Equipment monitoring

OVERVIEW
This manual looks critically at monitoring lubricants in service. It starts with real life problems and continues with articles that present best practices with or without oil sampling and analysis. Solving contamination problems, e.g. with filters, is covered and water contamination is discussed in detail.

INTRODUCTION
In the ideal world, condition-based maintenance takes predictive maintenance one step further by performing the inspections in a real-time mode. Sensors installed on the equipment provide signals that are fed into the computer system, whether it is a process control system or a building automation system. The computer then monitors and trends the information, allowing maintenance to be scheduled when it is needed. The trending is useful for scheduling the repairs at times when production is not using the equipment...

In real life, samples are taken and sent to the laboratory. **Before starting the programme, proper planning is essential. Basic questions must be asked:**

- **What do we want to get from our oil analysis program?**
- **What units need to be sampled?**
- **Where exactly does the sample need to be taken on the equipment?**
- **How are the samples going to be taken?**
- **How often do samples need to be taken?**
- **What tests are needed?**

We will look at these aspects in detail. For instance, most machines lack sampling points and the correct way is to install them during an overhaul. When there are no sampling points, other methods need to be used, e.g. drop-tube sampling. This is however not recommended for engines. Why? There is more than one reason: the machine has to be shut down, the tube's final point is difficult to control, and the tube may pick up contaminants on the way in.

The objectives of used oil analysis are:

(1) to evaluate the condition of the oil in service;

(2) to detect and measure contaminants;

(3) to evaluate the condition of the machine being lubricated.

Fighting contaminants becomes more important when one realizes how devastating contaminants can be. It's not always obvious. For example, one effect of particle contamination, one that is rarely discussed, is additive leaching. Many additives attach to particles and are removed along with the particles by filtration. Water contamination can also leach out additives.

In the last function, machine condition monitoring, the lubricant serves merely as the carrier of the information that is generated by the machine in the form of wear debris.

Oil sampling is just one aspect of the process. However, its importance cannot be under-estimated. There are basic rules, really a check-list, developed by Trico Corporation:

1. **Samples should be collected when machines are running** at normal operating temperatures, loads, pressures and speeds. This will ensure that insoluble and semi-soluble (dirt, water, and other debris) material is suspended evenly throughout the system.

2. **Sample upstream of filters and downstream of machine components** such as bearings and gears to obtain the best data. Sampling downstream from the filters should be performed if you wish to determine the effectiveness of your filtration system.

3. **Document oil sampling procedures for each system -** tools needed, line flushing requirements, sampling locations, sampling methods, and safety requirements are among some of the items to include in the written procedures. This ensures that each sample is taken in the same manner and from the same point. Procedures that are documented also help new employees quickly learn the process.

4. **Properly flush sampling valves, devices, and hardware** thoroughly prior to taking oil samples. To avoid cross-contamination, use a new sampling tube for each sample taken.

5. **Make sure that oil samples are taken at the proper frequency** and that the frequency is sufficient to identify problems. Sampling frequencies should be set specifically for a particular machine. Every machine is unique in its intended performance, condition, locality, operating environment, and maintenance schedule.

6. **Forward samples immediately to the lab** after sampling. Ideally, oil should be analysed within 48 hours of being sampled.

LABORATORY REPORTS

Is all this done in practice? Hardly! The following examples from a major, well organized international company in South Africa shows what really happens. Look at the sample of laboratory report on the opposite page. In a way, it is impressive, having a number of features which are explained as follows:

<u>Equipment identification</u>

Machine: H1061_PRE-HEATING_SCREW **Compartment:** GEARBOX

<u>Sample identification (first line)</u>

Lab No.	Sampled	Received	Oil brand	Severity
4149692	19-Aug-12	23-Aug-12	MOBILGEAR 632	NORMAL

<u>Graphics</u>

Kinematic viscosity @ 40 °C for the last 4 samples --- **What happened to the sample June-10?**
Wear metals in ppm: Iron, Chromium, Copper, Lead, Tin for the last 4 samples
Contaminants on blotted paper – enlarged

<u>Detailed results</u>

KV 40 (Kinematic viscosity @ 40 °C) --- **By the way, Mobilgear 632 is not ISO VG 220!**
Water (often given as 'ND' – not detected – the lab is equipped to run different test methods)
TAN (Total Acid Number – oxidation test – due to additives, the TAN of new oil is not 0)
ISO (ISO 4406 – cleanliness test – for this customer, carried out only on hydraulic fluids)
MPE (Microscopic Particle Examination – debris analysis of bigger particles, will be explained)
WPC (Wear Particle Count – optical method)

Wear metals: Fe (Iron), Cu (Copper), Pb (Lead,), Cr (Chromium), Al (Aluminium), Si (Silicon), Na (Sodium), Mo (Molybdenum), Sn (Tin), Ni (Nickel)

Base oil / additive metals: Ca (Calcium), Ba (Barium), Mg (Magnesium), Zn (Zinc), P (Phosphorus), B (Boron), K (Potassium), Li (Lithium), S (Sulphur), Sb (Antimony)

Petr Vavruch: Having examined a number of laboratory reports done for this customer, the comments by the lab reveal particularly bad horror story. See some examples, with my comments on page 4.

Customer:

Site: PLANT_1

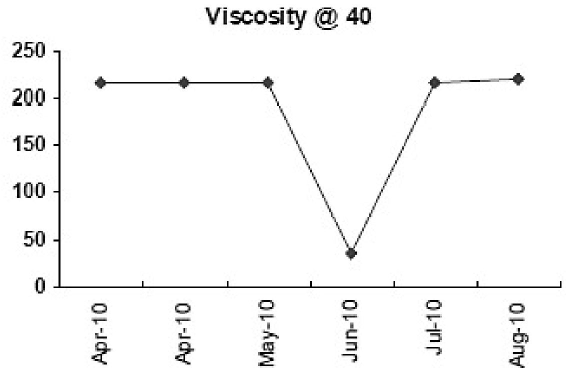
Machine: H1061_PRE-HEATING_SCREW

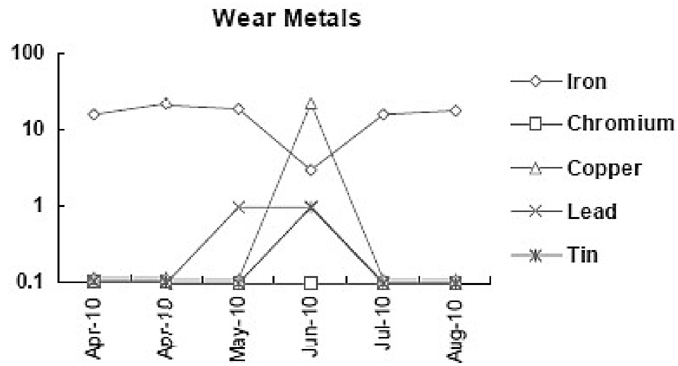
Compart: GEARBOX

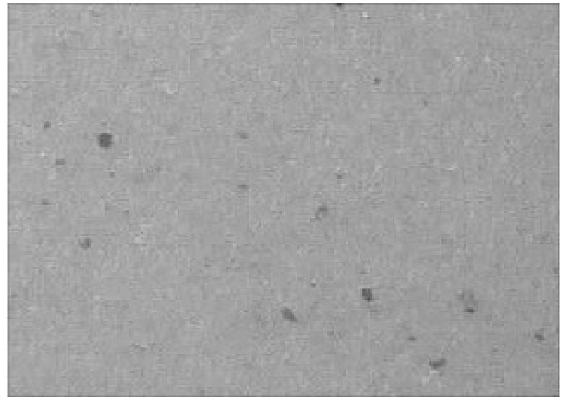
	Lab No	Sampled	Received	Oil Brand	Severity
1	4149692	19-Aug-	23-Aug-	MOBILGEAR 632	NORMAL
2	4146653	22-Jul-	26-Jul-	MOBILGEAR 632	NORMAL
3	4146705	18-Jun-	21-Jun-	MOBILGEAR 632	BORDERLINE
4	4139765	20-May-	24-May-	MOBILGEAR 632	NORMAL
5	4143181	23-Apr-	28-Apr-	MOBILGEAR 632	BORDERLINE

1364

NORMAL







	KV 40	Water	TAN	ISO	MPE	WPC	Fe	Cu	Pb	Cr	Al	Si	Na	Mo	Sn	Ni	Ca	Ba	Mg	Zn	P	B	K	Li	S	Sb
1	219.9	ND	0.41	/	1111	4	19	0	0	0	0	6	0	0	0	0	14	0	0	12	244	3		0	11380	0
2	216.9	ND	0.45	/	1111	13	17	0	0	0	0	5	1	0	0	0	10	0	1	13	206	3		0	11240	0
3	35.8	ND	1.15	/	1111	6	3	23	1	0	0	0	1	0	1	0	127	0	5	728	498	0		0	4729	0
4	217.1	ND	0.57	/	1111	9	20	0	1	0	0	6	0	0	0	0	9	0	0	13	255	1		0	12950	0
5	217.4	ND	0.42	/	1111	10	22	0	0	0	0	7	0	0	0	0	11	0	1	13	274	4		0	13580	0

Comments

1 Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. A microscopic particle examination of particles filtered from the oil revealed no abnormal contamination.

2 The oil in use appears to be an ISO 220. Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. A microscopic particle examination of particles filtered from the oil revealed no abnormal contamination

3 This sample does not appear to be from this component or oil brand and/or series and/or grade appears to have changed. The oil in use appears to be an ISO 32. Check manufacturers lubricant recommendations. Wear rates are normal. A microscopic particle examination of particles filtered from the oil revealed no abnormal contamination. Please return feedback.

4 The oil in use appears to be an ISO 220. Wear rates are normal and the sample provided appears free from unacceptable contamination or degradation. A microscopic particle examination of particles filtered from the oil revealed no abnormal contamination.

5 Wear rates are normal. Debris analysis revealed evidence of coarse dirt ingress, check for point of entry. The oil in use appears to be an ISO 220. Please confirm oil grade. Coarse dirt contamination makes the oil unfit for further use. Please return feedback.

COMMENTS

Engine:
1. The period oil has been in use is unknown. Wear rates appear normal. Tests indicate a slight internal coolant leak, as a precaution pressure test cooling system. Please return feedback. REPEAT PROBLEM: internal-coolant-leak x 2.

P Vavruch: Lack of complete information required makes diagnosis unreliable, e.g. it is quite useless to analyse the oil if it is not known how long it was in the machine. The lab is crying for feedback, there is complete breakdown in communications. It seems that nobody took any notice when a problem, internal coolant leak, was previously alerted in the report No. 2 (see below). In the report No. 2, it shows that the lab does not even know that the samples are always taken from drain when the oil is changed thus “Change the oil” is silly.

2. URGENT: The period oil has been in use is unknown. Ring and cylinder/liner wear rates are higher than normal. 12% Fuel dilution taking place – check fuel system for malfunction. Change the oil. Warning, high levels of fuel can dilute wear and other contaminant levels making readings appear normal or low. Check that blow-by is not excessive. Check for abnormal noise. Higher than normal sodium and other metal levels indicate an internal coolant leak into the engine - pressure test cooling system to locate leak. Please return feedback. REPEAT PROBLEM: fuel x 2.

Another engine:
Please supply all vehicle make and model details. The period oil has been in use is unknown. 0,2% Water present in the oil - check for point of entry. As a precaution pressure test cooling system. Slight fuel dilution evident. The oil is not fit for further use due to contamination. Recommend changing the oil. Please return feedback.

P Vavruch: This is particularly bad. If the lab does not know from what make and model the samples came, it is unable to apply its expertise based on results from similar equipment used by other customers. It diminishes the value of the lab's reporting. But the lab is trying as is evident from the following report about a gearbox.

Gearbox:
Gear wear rates are higher than normal. Debris analysis revealed a light concentration of very small wear particles. A trace of water present in the oil. Check for misalignment of drive train and vibration. Check for abnormal noise. Check magnetic drain plug for abnormal wear particles. Wear metal contamination makes the oil unfit for further use. Please return feedback.

Another gearbox:
1. URGENT: Debris analysis revealed evidence of abnormal wear taking place. Check for abnormal noise and vibration. Debris analysis revealed evidence of coarse dirt ingress, check for point of entry. The oil is not fit for further use due to contamination. Change the oil. Please return feedback. REPEAT PROBLEM: MPE x 2.

2. Debris analysis revealed a light concentration of very small wear particles. Debris analysis revealed evidence of coarse dirt ingress, check for point of entry. Recommend filtering the oil to remove contaminants. Please return feedback.

P Vavruch: And why the sample June-10 on the previous page had such a low viscosity? Simple! Another sample, from a hydraulic system where the usual viscosity is around 35 cSt, had in June-10 viscosity of 221 cSt!

Let's now have a look how oil sampling and all the rest should be done correctly...

1. The daily one-minute inspection (OMI)

By Jim Fitch, Noria Corporation

The most important maintenance function doesn't require an instrument or an oil sample. What it requires instead is an observant person or persons who carry out rapid, comprehensive and frequent inspections.

Learning machine "Sign Language"

Recognizing the "signs" or symptoms that the machine conveys is a required skill for those who work with machines and are responsible for their care. This involves training, practice and motivation!

Daily OMIs are critical snapshots of machine and lubricant condition. Such inspections need to be conducted by trained people who have frequent access to machines. It is often said that machine safety, production quality and machine reliability is everyone's responsibility.

Check lists are helpful when completing tasks. These can be incorporated into scheduling software, printed maintenance schedules and even attached on or near the machine itself. The range of inspections will vary considerably depending on the machine type. Below is a basic list of common lubrication-related inspection tasks:

1. **Temperature.** Use touch, gauges or heat guns to identify hot running conditions. Besides a number of mechanical explanations, high temperature can be caused by a wrong or degraded or contaminated lubricant, air in the lubricant (aeration), etc.
2. **Oil volume.** Use level gauges, sight glasses, dip sticks or inspection ports/hatches. Even a slight change in the oil level (up or down) can justify attention.
3. **Pressure.** Use gauges or pressure transducers at multiple points as needed. Varying temperature, viscosity, flow restrictions and aeration are among the many causes of pressure changes.
4. **Filter.** Examine delta-P gauges and bypass indicators to confirm that the filter is alright. When filters plug prematurely, there's usually an important reason why.
5. **BS&W.** Take bottom samples or examine bottom sediment and water (BS&W) bowls for abnormal accumulations of sludge, wear debris, free water, biomass and other contaminants.
6. **Ventilation.** Confirm serviceable condition of breathers and inspect for abnormal contamination, fumes, vapour and smoke.
7. **Clear and bright.** Pull samples or inspect sight glasses to check the oil colour, clarity, debris, bubbles, emulsions, fouling, etc.
8. **Leakage.** Use a powerful flash-light to inspect seals, gaskets, fittings, hoses, etc. Sudden leakage at multiple points is often caused by a change in lubricant quality.
9. **Fluid surfaces.** Through inspection hatches and ports look for foam, varnish, sludge, bathtub rings, rust and corrosion and vapours.
10. **Points of entry.** Inspect for potential entry points for contaminants.
11. **Dirty exterior.** Machines that are dirty on the outside are usually dirty on the inside as well. Keeping machines clean is the first step to contamination control.
12. **Spits and sputters.** Machines emit an assortment of audible signals; some are normal but other are not. Report abnormal whines, rattles, rumbles, pops, etc. If it is safe, use a rod, hose or stethoscope to localize the source of the noise.

13. **Grease condition/colour.** Inspect grease extruding from seals and along shafts for abnormal colour, consistency and condition.

2. Utilizing your senses as condition monitoring tools

Noria Corporation

An effective proactive/predictive maintenance program includes tools such as vibration, thermography and oil analysis to inspect and determine the condition of machinery. Do not, however, underestimate the value of your own senses.

Most operators and technicians are familiar with the machinery they maintain or operate, thus they are qualified to identify unusual conditions. They are aware of the "normal" sounds and appearance of the machines.

To see
Many sensory inspections are visual, and checking oil levels is the most common visual monitoring activity. Numerous potential machine failures are prevented by an attentive individual who notices a low or non-existent oil level.

Other parts of the visual inspection include detecting oil contaminated with water or other materials, badly degraded or oxidized oil, and excessive foaming, as well as other machine conditions including excessive vibration, loose belts and loose or missing fasteners. These should be routinely documented and scheduled for attention.

To hear
In some instances, sound can be a more sensitive monitoring tool than visual inspections. While visual inspections are fairly straightforward, audible inspections may require some degree of experience or training to interpret. However, it is likely that even the untrained or inexperienced ear will notice a change from the normal sound and can report the condition, even if a problem is not yet identified.

To smell
The human sense of smell is powerful and can be used to identify various adverse machine conditions and lubricant problems. Among the common lubricant issues are certain types of contamination such as solvents, fuel, refrigerants and other process chemicals. Additionally, oil that has become significantly oxidized has a distinct odour that once observed, is easily identifiable. Slipping belts or overheated components will often present an alarming smell that demands investigation.

The Human Senses: A valuable condition monitoring technique
There are often easily observable problems that, if unnoticed, could lead to a catastrophic failure. Unfortunately, it is quite common that the observed problems go unreported, or are reported but not acted upon. It is important to create a check list and reporting mechanism with defined follow-up actions to address the identified problems.

3. How to give your machine a physical

By Jim Fitch, Noria Corporation

The selection of inspections should be tailored to the machine design, criticality and operating environment. This means optimize the inspection process, not maximize. Use good judgement in selecting which inspections are needed and how frequently they should be carried out. Following is a list of problem-revealing tests and inspections relating to oil lubrication. They require limited technical proficiency and most involve no special tools or instrumentation.

1. **Oil colour change.** Monitor changes in lubricant colour through sight glasses and oil samples. Lubricants experiencing thermal and oxidative distress will exhibit marked darkening and opacity. Many types of contaminants will alter colour as well. Additionally, a wrong lubricant can often be recognized by visual inspection.
2. **Impaired air-handling ability.** Most healthy lubricants will rapidly release entrained air and do not foam excessively. However, distressed and contaminated lubricants may fail to release air from the body of the oil and may also foam on the surface. Aeration and foam are not the same problem. Also, they do not always indicate the condition of the oil but may point to mechanical conditions, such as broken seals. Sight glasses and inspection hatches may provide the first sign of a problem.
3. **Water separation.** Water and oil don't usually mix. However, if they are agitated and form an emulsion, the problem is usually associated with a change in the oil properties or contamination. Observing oil/water separation after violently mixing quantities of each in a sample bottle or laboratory glassware is an easy check.
4. **Blotter spot structure.** Place a couple drops of oil on blotter paper or card stock, then observe for radial structure to form (rings, star-burst, etc.). Uncontaminated oils don't produce structures. Instead, the oil will wick up into the paper leaving only a uniform gradient of oil colour.
5. **Patch test inspection of debris field.** This test provides information not only about particle size and count but, to the trained eye, can also provide information about particle composition and shape. The patch test kit enables instant visual analysis through an optical microscope of debris including bright and black metals, silica, fibres, elastomers, plastics and others.
6. **Bottom sediment and water (BS&W).** It is often said that what is bad for the oil is also heavier than the oil. Heavier substances will settle and should be routinely inspected using special sight glasses or taking bottom samples.
7. **The noise.** Few machines are quiet during operation and "a singing gear is a happy gear". This is often true, but not always. Machine sounds change for specific reasons. Try to locate where the noise comes from.
8. **Temperature.** A variety of tools including online temperature probes (thermocouples or resistance temperature detectors - RTD), thermal imaging cameras or hand-held heat guns. Common causes of abnormal temperature include wrong or degraded or contaminated or insufficient lubricants, wear, malfunctioning cooling systems, etc.
9. **Pressure.** Oil pressure can increase or decrease and anything that can change viscosity or surface properties of the lubricant can change system pressure.
10. **Filter life.** When filters plug prematurely, there is usually good reason. Soft contaminants (sludge, organic material, dead additive residue, biomass, etc.), dust and wear debris - what's plugging the filters and why is worthy of our attention. The filter is the final resting place for a variety of machine and lubricant operational waste products.

4. Six steps for more effective oil analysis

Aaron Black, Noria Corporation

Whether you currently have an oil analysis program in place, or are putting one together, it is imperative to ensure that equipment is properly sampled to meet the goals of a specific maintenance program.

To provide the program with the proper foundation, six basic questions must be asked:

- What do you want to get from your oil analysis program?
- What units need to be sampled?
- Where does the sample need to be taken on the equipment?
- How are the samples going to be procured?
- How often do samples need to be taken?
- What tests are needed?

Some of these steps can be performed simultaneously, while others must be done in sequence.

Step 1: The functions of an oil analysis program

This first step is critical. It provides the direction for nearly all future decisions regarding the oil analysis program. Can failures be caught early? Are there lube-mixing problems that need to be prevented or caught before resulting issues occur? Or does the lubricant health simply need to be monitored to provide accurate lube change intervals? The reasons for performing lubricant analysis can vary, but overall, the choice can have the most effect on what can be accomplished with an oil analysis program.

Step 2: Sampled units

The next problem to tackle is deciding which units to sample. Individual units do not need to be determined immediately, but for other steps later in the process, it will be necessary to decide what unit types to sample. Gearboxes only? Super-critical units? Everything? This step can be one of the most challenging, but when all of the fundamentals are combined, it is relatively simple due to the limiting factors some steps provide.

The most likely solution is to make a list of everything the user might want to sample and then prioritize them into groups (definitely want to sample, would like to sample, must be sampled). Therefore, if the cost is too prohibitive, the units can be pared down to sampling either less often or not at all.

Step 3: Sampling location

While this step can be performed in any order, it is useful in helping place limits on the scope of the sampling project. Sample location is sometimes cut-and-dried regarding where the sample can be pulled from on the equipment.

The pros and cons of each sampling option must be weighed against many variables including questions such as "What does the budget allow with the number of units that need to be sampled?" and "Which sampling method will allow me to monitor what I need to reach the goal of this project?" In some instances, drop tube sampling is appropriate. Other instances require a sample point to be installed to obtain accurate and useful data.

Selecting the proper location on equipment may not be as easy as it seems. If the wrong type of sampling is performed or the sample port is placed in an inactive zone, a unit may end up failing while the data analysis continues to show positive results.

Safety can also be an issue. Is the unit a high-pressure hydraulic? Be sure to check that if a sample port is being installed, the pressure rating is within the proper range.

Step 4: Procuring the sample

If the drop tube sampling method is chosen and only diesel engines are used, this choice is an easy one. Buy a vacuum gun and get to work. If, however, there are challenges with ensuring the proper location has been chosen for taking samples, this can be a significant problem. There are many reasons why particular units cannot be sampled at any point in time.

There is always going to be a unit that just doesn't have a feasible solution, but there are typically solutions for problems if one is willing to dig in and search. Make sure that when the equipment and sampling method have been selected, the ability to pull the sample exists as well.

If you encounter a problem while searching for a way to retrieve samples from a piece of equipment, the equipment vendor may be able to provide a solution. If there is no equipment vendor available, look up a sampling equipment vendor on the Internet (or just continue looking through this magazine - there are usually several). If the first vendor cannot find a solution to the problem, try another one.

Step 5: How often is a sample needed?

Sampling frequency can be dictated by two factors: what the user is trying to find and how fast it needs to be found. Cost can also be factored in because monthly sampling is not always an option. However, if cost for having the analysis completed becomes a major issue, the scope of the sampling project may have to be changed to effectively limit sampling to a financially manageable situation that doesn't involve randomly removing units from the sampling plan.

When determining the frequency of sampling, issues such as the likelihood of failure and equipment history should be addressed while deciding which interval to set up the equipment.

The more frequently sampling takes place, the more effective one will be at discovering problems before a failure occurs. Most oil analysis users have heard stories involving a failure that went from inception to disaster in a matter of days. While this is the exception rather than the rule, keep in mind that failures can happen quickly, and it is necessary to limit exposure to that magnitude of failure on units that will cripple operations if they go down.

A functional equipment history may be the difference between a good call and a complete miss with the analysis. A unit sampled yearly to monitor oil will not provide the analyst with much equipment history. Quarterly sampling may be the beginning of a stable and trendable equipment history, and with monthly sampling, there is a 90 percent range of problem detection before failure.

Step 6: Tests

Which tests are needed is strictly determined by what one wants to find with the testing. Viscosity and acid number tests may be useful if it is just to monitor lubricant health. To monitor equipment health, metals and ferrous density testing may be the route to take. Most oil analysis users look for a combination of equipment health, lubricant health and lubricant cleanliness.

Many oil analysis providers offer discounted packages for oil analysis geared toward general equipment types, so be sure to ask for any packaged tests that receive a discount to meet specific needs.

In conclusion, if all of these fundamental questions are brought to the table when traveling down the path of lubrication excellence, and the answers have proved appropriate, then an effective program which has a solid foundation and a rewarding outcome should be in place.

5. Oil sampling do's and don'ts

By Jason Kopschinsky, Noria Corporation

Oil analysis is a condition monitoring tool designed to monitor:

- fluid properties, or the condition of the oil and the additives;
- fluid contamination; and
- machine wear.

However, the analysis of a sample greatly depends on the quality of the sample itself. These simple rules will ensure that the sample is right. Oil sampling is a critical step in the oil analysis program. A poor sample creates inaccurate results. Garbage in equals garbage out.

Physically taking an oil sample the most important part of the program. The oil analysis program cannot recover from a poor sample and the erroneous data that it generates. Clean, new sample bottles and tubing, proper sampling ports and locations are all critical to the success of the program.

The oil sampling evaluation category goes beyond taking a physical sample. The plant should have a comprehensive list of all of the equipment sampled. The program should also include taking samples of the new oils delivered to the plant, both in bulk and in drums. This is necessary to ensure that quality control measures, primarily for contamination reasons, are adhered to by the oil supplier.

A written oil sampling procedure may sound like an unnecessary step, but it will help ensure consistency in the samples taken. The frequency and the consistency of samples can be determined from viewing the oil analysis reports and are important to the success of the program. Samples need to be sent to the lab within two working days to ensure the timeliness of receiving results back from the lab.

1) **DO sample from running machines. DO NOT sample “cold” systems.**

The proper oil analysis captures a “snapshot” of the system at the time of sampling. The timing of the sampling should be when the system is under the greatest amount of stress. Typically, the best time to sample a system is when the system is under normal working load and normal conditions. his can be a tricky task when sampling from a system that continuously cycles during normal production, such as the hydraulic system on an injection moulding machine. It’s under these conditions that we’ll capture a sample that best represents the machine conditions most likely to cause accelerated wear.

2) **DO sample upstream of filters and downstream of machine components.**

Filters are designed to pull out wear debris and contaminants, so sampling downstream of these data-strippers provides no value. However, taking a sample before and after a filter for a simple particle count will allow you to see how well the filter is currently operating. Obviously, we expect the particle count before the filter to be higher than after the filter. If it’s not, it’s time to change the filter. Condition-based filter changes can be very important for sensitive systems and expensive filters.

3) **DO create specific written procedures for each system sampled.**

DO NOT change sampling methods or locations. Everything we do in oil analysis and machinery lubrication should have a detailed procedure to back up the task. Each maintenance point in the plant should have specific and unique procedures detailing who, what, where, when and how. Oil sampling procedures are no different. We need to identify the sample location, the amount of flush volume, the frequency of sampling, the timing within a cycle to sample, and indicate what tools and accessories to use on that specific sample point based on lubricant type, pressure and amount of fluid required.

4) **DO ensure that sampling valves and sampling devices are thoroughly flushed prior to taking the sample.**

DO NOT use dirty sampling equipment or reuse sample tubing. Cross-contamination has always been a problem in oil sampling. The truth of the matter is that flushing is an important task that is often overlooked. Failure to flush the sample location properly will produce a sample with a high degree of noise. Flushing prior to sampling needs to account for the amount of dead space between the sample valve and the active system multiplied by a factor of 10. Flushing the dead space also will flush your other accessories such as your sample valve adapter and new tubing.

5) **DO ensure that samples are taken at proper frequencies. DO NOT sample "as time permits.**"

Many of those responsible for taking oil samples rarely see the results of the analysis. One of the most powerful aspects of oil analysis is identifying a change in the baseline of a sample and understanding the rate at which the change has occurred. For example, a sample of new oil should have zero parts per million (ppm) of iron when tested as the baseline. As regular sampling and analysis continues, we may see the iron level increase. An increase of 10 or 12 ppm per sample may be considered critical; however, if the frequency is not consistent, what is considered normal becomes very subjective. If our frequency of sampling is 12 months, a rise in iron of 12 ppm isn't a major cause of concern. If our frequency is weekly, a rise in iron of 12 ppm is very concerning. Setting up the appropriate sampling frequency and adhering to it will allow for precise analysis and sound maintenance decisions.

6) **DO forward samples immediately to the oil analysis lab after sampling.**

DO NOT wait more than 24 hours to send samples out. As mentioned earlier, oil sampling is much like taking a snapshot of your system at a point in time. he health of a lubricated system can change dramatically in a very short period of time. If a problem is detected in a system, the earlier it is detected, the less catastrophic potential it may have. Jumping on a problem early will not only allow you time to plan for a repair, but the repair will potentially be less significant.

Apply these rules today!

Each and every system will have unique and specific considerations for what to do and not do when sampling but the tips in this article can be applied to most systems in your sampling program.

6. World-class oil sampling - it is possible

By Jason Kopschinsky

When it comes to achieving a world-class oil analysis program and realizing all the benefits of condition-based maintenance, there are several milestones that must first be met.

One of the most important milestones of an oil analysis program is the sampling of the oil. The way a sample is collected, the frequency, the accessories used and the procedures followed all dictate how informative the oil samples will be and, subsequently, dictates how beneficial the results will be.

The following questions should be answered when designing a sampling program:

- Where is the best location to draw an oil sample to ensure the correct information is collected?
- What are the best tools for drawing a sample from a specific location?
- Who will be responsible for pulling the sample and how consistent will the sample be each time it's drawn from the specific location?

Sampling port location

Oil analysis is greatly assisted by the installation of sampling ports in various locations. Sample ports are classified into two categories, primary and secondary.

Primary sampling ports

The primary sampling port is the location where routine oil samples are taken. The oil fluid from this sample location is usually used for monitoring oil contamination, wear debris and the chemical and physical properties of the oil. They are typically located on a single return line prior to entering the oil reservoir.

Secondary sampling ports

Secondary sampling ports can be placed downstream from system components. This is where contamination and wear debris contributed by individual components will be found.

Consider a lube oil pump that feeds three sets of bearings. The return for the three bearings combines into a single return line before entering the sump. The primary sample port is on the single return line after all three bearing lines join and before the oil enters the sump. Four secondary sampling locations are immediately downstream of the pump (upstream of the three bearings) as well as downstream of all three bearings.

As an example, a particle count ISO 16/13 is reported (32% of which are ferrous particles). This level exceeds the target of 14/11 and reflects a problem in the system. This sample drawn from the primary sample port informs us that something has changed in the system, but not what has changed. The secondary sample ports pinpoint the precise location of the problem. The particle counts on the secondary sample ports indicate the cleanliness level of ISO 13/10 downstream of the pump. Therefore, the oil being delivered to the bearings is fairly clean suggesting that the pump is not the cause of the wear. The secondary samples after Bearing 1 shows ISO 14/11, after Bearing 2 ISO 18/15 with 25% ferrous, and after Bearing 3 ISO 14/11. The tests indicates Bearing 2 is showing wear.

Exception testing of the oil sampled from Bearing 2, such as analytical ferrography, is used to determine what is causing wear.

Secondary sample ports can also be used to monitor the general performance of filters. The primary port will show what's going into the filter while the secondary ports show what is coming out. This procedure enables a filter change based on condition, long before the differentiated pressure indicator shows a filter is in bypass.

Drop-tube sampling

Drop-tube vacuum sampling is a simple, low cost way to draw a sample for oil analysis. However, in order to draw a sample, the machine must be opened, and therefore the oil is exposed to the environment. Opening a machine potentially allows significant amounts of airborne contamination to enter the oil and cause damage.

The key to an effective oil analysis program is the ability to draw an oil sample from a specific location while the machine is in operation and under normal load. However, when using the drop tube method on a gearbox while it's running, the plastic tubing may be pulled into the gearbox. This presents safety concerns for the person taking the sample.

Other problems associated with drop-tube sampling include large required fluid flushing volume, difficulties in getting a consistent sample form the same location, and problems with sampling high-viscosity fluids. In summary, this method of oil sampling should be avoided when possible. In summary, drop-tube sampling is not recommended for engines because the machine has to be shut down, the tube's final point is difficult to control, and the tube may pick up contaminants on the way in.

Reservoir sampling valve

The ideal location for drawing an oil sample from a sump or reservoir is to get it as close to the return line, gear set or bearing as possible. However, as previously mentioned, for circulating systems the preferred location is on the return line, not the reservoir. Another rule-of-thumb is to sample at 50% of the oil level. Sumps and reservoirs were designed to hold a large volume of oil, to dissipate heat and to allow air to rise and contaminants to settle. Therefore, the most concentrated contamination is on the bottom of the sump or reservoir and the cleanest oil towards the top. Avoid using the drain plug for sampling if it sits on the bottom of the sump, even if you flush high volumes of oil before drawing a sample.

If the drain port is the only way to obtain a sample from the gearbox, there are commercially available sample tubes that can be installed on the bottom or the side of the sump. These inward pilot tubes can be manipulated to ensure that the sample is drawn from the most appropriate location of the sump or reservoir, and that the sample is taken from the exact same location inside your system each time. This method is a more consistent and representative way of sampling oil than drop-tube sampling.

Sample valves and trap pipes

There are several commercially available sample valves. Perhaps the most effective choice, typically used on larger systems, is the *Minimess* sample valve.

On pressurized systems, consider safety. Pressure reducing valves can be used with sample ports to reduce pressures 100 times. Another benefit to these types of sampling valves is that they retain only a very small dead volume of static oil. So less oil needs to be flushed prior to taking a sample.

Trap pipes are excellent for pulling a sample from a vertical, non-flooded line of pipe coming from a bearing housing or gearbox. Typically, vertical, non-flooded lines of pipe cause the oil to spiral down the inside wall of the pipe. The trap pipe traps a portion of the oil flow to draw a data rich oil sample in a representative location.

Sample bottles

Most oil analysis labs will supply sample bottles. It is important to be aware of the cleanliness of the sample bottle.

Choose a low cost bottle with a consistent cleanliness. Most bottles available fall into the "clean" category. "Clean" bottles have less than 100 particles greater than 10 microns/ml. "Super clean" bottles have less than 10 particles greater than 10 microns/ml. "Ultra clean" bottles are also available, they are usually glass bottles that have been thoroughly washed and dried in a "clean room" environment. These bottles might cost more than the oil analysis and once the bottle is opened in a typical work environment, it is no longer "ultra clean." (Refer to ISO 3722 for bottle cleanliness guidelines.)

Beware of the "sanitized" or "sterilized" lab bottles. Sterilized means that there is no bacteria living in the bottle, however, there may still be high concentrations of particle contamination inside the bottle.

Though bottle cleanliness is important, the cleanliness of a bottle will only affect results at higher oil cleanliness levels. For example, if the cleanliness code is an ISO 19/16, there are between 2500 and 5000 particles greater than 5 microns/ml in the sample. At this level of contamination, typically the bottle cleanliness will not interfere with the particle count or ISO Code. On the other hand, if the cleanliness code is an ISO 12/9 that means there are between 20 and 40 particles greater than 5 microns/ml in the sample. A bottle that falls under the “clean” category will have a disturbing effect on results because the contamination in the bottle can add up to 100 particles greater than 10 microns/ml.

The most popular bottle is made from PET (polyethylene terephthalate). This clear bottle allows the analyst to use sensory evaluation on the sample. This bottle is compatible with most industrial lubricants and is readily available.

Opaque HDPE (high-density polyethylene) bottles are also fairly inexpensive and offer excellent compatibility with a variety of liquids.

Glass bottles are excellent with respect to cleanliness, visual inspection and fluid compatibility. They cost more and are easy to break. Be sceptical of inexpensive glass bottles and question their actual cleanliness.

Sample port Identification

Label sampling ports with corrosion resistant tags. These tags should display the information needed by the technician to obtain a proper sample.

You may to include items such as:

- sample port number
- machine number
- lubricant name

Bar coding identification tags are another good way to label the port.

Summary

Your program should not depend on one person alone. Procedures and guidelines should be set up and monitored. These should include the frequency of the sampling on a given piece of equipment, the method and the tools used to get the sample, the amount of oil to flush prior to pulling the sample, how the bottle is to be labelled and what information it will contain, which tests are done on a regular basis and which tests are done on exception.

7. Establishing effective sampling frequencies

Noria Corporation

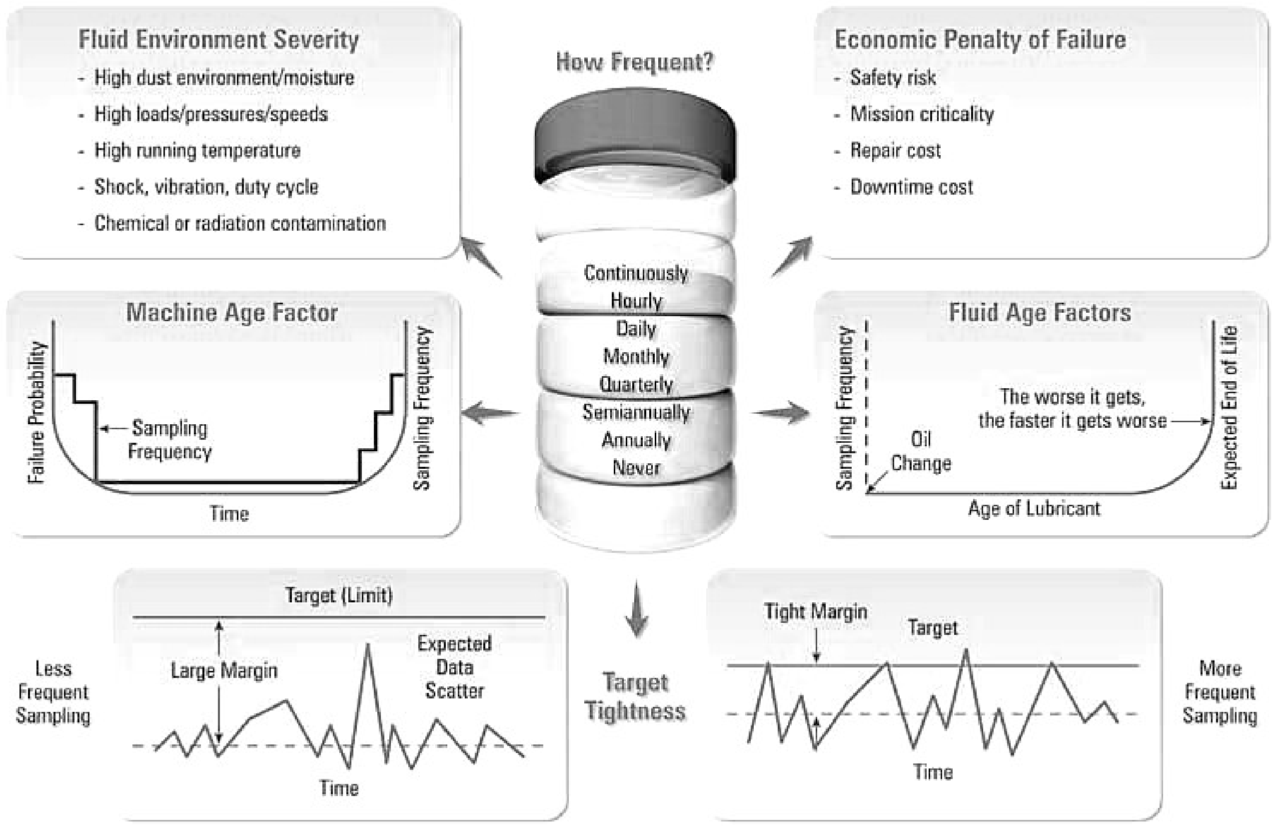
Every machine is unique and therefore, sampling frequencies should be set specifically for a particular machine. One of the most prominent questions in a person’s mind when discussing an oil analysis program design is, “How often should I sample this machine?” The simple answer is, “What is the required reliability of the system?” One simply cannot offer an opinion without understanding the value of the machine to the business, and the safety risks associated with failure.

Predictive vs. proactive

When selecting sampling frequencies, it is important to consider whether a predictive or proactive strategy is to be used. With a predictive approach, the program is geared toward looking for signs of impending failure. Because no warning sign is too soon, a predictive oil analysis strategy may mean more frequent sampling.

With a proactive approach, the key focus should be monitoring root cause parameters, such as contamination or lubricant degradation. In this case, the sampling frequency will depend on the criticality of the unit, the application and environment severity, the age of the lubricant and the machine, and how tightly goal-based targets have been set.

Although proactive oil analysis usually means higher cost due to the inclusion of more sophisticated tests, in the long term, it usually reduces overall sampling cost with more time spent solving root cause problems and less time recovering from failures.



Assume that for a specific machine, safety, process criticality and economic penalty of failure dictate that sampling should be online, and in real-time. These factors suggest the need to procure an online instrument. Conversely, if the sample frequency analysis reveals a three-month interval is appropriate, then a commercial laboratory service may be the answer. In this case, sample frequency influences not only how often an oil sample is taken, but also the entire approach to oil analysis program design.

Optimizing with the sample frequency generator

This is a systematic method with which to estimate the optimized sampling frequency, taking into account economic penalty of failure, fluid environment severity, machine age, oil age and the tightness of goal-based target like contamination control.

To use the tool, select the application in the 'best-fit' default frequency in Step 1. Then select the adjustment factors identified in Step 2.

Step 2 is pseudo-quantitative, meaning that one selects a number to represent his or her opinion. Because opinions vary, each machine type should be scored by a group of people.

Multiply Step 1 by the lowest score in Step 2 to arrive at the adjusted sampling interval.

Adjustment factors are explained on page 17.

Sample Frequency Generator

1. Select 'Best Fit' Default Frequency

Bearings	500 hrs	Gearing, Low Speed	1000 hrs
Chillers	500 hrs	Hydraulics, Aviation	150 hrs
Compressors	500 hrs	Hydraulics, Industrial	700 hrs
Differentials	300 hrs	Hydraulics, Mobile	250 hrs
Engine, Aviation Recip	50 hrs	Transmissions	300 hrs
Engine, Diesel	150 hrs	Turbines, Aviation	100 hrs
Final Drives	300 hrs	Turbines, Gas	500 hrs
Gearing, Aviation	150 hrs	Turbine, Steam	500 hrs
Gearing, High Speed Industrial	300 hrs		

Write Default Here

Default
Hrs

2. Score Application Adjustment Factors

Economic Penalty of Failure - Circle Factor

Very High				Normal					Low
0.1	0.25	0.5	0.75	1.0	1.25	1.5	1.75	2.0	

Consider downtime costs, repair costs and general business interruption penalty.

Fluid Environment Severity - Circle Factor

Very High				Normal					Low
0.1	0.25	0.5	0.75	1.0	1.25	1.5	1.75	2.0	

Consider pressures, load, temperature, speed, contaminants in oil and duty cycle.

Machine Age - Circle Factor

Infant					Middle Age					Old Age
0.1	0.5	1.0	1.5	2.0	2.0	2.0	1.5	1.0	0.5	0.1

Infant machines are those going through break-in and have operated for less than 1% of expected machine life. Old age machines are those showing symptoms of distress.

Oil Age - Circle Factor

Infant					Middle Age					Old Age
0.1	2.0	2.0	2.0	2.0	1.5	1.0	0.5	0.25	0.1	

Infant oils are those that have just been changed and are less than 10% into expected life. Old age oils are showing trends that suggest additive depletion, the onset of oxidation or high levels of contamination.

Target Tightness - Circle Factor

Tight				Normal					Loose
0.1	0.25	0.5	0.75	1.0	1.25	1.5	1.75	2.0	

Oil properties that trend extremely close to targets and limits are 'tight'. Oils that typically trend well within targets and limits are loose. For instance, an oil with a cleanliness target of 13/11 and trends around 13/11 is tight.

Place Lowest Circled Factor Here

Adjustment Factor

3. Sample Frequency = Default x Adjustment Factor

Sample Frequency
Hrs

Economic penalty of failure

The economic penalty of failure doubles the sampling frequency if the potential failure is not critical ("Low"), but would increases it ten fold if it is critical ("Very High"). The penalty of failure must take into account the cost of downtime, the cost of repair, the overall interruption to business and the impact on product quality and output.

Fluid environment severity

The opportunity for contamination, but also the demands placed on the lubricant by the machine. This includes the pressure, speed and load, as well as the duty cycle. The greater the risk of lubricant damage, the more frequent the sampling.

Machine age

Sampling frequencies must be modified according to the classic 'bathtub' curve. In general, component failure is most likely during break-in, due to infant mortality, and of course as a component reaches the end of its natural life. For this reason, sampling frequencies must be increased during these periods.

Oil age

Aside from the obvious new oil sample for baseline purposes, the lubricant needs a frequent recheck in the first 10 percent of its expected life to ensure that it is bedding in correctly. This is particularly true when a new oil type or supplier is used. A lubricant is more likely to suffer a mid-life crisis than a machine when exposed to accidental contamination. In the end, there is additive depletion, oxidation and heavy contamination.

Target tightness

If a fluid cleanliness target is ISO 15/13/10 and the average fluid cleanliness is normally around ISO 14/12/9, then this is considered tight (=close), while if it typically meets ISO 11/9/6, then this is considered loose. Tight targets require more frequent sampling because of the likelihood of exceeding the target.

Putting sampling intervals to work

In the worst-case scenario, an adjustment factor of 0.1 could indicate a daily sampling frequency. In this case, the use of online sensors is likely the most cost-effective strategy because the initial cost would soon be recovered in the savings on laboratory expenses, or even the manpower costs. However, an online portable unit might also be considered if a number of systems require daily sampling because one unit can be applied to a number of machines.

This approach is designed for a proactive strategy, which requires frequent analysis to check for root cause conditions. However, predictive programs designed to look for signs of impending failure also require frequent sampling, because a filter failure or a coolant leak can happen instantly and, if left unnoticed, will cause significant damage.

8. Finding the root causes of oil degradation

Greg Livingstone, Ept, Inc.; Dave Wooton, Brian Thompson, Analysts, Inc.

The objective of a root cause analysis (RCA) is to identify what happened, why it happened, and what can be done to prevent it from happening again.

Fluid degradation can be responsible for many kinds of equipment failures. A lubricant in service is subjected to a wide range of conditions which can degrade its base oil and additive system. Such factors include heat, entrained air, incompatible gases, moisture, internal or external contamination, process constituents, radiation and inadvertent mixing of a different fluid.

Oxidation is the reaction of lubricants with oxygen. It can be responsible for viscosity increase, varnish formation, sludge and sediment formation, additive depletion, base oil breakdown, filter plugging, foaming, acidity, rust and corrosion. In industrial applications, viscosity increase of 5% is ”caution” and 10% or more is “critical”.The acidity is measured by Acid Number (AN). AN increase of 0,2 is ”caution” and 1,0 or more is “critical”.

Thermal breakdown. Overheating can cause the light ends of the lubricant to vaporize or the lubricant itself or its additives can decompose, e.g. larger molecules can break into smaller molecules. This thermal cracking, often referred to as thermal breakdown, can induce polymerization or produce gaseous by-products, destroy additives and generate insoluble by-products. In some cases, thermal degradation can cause a decrease in viscosity.

Microdieseling, also known as **pressure-induced thermal degradation**. As the lubricant separates heavily loaded machine parts, air bubbles in the lubricant are pressurized resulting in adiabatic compression. This may produce localized temperatures in excess of 1000 °C, resulting in the formation of carbon deposits and accelerated oil degradation.

Additive depletion. Most additive systems are designed to be sacrificial. Monitoring additive depletion can be complex depending upon the chemistry of the additive component. Usually, more than 90% of the original additive level is acceptable, less than ”caution” and less than 75% is “critical”.

Electrostatic spark discharge. When clean, dry oil rapidly flows through tight clearances, e.g. in mechanical filters, internal friction within the oil can generate static electricity that may accumulate to the point where it produces sparks. These sparks, between 10 000 °C and 20 000 °C, can do a lot of damage.

Contamination. Metals such as copper and iron are catalysts to the degradation process. Water degrades some additives and and air provides a source of oxygen.

RCA must start with an understanding of the problem and its potential causes. A list should be generated identifying every possible cause. Care should be taken to not assign blame at this point in the investigation. For each potential root cause, experiments and tests should be constructed to test theory validity. Keep in mind that data proving any theory false (the devil's advocate approach), is as important as the normal approach - because this can also be used to support the correct root cause and destroy incorrect assumptions.

This is a part of a technical paper that appeared in the *Conference Proceedings* from Lubrication Excellence 2006. The full-length article with case studies can be found in the LE2006 *Proceedings.* The Internet version also gives description of various test methods.

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9. What's hot? Current trends in lubrication and oil analysis

Jim Fitch, Noria Corporation

The trends I want to emphasize are those that meet one or more of the following criteria:

- they have staying power;
- they are value-based (reduce costs and/or increase productivity);
- they are new problem-solvers (overcome previously unresolved problems);
- they are better problem-solvers (provide measurable improvements over prior

methods).

Trends in lubricant selection and use

Correct viscosity: More precise selection of viscosity is getting renewed attention. Viscosity affects a number of important factors, including energy consumption, wear and tolerance to contamination. This relates to not only the ISO viscosity grade, but also to the viscosity index.

Not selecting lubricants solely on film strength: Today's lubricants need a range of performance qualities, so choosing a lubricant that delivers the complete package is the greater priority. This includes (depending on lubricant type) such features as dispersancy, foam suppression, moisture-handling ability, corrosion protection, oxidative stability, viscosity index and good lubricity.

Judicious use of premium and synthetic lubricants: The rage to switch to premium and synthetic lubricants as a silver bullet for every problem is winding down. We are now more aware of the true strength of these lubricants and their appropriate application. They can indeed solve a plethora of problems, but not all problems. Precision lubrication means correctly matching these lubricants to the applications to which they are best applied.

Energy-conserving and environmentally friendly lubricants: In the past 10 years, huge strides have been made in this area, but even then, it seems we've barely scratched the surface. Brace yourself as the pace of change in this area greatly picks up steam.

Replacing grease with oil in mission-critical applications: The debate continues on the *grease versus oil* front. From my vantage point, the balance of power is tilting toward oil in a range of reliability-critical industrial applications.

See: http://www.machinerylubrication.com/Read/923/grease-oil

Dumping economy formulations: Buying lubricants from the lowest bidder is rarely a recipe for achieving machine reliability at the lowest possible cost. It's time to stop pretending to save money by buying cheap, commodity-grade lubricants to save a quick buck at the expense of tomorrow's need for reliability. Through greater awareness and education, large user organizations are finally getting the message.

Additive reconstruction: You wouldn't discard a new car the first time it ran out of windscreen wiper fluid. Despite cries of resistance from some industry players, when done using sound practices, many depleting lube oil additives are candidates for a booster shot, as more and more users are discovering.

Stopping contamination

The space above the oil level: Many contaminants enter a lubricant by means of the head space above the tank or sump oil level. There are methods to restrict this.

Smart filter carts: Filter carts can do much more than clean new or used oils. Many are instrumented with computers and oil analysis sensors, enabling them to perform a number of smart tasks - even while unattended.

Dryer and cleaner targets: Aggressive setting of target dryness and cleanliness levels is one of the best means to boost and sustain machine reliability.

More focus on a lubricant's air-handling ability: In the past, entrained air and surface foam weren't much more than a casual concern. Today's users are responding to aeration and foam issues before harm is done.

Addressing contaminant exclusion first: Restoring a contaminated lubricant to a clean and dry state can be costly. Keeping lubricants clean and dry is a much more economical alternative. Far greater attention and resources are applied to controlling ingress of contaminants rather than simply controlling contamination by filtration.

Varnish management: Varnish problems have reached nearly chronic levels in certain applications in recent years. In response, a flurry of new products and services has been rolled out to keep varnish in check. More such products are likely on the way.

Oil analysis

Multiple technologies in condition-based maintenance (CBM): Tools should work together and not in isolation to achieve reliability. Oil analysis is increasingly being teamed with vibration analysis, infra-red thermography and other technologies to enhance the machine reliability.

Particle counting of opaque fluids (like engine oil): Fluid cleanliness is as important in machines lubricated with opaque fluids as it is for those that use turbine oils and hydraulic fluids. After all, if it's important, you measure it. Particle counts of engine oils are currently being performed successfully by labs that have recognized this need.

On-site oil analysis in an instant-information world: Despite frequent claims to the contrary, many oil analysis labs can't seem to achieve quick turnarounds on oil analysis data. On-site labs for those who want to know now can be the answer.

Live zone sampling: Pulling samples from sump bottoms and large reservoirs is being phased out. Such defective practices cripple the potential value of oil analysis. Modern programs place primary and secondary sampling ports in active "live zones".

The database in your filter: The filter is the recipient of a vast amount of root cause and symptomatic information relating to your machine and oil. Start inspecting and analysing it.

See also: http://www.machinerylubrication.com/Read/826/oil-filter-analysis

http://www.machinerylubrication.com/Read/397/filer-element-examination

Reporting the RUL: Monitoring the remaining useful life (RUL) of a lubricant is one of the primary objectives of oil analysis. For instance, tracking the progressive depletion of additives provides a relatively good estimate of RUL.

Grease sampling and analysis: Despite its inherent challenges, new methods have been introduced to simplify the sampling of grease for analysis by labs the same way that oil has been done for years.

See also: http://www.machinerylubrication.com/View/1761/grease-sample-bearing

http://www.machinerylubrication.com/Articles/Search?query=grease

http://www.machinerylubrication.com/Read/296/grease-analysis

http://www.machinerylubrication.com/Read/26933/quick-easy-test-grease-conditions

Online sensors and real-time monitoring: There are now online sensors for nearly every data parameter.

Suppliers

Buying more than lubrication: The emphasis is less on cost and performance and more on a broader range of capabilities and lubrication deliverables, including quality, service, support, contamination control etc.

Chain-of-custody quality control: Many big-brand lube marketers are taking aim at quality at each link within the chain of custody. Included are additive and base oil suppliers, blend plants, distributors, transport companies and jobbers. Cleanliness and dryness now are being included in the definition of quality.

Packaging, storage, handling

Lubricant expiration dates: The use of visible expiration date markings on lube package labels is finally becoming widespread.

Graphical lubricant tagging: The risk of accidental use of the wrong lube in a machine is totally unnecessary. Modern tagging methods for lubes include the use of naming system, shape coding and colour coding that make cross-contamination of lubricants nearly impossible.

Good housekeeping: Well-designed and well-kept lube storerooms are a good start. Remove outdated tools such as unclean funnels that can contaminate the lubricant.

People and metrics

The death of the oiler: Pride in one's profession is good for the employee and good for the employer. Lubrication shouldn't be treated as a mindless task. An oiler is an oil can, not a living, thinking person. On the other hand, a lube technician is an individual who is trained, has the tools he needs, is empowered, works from the neck up and is paid well.

Working the metric: People respond to measurement (what gets measured gets done). There are all kinds of potential metrics, including those that are lagging and leading (what just happened, what's going to happen). Good metrics need to provide conspicuous reporting of program performance relative to goals. They need to include overall lubrication effectiveness (OLE) and preventive maintenance (PM) compliance.

The power of an educated and certified workforce

Training: Reliability and condition monitoring specialists are adding new technologies. Multiple certifications (in oil analysis, vibration and thermography) by individuals is increasingly more common.

PM, methods and tools

Machines: Most machines aren't ready for modern lube methods. They lack the basic accessories for live-zone sampling, contamination control, quality inspections, condition-based maintenance and correct re-lubrication. As a result, one of the first steps of lubrication excellence is to select the correct accessory items and fit them to the machine.

Not just any procedure: Procedure-based maintenance needs to deploy the "rights of lubrication" (i.e., the right lubricant, the right procedure, the right location, the right frequency, the right tools, etc.). Doing lubrication and doing lubrication "right" are two entirely different concepts and have different reliability outcomes.

Lubrication and the computer age: The opportunities are enormous and include automated delivery of work plans, dynamic routing, tools management, workforce and skills management, and material management.

One-minute daily inspections: Daily critical lube inspections often can be more effective than even the most sophisticated oil analysis program performed monthly. After all, you can't catch a fish unless your hook is in the water. Learn the modern skills of doing these daily inspections.

Bottom sediment and water: Nearly all of the things that you don't want in your oil are heavier than your oil. These include wear particles, sludge, water, antifreeze and dirt. Put BS&W on your inspection route.

Site glass oil analysis: Checking oil colour, foam, aeration and water on a daily basis is a smart idea, as many have found out. Put this on your inspection route, too.

Optimizing re-lubrication frequency: Many users are revisiting past decisions relating to re-greasing and oil drain intervals. This includes pro-actively improving the use of lubricants to extend service life as well as re-lubricating on condition or at least at intervals more closely relating to actual need.

Grease guns: Today's grease guns can be instrumented for more precise lubrication and include options such as volume meters, sonic pick-ups and back-pressure gages. The grease gun is still alive and well in the world of lubrication.

10. Wear limits vs. trends

John S. Evans, Wearcheck South Africa

Common questions asked by users of oil analysis include "What wear limits do you use?" and "What levels are normal and abnormal?"

These questions are not unreasonable. A number of original equipment manufacturers (OEMs) specify wear limits for their equipment; unfortunately, they are generally not an effective means of determining the health of a component. The levels of contamination and wear debris in an oil sample depend on too many factors for an equipment manufacturer to sort through; for example wear tables that say 0 to 50 is OK, 50 to 100 indicates a problem and over 100 is serious. This runs the risk of saying that 49 is acceptable and 51 is not when, in this case, the difference is insignificant.

Limits and trends

The wear limit tables produced by OEMs are based on extensive research and testing by manufacturers. These people understand the equipment but, at the end of the day, the tables reflect average situations and can be used only as a guideline. They are not specifically set rules or standards. Machines rarely work in average situations, and limits determined in certain environments often have little relevance in other environments, particularly in Africa, where a minimal amount of equipment is manufactured. What holds true for North America, Western Europe or Japan might not be the case for South Africa.

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

- type of equipment
- environment
- the job it is performing
- operator skill
- length of time the oil has been in use
- oil consumption

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

Wear limits do, however, have their uses. If a diagnosis is made on the health of a component based on oil analysis and a trend is used, then a minimum of three samples is required to establish that trend. This makes one-off samples difficult to diagnose. Wear limits are useful in these situations because they provide a guideline of how the average machine should behave under normal conditions. If the unit shows signs of being critical, then the diagnosis is easy to make. However, it is the in-between cases where problems might occur, which are difficult to assess on a one-off basis without the help of a trend.

Oil analysis detects minor problems and corrects them before catastrophic failures occur. Regular oil sampling, as opposed to taking samples only when a problem arises, is important in preventing unnecessary failures. Typically a one-off sample without a trend won't supply enough information to determine the cause of a problem.

Another problem with wear limits is the range of tests they cover. Traditionally, these limits have covered only wear metals and contaminants that are detected by a spectrometer. This test provides useful information, but has one major drawback: it can detect only particles smaller than eight microns, these particles are minute. Therefore, it is possible for the wear limit tables to indicate normal behaviour when a severe wear situation could exist with particles greater than eight microns, which cannot be viewed by the spectrometer.

These are frequent and valid explanations taking caution when using wear limits. By using wear limits, users sometimes assume that all results from the chemical and physical tests are studied in isolation, which is an inaccurate viewpoint. The results of oil analysis must be looked at holistically. Fifty ppm might be acceptable in one situation and unacceptable in another, and the only way to determine this is by studying other readings and available information. In other words, one must look at the whole picture. It is possible that identical samples from truck A and B reflect different diagnoses because the history (trend) for the two vehicles is different.

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

Dirt entry! ... Or is it?

Dirt, grit, airborne dust - it's all the same thing and is ubiquitous. It is also damaging to machinery because if it gets into the oil, it will form a grinding paste that causes wear rates to accelerate rapidly. Fortunately for the oil analyst, dirt is composed mainly of a compound called silicon dioxide, and silicon can be easily detected in oil by spectrometric analysis.

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

Example	Fe	Al	Cr	Cu	Na	Si	
1	35	8	3	15	12	15	Normal
2	92	29	16	20	16	69	Severe Dirt Entry
3	38	9	4	124	243	101	Internal Coolant Leak
4	35	8	3	15	12	250	Silicon Sealant Used
5	36	10	5	10	19	31	High Anti Foam Level
6	105	134	38	20	21	145	Fuel System Fault - Piston Torching

Table 1 High silicon

Example	Fe	Cr	Al	S	Si	
1	35	8	3	7	15	Normal
2	120	25	10	35	68	Dirt Entry - Detroit Two-stroke Engine

Table 2 Dirt entry

Example	Fe	Cr	Al	Zr	Mn	Si	
1	35	8	3	0	0	15	Normal
2	99	19	25	154	0	29	Dirt Entry - Richards Bay
3	104	18	27	0	217	28	Dirt Entry - Manganese Mine
4	35	8	3	15	12	250	Dirt Entry - Chrome Mine

Table 3 Dirt entry

Example	Cu	Pb	Sn	Fe	Na	Mg	Ca	
1	15	20	5	48	10	500	2,000	Normal
2	68	71	15	108	10	500	2,000	Bearing Wear
3	105	39	10	48	120	500	2,000	Internal Coolant Leak
4	105	39	10	48	10	500	2,000	Leaching - Oil Cooler Core
5	200	20	5	48	10	1000	100	Oil Additive

Table 4 High copper

Tables 1 through 4 portray a typical set of spectrometric results from an engine operating normally with no evidence of dirt entry.In **Table 1**, the second example shows an increase in silicon with higher wear readings. This is typical of dirt entry through the air induction system: the silicon indicates dirt during an increase in iron (from wear of liners), chrome (rings) and aluminium (pistons).

The third example also shows an increase in silicon, but this was caused by an internal coolant leak. When cooling water leaks into the engine, it typically evaporates. However, the additives (such as antifreeze) in the cooling water are left behind, and silicon may be part of the coolant conditioner make-up (sodium meta silicate). In this case, the sodium and copper readings increase but others do not. The sodium is also an additive and the copper is not a wear metal but has leached from the radiator core. The silicon is high but it is a contaminant from the cooling system and not abrasive dirt.

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

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

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

In **Table 2**, the first set of results shows a normal set of readings. The second set shows top-end dirt entry in a Detroit diesel two-stroke engine, where the iron, chrome and silicon have increased but the aluminium to silicon ratio seems incorrect and the tin level is higher. This is caused by the aluminium piston being covered with a flashing of tin to facilitate the conduction of heat.

Table 3 shows the normal readings and three examples of dirt entry through the air induction system (higher iron, chrome and aluminium) without the increase of silicon. These engines are running at Richards Bay - a mineral sands mine, a manganese mine and a chromium mine. Here, the dirt consists of the minerals that are a part of the environment where the machine is working and the silicon won't necessarily increase when dirt entry occurs.

These examples are seen on a fairly regular basis, except piston torching, as it tends to be a sudden death problem. They illustrate four situations:

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

Silicon is a good example for illustrating the value of trending and observing the oil analysis results holistically where an increase in readings can have different interpretations depending on other readings. This is one of the reasons why wear limits can be misleading and at times completely wrong.

Copper can be misleading too

Table 4 shows how an increase in copper can be caused by:

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

The first example in Table 4 shows a normal set of results. The second example indicates high copper levels with an associated increase in lead, tin and iron that would typically indicate bearing wear.

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

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

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

Generally, the spectrometric readings (elements) can be grouped into three classes: wear metals, contaminants and oil additives.

Most of the elements can belong to any one of these classes. Only by viewing the readings simultaneously can the correct class be assigned. It is important to remember that an elevated reading can be caused by more than one reason at a time.

In the example of the internal coolant leak, it is possible for other readings or tests not involving the spectrometer to be affected. An internal coolant leak may result in overheating, therefore viscosity and oxidation will increase and the base number (BN) will decrease. This is helpful because now four independent laboratory techniques will indicate the same thing.

Trends and regular sampling

Returning to the importance of trending and taking regular oil samples, let's re-examine the second example in Table 1 which shows an increase in silicon caused by top-end dirt entry and the associated wear of pistons, rings and liners. As dirt is by-passing the air filter, abrasive wear is occurring in the upper cylinder. Because of this, oil consumption will eventually increase. Higher oil consumption means the engine is being topped-off with fresh oil, resulting in the decrease of wear and contamination levels. Figure 1 illustrates a hypothetical situation, beginning with an increase in silicon (dirt entry) followed by an increase in iron (wear) and oil consumption, which eventually leads to a decrease in iron and silicon readings.

Following the trend of regular samples makes interpretation of the readings fairly straightforward. However, what would happen if only three samples up to 750 hours plus the last two samples at 2250 and 2500 hours were taken? This would show a smooth trend for iron and silicon, indicating no problem (Figure 2). Only an increase in the oil consumption would be noted, with no apparent explanation.

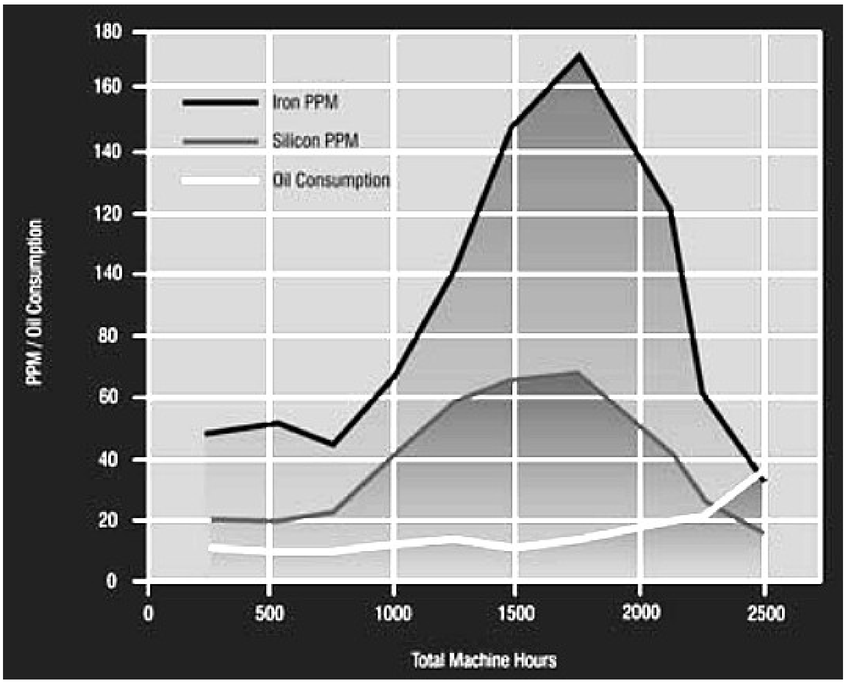

Figure 1

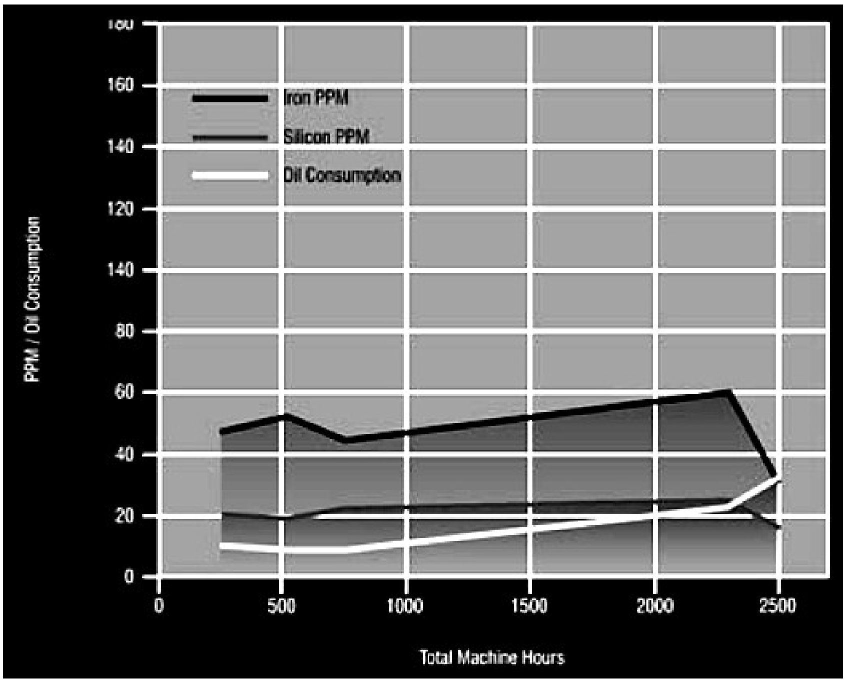

Figure 2 . Wear and Dirt Entry Related to Oil Consumption

Accelerated or abnormal?

The difference between accelerated and abnormal wear must be considered. If the lead readings were to increase in an engine sample, this typically indicates bearing wear. However, it could also be accelerated wear due to the machine working harder with all the bearings wearing a little more than usual, or it could be due to just one bearing wearing abnormally.

Many factors that affect oil analysis results are outside the control of the OEM, owner, operator and oil analyst, and these must be considered when making a diagnosis. Trending and viewing results in a holistic manner offers positive benefits for any type of condition monitoring technique, not just oil analysis. While wear limits can be beneficial, they should be used with caution. All it would require to distort a set of wear tables would be for some form of ultra filtration be fitted to filtered oil systems. The result would be the lowering of the alarm levels. One *WearCheck* customer has performed this across a large fleet of earthmoving equipment and the effect is noticeable. It is interesting to note that some of the strongest proponents of wear limits in the past are now acknowledging that wear readings also need to be trended.

11. Oil analysis: five things you didn't know

Mark Barnes, Noria Corporation

I'm sure that you are well aware of the value brought by oil analysis. Used appropriately, there is little doubt that an effective oil analysis program can help identify lubrication-related failures, often before any significant machine wear has occurred. But as a veteran instructor of oil analysis and lubrication courses, I find all too often that companies miss the boat on oil analysis simply because they don't understand what oil analysis can and can't do. So in the interests of setting the record straight, I present to you what I like to call the "five fallacies" of oil analysis - things that are often overlooked or not understood but vital to the long-term benefits of oil analysis as a conditioning monitoring tool.

Fallacy #1: Reservoir sampling is fine

Fact: Oil analysis, just like real estate, is all about location, location, location. While certain homogeneous properties such as viscosity are unchanged no matter where in the system you sample from, the concentration of suspended material such as wear debris, particles and moisture can vary by several orders of magnitude depending on where you take the sample. For maximum effectiveness, you should take samples immediately downstream of the component(s) of interest or source of contaminant ingression. In fact, in large circulating systems with significant reservoir capacity, the dilution effects alone can render the identification of active machine wear virtually impossible with reservoir sampling.

Fallacy #2: Routine oil analysis will always find active machine wear

Fact: In oil analysis, size really does matter. Depending of the wear mode and degree of severity, wear particle sizes are often 5 to 10 microns and larger. So, why does this matter? Size is important because the most commonly used test method to assess active machine wear - elemental spectroscopy - has a limit to the size of particles it can detect. Depending on instrument and methodology, conventional elemental analysis can't detect particles larger than 3 to 8 microns in size, rendering it useless in situations of advanced machine wear, or where the failure mode naturally generates larger particles, such as fatigue or severe sliding wear.

Fallacy #3: Particle counting is proactive

Fact: Particle contamination accounts for 60 to 80 percent of all lubrication-related failures. Because of this, most oil analysis practitioners recommend the use of ISO particle counting to measure fluid cleanliness, believing that particle counting is a proactive means to prevent many failures. But unless you have taken the time to determine exactly how clean each system needs to be and have a plan to address fluid cleanliness levels that are too high, particle counting will have little to no effect at reducing the overall number of machine failures.

Fallacy #4: Water is water is water

Fact: Water, in the form of wash down, airborne humidity or from the process itself is a dangerous contaminant. Because of this, all oil analysis labs test for water. However, in many instances, the test methods used by some labs are unable to detect the presence of water until it is five to 10 times higher than recommended for some machines. Like many oil analysis test parameters, labs have a variety of methods they can use to identify water and the test method used must meet minimum required detection limits.

Fallacy #5: Vibration analysis is better at finding failures than oil analysis

Fact: While it's true that some failure mechanisms, such as misalignment, are better detected using vibration, most experts - including those that specialize in vibration analysis - recognize that oil analysis will generally detect active machine wear before vibration analysis. The true value of vibration analysis is its inherent ability to localize the problem (inner race, outer race, cage wear, etc.) rather than any ability to find a problem earlier in the failure cycle. In truth, the combination of oil analysis for early detection coupled with the advanced diagnostic capabilities of vibration analysis make the benefits of these two techniques far greater when treated as team mates rather than opponents.

There you have it - the most misunderstood aspects of oil analysis. Get them wrong and you could be living with a false sense of security. Get them right and you should reap the benefits that many companies get from a well-engineered, reliability-focused oil analysis program.

12. How water causes bearing failure

Jim Fitch, Noria Corporation

It takes only a small amount of water (less than 500 ppm) to substantially shorten the service life of rolling element bearings. In fact, water's destructive effects on bearings can easily reach or exceed that of particle contamination, depending on the conditions.

Water can damage machine surfaces directly. For instance, water may lead first to premature oxidation of the base oil. When the oxides combine with more water, a corrosive acidic fluid environment exists.

Water with other contaminants cause sludge and increases oil viscosity. Both processes can impede oil flow and lead to damage of the bearing. Water and oxidative environment can keep air in the oil, amplifying lubrication problems even further.

Hydrogen-induced fractures. Often called hydrogen embrittlement or blistering, this failure mode is perhaps more acute and prevalent than most tribologists and bearing manufacturers are aware. The sources of the hydrogen can be water, but also electrolysis and corrosion (aided by water). There is evidence that water is attracted to microscopic fatigue cracks in balls and rollers by capillary forces. Once in contact with the free metal within the fissure, the water breaks down and liberates atomic hydrogen. This causes further crack propagation and fracture. High tensile-strength steels are at greatest risk. Sulphur from additives (extreme pressure (EP), anti-wear (AW), etc.), mineral oils and environmental hydrogen sulphide may accelerate the progress of the fracture. Risk is posed by both soluble and free water.

Corrosion. Rust requires water. Water gives acids their greatest corrosive potential. Etched and pitted surfaces from corrosion on bearing raceways and rolling elements disrupt the formation of critical elastohydrodynamic (EHD) oil films that give bearing lubricants film strength to control contact fatigue and wear. Static etching and fretting are also accelerated by free water.

Oxidation. The negative consequences of oil oxidation are numerous but include corrosion, sludge, varnish and impaired oil flow.

Additive depletion. Water aids in the depletion of antioxidants, but it also cripples or diminishes the performance of a host of other additives. These include AW, EP, rust inhibitors, dispersants, detergents and demulsifying agents. Water can hydrolyse some additives, agglomerate others or simply wash them out of the working fluid into puddles on sump floors. Sulphur-phosphorous EP additives in the presence of water can transform into sulphuric and phosphoric acids, increasing an oil's acid number (AN).

Oil flow restrictions. Water is highly polar, and as such, has the interesting ability to mop up oil impurities that are also polar (oxides, dead additives, particles, carbon fines and resin, for instance) to form sludge balls and emulsions. These amorphous suspensions can enter critical oil ways, glands and orifices that feed bearings of lubricating oil. When the sludge impedes oil flow, the bearing suffers a starvation condition and failure is imminent. Additionally, filters are short-lived in oil systems loaded with suspended sludge. In sub-freezing conditions, free water can form ice crystals which can interfere with oil flow as well.

Aeration and foam. Water lowers an oil's inter-facial tension (IFT), which can cripple its air-handling ability, leading to aeration and foam. It takes only about 1000 ppm water to turn your bearing sump into a bubble bath. Air can weaken oil films, increase heat, induce oxidation, cause cavitation and interfere with oil flow; all catastrophic to the bearing.

Impaired film strength. Rolling element bearings depend on an oil's viscosity to create a critical clearance under load. If the loads are too great, speeds are too low or the viscosity is too thin, then the fatigue life of the bearing is shortened. When small globules of water are pulled into the load zone the clearance is often lost, resulting in bumping or rubbing of the opposing surfaces (rolling element and raceway). Lubricants normally get stiff under load (referred to as their pressure-viscosity coefficient) which is needed to bear the working load.

However, water's viscosity is only one centistoke and this viscosity remains virtually unchanged, regardless of the load exerted. It is not good at bearing high-pressure loads. This results in collapsed film strength followed by fatigue cracks, pits and spalls. Water can also flash or explode into superheated steam in bearing load zones, which can sharply disrupt oil films and potentially fracture surfaces.

Microbial contamination. Water is a known promoter of micro-organisms such as fungi and bacteria. Over time, these can form thick biomass suspensions that can plug filters and interfere with oil flow. Microbial contamination is also corrosive.

Water washing. When grease is contaminated with water, it can soften and flow out of the bearing. Water sprays can also wash the grease directly from the bearing, depending on the grease thickener and conditions.

The obvious solution to the water problem is a proactive solution; that is, preventing the intrusion of water into the oil/grease and bearing environment.

13. Water in oil contamination

Mark Barnes, Noria Corporation

Water can exist in oil in three states or phases. The first state, known as dissolved water, is characterized by individual water molecules dispersed throughout the oil. Dissolved water in a lubricating oil is comparable to moisture in the air on a humid day - we know the water is there, but because it is dispersed molecule-by-molecule, it is too small to see.

For this reason, an oil can contain a significant concentration of dissolved water with no visible indication of its presence. Most industrial oils such as hydraulic fluids, turbine oils, etc., can hold as much as 200 to 600 ppm of water (0.02 to 0.06 percent) in the dissolved state depending on the temperature and age of the oil, with aged oils capable of holding three to four times more water in the dissolved state than new oil.

Once the amount of water has exceeded the maximum level for it to remain dissolved, say above 0,1%, the oil is saturated. At this point, the rolling element bearing life can be reduced to 25% and the water is suspended in the oil in microscopic droplets known as an emulsion. This is similar to the formation of fog on a cool, spring day. In this case, the amount of moisture in the air exceeds the saturation point, resulting in a suspension of small droplets of moisture or fog. In a lubricating oil, this “fog” is often referred to as haze with the oil said to be cloudy or hazy.

The addition of more water to an emulsified oil/water mixture will lead to a separation of the two phases producing an additional layer of free water. This is like rain falling when the amount of moisture in the air becomes excessive. For mineral oils and PAO synthetics whose density is less than 1,0, this free water layer is found on the bottom of tanks and sumps.

In a lubricating system, the two most harmful phases are free and emulsified water. In journal bearings for example, the incompressibility of water relative to oil can result in a loss of the hydrodynamic oil film that in turn leads to excessive wear. As little as one percent water in oil can reduce the life expectancy of a journal bearing by as much as 90 percent. For rolling element bearings, the situation is even worse. Not only will water destroy the oil film strength, but both free and emulsified water under the extreme temperatures and pressures generated in the load zone of a rolling element bearing can result in instantaneous flash-vaporization causing erosive wear to occur.

Under certain conditions, water molecules can be ripped up into their constituent oxygen and hydrogen atoms as a result of the high pressures generated in the load zone of a rolling element bearing. Due to their relatively small size, the hydrogen ions produced by this process can absorb onto the surface of the bearing raceway resulting in a phenomenon known as hydrogen embrittlement. Hydrogen embrittlement is caused by a change in subsurface bearing metallurgy. This change causes the bearing material to become weak or brittle and prone to cracking beneath the surface of the raceway. When these subsurface cracks spread to the surface, the result can lead to pitting and spalls.

Because the effects of free and emulsified water are more harmful compared to dissolved water, a general rule of thumb is to ensure that moisture levels remain well below the saturation point. For most in-service oils this means 100 to 300 ppm or less depending on the oil type and temperature. However, even at these levels, a significant amount of damage can still occur. Generally speaking, there is no such thing as too little water.

The effects of water on a lubricant

Not only does water have a direct harmful affect on machine components, but it also plays a direct role in the ageing rate of lubricating oils. The presence of water in a lubricating oil can cause the progress of oxidation to increase tenfold, resulting in premature ageing of the oil, particularly in the presence of catalytic metals such as copper, lead and tin. Also, certain types of synthetic oils such as phosphate esters and dibasic esters are known to react with water, resulting in the destruction of the base stock and the formation of acids.

It is not just the base oil that can be affected by moisture contamination. Certain additives such as sulphurous AW and EP type additives and phenolic antioxidants are readily hydrolysed by water, resulting in both additive mortality and the formation of acidic by-products. These acidic by-products can then cause corrosive wear, particularly in components containing soft metals such as Babbitt used with journal bearings and bronze and brass components. Other additives such as demulsifying agents, dispersants, detergents and rust inhibitors can be washed away by excessive moisture. This results in sludge and sediment build-up, filter plugging and poor oil/water demulsibility.

Measuring water
In order to control moisture levels, one must be able to detect its presence. There are five basic test methods used to determine the moisture content of a lubricating oil. These methods range from a simple apparatus to a more complex chemical test or slightly more expensive percent saturation probe test ideal for on-site screening purposes. It may also include more advanced technology typically used in laboratories for precise determination of the water level in ppm.

The most basic is the Crackle Test. In this test, a hot plate is held at 130 °C and a small drop of oil placed in the centre. Any moisture present in the oil is reflected in the number of bubbles observed as the water vaporizes. Depending on the lubricant, relatively few small bubbles indicate approximately 500 to 1000 ppm (0.05 to 0,1 percent) water. Significantly more bubbles of a larger size may indicate around 1000 to 2000 ppm water, while an audible crackling sound indicates moisture levels in excess of 2000 ppm. The Crackle Test is sensitive only to free and emulsified water.

14. Systematic oil analysis interpretation

Jose Paramo

The following steps should be followed:

1. Read carefully - Consider all the information in the oil analysis report concerning the equipment, operation conditions, sample date, recent maintenance performed between samples, etc.

2. Take into consideration all sample details -

- Where was the sampling point (before the filter, from the return line, etc.)?
- Was the machine running?
- How was the sample taken?

Not all information may be available; nevertheless, it is important to consider all available data/information to make the best recommendations.

3. General observations – Include type of machinery, type of industry, equipment work environment, etc.

4. Normalization - Normalize the data if necessary. See “Terminology” at the end of this article for details.

6. Baseline and last sample data analysis – Compare oil analysis results with baseline information. Refer to previous oil analysis results and review data of historical samples, then identify trends.

7. Setting limits - Based upon baseline data, determine caution and critical limits for each property. These will vary based on factors such as machine type and criticality.

As an example, there is a report showing an increased viscosity of an ISO VG 46 hydraulic fluid. The common causes for viscosity increase include:

1. Polymerization
2. Oxidation
3. Evaporation losses
4. Insoluble materials increase (such as soot and some oxidation products)
5. Emulsions due to water contamination
6. Incorrect oil (such as higher viscosity)

Oxidation signals may be an increase of colour and a higher acid number than the baseline reference. Our sample is clear and bright and the current AN value is similar to baseline safely under the limit, thus oxidation is not the cause of viscosity increase.

Operational temperature is not high (but it increased by 5°C). Therefore, evaporation of lighter base oils may not be the reason for the viscosity increase. There are no insoluble materials, no sediment observed and water content is under limits.

Also, and anti-wear additives (zinc).

Flash point is higher than the baseline reference. The temperature has increased by 5°C, which may happen when the viscosity of fluids in hydraulic systems is increased due to fluid friction. N**ote how important it is to include the machine condition on the sample label.**

Contamination with a higher viscosity oil is a possible cause for viscosity increase. It is recommended to verify if a higher viscosity fluid (such as hydraulic oil ISO VG 68) has been added to the reservoir.

GLOSSARY

• **Baseline** – This represents the original characteristics and properties of the new oil to be applied in the equipment (viscosity, AN, BN, additive content, oxidation stability, RPVOT for turbine oils). It is important to measure the baseline data from the beginning when implementing an oil analysis program. Note that the data in product data sheets (PDS) is not useful for defining baselines because the lubricant manufacturer includes only general data. Changes in formulation (such as additive changes) are not always printed in PDS, which may lead to confusion and errors when interpreting results. All new oil should be analysed.

• **Caution limits** - Exceeding caution limits results in abnormal conditions and requires corrective actions.

• **Critical limits** - Exceeding critical limits indicates a critical situation and requires immediate action.

• **Goal-based limits** - These limits are set as predetermined values of properties (such as ISO code cleanliness, maximum water content, etc.).

• **Ageing limits** - These limits are a result of the oil's normal ageing process. For example: the highest permissible limit of acidity, oxidation or nitration; the lowest additive concentration, etc.

• **Statistical limits** - These limits are statistically determined. Data average and standard deviation are obtained. Caution limit is set at an average of +/-1 standard deviation, and critical limit is set at an average of +/-2 standard deviations. Statistical limits may be applied to wear metals.

• **Normalization** - When collecting samples with different time intervals in reference to set frequency, it is easy to make mistakes and come to the wrong conclusions. Consider the following example: If the objective is to monitor iron wear every 500 hours and the data is 40 ppm (400 hours), 55 ppm (580 hours), 30 ppm (450 hours) and 68 ppm (500 hours), then the analyst observes which samples were taken at different time intervals Therefore, the data should be normalized in the following manner: For the first data, if during 400 hours the iron wear was 40 ppm, then what would the iron wear be in 500 hours? Answer: (40 ppm iron) (500 hours) / 400 hours = 50 ppm iron. This is the normalized iron wear data. For the other examples, values would be (in respective order): 47.4 ppm, 33.3 ppm, 68 ppm. NOTE: When taking samples, if time intervals vary less than +/-10 percent versus set frequency, normalization may not be necessary.

15. Reducing wear particle generation

Ted Naman, ConocoPhillips; Ken Nicholas, Schroeder Industries; Richard Winslow, Pacificorp - Naughton Plant

A coal-fired power plant operating in the western United States was experiencing short gearbox life in its coal pulverizing operation. The AGMA 6 EP (ISO 320) gear oil recommended by the original equipment manufacturer (OEM) failed to provide adequate lubrication and protection based on oil analysis results and gearbox inspection after one year of operation. This was confirmed by excessive wear metals and lower viscosity in the used oil reports. Further analysis of the used EP gear oil indicated excessive build-up of particulate contaminants in the lubricant and depletion of the EP additive package.

The particulate contamination consisted primarily of dirt and coal dust, and metallic particulates being generated by bearing and gear tooth wear. A chain reaction of excessive wear was taking place.

The pulverizer gearbox design dates back to the early 1960s. A steel worm gear driven by a large 800 rpm electric motor powers a bronze bull gear that is directly connected to a grinding table. The sump holds 255 gallons. The gear oil temperature is controlled by an integral water-cooled heat exchanger. The ISO VG 320 EP gear oil is recommended by the gearbox OEM.

Although this gearbox design is rugged and simple, maintenance costs were becoming excessive and maintenance outage/overhaul intervals did not support power generation schedules. Typical maintenance costs and intervals for each pulverizer gearbox were:

- Oil changes were required every 12 months at a cost of $5000 in material and labour and $20 000 to $50 000 in lost production.
- After 10 years of operation, the bronze bull gear was rotated to expose the unworn gear teeth face side. This required four weeks of turnaround time including maintenance work at a total cost of $300 000 per unit.
- Every 20 years of operation, a complete rebuilding of the gearbox was required. Parts and labour for this effort exceeded $450 000 per gearbox with lost production costing another $250 000 per pulverizer.

Plant personnel suspected the wear patterns on the bronze bull gear faces were attributed to the following:

- High particulate loading of coal dust and dirt in the gear oil
- Chemical attack of the EP additive package during operation, likely due to a sulphur-phosphorus EP additive active on the bronze bull gear, resulting in high levels of copper in the gear oil
- Catalytic reactions between the gear oil additives and some of the particulates

generated

Plant personnel began to address these issues on multiple fronts:

- Search for methods to better seal the gearbox from particulate ingestion (primarily coal dust)
- Filtration methods/options for the gear oil to quickly capture the particulates and generated wear particulates
- Enhanced lubricant technology (both base oil and additive packages) to provide extended maintenance intervals without energy use penalties

Particulate Ingress - Desiccant breathers were installed for the first time on the gearbox vents. The worn and ineffective grinding table seals were changed. Initial ISO cleanliness of 23/21/18 was achieved.

Filtration method and customer requirements - Historically, the ability to filter ISO 320 and 460 gear oils in a coal pulverization environment proved difficult.

Plant personnel determined that one of the options for removing particulate contaminants from the pulverizer gearbox and to address the gear wear issue is through a kidney loop filtration system. This system had the following characteristics:

- Adequate flow rate to handle the higher viscosity gear oil
- High dirt-holding capacity
- Low maintenance. Filter changes should not exceed once per month under normal operating conditions
- The ability to show gear oil clean-up within one week after maintenance is performed on the gearbox
- Continue to clean up the gear oil and maintain target cleanliness code of 18/15/11 per ISO 4406-1999
- Provide pre- and post-filtration sampling points for evaluation of filter effectiveness
- Suction and discharge locations designed to eliminate fire hazards, and the entire gearbox oil sump was turned over every 30 minutes
- Mounting skid size that did not interfere with normal maintenance activities

This system is sometimes referred to as off-line filtration or a stationary version of the mobile filtration system. It has its own pump. The system installed has a high efficiency, high dirt-holding capacity with synthetic filter media. The package uses two filter housings were mounted in series, with a common-sized element in both housings.

The filter elements initially recommended for the trial installation were rated at $beta_{25}$ = 200 in the first stage and $beta_{10}$ = 200 in the second stage. Oil flow is delivered by a vane pump rated at 10 GPM for a 460 cSt gear oil. Temperature ranges of the system fluid varies from 18 °C when idle and up to 55 °C during normal operation. The filtration package has a suction line coming into the filter bank directly from the bottom of the reservoir; the outlet, or filtered discharge line, is piped into the top of the reservoir.

The OEM recommended an ISO 320 gear oil for the pulverizer gearbox. Evaluation of the wear patterns on the gear teeth indicated the EP additive package in this gear oil was too active on the bronze bull gear and was causing premature wear in conjunction with the contaminants in the gearbox. Analysis of used gear oil samples confirmed that the EP additive package was being depleted. Depletion of this package was determined to be from continuous sliding of the bronze steel gears and exposure to high temperatures, which was confirmed with IR thermographic imagery. High dirt and particulate loading was confirmed by the ISO cleanliness code. It was now obvious that the OEM recommended EP gear oil did not provide adequate protection for the gears.

Based on these findings, and after consulting with the lubricant supplier, it was determined that ISO 460 synthetic gear oil would best protect the gearbox in this application. The higher viscosity grade and improved lubricity of this synthetic gear oil, coupled with R&O additive chemistry, provided a higher oil film strength than the OEM's recommendations, and would extend the life of the gearbox, taking into account the temperature requirements and gearbox longevity.

In the past, plant personnel evaluated the feasibility of using a synthetic gear oil in the pulverizer gearbox, but it was determined the high dirt loading in the gearbox made this uneconomical due to frequent oil changes. However, with improved filtration that provided a potential oil life of at least three years, the economics of using a synthetic gear oil were justified. The synthetic ISO 460 gear oil offers several benefits including:

- Enhanced pumpability at lower temperatures, thereby enhancing filterable;
- Higher oxidation resistance and thermal stability;
- Higher film strength at high and low temperatures;
- Extended service life in a clean, filtered environment.

The pulverizer gearbox was overhauled and all major rotating components replaced, with the exception of the steel/worm gears. The gearbox was wiped clean with lint-free rags as part of the overhaul process. The steel worm and bronze bull gears were precision aligned and blue checked. The reservoir was flushed with an ISO 460 mineral oil and filled with the synthetic ISO 460 gear oil. A baseline gear oil sample was drawn from the reservoir and analysed for particle count per ISO 4406-1999. The ISO cleanliness code result was 23/21/18. The pulverizer gearbox was put into service along with the filtration system. Following three hours of run time, the particle count was reduced to 21/19/11.

After 48 hours of run time the plant installed a set of $beta_5$ = 200 filter elements in each housing to reduce system contamination and achieve the target ISO cleanliness code 18/15/11. The pulverizer gearbox and filtration system continued to run for another two weeks with the element condition monitored using differential pressure gauges. As a result of using this filter during these two weeks, the target ISO cleanliness code 18/15/11 was reached.

Filter element service life was also monitored during the trial installation. Results indicated the high dirt capacity media exceeded expectations, given the initial clean-up of the system, plus the service life during ongoing usage has been above the norm. Average service life to date, using the $beta_5$ = 200 media, is one year.

During the trial installation, oil samples were taken and analysed for physical and chemical properties, particle count and analytical ferrography. The results showed reduced wear metals and the oil cleanliness was maintained.

Given the success of the initial installation, the power plant continues to achieve the following benefits by using the ISO 460 synthetic gear oil and new filtration system:

- Improved gear and bearing lubrication;
- Minimal to non-existent wear metals in the gearbox based on the oil analysis reports;
- No increase in drive motor energy consumption due to employing a higher viscosity synthetic gear oil. Some plant instrumentation measurements indicated a one percent drop in motor amperage (4160 W motors).

ACKNOWLEDGEMENTS

The articles used in this manual were selected from hundreds similar articles available on Internet. All of them are marked © NORIA CORPORATION. Unfortunately, there has been no response to my following e-mail to the publisher, Mr Mike Ramsey:

-------- Original Message --------
From: Petr Vavruch <35vavruch@telkomsa.net>
To: mramsey@noria.com
Subject: Articles reproduced in South Africa
Date: Mon, 20 Sep 2010 22:54:03 +0200

Dear Mr Ramsey,

I'd like to print some of your articles on oil analysis for participants (perhaps 10 to 15) of my lubrication workshop that will be run by our engineering society.

The articles would be discussed during the course.

Under what conditions am I allowed to do that?

Yours truly

Petr R. Vavruch
Cape Town
South Africa

QUESTIONS

All articles: What is the main point(s) or main message(s) of each article.

1. Write down and explain the 13 inspection tasks.

2. Describe how you can use hearing, seeing and smelling to check machinery.

3. Explain the 10 problem-showing inspections.

4. What are the 6 steps described in the article.

5. Explain the 6 rules.

6. What is important about sampling point locations? - What methods and tools are described in the article? - Discuss sampling bottles and their cleanliness.

7. First step in calculating sampling frequencies. - Step 2: (a) list all factors to be considered; (b) describe the ‘bathtub’ curve. - The last step in calculating frequencies.

8. Write down and explain the common fluid degradation mechanisms.

9. Describe some trends in lubricant selection and use. - How to fight contamination? - What’s new in oil analysis? - Describe some (4 to 5) other trends.

10. Why are the reasonable questions: "What wear limits do you use?" and "What levels are normal and abnormal?", not effective means of determining the health of a component? - What could an increase in the silicon level indicate? - What could a high copper reading indicate? - Why is it so important to take regular oil samples to show trends?

11. What are the five fallacies? Explain!

12. What figure (in ppm) is mentioned as “small amount of water” that can shorten the service life of rolling element bearings? - What can damage machine surfaces? - How can water reduce the oil flow? - Write down and explain all the problems caused by water.

13. By how many % can companies reduce failure rates simply by controlling fluid cleanliness? - How many ppm (and how many %) can industrial oils such as hydraulic fluids or turbine oils hold in the dissolved state? - Describe the difference between the dissolved state and the saturated state. - What causes free water to appear and where is it found? - What can reduce the life expectancy of a journal bearing by as much as 90 percent? - What are the effects of water on a lubricant? - Describe the Crackle Test.

14. What are the recommended steps? - Describe the example. - Use the example to show how important it is to include the machine condition on the sample label. - Describe all the terms in the glossary.

15. What were the problems with the original oil? - Describe in detail the steps taken to eliminate the problems. - What oil was used *before* and *after*?

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