Particle Counting: Getting Started and Best Practices

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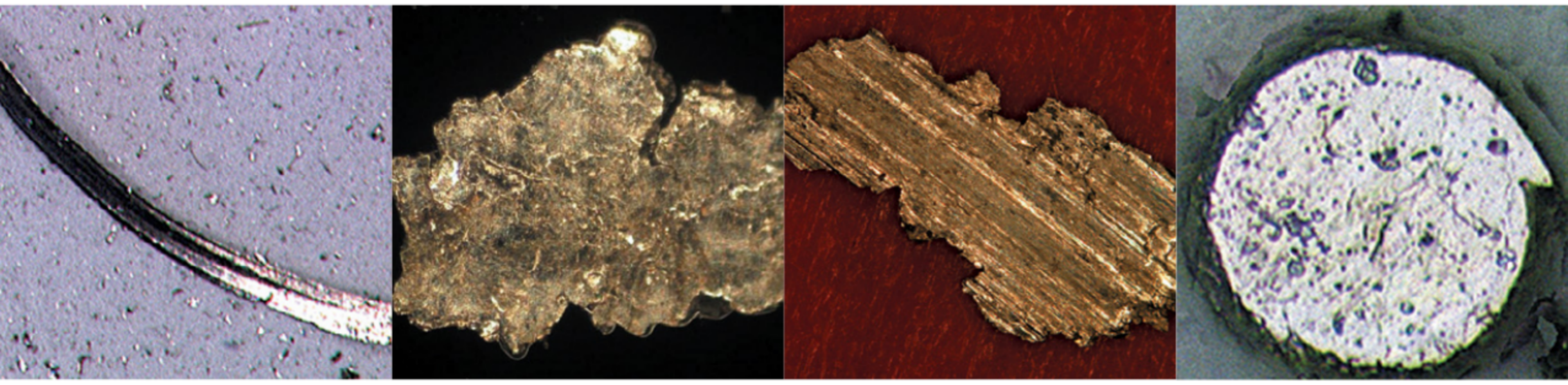
Considered to be one of the most crucial tests in oil analysis, the importance of particle counting can't be overstated. Particle counting helps identify potential problems in fluids and lubricants by monitoring and detecting the number and size of different particles in the oil sample. From spotting high contamination or wear conditions to checking turbine oil cleanliness, particle counting is an invaluable part of any oil analysis or condition monitoring program.

Although pioneers like Dr. E.C. Fitch showed the value and utility of counting particles in lubricant systems by the 1970s, it took over a decade before it was widely used by industrial plants. This guide is designed to help those who want to get more value and actionable insights from particle counting or start a new program. We will also cover advances in digital particle counting, such as the ability to identify wear particles or distinguish particles from bubbles to improve root cause analysis and PdM activities.

Determining the Absolute Number of Particles

There are a few methods currently in common use for particle counting; each has its own strengths. Which you choose for a given application depends on your needs and goals. Consider the criticality of your equipment and select a particle counting tool that will give you the insights needed to improve reliability and reduce total cost of ownership.



Four types of wear debris particles

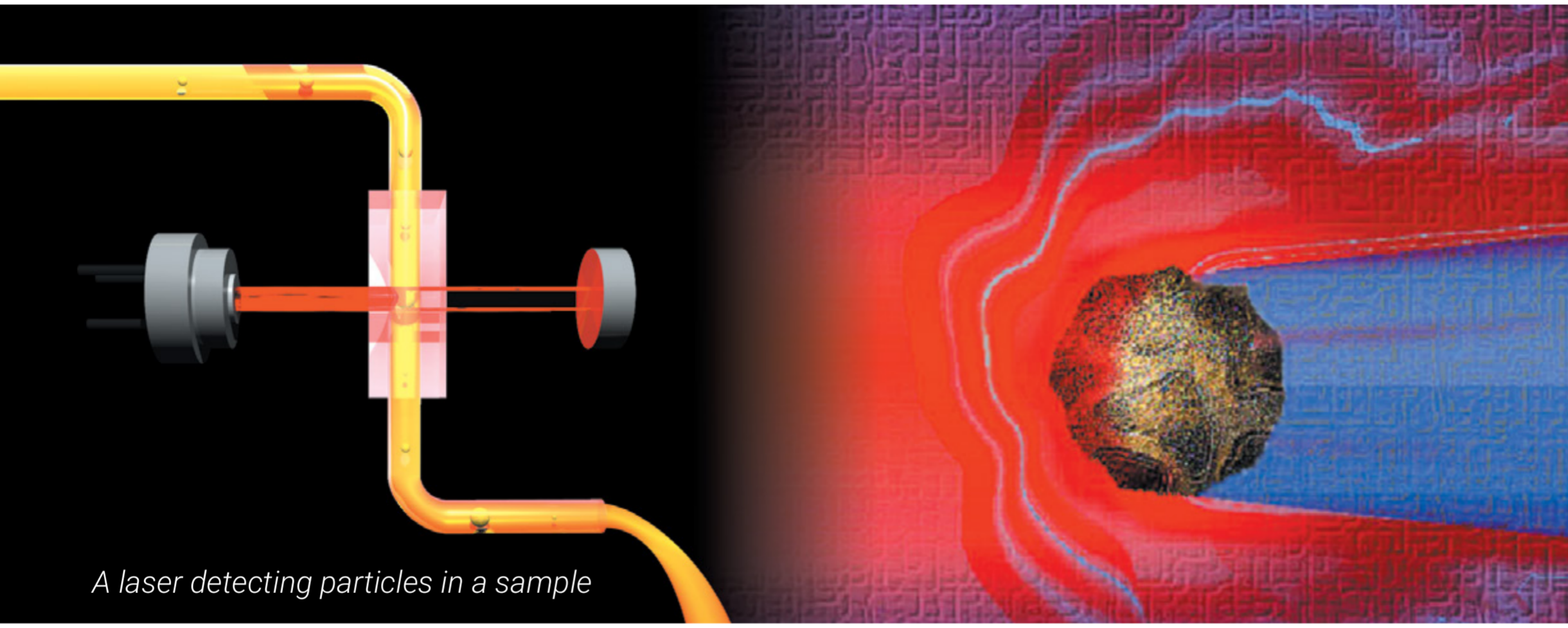
Optical Microscopy

Also known as ISO 4407, optical microscopy is the original method for determining the cleanliness level of a fluid by taking a portion of the oil sample and examining it under an optical microscope. During this procedure, a sample of the oil is taken, and the particles are counted manually. This number can then be used to determine the cleanliness of the entire fluid amount. While this method requires manual power and can be slow at times, it is still considered one of the most reliable and accurate methods available for particle counting.

Basic Optical Particle Counting

Automatic optical particle counting, or ISO 11500, is one of the most widely used methods for determining fluid cleanliness. Unlike optical microscopy, this method uses a commercial instrument to help determine the particle count. Machines can range from more cost-effective portable units to large, full-scale lab-based instruments. No matter which machine option you choose, all will use either a white light source or a laser to count the particles.

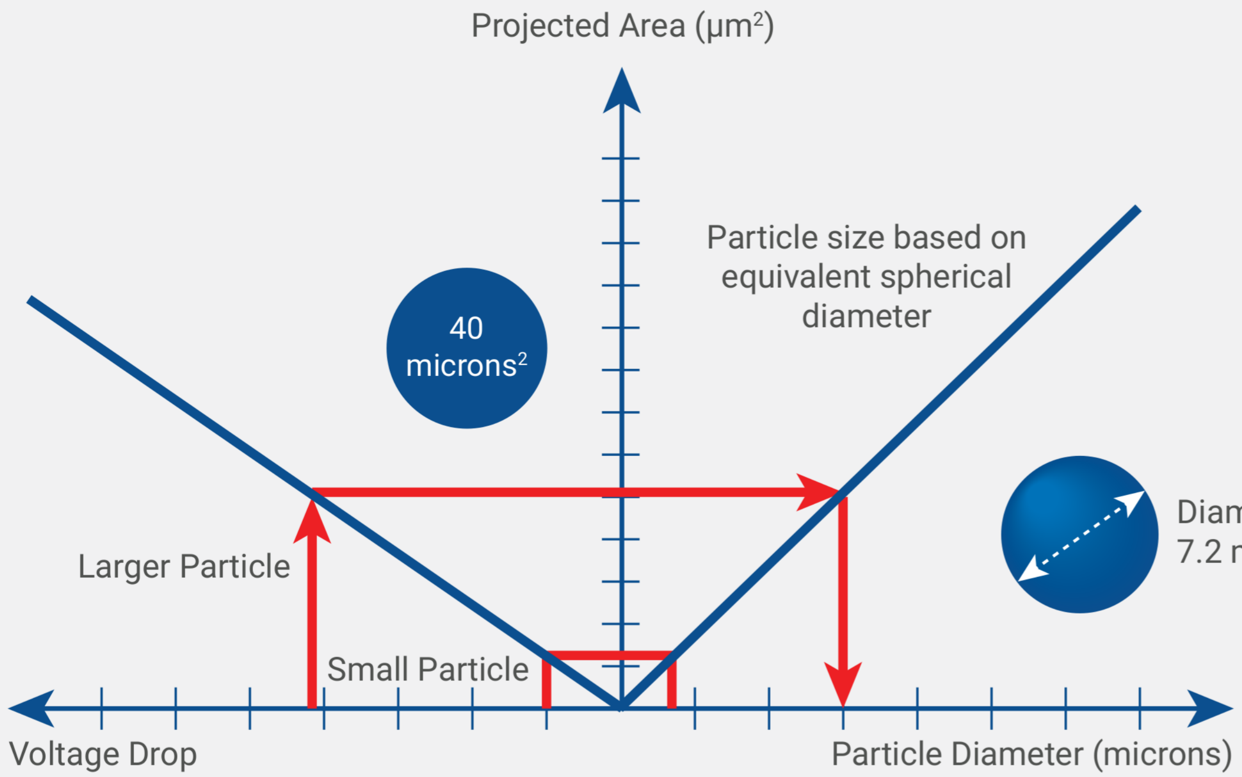
With laser-based instruments, the light is focused into an unimpeded beam and focused on a specific point. As particles pass through the instrument, they come into contact with the laser and light scatters onto the photocell. The change in voltage across the photocell directly relates to the size of the particle that passed through.



A laser detecting particles in a sample

With white light instruments, particles pass through a specific detection zone and create a shadow on a photocell detector. The photocell detector has a continual stream of voltage running through it, and when a particle comes into contact with it, the voltage drops and creates a shadow. This shadow directly correlates to the size of the particle passing through it.

There are several factors that should be considered when looking into automatic optical particle counters. The first aspect to consider is that most particles from used oil samples are not a perfect sphere. To counteract this, the equivalent spherical diameter method was developed. With this method, the particle is counted in the size range under which its shadow would have appeared if the particle had been a perfect sphere. This means the average fluid cleanliness is estimated which allows for the ISO code, which will be discussed later, to be monitored and trended over consecutive samples.



Four types of wear debris particles

The next factor to consider is false positives. Using the optical particle counting method, air bubbles, free water, and emulsified water all appear like they are particles. While most of the air and water can be nullified using ultrasonic baths, vacuum degassing, and solvent extractions, there is still a potential for false positives to show in the report. This can happen through multiple particle coincidences and additive floc. Because of this, special care and attention must be given to procedural details when using many optical particle counters, however there are newer technologies helping to solve these issues through the use of "true optical" technology.

"True Optical" Particle Counters

Most optical particle counters provide basic count results, but newer technologies that employ high-definition lenses and cameras (known as "true optical" systems) are able to identify particles in addition to counting them, even reporting what type of wear is taking place.

With these deeper insights, an IoT system like the Atten2 S120 OilWear can help identify wear and failure conditions earlier, allowing you to take corrective action as needed. This can both extend the interval between certain service activities and help ensure that necessary actions are taken at the earliest signs of problems.

Standard automatic optical particle counters have problems differentiating bubbles from particles as described above, but a true optical system that is able to ignore bubbles and other interference can improve the accuracy of data trending and avoid inaccurate readings. Using basic optical particle counters may mean you are spending time and resources on misguided maintenance activities if air bubbles are being counted as particles, causing false high contamination readings.

In highly critical applications, getting accurate insights about machine health and wear conditions can be invaluable in preventing expensive downtime without performing maintenance activities unnecessarily.

Pore Blockage Particle Counting

The pore blockage particle counting method, or BS3406, is the method by which a volume of fluid is passed through a mesh screen with a well-defined pore size. The pore size is typically around 10 microns, and there are two instruments that take advantage of this method.

The first measures how the flow decreases across the membrane when it gets plugged, first by larger particles, and then by smaller ones as the larger ones begin to fully plug up the screen. The second measures the increase in differential pressure across the screen as it becomes plugged with particles. Both instruments rely on a continual, constant flow of oil and are tied to software algorithms that turn the results into an ISO cleanliness rating based off of ISO 4406:99, which will be discussed later.

While pore blockage particle counting doesn't have to deal with false positives caused by air, water, and dark fluids, they don't currently have the same range as an optical particle counter. This is because the particle size distribution is only a rough estimate and is dependent on the accuracy of the algorithm to correctly report ISO fluid cleanliness codes. Despite this, pore blockage particle counting does report the accumulated concentration of particles in the oil and in some instances, it does offer advantages, such as with heavily contaminated oils and dark fluids.

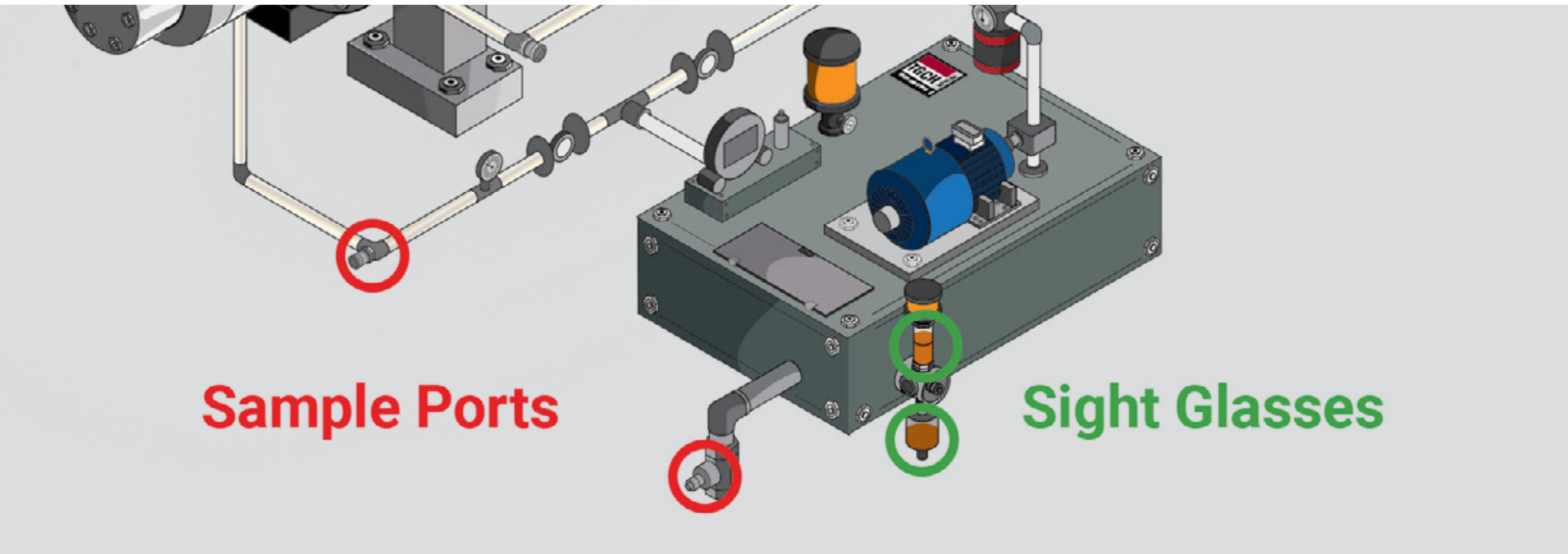
No matter what method (or combination of methods) you choose, keep your end goals in mind. Once you have the tools you need, gaining an understanding certain sampling best-practices and lubrication concepts will help you to get more value from your equipment.

Understanding Particle Count Data

Before Sampling

There are several variables that can affect an oil analysis's results during a particle count. To make sure you are getting an accurate picture of your lubricant's health and the state of your machines, samples should only be collected before the filters. By taking samples after the filter, it would only be testing the efficiency of the filter and not the cleanliness of the oil itself. For solid, reliable data, the process used for collecting samples must be consistent. This includes making sure to sample from the same point and using the same sample method each time. This ensures you are trending accurate data for the oil. The sampling equipment and collection bottles should also be devoid of any dirt or moisture, and should only be removed from their storage when necessary to avoid extra contaminants.

Before taking a sample, it is extremely important to clean the machine's sample port with a lint-free cloth to avoid adding to the particle count. You should also consider using a new zip-lock bag to open and close the sample bottle to help keep as much environmental dust and moisture out of the sample as possible.



A machine modified with sample ports and sight glasses for easier and more accurate data collection.

Not only do your sampling methods need to be proactive and protective, but if you send your samples off for testing, you need to make sure it's a reliable laboratory. If the lab is not handling samples correctly, the test results will be distorted, and could potentially lead to a false positive. If the facility is near you, taking a surprise visit is a great way to see how samples are processed and how clean the facility is.

Sampling Results

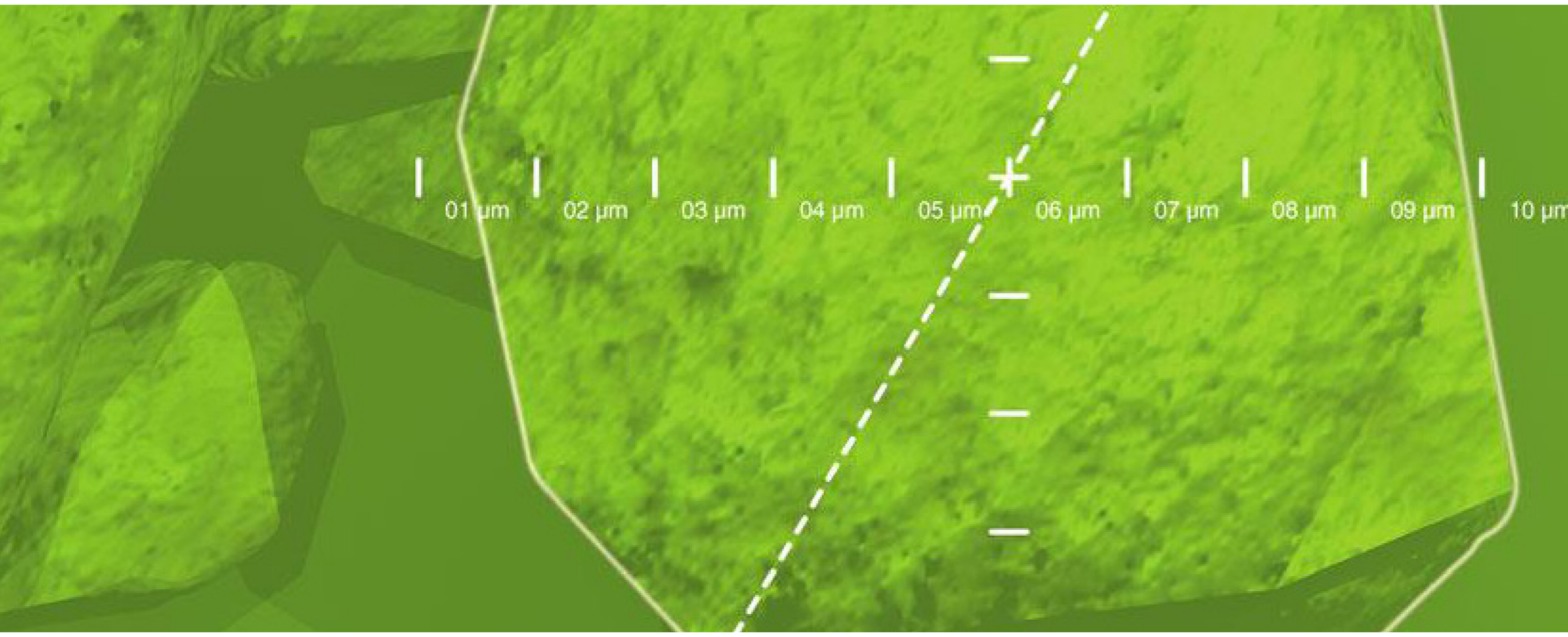
Once you have conducted your particle counting tests, it's time to decode the information so that the results may be used to understand the current contamination level of the machine. To ensure that results could be understood across any industry and testing method, the ISO developed a set of regulations for decoding the data. This made it easier for technicians to transcribe the information in a universally agreed-upon method. Over the decades, a number of methods have been used as the standard, and each new standard evolves and effectively solves an issue that came up in the previous method.

Who is ISO?

The International Organization for Standardization, or the ISO, is a global organization made up of international representatives and experts that help establish different standards for a variety of industries including commercial and industrial. The ISO operates in more than 160 countries and helps set guidelines and standards for a variety of products that make international trade and business transactions more accessible and straightforward.

NAS 1638

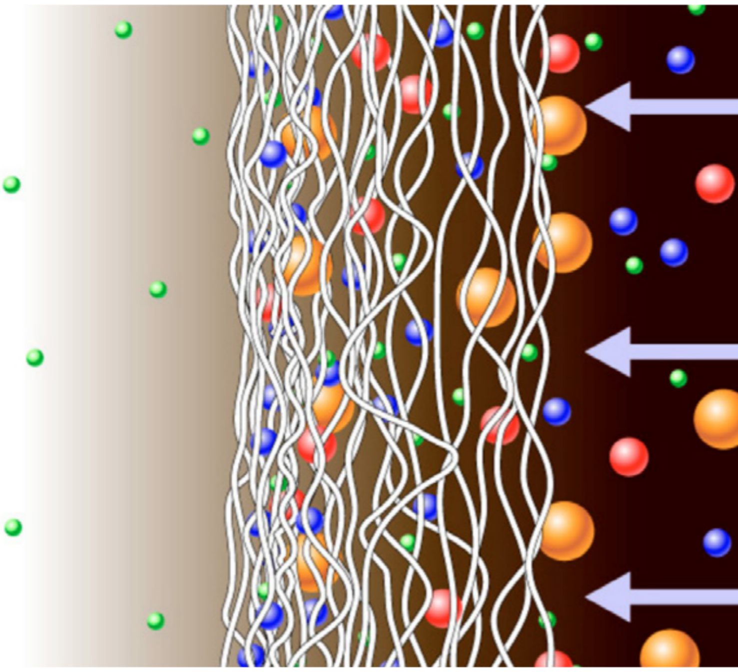
To help industry professionals better disseminate particle count information in a consistent and formatted context, ISO 4406 was developed. ISO 4406 helped create a standardized method for reporting particle count data. Despite its name, this standard was first developed by the National Aerospace Standards (NAS) organization as a response to the chaotic world of aircraft hydraulic fluids by establishing set standards for particle counting and was originally titled NAS 1638.



In the first version of this standard developed in the 1970s, professionals would use an optical microscope to measure the size of solid particles in one milliliter of oil and then place them in one of five size categories:

- **5-15 microns**
- **15-25 microns**
- **25-50 microns**
- **50-100 microns**
- **>100 microns**

These numbers were then imputed into a chart that helped classify the oil's cleanliness by ranking it from 00 to 12 based on the total number of particles in each of the size ranges. The lower the number, the cleaner the oil. But as particle filters became more efficient and advanced at removing large particles from oil, it made the upper size ranges of NAS 1638 less accurate at depicting the particle distribution in the oil.



Particles being captured by filter media

As filters continued to advance, ISO decided it wasn't necessary to continue to report on the concentration of these larger particles. By recognizing that hydraulic oil cleanliness is a top priority and that the current system of measuring particles wasn't keeping up with the industry, ISO set out to create a new particle counting standard that more accurately reflected the concentration of particles they were seeing. What they created became known as ISO 4406.

The Creation of ISO 4406

Not only did ISO set out to create a classification tool that more accurately reflected the particle counts, but they wanted the system to be easier to understand. This also included expanding the classification standards to include all lubricating fluids so there was one core standard accepted across all industries.

With their first round of edits, the ISO cut down the number of categories from five to two, with a potential third category for special circumstances. For the representative particle sizes, they chose 2, 5, and 15 microns, with 2-microns being the optional category. The next significant alteration that was made involved changing the entire scale. Also known as the Renard table, ISO created a scale that ranged from 0.9 to 30, which allowed for a simplified method of expressing small and large particles using a single value.

This system stayed in place until the 1990s when it became apparent that the current method of calibrating the automatic particle counters wasn't meeting the requirements set out by the ISO 9000 standard. Not only was there a lack of control over the calibration material, but it was also discovered that the particles sizes were not being reported the same. This led to their final edit of the particle measuring system – ISO 4406:99.

ISO 4406:99

With the increased efficiency and accuracy of microscopic telescopes, it became easier and more reliable to report on particle sizes smaller than 5 microns. Combine this with the knowledge that smaller particles were becoming an increasing concern over larger particles, and it is easily understood why ISO decided to officially create a third cleanliness code.

ISO set the new cleanliness codes at 4, 6, and 14 microns as this provided the best representation of the particles that were the closest to the oil's thickness, which cause the most damage to surfaces.

NUMBER OF PARTICLES PER mL		
More than	Up to and Including	Range Number
5,000,000	10,000,000	30
2,500,000	5,000,000	29
1,300,000	2,500,000	28
640,000	1,300,000	27
320,000	640,000	26
80,000	160,000	25
80,000	160,000	24
40,000	80,000	23
20,000	40,000	22
10,000	20,000	21
5,000	10,000	20
2,500	5,000	19
1,300	2,500	18
640	1,300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8
0.64	1.3	7
0.32	0.64	6
0.16	0.32	5
0.08	0.16	4
0.04	0.08	3
0.02	0.04	2
0.01	0.02	1

ISO 4406 Chart

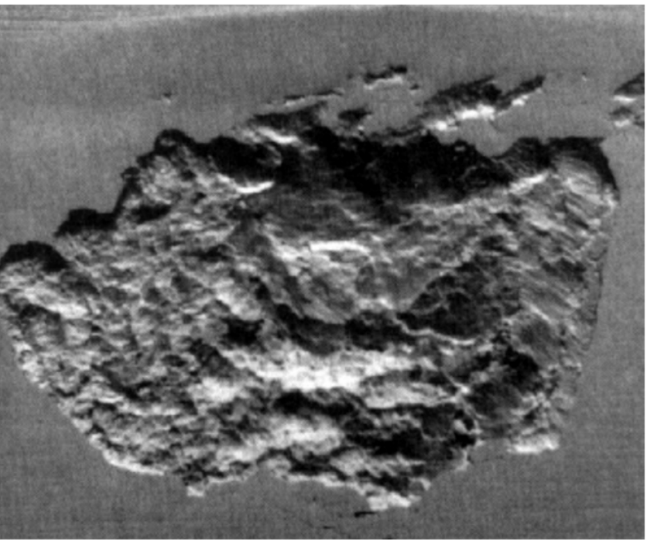
SAE AS4059

Although ISO's newer standards have been widely adopted, it is important to note that some industries and countries still use the SAE AS4059 system to measure the particles in their oils. This reporting method may already be somewhat familiar to some in the industry because it utilizes the same reporting table as the previously mentioned NAS 1638 method. While they might take advantage of the same reporting table, the SAE method has an optional reporting method where instead of a single code that represents the oil's cleanliness, it can report on the specified cumulative particle size count. This can be identified by a suffix letter after the class number that will tell you what cumulative particle size count category the code represents.

While there isn't an incorrect cleanliness standard, it is important to be aware of other standards as you conduct business with other industries and countries.

Reasons for High Particle Counts

4 Common Possibilities



Undetected contamination can cause severe damage

After testing the oil and receiving the results back, if the particle count is high, there are generally four possible explanations.

The first is that the machine is not in any immediate danger, but either a filter has failed, or a new source has developed for particles to enter through. This can be solved by fixing the filter or correcting the source of the particle ingression.

The second is that there is a new ingression source, or a filter failure and the machine is in immediate danger because of the resulting high particle count. This is corrected by swiftly cleaning up the oil and by fixing the failed filter or ingression source.

The third is that the high particle count is due to abnormal wear particles that will threaten the machine's overall reliability. This is resolved by performing a root cause failure analysis and following up with the appropriate remediations and clean-up procedures.

The final is that the high reading is due to either a sampling error, an analytical error such as with the particle counter's calibration, or soft particles such as dead additives.

Setting up an Onsite Oil Analysis Program

There are many reasons for wanting to set up an onsite oil analysis program, but no matter the reason, one of the first questions that usually comes to mind is "What particle counter should I use?"

While there are a number of high-quality particle counters to choose from, consider your end goal—if you are taking particle counts to help identify wear and failure conditions earlier, a "true" optical system like the Atten2 S120 OilWear may be a good choice. With this system, you not only get the ISO code and mass number, but the system is also able to differentiate between air or water bubbles and actual debris particles, giving you more accurate readings and trend lines even when bubbles are present.

A true optical particle counter can distinguish different particles in the oil, even classifying them based on a library of samples built into the system. This library will help the system identify exactly what type of wear is taking place, such as cutting, sliding, and/or fatigue wear.

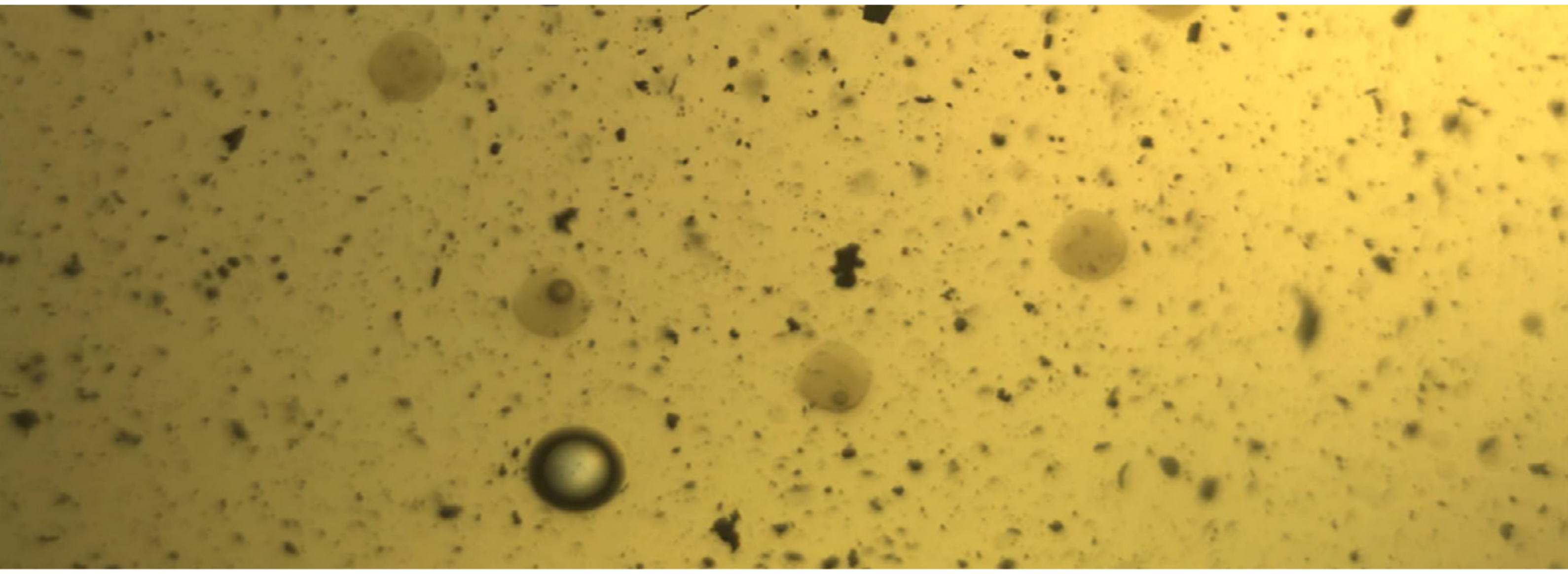
No matter what system you choose, there are many uses for particle counting:

- **Contamination**
- **Verifying filter performance**
- **Confirming corrective maintenance**
- **Verifying stored lubricant cleanliness**
- **Identifying botches machine repairs**
- **Identifying new filter defects**
- **Identifying abrasive wear conditions**
- **Mechanical wring out**
- **Allowing for on-demand lab oil analysis**
- **Verifying pump conditions**
- **Identifying changing atmospheric contamination**
- **Troubleshooting and isolating problems**
- **Detecting high corrosive wear**
- **Determining new oil cleanliness**

Standard optical particle counters can give you basic details like ISO codes. In low-criticality applications you may not require much more information than that, but for high-criticality assets, such as turbine oil systems, a more advanced solution will help you get a better picture of lubricant and machine health.

How to Conduct More Accurate Particle Counting

Once the appropriate particle counter has been selected, there are several steps you can take to ensure you are producing an accurate particle count.



The Atten2 can detect and identify different types of wear particles while also distinguishing them from bubbles for more accurate readings.

1. Make sure the sample is taken from the correct location using proper sampling procedures. Take special care to minimize contamination during sample collection and leave headspace in the bottle.
2. Make sure the sample bottle is at least 2 ISO range codes cleaner than the desired lowest levels of ISO fluid cleanliness.
3. Remember to dilute viscous fluids and contaminated samples using a reagent-grade kerosine that has been prefiltered before counting particles. The substance used to dilute the viscous fluid can also be prefiltered if its cleanliness is in question.
4. Test for free and emulsified water using a moisture screening method, such as the crackle test. If there is water present, it can be vacuum dehydrated or treated with a 50:50 mix of the oil and a mixture of three parts toluene and one part isopropyl alcohol.
5. If a few minutes pass between sampling and testing, make sure to reagitate the sample for five minutes using a paint shaker.
6. Ensure the effects of the air bubbles are negated by using a vacuum ultrasonic bath and/or a vacuum degreaser.
7. Don't leave the onsite particle counter idle on the shelf; make the most of the invaluable asset each day.

How to Get the Most from Your Particle Counter

Particle counting machines are one of the best tools for measuring and understanding the root cause a machine's failure due to particle contamination. By understanding what the particle counter is revealing, you effectively use the information collected from your oil samples.

Although it is good practice to set goals and targets based upon the numbers you receive from the ISO 4406:99, you cannot overlook the results from the particle counter itself. A general rule is that for every increase in the ISO code that you experience, the amount of particles in your oil sample effectively doubles. Therefore, you cannot solely rely on the ISO code to dictate your follow-up actions. When you receive your report back from the onsite lab, examine the individual counts and then begin to gauge whether the actions you are taking to achieve your cleanliness targets are effective.

For example, if your target goal is to have an ISO code of 18/16/13 but your code numbers are coming back as 19/17/14, your natural reaction may be to think that your oil is dirty. But, if you check the individual particle counts, you can see how far off you actually are for achieving your goal, down to a singular particle. From here, a quick round of filtering may be all you need to reach your target cleanliness goal.

8 Proactive Uses for Your Particle Counter

- **Routinely check that oils that are in service are within targeted cleanliness levels.**
- **Check the cleanliness level of new oils.**
- **Identify failed or defective filters.**
- **Check that seals and breathers are working effectively.**
- **Confirm that systems are properly cleaned and flushed after repair work.**
- **Confirm that new hydraulic systems are cleaned and flushed before use.**
- **Identify poor maintenance practices.**
- **Identify the need and timing for portable filtration systems.**

Other Uses for Particle Counters

Monitoring individual particles sizes can provide other important information. Take filter performance, for example. By using a particle counter and taking samples before and after the filter, you can look at the individual particle counters to determine if the filter efficiency and micron values are similar to what they were advertised to be.

Particle counting also helps you select filters for specific machines and understand a filter's life expectancy. For example, if you analyze particle counts both before and after the filter, you can evaluate whether the filter is deteriorating. The father apart the particle count numbers are, the better the filter is performing.

A particle counter is a great tool for any lube technician and plant. As long as you are conscious of how you handle the machine and evaluate the results, the benefits of a particle counter are truly limitless.

Atten2 OilWear On-Line Particle Counter 2.0

Stop Guessing. Know For Sure That Your Equipment Is Safe

- **Prevent Catastrophic Loss Of Assets**
- **Remote Real-Time Digital Lubrication Monitoring**
- **15 Years Of Technological Development | 7 Patents Issued**
- **The Only True Optical Technology on the Market**
- **Interactive Dashboard Lets You See Your Entire Fleet**

Using high-definition lenses, cameras & lighting, this system takes the guesswork out of what's in your fluid by actually identifying particles in addition to counting them, then going even further by recognizing the exact type of wear taking place.

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