Defining And Maintaining Fluid Cleanliness For Maximum Hydraulic Component Life

By Brendan Casey

Many factors can reduce the service life of hydraulic components. Contamination of hydraulic fluid by insoluble particles is one of these factors. To prevent particle contamination from cutting short component life, an appropriate fluid cleanliness level must first be defined and then maintained on a continuous basis.

Particle Contamination And Its Consequences

Particle contamination in hydraulic fluid accelerates wear of system components. The rate at which damage occurs is dependent on the internal clearances of the components within the system, the size and quantity of particles present in the fluid and system pressure. Typical internal clearances of hydraulic components are shown in exhibit 1.1.

Exhibit 1.1

COMPONENT TYPE	TYPICAL INTERNAL CLEARANCE IN MICRONS
Gear pump	0.5 – 5.0
Vane pump	0.5 – 10
Piston pump	0.5 – 5.0
Servo valve	1.0 – 4.0
Control valve	0.5 – 40
Linear actuator	50 - 250

Particles larger than a component's internal clearances are not necessarily dangerous. Particles the same size as the internal clearance cause damage through friction. But the most dangerous particles in the long-term are those that are smaller than the component's internal clearances. Particles smaller than 5 microns are highly abrasive. If present in sufficient quantities, these invisible 'silt' particles cause rapid wear, destroying hydraulic components.

Quantifying Particle Contamination

Some level of particle contamination is always present in hydraulic fluid, even in new fluid. It is the size and quantity of these particles that we are concerned with. The level of contamination, or conversely the level of cleanliness considered acceptable, depends on the type of hydraulic system. Typical fluid cleanliness levels for different types of hydraulic systems, defined according to ISO, NAS and SAE standards, are shown in exhibit 1.2.

Exhibit 1.2

TYPE OF HYDRAULIC SYSTEM	MINIMUM RECOMMENDED CLEANLINESS LEVEL			MINIMUM RECOMMENDED FILTRATION LEVEL IN MICRONS ($\beta_{\chi} \geq 75$)
	ISO 4406	NAS 1638	SAE 749	
Silt sensitive	13/10	4	1	2
Servo	14/11	5	2	3-5
High pressure (250–400 bar)	15/12	6	3	5-10
Normal pressure (150-250 bar)	16/13	7	4	10-12
Medium pressure (50 -150 bar)	18/15	9	6	12-15
Low pressure (< 50 bar)	19/16	10	-	15-25
Large clearance	21/18	12	-	25-40

ISO 4406 defines contamination levels using a somewhat complicated dual scale numbering system. The first number refers to the quantity of particles larger than 5 microns per 100 milliliters of fluid and the second number refers to the number of particles larger than 15 microns per 100 milliliters of fluid.

The complicated part is that the quantities of particles these numbers represent are expressed as powers of the numeral 2. For example, a cleanliness level of 15/12 indicates that there are between 2^{14} (16,384) and 2^{15} (32,768) particles larger than 5 microns and between 2^{11} (2,048) and 2^{12} (4,096) particles larger than 15 microns, per 100 milliliters of fluid. A modified version of ISO 4406 includes 2 micron particle counts, in addition to the standard 5 micron and 15 micron counts.

Defining A Target Cleanliness Level

As an example, let’s assume that we have a normal-pressure system and using exhibit 1.2 we define our target cleanliness level to be ISO 16/13. Having established the minimum fluid cleanliness level required for acceptable component life in this type of system, the next step is to monitor the actual cleanliness of the fluid to ensure that the target cleanliness level is maintained on a continuous basis. This involves taking fluid samples from the system at regular intervals and testing them for cleanliness.

Testing Fluid Cleanliness

There are two ways of testing fluid cleanliness. The first involves sending a fluid sample to a laboratory for analysis. The lab results contain detailed information on the condition of the fluid. The information normally included in a fluid condition report, along with typical targets or alarm limits, are shown in exhibit 1.3.

Exhibit 1.3

CONDITION CATEGORY	RECOMMENDED TARGETS OR ALARM LIMITS
Fluid cleanliness level	Within targeted range chosen for the system or recommended by the manufacturer (ISO 4406)
Wear debris level	(Al) 5 ppm, (Cr) 9 ppm, (Cu) 12 ppm, (Fe) 26 ppm, (Si) 15 ppm
Viscosity	± 10 % of new fluid
Water content	< 100 ppm
Total Acid Number (TAN)	+ 25% of new fluid
Additive level	− 10% of new fluid

The second way to test a fluid's cleanliness level is to use a portable, electronic instrument designed for this purpose. This method is convenient and results are almost instant, however it shouldn't be considered a total substitute for lab analysis because the results do not include wear debris levels, viscosity, water content and other useful data. But when the two methods are used in combination, the frequency of lab analysis can be reduced.

Whichever method is employed, it is important that the equipment used to capture and contain the sample is absolutely clean. If you are taking multiple samples from different systems, take care not to cross-contaminate one fluid sample with another, and never take samples from drain plugs or other low lying penetrations in the system, otherwise the results will be unreliable. Ideally, samples should be taken from the return line, upstream of the return filter, with the system working at operating temperature.

Achieving A Target Cleanliness Level

Going back to our example, let's assume that we have sampled the fluid in our system and received the fluid condition report. The report indicates an actual cleanliness level of ISO 19/16, well outside our target of 16/13. We know we are not going to get optimum service life from our system's components with this level of contamination in the fluid, so we need to fix it.

As you can see from exhibit 1.2, there is a correlation between fluid cleanliness level and the level of filtration in the system. Therefore, we need to check the system's current level of filtration. But first, let me explain filter ratings in more detail.

Hydraulic Filter Ratings

Hydraulic filters are rated according to the size of the particles they remove and the efficiency with which they remove them. Filter efficiency can be expressed either as a ratio (Beta, symbol β) for a given particle size (χ) or as a percentage. Filter Beta ratios and their corresponding efficiency percentages are shown in exhibit 1.4.

Exhibit 1.4

FILTER BETA RATIO AND PERCENTAGE EQUIVALENTS					
β	%	β	%	β	%
2.0	50.00	5.8	82.76	50.0	98.00
2.4	58.33	16.0	93.75	75.0	98.67
3.0	66.66	20.0	95.00	100.0	99.00
4.0	75.00	32.0	96.875	200.0	99.50

Filters are commonly classified according to *absolute* or *nominal* ratings. A filter that is classified *absolute* has an efficiency of 98% or better ($\beta\chi\geq 50.0$) at the specified micron size, and a filter that is classified *nominal* has an efficiency of between 50% and 95% ($\beta\chi 2.0$ - $\beta\chi 20.0$) at the specified micron size.

This can get a bit confusing, but the important thing to remember when purchasing filters for your hydraulic equipment, is that there is a significant difference in effectiveness between a 10-micron *nominal* and a 10-micron *absolute* filter element.

Checking The Filtration Level

According to exhibit 1.2, a filtration level of 10-micron with an efficiency of 98.67% ($\beta_{10} \geq 75$) is required to achieve a cleanliness level of ISO 16/13. This means that unless there is at least one filter in the system with a rating of 10-micron *absolute*, it is unlikely that a cleanliness level of 16/13 will be achieved, regardless of how many times the filters are changed. If a check of the existing filters reveals that this level of filtration is not present somewhere in the system, then either the level of filtration must be improved or the target cleanliness level must be revised downward.

Don't automatically assume that the existing filter elements in a system can be automatically substituted with elements of a smaller micron size and/or higher efficiency. This will increase the restriction (pressure drop) across the filter and consequently the filter may no longer be able to handle its designed flow rate. If this happens, the filter's bypass valve will open and the filter will be ineffective. Filter manufacturers publish graphs that plot pressure drop against flow rate at a given fluid viscosity, according to an element's area, blocking size and efficiency. This information should be consulted before upgrading the elements in existing filter housings.

Rectifying Abnormal Contamination Load

Going back to our example, let's assume that the system's tank-top mounted return filter is rated 10-micron absolute ($\beta_{10} \geq 75$). Therefore, according to exhibit 1.2, our target cleanliness level of ISO 16/13 should be achievable with the existing level of filtration. So how do we explain the high level of particle contamination in the fluid?

If we are just starting our preventative maintenance program, this could be explained by a filter change that is long overdue. If we have some previous history on this system and the results of our last fluid sample were acceptable, we need to look for any abnormal source of contamination that is overloading the filters. Keep in mind that particle contamination can be generated internally or externally ingested.

Check the wear debris levels in the fluid condition report. This will indicate if the level of contamination being generated internally is abnormal. If wear debris levels are above alarm limits, this usually indicates that a component in the system has started to fail. Any metal-generating components need to be identified and changed-out.

Common entry points for externally ingested contamination are through the reservoir air space and on the surface of cylinder rods. Check that all penetrations into the reservoir air space are sealed and that the reservoir breather incorporates an air filter of 3-micron absolute or better. If the reservoir is not properly sealed and/or the breather not adequately filtered, dust can be drawn into the reservoir as the fluid volume changes.

Check that the chrome surfaces of all cylinder rods are free from pitting, dents and scores, and rod wiper seals are in good condition. Damaged cylinder rods and/or rod wiper seals allow dust that settles on the surface of the rod to enter the cylinder and contaminate the fluid.

Flushing The Fluid

The next step is to change all of the filters in the system. Because our example system's current fluid cleanliness level of ISO 19/16 is well outside target, the fluid in the reservoir should be flushed before the filters are changed. This involves circulating the fluid in the reservoir through external filters for an extended period, or ideally, until the target cleanliness level is achieved. The equipment for doing this is commonly called a filter cart, which normally consists of an electric transfer pump and a set of filters mounted on a trolley.

The benefits of flushing the fluid in the system before changing the filters are that the system will be operating with cleaner fluid sooner, and the new filters don't have the job of cleaning up the fluid – they only have to maintain fluid cleanliness.

If you don't have access to a filter cart or it isn't practical to use one, purchase two sets of replacement filter elements at this time. Fit the first set immediately and replace them with the second set after 20 to 50 hours of service. The idea is that the first set of filters cleans the fluid and the second set keeps it clean. Either way, the fluid cleanliness level should be checked again after 50 hours of service to ensure the target cleanliness level has been achieved.

Benefits Of Fluid Condition Monitoring

Monitoring and maintaining fluid cleanliness involves a continuous cycle of testing and corrective action. The benefits of regular fluid condition monitoring are illustrated in the following example.

Several years ago, I was responsible for a preventative maintenance program in a large, manufacturing plant. This plant operated 24 hours per day, 7 days a week. The manufacturing process was complex and highly integrated, such that a breakdown in one section of the plant would stop production across the whole plant. Consequently, unscheduled downtime was very costly in terms of lost production. As part of the preventative maintenance program, the fluid condition of the plant's 30 individual pieces of hydraulic equipment was closely monitored.

One day, as I was analyzing the latest batch of fluid condition reports, I noticed that one system was showing chromium levels way above normal. Investigation revealed that these high levels of chromium wear debris were being generated by a large diameter cylinder that had started to fail. The significance of the problem intensified when a check of the plant's spare parts inventory revealed that there was no spare on site and because the cylinder was unique to this piece of equipment, delivery time on a replacement was several weeks.

Early warning of this impending failure enabled a replacement cylinder to be manufactured and downtime to be scheduled for its change-out. This averted a long and costly period of unscheduled downtime. The management of this company needed no further convincing of the value of this aspect of the preventative maintenance program.

About the Author: Brendan Casey has more than 15 years experience in the maintenance, repair and overhaul of mobile and industrial hydraulic equipment. For more information on reducing the operating cost and increasing the uptime of your hydraulic equipment, visit his Web site: http://www.insidersecretstohydraulics.com/