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New Oil Should be Clean Oil

An Analysis of New Oil Cleanliness

by Mike Johnson, CMRP

Recently a mid-sized company conducted a study on the state of delivered oil cleanliness as part of a planned lubrication program development. There were two key objectives to this abbreviated study.

1. Measure the current state of delivered lubricant cleanliness (solids and moisture) for five product types.
2. Use the results to establish a pass/fail threshold for lubricant vendors interested in supplying lubricants to the various company sites.

Samples were collected for four different product types (diesel engine oil - DEO; gasoline engine oil – GEO; transmission oil – TO; hydraulic oil - HO) from 135 discrete lubricant containers, including 61 samples from bulk tanks, 11 from semi-bulk totes (semi-bulk containers), 34 from drums, and 29 from pails. A sample collection protocol was established and the sample materials were provided by the oil analysis laboratory. The quality of the sample collection process itself was subject to variability since multiple individuals were involved in sample collection. It is possible, but unlikely, that the data is invalid due to poor sample collection.

Particle counts were conducted with a laser-type automatic particle counter, and the data provided in the form of industry accepted International Standards Organization (ISO) particle count (PC) range values for concentrations equal to or greater than four microns, 6 microns and 14 microns respectively. ISO range values are provided for Average, Maximum, Minimum, and Standard Deviation for each product type.

Moisture analysis is conducted using the Karl Fisher method, and is provided in a parts per million value. Average, maximum, minimum, and standard deviations are provided for moisture concentrations for each product type.

The results from the survey are represented in this case study. The correlation between container size and lubricant type was low, but will not be covered in this article due to space limitations. It is the author's belief that the displayed results represent the state of art, for better or worse, for how lubricants are handled and delivered to commercial and industrial users.

The Risk of Dirty Oil

There is a growing awareness of the significant negative impact that solid contaminants can have on lubricated component surfaces. Multiple studies have been conducted by component manufacturers and industrial research organizations showing the relationship between lubricant cleanliness and component lifecycles.

The lubricant film that forms between moving components provides an extraordinary level of protection and withstands similar extraordinary abuse. The film cannot however offset the destruction that occurs when particles are able to enter the microscopic gaps between the interacting surfaces. If the particles are smaller than the dynamic (operating) clearance then they may pass through without any contact with the machine surface. If the particle is small enough to enter, but too large to pass cleanly through then the particle closes the gap, absorbs and transfers the load between the surfaces.

For components that roll against one another (element bearings, gear teeth), the particles can transmit the entire dynamic load into and area that is much smaller than the component designer intended. When this occurs the unit loads exceed the material strength of the component materials, and microscopic stress cracks form below the component surfaces. When crack concentration is high the cracks intersect, open larger cracks and eventually grow to a state that allows surface materials to separate and float free. These microscopic sized pieces are surface metal are then measured and reported in the form of machine wear debris. This wear condition is called micro-pitting.

As a surface imperfection opens up on a highly loaded surface, and the edges of the roughed up surface are 'worked', the micro-pit will grow much the same way that a small hole in a concrete roadway will grow as tires pass repeatedly over the edges.

Particle damage to sliding surfaces occurs in a slightly different way. With sliding surface component interactions, the clearance size particle enters the working area and is pressed into the softer of the two surfaces (there is nearly always one hard surface and one softer

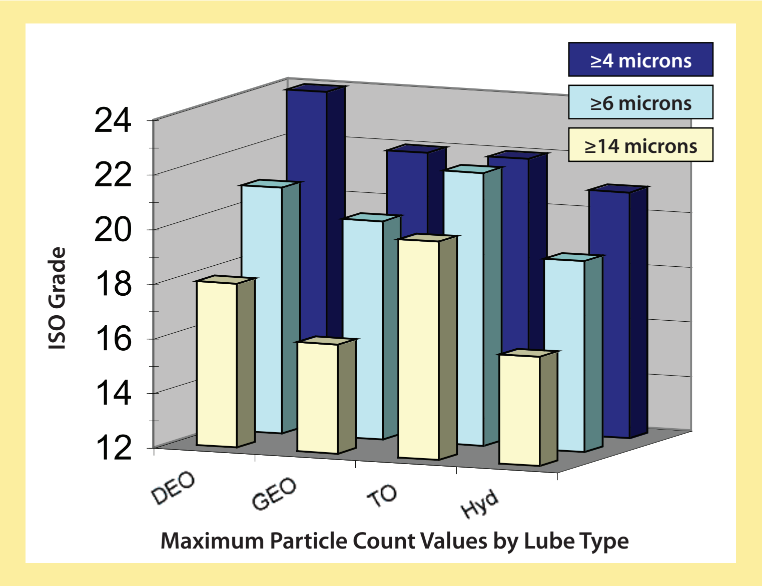

Figure 1 - Maximum Particle Concentration (PC) from the test group for each product type.

surface with a sliding interface). The particle hangs there until eventual repeated contacts either dislodge or break the offending particle, or the particle cuts away enough machine material that a gap opens between the lodged particle and the opposite surface eliminating further contact.

One last interesting detail should be understood: particles that are small enough to pass into, but not cleanly through, the dynamic component working area range from one to five microns in size, which is around the size of a red blood cell. The particles are very, very tough. Larger particles may crumble under the load of the machine, but at these very small sizes the particles are actually harder than the machine metal surfaces. This seems unlikely, but is true for many types of commonly found particles. Even the wear debris that is produced is hard enough to create more surface damage on surfaces with the same relative material hardness. Abrasive wear can become a rapidly escalating problem for highly loaded surfaces if solid particles are not controlled.

The new lubricant is one of many sources of solid particle contaminants. The lubricant raw materials are not pre-cleaned before being combined into a finished lubricant. The vessels used to blend the raw materials fill with blend-plant atmosphere each time the vessel is emptied. Additionally, each time the transport container (transport, haul truck, drum, oil can) drains down it is filled with the air from the immediate environment. Often the immediate environment is rich with microscopically sized particles. This study reveals the nature of the contaminant threat imposed by new lubricants.

Figure one shows the particle concentrations of the worst samples in each of the four groups tested. The least egregious of the four (i.e., the cleanest sample of the four 'worst case scenarios') belongs to the hydraulic sample, with a ISO grade of 21/19/16. This could be characterized as a very poor quality level for delivered cleanliness, even though it may not sound like a large amount. Lets consider what the score really tells us.

Each color of the Figure 1 graph represents a concentration of particles for a given size. The dark blue bar represents the concentration of all particles greater than four microns in size. As Table 1 demonstrates, at a range value of 21, this sample could contain up to two million particles greater than four microns in the 3.38 ounce bottle. The light green bar represents a set of larger particles found within the dark blue bar. This value, at 19, tells us that the sample could contain between 250k and 500k particles greater than six microns in the sample bottle. The yellow bar represents the concentration of largest particles, those greater than 14 microns in size. This last group count is included in both of the previous groups, so it is now being counted for the third time, but for the first time as a separate category. This ≥ 14-micron category has a range value of 16, meaning that this sample contains between 32 and 64 thousand particles greater than 14 microns in size in the 3.38 ounces of fluid in the bottle.

In round terms, this sample contains roughly 10 parts per million of solid material. That doesn't sound like a large number but it is.

One can get a sense of the concentration for each micron size for each lubricant type using the chart in Table 1. For instance, the dark blue bar (≥ 4 micron particles) for the DEO, with a range value of 24, represents between 8 million to 16 million particles per each sample bottle full. That would obviously be abrasive. Try to estimate for yourself what the concentrations would be for the ≥ 6 micron particles (= 21) and ≥ 14 micron particles (= 18).

These numbers represent the worst-case condition for each size classification for each lubricant category. Fortunately, the best-case scenario is quite a bit better. Figure 2 shows the best-case particle ranges for each particle size by lubricant category. Once again, the HO (hydraulic oil) reveals the lowest concentration for a particle size category, the ≥ 14-micron category, at a respectable value of 11.

This means that for this sample scenario, the lubricant in the bottle would only have 1000 to 2000 particles greater than 14 microns in size. Since hydraulic components are

Number of Particles Per 100 ml of Fluid		ISO Range Numbers	Number of Particles Per 100 ml of Fluid		ISO Range Numbers
More Than	Up To & Including		More Than	Up To & Including	
8,000,000	16,000,000	24	2,000	4,000	12
4,000,000	8,000,000	23	1,000	2,000	11
2,000,000	4,000,000	22	500	1,000	10
1,000,000	2,000,000	21	250	500	9
500,000	1,000,000	20	130	250	8
250,000	500,000	19	64	130	7
130,000	250,000	18	32	64	6
64,000	130,000	17	16	32	5
32,000	64,000	16	8	16	4
16,000	32,000	15	4	8	3
8,000	16,000	14	2	4	2
4,000	8,000	13	1	2	1

Table 1 - Standard Range Concentration Chart for 100 ml sample volume.

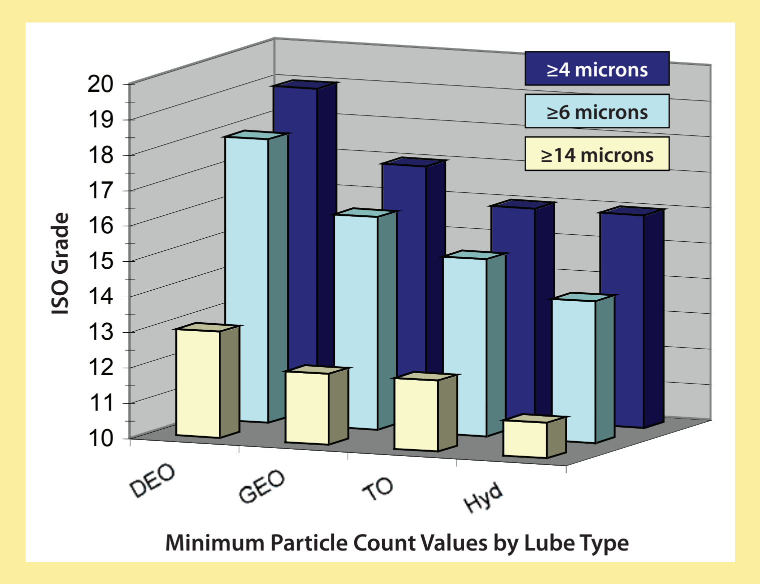

Figure 2 - Minimum Particle Concentrations by particle size for each lubricant category.

	Composite Values - Average			
	Water	≥ 4	≥ 6	≥ 14
DEO	2,409.3	21.2	19.9	14.9
GEO	1629.9	20.2	18.7	14.1
TO	1449.2	20.8	19.6	14.4
HO	259.9	18.0	16.6	13.2

Table 2 - Average of particle range values for all samples.

	Standard Deviation			
	Water	≥ 4	≥ 6	≥ 14
DEO	615.7	0.9	0.8	1.0
GEO	729.5	1.1	1.0	1.1
TO	796.0	1.5	1.7	1.6
HO	176.6	1.1	1.0	1.3

Table 3 - Standard Deviations for all ranges by product type.

particularly sensitive to hard particles this is relatively good news.

It is interesting to note that the cleanest sample collected for the DEO had a (rounded) range value of 19 (250K to 500K particles per 3.38 oz. sample bottle) at ≥ 4 micron particle size. For a best case scenario, this leaves a lot of room for improvement.

Setting Condemning Targets for Future Lubricant Receipts

A central reason for this study was to try to determine an appropriate target range for condemning a lubricant as unacceptable. For that purpose, an average was calculated for each particle size range for each lubricant type. The sample population size is large enough that it should represent a credible average and range with which to try to set target values. Table 2 and Figure 3 provide the data in both numerical and graphical form. Table 2 reveals the actual range values per category, and Table 3 shows the standard deviation for the whole data set per lubricant category. With these two sets of values, it is possible to arrive at a reasonably tolerant 'not-to-exceed' limit for each lubricant delivery, regardless of whether it is a truckload or a single pail.

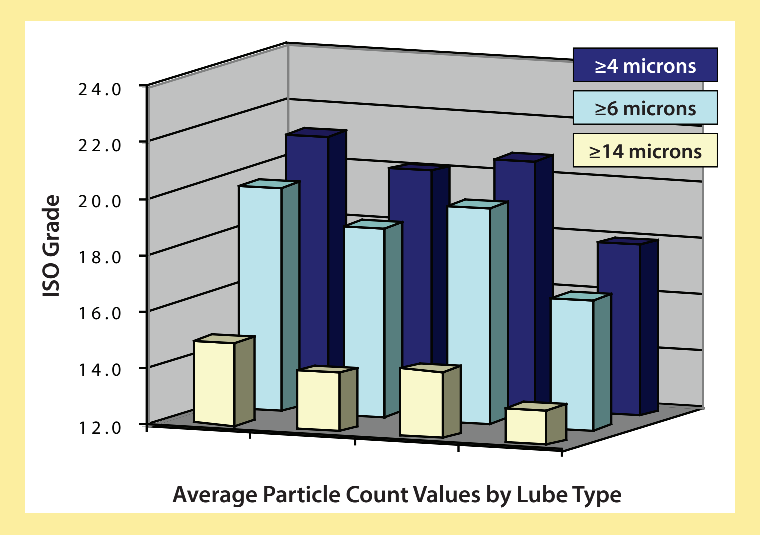

Figure 3 - Particle Count Averages for all product categories.

Once known, a plus-one, two or three standard deviation rule can be applied to the average range value to set a condemning limit.

For example, the average hydraulic oil ISO cleanliness rating is 18/16/13. For a low-technology type of system (low to medium pressures, low temperatures, gear or vane pump, simple controls) this is a reasonable target cleanliness level. However, for a sophisticated CNC system (high pressures, variable volume piston pumps, servo control values, low clearance work requirements), the owner would be wise to set the routine target to a much lower threshold, around 15/13/11.

It is obvious that the average cleanliness quality oil will not be adequate for the higher criticality machine. The reliability manager might use the average (18/16/13) less one or two standard deviations to establish the acceptable routine threshold for hydraulic oil cleanliness for lubricants purchased for the CNC application.

For purpose of this discussion, assume that a one-standard-deviation improvement is applied to the standing average. The new in-plant target (in whole numbers) would be: Obviously, the range can float to whatever value is considered acceptable. For a broad based condemning limit, consider the effect of allowing the average of all the site's measured particle counts PLUS one standard deviation. For the hydraulic oils, the (whole number) results would be as follows:

Current Avg.	Less 1 Std. Dev.	ISO Target
≥4 = 18	- 1.1 * 1 = 1.1	16
≥6 = 16	- 1.0 * 1 = 1.0	15
≥14 = 13	- 1.3 * 1 = 1.3	12

Current Avg.	Plus 1 Std. Dev.	ISO Target
≥4 = 18	+ 1.1 * 1 = 1.1	20
≥6 = 16	+ 1.0 * 1 = 1.0	17
≥14 = 13	+ 1.3 * 1 = 1.3	15

In this particular analysis exercise the standard deviations for the diesel engine oil was less than the other product groups. Although the diesel oils were appreciably more dirty, there was less variability in the set of samples (which explains the lower standard deviation). So, when this approach is applied to diesel engines oils the following results are produced:

Current Avg.	Plus 1 Std. Dev.	ISO Target
≥4 = 21	+ 0.9 * 1 = 0.9	21
≥6 = 19	+ 0.8 * 1 = 0.8	19
≥14 = 14	+ 1.0 * 1 = 1.0	15

There was no movement. Given the already high levels, this result may be good, but that would be a purely subjective call. If management determines that the standing condition is unacceptable, and chooses to set the target at the average less one standard deviation, then the new target becomes 20/18/14.

This approach does not suggest a single correct answer. It is only intended to provide an easy-to-calculate and easy-to-explain objective basis for setting a cleanliness target, and is also rooted in, to some degree, a state of practical reality.

A similar approach could be applied to desired dryness of the lubricant. The sample data reveals an expected condition with combustion engine oils: the oils have relatively high concentrations of moisture because of a specific type of additive (dispersant) that is present, particularly in diesel engine oils. The additive helps to prevent soot from plating out inside the engine cavity. The additive treats soot and water the same way – it traps and holds the contaminant in suspension. Consequently, engine oils tend to have naturally high moisture levels. This is not a problem since the operating temperature of engines is high enough to drive moisture off shortly after beginning operation.

Maximum, minimum and average water concentrations from the sample group are displayed in Figure 4, and the actual numbers are shown in Tables 2 and 3. The lubricant user could subtract one or two standard deviations from the maximum, or could add one or two standard deviation to the minimum, or could do either from the average of all samples to establish a threshold. As is the case with solid particles, lower levels would be better for the lubricant and the machine, particularly for industrial lubricant and machines.

Conclusion

This analysis provides some quantitative insight into the extent to which different lubricants are contaminated with common environmental contaminants during the manufacturing and handling process. The data does not suggest any great benefit may be seen from purchasing lubricants in a particular type of container (drum, pail, bulk). All containers showed relatively high levels of solid and moisture contaminants.

The model for selecting a target threshold is intended to be quantitative, practical, easily adjustable, and easily explained. It is not intended to suggest a best practice, but is intended to offer an objective approach that can be used throughout an organization.

Mike Johnson is the founder of Advanced Machine Reliability Resources Inc., a firm that provides precision lubrication program development, consulting and training. He has written and presented numerous technical papers at symposia and conferences throughout North America about how to use machine lubrication to drive machine reliability. Mike is happily married, plays and coaches soccer, and has 3 young children that consume his remaining time and attention. He can be reached at mjohnson@amrri.com or 615-771-6030.

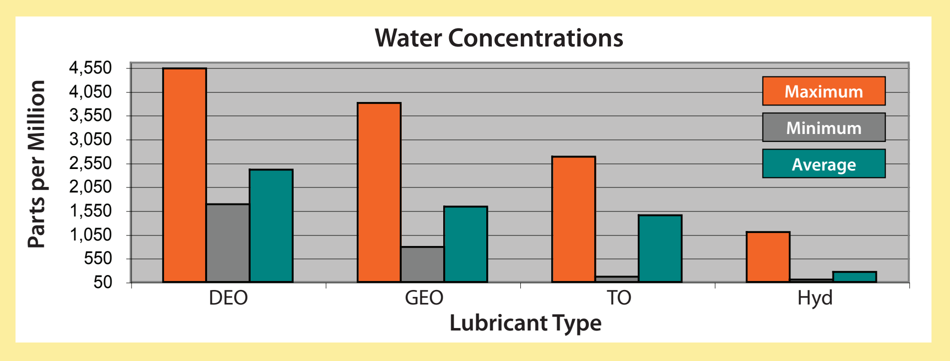

Figure 4 - Water contamination levels for each product type.