Real Time Oil Condition Monitoring, Practical Examples of Trend Analysis & Failure Prevention

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Abstract

The purpose of this paper is to discuss the practical reality of traditional oil analysis methods for hydrocarbon based oils and how the adoption of real time oil condition monitoring can deliver significant operational and financial benefits. It will then give an understanding of how real time oil analysis works at a technical level followed by presenting a series of actual case studies, which clearly show real time oil condition monitoring in action. These case studies highlight in practical terms, the various operational issues and failure modes which can easily be identified from the trend data generated from our sensor and its associated sensing technology.

Keywords: Real Time Oil Analysis, Failure Prevention, Increased Service Intervals, Improved Reliability and Failure Prevention.

Introduction

Oil whether mineral, semi-synthetic or fully synthetic is often referred to as the lifeblood of any piece of equipment. Oil is used as a fuel, lubricant, transfer method and insulator across many applications. Poor quality and incorrect oil can cause major reliability and efficiency issues resulting in significant maintenance costs, a massive global market in oil filters and more recently, in oil condition monitoring.

The instant oil is used its condition starts to deteriorate. Deterioration of oil condition is caused by general stress of use and the introduction of contaminants such as carbon, acid, water, soot and particles. As the oil deteriorates so too does its performance, with a direct and material effect on the equipment of increased wear and reduced efficiency.

Laboratory analysis of used oil samples has been used since the early 1960s as a component of Condition Based Maintenance programs. As with any Condition Based Maintenance program, the key is the accurate trending of data over time to establish the current condition of a piece of machinery. It is widely accepted and our experience that over 90% of all readings taken during Condition Based Maintenance activities will show normal operation and will therefore require no further action. Unfortunately, as each sample analysed incurs a cost, the use of oil analysis can very quickly become expensive and in general, only a limited number of assets will be monitored using this technique. Consistent sample taking is another vital key to ensuring accurate and repeatable results. Finally, one of the most significant limitations of laboratory analysis is the inherent delay in receiving the actual results combined with operational issues ensuring any necessary action takes place in an appropriate timescale.

The Technology

In order to understand how real time oil technology works, it is firstly important to understand how oil wears and deteriorates. As can be seen in Figure 1, oil consists of a long chain of hydrocarbons, which as it wears, changes in chemical properties as seen in Figure 2, which produces polar compounds. There are a number of factors that cause a change in the chemical composition of the oil and the production of polar compounds, all of which are associated with the degradation of the oil.

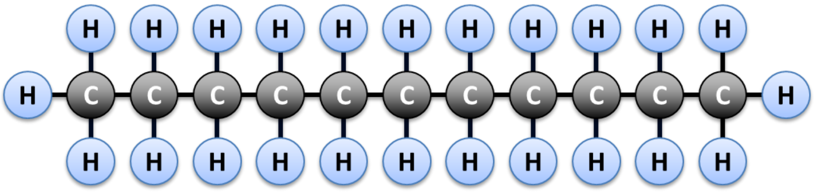

Figure 1: A typical Hydrocarbon chain (for illustrative purposes only)

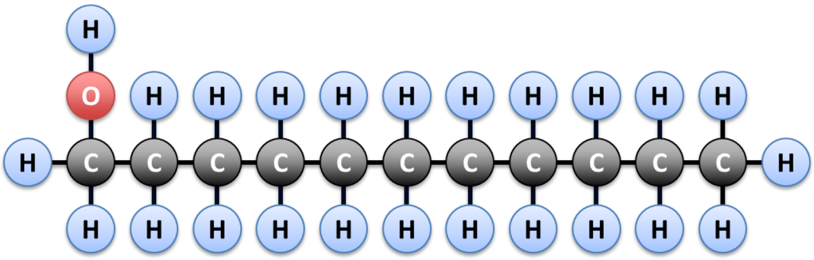

Figure 2: A typical Hydrocarbon chain showing oxidation (for illustrative purposes only)

Recently, a number of technologies have emerged which have made it possible to rely on sensing technology to give real time readings of individual oil parameters or overall oil condition. The sensors based on these various technologies are divided into two main groups – *broad spectrum sensors* that give an index value of overall oil condition, and *specific reading sensors* – that give a specific output for a single parameter.

The single parameter sensors such as viscosity, relative humidity or particle counters can be very useful in identifying single failure modes, however their application is limited as oil wear is complex and you are rarely looking for a single failure mode. Some also have the added issue of requiring regular calibration and are not always appropriate for harsh environments with high levels of shock and/or vibration.

Broad spectrum sensors generally use a single simple or single complex measurement to assess overall oil condition. Sensors that use a single simple measurement such as a dielectric measurement, suffer from having very limited sensitivity which is compounded by temperature instability.

One sensor that overcomes this issue by using a patented, single complex measurement method is the Tan Delta sensor. The Tan Delta sensor measures the electrochemical properties of the oil, specifically the ratio between the conductive and capacitive properties of the fluid at high frequencies to give an accurate single index value of overall oil condition. Initially the sensor is configured for the fluid it is being used in, so that the baseline electrochemical properties are known to the sensor. A high frequency AC wave form is then introduced by the sensor to determine the current state of the oil by measuring how much of the energy introduced is lost, this measurement is called the Loss Factor.

Theoretically in a perfectly clean oil when the energy is introduced there would be no means for this energy to be used up (dissipated) and so all of it would be stored during one half-cycle and given back on the next, so the sensor would return a reading of 0% Loss Factor. As the oil oxidises, degrades and/or becomes contaminated there is a change in the proportion of polar molecules and energy absorbed by these molecules being forced to oscillate or stretch or bend the intra-molecular bonds in the fluid. Now when the energy is introduced into the oil it will be dissipated as heat rather than stored by these mechanisms, this will in turn increase the amount of energy which is now lost, and so cause an increase in Loss Factor. It is important to note that fuel ingress is one specific failure mode that will cause the Loss Factor reading from the sensor to reduce due to the fuel diluting and thinning the oil and therefore reducing the amount of energy absorbed in making the molecules move.

By introducing the very high frequency AC waveform, the Tan Delta sensor is able to accurately measure the oil's ability to store energy (capacitance) and its ability to conduct current (conductance). There is a very strong relationship between the changes in capacitance and conductance and the quantity of polar molecules within the oil, as polar molecules absorb and dissipate energy, causing conductance of the electrical currents to ground, while the bulk unpolarised oil makes a good dielectric, storing energy (capacitance). The ratio of these two factors is measured in order to determine the change (and therefore damage) that has occurred to the oil. The measured ratio is called the Loss Factor and is given a percentage, which represents the change from a baselined new oil.

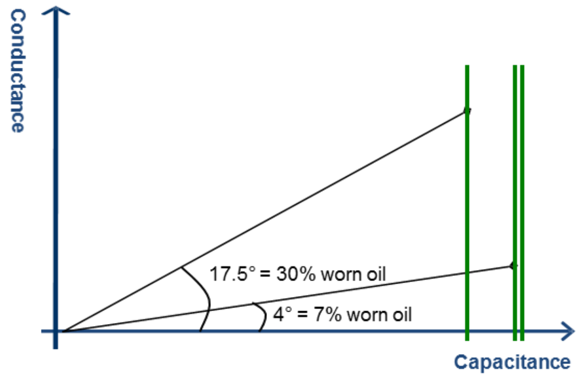

Figure 3: Capacitance Measurement

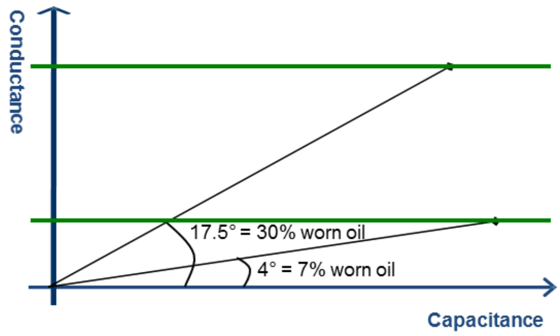

Figure 4: Conductance Measurement

In order to achieve accurate results it is essential to measure both the conductance and capacitance (as a ratio – patented method), not just the capacitance. As can be seen in Figures 3 and 4, as an oil degrades, the Phase Angle or Loss Factor increases, meaning the capacitance of the oil reduces and the conductance increases. As shown in Figure 3, if a sensor was solely measuring capacitance with a loss factor of 7% and 30%, there would be a decrease of 0.25% and 4.5% in capacitance respectively - a very small variation to measure. Loss Factor directly correlates to the conductance (7% change in conductance corresponds to 7% Loss Factor) resulting in a significantly broader and more accurate measuring range of conductance than capacitance alone.

Field Applications

The constant challenge for any equipment operator is the balance of maintenance whilst in operation. The more maintenance, the less wear and breakdowns, but less productivity – with the opposite being the case when maintenance schedules are extended. The ability to accurately and reliably measure the condition of a machine's oil in real time whilst in operation, enables operators to make maintenance decisions based upon condition rather than a time-based schedule.

The technology also benefits operators using time-based servicing, as it is common for intervals to be disrupted due to lack of available resources. From our experience, it is often via random selection as to which piece of equipment will be serviced and which will be pushed beyond the service interval. Using real time oil condition monitoring allows for informed decision to be made as to which items get serviced and which can have their intervals extended.

The benefits are considerable and measurable:

- Maintenance and resource scheduling is optimised with equipment being serviced when it needs to be.
- Increased component and equipment life and fewer breakdowns due to reduced day-to-day equipment wear from suboptimal oil.
- Early detection of oil contamination which can lead to costly and unexpected equipment failures.
- Increased equipment efficiency through understanding the relationship between oil quality and equipment output.

Sensors can be used in a wide variety of applications, but in general they are best suited for applications where the cost of failure is high – whether related to the cost of replacement equipment or downtime caused. Such an example is a power generation application, where waste gas generated from landfill sites is used to create power. Table 1 shows the laboratory results from oil samples taken regularly over the same period (labelled A to R), combined with the output from the sensor (Oil Condition Column). Figure 5 shows this data in visual form.

Table 1: Lab Samples & Sensor Data

Sample	TAN	TBN	Oxidation	Iron	Silicon	~Hours Run	Oil Condition
A	1.12	6.2	5	2	16	0	0.0
B	1.32	5.6	6	2	46	168	3.5
C	1.55	4.7	8	2	77	336	6.4
D	1.84	3.9	9	3	106	504	8.4
E	2.06	3.2	10	3	138	672	10.3
F	2.37	2.3	12	4	167	840	13.5
Sample	TAN	TBN	Oxidation	Iron	Silicon	~Hours Run	Oil Condition
G	1.29	6.2	5	2	17	0	0.1
H	1.57	5.7	7	4	48	168	2.8
I	1.83	4.9	8	4	77	336	5.8
J	2.02	4.5	9	6	106	504	9.0
K	2.33	4.1	10	7	135	672	12.0
L	2.54	3.6	11	7	163	840	14.3
Sample	TAN	TBN	Oxidation	Iron	Silicon	~Hours Run	Oil Condition
M	1.27	6.5	5	2	18	0	0.1
N	1.52	6.0	7	3	50	168	2.2
O	1.83	5.3	8	5	82	336	4.2
P	2.09	4.4	9	7	110	504	8.1
Q	2.42	3.6	10	7	138	672	10.9
R	2.79	3.2	11	9	167	840	14.2

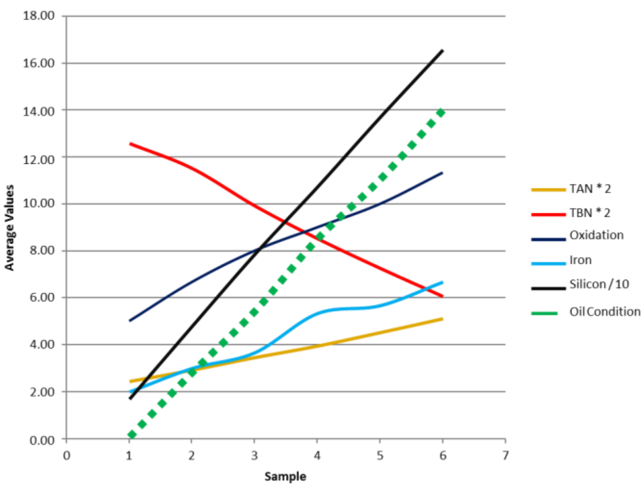

Figure 5: Table 1 data represented graphically

Figure 6 shows the oil analysis results from Table 1 (labelled A to R) plotted onto the output from the sensor (Oli Condition Column), with a very strong direct relationship between independent oil analysis and the sensor output.

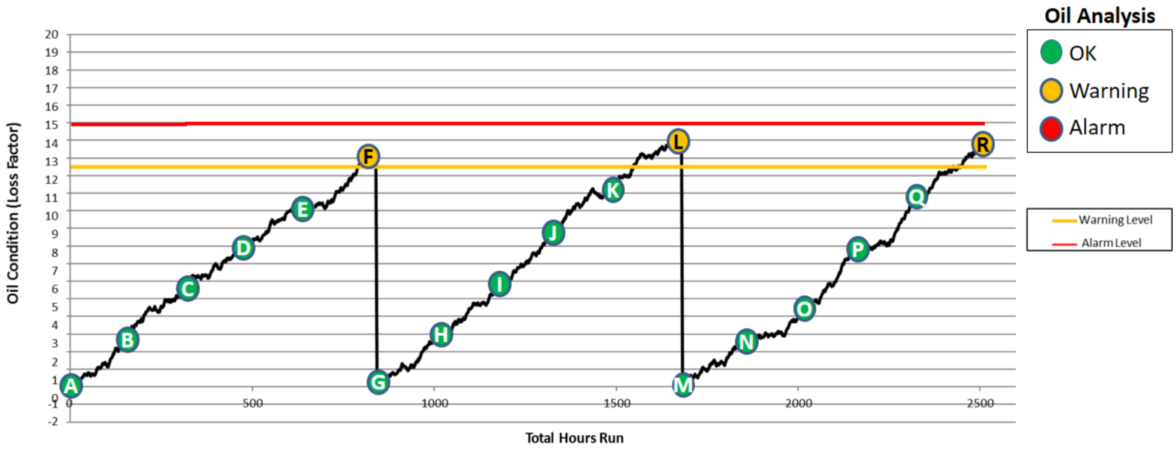

Figure 6: Oil Condition Vs Hours Run

Failure Mode Analysis

One of the primary benefits of real time oil condition monitoring is the ability to detect changes in the behaviour of oils and detect potential failure modes before failure occurs. The most common failure modes associated with oil that can be detected and prevented are as follows:

Oxidation
Oxidation of oil is a chemical reaction that occurs between an oil and oxygen. The rate of oxidation is accelerated by high temperatures, water, acids and other catalysts such as copper. Oxidation leads to an increase in an oil's viscosity and deposits, and can dramatically reduce the life of an oil as stated in the Arrhenius Rate Rule, in that once lubricants exceeded their base activation temperature, they will oxidize twice as fast for every 10 degrees C increase in temperature. As shown in Figure 7, the 2,000 oil samples gathered over a six month period show there is a direct correlation between the sensor readings and oxidation of the oil.

TAN and TBN Changes
The Total Acid Number (TAN) is a measurement of the acidity of the oil and the Total Base number is a measurement of the alkalinity of an oil. The TAN and TBN values are used to estimate the amount of additive depletion, acidic contamination and oxidation within an oil and therefore its ability to neutralise acidic materials and the remaining additive levels. Typically as an oil wears the TBN decreases and the TAN increases as show in Figure 7 the changes in these values directly correlates to the output from the sensor.

Particulate Contamination
Particle contamination is considered by many to be the single most important test used in oil analysis as an increase in particle contamination can quickly give way to a host of problems caused by abrasive wear, reduced combustion efficiency, increased viscosity or deposits. Particle contamination can arise from a number of different sources such as: wear debris (metal particles), environmental debris (dust, sand, etc), partially burned fuel or the combustion process (soot). As can be seen on Figure 8 (which shows wear debris), as the

particle count in an oil increases, there is a noticeable increase to the amplitude of the data. In addition, where soot is present and accumulating at an abnormal rate, the sensor will detect an abnormal rate of change and deterioration in the overall quality of the oil.

Fuel Dilution
Fuel dilution is often associated with leakage, fuel injector problems or impaired combustion efficiency, all of which pose a potential failure mode which cannot be prevented by a simple oil change. As can be seen in Figure 9, when fuel dilution occurs, the rate of change of the oil is noticeably reduced.

Water Dilution
Water is one of the most destructive contaminates to oil as it attacks additives, induces oxidation and interferes with oil film production. Water contamination severely effects the overall performance of an oil and is usually indicative of a larger problem which cannot be resolved by a simple oil change alone. Figure 10 shows a significant change in the overall quality of the oil as water dilution occurs with the overall quality fluctuations due to water boiling off as the engine warms up.

Coolant Contamination
Coolant can enter engine oil as a result of defective seals, blown head gaskets, cracked cylinder heads, corrosion damage or cavitation. Coolant contains Glycol, which if mixed with oil can cause soot to coagulate, increase wear rates, cold seizures and changes in viscosity as well as being highly corrosive to equipment. Coolant contamination can present itself in one of two ways. Firstly, it may present similarly to water as shown in Figure 10. Secondly, if the oil is continually running hot, then the water within the coolant will boil off and instead, the wear rate of the oil will increase due to the presence of the residual chemicals within the coolant, such as Sodium and Potassium which are common in many commercially available automotive coolants.

Poor Oil Change
With the demand to reduce equipment downtime and therefore speed up servicing, the possibility for oil changes to be done incorrectly in increased. If an oil is not correctly changed, a residual amount of poor quality oil remains, containing the contaminates associated with worn oil. In addition, the oil may not last the specified time interval until the next change. Figure 11 shows the effect of oil not being changed correctly with the figure failing to return to zero.

Incorrect Oil Type
It is not uncommon for the wrong oil to be used for the wrong purpose, which often results in the oil not performing as expected. As the Tan Delta sensor contains baseline oil data, the oil will not behave as expected as seen in Figure 12 where the oil condition is highly erratic and follows the oil temperature.

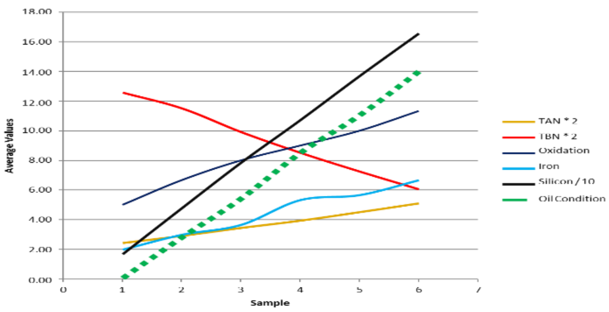

Figure 7 Oil Condition Vs measured properties

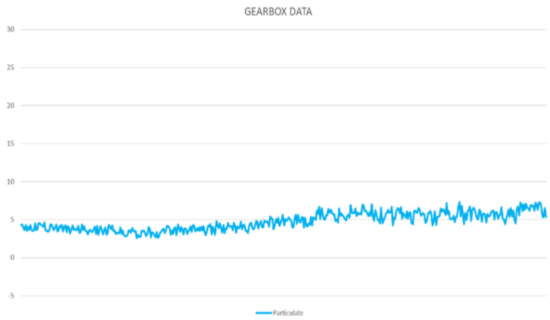

Figure 8: Particle Contamination

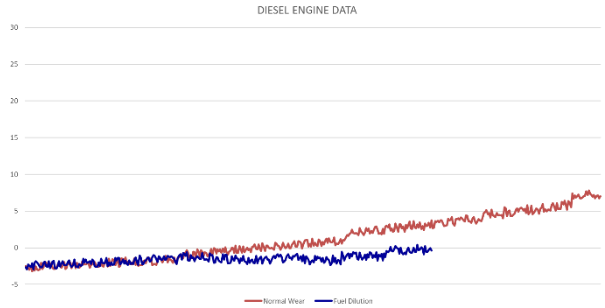

Figure 9: Normal Wear (red) & Fuel Dilution (blue)

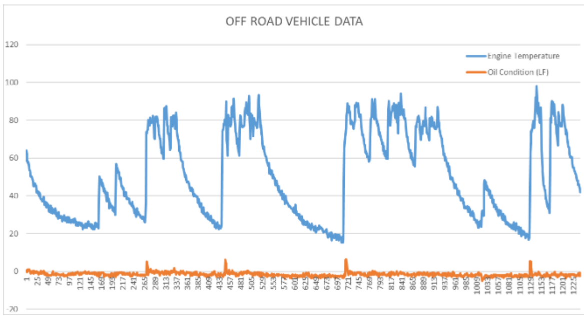

Figure 10: Gradual Water Ingress

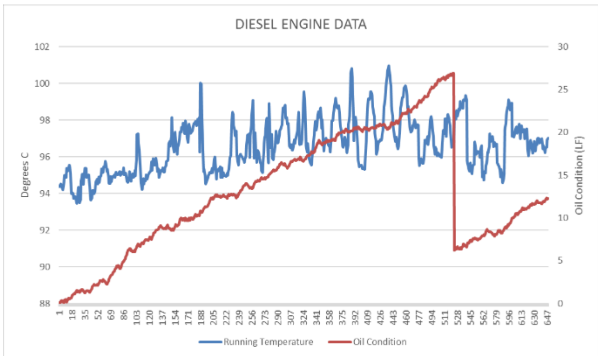

Figure 11: Incorrect Oil Change

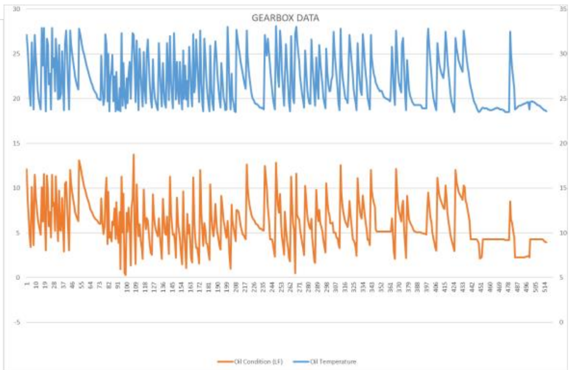

Figure 12: Incorrect Oil Type

Conclusion

Real time oil analysis offers the ability to adopt a proactive condition-based maintenance regime based on quantitative data as opposed to potentially less effective qualitative methods that result in over maintenance and increased equipment downtime. Utilising a proactive oil condition monitoring system increases equipment availability and reliability leading to increased productivity and equipment life cycles.

Research shows the importance of measuring the ratio of conductance and capacitance to accurately measure the level of change, and therefore damage, that has occurred in an oil. By measuring the relationship between conductance and capacitance, the system is able to deliver highly accurate figures relating to the oil's performance, giving an overall indication to the health and quality of any given oil.

Each type of failure displays its own unique signature, allowing for early identification of problems within an oils performance and subsequent early intervention to prevent future failures from occurring. Early intervention leads to considerable financial savings due to the avoidance of high failure costs due to equipment replacement and equipment downtime.