TECHNICAL BULLETIN

ISSUE 15 - WEAR LIMITS VERSUS TRENDS

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What wear limits are normal?

Common questions asked by people using oil analysis are `What wear limits do you use?', 'What levels are normal?', and 'What levels are abnormal?'

These are not unreasonable questions. A number of OEM's (original equipment manufacturers) do have wear limits for their equipment but unfortunately they are not an effective means of determining the health of a component. The levels of contamination and particularly wear debris in an oil sample are dependent on too many factors for an equipment manufacturer to set out nice, neat wear tables that say, for example, 0 - 50 is okay, 50 - 100 indicates a problem, and over 100 is very serious. This runs the risk of saying that 49 `whatevers' is acceptable and 51 is not when, in this case, there is only a difference of 4%.

Limits and trends

The wear limit tables produced by OEM's are based on extensive research and testing by the people who manufacture the equipment. These are the people who know the equipment best but, at the end of the day, these tables reflect average situations and are to be used as a guideline only. They are not rules or laws cast in stone. Machines rarely work in average situations and often limits determined in a certain environment can have little relevance in other environments, particularly in Africa, and very little equipment is manufactured here. What holds true for Japan, Western Europe or North America might not hold true for South Africa.

[*Page 1* : **Wear limit tables should be used as a guideline only**.]

The common factors that influence the concentration of wear debris and contaminants in an oil sample are:

- the type of equipment
- the environment in which it is working
- the job that it is doing
- the skill of the operator
- the length of time that the oil has been in use
- oil consumption

Because of these factors, each piece of equipment must be treated on its own merits. It is far more beneficial to assess the wellbeing of a machine or lubricant on the basis of a trend analysis.

[*Page 2* : **Trend analysis is a better method of assessing machine or oil wellbeing.**]

Wear limits do, however, have their uses. If a diagnosis is to be made on the health of a component based on oil analysis and a trend is to be used, then this requires at least three samples to establish that trend. This makes one-off samples very difficult to diagnose. Wear limits are useful in these situations as they give a guideline of how the average machine should behave under average conditions. If the unit is very obviously normal or very obviously in a critical way then the diagnosis is easy to make. However, it is the in-between cases where something might or might not be starting to go wrong, that are difficult to assess on a one-off basis without the help of a trend.

This is what oil analysis is all about, detecting minor problems and correcting them before they become catastrophic failures. There is no point in taking an oil sample, being told that the wheels are about to fall off and finding out that this is the case. The problem should have been identified long before that situation is reached. This also serves to illustrate the importance of *regular* oil sampling as opposed to taking samples only when things go wrong. A one-off sample without a trend often won't supply enough information to determine the cause of a problem. We will return to the question of regular sampling later.

Another problem with wear limits is the range of tests that they cover. Traditionally, these limits have only covered wear metals and contaminants which are detected by a laboratory instrument called a spectrometer. This test provides a tremendous amount of useful information but it does have one major drawback: it can only detect particles smaller than 8 microns (a micron is 1/1000th of a millimetre and a human hair is about 50 micron in diameter). These particles are vanishingly small and so the wear limit tables could indicate everything as being normal when a severe wear situation could exist with particles greater than 8 micron which cannot be seen by the spectrometer.

These are the most frequently given explanations for using wear limits with extreme caution and they are very valid ones. There is another critical point: the use of wear limits makes the assumption that all the results from the chemical and physical tests are looked at in isolation, and this is a fundamentally wrong way of looking at things. The results of oil analysis must be looked at holistically. Fifty `whatevers' might be acceptable in one situation and critically bad in another and the only way to determine this is by looking at other readings and available information. In other words, you must look at the whole picture. It is quite possible that identical samples from truck A and truck B reflect different diagnoses because the history (trend) for the two vehicles is different.

The following discussion is a good example of looking at trends and, in particular, looking at the results holistically.

[*Page 3 :* **Oil analysis detects and corrects minor problems before they become catastrophic failures**.]

Dirt entry . . . or is it ?

Dirt, grit, airborne dust - whatever name you give it, it is ubiquitous. It is also very damaging to machinery because, if it gets into the oil, it will form a highly effective grinding paste which will cause wear rates to accelerate rapidly. Fortunately for the oil analyst, dirt is mostly made up of a compound called silicon dioxide, and silicon can be very easily detected in oil by spectrometric analysis.

So, would an increase in the silicon level indicate to the oil analyst that the level of dirt entering the system is increasing ? The answer to this is: 'Yes, sometimes,,, but not necessarily'.

The tables on the next page show a typical set of spectrometric results from an engine that is operating normally with no evidence of dirt entry. In Table One, the second example shows an increase in silicon with higher wear readings. This is typical of dirt entry through the air induction system: the silicon indicates dirt whilst there is a rise in iron (liners), chrome (rings) and aluminium (pistons).

The third example also shows an increase in silicon, but it is due to an internal coolant leak. When cooling water leaks into the engine, the water usually evaporates off. However, the additives (e.g. anti-freeze) in the cooling water are left behind and silicon can be part of the coolant conditioner make-up (sodium meta silicate). In this case the sodium and copper readings rise sharply but the other readings do not. The sodium is also an additive and the copper is not a wear metal but has leached from the radiator core. The silicon is high but is a contaminant from the cooling system and not abrasive dirt.

The fourth example shows a very high level of silicon but all the other readings remain more or less constant. This is an example of a silicone-based sealant or gasket compound being used. These compounds leach into the oil but do not do any harm. If this high silicon level were due to dirt entry then it would be expected that the wear readings would increase due to the abrasive nature of the dirt. It should also be noted that dirt is generally a mixture of silicon oxide and aluminium oxide so, in the case of dirt entry, the aluminium level should rise as well. A rough rule of thumb is that for dirt, the aluminium to silicon ratio varies between Al:Si = 1:10 - 1:2, depending on the component and the environment. In this case, the silicon is still a contaminant but is not abrasive and is of no concern.

The fifth example shows a slight increase in the level of silicon but this is caused by an additive in the oil, poly methyl siloxane, which is used to prevent the oil from foaming. It does not cause the wear readings to rise and, therefore, does not do any harm.

The final set of readings in table one shows an increase in silicon, iron, chrome and aluminium and looks very much like the second example of dirt entry through the air induction system. However, the aluminium to silicon ratio is almost 1:1 which is unusual. This is an example of piston torching. If an injector is faulty, it can allow fuel to lie on top of the piston and burn. The resulting high temperatures can cause the piston to melt with the resulting increase in aluminium (piston), iron (liner) and chrome (ring). The rise in silicon is the result of silicon carbide being alloyed with the piston material in order to reduce the coefficient of expansion of the aluminium. In this case, the silicon is a wear element and is not identified as such because of the high level but because of the ratio of aluminium to silicon.

In Table Two, the first set of results again shows a normal set of readings. The second set shows top end dirt entry in a Detroit diesel two-stroke engine, where the iron, chrome and silicon have all increased but the aluminium to silicon ratio seems wrong and the tin level is higher. The reason for this is that the aluminium piston has been covered with a flashing of tin to facilitate the conduction of heat.

Table Three shows the normal readings and three examples of dirt entry through the air induction system (higher iron, chrome and aluminium) without the increase of silicon. These are engines working at Richards Bay, a manganese mine and a chromium mine. Here, the dirt consists of the minerals that happen to be in the environment where the machine is working and the silicon won't necessarily rise when dirt entry occurs.

[Tables on page 4

THEORETICAL EXAMPLES OF SAMPLES SHOWING HIGH SILICON/DIRT ENTRY AND CAUSES OF HIGH COPPER

Fe	Al	Cr	Cu	Na	Si	TABLE ONE
35	8	3	15	12	15	Normal
92	29	16	20	16	69	Severe Dirt Entry
38	9	4	124	243	101	Internal Coolant Leak
35	8	3	15	12	250	Silicone Sealant Used
36	10	5	10	19	31	High Anti Foam Level
105	134	38	20	21	145	Fuel System Fault - Piston Torching

Fe	Cr	Al	Sn	Si	TABLE TWO
35	8	3	7	15	Normal
120	25	10	35	68	Dirt Entry - Detroit Two Stroke Engine

Fe	Cr	Al	Zr	Mn	Si	TABLE THREE
35	8	3	0	0	15	Normal
99	19	25	154	0	29	Dirt Entry - Richards Bay
104	18	27	0	217	28	Dirt Entry - Manganese Mine
128	73	30	0	0	31	Dirt Entry - Chrome Mine

Cu	Pb	Sn	Fe	Na	Mg	Ca	TABLE FOUR
15	20	5	48	10	500	2000	Normal
68	71	15	108	10	500	2000	Bearing Wear
105	39	10	48	120	500	2000	Internal Coolant Leak
105	39	10	48	10	500	2000	Leaching - Oil Cooler Core
200	20	5	48	10	1000	100	Oil Additive

All readings in PPM

Al Aluminium
Zr Zirconium
Mn Manganese
Cu Copper
Sn Tin
Cr Chromium
Si Silicon
Na Sodium
Fe Iron
Pb Lead
Mg Magnesium
Ca Calcium

Page 5 : **Oil analysis results must be viewed holistically.**]

These few examples are not that unusual and are seen on a fairly regular basis, except piston torching as it tends to be a sudden death problem. They illustrate four situations:

- silicon increasing due to dirt entry
- silicon increasing, not due to dirt but still a problem
- silicon increasing where no problem is indicated
- silicon remaining more or less constant when dirt entry is taking place

The only way that these situations have been correctly identified is by trend analysis and looking at the results in a holistic manner. This is why wear limits can be very misleading and in some cases totally wrong.

Copper can be misleading too

Silicon happens to be a good example for illustrating the value of trending and looking at the oil analysis results holistically, but an increase in almost any reading can have different interpretations depending on what any number of other readings are doing. Table Four shows how an increase in copper can be due to:

- an abnormal wear situation
- contamination (a problem)
- contamination (not a problem)
- an additive in the oil

The first example in Table Four shows a normal set of results. The second example indicates higher copper levels with an associated increase in lead, tin and iron which would typically indicate bearing wear.

The third example reveals an increase in copper due to an internal coolant leak (discussed with silicon above). Note that the lead and tin also rise slightly due to the use of solder in the cooling system but, because the sodium goes up and the iron does not, the copper is coming from the cooling system and indicates a problem.

The fourth example is almost the same as the third except that the sodium does not increase. In this case the copper is still coming from the cooling system but it is being leached from the oil side of the cooler. This is a common occurrence and, although it looks alarming, it does not indicate a problem.

In the final example, the copper increases, as does the magnesium, and the calcium decreases, whilst there is no change in the wear readings. In this case, the copper is part of the oil additive package (an anti-oxidant). Wear limit tables do not take into consideration the elemental make-up of the oil used.

Generally, the spectrometric readings (elements) can be grouped into three classes:

- wear metals
- contaminants
- oil additives

Most of the elements can belong to any one of these classes. Only by looking at all the readings together, can the correct class be assigned. To make things really difficult, it is important to remember that an elevated reading can be caused by more than one thing at a time.

In the example of the internal coolant leak, it is possible for other readings or tests that do not involve the spectrometer, also to be affected. An internal coolant leak may result in overheating, in which case viscosity and oxidation will increase and the TBN (Total Base Number) will decrease. This is most helpful because you now have four independent laboratory techniques all indicating the same thing.

[Graphs on page 6]

[*Page 7 :* **Wear limit tables do not consider the elemental make-up of oil.**]

Trends and regular sampling

To return to the importance of trending and taking regular oil samples, let us re-examine the second example in Table One which shows an increase in silicon caused by top end dirt entry and the associated wear of pistons, rings and liners. As dirt is by-passing the air filter, abrasive wear is taking place in the upper cylinder. Because of this, oil consumption will eventually increase. Higher oil consumption means that the engine is being topped up with fresh oil with the result that the wear and contamination levels appear to decrease. Graph One illustrates a hypothetical situation, starting with an increase in silicon (dirt entry) followed by an increase in iron (wear) and an increase in oil consumption which eventually leads to a *decrease* in iron and silicon readings.

Following the trend of regular samples makes interpretation of the readings fairly straightforward. However, what would happen if only samples 1, 2, 3, and 10 were taken? This would show a smooth trend for iron and silicon, indicating no problem at all (see Graph Two). Only an increase in the oil consumption would be noted, with no apparent explanation.

Accelerated or abnormal ?

Something else that needs to be taken into consideration is the subtle difference between accelerated wear and abnormal wear. If the lead readings were to increase in an engine sample, this would usually indicate bearing wear. However, this could be accelerated wear due to the machine possibly working harder with *all* the bearings wearing a little more than usual, or it could be due to just one bearing wearing abnormally.

[Page 8 : **Trending is beneficial in any condition monitoring technique.]**

There are many factors that affect oil analysis results which are outside the control of the OEM, owner, operator and oil analyst and all of these must be borne in mind when making a diagnosis. Trending and looking at results in a holistic manner offer the greatest benefits for any type of condition monitoring technique, not just oil analysis. Whilst wear limits do have their uses, they are not golden rules and should be used with caution. All it would require to distort a set of wear tables would be for an owner to fit some form of ultra filtration to filtered oil systems. The result would be the lowering of all the alarm levels. One Wearcheck customer has done this across a large fleet of earthmoving equipment and the effect is very noticeable. It is interesting to note that some of the strongest proponents of wear limits in the past are now acknowledging that the wear readings also need to be trended. *[Wearcheck tick*]

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