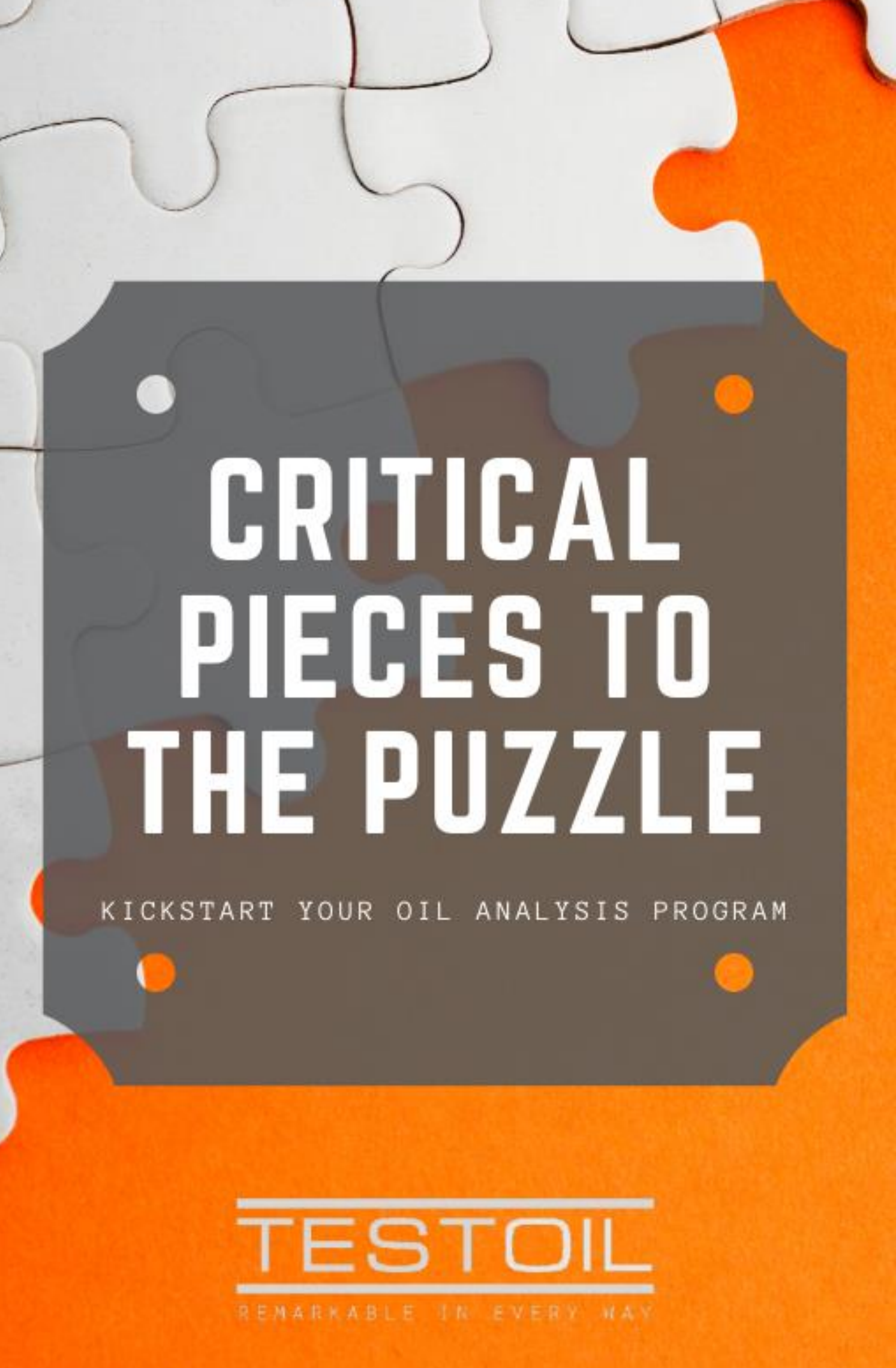


CRITICAL PIECES TO THE PUZZLE

KICKSTART YOUR OIL ANALYSIS PROGRAM

TESTOIL

REMARKABLE IN EVERY WAY

TABLE OF CONTENTS

INTRODUCTION

Oil analysis can uncover, isolate, and offer solutions for abnormal lubricant and machine conditions when used as a predictive maintenance tool. These abnormalities can result in expensive, sometimes catastrophic damage causing lost production, extensive repair costs, and even operator accidents.

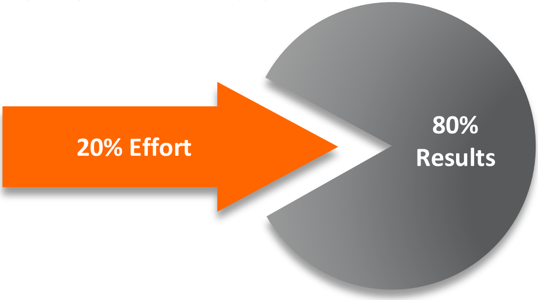
The goal of an effective oil analysis program is to increase the reliability and availability of machinery while minimizing maintenance costs associated with oil change-outs, labor, repairs, and downtime. Accomplishing this goal takes time, training, and patience. However, the results are dramatic and the documented savings and cost avoidance are significant.

Many organizations throughout the world have implemented oil analysis programs to help manage equipment reliability. Some have experienced substantial savings, cost reductions, and increased productivity, while others have received only marginal benefits. A successful oil analysis program requires a dedicated commitment to understanding the equipment, the lubricant, the operating environment, and the relationship between the test results and actions to be performed.

SECTION 1

MACHINE CRITICALITY RATING

An effective oil analysis program should focus a rigorous test slate and frequency on select pieces of equipment, rather than a minimal test slate on all pieces of equipment. The logic is based on the Pareto Principle, a.k.a. the 80/20 rule, which would suggest that 80% of the downtime or reliability issues are caused by only 20% of the equipment



Deciding which equipment to include in an oil analysis program can be a daunting task, but it is best to concentrate on the most critical equipment first.

Critical equipment often does not have a backup. In addition, major repairs and overhaul of critical equipment often require a complete plant shutdown, substantial manpower and subsequent loss of production activities.

Machine criticality is often evaluated through five ratings, or some version similar, with 5 being the most critical and 1 being the least critical:

5	Critical to overall operation and/or very high costs (parts, labor, downtime) **without** redundancy
4	Critical to overall operation and/or very high costs (parts, labor, downtime) **with** redundancy
3	Non-critical or less critical to overall operation and/or moderate costs (parts, labor, downtime) **without** redundancy
2	Non-critical or less critical to overall operation and/or moderate costs (parts, labor, downtime) **with** redundancy
1	Non-production equipment and non-critical to overall operation and/or low costs (parts, labor, downtime) with or without redundancy

SECTION 2

★☆☆

SAMPLE POINT OPTIMIZATION

Sample Point Location

An ideal location is determined by the characteristics of the individual machine. A sample must be taken from a location that will provide good data, since poor data can cause false assumptions that either miss detection of a fault leading to unscheduled downtime (false negative), or misleadingly indicate a non-existent fault causing unnecessary inspections or repairs (false positive).

Sometimes accessing the fluid at an ideal location requires the use of specialized hardware permanently installed in the machine or component from which an oil sample can be extracted.

Samples should be taken from a live, circulating zone; these are typically found on return lines, in the working area of a reservoir or in the agitated area of a sump. Samples taken from these locations provide representative data of the actual conditions of the fluid at the time of sampling.

Sample should never be taken from dead legs of piping, and in general, should not be taken from locations such as directly from a sight glass or from low-point drains without additional hardware. Samples taken from these locations are comprised of mostly stagnant fluid that has not circulated since the last sampling and do not provide representative data. Pitot tube adapters exist with either an integrated sight/level gauge or drain valve, allowing use of existing ports within a system.

Sample Point Location Criteria:

- Sample point locations should provide a good representation of the oil in the system
- Sample point location and procedure must be consistent
- Samples should be taken from a live zone
- Samples should not be taken on a “dead leg”

Sample Point Rating

The following criteria rates the quality of the location:

★ A sample location that increases the potential for system contamination through its use, such as a hatch, breather, dipstick or fill cap

★ ★ A sample location that is a drain at the bottom of a sump or reservoir

★ ★ ★ A sample location that is outside of an active zone, and requires extensive flushing

★ ★ ★ ★ A dedicated sample port that either requires briefly shutting down the machine for access or extensive flushing to obtain sample

★ ★ ★ ★ ★ A dedicated sample port installed where a sample can be pulled while the machine is running with minimal flushing, drawing from an active zone

SECTION 3

SAMPLING BEST PRACTICES

Common Best Practices

A well thought out and documented procedure will ensure the best results. Here are some general tips for a variety of situations.

When using a vacuum pump, always use a new piece of sample tubing.

For sampling a reservoir, the proper length of tubing should be sufficient to reach the middle of the reservoir without touching anything. In general, the tube end should be at least two inches from the bottom of the sump, two inches from the sides, two inches below the oil level and at least two inches from any moving parts.

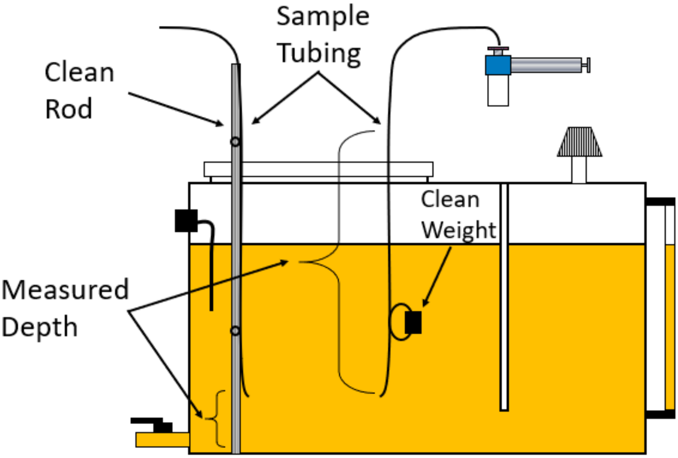
For sampling from pressurized systems, the extraction is simpler because a vacuum pump is not required. If tubing is necessary, only a short length is needed. If the sample is to be obtained from a high-pressure location in the system, additional steps such as the use of a pressure regulator may be required for safety.

As with the drop tube method, begin by flushing the sample valve and tubing with 6 times the pathway volume to a waste oil container before collecting the sample to be analyzed. Another hardware requirement for pressurized sampling is a vented sample bottle cap. If such a cap is not available, attach the sample bottle to a standard vacuum pump to allow the bottle to vent.

While there are several acceptable sampling methods for each machine, there is usually one best way. The best sampling methods will typically require some work up front. This may include installation of sampling hardware, but the end result will be well worth it. Using fixed hardware installed in the correct location, will provide consistent, valid data for superior interpretation about machine and lubricant condition.

With the sample location selected and the proper hardware installed, all that is left is documenting a detailed, stepwise procedure that will ensure the sample will be taken correctly no matter who takes it.

When a sampling valve cannot be placed below the fluid level or near a live zone, e.g. gearboxes and other bath lubricated systems, a minimess-type sampling port with a pitot tube is the usually the best option. This apparatus uses a fixed tube which can be cut to length and positioned in a desirable location in the sump. This is similar to the “drop tube” method but it eliminates the most common problems associated with drop tube sampling which are inconsistent placement of the sampling tubing, the excessive sampling pathway volume, and overall difficulty or time requirement to collect the sample. The use of a pitot tube coupled with a sampling valve minimizes the sampling pathway and ensures a consistent extraction point.



Drop tube sampling refers to the use of a flexible tube which is inserted into the sump by hand. This method may produce valid results but requires greater care. While a minimess-type sampling port is certainly the preferred method, drop tube sampling is an acceptable alternative. Most other sampling methods, such as drain port sampling, will not yield useful results and should be eliminated from a sampling program.

For hydraulic systems, the primary sample point should be on a pressurized portion of the system upstream of system filters. All pressurized systems offer easy, consistent sampling if they are properly fitted with sampling hardware. The same type of minimess-type sampling port can be utilized without a pitot, and if the sample bottle cap is vented there is no need for a vacuum pump.

To address safety concerns, sometimes it is desirable to use a low-pressure portion of the system such as the pump case drain or a bypass circuit. These locations offer easy sampling, safe pressures, and consistent data about the pumps and the fluid cleanliness.

Establishing a Sampling Procedure

Obtaining a good sample does not need to be complicated, in fact, the simpler the procedure the fewer the opportunities for errors or inconsistencies.

Essentially, the complete procedure is summarized by five steps:

Wipe
Wipe area around and above the sampling valve. Cleaning the sample location area prior to sampling prevents outside contamination that would otherwise skew data to suggest a greater problem exists than reality.

Flush
Flush the sampling pathway until the oil comes out hot, as cold oil is indicative that it is not 'live' oil and does not properly represent the true conditions of the lubricant. Flushing helps ensure there is no accumulation of wear particles or contaminants that would also exaggerate results

Technicians often choose to use a dedicated waste oil bottle for flushing that is larger than the sample collection containers so they can typically complete a sampling route without having to empty the waste bottle.

Fill

Fill the bottle 75-80% full, there must be 20-25% headspace in the bottle to provide the lab the ability to thoroughly mix the sample using a mechanical shaker before opening the bottle.

Cap

Cap the bottle immediately to prevent contaminants from being introduced into the bottle and further exaggerating the results. If the bottle was not labelled in advance, take this opportunity to label the bottle.

Send

Send samples in a timely fashion. The most common delay in receiving results comes this step, as TestOil's turnaround for routine testing is always same day for all samples received that day.

SECTION 4

TEST SLATES

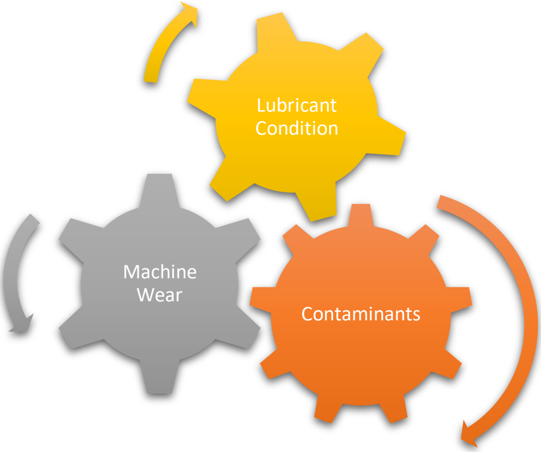
Having oil analysis done on a regular basis establishes a baseline of normal wear and can help indicate when abnormal wear or contamination is occurring. A detailed analysis of an oil sample is a valuable preventive maintenance tool. In many cases, it enables identification of potential problems before a major repair is necessary and has the potential to reduce the frequencies of oil changes.

Oil analysis test packages should be carefully considered. Different equipment will have different test profile requirements. When determining what test packages to choose, the actual equipment and the surrounding environment should dictate what tests are appropriate.

Keep in mind that with oil analysis your goal is to increase machine reliability through improved fluid condition and early detection that otherwise would not be obvious unless it causes machine failures. Having an idea about what the various tests are, what they can accomplish, and considering the maintenance philosophy being practiced, test packages can easily be drawn up to accomplish the desired results.

For example, you may know that some equipment can be run to failure much less expensively than the cost of performing a regular oil analysis. On the other hand, on machines with smaller reservoirs when oil quality is all that would be monitored, it may be best to continue with regular or even increased frequency of oil changes.

Utilizing test slates optimized to determine lubricant condition, equipment condition, and the presence of contamination give an overall view of the health of the lubrication system. Each test reveals information that addresses one, two, or all three of these conditions.



The following tables provide general recommendations for the frequency of testing for several machine types, cross-referenced with suggested routine tests. Depending on the historical reliability of a machine, or any known, on-going issues, additional tests or alternate frequencies may be in order.

Compressors

Fluid Properties	Elemental Spectroscopy	🟩
	Viscosity	🟩
	Acid Number	🟩
	Base Number	
	FT-IR Ox/Nox	🟩
	RULER	
	PRVOT	
	Ultra-Centrifuge	
	Demulsibilty (Water Separation)	
	Foaming Tendency	
	Rust Prevention	
	Resistivity	
	Specific Gravity	
Contamination	Crackle Test (KF by Exception)	🟩
	Karl Fischer Water	🟩
	Particle Count	🟩
	Membrane Patch Colorimetry (MPC)	
	Fuel Dilution	
	Glycol Contamination	
Wear Debris	Analytical Ferrography	🟦
	Ferrous Wear Concentration	🟩
	Filter Debris Analysis	🟦

Monthly	🟩
Quarterly	🟨
Annually	🟥
By Exception	🟦

EHC Fluids

Fluid Properties	Elemental Spectroscopy	🟩
	Viscosity	🟩
	Acid Number	🟩
	Base Number	
	FT-IR Ox/Nox	🟩
	RULER	
	PRVOT	
	Ultra-Centrifuge	
	Demulsibilty (Water Separation)	
	Foaming Tendency	
	Rust Prevention	
	Resistivity	🟩
	Specific Gravity	🟩
Contamination	Crackle Test (KF by Exception)	🟩
	Karl Fischer Water	🟩
	Particle Count	🟩
	Membrane Patch Colorimetry (MPC)	
	Fuel Dilution	
	Glycol Contamination	
Wear Debris	Analytical Ferrography	🟦
	Ferrous Wear Concentration	
	Filter Debris Analysis	

Monthly	🟩
Quarterly	🟨
Annually	🟥
By Exception	🟦

Engines

		Diesel	Gasoline	Nat. Gas
Fluid Properties	Elemental Spectroscopy	🟩	🟩	🟩
	Viscosity	🟩	🟩	🟩
	Acid Number			🟩
	Base Number	🟩	🟩	
	FT-IR Ox/Nox	🟩	🟩	🟩
	RULER			
	PRVOT			
	Ultra-Centrifuge			
	Demulsibilty (Water Separation)			
	Foaming Tendency			
	Rust Prevention			
	Resistivity			
	Specific Gravity			
Contamination	Crackle Test (KF by Exception)	🟩	🟩	🟩
	Karl Fischer Water		🟩	🟩
	Particle Count		🟩	🟩
	Membrane Patch Colorimetry (MPC)			
	Fuel Dilution	🟩	🟩	
	Glycol Contamination	🟦	🟦	🟦
Wear Debris	Analytical Ferrography	🟦	🟦	🟦
	Ferrous Wear Concentration	🟩	🟩	🟩
	Filter Debris Analysis	🟦	🟦	🟦

Monthly	🟩
Quarterly	🟨
Annually	🟥
By Exception	🟦

Gearboxes

Fluid Properties	Elemental Spectroscopy	🟩
	Viscosity	🟩
	Acid Number	🟩
	Base Number	
	FT-IR Ox/Nox	🟩
	RULER	
	PRVOT	
	Ultra-Centrifuge	
	Demulsibilty (Water Separation)	
	Foaming Tendency	
	Rust Prevention	
	Resistivity	
	Specific Gravity	
Contamination	Crackle Test (KF by Exception)	🟩
	Karl Fischer Water	
	Particle Count	
	Membrane Patch Colorimetry (MPC)	
	Fuel Dilution	
	Glycol Contamination	
Wear Debris	Analytical Ferrography	🟦
	Ferrous Wear Concentration	🟩
	Filter Debris Analysis	🟦

Monthly	🟩
Quarterly	🟨
Annually	🟥
By Exception	🟦

Hydraulic Oils

Fluid Properties	Elemental Spectroscopy	🟩
	Viscosity	🟩
	Acid Number	🟩
	Base Number	
	FT-IR Ox/Nox	🟩
	RULER	
	PRVOT	
	Ultra-Centrifuge	
	Demulsibilty (Water Separation)	
	Foaming Tendency	
	Rust Prevention	
	Resistivity	
	Specific Gravity	
Contamination	Crackle Test (KF by Exception)	🟩
	Karl Fischer Water	
	Particle Count	🟩
	Membrane Patch Colorimetry (MPC)	🟨
	Fuel Dilution	
	Glycol Contamination	
Wear Debris	Analytical Ferrography	🟦
	Ferrous Wear Concentration	
	Filter Debris Analysis	

Monthly	🟩
Quarterly	🟨
Annually	🟥
By Exception	🟦

Turbine Oils

Fluid Properties	Elemental Spectroscopy	🟩
	Viscosity	🟩
	Acid Number	🟩
	Base Number	
	FT-IR Ox/Nox	🟩
	RULER	🟨
	PRVOT	🟥
	Ultra-Centrifuge	🟨
	Demulsibilty (Water Separation)	🟥
	Foaming Tendency	🟥
	Rust Prevention	🟥
	Resistivity	
	Specific Gravity	
Contamination	Crackle Test (KF by Exception)	🟩
	Karl Fischer Water	🟩
	Particle Count	🟩
	Membrane Patch Colorimetry (MPC)	🟨
	Fuel Dilution	
	Glycol Contamination	
Wear Debris	Analytical Ferrography	🟦
	Ferrous Wear Concentration	
	Filter Debris Analysis	

Monthly	🟩
Quarterly	🟨
Annually	🟥
By Exception	🟦

SAMPLE FREQUENCY

There is no universal formula for determining oil sampling frequency, but many consider quarterly sampling to be the minimum frequency for most machinery.

However, when making this decision, it is important to consider the objectives of the oil analysis program. If the only objective is to perform condition-based oil changes, the sampling frequency should be determined relative to the lubricant's expected service life, which is defined by the OEM recommended oil change frequencies.

In most situations, this is not the only objective, or even the most important one. The real value of oil analysis is its ability to serve as a proactive condition-monitoring tool, allowing for the detection and quantification of particle contamination, moisture, foreign lubricants or fluids and assessing overall lubricant condition.

In addition to the criticality of the asset, one must consider how the machine would be affected by the amount or source of contamination or other abnormal condition. If oil analysis is used as a predictive condition-monitoring tool, the biggest consideration is the likely time period between detection and failure. This may change as the oil or the equipment reaches the end of its life expectancy. Obviously, the sampling frequency must be shorter than this period to be successful.

Sampling Frequency Criteria	
Criticality	- Extremely Critical – Bi-monthly - Critical – Monthly - Non-Critical – Quarterly
Expense	Equipment with high downtime-associated costs should be sampled more frequently.
Reliability	Equipment prone to failure should be sampled more frequently.
Environment	Equipment with a risk of oil contamination should be sampled more frequently.
Operation	Equipment operating at elevated temperatures, speeds or load should be sample more frequently.
New Oil	Bulk sampling to verify type and quality.

Sampling frequencies must be set appropriately and adhered to rigidly, otherwise the following issues may arise:

- Sampling too infrequently causes predictors to be missed
- Sampling too frequently leads to overload or complacency
- Sampling too irregularly creates noise within the data, which makes proper data interpretation more difficult

SECTION 6

TARGET ALARMS DEVELOPMENT

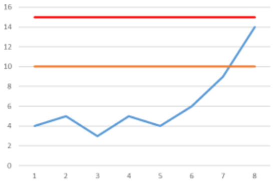
Trending Versus Static Alarm Limits

At TestOil, we prefer to employ trending techniques when evaluating the sample data, versus relying on static alarm limits. The following is a brief explanation describing the benefits of our linear-regression method.

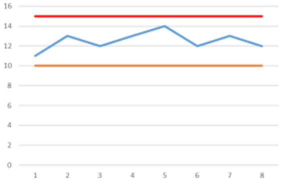
Many static alarm limits are based on statistical analysis of a common grouping of machines under similar operating conditions. As long as machine is operated under similar conditions (load, speed, temperature, ambient environment) for a similar sampling and drain interval, the limits may have merit.

When any variable is different, the limit quickly loses relevance. The most common variable is the sampling interval, as most limits are set for an end-of-service (scheduled drain) interval or as a condemning limit. Samples taken early in the expected life of the lubricant usually have significantly lower results than these limits, so the alarm limit is perceived as being set too high.

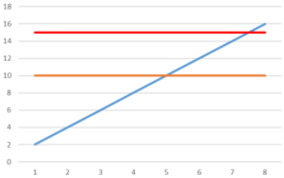
When an alarm is set too high, the risk is that the lubricant or the machine may enter into a failure mode without setting off an alarm.



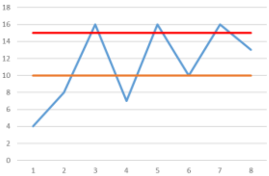
Conversely, if an alarm limit has been set too low for the operating conditions or drain interval, the result is an ever-present alarm on the lubricant and/or the machine. This typically results in a "cry wolf" effect where alarms end up being ignored, even if they represent a true failure mode.



Another issue, typically seen when desiring condition-based oil drains, or simply extending drain intervals, is referred to as the eventuality factor. Given a long enough service interval on the lubricant, the alarm should eventually be exceeded, yet, for many parameters, this does not necessarily signify a problem.



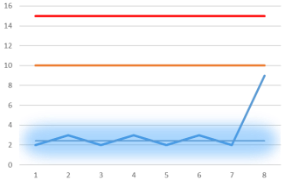
Lastly, over-reliance on alarms tends to shift the focus from detecting an underlying trend that may serve to truly predict a failure before it occurs, to whether or not the lubricant or machine is simply in alarm.



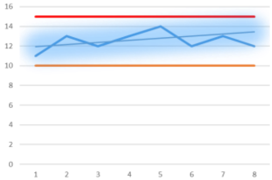
Using linear-regression as the predominant method for evaluating the data eliminates such problems. Linear-regression

begins on the fourth sample from the same machine, as a minimum of data is required for the calculations to be practical. Based on historical data, the software predicts a range for the latest result; data within this range is considered normal for that individual machine, therefore alarms may appear at differing values for similar machines.
Static alarm limits can still be applied as a secondary evaluation, which may be necessary if certain targets must remain for warranty/service agreements, or for regulatory compliance, or until enough historical data has been obtained.

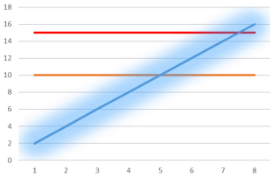
In cases where an existing alarm limit has been set too high, linear regression is able to trigger an alarm even if the value is well below the limit.



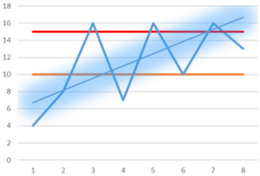
In cases where the alarm limit is too low for the given operating conditions, linear regression rewards consistency and will not trigger an alarm even when it is above the limit.



The eventuality factor is also dealt with, as steady changes are expected with continued service on the lubricant. Only cases where the rate changes significantly will be alarmed, while normal trend will not be alarmed even when the static limit has been exceeded.

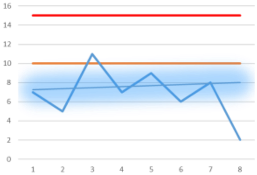


Underlying trends are also identified, providing more feedback to the end-user, even in situations where the lubricant or machine is constantly going in and out of alarm (often due to fluid changes).



One fringe benefit that linear regression offers is identification of an abnormality that is both below an alarm limit and below historical results. Typically, this data would be ignored under the presumption that previous results were worse and no failure occurred.

Another benefit is identification of an abnormality under the guise of a significant improvement. Often, results close to new oil values are perceived as ideal, however, in some cases, a sudden departure from a trend, even towards new oil values, indicates a serious concern.



Trending provides greater depth to the interpretation, allowing for more relevant alarms that account for variations in operating conditions, and providing an ability to predict and anticipate a future sample exceeding an alarm, instead of waiting for the alarm and having to react with greater immediacy.

The rest of this section provides useful information pertaining to basic interpretation of the standard oil analysis tests. Please note the alarm parameters given for each test are not meant to be treated as absolute limits. They are mostly provided to indicate general limits that are used before sufficient data has been obtained to perform linear regression.

REPORT INTERPRETATION

Proper report interpretation is crucial to the success of an oil analysis program; however, many users struggle to decipher the more than 40 pieces of data included on a routine report. The best procedure is to read the whole report in a methodical order, section by section. The following three steps will outline how this can be done yet take less than two minutes per report.

Read the whole report

Read the whole report from top to bottom, without skipping any information or jumping to highlighted sections. Starting at the top, look at which machine the sample belongs to, and how the sample was rated. Consider known information about the machine (recent issues, maintenance or failure history) and then review the severity (normal, marginal or critical) of both the machine and the lubricant.

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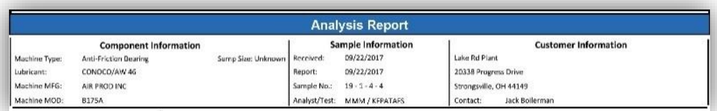
Machine Condition: CRITICAL
Lubricant Condition: CRITICAL
Machine Name: B ID FAN BEARING LUBE OIL
Machine ID: BBV2543-6

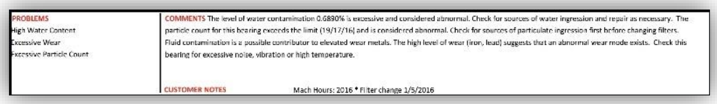
Next, review the machine and lubricant information to establish expectations; e.g. is this a gearbox that is expected to have higher wear compared to hydraulic system? or does the machine lack filtration and particle counts are expected to be higher? Is this an AW (antiwear), EP (extreme pressure) or R&O (rust and oxidation inhibited) oil? and what is its grade?



Analysis Report

Component Information			Sample Information		Customer Information	
Machine Type:	Anti-Friction Bearing	Sump Size: Unknown	Received:	09/22/2017	Lake Rd Plant	
Lubricant:	CONOCO/AW 46		Report:	09/22/2017	20338 Progress Drive	
Machine MFG:	AIR PROD INC		Sample No.:	19 - 1 - 4 - 4	Strongsville, OH 44149	
Machine MOD:	B175A		Analyst/Test:	MMM / KFPATAFS	Contact:	Jack Bollerman

Then review the laboratory's comments to get a preview of the factors that drove the report's severity.



PROBLEMS
High Water Content
Excessive Wear
Excessive Particle Count

COMMENTS The level of water contamination 0.6890% is excessive and considered abnormal. Check for sources of water ingression and repair as necessary. The particle count for this bearing exceeds the limit (19/17/16) and is considered abnormal. Check for sources of particulate ingression first before changing filters. Fluid contamination is a possible contributor to elevated wear metals. The high level of wear (iron, lead) suggests that an abnormal wear mode exists. Check this bearing for excessive noise, vibration or high temperature.

CUSTOMER NOTES Mach Hours: 2016 * Filter change 1/5/2016

Decide if values appear to be abnormal

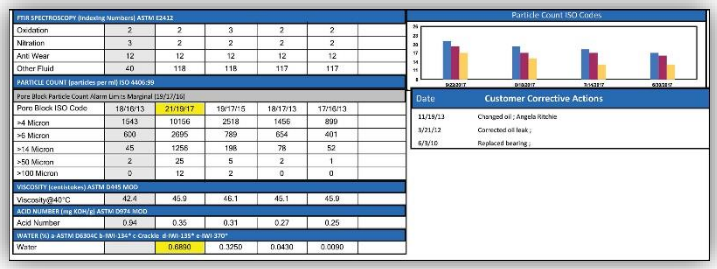
Decide which values appear to be abnormal, but do not attempt to decipher how or why, simply assign each abnormal value a label of "cause" or "effect".

Upon beginning to look at the sample data portion of the report, first review the lubricant and machine hours (if reported) to ascertain the predicted trend, i.e. continued service would suggest wear, contamination and degradation to increase, whereas a recent oil change would see the opposite effect.

	Date Sampled	NEW OIL	9/22/2017	8/18/2017	7/14/2017	6/30/2017	
	Lab No	1278905	168113	168112	168111	168110	
	Machine / Lube Cond.		C / C	N / M	N / N	N / N	
	Lube Hours		2016	1176	336	0	
	Machine Hours		2016	1176	336	0	
ELEMENTAL SPECTROSCOPY (ppm) ASTM D5185 Mod (-) indicates below detection limit							
Wear Metals	Iron	-	85	25	5	-	
	Copper	-	-	-	-	-	
	Lead	-	49	9	-	-	
	Aluminum	-	-	-	-	-	
	Tin	-	-	-	-	-	
	Nickel	-	-	-	-	-	
	Chromium	-	-	-	-	-	
	Titanium	-	-	-	-	-	
	Vanadium	-	-	-	-	-	
	Silver	-	-	-	-	-	
Additives	Calcium	174	50	44	39	41	
	Magnesium	2	-	-	-	-	
	Phosphorus	429	329	318	341	321	
	Zinc	659	495	495	472	484	
	Barium	-	-	-	-	-	
	Molybdenum	3	-	-	-	-	
Contaminants	Silicon	4	14	7	9	6	
	Boron	-	-	-	-	-	
	Lithium						
	Sodium	-	-	-	-	-	
	Potassium	-	-	-	-	-	

From this first section, iron and lead are clearly abnormal and would likely be labelled as "effects", since some other mechanism (time, viscosity, contamination) would have caused the wear metals to appear. Though silicon was not highlighted by the lab, it could be labelled a "cause" since high iron or lead would not cause silicon to appear, but high silicon could cause more iron and lead wear.

Continue reading, allowing previously assigned labels to be changed, if warranted.

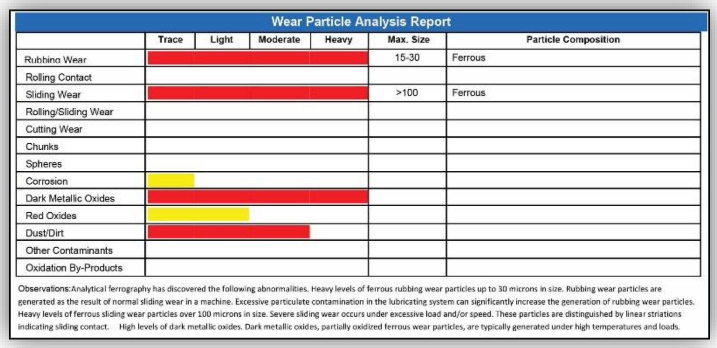


FTIR SPECTROSCOPY (Indexing Numbers) ASTM E2412						
Oxidation	2	2	3	2	2	
Nitration	3	2	2	2	2	
Anti Wear	12	12	12	12	12	
Other Fluid	40	118	118	117	117	
PARTICLE COUNT (particles per ml) ISO 4406:99						
Pore Block Particle Count Alarm Limits Marginal (19/17/16)						
Pore Block ISO Code	18/16/13	21/19/17	19/17/15	18/17/13	17/16/13	
>4 Micron	1543	10156	2518	1456	899	
>6 Micron	600	2695	789	654	401	
>14 Micron	45	1256	198	78	52	
>50 Micron	2	25	5	2	1	
>100 Micron	0	12	2	0	0	
VISCOSITY (centistokes) ASTM D445 MOD						
Viscosity@40°C	42.4	45.9	46.1	45.1	45.9	
ACID NUMBER (mg KOH/g) ASTM D974 MOD						
Acid Number	0.94	0.35	0.31	0.27	0.25	
WATER (%) a-ASTM D6304C b-IWI-134* c-Crackle d-IWI-135* e-IWI-370*						
Water		0.6890	0.3250	0.0430	0.0090	

Particle Count ISO Codes

Date	Customer Corrective Actions
11/19/13	Changed oil ; Angela Ritchie
3/21/12	Corrected oil leak ;
6/3/10	Replaced bearing ;

In this next section, the elevated particle count would definitely be labelled a "cause", along with the previously assigned silicon. Though acid number is trending higher, it has followed a very smooth 0.04 increase between each sample. Water, however, has not and should be considered abnormal and would also be labelled as a "cause".



Wear Particle Analysis Report

	Trace	Light	Moderate	Heavy	Max. Size	Particle Composition
Rubbing Wear	🟥	🟥	🟥	🟥	15-30	Ferrous
Rolling Contact						
Sliding Wear	🟥	🟥	🟥	🟥	>100	Ferrous
Rolling/Sliding Wear						
Cutting Wear						
Chunks						
Spheres						
Corrosion	🟨					
Dark Metallic Oxides	🟥	🟥	🟥	🟥		
Red Oxides	🟨	🟨				
Dust/Dirt	🟥	🟥	🟥			
Other Contaminants						
Oxidation By-Products						

Observations:Analytical ferrography has discovered the following abnormalities. Heavy levels of ferrous rubbing wear particles up to 30 microns in size. Rubbing wear particles are generated as the result of normal sliding wear in a machine. Excessive particulate contamination in the lubricating system can significantly increase the generation of rubbing wear particles. Heavy levels of ferrous sliding wear particles over 100 microns in size. Severe sliding wear occurs under excessive load and/or speed. These particles are distinguished by linear striations indicating sliding contact. High levels of dark metallic oxides. Dark metallic oxides, partially oxidized ferrous wear particles, are typically generated under high temperatures and loads.

In the final section it is first noted that rubbing wear is very high, yet rubbing wear is considered a normal wear mode. What makes it an issue is that normal rubbing wear generates small particles (near 5 microns), but abnormal rubbing wear generates larger particles. Though it is a wear mode, rubbing wear would be labelled as an “effect” since some other factor would be driving it.

The same can be said for sliding wear, which is never considered normal, regardless of size. Corrosion is also an “effect”, as would be red oxides, as they were likely accelerated by the water content noted earlier. Dark metallic oxides are caused by high contact pressure, usually from lubricant starvation, so they must be labelled as an “effect”.

Lastly is the elevated level of dust/dirt which will likely be labelled as a “cause”, which would force silicon and particle count to be relabeled as “effects”, since dust/dirt could cause both to increase.

Upon reaching the end of the report, there should only be one or two causes, with every other abnormal value labelled as an effect of one or more of these causes. For this report, the causes would be elevated dust/dirt and water content.

Decide how to follow-up

Decide what follow-up action would either confirm the cause or remedy the situation. The best action is rarely to simply change the oil.

In this case, investigating all points of ingression (fill cap, dipstick, breather, hatch cover, etc..) could potentially address the root cause of both “causes”. While simply changing the oil would see these abnormalities disappear from the next sample, the same problem would recur in due course.

Even if an obvious fault was found, e.g. broken or missing breather, even after the repair the oil should not be changed. If the current level or wear or contamination can be tolerated, leaving the same fluid in service gives the next sample the definitive ability to confirm if the repair was successful by returning with nearly identical results, not lower/better.

Following these three steps will:
1) Prevent missing anything by reading the whole report
2) Decrease the time spent reading reports by avoiding partial interpretations along the way
3) Improve the effectiveness of follow-up actions by addressing causes, not symptoms or effects

SECTION 8

MAINTENANCE/CORRECTIVE ACTIONS

Work with your CMMS and lab

From enterprise solutions to simple spreadsheets, tracking lubrication-related maintenance actions can lead to valuable insights into how resources are allocated and how actions correlate to OA data. For this reason, tracking should be done in a way that actions can be searched or queried (by person, machine, task, date, etc). Correlations can be a two-way street – OA results can trigger PDMs, but PDM tasks can impact future OA results. This needs to be kept in mind when reviewing data and having simple but well-kept records can save time when evaluating results.

Have a plan – specific types of alarms should trigger specific maintenance actions. For example, an elevated particle count result indicates dirty oil which will lead to premature wear. The proper response to this should be to stop the oil from becoming dirty (stop ingression – inspect seals and other areas for sources of contamination and repair) and remove the dirt from the oil (filtration, could be supplemental if already inline).

The particle count alarm on a report is the trigger for this maintenance action. This action should have a code in a CMMS system, which could also be a code included in the report comments. It is possible to turn the sample report, including a maintenance action code triggered by the results, into a data file that is sent to your CMMS and automatically generates a work order. In this way, the work is done under the hood to turn oil analysis data into maintenance actions.

Different alarms will result in different actions, and sometimes no action. That is a topic for conversation with your lab, but if a sample result is in marginal alarm and by a small margin, it might be best to wait until the next sample to see if the out of spec result changes or repeats.

Egregious changes or other critical alarms should be verified. TestOil retests all results that cause a critical alarm for verification, but it does not hurt to call TestOil or your lab to ask for a retest when a result is in critical alarm and has never been in the past. Once a result is verified, it is recommended to resample for further verification. A simple mistake such as mislabeling a sample or smudging the inside of a sample bottle lid can cause errant results that are not actually caused by machine or lubricant problems.

Once an alarmed result is established, action can be taken. Here are some common maintenance actions resulting from oil analysis results:

Problem / Test Result	Action
High Wear Metals	Inspect for problem – thermography, ultrasonic sensors, vibration analysis can help pinpoint a component wear problem.
High Acid Number	Partial or full oil change
High Particle Count	Inspect for sources of contamination. Small sump – oil change, Large sump – check/replace filters or implement supplemental filtration
Excessive Water	Inspect for sources of contamination. Remove water from low drain, top off or replace oil. Resample for demulsibility testing. Implement dehydration or other water removal.
Low / High Viscosity	Investigate the oil that is being put in the machine and test the new oil for proper viscosity. Partial drain & fill to achieve proper viscosity range or replace oil.

Every organization should have a chart like this listing how to react to OA test results. These actions do not have to be written in stone, but they are guidelines that can be reviewed with the appropriate personnel and can save time when organizing maintenance activities.

How-to Set Goals and Why

An oil analysis program must have a goal in mind for it to be effective, and the goal ultimately determines some of the factors associated with the program.

As examples, common goals may include, reducing oil consumption, extending equipment life and increasing reliability.

When setting a goal of extending drain intervals, the most important factor involves measuring the lubricant's condition, and therefore has a direct bearing on the frequency of sampling and a test slate focused on degradation of the lubricant.

When the goal is extending the equipment life, the focus shifts to measuring wear, with less concern on the fluid condition, and this has a direct bearing on the sampling location and procedure.

For increased reliability, Root Cause Analysis emphasizes measuring contamination and performing more advanced testing on a tiered schedule.

No program will receive approval from upper management without a form of justification, typically economical.

A solid analysis program results in making condition-based decisions both on the state of the equipment and the lubricant. The oil might be in good condition (minimal contamination, degradation, etc.), but an alignment/load problem may occur that may manifest as higher wear rates as determined by oil analysis. Maintenance supervisors can then look into possible causes (check vibration data) and correct problems before they develop into failure modes.

Even if no premature failures have occurred, it is a risky proposition to operate in such a severe environment without predictive maintenance tools such as oil analysis.

After the goals have been set all the costs must be tallied to determine a program budget. Justification is determined by the potential benefits or savings, should the plan be successful, exceeding the costs; therefore, it is important to exercise caution when estimating the projected savings.

The assumption must not be that losses and failures will be completely avoided, but rather simply that the severity will be decreased due to earlier detection and that the likelihood of failure will be reduced due to on-condition maintenance.

There is little sense setting a goal or creating a direction for a team to follow if it is not reviewed periodically for compliance. A common method is to employ some Key Performance Indicators (KPIs).

One common KPI is keeping records of all predictive oil changes, filtration requests, dehydration requests, and so on. Tracking changes in the frequency of these activities can show the effectiveness of the program.

KPIs are useful for helping to set small, achievable goals to show progression and earn buy-in from all levels of management and reliability. Even one as simple as the compliance of the number of samples pulled can help steer a program back on the track to success, before moving on to a bigger goal like reducing the number of samples that are alarmed.

A review should be done annually, which includes a cost-benefit evaluation of money saved by avoiding maintenance issues or machine downtime due to oil analysis. Evaluation allows for continuous improvement of the program by realigning the program with either preexisting or new reliability objectives.

Example of Oil Analysis Key Performance Indicators:

Oil Analysis KPIs	
SAMPLE RESULTS	**Month**
Total Number of Samples	80
Total Problem Samples	37
# of Flagged Samples	32
Critical Samples	9
Marginal Samples	6
Normal Samples	17
Delinquent Samples	7
Total # of Recurring Exceptions	5
Machine Exceptions	3
Lubricant Exceptions	2
PERCENTAGES	
Critical Samples	11%
Marginal Samples	8%
Normal Samples	21%

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