Oil Condition Monitoring Case Study

BUREAU VERITAS

OIL ANALYSIS VS. MICROSCOPIC DEBRIS ANALYSIS - WHEN AND WHY TO CHOOSE

ABSTRACT

For situations where spectrochemical oil analysis alone may not provide the most complete wear profile of your machinery, the results from specialized microscopic and instrument based tests which focus on particle and wear debris may prove to be a critical resource. Knowing the science behind the particle size range strengths and weaknesses of each of these tests will help you choose when and how to use these tests in conjunction with your existing oil analysis program to obtain maximum benefits from the insights they provide.

INTRODUCTION

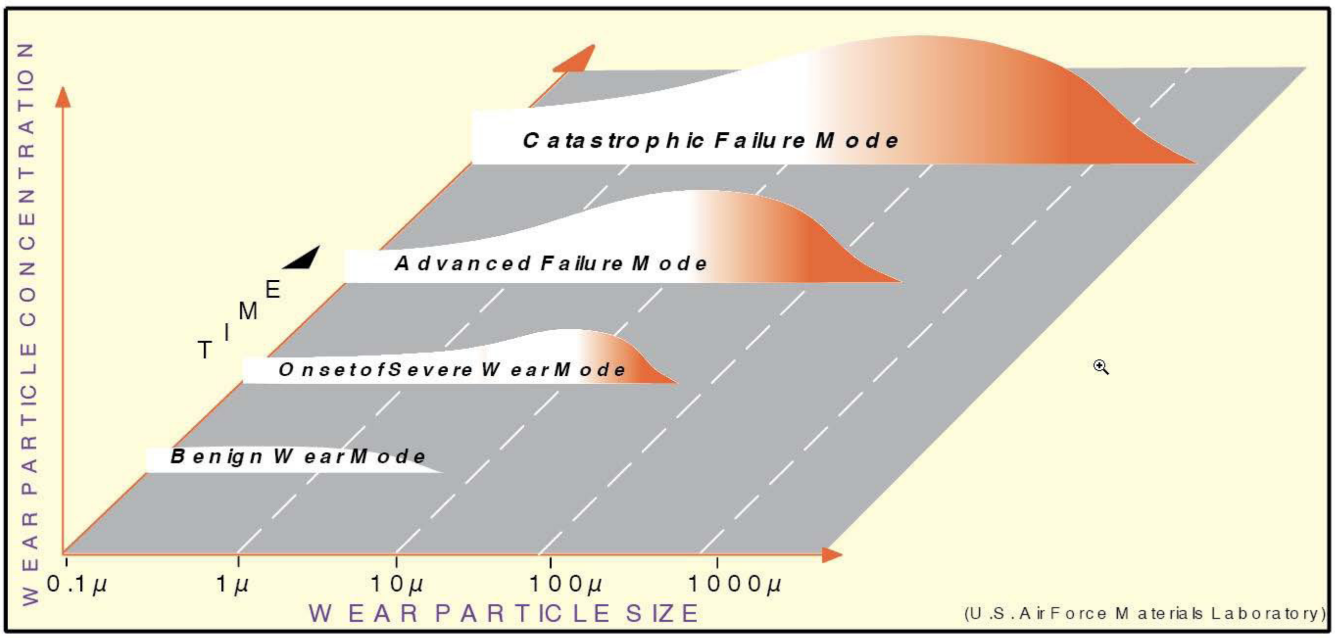
In researching this paper, I ran across a 1998 posting on Noria's Questions About Oil Analysis bulletin board which seems to perfectly summarize the oil analysis practitioners' point of view for the topic at hand. Jeff St. Amand — then with AEP—wrote, "In selecting tests for wear metals, is there any known rule of thumb for when to switch between AES [atomic emission spectrography] and RFS (or another method) based upon DR ferrography DL/DS proportions, ISO cleanliness levels or other criteria to obtain a more accurate idea of the extent of wear debris? Are there other tests that should be considered based upon increasing levels of particles greater than the 3 - 8 micron size limit of AES?"

Oil analysis has been called, with varying degrees of accuracy, a "blood test" for fluid lubricated mechanical systems. Have you ever stopped to think about how many blood tests depend upon an analysis of solid particulates carried in our blood? For instance, any blood test involving "cells"—'red' or 'white' blood cells, T-cells (immune system) or platelets (clotting)—depends on solid particle analysis. As in our particle counting, these tests are predominantly microscopic identifications by type and count, but this is where the analogy breaks down. Unlike the oil-borne solids we are interested in, blood-borne solids tend to be found in a narrow particle size range—only about 8 to 15 microns—due to the minimum blood vessel size in the human body. Oil analysis laboratories and practitioners must consider a much wider range of solid particle sizes—sub-micron (<1 micron) to_over_1000 microns—when diagnosing wear and its modes. Complicating this effort, both rotating disc electrode (RDE) and inductively coupled plasma (ICP) atomic emission spectrochemical analysis methods, long the backbone of conventional oil analysis, have well-documented upper limitations on the particle size(s) that they can effectively measure. So is there a way for us to solve spectrochemical oil analysis's weakness in detecting the particles most diagnostic for abnormal wear?

BIGGER IS NOT BETTER

One of he 'givens' in mechanical system operation is when system parts wear abnormally, the particle quantity and size progression in wear severity is from smaller to larger. Figure 1 illustrates this relationship. This size change is related to stress increases as loaded surfaces depart from their original shapes and clearances, the effect of higher temperatures on lubricant films and alloy structures, and the cascade effect of wear as already worn parts release successively larger particles which act to dent and abrade these very same damaged surfaces. This accelerating deterioration in mechanical condition is a primary driver for the early diagnosis of abnormal wear.

Figure 1. Particle size progression in Abnormal Wear.



PARTICLE COUNTING—SIZING UP THE SITUATION

So our goal should be to specify and direct additional testing to supplement spectrochemical analysis with a tool easy for any oil analysis practitioner to obtain and use. And there is such a tool—the *particle count*—and it's a powerful tool indeed. The particle count is a familiar, well-standardized and almost universally available method, already part of many oil analysis packages. Particle counting possesses an ability to look straight across the multiple size ranges diagnostic to abnormal wear. It is not limited to a particular element, and shifts in the counts by range can be correlated to increasing wear. Simply put, using the particle count to compare the particle distribution to the sensitivity ranges of the various particle analysis technologies maximizes your ability to choose the most effective means to supplement conventional oil analysis.

WEAR MODES AND PARTICLES GENERATED

A crucial step in expanding your wear-detecting vision with particle counting involves understanding the general size ranges into which typical wear and contaminant particles fall into. The forces and conditions that generate particles push them to form in typical particle configurations and sizes. These size ranges are primarily influenced by material type, wear mode and severity progression and secondarily influenced by a series of engineering and lubrication considerations beyond the scope of this paper. The overall point to remember is that as wear worsens, the average particle size increases, so any proactive approach to wear monitoring must detect this size shift immediately. Figure 2 illustrates some basic information on this topic, and provides perspective by relating the particles of wear to the real-world objects whose sizes they approximate. Please note that this illustration is not an exhaustive listing of wear forms or types, and that most particles of wear pass through a smaller-to-larger sequence as wear progresses. The size ranges chosen are those associated with wear or contamination which has reached a demonstrably serious phase, one where your proactive intervention will be well justified.

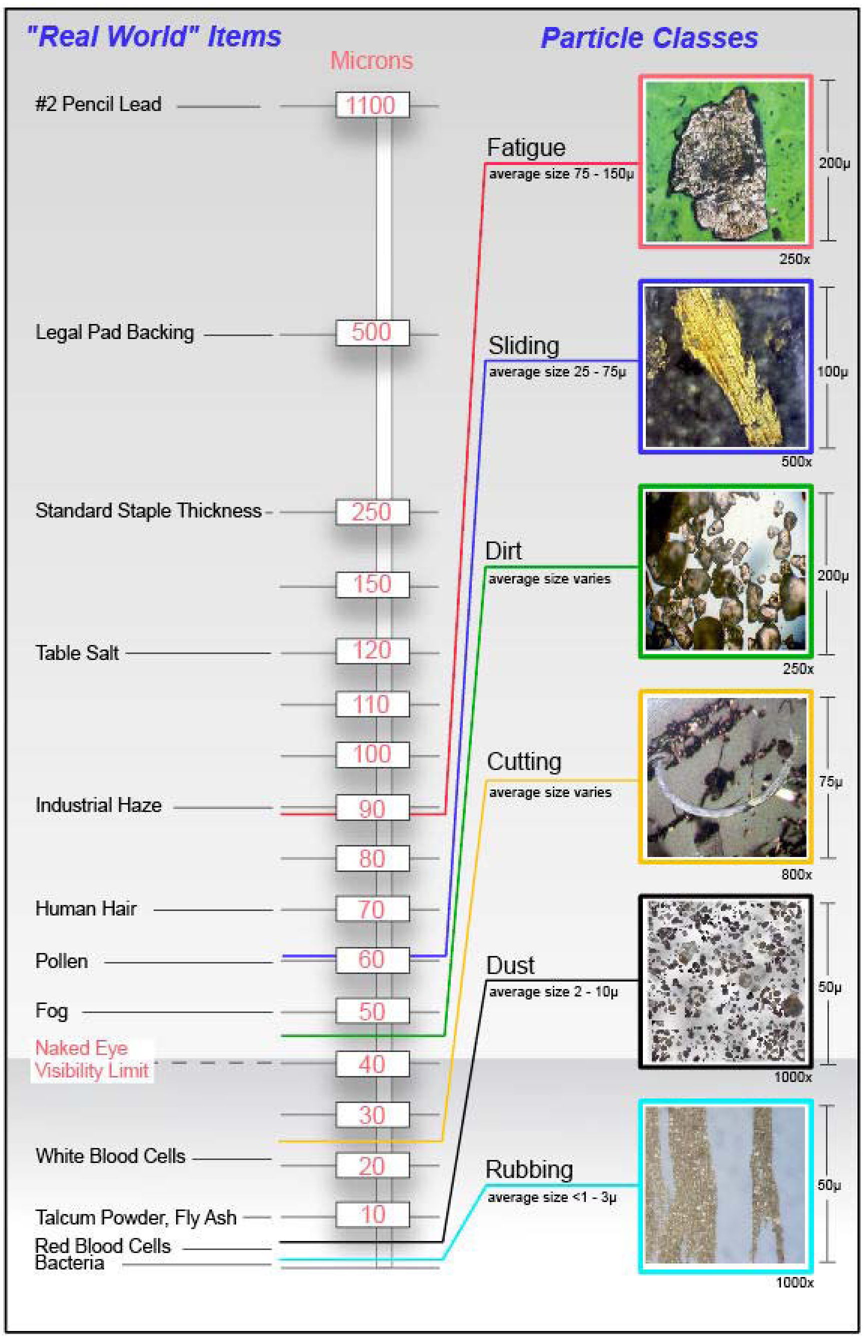


Figure 2. Typically Encountered Particles and Their Sizes

USING OUR TOOLBOX

There is more than one route available to the oil analysis practitioner attempting to investigate wear modes in the larger, more critical size ranges beyond conventional AE/ICP spectrochemical methods. You can opt for instrument/numerical result type tests, or choose visual/microscopic analyses. Instrumented methods have historically focused on iron when attempting to fill in this so-called "blindspot", since iron is typically the most important single element in mechanical system wear analysis and researchers and instrument designers alike know that ferrous alloys are subject to manipulation with magnetism. Ferromagnetic approaches underlie some, but not all, of the most widely accessible lab and field analytical techniques less influenced by — or deliberately designed to avoid--particle size limitations. But any generally available laboratory or field procedure which points to the presence of or measures large wear particles is a tool we want to become familiar with. Figure 3 is a graphic survey of off-line, generally encountered technologies (not an exhaustive list). You or your off-site laboratory should readily have access to these tests when needed.

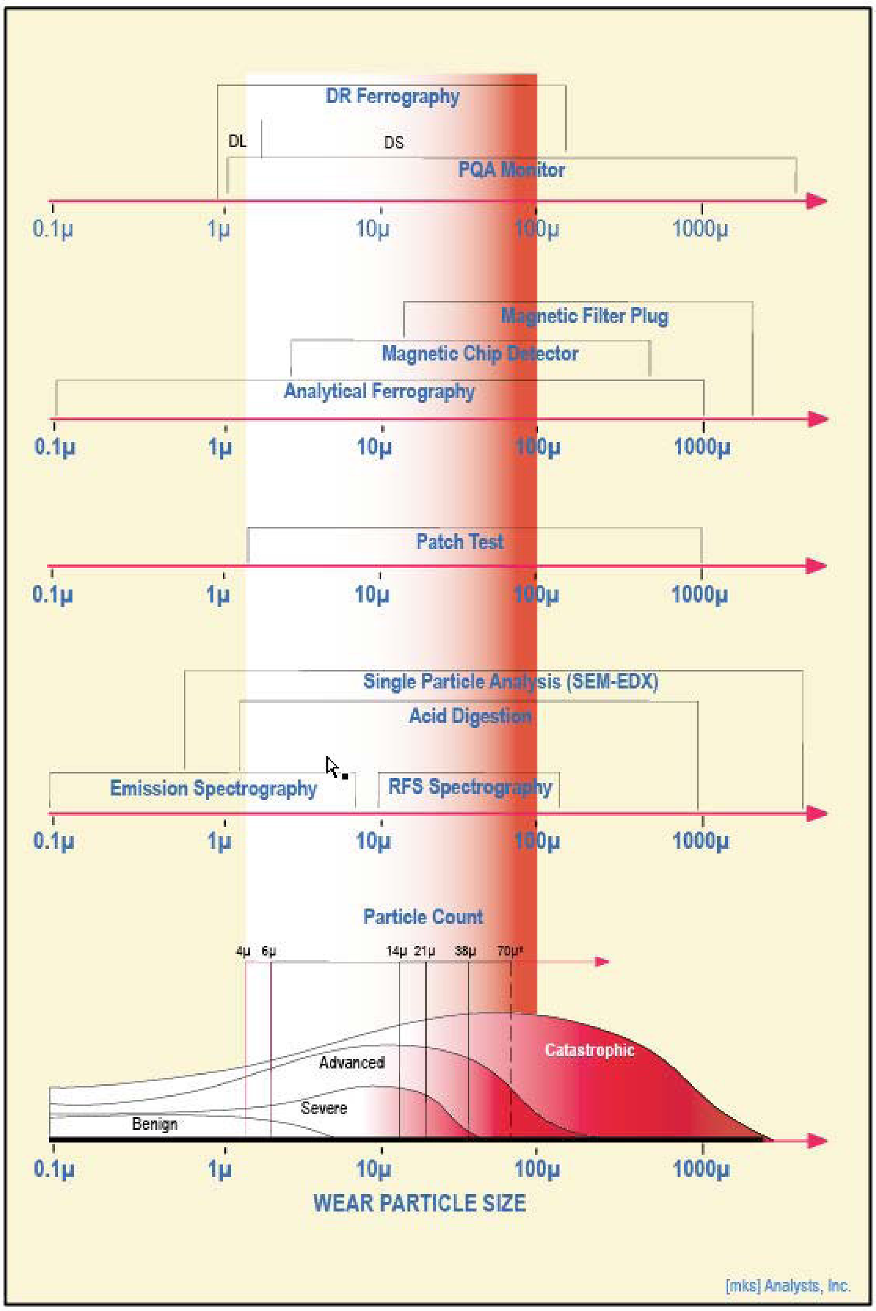


Figure 3. Particle Analysis Technologies and Size Sensitivities

Referencing Figure 3, you can see that the 5-range ISO 11171 particle count runs through the heart of the ranges of most of the large-particle detection technologies. (The asterisk after the 70µ range references the fact that this is a 70µ and greater range; some counter sensors go up to 400µ).

This following section contains tips and notes which will help you define which monitoring or investigative technology is best for you.

DEBRIS AND PARTICLE ANALYSIS – USAGE TIPS

	Interpretive Method	Particle Size Range	Type of Debris Detected	How Debris is Collected
Instrument-based Magnetic Attraction / Flux Techniques				
Direct Reading Ferrography	Trend and/or fixed limits depending on application.	Two ranges: (1) DS: 1 µm to 3 µm (2) DL: 5 µm to 100 µm	Ferromagnetic particles of iron and steel	Oil sample
PQA Ferrous Debris Monitor	Trend and/or fixed limits depending on application.	1 µm to 1,000 µm (Slight efficiency fall off below 5 µm).	Ferromagnetic particles of iron and steel	Oil sample
Microscopic Analysis-based Magnetic Attraction Techniques				
Magnetic Filter Plug	Visual/microscopic inspection for density, size, shape, etc.	Depends on magnification, particle type, viscosity and flow rate. Typically 25 µm to >1,000 µm.	Ferromagnetic particles of iron and steel	Removable magnetic plug
Magnetic Chip Detector	Visual/microscopic inspection for density, size, shape, etc.	Depends on magnification, particle type, viscosity and flow rate. Typically 25 µm to 1,000 µm.	Ferromagnetic particles of iron and steel	Removable magnetic cartridge
Microscopic Analysis-based Filter Debris Techniques				
Patch Test	Visual/microscopic inspection for density, size, shape, etc.	Depends on magnification power and membrane pore size. Typically 3 µm to 1,000 µm.	All types of filterable debris	Oil sample
Rotrode Filter Spectroscopy (RFS)	Trended multi-element measurements reported in ppm. No standardized measurments due to proprietary test methodology.	5 µm to 150 µm	Wear debris and contaminate particles	Oil sample
Acid Digestion	Typically run as an exception test. Provides absolute quantification of the concentration soluble and insoluble elemental constituents in the oil, sludge, sediment, etc.	Generally not limited by particle size, i.e., from soluble to insoluble suspensions >1,000 µm.	Wear debris and contaminate particles	Samples of oil, sludge, sediment and filter residue
Single Particle Analysis such as SEM-EDX (also referred to as chip analysis)	Typically run as an exception test to identify elemental constituents, including alloying elements, of specific particles in a failure investigation.	From submicron to macroscopic size particles (32 mm insome instruments).	Wear debris and contaminate particles	Samples of oil, sludge, sediment and filter residue

Let's look at an example of how this information in this paper might be used. You have been trending particle counts on a particular screw compressor and your third ISO contamination class code (which references total particles >14µ) has increased from /14 to /16 since the last sample. Looking over the count itself, you see that the increase is based primarily in count range 5 (38µ). Comparing this to Figure 1, you see that this particle size range may be associated with serious wear or contamination—and using Figure 2, that sliding wear is a possible wear product which might fall in this size range. After making arrangements to reduce load on the compressor pending further investigation, using Figure 3 and the Usage Tips above, you review the available investigative technologies for that particle size range, and choose analytical ferrography. Once the report returns, indicating that iron alloy wear fragments potentially associated with misalignment of the compressor screws are present, you take maintenance action and then adjust the testing slate to include PQ, which will provide added ongoing insight on whether or not larger iron-based particles are present.

A CLOSING THOUGHT — AND A RULE OF THUMB

You see now that a simple test such as particle counting can help you plan a strategy to overcome the analytical limitations of rotating disc and ICP emission spectrometers. Utilizing the information presented here and any specifications available on recommended cleanliness levels, you should be better able to make informed decisions on the need for additional testing and which tests to select. Hopefully, this will incite your curiosity to investigate and consider monitoring approaches and test methods not discussed in this paper.

A rule of thumb — and it's just that, not a rigid guideline: If a particle count's ISO Contamination Code changes by two ISO classes if it previously was between ISO 10 and 20 (e.g., from /13 to /15 or /19 to /21), or by one ISO code number if it previously was above ISO 20 (/21 to /22), it's time to ask "Why?". Keeping in mind your overall cleanliness guidelines and targets, and that a low ISO number such as 10 or 11 is only proportional to 10 or 20 actual particles per milliliter of sample, the answer may be maintenance, a known performance problem, a charge of new unfiltered oil…or an unseen wear problem reaching for your bottom line profitability.

REFERENCES

Anderson, D. (1982). Wear Particle Atlas (revised edition). Report NAEC-92-163.

Bensch, Dr. L. E.. (1991). A Modern Review of Field Contamination Levels Based On Analyses of 25,000 Samples.
Retrieved from http://www.particle.com/whitepapers_hiac/benscha.htm.

Ding, Dr. J. (2003, September – October). Determining Fatigue Wear Using Wear Particle Analysis Tools. Practicing Oil Analysis.

Dory, S. H. (2003, September – October). Magnetic Plug Inspection Enhances Condition-Based Maintenance. Practicing Oil Analysis.

Hunt, T. and Roylance, B. (1999). The Wear Debris Monitoring Handbook.

Omole, S. (2001, November-December). New Dimension to Failure Analysis, Using XRF Technology. Practicing Oil Analysis.

Rhine, W. E., Saba, C.S., and Kaufman, R.E.: (1986, Vol. 42, #12). Metal Particle Detection Capabilities of Rotating
- Disc Emission Spectrometers. Lubrication Engineering