Lessons from the Oil Sump

Analysis of used engine, transmission, and hydraulic oils can yield invaluable diagnostic data to help predict and avoid mechanical failures.

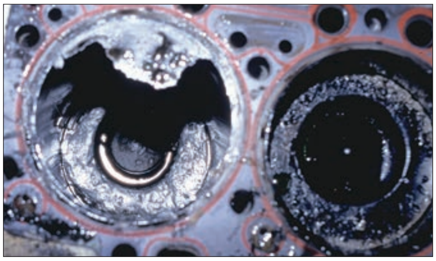
Text and photographs by Steve D'Antonio

Above—*This magnetic drain plug and the slurry of metal and oil it has captured clearly signal the demise of a transmission. Predictive maintenance informed by a comprehensive oil analysis program could alert owners and service crews to problems long before they reach this critical stage.*

A staple of any good yard's maintenance schedule for each boat in its care is to change the oil and filters based on use or regular seasonal service. As a result, boat owners already spend hundreds if not thousands of dollars on engine and hydraulic oil and filter changes every year. But most of that used oil is unceremoniously disposed of along with a wealth of information that could be extracted from it at modest expense by participation in an oil-analysis program.

Commonly referred to as predictive and condition-based maintenance, studying fluid drained from engines, generators, transmissions, hydraulic stabilizers, thrusters, and steering and cooling systems can frequently help identify problems in mechanical components. Modifying maintenance protocols based on the results of oil tests can prevent catastrophic failures. Commercial industries from manufacturing and mining to oil drilling and transportation, as well as military and research institutions, spend millions of dollars annually on oil sampling and analysis. It's unlikely they would make such an investment unless it offered a tangible return.

The diagnostic information that fluid analysis can provide includes abnormalities such as excessive bearing wear, failed or clogged air filters, fuel-injection system malfunctions, fuel dilution, increased lubricant acidity, incorrect oil weight, glycol/coolant contamination, diminished corrosion resistance, leaking heat exchangers,



A diesel engine after a catastrophic meltdown; the aluminum at the top of the cylinder, once molten, is now solidified. Regular oil analysis would likely have revealed, among other things, elevated levels of aluminum and iron that preceded the failure.

and failed head gaskets. In short, the information gleaned from regular analysis of engine, generator, and transmission gear oil, as well as hydraulic and cooling system fluids, is easily obtained and too valuable to forgo.

Oil-Analysis Basics

Tribology is the science of interacting surfaces in relative motion, including the study of lubrication, friction, and wear. Tribological wear occurs as a result of relative motion, which is precisely what takes place within the internally lubricated portions of all marine internal-combustion engines, generators, transmissions, and hydraulic systems, including stabilizers, thrusters, windlasses, cranes, steering units, and transmissions.

Oil analysis has been around about half as long as mass-produced internal-combustion engines. In the United States, credit for adopting this diagnostic and maintenance tool goes to railroads in the early 1940s. On the strength of its usefulness in maintaining locomotives, oil analysis was embraced by the U.S. Navy in the 1950s to monitor and prevent failures in then-new jet airplane engines exposed to the harsh conditions on aircraft carriers. Rolls Royce, the British aircraft engine manufacturer, also adopted oil analysis as a maintenance protocol at about the same time.

Programs like these spawned a process known as condition-based maintenance (CBM), which augmented or replaced rigidly scheduled maintenance by providing service and repairs when analysis indicated they were needed, rather than on an hourly or calendar-based system.

While a single sample may reveal some impending catastrophic fault—high levels of glycol, for instance, often indicate a leaking head gasket or cracked head or block—more often, taking multiple samples over time reveals a gradual trend toward a problem looming far off in the future and allows plenty of opportunity for corrective action. Such trends are most effectively identified by comparing a used-oil sample with an unused sample of the same brand, grade, and weight of oil and with results from previous used samples from the subject mechanical system. A solitary sample, while undeniably advantageous in its own right, supplies the analyst with less-valuable information, and makes determining the cause of a problem more challenging and less certain. That said, a single sample and the report it generates are still valuable. This is particularly true of pre-purchase surveys and troubleshooting in instances when no analysis has been carried out over the life of the vessel.

For the owner, captain, or service yard responsible for the long-term care of a modern boat, establishing a regular oil-analysis program allows the application of CBM rather than a scheduled maintenance program. This approach is beneficial for virtually any engine, gear, or hydraulic system; and if an engine or hydraulic system utilizes bypass filtration, which allows it to operate under an extended oil change regimen, then oil analysis becomes mandatory. (Bypass filtration systems, with filters as fine as 1 micron, are added to engines to treat a small portion, typically about 10%, of the lube oil for each full circuit the oil makes through the standard full-flow filter.) It must be specifically tailored to detect the contaminants and potential failings peculiar to extended oil drain intervals. More on this below.

The goal of establishing an oil-analysis program is to be predictive, preventive, and proactive in ways that simple scheduled-based maintenance doesn't allow. However, this more technically sophisticated maintenance protocol requires vigilance, commitment, and a specialized understanding to read the early warnings in regular oil-testing data.

Wear Metals, Additives, and Contaminants

Contamination of engine, transmission, or hydraulic oil with small particles of metal, dust, soot, or liquids alters the oil's viscosity or lubricity, impairing its performance as a lubricant. By applying elemental and spectroscopic analysis, a laboratory can determine how much of any particular contaminant is in a lubricant sample. An inductively coupled plasma (ICP) test can isolate and identify 24 metals likely to be found in engine, transmission, or hydraulic oil. The presence of some of these metals even in a single test can indicate excessive wear and impending failures (see chart on page 69). High levels of aluminum, for instance, could be from piston scuffing or broken thrust washers, while high copper content may indicate excessive valve-guide or shell-bearing wear, or slipping clutches.

Other metal and mineral contaminants are introduced from outside the lubricated system. These typically include silicon dioxide and aluminum oxide (otherwise known as dust or dirt), which can enter through damaged air filters or crankcase breathers; sodium, which may be either a lubricant additive or a sign of seawater intrusion; and potassium, which is

***Top right**—Aluminum from this severely scuffed piston was deposited on the cylinder wall **(right).** Long before the catastrophic failure required a complete engine rebuild, an oil analysis report could have identified the problem in time to take corrective measures.*

The tan deposit on this valve is the result of coolant leaking into the cylinder. Oil analysis alerted the user to the presence of glycol before symptoms more serious than some coolant loss manifested.

either a coolant additive (indicating a coolant leak into the oil) or an airborne contaminant.

Multi-source metals include molybdenum, antimony, manganese, lithium, and boron, some of which are additives found in lube oil and hydraulic fluid, while others are coolant inhibitors or alloying agents with other metals. Metals that are commonly added to lube oil to enhance or fortify its properties include magnesium, a detergent/dispersant; calcium, also a detergent; barium, typically an additive found in synthetic lubes; and phosphorus and zinc, antiwear additives in zinc dialkyldithiophosphate (ZDDP).

ICP is capable of measuring all these metals in parts per million (ppm), provided the particles are smaller than 8 to 10 microns (a grain of salt is about 60 microns). Other methods I'll discuss later are available to quantify and qualify larger metal particles.

While wear and multi-source metals may cause a lubricant to become somewhat abrasive, dust or dirt mixed with oil can form a grinding compound of sorts that will slowly abrade bearings and other polished surfaces. Laboratories rely on a process known as Fourier transform infrared spectroscopy (FTIR) to measure, as a percentage of volume, contaminants such as soot, oxidation, and nitration by-products, glycol, fuel, and water. Identifying the presence and quantity of these substances in used oil can tell a knowledgeable technician a lot about the system the sample was taken from. Take soot for instance. All diesel engines produce it, but soot is abrasive, and if enough accumulates, it can cause oil to thicken, which starves bearings and other surfaces of lubrication. Possible causes of increased soot include over-fueling, which frequently occurs when props are fouled or not properly matched to their engines; restricted air filters; excessive back-pressure, a common result of improperly designed exhaust systems; and worn piston rings, which facilitate the entry of soot into the crankcase.

Similarly, diesel fuel in the lube oil can wreak havoc by reducing oil viscosity. Its presence in a sample suggests a malfunctioning injector or injectors; a leaking injection pump shaft seal; a leaking low-pressure lift pump; excessive cool running, which in turn is caused by chronic underloading; or a high-pressure fuel-line leak on engines whose injectors are located beneath the valve cover.

Water contamination in a sample is likely from condensation, often caused by excessive idling or cool running; a restricted crankcase-ventilation system; overly high bilgewater; or deck leaks. Glycol from engine coolant is often an indication of a failed head gasket, a leaking turbocharger gasket, or cracked head or block. In high enough concentrations, water and/or glycol mixed with oil will create a thick, cream-colored, milkshake-like mixture that is not easily removed from the engine. Oil analysis pays dividends in the early stages of contamination when it's not visible to the naked eye. Once this occurs, the oil and filter must be changed multiple times in short succession to flush out the congealed contamination. In extreme cases, the engine may require disassembly to remove the contamination.

The same FTIR testing technique can detect symptoms of oxidation and nitration, two chemical changes detrimental to oil quality. Both these molecular-level deteriorations are caused by age and operating conditions.

Oxidation is accelerated by excessive engine heat (if an engine overheats, its oil and coolant should be changed as soon as possible). Oxidation can increase oil viscosity and impair the performance of oil additives intended to maintain an acid-neutralizing reserve. A drop in the total base number (TBN) indicates increased acidity and that the oil is "worn out." The oxidation rate of oil doubles with every 18°F (10.8°C) increase in temperature. Typical ideal engine-oil temperatures range from 180°F to 220°F (82°C to 104°C).

Nitration is an indication of excessive blowby, which is typically caused by worn piston rings, cylinder walls, or both. It's also an indication of the presence of nitric acid, which promotes oxidation. Increased nitration elevates the oil's total acid number (TAN) too, while the TBN will consequently drop. Tellingly, a disparity between nitration and oxidation levels often indicates a problem with the air-to-fuel ratio caused by faults in the fuel-delivery system, turbocharger, or intercooler.

Sludge and Varnish

Some not-so-subtle symptoms of oil contamination are the presence of the residues sludge and its older variant, varnish. Sometimes called gum, resid, lacquer, or tar, this phenomenon is caused by the slow accumulation of solid particles and moisture contaminants in the oil and can damage internal-combustion engines and hydraulic systems. By-products of oxidation include acids, ketones, and aldehydes, which eventually form polymers and other dense compounds that may reach a high enough concentration within the oil to cause

The amber coloration on this camshaft's rough surfaces is evidence of varnish accumulation.

***Left*—Buildup of thick sludge like this can contribute to a host of mechanical problems, from clogged crankcase ventilation systems to bearing failures. *Right*—While not as scientific as lab testing, dissecting oil filters on the workbench can reveal significant accumulation of wear metals as well as sludge and varnish.**

sludge and varnish formation.

Varnish, the older hardened variant, is a tough, adherent oxide that can be caused by several conditions: high localized temperatures such as those found around turbochargers; localized cylinder overheating caused by cooling system deposits and blockages; exposure to certain metals such as iron and copper; oxidation; and air entrainment.

Sludge, a softer grease-like variant, often forms first. It tends to remain suspended in oil, floating around the engine and accumulating in low areas such as oil pans and horizontal cylinder-block-reinforcement webbing. As more particles accumulate within the oil, its viscosity often increases until it can no longer support the volume of suspended solids, at which point the oil is said to "throw sludge" thick enough to block oil passages. Varnish also may inhibit oil flow, but because it's harder it can act as an abrasive when drawn into bearings and bushings, and can ruin the control, check, and spool valves in hydraulic systems.

Several tests for sludge and varnish can be performed without the services of a lab. Start with a visual test. Does the area under the valve cover or the underside of the oil fill cap look brown and sludgy? With the exception of a thin film of oil, there should be nothing that can be wiped or scraped off. Likewise, periodic examination of the inside of used oil filters should reveal dirty oil but no brown, resinous deposits. (Cut open filters on a lathe to minimize the likelihood that excess metal shavings from a saw will be introduced into the sample.) Next, use your nose to test "old" oil (minimum of 50 hours run time) at the fill cap, preferably when it's warm. Does it have a pungent, burnt, or sulfurous smell, often indicative of intense heat? A few hours after an oil change, compare it to a sample of warm but lightly used oil.

Perform a blotter test by placing a few drops of oil on blotter paper (available from lab suppliers) or on high-cotton-content (25% or greater) stationary. Let the sample soak for a few hours. If the drop has formed a *well-defined*, darker center with a lighter outer periphery, then the oil may contain excess carbon or oxide insolubles, otherwise known as sludge and varnish.

If you suspect that an engine or hydraulic system is plagued by varnish or sludge, a lab can confirm this. FTIR and an ultracentrifuge, which separates the varnish and sludge from the oil under 35,000 g's, can provide some definitive diagnosis of the problem. If an engine is suffering from sludge or varnish formation, test results may reveal the immediate cause or suggest that you may have to review an owner's or crew's operating habits.

In addition to accumulating on horizontal surfaces, suspended sludge and would-be varnish particles are often attracted to cool surfaces as well. Therefore, running an engine in a chronically underloaded and thus "cool" oil state—an all-too-common scenario for many sailing and displacement power vessels—creates an environment conducive to sludge formation and accumulation.

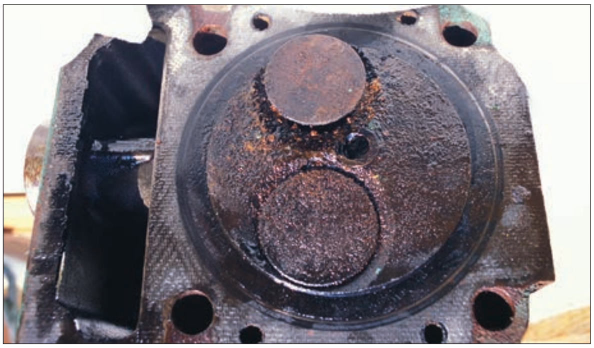
Lab Analysis

Knowing how much different information can be hidden away in engine and hydraulic oil, let's consider next just what tests you should ask the lab to run.

Viscosity Testing. Viscosity has been described as oil's most important physical characteristic. At the most basic level, any change in viscosity is cause for concern. Depending upon the application, viscosity should be tested for at either 40°C or 100°C (104°F or 212°F). Typically, internal-combustion engines have their oil's viscosity checked at 100°C, which closely approximates normal operating conditions. Lighter-weight fluids, such as those in hydraulic systems, are usually tested at 40°C.

Machinery that exhibits a tendency to increase or decrease its oil's

Provide a sample of new oil (left) of the same brand and type as the used oil (right) submitted for laboratory testing. This benchmark allows technicians to draw meaningful comparisons.



Water contamination from a faulty exhaust system sent this engine to an early grave. Traces of water and/or sodium in the crankcase oil of an engine with a closed cooling system are frequently caused by exhaust-system defects.

viscosity is often suffering from contaminants such as soot, sludge, or fuel dilution—problems that will usually show up in the elemental analysis. Because increased wear can occur rapidly if viscosity is off-spec, it is important that these results be acted upon immediately.

Acid Testing. Acid formation is common in internal-combustion engine lubricants, particularly those in diesel engines. That's because the sulfur in diesel fuel eventually makes its way into the lubricating oil, where, when mixed with the water from ordinary condensation in the presence of the combustion process, results in sulfuric acid. Nitric acid, a by-product of nitrogen oxides produced in diesel combustion, can also raise lube oil's acid level. The total acid number (TAN) is a measure of accumulated acid, while the total base number (TBN) is a measure of the strength of additives in crankcase oils designed to neutralize accumulated acid. As acid is produced, the oil's base stock additive is consumed, so when the TBN and TAN approach the same figure, it's time for an oil change.

It's also possible to "sweeten" the oil by adding a quantity of new oil to restore its TBN. This is a particularly common process in engines equipped with bypass filtration systems, which enable extended oil-change intervals. Labs nearly always request so-called make-up oil quantities with the oil samples sent for testing; thus a record must be kept of all additions.

Uncorrected high acid content can corrode and pit bearings and polished surfaces such as cam lobes, lifters, and bearing journals. Your oil analysis report should indicate TAN and TBN readings. Ideally, the TBN of a new sample of the same brand, grade, and weight of oil will be shown for comparative purposes. If the report indicates excessive acidity, your oil-change interval may need to be shortened, or some other problem may be present.

Ferrography. As the name suggests, this test process is a measure of ferrous metal content, although other metals and materials are captured in the process. The primary types of ferrography are analytical (AF), and direct read (DR). AF is a *qualitative* rather than quantitative analysis of wear metals. Using a strong magnetic field, ferrous particles are captured and placed on slides for analysis under a microscope to determine whether they are metallic; their alloy composition; heat treatment; size; color; shape; and, if possible, where they originated within the equipment. The test analyzes a digital image of each particle, and is ideally suited to those larger than approximately 5 microns. Because the metal is visible, its size and composition can be determined as well as the type of wear—rubbing, sliding, cutting, galling, spalling, etc.—it creates or is created by.

Direct-read ferrography is a *quantitative* analysis of ferrous particles in an oil sample, providing a ratio of large particles (larger than 5 microns) to small particles (smaller than 5 microns). If the number of large particles is greater, then AF should be performed. But if the numbers in the ratio are close, or the smaller particles are more numerous, then spectrographic or ICP analysis should be applied. DR is most useful in analyzing lubricants in unfiltered, geared (as opposed to hydraulic) systems such as small transmissions, which have a high tolerance for large particles.

Particle Counting. Any particles that make their way into lubricating and hydraulic oils typically break down until they reach the working clearances of the machinery, where they are then capable of doing the most damage. For instance, a single 38-micron particle, which is slightly smaller than can be detected by the naked eye, may break down into hundreds of 5-micron particles, with a consequent eight-fold increase in potentially destructive surface area. Additionally, smaller particles tend to remain in suspension in the oil column for longer periods, attracting more water and expending more of the oil's additive package in neutralizing their oxidative effects. These damaging smaller particles are the target of bypass filtration.

An accurate particle count from an oil test can tell you how many of each particle size are present in whatever system you are testing. The test quantifies *all* particles, whether they are large or small, metallic, nonmetallic, fiber, dirt, water, bacteria, etc. The test results are expressed in a two- or three-digit system (using ISO Standard 4406) that measures and then codifies particles of 5 and 15 microns (the two-code count) or particles of 4, 6, and 14 microns (the three-number count) per milliliter of lubricant.

Particle counting has some limitations because it relies on fluid clarity. Opaque lubricants such as used diesel-engine-oil must be heavily diluted for testing, which often makes the results suspect. Hydraulic systems, on the other hand, benefit greatly from particle counting, as the type of contamination it identifies often causes the greatest amount of wear.

Interpreting the Data

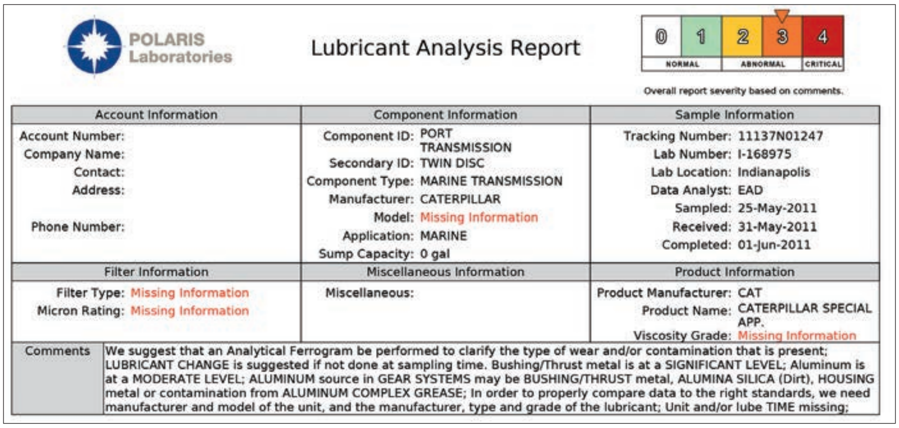
So you've got all these raw data from test results, but how do you make sense of them? A good test lab will tell you how much contamination or wear metal is a problem, and even the sources of those contaminants. If lab technicians are comparing your oil to a new sample of the same oil, as they should be if you supply a reference sample, and they know the amount of time the lubricant has been run in the engine, gear, or hydraulic system, then the rest is relatively easy—meaning, it is critical that the lubricant time is accurately conveyed to the lab. For instance, a report of "50 ppm silicon" (50 parts per million of silicon or dust/dirt) may be considered just a "cautionary" level for a hydraulic system with 500 hours of lubricant time, or it may raise a huge red "severe" flag for fluid with just 25 hours of lubricant time. Engine oil with 100 hours of lube time and 10–30 ppm of silicon isn't terribly unusual; if the lube time were just 40 hours, then there's likely a problem. Or if a copper reading of 10–30 ppm isn't unusually high for 100 or more hours of lube time, it would raise concerns for just 25 hours. (Note that new engines nearly always generate high levels of bearing-wear metals, copper, lead, tin, for the first few oil analyses; these should settle down to "normal" levels within a few hundred hours.)

The combinations of metals and other contaminants revealed by an analysis report are as important as the quantities in which they appear. For instance, 10–30 ppm of copper per 100 or more hours of lube time is normal, but more could indicate bearing wear or an oil cooler that is passivating, or "shedding," copper into the oil as a result of high acidity. Copper and lead, on the other hand, almost always indicate bearing wear, because they are both found in crankshaft and connecting rod shell bearings. If glycol (coolant) is also present in the test results, the combination could indicate lead solder and copper-core material emanating from a heat exchanger and head-gasket leak. Likewise, silver and tin are bearing materials, but both may also be components in engine- and oil-cooling systems.

An increase in silicon (dirt), iron, chrome, and aluminum is a classic case of a failed air filter, which allows dirt to enter the engine, where it grinds away the cylinder walls (iron), rings (chrome), and pistons (aluminum). Even tidy enginerooms kept free of common dust and exterior particles may be contaminated with material from deteriorating insulation and fan belt shedding. But silicon is also found in coolant; so if it shows up in a report without other wear metals or perhaps with copper from a heat exchanger core, it does not suggest an air-intake problem but rather a closed-cooling-system leak into the engine's lube oil. In addition, silicon is sometimes employed as an anti-foaming agent in lube and gear oil, where, far from being harmful, it is actually desirable (foaming causes low oil pressure, excessive wear, and transmission slippage problems). Again, the better test labs will include in their synopsis of the results some diagnostics based on the contaminant combinations found in their analysis.

Creating an Oil-Analysis Program

When picking your test lab, you have more than 200 to choose from in the U.S. alone. While a bit daunting, the high number is beneficial, as in this instance competition has



POLARIS Laboratories

Lubricant Analysis Report

0	1	2	3	4
NORMAL		ABNORMAL		CRITICAL

Overall report severity based on comments.

Account Information	Component Information	Sample Information
Account Number:	Component ID: PORT TRANSMISSION	Tracking Number: 11137N01247
Company Name:	Secondary ID: TWIN DISC	Lab Number: I-168975
Contact:	Component Type: MARINE TRANSMISSION	Lab Location: Indianapolis
Address:	Manufacturer: CATERPILLAR	Data Analyst: EAD
	Model: Missing Information	Sampled: 25-May-2011
Phone Number:	Application: MARINE	Received: 31-May-2011
	Sump Capacity: 0 gal	Completed: 01-Jun-2011
Filter Information	**Miscellaneous Information**	**Product Information**
Filter Type: Missing Information	Miscellaneous:	Product Manufacturer: CAT
Micron Rating: Missing Information		Product Name: CATERPILLAR SPECIAL APP.
		Viscosity Grade: Missing Information

Comments	
	We suggest that an Analytical Ferrogram be performed to clarify the type of wear and/or contamination that is present; LUBRICANT CHANGE is suggested if not done at sampling time. Bushing/Thrust metal is at a SIGNIFICANT LEVEL; Aluminum is at a MODERATE LEVEL; ALUMINUM source in GEAR SYSTEMS may be BUSHING/THRUST metal, ALUMINA SILICA (Dirt), HOUSING metal or contamination from ALUMINUM COMPLEX GREASE; In order to properly compare data to the right standards, we need manufacturer and model of the unit, and the manufacturer, type and grade of the lubricant; Unit and/or lube TIME missing;

All too frequently, samples are sent to labs with less-than-complete data. Depending upon what's missing, the report's results are questionable at best. To see examples of full oil analysis reports, visit the magazine's website, www.proboat.com.

provided the consumer with better service and higher quality products. Factors to consider when choosing a lab include the company's familiarity with the marine industry as well as likely turnaround time for test results—it should take a week or less to receive e-mailed results. Many labs will call or text you if the results indicate urgent actions are required.

Before making a decision, review a sample report, often available on the candidate's website. Is it clear, readable, and understandable? Does it include a graphic representation of the current and previous analyses it has carried out? At the very least, for trend analysis it should include the results, whether shown graphically or numerically, of at least the three most recent analyses.

Many labs provide a guide to reading their particular style of oil-analysis reports. Ideally, the report should include indicators that will catch your attention, such as "normal," "alert," or "critical." The lab I use not only includes results from new lube, which can be useful for comparison, it also flags numbers that exceed established warning parameters and/or require action by the operator. When I review the report, my eye is immediately drawn to those marked or highlighted entries.

Once you've reviewed the report and the analyst's written recommendations, it is important that you can call the lab for consultation. If you can't rely on the lab for meaningful interpretation of its analysis, unless you are a trained tribologist, its value to you is limited.

As with most services, you get what you pay for from oil-analysis labs. If you are going to recommend that your customers analyze the oil from engines, gears, hydraulic systems, and generators once or twice a year, or you intend to take advantage of the program for your own equipment, why skimp by selecting a lab based solely on its low-bidder status? Choose a lab as you would choose a medical specialist, based on his or her abilities, reputation, and service rather than on geographic convenience or cost.

Test Frequency

How often should oil analysis be carried out? The answer depends on how the vessel and its equipment are operated. My preference is to test propulsion-engine, generator, and gear oil with every oil change, which will typically be somewhere between 100 and 250 hours. If the boat is fitted with a bypass oil-filtration system enabling extended drain intervals of hundreds of hours, oil analyses should be carried out with greater frequency. Consult your lab for its recommendations and discuss the type of testing this particular propulsion-engine lube oil should undergo. Hydraulic systems (including hydraulic transmissions) will benefit from a similar analysis frequency of every 150 hours of use, or seasonally.

Many labs offer "basic" and "advanced" analysis for engines as well as gears and hydraulic equipment. The differences are subtle but important. Basic engine-oil analysis typically includes ICP (checking for metal content), viscosity (checked at 100°C), as well as fuel, soot, and water content. The advanced version of this test should provide the additional information you'd want if running this boat at extended drain intervals, and include TBN (measuring the base neutralizing additive condition), oxidation, and nitration.

Analysis of gear oil from geared, as opposed to hydraulic, transmissions, as well as V drives, falls into similar categories. Basic includes ICP, water, viscosity (measured at 40°C), and TAN (measuring for acid buildup). The advanced version would also include oxidation, particle quantification (also know as PQ or ferrous density, which uses a magnetic field to create an index that correlates with DR ferrography), and DR ferrography.

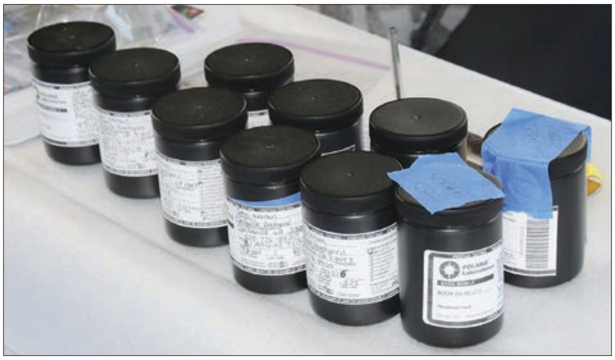
Basic hydraulic-system analysis includes ICP, water, viscosity (at 40°C), TAN, and oxidation tests. While many labs consider particle counting to be in the advanced hydraulic test package, based on the value of the information it provides, I'd consider it essential.

Sampling

Be sure to follow the lab's sampling procedures *to the letter*. Strong evidence supports the theory that many anomalous oil-analysis results are caused by poor sampling procedures.

Here are a few tips to avoid erroneous results:

- Observe absolute cleanliness. Don't open the sample bottle until you are ready to add oil into it. Seal the bottle immediately once the oil has been added.
- Take samples when the equipment is in its normal operating state, i.e., hot and having just been run under load (this includes hydraulic systems).
- Don't draw samples from the top



Taking good samples requires fastidious attention to detail to avoid cross-contamination and cross-labeling.

or bottom of a sump or reservoir, where contaminants may be concentrated and thus produce results that will not represent the majority of the lubricant the machinery is using.

- If you are collecting oil during a drain sequence, stop midway through the drain to take your sample.

On vessels or engines/generators that experience high usage, and therefore require more frequent sampling, consider installing an oil-sampling valve specifically designed for the purpose and permanently plumbed to the oil gallery. These valves allow oil to be drawn or bled while the engine is running, ensuring a homogenous sample. They avoid the need for vacuum pumps and tubing, thereby reducing the likelihood of sample contamination.

Many labs publish detailed "oil collection instructions" and provide inexpensive vacuum pumps to draw oil from a reservoir or sump. In addition to sending an uncontaminated oil sample, provide the lab with *all* the written information they've requested, including: lube time; unit time (the number of hours on the engine, gear, or hydraulic system); application (marine propulsion engine, generator, hydraulic stabilizer, etc.); sump capacity; filter micron ratings (especially important for hydraulic systems in analyzing particle count); and makeup oil (if 5 quarts of oil have been added during the lube oil's lube time and the sump holds only 4, the oil has essentially been changed, which will skew the results if not taken into account). And when you receive the report, avoid the temptation to go directly to the results; instead, ensure that all the data you provided have been transcribed properly.

In my experience, reports provided by engine dealers' labs are designed for professionals (although few dealers I've encountered can thoroughly analyze or explain report results), and as a result are often less user-friendly. Synopses, if provided, are less detailed, results are typically not e-mailed directly to you, and lab analysts are not accessible to you for follow-up queries. For more information or clarification, you must go through the dealer. If the analysis involves a potential warranty claim, it may be worthwhile to take double samples, reserving one set to send to an independent lab of your choice. Whichever route you take, I recommend that when your yard adopts an oil-analysis program, you provide precisely this sort of training for one or more employees. Without the means to interpret results meaningfully, you'll have recommended a service without having the tools to help your customers take full advantage of its benefits.

Oil analysis is simply one of several tools available to the marine industry professional for identifying latent or insidious problems that, if left unchecked, could lead to serious and costly failures. Not only will an oil-analysis program pay dividends for the vessel's preventive and predictive maintenance, it will often enhance its value. A boat whose owner's file includes several years' worth of oil-analysis reports is surely more valuable then one whose owner simply indicates that the oil was changed seasonally. At a standard rate of $25 to $30 per analysis, this is some of the most affordable and reliable diagnostic information you can buy.

In addition to benefiting your customers' boats, oil analysis for the yard's equipment and vessels will almost certainly improve reliability and minimize costly downtime, thereby reducing operating costs. PBB

Left—*Crankcase oil has a temperature sweet spot. When it runs cold, carbon and varnish production increase; and when it runs too hot, it oxidizes and ages prematurely. Oil samples are best taken when the equipment is hot and has just been operated under load.* ***Right***—*For periodic sampling, the vacuum pump and dip tube approach, shown here, works well; the proper collection procedures must be followed to avoid erroneous results. Oil sampling valves provide more consistent samples and reduce the likelihood of contamination.*

About the Author: *For many years a full-service yard manager, Steve now works with boat builders and owners and others in the industry as "Steve D'Antonio Marine Consulting." He is the technical editor of* Professional BoatBuilder*, and is writing a book on marine systems, to be published by McGraw-Hill/International Marine.*