

Oil Analysis Prevents Paralysis

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Monitoring engine lubrication can help avoid wear and breakdowns.

How often do you change the oil in your car engine? Every 3000 miles, every 6000 miles, or maybe when the oil warning light comes on? Most of us do it because the oil and car manufacturers tell us that it's in the long-term interest of the engine components. But what are the real implications of not changing the oil or changing it less frequently? We know that it's important, but do we really know why?

What is the worst thing that could happen if you neglected to change your oil? Well, over time, the level would probably drop, which would affect the lubricating efficiency. Eventually, you might get premature wearing of an engine component, which could result in overheating and, in an extreme case, engine seizure. It would be expensive, but probably not catastrophic (only to your bank account).

Imagine the implications of neglecting to check the lubrication systems of much larger vehicles, like aircraft, ships, locomotives, heavy trucks, construction equipment, or earth-moving machinery. Failure here would be both catastrophic and unbelievably expensive, not only because of the cost of repairing the physical damage, but also because of the time it takes to fix the problem and the revenues lost from the

equipment/vehicle being out of service.

For this reason, many manufacturers, suppliers, and users of these types of equipment implement a preventive maintenance program, in which a sample of the oil is taken on a regular basis, and a combination of physical and chemical test methods indicate how well an engine, gearbox, or hydraulic system is performing (1). So instead of changing the oil every 3000 miles, like many of us do, mechanics monitor the oil's physical properties, contamination levels, and wear debris fingerprint over time to get a better understanding of the lifetime of the moving parts. This preventive maintenance approach offers considerable savings on the cost of oil changes and can also give an early warning of problems before they get too serious.

So what kind of oil analysis are we talking about? Let's use the example of a diesel or gasoline engine. We make the basic assumption that it consists of two essential components: moving parts and the lubricant. Anything else present in the system should be considered foreign material. So, as the engine begins to wear, microscopic particles and products of heat and the oxidation process will be suspended in the oil. These particles and products can provide critical information as to what moving parts are wearing or whether there is contamination from external sources, like road dust or the cooling system (2). Even though there are many different test methods and approaches to this problem, it is generally accepted that an oil analysis program must perform

three steps to be effective. These three steps are:

- examine changes in physical properties,
- monitor external contamination, and
- analyze wear debris.

Changes in Physical Properties

The physical properties ensure the fundamental quality of the lubricating fluid. It is therefore essential to know the physical properties of the new, unused oil before the engine has been run. By monitoring criteria like viscosity, acidity, oxidation, nitration, flash point, and specific gravity on a regular basis, the physical properties of the used oil can be an initial indicator of oil degradation. Some causes of these physical changes include:

Consumption. This is probably the most simple test to perform. High consumption is a result of oil breakdown. Simply checking the oil level may signal excessive wear in some of the engine components.

Age of the oil. As the oil gets old and the hydrocarbons naturally break down with heat, the viscosity and specific gravity of the oil will change. Simply monitoring the "thickness" of the oil at different temperatures with a viscometer will indicate when this is happening.

Oxidation/nitration process. This is caused by a chemical reaction between the oil and oxygen and/or nitrogen. It can make the oil very thick, produce deposits on pistons, and also cause piston rings to stick. Looking at the structure of molecular bands with infrared spectroscopy can help you understand these oxidation and nitration processes.

Production of soot. Soot is basically unburned fuel products. In excessive amounts, it can plug oil filters, deplete oil additives, and accelerate the formation of deposits. Infrared analysis can indicate an excessive amount of soot in your oil.

SO₂/SO₃ formation. Sulfur is a byproduct of diesel fuel consumption. Sulfur reacts with oxygen to form oxides like sulfur dioxide (SO₂) and sulfur trioxide (SO₃). In the presence of water vapor, these oxides form highly corrosive sulfuric acid (H₂SO₄), which attacks valve guides, piston rings, and liners. Measuring the sulfur content by infrared analysis or the pH (acidity number) of the oil can often be a good indicator that this is happening.

External Contamination

Despite the use of oil filters and separators, contaminants are the most common cause of metal surface destruction that eventually leads to engine failures. In addition, particles, moisture, and other types of "external" contamination are the principal cause of the breakdown of oil and its additives. For this reason, it is important to perform basic tests like particle counting, elemental analysis, moisture analysis, glycol analysis, and fuel-dilution testing. Some of the more common types of external contamination include:

Antifreeze. Coolant is probably one of the most common contaminants found in engine oil. Antifreeze, one of the main chemicals found in the coolant, will cause bearing failure, piston wear, and liner damage. It is normally detected using spectrographic analysis, by looking for trace amounts of elements like sodium, potassium, and boron, which are all components of water treatment chemicals.

Fuel. Gasoline or diesel fuel can get in engine oil by a variety of means, but it is usually the result of a faulty fuel injection system. Fuel in the oil signals serious problems that

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need immediate attention. It will dilute the oil's lubricating properties and can lead to bearing failure and seizure of the pistons. Viscosity and fuel-dilution tests are commonly used to monitor this potential problem.

Dirt. If common, everyday dirt gets into the oil compartment, it can cause havoc. It literally becomes a grinding compound and removes metal from the surfaces of components. Testing for silicon, a major constituent in dirt, is the main indication that this could be taking place. Although small concentrations of silicon could come from sealant greases, coolants, or additives, they are insignificant to the amount found in dirt. Spectrographic analysis is normally used to detect the presence of silicon in oil.

Table 1

Typical Sources of Wear Metals in Oil

Element	Possible Source
Aluminum	Pistons, bearings
Chromium	Piston rings
Copper	Thrust bearings
Iron	Cylinder liners, camshafts, rocker arms
Lead	Bearings
Vanadium	Surface coatings on piston rings

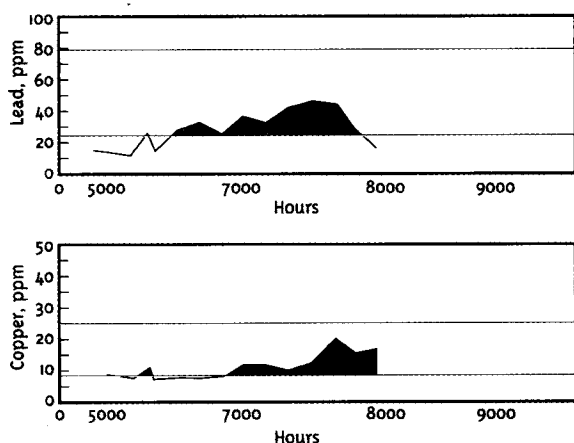
Water. This is normally caused by condensation in the crankcase. In small amounts, it will cause no real damage, but in large amounts, it produces emulsions that can plug filters and contribute to the formation of metal-corroding acids. Moisture analysis is normally used to determine the water concentration of an oil sample.

Wear Debris Analysis

Unlike physical properties and contamination analysis, wear debris analysis relates specifically to the health of the engine. Because moving engine parts slowly shed different-sized particles over time, the size, shape, and concentration of these particles reveal the condition of individual components within the engine. The trend in the relative concentrations of the major, minor, and trace elements in the oil will help identify the likely surfaces from which they came

Figure 1

Trend in the Lead and Copper Levels of an Oil Sample Taken from an Engine Containing Bronze Bearings



(3). Table 1 shows some typical sources of wear metals in oil.

An example of the trend in wear metal composition of the oil can be seen in Figure 1, which shows the change in lead and copper levels over time in an oil sample taken from a crankcase of an engine, which contains multicladd journal bearings. These bearings, which are commonly used in diesel/compressor engines and some turbo machinery, are made of bronze. Lead and copper levels both start to rise quite dramatically after about 7000 hours of engine use, which is a strong indication that the bronze bearing is starting to fail.

There are two common methods of measuring the size and elemental makeup of these wear particles—emission spectroscopy and ferrography.

Emission spectroscopy. This is by far the most widely used technique to determine wear metal particles in oil. Although there have been many different variations of atomic spectroscopy instrumentation used over the years, three approaches have gained dominance: inductively coupled plasma optical emission spectrometry (ICP-OES), arc/spark emission spectroscopy (A/S-ES), and X-ray fluorescence (XRF).

ICP-OES has become the most widely used of the three approaches, probably because of its low detection capability and high speed of analysis. With this technique, a sample of oil is diluted with a suitable solvent like kerosene or xylene and then aspirated into a high-temperature argon plasma discharge. The plasma excites the outer electrons of the ground-state atoms, which emit wavelength-specific light characteristic of the trace metals in the oil sample. The light is then detected with an optical system and quantified using calibration standards of known elemental concentration. The limitation of ICP-OES is that, by the very nature of the sampling and preparation process, it can only detect particles that are $<10\ \mu\text{m}$. While this information is useful, it cannot detect the larger particles, which are most indicative of severe wear modes. ICP-OES has found most use as a rapid screening tool for showing a trend in the elemental fingerprint of the oil over time. Modern ICP-OES systems equipped with solid-state detectors can process 400–500 samples per 8-hour work day (4). For this reason, it has become the preferred mode of

wear debris analysis for companies with large fleets of vehicles that need to take oil samples every 200–300 hours of engine operation.

A/S-ES, like ICP-OES, relies on the principle of atomic emission. However, the main difference is that the sample of oil does not need to be diluted, because the excitation is produced by a dc arc or an ac spark, which is applied directly to the oil on a disk electrode. Although a common technique, A/S-ES can detect only small particles suspended in the oil. Because of this limitation, a technique called rotrode filter spectroscopy (RFS), a variation on the emission approach, is becoming more popular (5). With RFS, a porous carbon disk is rotated through a small reservoir of oil placed in a sample cap. The rotation has the effect of concentrating both the small and the large particles onto the disk. The oil is filtered under vacuum with a suitable solvent, leaving the dried particles on the surface of the disk. A spark is then applied to the disk, while it is rotated through clean oil. Although this technique ensures that the large particles are sampled, the filtering process is time-consuming and can take more than 30 minutes to filter some dirty engine oil samples.

XRF differs slightly from optical emission in that it doesn't rely on excitation of atoms by an argon plasma or an electric current. XRF uses the principle of exciting the sample by bombarding it with high-energy X-rays. This has the effect of exciting the innermost electrons, and, by a process of fluorescence, the atoms then emit X-rays at an amplitude characteristic of the element's atomic mass. Although XRF has been used successfully on clean oils, it has great difficulty with dirty oil samples because of X-ray scattering and absorption effects. As a result, it hasn't gained real acceptance as a technique for determining wear metals directly in used oil. However, it has found a niche in analyzing the fine debris in oil filters (6). Because these filters take out the fine particles suspended in the oil, this information is normally lost to the analytical spectroscopists. By taking the debris from the filters and analyzing the solid material by XRF, it can provide an insight into the condition of the engine much earlier than traditional wear metal analysis. The benefit is that the potentially harmful fine particles are taken out with the filtering system and are then used to diagnose the condition of the engine components. The current limitation of this approach is that it is labor-intensive, so until it is truly automated or adapted to on-line sampling, it will have limited appeal as a diagnostic tool.

Ferrography. This technique is a visual examination of the particles suspended in the oil. This is traditionally done by looking at the sample through a microscope to detect subtle changes in the size and shape of the wear particles. Ferrography gives valuable information, but because it only has a limited ability to identify elemental characteristics of the particles, it is normally used in conjunction with wear metal analysis. However, it is an important ingredient in preventive maintenance programs, because in the hands of an experienced tribologist, it is unique in its ability to predict many types of wear mechanisms.

Conclusions

There are many documented cases in which preventive maintenance programs have averted catastrophic failures. Because of this success, a variety of analytical tools can provide vital information about the state of your engine, gear-

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box, or hydraulic system. Which program to use really depends on a number of criteria, including the nature of the machinery, the size of the fleet, and the expertise of the operators. There is no question that no matter which one you choose, routine oil analysis works if implemented correctly. Whether it's particle counting, viscometry, infrared analysis, ICP-OES, or ferrography, these techniques give you a piece of the jigsaw puzzle. When all the pieces are put together, you have a preventive maintenance program that ensures the maximum operation time of your machinery. Large multinational companies like Caterpillar, John Deere, Pratt and Whitney, Texaco, and Mobil, who have all successfully implemented these types of programs, are firm believers that prevention is definitely better than cure.

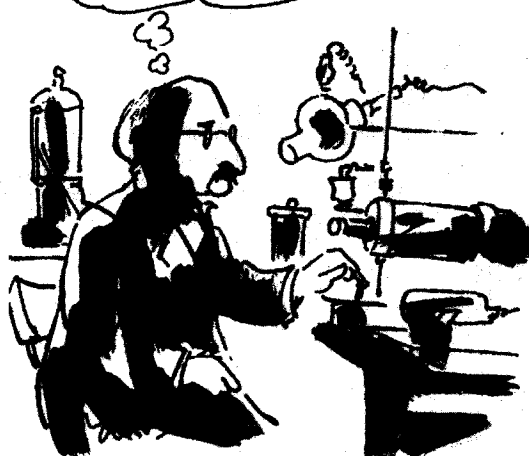
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J.J. THOMSON DISCOVERS THE ELECTRON

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