WEAR CHECK
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HOLISTIC DIAGNOSIS

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Anyone reading this technical bulletin will be familiar with the condition monitoring technique of oil analysis. A small sample of oil is drawn from a lubricated piece of machinery and analysed for the presence of wear debris and contaminants, as well as an assessment of the health of the oil itself.

So far, so good, the oil (or grease) can be subject to a whole battery of physical and chemical tests which, in turn, can provide upward of 50 (in the case of a fully comprehensive analysis) different parameters that need to be assessed in order to determine the health of the machine, the health of the oil and the levels of contamination.

How does this assessment take place? A question commonly asked by users of oil analysis is 'Can I have a copy of the limits that you use?' The use of limit tables is highly simplistic and in some cases can be very badly misleading. In essence, what the user wants to be able to do is the job of an oil analysis diagnostician by simply looking at a few sheets of paper – it is a little more complicated than that. The WearCheck diagnostics department has eight diagnosticians with a combined experience of over 150 years and more than 7.5 million samples, five members of the team have diagnosed more than a million samples each. That is a huge wealth of experience that cannot be condensed into a couple of charts and tables.

There are many reasons why wear limits can be dangerous (although they do have their uses in some situations) but this technical bulletin will focus on the concept of holistic diagnosis. The problem with limits is that they look at laboratory readings in isolation: 0 – 50 is okay, 50 – 100 is a problem and over 100 is critical. In its simplistic form that is fine, but it is often the case that 50 – 100 might only be a problem depending on what *the other readings are doing.* 75 might be critical in one situation and perfectly normal in another.

SOURCES OF SILICON

Silicon provides a wonderful example of how vital it is to look at the whole picture. To most people familiar with oil analysis, silicon is used as an indication of dirt entry. Dirt, dust, sand, grit, whatever you want to call it, is mostly composed of a chemical called silicon dioxide, and silicon can be easily detected by a laboratory instrument called a spectrometer. The important thing to note here is that the instrument is detecting the chemical element silicon, not the compound silicon dioxide. Unfortunately, life is never simple, and the silicon found in oil can have many other sources.

So, how do we tell whether the silicon is due to dirt entry or some other origin? Simple, you have to look at what the other readings are doing in order to determine where the silicon is coming from, in other words, perform a holistic diagnosis. The table below outlines a number of highly plausible scenarios:

Example	Iron	Aluminium	Chrome	Tin	Copper	Sodium	Silicon	Explanation
1	36	9	4	1	13	10	15	Normal sample
2	97	29	13	2	14	9	61	Severe top end dirt entry
3	43	12	4	3	136	211	99	Internal coolant leak
4	35	10	3	1	14	12	127	Silicone sealant
5	35	8	2	2	16	11	45	High additive level
6	123	150	32	2	19	9	133	Piston torching
7	95	15	15	29	10	10	59	Detroit engine dirt entry
8	100	32	75	4	15	11	25	Dirt at a chrome mine

Dirt is highly abrasive and when it comes in contact with oil it essentially forms a kind of grinding paste that causes accelerated wear of the component being lubricated. Let's take a diesel engine as an example. If fine dust were to get past the air cleaner and into the upper cylinder area, it would cause immediate wear to the pistons, rings and liners. In most cases the pistons are made of aluminium, the rings of chromium and the liners of iron – not only would we expect silicon to go up, but the iron, chromium and aluminium would increase too, and this is exactly what happens, producing a very common wear profile.

In the next scenario the silicon also goes up, the iron, aluminium and chromium hardly increase at all but the copper and sodium go through the roof – what is going on here? This is an example of an internal coolant leak; when this occurs, water leaks from the cooling system, through a pitted liner for example, into the engine oil, but at operating temperatures and pressures the water evaporates off. However, the coolant conditioner chemicals get left behind in the oil. One of the chemicals commonly found in coolants is sodium metasilicate, a compound that contains both silicon and sodium which now show up in the oil. The high copper comes from normal leaching of the cooling system.

The next example shows high silicon on its own with no increase in any of the other readings. In this case the origin of the silicon is from a silicone based gasket or sealing compound. If a repair has recently taken place and one of these compounds has been used then it is possible for them to leach into the oil. The silicon rockets, but because this form of silicon is non-abrasive, no increase in wear is noted.

What can be confusing in this situation is that the engine might be brand new, results might be elevated due to bedding in and a silicone assembly grease may have been used. How do you determine what is going on in this case? A further aspect of holistic diagnosis needs to be considered here. If there are only 15 000 km on the truck then it is highly likely that this is a bedding in situation, however, if the truck has over a million on it then it is probably abnormal wear caused by dirt entry. All the information supplied with the sample needs to be considered.

Next we can look at a very similar situation, but here the silicon has only increased slightly, to the point that the silicon is elevated but not critical and once again the wear readings are all normal. All engine oils contain an additive called poly-methyl-siloxane (yes, another source of silicon). This additive stops the oil from foaming, occasionally oil companies get their blends wrong and can either over- or under-dose on a particular additive. This particular situation has been noted twice in the last ten years. Normally the silicon level in new oil is between five and 10 ppm but new oils with silicon as high as 60 ppm have been analysed. This has an interesting effect on the particle count that now goes up, but when the oil is filtered and examined under a microscope, no contaminants can be detected; yet another example of holistic diagnosis.

Silicon dioxide is not the only constituent of dirt – it is usually accompanied by aluminium oxide, so if actual dirt entry is taking place one would expect the aluminium to increase in a fixed ratio to the silicon. This is, in fact, what happens in engines, transmissions and hydraulics the Si:Al ratio is around 2:1, in drivetrain components it tends to be a little higher, maybe as high as 10:1. In our next example we see an increase in our familiar four, iron, chromium, aluminium and silicon but in this case the silicon and aluminium readings are almost the same – something does not look quite right. This is a very rare example as it is a sudden death failure that is hardly ever caught by oil analysis. This is a case of piston torching with dirt generally not being involved. A faulty spray pattern on an injector can cause fuel to lie on the crown of the piston and burn, obviously this will mean the iron, chromium and aluminium will increase but where is the silicon coming from? Aluminium pistons are often alloyed with silicon carbide which reduces the coefficient of expansion and this is where the silicon comes from when torching takes place.

But wait, there's more! What happens in the opposite situation where dirt entry is happening but the aluminium to silicon ratio is close to 1:10? Another aspect of holistic diagnosis needs to be considered here – the information supplied by the customer. Detroit diesel two stroke engines have a tin flashing on their pistons, and what would be observed here is an increase in iron and chromium and, obviously, silicon, but, with the tin flashing (an efficient conductor of heat) the aluminium does not go up nearly as much. What you do see is an increase in the tin, an element normally associated with bearing alloys, but in this case its origin is the piston.

Before we leave silicon, there is one last aspect that needs to be looked at. Dirt is an environmental contaminant and in the vast majority of cases it will be a mixture of silicon and aluminium oxide, but what happens if these compounds are *not* in the environment? The last silicon example shows an increase in aluminium and iron, a massive and disproportionate increase in chromium and virtually no increase in silicon. This is what dirt entry might look like on a chrome mine.

CONFUSING COPPER AND MUDDLING MOLYBDENUM

Silicon is not the only element that can have more than one source. Like silicon, copper can be a contaminant, wear metal and, on very rare occasions, an additive. Copper is a metal found in brass and bronze alloys and makes up bushes and thrust washers in various components. In a wear situation one would expect associated metals, such as tin and lead, to increase and maybe zinc and maybe even iron. As a contaminant, you often see copper leaching from the cooling system. If it leaches from the oil side, astronomically high copper would be noted but none of the other readings would change. If the copper comes from the water side of the cooling system, then coolant additives such as sodium, silicon, boron or molybdenum would probably be noted.

This brings us on to molybdenum, another metal that can be a contaminant from both the cooling system and greases, an oil additive as an anti-oxidant or a solid additive, and as a wear metal found as a coating on piston rings or in synchromesh gearboxes.

In fact, most elements detected by the spectrometer can belong to more than one of the three main groups (additive, contaminant, wear metal) and often to all three. What can be particularly difficult to assess is when an element belongs to more than one group *at the same time.* This is why a simple wear limit table is simply just not going to be able to cut it. It requires a huge body of knowledge and years of experience to become a skilled and accurate diagnostician. These few examples have just looked briefly at only three of the 30-odd elements that can be analysed – it would require a lengthy book to cover all aspects and years of experience to put it all into practice.

When analysing oil samples, the ICP (inductively coupled plasma) machine provides data such as contamination and wear levels that can be used as part of a holistic diagnosis of the sample

TRENDS AND RATIOS

Let's move away from how the elements interact with each other and consider ratios and customer supplied information. In the normal course of events, 20 ppm lead (a coating found on main and big end bearings) in an engine is probably acceptable. Iron can sometimes be used as an internal reference in the fact that in any mechanical system, it is the major wearing element. This can then be used as a benchmark and other readings compared to it. 20 ppm lead might be acceptable in an engine, but, if the iron reading is only 25 ppm, then something does not look right as there is so much more iron in an engine than lead. In this case it is not the actual concentration that is of concern but the ratio of the two elements in question. We have already encountered the importance of ratios when looking at aluminium and silicon in order to assess the possibility of dirt entry.

Trends are another aspect that need to be considered; a trend of 50 ppm iron might be normal, but if it jumps to 85 ppm, that might indicate a problem. Likewise, a trend of 30 ppm might also be normal but a jump to 50 ppm could indicate something is going wrong. In one situation 50 is acceptable, in another it is not and it is only by looking at the history of the component that its well-being can be assessed.

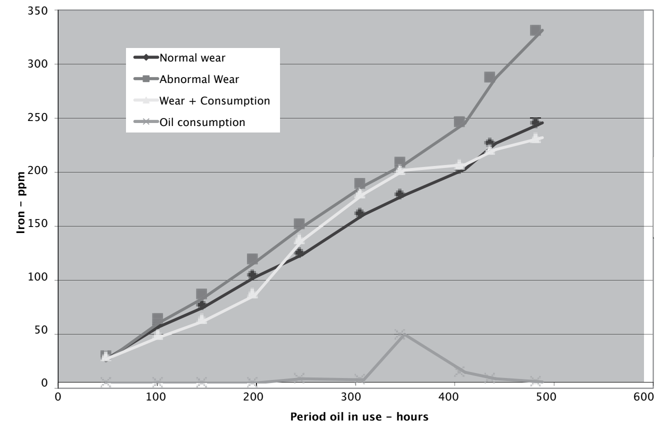
Finally, customer supplied information is absolutely critical – things like application, environment, oil and fuel types, machine age and oil consumption can have a huge impact on how an oil sample report is assessed. The more information that the diagnostician has, the better the diagnosis will be. It should be noted that *the* primary cause of the failure of an oil analysis programme is down to wrong or missing information accompanying the oil sample.

Perhaps the most vital piece of customer supplied information is how long the oil has been in use. 50 ppm iron might be fine after 250 hours of operation, but critical after only 50 hours and suspiciously low for 500 hours. If the oil has been in use for twice as long, one would expect there to be twice as much wear and contamination. A high value where the oil has been in use for a long time needs to be judged as 'normal for the period the oil has been in use'. In the case of the suspiciously low iron reading, maybe the oil consumption is elevated.

The final graph shows how lack of information can lead directly to an incorrect diagnosis. Oil consumption (something very few people measure) has been mentioned above. If the oil consumption is unacceptably high, firstly you already have an indication that something is going wrong, but secondly, the addition of large quantities of fresh oil will dilute contamination and wear levels – in essence you are analysing fresh oil.

The first line shows iron increasing regularly over a period of time with oil samples being taken at regular intervals – this can be considered normal wear. The second line shows an increasing wear rate with higher iron readings indicating that an abnormal wear situation might be developing. The final line shows the second situation coupled with high oil consumption such that the end point is indistinguishable from the normal wear situation. The high oil consumption has masked (diluted) the abnormal wear taking place.

The effect oil consumption has on wear readings



EVERY PICTURE TELLS A STORY

The diagnosis of oil samples is so much more than following a few simple rules and limits. You have the laboratory supplied information (the tests) and the customer supplied information (submission form) and the two need to be carefully married to get a clear picture of what is going on. Once that marriage has been assessed, taking into consideration all the information the customer has supplied, all the tests from the laboratory, all the history on the component along with knowledge of how similar components behave in similar situations, only then can a story be formulated. Diagnosis, in essence, is forensic chemistry, trying to figure out what is going on from a few simple clues. These simple clues can be used to paint incredibly complex and detailed pictures but this can only be done when the data available is considered as a whole. Only a holistic assessment of the data will provide the correct answer, looking at readings in isolation only gives a blurry picture in black and white and can often miss the rich tapestry of colour that can be achieved from a holistic perspective.

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