

Greek for Beginners (Part 1)

or

The Tests and What They Tell Us

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Two of the most common questions Wearcheck's diagnosticians are asked are: 'What tests do you do?' and 'How do I interpret the results?' The first question is easy to answer, the second not quite so.

In addition to their formal academic instruction, all Wearcheck diagnosticians undergo a six month internal training programme before they get their wings. During this time they diagnose twenty-five to thirty thousand samples, each of which is vetted by a qualified diagnostician before being accepted. The reasons for this are that the tests are so inter-related and mutually dependent that interpretation of the results is not always straightforward. Knowing this it is easy to appreciate the impossibility of putting the whole process of diagnosis into a few lines.

Another irritation for the aspirant DIY diagnostician is that some results are apparently contradictory. For example, in an engine a sodium (Na) reading of 300 ppm may be

ignored in one case, and 50 ppm may generate a warning in another. The significance of the reading is determined by considering other readings and tests, and unfortunately there are simply too many variables to take into account than can be put down on paper.

The complexity of interpretation is our reason for supplying a diagnosis with each and every sample. If diagnosing the results were that easy, we would not bother with supplying one. Thus, rely on the diagnosis, and refer to the readings on the back for clarification. If more clarification is needed, the diagnosticians may be contacted by fax, telephone or e-mail and are only too happy to help.

Another point which must be emphasised is that Wearcheck does not generally work to limits. We rely on *trends*. We establish trends through regular samples on a component, ideally done at regular intervals. By comparing the results of the latest sample against those of previous samples, we see what readings have changed substantially from previous samples, and make a diagnosis accordingly. For example,

Wearcheck works mainly to trends, not limits.

ICP spectroscopy is the most useful test in used-oil analysis.

in a differential, 300 ppm iron might be the norm for one type of operation, but on the same vehicle doing a different type of operation, and with a different period oil in use, 1500 ppm iron may well be acceptable. A pre-imposed limit of say 1000 ppm here would have excluded a perfectly good oil from further service.

This bulletin and the one following intend to take a look at the various tests Wearcheck performs and basic interpretation of the results. This bulletin examines the four tests that are performed on every sample; the next one examines tests which are performed on only particular sample classes, or under special circumstances.

SAMPLE CLASSIFICATION

When samples arrive at Wearcheck they are grouped in racks of 20 according to the following broad classes:

- Engines
- Drivetrains (gear systems, such as manual gearboxes, differentials and industrial gearboxes)
- Transmissions (automatic transmissions)
- Hydraulics
- Compressors and turbines

There are also other smaller special classes, such as aircraft engines and refrigeration compressors.

Every sample gets four basic tests:

1. ICP spectroscopy
2. Particle quantification
3. Viscosity at 40°C
4. Water screening

1. ICP spectroscopy

Spectroscopy is the study of light (or more generally electromagnetic radiation) and its interaction with matter. There are approximately 30 different types of spectroscopy. One type, inductively-coupled plasma (ICP) spectroscopy, measures light in the visible and ultraviolet regions of the spectrum. It is an atomic emission (AE) procedure whereby the diluted oil is passed through an argon gas plasma. The plasma is produced by induction and is maintained at a temperature of approximately 8000°C, hotter than the visible surface of the sun. In the upper region of the plasma, acquired energy is released as a result of the electronic transitions, and characteristic 'light' emissions occur. Different elements produce different frequencies or colours. The intensity of the light emitted is directly proportional to the concentration of the element. ICP spectroscopy is used to measure the concentration of different elements in the oil. Wearcheck has two ICP spectrometers at its main laboratory, each of which measures the concentrations of up to 30 elements simultaneously.

The elements are divided into three broad categories on the reports:

- wear metals, such as iron from gears
- contaminants, such as lithium, which would indicate the presence of grease
- oil additives, like phosphorus which is found in extreme pressure and anti-wear additives.

Some elements can belong to more than one category. For example, silicon can be a component of wear debris (piston crown material), of the additive package (antifoaming agents), and of contaminants (dirt). Only by looking at a com-

Wearcheck sometimes uses limits for contaminants.

plete set of results is it possible to predict the source of the particular element.

ICP spectroscopy is perhaps the most important and useful test in used-oil analysis, but it does have its limitations. Perhaps the biggest drawback is the size limit of the particles it can see. Particles above approximately 5 to 8 microns in size do not get detected. Looking at an extreme example: processing a sample of oil with a solid ball-bearing ball sitting at the bottom would return an iron reading of zero. Clearly there is a lot of iron in the sample though. If that same ball were ground to a fine powder and the sample re-analysed, the iron reading would be very high. So perhaps it would be better to refine the definition of an ICP's function from measuring the concentration of different elements to that of measuring the concentration of elements found *in particles of less than 5 to 8 microns in size*.

Whilst this limit does not affect the detection of most wear situations, there are times when it could be a problem. For instance, when a component begins to fail due to fatigue, the wear particles generated tend to be larger than normal (this process is called spalling). These larger particles will not get detected by the ICP, so upon examining the trend the iron level might be seen to be dropping, even though the component is actually in trouble. Given that this limitation exists, other tests need to be employed to provide an effective monitoring solution.

It is also generally not possible to use ICP analysis to measure the additive depletion of an oil. Take, for example, the detergent additive one might find in an engine oil. This would reflect in the calcium (Ca) value. If one measured the calcium level of both a new and a used oil, they would be very similar, even though in the used oil the detergent has been depleted. The reason for this is that the amount of actual calcium in the oil has not changed. What has changed is the form, or compound, in which the calcium exists. Before being 'used', the calcium was present in a compound with detergent properties. After being used, the calcium is still present, but now in an inactive form. Therefore the ICP should not be used to measure additive depletion.

There are sometimes exceptions to this, albeit ones which cannot be relied upon. Most notable is the case of borate gear oils contaminated with water. In this case the extreme pressure additive containing the boron precipitates out of solution and forms a sludge at the bottom of the gearcase. If this precipitate is not captured in the sample, the boron level will read much lower than normal, indicating the oil is not fit for further use due to extreme pressure additive depletion. The converse, however, is still not necessarily true: if the boron level is correct, the oil may not necessarily still be fit for use.

In certain cases Wearcheck uses limits for contaminants. In the case of dirt, we will generally observe the limits in the table below:

Test Class	Silicon Limit [ppm]
Engine	25
Drivetrain	100
Hydraulic / compressor / turbine	35 - 45
Automatic transmission	35 - 45

Table 1. Silicon contamination limits

Table 2.
The
more
common
elements
in ICP

Element	Symbol	Found in
Iron	Fe	Gears, roller bearings, cylinder/liners, shafts
Chromium	Cr	Roller bearings, piston rings
Nickel	Ni	Roller bearings, camshafts and followers, thrust washers, valve stems, valve guides
Molybdenum	Mo	Piston rings, additive, solid additive (Mo-di)
Aluminium	Al	Pistons, journal bearings, dirt
Copper	Cu	Brass/bronze bushes, gears, thrust washers, oil cooler cores, internal coolant leaks
Tin	Sn	Bronze bushes, washers and gears
Lead	Pb	Journal bearings, grease, petrol contamination
Silver	Ag	Silver solder, journal bearings (seldom)
Silicon	Si	Dirt, grease, additive
Sodium	Na	Internal coolant leaks, additive, sea water contamination
Lithium	Li	Grease
Magnesium	Mg	Additive, sea water contamination
Zinc	Zn	Additive (anti-wear)
Phosphorus	P	Additive (anti-wear, extreme pressure)
Boron	B	Additive, internal coolant leak, brake fluid contamination
Sulphur	S	Lubricant base stock, additive

Situation	Results
Dirt entry	Si and Al present, usually in the ratio range of Si:Al between 2:1 and 10:1. Watch the increase in the trend. Often accompanied by associated wear when present over acceptable limits.
Piston torching	Al and Si in ratio Al:Si = 2:1. The Si originates from silicon carbide in the piston crown used to reduce the co-efficient of expansion. Seldom seen, as failure is usually rapid, and statistically there is little chance of getting a sample whilst occurring.
High Fe (alone)	As iron is the most used construction material, sources are often varied. Consider valve gear and oil pump wear. Rust formation also produces high Fe.
High Si (alone)	Silicon by itself comes from a few main sources - antifoaming agent additive, grease and silicone sealant. Usually seen in new/recently overhauled components. Usually can be ignored.
Top-end wear (engines)	Characterised by increased Fe (cylinder liner), Al (pistons) and Cr (rings) levels. The presence of Ni usually indicates camshaft/cam follower wear.
Bottom end wear	Characterised by increased Fe (crankshaft) and Pb, Cu, Sn (white metal bearings and bronze bushes) levels. Often this wear is precipitated by reduced TBN or overcooling as bearings become subject to corrosion from combustion by-products (acids). Fuel dilution often causes this too, but effects may be masked as diesel dilutes the oil and the wear readings.
Overheating (some cases) in engines	Increased additive levels (Mg, Ca, Zn, P & S) and viscosity. When light ends in the oil vaporise off, the oil level decreases. Topping up increases the additive concentrations, as the additives themselves do not evaporate. Oxidation often not evident, as topping up replenishes anti-oxidants and boosts the TBN. Often accompanied by Pb, Sn and Cu as bearing wear can result from this situation.
Bronze bush wear	Increased Cu and Sn levels. Cu:Sn ratio usually approximately 20:1.
Bronze gear/thrust washer wear	Increased Cu and Sn levels. Cu:Sn ratio usually approximately 20:1.
Internal coolant leaks	Increased Na, B, Cu, Si, Al and Fe. Not all elements may be present. Often accompanied by increased Pb, Cu and Sn as white-metal bearing wear often accompanies this. Water usually not evident, as it tends to boil off at normal operating temperatures.
Roller-bearing wear	Increased levels of Fe, Cr and Ni levels, all components of race and roller materials. Increased Cu might result if brass/bronze cages are employed.
Hydraulic ram wear	Increased levels of Fe, Cr and Ni.

Table 3. Common wear situation as indicated by the ICP

Sample submission information is vital.

Silicon, though, is not only found in dirt. It may be found in grease, oil additives and silicone sealant too. It is possible to see engines and hydraulic systems with silicon readings in excess of 100 ppm, yet which are still considered normal.

Table 2 on Page 4 lists the most commonly occurring elements and their probable sources.

Knowing where the elements may be found is useful, but it is more important to be able to determine the actual source as accurately as possible. Table 3 on Page 4 shows a few typical cases of wear and contamination, and how they typically appear:

At this stage the importance of sample submission information, particularly service meter reading, overhaul/replacement information and period oil in use must be strongly emphasised. As far as service meter reading and overhaul/replacement information goes, this tells the diagnostician what sort of wear rates to expect. A new component can be expected to wear faster as it beds in than a component in the middle of its life span. A component with high hours can be watched for increased wear as fatigue sets in.

The period oil in use strongly

influences what can be considered normal. An engine with 100 ppm Fe at 250 hours is very likely to be healthy. The same reading at 10 hours probably indicates a serious problem. The chances of inaccurate diagnosis, particularly in the latter situation, are increased without this information. Furthermore, indicating a period oil in use in months, particularly for automotive components, is not particularly helpful - the vehicle could have been parked off for that time or it could have been working double shifts. For components without service meter readings, such as industrial gearboxes, an educated guess in months or years is better than nothing.

2. Particle Quantification Index (PQ or PQI)

In this test each sample is passed over a sensor which measures the bulk magnetic content of the oil. As iron is the major wear element in virtually all components, the PQI is really a measure of how much iron is present in the sample, the amounts of other magnetic elements being negligible. The PQI makes no mention of size - the bigger the number, the more iron. What the PQI is communicating could be interpreted as a mass per capacity concept or, in metric terms, something like grams iron per litre of oil.

Table 4. Iron (Fe) and PQI relationship

Situation	ICP Iron (Fe)[ppm]	PQI	Inference	Wear Profile
1	Low	Low	Few wear particles	Normal wear profile
2	High	Low to medium	Lots of small particles, few or no large ones	Accelerated wear (type of operation) Wet-brake systems (normal or abnormal) Dirt entry (abnormal)
3	Low	High	Few small particles, many large ones	Fatigue
4	High	High	Lots of particles of all different sizes	Serious wear likely, catastrophic failure possible

The PQI estimates the distribution of wear particle sizes.

The PQI, unlike the ICP, does not have particle-size limitations. As such it does not give us any indication of the sizes of the particle. Casting our minds back to the example mentioned in the previous section of a ball bearing ball in a sample: a solid ball bearing and the same one ground to powder should give the same PQI.

Used in conjunction with the ICP iron reading, the PQI is invaluable in making an estimate of the distribution of wear particle sizes. Table 4 on Page 5 illustrates this relationship. 'High', 'medium' and 'low' are relative concepts and should be interpreted in the context of other samples in the component's history.

Situation 2 has various possible origins. It can be typical of a component experiencing accelerated, but not abnormal, wear, i.e. the component is working harder than normal. The classic illustration of this may be found in comparing the wear readings of differentials of identical trucks in different operations, for example short and long-

haul operations. The truck hauling cane through muddy fields with its differentials locked can be expected to wear more than its counterpart cruising the Cape Town to Johannesburg route. Differences in what can be considered 'normal wear' for each situation can be up to two orders of magnitude. This situation is also typical of normal brake wear in immersed-brake systems (such as most front-end loaders). Dirt entry causing abnormal wear also generates this Fe-PQI relationship.

3. Viscosity

There are two types of viscosity: kinematic and dynamic (or absolute). Oil analysis concerns itself almost exclusively with the former. Kinematic viscosity is measured in centistokes (cSt) and is a measure of a fluid's resistance to flow or, more simply, its thickness. It must always be quoted at a stated temperature as a fluid's viscosity will change with temperature. At 40°C a 200 cSt oil is thicker than a 100 cSt one.

Component	Viscosity change	Cause
Engine	Increase	Overheating. (May or may not be accompanied by oxidation) Sludging (poor combustion or overextended use) Fuel dilution (marine engines fired with heavy fuel oil) Severe water contamination
	Decrease	Fuel dilution Breakdown of VI improver additive in multigrade oils with extended use
Other components	Increase	Overheating Grease contamination Severe water contamination General breakdown of the oil Mixture of oils
	Decrease	Contamination by a volatile substance Breakdown of VI improver additive (particularly noticeable in transmissions filled with a multi-grade) General breakdown of the oil

Table 5. Interpretation of changes in viscosity

As oil temperature increases, its viscosity decreases.

Wearcheck carries out a viscosity measurement at 40°C on every sample. A viscosity measurement at 100°C can also be carried out, but this service carries an extra charge. They are performed on one of five Houllon viscometers, four measuring viscosity at 40°C and the last measuring viscosity at 100°C. The process is simple: a glass tube (the ends of which are kept open to the air) is immersed vertically in a bath at the required temperature; oil is introduced at the top and, as it flows down, it is brought up to the correct temperature. Its flow is then timed between two marks. This time measurement is converted to a viscosity.

There is another property of an oil related to its viscosity. This is the viscosity index (VI). It is known that as the temperature of an oil increases, its viscosity decreases. The VI of an oil tells us by how much it is going to thin out. A monograde oil has a lower VI than a multigrade, which tells us the monograde will tend to thin out more than the multigrade with increasing temperature. For example, a typical SAE 30 monograde and a typical SAE 15W/40 multigrade can both have a viscosity at 40°C of 100 cSt. But at 100°C they have respective viscosities of 10 and 15.

The way to determine the VI of an oil is to measure its viscosity at both 40 and 100°C.

Table 5 on Page 6 illustrates some of the causes of changes of viscosity.

It is important to note that concurrent conditions can mask the effects of changes of viscosity. Fuel dilution accompanied by overheating could leave the viscosity reading looking normal.

Once again the importance of accurate submission information is

underlined here. Perfectly good oil may be recommended for changing due to large differences between the viscosity of the oil described on the submission form and the viscosity of oil actually in the component. Furthermore, an engine described as having an SAE 30 or a SAE 15W/40, but actually running an SAE 40 or SAE 20W/50, may go unchecked for fuel dilution, as the decreased viscosity resulting from fuel dilution may compare favourably with the normal viscosity of the described oil.

During diagnosis we will usually allow the viscosity of an oil in use to vary by approximately 30% either side of its starting viscosity before commenting.

4. Water

Water is one of the more common contaminants. It can be introduced into a system via internal coolant leaks, high-pressure hose cleaning procedures, or by condensation from the air as the system cools.

Water has several negative effects on the performance of oil.

- It causes rust, which in turn contaminates the oil.
- The load-bearing capacity of water is not as high as oil, so wear is promoted as water replaces the oil film.
- In engines it tends to flash to steam as the temperature rises rapidly in the bearings, effectively steam-cleaning them.

It is important that water contamination be kept to the absolute minimum. Seals and breathers should be regularly inspected and maintained. Pressurised cooling systems need to be pressure-tested from time to time to confirm their integrity.

Low concentrations of water due

Water contamination should be kept to a minimum.

Component	Limit (%)
Engine	0.0
Drivetrain	1.0
Transmission	0.5
Hydraulics	0.5
Compressors	Variable according to type

Table 6. Water limits

to condensation may be evident in samples that were not taken at the operating temperature of the component. As we assume every sample is taken correctly, taking a cold sample could lead to unnecessary oil changes.

Engine samples are screened for water using FTIR analysis (see next bulletin), and every other sample is screened for water using the crackle test. This test involves putting a drop of oil onto a steel surface which is maintained between the boiling points of water and oil. If the oil drop contains water it spits and crackles, hence its name. The crackle test can detect water contamination of less than 0.1%.

If a sample fails the crackle test the actual water content is measured. The water test involves mixing calcium hydride with the oil. This reaction generates hydrogen gas, the volume of which is measured and converted to a percentage water content of the oil.

Once again, tentative limits for water contamination are used (see Table 6 above), although these will vary in situations of abnormal or unusual usage.

Water should not be relied upon as an indication of an internal coolant leak, particularly in engines. It tends to evaporate off at normal operating temperatures. ✓

In the following bulletin the remainder of Wearcheck's tests will be covered.

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