quantities of contamination from a system, they are not suitable in most cases for maintaining defined cleanliness classes. Owing to their design, they do not offer much resistance, (the counterpressure built up across the filter is very low), below 15 psi for the most part. That is why this filter type is frequently used in the full flow when feeding cleaning fluid into the washing or flushing chamber. The filter housings are equipped with pressure gauges for monitoring the proper functioning of the filter.

Bag filters pose the risk that overloading can cause the bag to be destroyed and large contaminant quantities released. That is why it is advisable to additionally define minimum change intervals and to regularly monitor the cleanliness of the washing fluid in addition to the standard parameters like pH value or microbial count.

Residual dirt values of cleaned components are increasingly being defined and specified as an acceptance criterion for the cleaning system. It is of paramount importance that constant adherence be maintained to these values. It is also imperative that the quality of the cleaning fluid be maintained at a high, constant level.

This can be achieved by use of the targeted microfilters, featuring a constant and absolute separation rate. In most applications, tube filters or disk filters are used. The advantage of these filter types as compared to standard hydraulic filter elements is their high contaminant retention rate owing to their depth effect.

The high contaminant separation rate offered by these filter types removes a high amount of contamination from the washing fluid. This causes the filters to become quickly exhausted and blocked. A sufficiently long service life coupled with high washing fluid cleanliness can be achieved by combining filters for removing the main portion of contaminants from the system with absolute microfilters.

Example: At a leading automotive supplier, the camshafts were to be cleaned to a defined cleanliness of 9 mg / component. Point of departure:

Technical Specifications of the Washing Machine Present on Site

Tank Volume:	21 gal. (80 l)
Pump Delivery Rate:	66 gpm (250 l/min) (centrifugal pump)
Washing Agent:	Ardox 6478 – Chemetall Group
Concentration:	2.3 – 3%
Bath Temperature:	ca. 122°F (50°C)
Filtration:	Backflush filter downstream of pump, 50 µm filter rating

Process Data

Bath Change Frequency:	1 time/week
Throughput:	3,000 - 4,000
Wash Cycle:	15 s/component

Challenge: Clogging of the tank, Quality no longer sufficient after 2-3 days, Fluctuation in the contamination content of the components upstream of the line: 30 – 50 mg. Cleaning costs could not be allowed to increase, although quality still had to be improved.

Removal of Particulate Contamination

Goal of Optimizing the Cleaning Line

- Achieve a residual contaminant value of a maximum of 9 mg/camshaft
- Cleanliness of washing fluid of < 30 mg/liter
- Extend the service life of washing fluid, i.e. save costs associated with changing the fluid
- Prevent clogging of the tank, e.g. save cleaning time
- For process reliability reasons, a low-maintenance cleaning system was added to the result which enabled the camshafts to be cleaned to a residual contaminant content of 9 mg/component, this to be done cost-effectively

Result of Optimization

The service life of the cleaning fluid was extended from 1 week to 8 weeks. There was no more clogging of the tank. Changing the bath fluid was done on account of the increased chloride content, not on account of contamination.

The residual contaminant values of max. 9 mg/camshaft and max. 30 mg/liter of bath fluid (when using a 5µm membrane for analysis) were achieved and maintained at this level.

By optimizing the fluid maintenance of this washing line, an improvement in quality was achieved at no added cost and without comprising process reliability.

This example shows that prior to any such optimization or in new facilities the cleanliness of the components upstream of the system, throughput, technical details, targets have to be known and defined, for only in this way can the success of such an endeavor be ensured.

Economic Efficiency Analysis

	Investment ($)	Recurring Costs ($)	Savings/Year ($)
Off-line Filtration	**5,000.00**		
Filtration Costs		**7,500.00**	
Extension of the Service Life of the Bath			**10,000.00**
Lower Reworking Costs			These costs can’t be quoted.
Down Time of the Washing Machine for Cleaning			These costs can’t be quoted.

Functional Testing

Function Testing

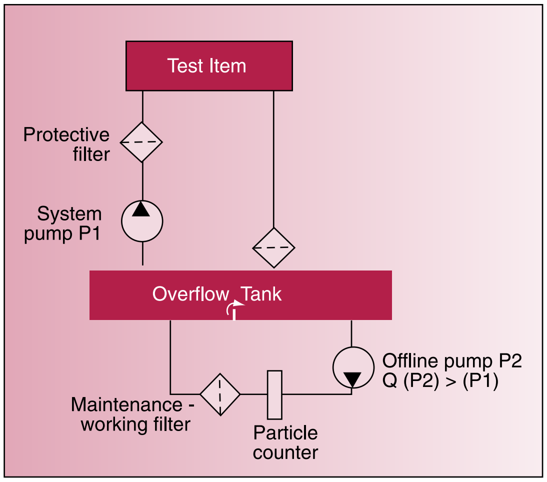


Figure 28. Schematic illustrates the basic setup of most test stands

Most systems come into contact with the hydraulic fluid during initial system filling or function testing. This process affords the manufacturer a substantial opportunity to impact the final cleanliness of the entire system. By using suitable filtration of the filling and test fluids, system cleanliness can be quickly optimized upon delivery or commissioning.

The cleanliness of the final product can be controlled via function testing in the same way as by a washing machine. Some companies have the following motto: ***"The test stand is our last washing machine."***

This statement might be true, however it is an expensive approach in practice. Yet when performing process reliability measures for supplying systems with a defined cleanliness, this is the first approach.

On a function test stand not only function testing is performed but the components and systems are run in as well. A frequent side effect of this is the flushing effect of the system undergoing testing. By employing targeted fluid maintenance and cleanliness monitoring, this flushing effect can be used to ensure that systems possess a defined, constant cleanliness status upon delivery.

Cleanliness monitoring provides information on the process stability of the upstream fabrication and cleaning steps. Frequently, continuous monitoring of test fluid cleanliness results in the cleanliness of the entire system as supplied being documented. This approach is used in mobile hydraulics, turbines or paper machinery upon delivery or during commissioning in order to demonstrate to the final customer that his system is being supplied with the specified cleanliness.

Example: The following study illustrates the cleaning process of a pump during commissioning:

The cleanliness of the test fluid upstream of the test item is maintained at a cleanliness rating of 16 / 14 / 11 (c). After 5 minutes of testing the pump speed is briefly increased to the maximum speed. The test run is concluded after 10 minutes.

In this case, the dirt content of the test item amounted to 1 *mg/kg* component weight upon the conclusion of the test run.

As the schematic below shows, the particle concentration continuously drops during the first 4 minutes of the test run. The particle concentration jumps when the pumps are turned up to full speed after 5 minutes. The next 5 minutes are again used for cleaning the system. Now the following can be asked: "How clean are the valves that leave this test stand?"

The flushing procedure can be monitored by occasionally disassembling the valves in a defined clean environment and evaluating the dirt content of the individual components.

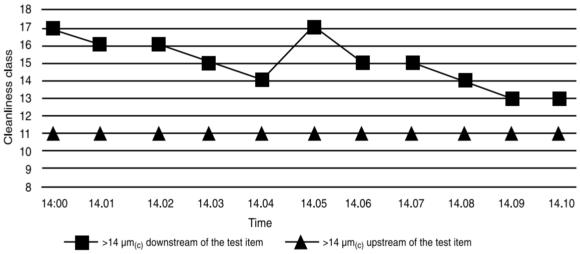


Figure 29. Pump commissioning Particle Count

Preventing Contamination

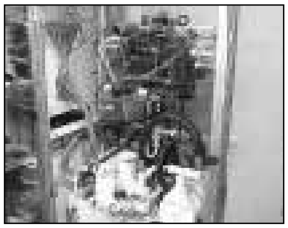


Figure 30. Valve Test Stand with 5 µm Filtration

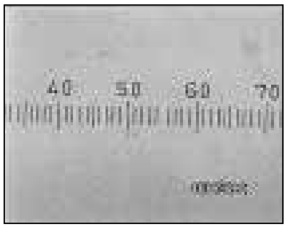


Figure 31. Cleanliness Class Achieved by the Test Fluid: NAS 3

Storage, Logistics and Ambient Conditions

Unfortunately, improper component storage is not uncommon. Seals and gaskets which arrive at the assembly line clean and packed in bags are unpacked and filled into containers which are dirty for the most part as this involves less work and effort.

In most cases, these factors are not taken into consideration and substantial savings potential that could be easily utilized through improved packaging and storage is overlooked.

Supplier Parts and Components Manufactured In-house

Suitable cleanliness specifications for internally produced and sourced parts enable the ingress of contamination into systems to be minimized right from the beginning.

Commissioning Flushing

Commissioning flushing is most frequently chosen for large systems in order to minimize wear during commissioning.

The filtration of the flushing stand has to be designed so that during subsequent analysis the contaminants flushed out of the system undergoing testing are removed and other measurements aren't skewed. As an alternative, cleanliness can be measured and recorded upstream and downstream of the test item during the entire measurement sequence.

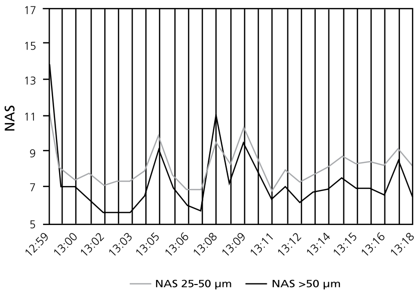
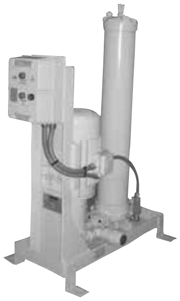


Figure 32. Examination of the Hydraulic System of a Mobile Crane

In a mobile crane application, a specified sampling point was located directly downstream of the pump and an online particle counter connected.

The crane jib was extended after 6, 8 and 10 minutes. The graph clearly shows that every time a new area was brought on line contaminant sediments were flushed out.

When a system's characteristic curve/behavior is known, cleanliness testing can be performed at the end of function testing and, thus, system cleanliness described subsequent to commissioning. This method enables process control to be implemented quickly and reliably during series testing/commissioning. The cleaning curve plotted over time is an indication of the ingress of contaminants during assembly.



X-Series Flushing Skid

Why Contamination Control is Important

Economic Efficiency Analysis

- The core aspects of contamination management are a cost analysis and efficiency review. The following costs are considered in the cost analysis:
- Warranty and non-warranty courtesy work
- Energy costs (e.g. cooling and reheating of washing machines during fluid changes)
- Test stand costs (test item time)
- Costs of the tools and dies of machine tools (increased wear due to high particle concentrations)
- Fluid costs (washing machines, test stations, machine tools)
- Labor costs (reworking, cleaning of washing machines, machine tools, etc.)
- Filter costs

	One-Time Investment	Recurring Costs / Year
Function Test Stands (5)	6,500 x 5 = 32,500	7,500 x 5 = 35,000
Storage Conditions	2,500	
Coverings for the Pallets		
Washing Machine for Cleaning the Pallets	50,000	25,000
Machining Process		2,000 x 7 = 14,000
Manpower/Cleaning	750 x 7 = 5,250	
Filtration	1,250 x 7 = 8,750	
Consulting Expenses	10,000	1,750
Total	109,000	75,750

The economic efficiency analysis (above) describes the success of contamination management as illustrated by a manufacturing line in the automotive industry with an output of 3,000 systems/day. Manufacturing is done 260 days/year (3,000 x 260 = 780,000 systems/year). A contamination review showed that the cleanliness of the function test stand fluid, the intermediate storage conditions and a machining process had to be optimized.

The next step involved forwarding the cleanliness specifications to the suppliers, who received orientation training and are periodically monitored.

The results of optimization:

- Less tool wear in surface machining
- Longer service life of the machining fluid
- Enhanced effectiveness of the downstream washing processes as less dirt had to be removed thanks to optimized storage and machining
- Longer intervals between changing the washing and flushing fluids, consequently "Saturday shifts" could be dispensed with
- Fewer outages at the test stand, i.e. the system is checked up to 3 times when performance deviations occur. These "idle cycles" were reduced by 90%, thus resulting in increased productivity.
- Drop in warranty and non-warranty courtesy work by 50% as the main reason for the outages turned out to be particulate contamination, which resulted in leakage and imprecise control in the system.
- Shortening of the test stand time.

Unfortunately we were not permitted to publish the detailed data behind these savings. Following from an economic efficiency analysis conducted by the customer in-house, savings of **$0.60** per system were achieved.

Cost Savings Per Year	780,000 systems x $0.60 = $468,000
Amortization of One-Time Investment Over 3-Years (109,000 / 3-Years)	$36,333
Recurring Costs Per Year	$75,750
Total Savings Per Year (for first 3-years)	**$355,917**

This economic efficiency analysis also includes the expenses associated with contamination management (seminars, consulting fees, analysis costs).

Contamination Management in Practice

In the previous pages we discussed the impacts of particulate contamination on the service life and reliability of hydraulic systems, how the cleanliness of fluids on components can be specified, and how contamination monitoring is performed. Deploying contamination management results in the following tasks for all participants in the production process:

Suppliers: Ensuring the defined as-supplied condition of products. Selecting the packaging of products to be supplied so that no additional contamination occurs during transportation and storage.

System vendors and manufacturers: Careful transportation, handling, storage and unpacking of products. Keep products clean after they are unpacked or after seals/plugs have been removed. Assemble/install the components in a suitably clean environment.

The following example shows how these individual parts can be combined in contamination management.

Description of the Point of Departure

System X has been successfully manufactured and marketed for years. During the past few years, System X has been developed further and a new generation, System Y was created. Y features improved performance properties, is more compact than X, and operates at higher system pressures than X. The result is that System Y is somewhat more sensitive to particulate contamination.

This is reflected in increased performance deviations during function testing. This deviation no longer occurs when Y is passed through the test stand a second or third time. An investigation of the matter has shown that this unwanted behavior is the result of coarse particulate contamination.

The goal of contamination management is now to improve the degree of cleanliness so that this undesirable behavior no longer occurs on the test stand and the associated costs of warranty and non-warranty courtesy work are reduced.

Step 1: Analysis of the Test Fluid

The cleanliness of the test fluid is determined. The analyses show that the test fluid cleanliness upstream of the test item amounts to a cleanliness rating of 22 / 20 / 18 according to ISO 4406, the largest metallic particles are 400 µm in size, and the largest fibers measure 3,000 µm.

Step 2: Optimizing the Function Test Stand

By additionally integrating bypass microfiltration, which maintains test fluid cleanliness at 15 / 13 / 10, 95% of the performance deviations can be prevented. This also results in a drop in warranty and non-warranty courtesy work.

Step 3: Lowering the Filter Costs at the Test Stands

By performing a contamination monitoring audit, it might be determined a large amount of particulate contamination is being transported into the system by the manufacturing processes and sourced components. This particulate contamination has to be removed from the system at the function test stand, which functions here as the last washing operation. This results in costs that could otherwise be avoided.

A concept is developed in which the washing, machining processes, and intermediate storage are optimized.

A cleanliness specification along with a test plan for system fluids is drafted. This specification is forwarded to external as well as internal suppliers and the components supplied with a defined, constant cleanliness.

Step 4: Integrating Particle Counting in Quality Assurance

A particle sensor is integrated in the function test stand for the purpose of continuous quality control of the as-supplied quality of System Y. A limit is defined for the maximum contamination of the test fluid in the return line. Intervention can be done immediately if this value is exceeded, thus ensuring that no contaminated systems leave the factory. Random sampling is done to check the supplier quality and non-conformant components returned to suppliers or washed in-house at the supplier's expense.

Step 5: Economic Efficiency Analysis

Contamination management started off with analyzing the costs associated with warranty and non-warranty courtesy work as the result of increased malfunction at the test stands. These costs are reanalyzed after optimization and compared. The savings achieved through optimization are briefly described in Economic Efficiency Analysis. The cost savings in that case amounted to *ca. e 355,917/year* (close to half a million dollars). This optimization process lasted *ca. 2 years.*

Step 6: Documentation and New Projects

The contamination management findings are collected in a database and used in the development of new systems. The defined maximum residual dirt content becomes standard in new systems in the same way that dimensions, surface grades and tolerances have been. This residual dirt content is primarily in reference to the specification that applies to System Y.

The specification is adapted in keeping with the experience gained with the prototypes. Cleanliness and cleaning costs are primarily determined by the design of new systems.