OIL LABORATORIES - PNG
A Dunlop PNG Company

A Guide to Oil Analysis

What it is and how you can get the most from it.

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INTRODUCTION

In carrying out their function lubricants are expected to carry out many tasks: these include; reducing friction and wear, transfer power, remove and control contaminant. Consequently, the analysis of used lubricants can reveal vital information about the continued serviceability of the lubricant and the condition of machinery the lubricant is used in. In some applications, an aged lubricant can start to cause damage to machinery rather than protect it. Whether this is due to excessive contamination or chemical degradation, oil analysis is the most effective means of detecting this common problem and optimising service intervals. Additionally, oil analysis is one of the most effective ways of identifying and trending wear.

To optimise the findings of a used oil analysis, the Oil laboratories – PNG Laboratory Information Management System or LIMS has been designed to be an early warning system that identifies the "signatures" of increased wear, and unwanted contaminants or lubricant degradation. This condition-monitoring service allows, you, *the system user,* to implement an effective preventative and predictive maintenance.

A well-managed used oil analysis program can provide the following benefits:

- Analyse the condition of your lubricant, allowing you to act before it stops lubricating and begins causing damage.
- Analyse the wear debris generated by your machinery, allowing you to detect 'abnormal' wear.
- Optimise the balance between maintenance costs and machine availability.
- Detect machine inefficiencies and faults, via the detection of 'tell-tale' contaminants.
- Reduce your lubricants spend via condition-based servicing.

Oil Laboratories - PNG has prepared this document as a guide only. It is intended to provide you with information to assist you achieve maximum benefit from the oil analysis service provided by Oil Laboratories - PNG.

This document has been prepared in good faith as a service to Oil Laboratories - PNG customers and should only be used as a reference please discuss any concerns or questions you may have with our staff.

If you have any questions that are not answered in this guide, please contact Oil Laboratories - PNG: Cell 7177 9495 or land-line +675 472 0711 email enquiries@oillabspng.com.pg.
Just give us a call to discuss how oil analysis can help you, we are passionate about oil analysis and always happy to chat.

Unfortunately used oil analysis will not detect all machine problems

Collecting oil samples for used oil analysis

Lubricant condition monitoring analysis uses an oil sample of 80 to 100ml to represent a system that may contain two litres to several thousands of litres of oil. The importance of taking a representative sample cannot be over emphasised. The first sample you take you will begin to develop a program that if carried out in a sustained manner can increase a systems operating time and substantially reduce its maintenance costs. However, this can only be achieved ***if every sample truly represents the oil*** in the system and this can only be achieved if every sample is taken correctly.

When you take a sample, it must fully represent the oil in the equipment, that sample must contain all the components of the oil that will come in contact with the bearings and working surfaces of the machine. It must contain the base oil, additives, wear metals and contaminants such as, dust and water. Contaminants and wear particles of just a few microns in size will remain suspended in the oil, but larger particles will quickly settle to the bottom of lubricated systems once equipment is shut down. This means that large wear particles, water and dust will not be in the sample you send to the lab unless samples are drawn correctly.

Samples must be collected into clean dry sample bottles, from active zones of the lubrication system at the normal operating temperature.

When taking samples in locations where contamination (dust or water) could enter the samples extra care must be taken to shield the sample tube and sample bottle.

Sampling from Circulating Systems

The best location for sampling circulating systems, is from the live zone before the filters, this is where contaminants and wear debris will be the most concentrated. Usually, this means sampling from fluid return lines or drain lines so long as they are live lines. For pressurised systems where oil drains back to a sump without being directed through a line draw from the pressure line immediately after the pump and before the filter.

Care should be taken when installing fixed sampling points on circulating systems. The ideal locations are at elbows rather than straight sections. This will help to ensure that the flow at the sample point is turbulent and that wear, and contaminant particles do not ‘drop out’ of suspension.

Sample point

Sample point at elbow, before filter

Sampling from Reservoirs

Sumps and Tanks

Always avoid sampling from dead zones of static tanks and reservoirs. In particular, sampling from the bottom of sumps must be avoided at all times as the wear debris and contaminants in the system will deposit there over time and a sample from this zone may represent current operating conditions. The best sample point should be at the mid-point between the surface of the oil and the floor of the tank/sump and away from walls.

Sampling from Splash, Slinger Ring and Flood Lubricated Components

Splash, slinger ring and flood-lubricated components are best sampled from the dip stick or fill points. Drain plugs are the last resort then only as a mid-point sample. *A **mid-point sample*** is one that is taken from the drain plug oil stream but only after a reasonable volume of oil has flowed out of the system. A similar caution applies to permanent valves in sumps the valve should be wiped clean and then flushed prior to sampling to ensure that any 'dead-leg' debris is excluded from the sample.

Vacuum Pump Sampling

When vacuum pump sampling the person taking the sample must follow the recommended procedure to the letter, to ensure representative samples are taken. The vacuum pump sampling system utilises as the name implies a vacuum pump and plastic tubing to draw samples via the dipstick tubes and filler plugs on gear boxes and transmissions.

NOTE - To prevent cross contamination a sample tube may only be used for one sample then must be discarded.

Hints for successful suction tube sampling

Hint 1: - Define the length of sample tube require to take a mid-point sample from the top of the dipstick and mark this point with a permanent marker then cut the tube from the roll 500 mm from that point. This should be done for each type for machine to be sampled by suction tube sampling.

Hint 2: - Plastic tubing can be difficult to control once it enters a system via a filler plug. To prevent the tube end drawing oil from the sides or bottom of systems it may be necessary to use a custom-made dipstick, as shown in the following photos. The sampling tube slides down the inside of a hollow dipstick to the depth mark on the sample tube then the sample extracted. The use of the dipstick sampling technique removes the possibility of the sampling tube being fed into the path of meshing gear teeth, this is very messy when it happens, and gives the sampler a huge fright.

Custom made Dipstick Sampler

Dipstick sample unit installed on a large gearbox

The procedure to be used when sampling with a vacuum pump/tube system

- Loosen the top knurled nut then insert about 2.5cm of the cut to length plastic tubing into the top of the pump then tighten the nut, sealing the tube.
- Screw a sample bottle onto the pump over the protruding tubing. Assemble firmly to ensure a good seal.
- Push the pump piston completely forward and insert the free end of the sample tubing into the compartment to be sampled, if via dipstick to the depth mark on the tube
- Holding the bottle and pump assembly in one hand, draw the piston backwards with a slow, steady stroke. Repeat as necessary.
- Always be sure to draw sufficient of the sample to fill the bottle to 80% level. This will ensure that there is adequate sample to complete all tests and will ensure adequate ullage to allow sample agitation by the laboratory.
- Remove tubing from the oil bath.
- Remove the bottle from the pump and screw the cap on firmly.
- Replace the compartment plug or dipstick
- Dispose of sample tube as tubes must never be reused, as reuse will cause cross contamination of samples.

Note - It is very important that the pump/bottle assembly is kept upright when in use to prevent oil entering the pump. Should oil enter the pump, disassemble it immediately and flush thoroughly with white spirit or kerosene. Dry before reassembling. **DO NOT FLUSH PUMP WITH PETROL OR DEGREASING FLUID.**

It is important that the chosen

A vacuum pump sampler in use

Frequency of Sampling

The more frequently (to a point) oil samples are submitted for analysis the more accurate will be the trending and the likelihood of successfully detecting problems before serious damage occurs. However, frequent sampling can be expensive so a compromise must be reached, the following is a guide that will assist you to decide on the optimum frequency for each class of samples.

The frequency of sampling for any particular machine depends on a range of variables:

- **How important is the machine?** For those machines that are vital to productivity and the risk of unplanned down time must be reduced. Usually, this means sampling more frequently in order to increase the probability of early detection of potential failures. In general, the more important the machine, the more frequently it requires sampling.
- **What is the cost or time to repair or replace**? In some operations there are machines that are extremely costly to repair or replace, others that the lead time for a replacement unit is extremely long additionally the cost of holding a spare is prohibitive. In these cases, a high oil analysis frequency, so as to monitor oil and machine condition, is fully justified.
- **Operating Temperature** – As the lubricant operating temperatures increases beyond 65°C, the rate of oxidation in the oil increases rapidly. Equipment with elevated operating temperatures must be sampled and the oil analysed more frequently than similar equipment operating at lower temperatures.
- **Contaminated environments** – The sampling frequency for machines, operating in environments where the probability of contamination is elevated, should be higher than the frequency for similar machines operating in clean environments.
- **Identified problem** – Once a problem has been identified in a lubricant or machine that is not critical then the sampling frequency must be reduced to confirm the problem and to establish the rate of wear/failure/degradation so as to allow a planned change.
- **Machine Age** – Machinery should be sampled more frequently at the start of life, after major maintenance and at the end of their expected service life. In the initial period of operation, frequent sampling allows a database to be established in a relatively short period of time. Once a steady state operating condition is established, the frequency of sampling can be reduced, but only if operating conditions are to remain constant. If abnormal behaviour is detected, the frequency of sampling should be increased until the machine's condition is brought under control.
- **Safety Consideration** – An increased sampling rate may need to be increased for machinery where unexpected failure could create a safety or environmental hazard.

The table following provides guidelines for sampling frequencies that are suitable at the beginning of programs. The frequencies should be increased or decreased to account for the factors listed above.

Machine or System Type	Oil Sampling Frequency
Diesel engines – mobile	250 hours (20,000km)
Diesel engines – stationary	500 hours
Diesel engines – mobile (extended oil drain)	500 hours (40,000Km)
Transmissions	1000 hours (80,000km)
Differentials and Final Drives	1000 hours (80,000km)
Hydraulics – mobile equipment	1000 hours (80,000km)
Radiators – Engine Coolants	500 hours (80,000km)
Gas Turbines	500 hours
Steam Turbines	500 hours
Air & Gas Compressors	500 hours (if on a mine drill 250hrs)
Chillers (Refrigeration)	500 hours
Gear Boxes – high speed	500 hours
Gear Boxes – low speed	1000 hours
Bearings – journal and rolling element	500 hours

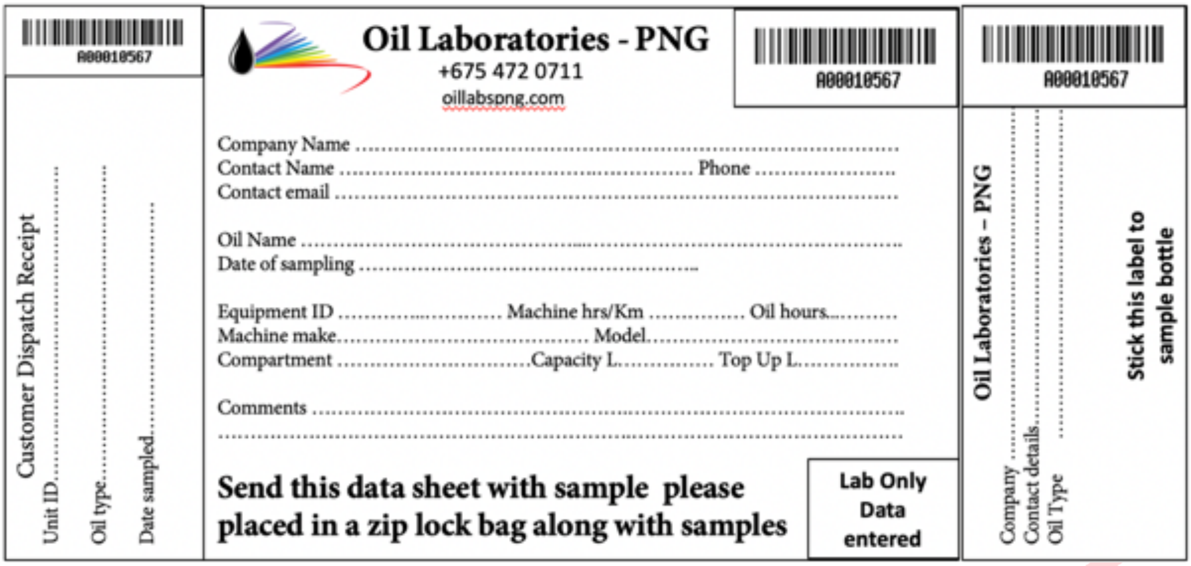
Suggested sampling frequencies

Sample Identification

In order for our laboratory to provide you with correct analysis and diagnostics the samples you send us must be correctly identified. Laboratories – PNG use a **unique Sample number and bar code** for each sample. This allows us to track the sample through the lab and assign analysis results to the correct sample.

To ensure we can trend results it is vital that you always use the same unique machine identification for each sample from that machine, i.e. HT240 engine. This will allow us to file the current analysis result in date sequence with previous analysis results from that machine and compartment. This allows us to build an analysis history for that machine and compartment that can be trended, this may allow us to identify pending problems.

This is an example of a sample ID label; this must be **fully** completed for each sample you submit for analysis.



A00010567

Customer Dispatch Receipt

Unit ID.............................

Oil type.............................

Date sampled.............................

Oil Laboratories - PNG
+675 472 0711
oillabspng.com

A00010567

Company Name ....
Contact Name .... Phone ....
Contact email ....

Oil Name ....
Date of sampling ....

Equipment ID .... Machine hrs/Km .... Oil hours..........
Machine make.. Model.......................................
Compartment ....Capacity L............... Top Up L................

Comments ....
....

Send this data sheet with sample please placed in a zip lock bag along with samples

Lab Only Data entered

A00010567

Oil Laboratories – PNG

Company ....
Contact details..............................
Oil Type ....

Stick this label to sample bottle

Company name –	The name of the company submitting the samples
Contact Name -	**This MUST be included in case we need to contact you**
Phone Number-	**This MUST be included in case we need to contact you**
E-mail Address-	**This MUST be included to allow us to send you the analysis results**
Oil Name–	**The full name is required** including the manufacturer, product name and viscosity grade, i.e. Total Rubia Optima 1100 15w-40
Date of sampling-	The date when the sample was actually taken
Equipment ID –	This is often the Fleet Number or Registration Number but must be the same for every sample from that unit.
Equipment Hrs/kms-	This Info assists with problem diagnosis
Oil Hours-	This Info assists with problem diagnosis
Equipment Make-	This Info assists with problem diagnosis
Equipment Model-	This Info assists with problem diagnosis
Compartment-	This is vital data as often each compartment uses a different oil
Oil Capacity Litres-	This Info assists with problem diagnosis
Top-Up Litres-	This Info assists with problem diagnosis
Comments-	Optional but allows you to include any information that you consider we need to know about the machine and it condition.

Lubricant Degradation and Contamination Related Analysis

The following analyses allow us to assess if the lubricant is degrading or is contaminated.

Viscosity

Viscosity is a measure of an oil's resistance to flow at a particular temperature. Viscosity is usually reported in centistokes (cSt). One centistoke is approximately the viscosity of water at 20°C.

The viscosity of a lubricant varies with both temperature and pressure, but for oil analysis purposes we only consider the effect of temperature. Viscosity is measured at either 40°C and 100°C the temperature selected is the one that most closely aligns with the normal operating temperature.

The viscosity of oils will often change during service due to degradation and contamination. The impact is either a thickening or thinning of the oil. A further reason for a change in viscosity is the machine has been topped up with the incorrect oil.

Duel bath Viscometer 40°C and 100°C

When there has been a significant change in viscosity the following situations are possible:

Effect	Cause	Reason
Increases in Viscosity	**Oxidation**	The products of oxidation are complex but the recognisable effect on the oil is typically an increase in viscosity and an increase in the acid content of the oil. The thickening is the result of larger molecules being produced as the oil oxidises. These larger molecules increase the internal resistance of the oil as a result its resistance to flow is increased.
	Soot	When a diesel engine oil's ability to disperse soot depletes, particles of soot which are not 'captured' by dispersants in the oil will have a natural tendency to 'join' together to form larger conglomerations. The physical size of the soot conglomerations act to slow the flow of the lubricant and increase the lubricant viscosity.
	Topped up with a different oil	If an incorrect oil grade is used for top-up, the viscosity of the mixture will change.
	Water	In applications where there are high shear stresses (engines), free water is likely to be emulsified. As well as promoting corrosion, the rate of viscosity increase is illustrated in the following examples: 2% water contamination will result in a 5% viscosity increase 6% water contamination will result in a 15% viscosity increase.
Decrease in Viscosity	**Fuel**	Fuel contamination is a possible reason for low viscosity. The first check for fuel dilution is an FTIR scan.
	Topped up with a different oil	If an incorrect oil grade is used for top-up, the viscosity of the mixture will change.
	Permanent Shear Loss	In multi-grade mineral oils Viscosity Index Improvers are used to provide multi-grade performance. At low temperatures the VI Improver acts in a manner to give minimum resistance to oil flow. As temperatures increase, they thicken to offer greater resistance to oil flow. Under high shear stress conditions these additives may be destroyed, and multi-grade performance compromised.

Detection

Viscosity is usually measured using a tube viscometer, with the results being reported in centistokes (cSt) at 40°C or 100°C. The viscosity of engine oils is typically tested at 100°C as this is close to the engine operating temperature and one of the standard measurement temperature engine oils are tested at. Industrial oils such a gear, hydraulic, turbine and compressor oils are tested at 40°C.
An alarm Level of +/ - 20% from the specified reference viscosity is usually used to trigger alarms.

For machines such as turbines, extrusion plants, steel mills and paper mills which often have circulating systems which contain thousands of litres of oil the alarm levels associated with viscosity is usually significantly lower. An alarm level of +/– 10% is usually applied.

Water

Water is often found in lubricating oils, it can be dissolved, emulsified or as free water. Free water is of greatest concern as the impact it has on machine components such as bearings can start long before the oil takes on a cloudy appearance. The amount of water in oils will depend on the oil type, operating conditions and atmospheric condition such as humidity. Washdown, rain and incorrect lubricant storage have been found to be the greatest contributors to water in lubricants.
Ideally there should be no free water in the system oil, however some oils have been specifically designed to be able to continue to provide adequate lubrication while carrying water in the form of a stable water/oil emulsion. This is the case for some stern tube oils.

Water that does enter lubricated compartments is usually the result of condensation, leaks or improper storage and handling practices.

Is contamination from storage really a problem?
A drum of oil ready for use and transfer containers alongside

Condensation can be a significant factor when machinery operates in a ‘stop-start’ manner in humid conditions. As it cools humid air is drawing into the machine when water in the air can condense out. As most industrial equipment operates well below the boiling point of water this can be a major problem. There are a number of breathers available on the market nowadays that will prevent humidity entering a machine compartment, i.e. Donaldson’s “TRAP” breathers.

One of the biggest causes of water contamination is incorrect storage and poor transfer of lubricants. Accumulation of water in bulk tanks can be prevented by routine water drains and the installation of tank breathers

In engines water contamination is mainly due to cooling system leaks, seal failures or a leaking cylinder head gasket. In the case of slow small leaks, the water evaporates. The leaks in these cases are detected by the corrosion inhibitor showing up in the metal’s analysis or as Glycol, if used, by the FTIR.

Water contamination of lubricants has a significant impact on wear rates. In those cases where water is present either free or as an emulsion, a significant reduction in service life of mechanical components can be expected.

When an oil is heavily contaminated with water an increase in viscosity can be expected for example 2% of water can increase the oil viscosity by 5%, while 5% of water can cause a viscosity increase of up to 13%.

Detection

Often water will be observed in the sample when it is received during the registration process triggering action. More often water will be detected by the FTIR and if glycol is used in the coolant this will also be detected during the FTIR analysis.

At Oil Laboratories - PNG all samples are subjected to a routine crackle test; this is simple yes or no test that if positive confirms the FTIR result.

If required further testing is requested, this would be done via the Karl Fischer method at an external lab. This will impact on the cost analysis.

Alarm Levels - > 0.1% moisture or 1000 ppm for most equipment.

It should be noted that in equipment operating at high temperatures such as engines, water leaks will usually be identified via the detection of coolant additives in oil samples, as the water entering the lubricant may evaporate under normal machine operation conditions. Only with severe leaks will free water be present in the oil.

FUEL DILUTION

Fuel dilution is in fact oil dilution cause by fuel entering the lubricant. This results in the lubricant losing viscosity, that in turn means that the oil films formed are weaker and less capable of withstanding high loads that can occur in the engine, such as the rod bearings and crankshaft areas. A further problem is that the gases generated in sump can become explosive and may result in a crankcase explosion.

Fuel dilution is usually caused by leaking fuel lines, dribbling injectors, defective spray patterns, worn injector pump, worn rings and incorrect injector timing.

Detection

There are two first indicators of fuel dilution low viscosity and the FTIR will detect the presence of fuel in the sample. Further testing can be don but usually a positive for fuel in the FTIT result coupled with a low viscosity is sufficient confirmation. To recommend and oil change and investigation.
Alarm Levels >2% fuel dilution.

Soot Index

Soot Index is a measure of the partially burnt solid and semi-solid products of fuel and oil present in a used engine oil such as carbon (soot particles) and incompletely burnt lubricating oil.

Soot is produced when fuel such as diesel is incompletely burnt producing carbon rather than carbon dioxide or carbon monoxide. While most soot will exit the engine with exhaust gases as ‘particulates’, some bypass the compression rings and enter the lubricating oil where it should be dispersed by additives in the oil. The dispersants are polar compounds that attach to soot particles in order to prevent particle conglomeration.

Engine design and condition and operating conditions such as work rate and atmospheric conditions can affect the rate of soot loading of engine oils. For example, poor injection spray pattern, delayed injection timing, poor combustion chamber swirl patterns, poor ring seal, restricted intake air availability, insufficient turbo boost for altitude, can all lead to high soot loading. Generally, the rate of soot accumulation in an engine oil will increase predicably with operational hours or distance travelled providing that operating conditions are constant.

As the ability of an engine oil to disperse soot depletes it becomes more probable that soot amalgamations will form. These will have the unwanted effect of increasing the oils viscosity and contributing to abrasion of wear interfaces in the engine. These amalgamated particles will also have a tendency to fall out of suspension due to their increased density and contribute to engine deposits, sludges and blockages. Because of this it is essential that the soot levels and dispersancy performance be monitored.

Detection
The Soot Index is measured by the FTIR, with the result correlated against ASTM E2412. The Soot level in an oil, as reported by Oil Laboratories - PNG, is percent weight of soot held in the oil.

Alarm levels for soot index will vary depending on the type of oil in used (API rating), the engine type, the duty cycle and the altitude the engine is working at.

When high soot levels are determined in an analysis the next item to examine is the viscosity of the oil, if the viscosity has increased to a level beyond the OEM's recommendation, then the soot level is impacting the oils performance. The oil must be changed, and the source of the increased soot level found.

Eralytics FTIR

Total Based Number (TBN) or Base Number (BN)

The Total Based Number is a measure of a lubricants' ability to neutralise acidic combustion products, these are formed by the reaction of air with the components of the fuel during combustion. These acidic products can be, sulphurous acid from sulphur and various oxide form of nitrogen when these mix with atmospheric water produce acidic compounds that can react with the metal in an engine, particle in the piston ring pack area. The TBN or BN is a measure of the remaining alkaline reserve in an engine oil. This alkaline reserve is one of the critical factors for extended oil life.

Engine oils contain a range of additives each with specific function. As the oil neutralises the acidic by-products of combustion these additives are 'depleted', and the TBN value falls. If new oil is added by way of top up the TBN will increase.

Low TBN can also be associated with poor combustion, excessive blow-by, low oil make-up, or dilution with an incorrect low TBN oil.

Detection

The gold standard for determining TBN is via titration. There are several standard methods available ASTM D2896 and D 4739 the most common method used for new oils is ASTM D2896. While ASTM D 4739 is often used for used engine oils as it does not react with wear metals that may be present in the oil.

For routine oil analysis TBN is determined using FTIR with the results produced aligning with ASTM D2896.

Alarm Levels will be determined for the type of engine oil in use and the sulphur content of the fuel the results are expressed in mg KOH/g. For a 40 TBN oil a warning should be issued at >20 TBN while an 11 to 15 TBN oil a warning would be issued at >7.

Oxidation Nitration and Total Acid Number (TAN)

These three analyses are related in that the by-products of oxidation and nitration will cause, amongst other things, an increase in the acidity of the oil. The Total Acid Number is a measure of the acidity that gives an indication of the deterioration of an oil in service mainly due to oxidation and nitration.

The by-products of oxidation and nitration are complex long chain molecules that can contribute to unwanted problems such as an increase in viscosity due to large molecules; thickening of the oil and the formation of sludge or varnishing.

The TAN of an oil will increase during service. For the majority of an oil's service life the effects of aging will be controlled by means of additives such as anti-oxidant additives allowing the TAN to remain relatively steady. As these additives deplete the TAN will begin to increase and will do so at an exponential rate as the products of oxidation act as a catalyst for further oxidation.

Increased acidity will contribute to corrosion related wear. In particular, metal that are often used in plain bearings and overlay material such as copper, tin and lead are likely to reveal the first signs of corrosion. Elevated operating temperature and aeration will accelerate oxidation. Contaminants and wear metals can act in as a catalyst increasing oxidation and oil deterioration.

Nitration related problems appear to be confined to natural gas and occasionally LPG engines where the crankcase ventilation is inadequate, there is excessive blow-by, faulty or too lean a fuel/air mixture.

Detection

The FTIR is used to determine oxidation, nitration and TAN correlating to ASTM D664. If the TAN levels are of concern further testing, such as the titration method ASTM D974 or ASTM D664).

It is difficult to set an absolute alarm level in the case of oxidation. What is important is the rate of change, note the absolute value. Therefore, a trend analysis should be use for TAN. A warning should be given when acidity increases significantly or sharply.

Oxidation and nitration raise an alarm if there is an increase of 25 absorbance units per cm above the previous sample

Appearance

Appearance is the visual comparison of fresh oils and used oils against a set of reference photos. The appearance of an oil provides a number of discrete indicators of the oils condition.

Determination

To establish this evaluation a series of oils are photographed under identical conditions the physical condition of the oil is measured, these photographs are then assembled in to a catalogue to oil samples to ensure consistent naming set colour terms are used these include, clear and bright, milky, and free from suspended solids.

Metals Analysis

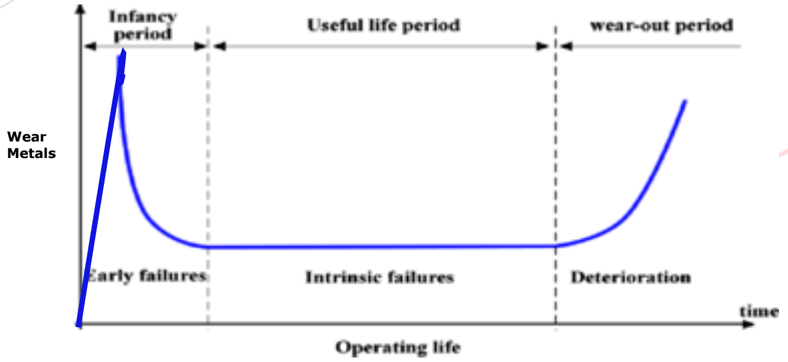
The “Metals” analysis tells us about three areas,

(1) The condition of the additive pack in the oil, is the additive pack correct for that oil and is the additive pack depleting.
(2) Is the oil being contaminated by solids
(3) Is the machine wearing if so, what components are wearing and at what rate?

As all machines, no matter how well they are lubricated or the precision to which they are manufactured will generate some microscopic wear particles during the course of their operating lives. This is due to the deformation and removal of surface material, asperities, on interacting components such as gears, pistons, cylinders, cams and bearings.

Aside from point 1 and 2 above the primary purposes of a used oil analysis program is to monitor the rate of generation and metallic composition of wear debris.

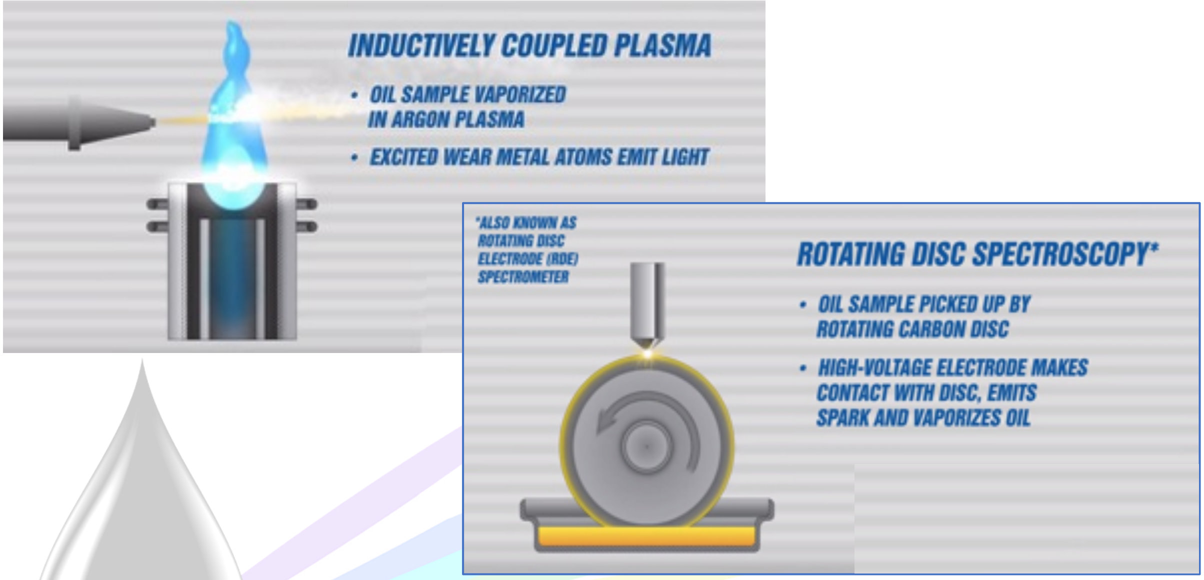
When a machine is initially commissioned new or after a major overhauled there will be a running-in period during which the surface roughness of lubricated surfaces caused by manufacturing machining processes is removed. During this period the size of wear particles can be relatively large, with the rate of wear particle generation usually will rapidly increase to a peak and then drop back to a low-level steady state. After a machine has been through the running-in period it will usually enter a long period of normal wear. During normal wear the particles generated will typically be up to around 10 microns in size and are predominantly classified as rubbing wear.



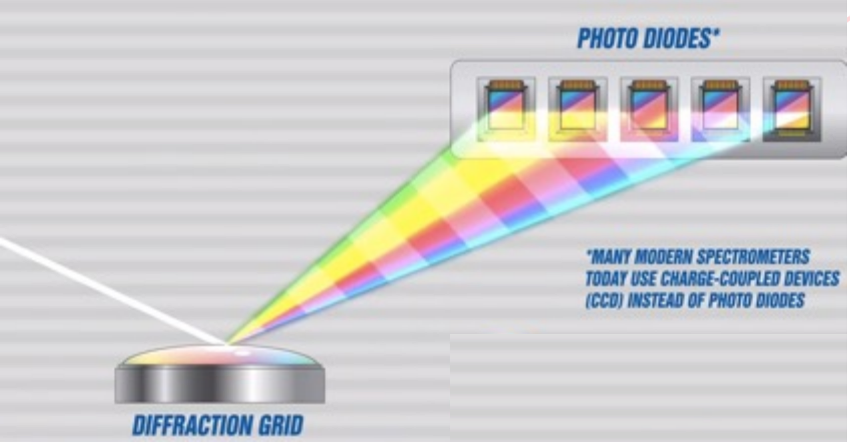
Normal wear should continue until either operating condition changes due to such events as lubricant contamination, misalignment, overloading, shock loading or until the machine begins to wear out due to fatigue. Conditions such as these will cause abnormal wear and generate larger wear particles that may be up to and beyond 50 microns in size, and this can be a problem as these larger particles are difficult to sample and analyse.

Spectral analysis

There are two main techniques used by oil laboratories to analyse metals, though many others exist. These are Inductively Coupled Plasma (ICP) and Rotrode Disc Spectrometry (RDS). Each has its advantages and disadvantages.



The key differences are the way the metals are excited either a plasma or and electric spark, but after this the method of analysis is near identical.



These spectrographic techniques allow the elemental identification and the concentration of wear particles, contaminants, and additives in the oil.

The table below provides examples of possible alloy composition of some common components.

	ELEMENTS (%)								
COMPONENTS	**Fe**	**Cu**	**Zn**	**Pb**	**Sn**	**Ni**	**Cr**	**Mo**	**Mn**
Bearing Cages		60.5	39.4	0.1					
Rolling Element Bearings	96.8						1.36		0.52
Gears	94.72					3.4	0.85	0.17	0.45
Gear Selectors		87.0	2.0	3.5	7.5	1.0			
Shafts	95.74					1.55	1.15	0.27	0.57
Gearbox Casing	93.37								0.3

Spectrographic analysis allows the monitoring wear metals, additives and contaminants in an oil however to obtain a full understanding as to the oil condition and the source and severity of problems complimentary test are required. These include Ferrous count and Particle Counting.

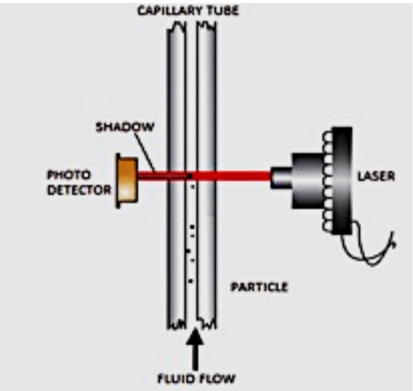
Ferrous Count

The Ferrous count unit uses an electromagnetic technique where by samples are placed in close proximity to an electromagnet and the resultant change in the magnetic field between the magnet and the sample is measured. The electromagnetic response is directly related to the concentration of Ferrous material in the oil sample, the result is reported in PPM of Iron.

The value of a Ferrocount Iron result comes to the fore when it is compared to the spectrograph result. The Ferrocount result is for all the magnetics (iron) in the oil, large and small particles. Whereas the Spectrographic result is, usually, only for the very fine iron in the sample (normal wear). If both results are similar, then the iron is attributed to fine or normal wear and is usually of little concern. However, if the Ferrocount result is considerably higher than the spectrographic result then there is large particle wear in progress, and this can lead to catastrophic breakdowns

Particle Size Distribution

Particle Size Distribution is the term used to describe the size and quantity of particles present in lubricating oils and hydraulic fluids. Most particle counting methods do not differentiate between different particle types with respect to shape, colour, origin, composition and hardness.



Depending on the method employed, results can vary considerably. Because of this it is important that the chosen method is understood and applied consistently.

There are three common methods:

Manual Method – This method is the most laborious way to establish Particle Size Distribution. It can also be one of the best methods provided that the operator is highly skilled in the method.

Optical Light Obscuration Method the technique used by laser particle counters – This procedure is the most common in the lubricant condition monitoring industry and the one used by Oil Laboratories – PNG.

Filter Mesh Obscuration Method – This method measures the rise in pressure differential across a set of mesh type filters that are fully characterised with respect to pore size and number. These are mainly as in line systems on large hydraulic system that are sold by Pall Filtration and Rockwell Automation.

Particle Size Distribution testing is typically undertaken in order to establish contamination levels of lubricating oils and hydraulic fluids or to attempt to trend wear behaviour by relating changes in Particle Size Distribution results to changes in wear behaviour or external contamination.

It is widely recognised that particulate contamination is a major cause of premature wear via mechanisms such as abrasive wear, fatigue and erosion. The severity of these wear conditions depends not only on the Particle Size Distribution result, but also on the physical characteristics of the particles, particularly their hardness, and their size relative to clearances and oil film thickness in different machinery.

No matter what the method used, it is critical that the limitations and sensitivities of the counting method be understood. For example, the light obscuration method is the most commonly employed method of particle counting because it is reliable and cost effective. Nonetheless, people who use this method must be aware of limitations associated with issues such as air entrapment and water contamination that can distort results.

Particulate Contamination

Oil analysis has a major advantage over all other forms of condition monitoring, this is its ability to identify and monitor levels of contamination within the lubricant. One of the main issues associated with oil contamination is the ingress of hard particles, these have potential to accelerate wear. The extent of the wear caused by this type of contaminant is related to both the size of the particles and their hardness – the harder the particles the greater the potential for wear.

Some common causes of contamination are listed below:

- Inadequate or blocked filters
- Filters running in bypass
- Air leaks into clear air side of induction systems
- Dirty oil dispensing equipment

- Poor lubricant storage practices
- Installation/assembly/maintenance
- Incorrectly fitted or missing oil filler cap
- Ineffective reservoir breather
- Dirty sampling equipment

The composition of air borne dust from different mining and quarrying operations can vary significantly. For some operations the composition can vary depending on the area being mined, for example, mining over burden versus rich ore.

INDUSTRY	CONTAMINATION
Mining	Dust, ore, water
Process Plant	Process material, dust, water, chemicals
Quarrying	Rock dust, water
Component Manufacture	Cutting fluids, dust, swarf, corrosion inhibitors
Steel Making	Mill scale, dust, water, iron ore, process solids
Ceramic	Clay, dust, water

Common types of particulate contamination

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CONTAMINANT	ELEMENTS DETECTED
Gypsum	Calcium, Sulphur
Clay	Silica, Aluminium, Calcium, Iron
Stone Dust	Silicon, Calcium, Magnesium, Aluminium, Sodium

Elements indicating contaminant types

Warning levels for wear and other important oil parameters.

It is important to note that 'Normal' wear metal levels may vary significantly for different types of equipment, differing duty cycles and differing operating conditions. The warning levels Oil Laboratories – PNG offer are based on our experience and knowledge of machines operating in similar conditions and should serve as a guide only. The true value of oil analysis is in establishing a wear trend for each piece of machinery which will be specific to that item of machinery, its duty cycle, and its operating environment. Hence, the values in initial reports may be considered as a starting point, from which an iterative process can be applied in order to establish site / machine specific values.

If you are concerned with the diagnostics of Oil Laboratories – PNG provided to you with, you should immediately ask us why we came to that conclusion and if you wish seek advice on the interpretation of wear metal trends from the equipment manufacturer (OEM).

It is also important to remember that the absolute values of wear metals will vary according to a range of factors such as:

Oil drain intervals – Oil Drain Interval is the period of time that an oil is in service measured in either hours or distance travelled. Machinery that is operating to extended oil drain intervals are expected to reveal higher absolute wear values at the end of each service period than machinery operating to shorter oil drain intervals. Hence, the rate of wear is often a more valuable parameter than the absolute wear level. Generally, the wear rate of machinery should be linear. Therefore, the concentration of metals in an oil will increase with increasing oil hours or distance travelled. An acceleration of wear should be treated as a potential serious problem.

Oil top-up rate – Oils will always hold some micron sized wear debris and soot in suspension. As oil is consumed during operation, combustion or leaks, so are the contained contaminants and wear debris. The resultant of this oil consumption and subsequent top-up is the" dilution of the oil" and a reduction in the concentration of contaminants and wear debris in the oil. As a result, a wear problem can be 'hidden' by an increasing rate of oil consumption and top-up.

Where do the Wear Metals come from?

Sources of metals in Engines

WEAR METALS	POTENTIAL SOURCE OF METALIC WEAR
Fe (Iron)	Cylinder walls/liners, crank and camshafts, valve guides, rockers, rings, bearings, gears, shafts.
Pb (Lead)	Generally used as an alloy (Babbitt, Copper-Lead) in bearings. Big-end and crankshaft bearings, thrust washers.
Cu (Copper)	Usually alloyed in the form of brass, bronze or as sintered copper-lead. Big-end and crankshaft bearings, bushings, oil coolers and cooler core tubes, or copper-type anti-seize compounds, thrust wasters. Fuel transfer pump, governor bushings and wrist pin bushings.
Cr (Chromium)	Commonly used as plating for cylinder liners and piston rings, valve stems. Chromate treated cooling systems.
Si (Silicon)	Dirt. Highly abrasive. Sources include inadequately filtered air due to cracked induction piping or hoses, defective or incorrectly fitted air filters and gaskets. Dirty oil filling or sampling equipment. Incorrectly fitted or missing oil filler cap. Ineffective reservoir breather. May also be Silicone-based gasket/joining material. Also, anti-foam additive.
Na (Sodium)	Coolant leakage, water or using the same container for coolant as for oil.
Al (Aluminium)	Pistons (scuffing, scoring or burning). Aluminium bearings. Alloy housing wear. In turbo-chargers it can be housing or rotor wear. May also be associated with high Si levels in the form of clay or stone dust contamination.
Sn (Tin)	Top bearing or slide bearing. Camshaft bushings.

Note:

1. Upper engine wear is characterised by high levels of Fe, Cr, Al and Si.
2. Lower engine wear is characterised by an increase in Pb, Sn and Cu.

Sources of metals gear boxes and transmissions

WEAR METAL	POTENTIAL SOURCE OF METALIC WEAR
Iron	Gear teeth, splines, bearings, shafts. Brake drums (wet brake transmission fluids)
Lead	Bearings
Copper	Bearings, thrust washers (final drive and diffs.) Transmissions - Transmission discs, powershift transmission, steering clutch discs and gear bushings in direct drive transmissions Oil tubes and pump bushings in track type tractor final drives
Aluminium	Transmissions - Pump housing, torque converter and impeller or turbine Oil pump drive gear Dirt (see Silicon)
Silicon	Brake linings - transmissions Dirt - contamination from external sources (check condition of breathers) or contamination through poor housekeeping. Increases in levels of Si may be accompanied by increases in Al which is an additional element in clay and rock dust

Sources of metals in hydraulic systems

WEAR METAL	POTENTIAL SOURCE OF METALIC WEAR
Iron	Pumps, valves, oil reservoirs.
Lead	Pump bearings, solder in coil coolers.
Copper	Pump bearings, oil return lines, oil coolers.
Silicon	Dirt - highly abrasive. May come from: - oil filling - built-in dirt from construction - breather in reservoir - return line filter - cylinder ram seals - pump Silicon-based joining/seal fluids.

Lubricant physical condition problems

Diesel Engines

Additives play a vital role in all diesel engine oils these include:

- Alkaline reserves capable of neutralising acidic products of combustion to combat acidic wear. This is partially important in PNG where high sulphur diesel is used.
- The detergents used to control the formation of deposits and piston deposits that may cause ring sticking must be thermally stable.
- Dispersants capable of suspending combustion soot to prevent the formation of deposits in crankcase oils ways and sump. This is a vital need now that a large number of engines use EGR systems to manage emissions.
- Anti-oxidants and anti-coagulant dispersants to control oil thickening promoted by soot and/or oil oxidation.
- Anti-wear additives.
- Anti-rust and anti-corrosion additives.
- Anti-foam agents to break up any foams caused by the agitation of the oil.

The most common problems encountered in diesel engines are:

- Cooling water ingress
- Fuel dilution

Additionally, the following comments should be noted with respect to **increasing soot levels:**

- The viscosity at 100°C is also increasing,
- wear rates maybe increasing,
- filter blockage is common
- extensive deposits (varnish) are noted inside the engine

TEST	POSSIBLE CAUSES
VISCOSITY @ 100^{0}C **Increase or decrease**	Increase in Viscosity: • Due to high level of contaminants, oxidised oils, high soot, excessive blow-by. • Addition of higher viscosity oil. • Presence of glycol. Decrease in Viscosity: • Fuel dilution • Dilution with a lower viscosity oil.

FUEL DILUTION	Leaking fuel lines; dribbling injectors; leaking transfer pump; worn injection pump; defective spray pattern.
WATER	• Cooling system leak; • condensation from cold crankcase conditions; • Improperly closed filling holes, • In correct storage or handling of lubricant.
SOOT	• Poor combustion; • Excessive blow-by.
DISPERSANCY	• Poor dispersancy is an indication that the additives in the oil are no longer capable of holding the soot in suspension, i.e. they have been occupied. • How quickly an oil will use up its additive pack is related to engine health, degree of blow-by, fuel injection rates, excess fuelling, etc.
TBN – Total Base Number	Low TBN is a result of the depletion of the alkaline additives in the oil due to acid formation during combustion, a result of using high sulphur fuel.

Industrial Gearboxes and Transmissions

The most common problems found in gearboxes and transmissions is water ingress and dust contamination, the next is heat-induced oxidation. Another common problem is the incorrect grade lubricant being used during the oil change or for top-up.

Contamination by air borne dust is probably the most common form of contamination in process plants. This contamination is most often the result of poor lubricant handling practices and the selection of and maintenance of system the breathers.

The use of an oil with too high a viscosity will have a major impact on the operation of these systems. An increased viscosity will contribute to power losses and higher bulk oil temperatures. The higher oil temperature will accelerate oil oxidation which, in turn, will contribute to increased viscosity.

TEST	POSSIBLE CAUSES
VISCOSITY @ 40^{0}C	Higher Viscosity: • Oxidation, • Emulsified water, • Contamination with a higher viscosity lubricant. Lower Viscosity: • Contamination with a lower viscosity lubricant.
WATER	• Condensation, • Wash down contamination, • Incorrect type of breather • Location of breather
WEAR METALS	
Iron	Gears, housing, shafts, bearings.
Chromium	Rolling element bearings.
Silicon	Abrasive dirt - may be introduced via poor housekeeping and/or, inadequate breather. (low level could be anti-foam additive)
Copper	Bearings, thrust washers, bushings.
Lead	Bearings, thrust washers, bushings.
Tin	Bearings, thrust washers, bushings.

Hydraulic systems

The expected service life of a hydraulic fluid is usually considerably longer than an engine oil. As a result, the resistance of the oil to oxidation is very important, especially when many oil coolers are manufactured using copper-based components – a metal that is known to be a catalyst for oil oxidation when water is present. Therefore, the water separation properties of hydraulic fluids must be excellent. Free water in the oil can also lead to stripping of anti-rust additives and the presence of fine rust.

Hydraulic fluid cleanliness is extremely important for the reliability and long-term performance of hydraulic systems. The size and type of contaminants aligned with the manufacturing clearances of components within the system will determine the likelihood of wear caused by abrasion or erosion.

TEST	POSSIBLE CAUSES
VISCOSITY @ 40^0C	Higher Viscosity: • Contamination with higher viscosity oils; • Water contamination. Lower Viscosity: • Contamination with lower viscosity oils.
TAN* (Mg KOH/g)	Oxidation of oil due to increased operating temperatures.
APPEARANCE	Water will show milky, cloudy, or hazy.
ODOUR	Contamination with gear oil or advanced oxidation.
WATER	Condensation, poor housekeeping/unclean fill containers, blocked or no breather on tank.
WEAR METALS:	
Iron	Pumps, valves, oil reservoirs, oil lines
Chromium	Chrome-plated components, bearings.
Silicon	Abrasive dirt – incorrect top up, reservoir, breather, return line filter, faulty cylinder rod seals, pump. Consider Silicon-based joining/seal fluids.
Copper	Bearings, oil coolers, copper piping.
Lead	Bearings, solder materials.
Tin	Bearing material.