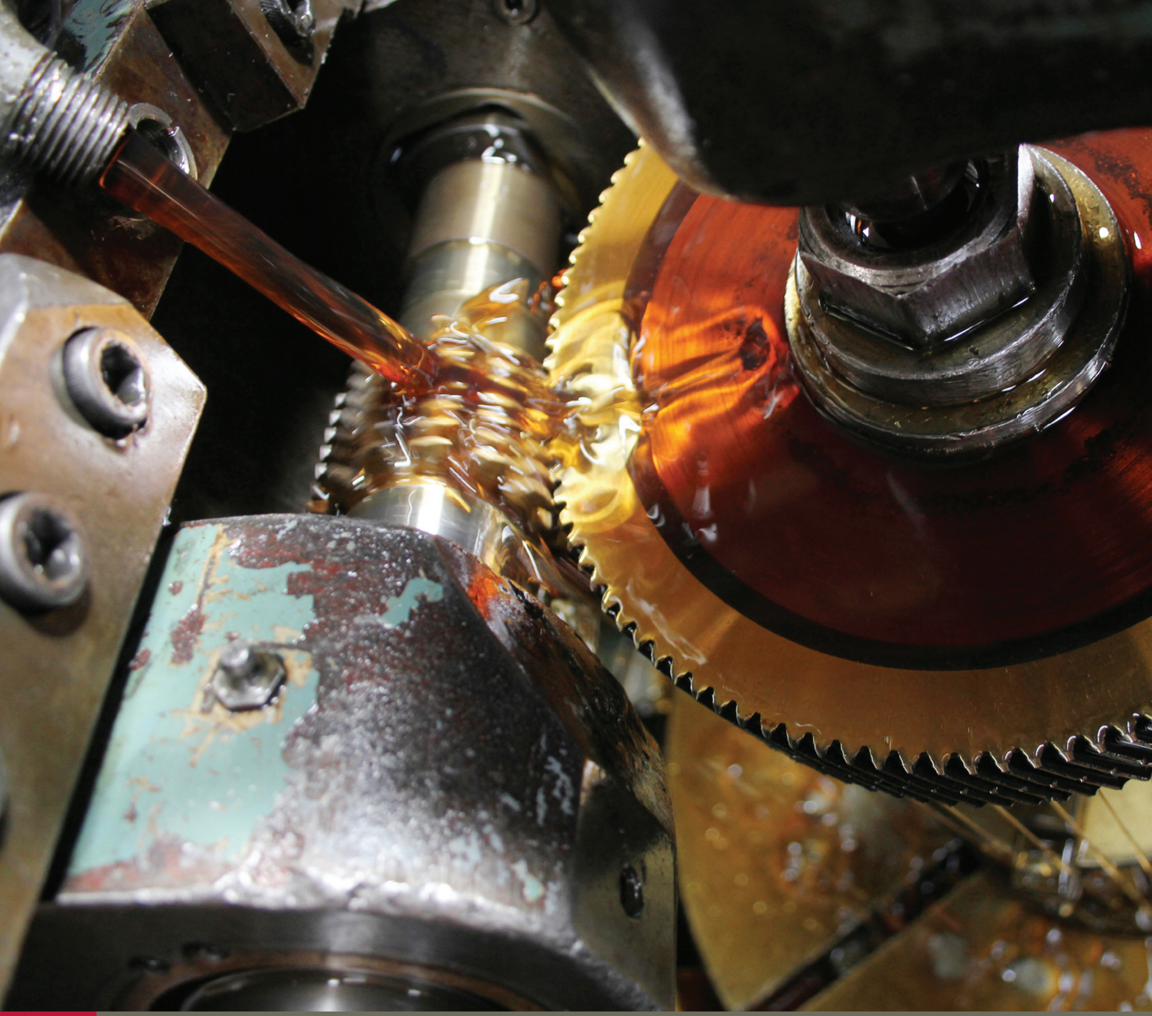

5th Edition

BASICS OF OIL ANALYSIS

BUREAU VERITAS

Move Forward with Confidence

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The Evolution of an Industry

For decades, oil analysis has helped diagnose the internal condition of oil-wetted components and their lubricants in virtually every industry that involves heavy duty machinery or stationary industrial equipment. While early test methods were shockingly simple, present-day processes employ the most advanced analytical tools and technologies.

Commercial oil analysis uses a combination of physical and chemical tests to monitor component wear, lubricant condition and contamination. These tests are established and continually reviewed by a number of global agencies, including the International Organization for Standardization (ISO), the American Society for Testing and Materials (ASTM) and the Society of Automotive Engineers (SAE). Additionally, a variety of laboratory and personnel certifications have emerged to ensure the highest levels of testing and analytical quality.

We have designed this book to help our oil analysis customers improve their maintenance programs with a better understanding of both the oil condition monitoring concept and the fundamentals of a world class oil testing and analysis program based on industry best practices.

The Bureau Veritas Value Proposition

Optimal equipment performance starts with consistent machinery fluid testing and analysis. The Bureau Veritas global network of state-of-the-art testing facilities provides accurate, reliable results you can depend on to keep your machines up and running.

Together, our customer-driven reporting tools and solutions-oriented data analysts take those quality results a step further, bridging the gap between good data and good business decisions. Allowing for effective monitoring of equipment conditions, these tools empower you to take decisive maintenance actions that maximize uptime and boost production levels.

Why Test With Us

Data management solutions that keep you ahead of critical maintenance events.

With Bureau Veritas' exclusive Lube Oil Analysis Management System (LOAMS^{SM}), maintenance personnel can optimize equipment reliability and productivity using real time oil analysis data to:

- Manage equipment around the globe in one centralized database
- Monitor changes in machine condition across an entire plant or fleet to identify minor problems before they become catastrophic failures
- Streamline communications to get the right information to the right people at the right time

A partnership with experienced data analysts whose informed maintenance recommendations are based on equipment-specific knowledge.

- Rely on smart analytical systems that differentiate between normal samples and those that require more in-depth communication with an analyst
- Accurately interpret test results to quickly identify an immediate plan of action in critical situations

Engagement with a staff of laboratory professionals that takes a personal interest in adding true value to the Bureau Veritas oil analysis experience.

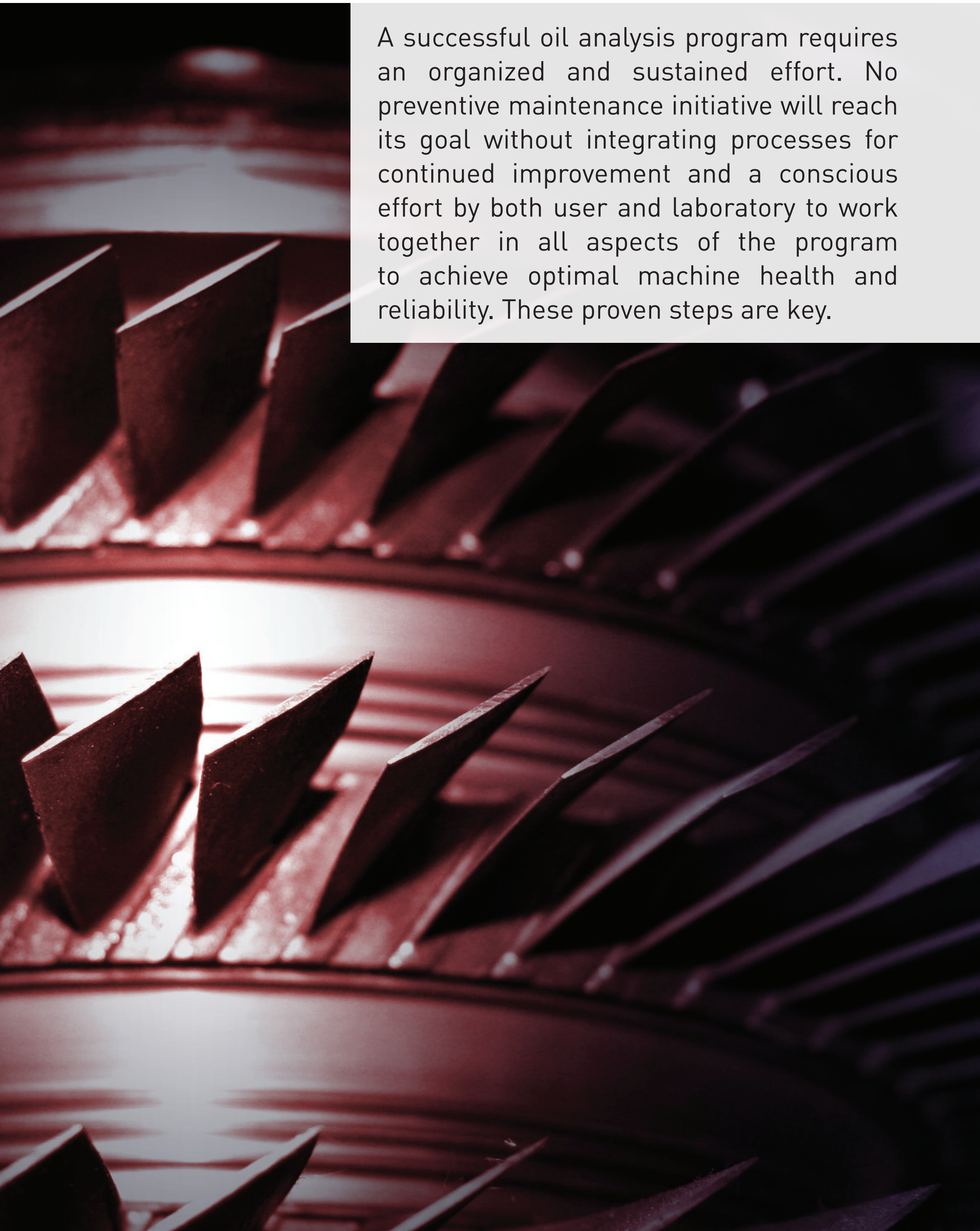
- From ordering test kits to interpreting results to managing the data, Bureau Veritas provides customer-focused solutions for maintaining equipment reliability through expert fluid analysis
- Competent customer service representatives, free training webinars and a dedicated LOAMS Help Desk allow you every opportunity to maximize your information and create a positive impact on your company's bottom line

Bureau Veritas employs more than 66,500 employees in 1,400 offices and laboratories in 140 countries. We serve more than 400,000 clients around the world through our eight global businesses, which include Marine & Off-Shore, Industry, In-Service Inspection and Verification, Construction, Certification, Commodities, Consumer Products and Government Services and International Trade.

Our oil analysis services are positioned within the Bureau Veritas Commodities business line, which provides a wide range of inspection and laboratory testing services for all types of commodities: Oil & Petrochemicals, Oil Condition Monitoring, Metals & Minerals, Exploration & Mining, Coal and Agri-Commodities & Fertilizers.

KEYS TO SUCCESSFUL OIL ANALYSIS

A successful oil analysis program requires an organized and sustained effort. No preventive maintenance initiative will reach its goal without integrating processes for continued improvement and a conscious effort by both user and laboratory to work together in all aspects of the program to achieve optimal machine health and reliability. These proven steps are key.



1

Clearly define program goals and requirements to be sure the test packages utilized are appropriate for the application and the service is being fully utilized on a regular, on-going basis.

2

Take representative samples that are indicative of the true condition of the lubricant and the component so that the testing and analysis performed is accurate and reliable.

3

Promote frequent, two-way communication between laboratory and customer to optimize both laboratory interpretations and recommendations as well as customer diagnostics and maintenance action.

4

Provide complete and accurate sample information so that data analysts may provide an accurate interpretation of the test results with well-informed, actionable maintenance or diagnostic recommendations.

5

Review test reports promptly to be sure abnormal or critical machine or lubricant conditions are addressed quickly and equipment damage and production losses are minimized.

ESTABLISHING AN EFFECTIVE OIL ANALYSIS PROGRAM

Oil analysis is an integral part of the maintenance plan for power generation and manufacturing plants, over-the-road trucking fleets, off-road construction equipment, HVAC and refrigeration systems and processing and chemical plants. Any piece of equipment that has a lubricating system is a potential candidate for oil analysis.

Determine Primary Program Objectives

Oil analysis can be applied to equipment and lubricant utilization, maintenance and management.

Utilization

- Decrease unscheduled downtime
- Increase overall component lifespan
- Control lube consumption and oil disposal costs
- Assist with product selection, comparison and verification

Maintenance

- Identify and quantify lube contamination and component wear for targeted corrective action
- Reduce in-service failures and field repairs
- Establish proper lubricant service intervals

Management

- Improve reliability, product quality and productivity
- Improve cost control for equipment, labor and materials
- Eliminate needless inspections or repairs
- Control spares and replacement costs

Carefully Consider The Best Choice For An Oil Analysis Provider

The best choice for an oil analysis provider is a laboratory prepared to help you achieve the primary goals and objectives of your testing program. The laboratories you consider should be equipped with state-of-the-art instrumentation, robust data management solutions and staffed with well-trained, experienced technicians and data analysts that can be available to address your questions.

Quality Testing, Data Interpretation & Automation

Bureau Veritas laboratories operate according to the highest standards for testing and calibration laboratories. Each of our US laboratories is ISO 17025 accredited with a scope of testing among the most comprehensive in the industry. ISO 17025 accreditation, with this level of inclusion, is a testament to top management's commitment to greater quality awareness, accuracy and continuous improvement.

We staff our laboratories with experienced data analysts who have the equipment-specific knowledge to make well-informed, actionable maintenance recommendations. They hold both Certified Lubrication Specialist (CLS) and Oil Monitoring Analyst (OMA) certifications from the Society for Tribologists and Lubrication Engineers and the International Council for Machinery Lubrication.

By partnering with the leading instrument manufacturers and participating in the development of industry-specific standard test procedures, Bureau Veritas is in touch with the latest technological advances. Our commitment to continuous progress and advancing technology results in value-added testing, the latest in automation and the highest levels of efficiency.

A Partnership in Data Analysis

Bureau Veritas makes substantial investments in the advancement of technologies that continually improve the benefits of oil analysis for our customers. Our self-learning data analysis system provides a comprehensive evaluation of normal sample results based on a database of like sampling histories, sampling points and the maintenance recommendations applied to them. This allows our data analysts to address critical samples and work closely with those customers to provide the diagnostic and maintenance recommendations necessary for preventing catastrophic equipment failure.

Online Applications for Optimizing Oil Analysis Data

Our Lube Oil Analysis Management System – LOAMS – not only provides customers quick access to test reports but also offers a full range of data management tools for managing every aspect of a world class oil analysis program. Key features include simplified sample submission, graphical trend analysis, management and diagnostic reporting, global equipment management and easy results distribution and communication.

Equipment & Sample Report Management

- Keep equipment lists clean and sampling histories intact with the power to add, delete, update, merge and move units between locations
- Maintain scheduled sampling intervals
- Print bar-coded jar labels and register trackable sample information online prior to the sample's arrival at the laboratory
- Create custom search filters to easily locate data using multiple equipment parameters
- Save filters to quickly locate commonly viewed test results and download, print or email to others

Trend Graphing

- Track trends in abnormal test results for individual pieces of equipment using multiple test parameters
- Overlay test results by make or model to compare equipment performance between individual units or across populations of units
- Chart sample condition for specific components to view performance compared to similar models or families of component types

Management Reports

Fluid analysis only saves you money if you are saving equipment. The management reports within LOAMS provide a comprehensive view of all your fluid analysis data.

- Document your program's strengths and eliminate its weaknesses to elevate overall program performance
- Know that samples are shipped to the laboratory as soon as they are taken
- Monitor sample transit time to pinpoint issues that could be slowing turnaround time and costing you money in delayed maintenance action
- Enforce compliance with required sampling schedules to catch small problems in all of the components you are testing before they become catastrophic failures
- Address critical samples immediately and monitor those at lesser severities for changes in sample condition – trend analysis is key to achieving "normal" sample results across the board, which is the true measure of a successful fluid analysis program

Diagnostic Reports

The diagnostic reports within LOAMS are designed to identify equipment-specific issues. Contamination, wear and fluid degradation are the most common causes for equipment failure and the top three reasons for monitoring both fluid and equipment condition.

- Track the generation of wear metals, dirt ingression, fuel dilution and coolant leaks - the biggest concerns for engine health in heavy duty applications
- High cleanliness standards, extreme operating conditions and high replacement costs make it necessary to monitor acid number, viscosity and particle contamination in many industrial applications.

Together, the management and diagnostic reporting capabilities in LOAMS give users quick access to comprehensive data that can elevate a fluid analysis program to higher levels of performance. Documenting the cost savings of a high performance fluid analysis program can justify the maintenance budgets necessary for successfully managing a world class sampling program.

System Configuration & Administration

- Designate roles, permissions and preferences to determine how data is received, displayed and communicated to others

Communications & Distributions

- Utilize filters to automate email distributions of sample reports and management reports specific to other LOAMS users and non-users

Technical Support

- Help icons on each menu tab explain the tab's functionality
- Quick Links give users access to detailed training videos, quick start guides and Frequently Asked Questions
- The LOAMS Help Desk is available to demonstrate LOAMS features or answer questions at 1.800.655.4473 or loams@analystsinc.com.

Build A Strong Program Foundation Before Testing Begins

Providing as much relevant, accurate machine information to the laboratory as possible is imperative for receiving quality, in-depth analysis of the test data. Laying the proper groundwork dramatically increases the value – and the success – of any oil analysis program.

Unit Criticality

Assessments that consider criticality to production and cost of repair and replacement should be used to help define the units to be tested. These assessments should also be based on operational history or known wear issues. Once these units have been identified, all relevant unit information should be accurately recorded and communicated to the laboratory – unit ID, make, model, lube type and hours/miles as all of this information has significant impact on the interpretation of test results.

Testing

Spectrochemical analysis and physical property tests are used to assess the condition of both lubricant and machine condition and should be performed according to a unit's criticality to production or a pre-determined preventive maintenance schedule. Physical tests focus on measuring specific lubricant characteristics such as viscosity, the formation of degradation byproducts, acid and base number, while spectrochemical analysis measures concentrations of wear, contaminant and additive elements. Bureau Veritas has developed multiple test packages to cover the general testing needs of broad industry classifications such as Power Generation, Manufacturing, Construction, Mining and Transportation. While these packages meet most testing needs, test slates can be customized to meet specific program goals and objectives.

Industrial Premium Test Package

Test	Components			
	Diesel / Nat. Gas Engines	Gear Systems / Motors	Compressors / Bearings	Hydraulic / Turbine
Metals Analysis *(Wear Metals, Contaminant Metals, Additive Metals)*	✓	✓	✓	✓
Viscosity (100° C)	✓			
Viscosity (40° C)		✓	✓	✓
FTIR *(Fuel Dilution, Fuel Soot, Glycol, Oxidation, Nitration)*	✓			
Water by Karl Fischer (ppm)	✓ (Water %)	✓	✓	✓
Base Number (TBN)	✓			
Acid Number (TAN)	✓	✓	✓	✓
ISO Particle Count		✓ (PQ)	✓	✓

Heavy Duty Premium Test Package

Test	Components			
	Diesel / Gasoline Engines	Natural Gas Engines	Non-Engine (Transmission, Differential, etc.)	Hydraulic
Elemental Analysis *(Wear, Contaminant & Additive Elements)*	✓	✓	✓	✓
Viscosity (100° C)	✓	✓		
Viscosity (40° C)			✓	✓
FTIR *(Fuel Dilution, Fuel Soot, Glycol, Oxidation, Nitration)*	✓	✓		
Water %	✓	✓	✓	✓
Base Number (TBN)	✓			
Acid Number (TAN)		✓	✓	✓
PQ Index			✓	✓

Sampling Intervals

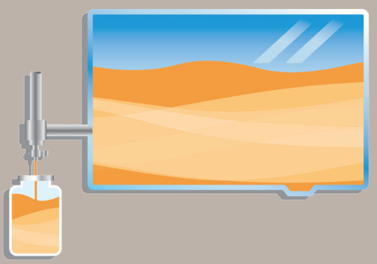
Upon program implementation, all units/components included in the criticality assessment should be sampled to establish initial baseline data and identify any serious existing component issues. Both client and laboratory together can then determine proper routine sampling intervals based on the results of the preliminary work, component manufacturer guidelines, the client's maintenance procedures and laboratory experience with similar components and applications.

General Sampling Interval Recommendations		
Unit Type	Recommended Sampling Frequency	
	Routine Use	Intermittent Use
Mobile Equipment (On Road)		
Diesel Engines Gasoline / LPG Engines	15,000 miles / 250 hours 5,000 miles / 150 hours	Quarterly
Non - Engines	30,000 miles / 500 hours	Quarterly
Mobile Equipment (Off Road)		
Diesel Engines Gasoline / LPG Engines	250 hours / monthly 150 hours / monthly	Quarterly
Non - Engines	500 hours / monthly	Quarterly
Marine		
Main Engines Support Engines	250 hours / monthly 150 hours / monthly	Quarterly
Non - Engines	500 hours / monthly	Quarterly
Industrial / Stationary		
Diesel / Natural Gas Engines Gas Turbines	500 hours / monthly 250 hours / monthly	Quarterly
Compressors, Steam Turbines	250 hours / monthly	Quarterly
Geared Drives, Bearings	500 hours / monthly	Quarterly
Hydraulics	500 hours / monthly	Quarterly
Aviation		
Piston Engines Turbine Engines	50 hours / at oil change 150 hours	Oil change, 100 hour inspection & annual
Geared Drives	350 - 500 hours	100 hour inspection
Hydraulics	150 - 250 hours	100 hour inspection
Refrigeration		
Chillers (all refrigerant types)	Beginning, Middle, End of Season	

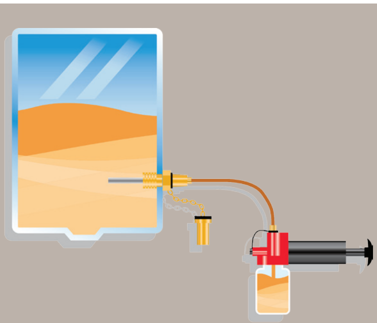
Obtaining Representative Samples

If a sample does not represent the actual condition of the lubricant and the component during operation, the reliability of both the test results and their interpretation is affected. Taking samples at regularly scheduled intervals and during normal operating conditions or within 30 minutes of shutdown allows for accurate trend analysis and the proper evaluation of any change in lubricant and component condition as wear particles and contaminants will remain thoroughly mixed and suspended.

Sampling from the sump or at the reservoir drain is the least recommended method for taking samples as wear particles and contaminants that tend to settle in these areas are not indicative of the concentrations present during operation. We recommend the following sampling methods and locations.



A permanent sampling port provides a consistently accurate sample collection source and is applicable to both pressurized and non-pressurized systems.



Samples drawn from a common return line collection point provide superior accuracy when the valve is installed upstream of the filter. This is the best sampling method for assessing machine contamination.

A petcock valve or similar sampling device is permanently installed upstream of any filters. A vacuum pump draws fluid through tubing and into the sample jar.

Consistent Baseline Information

Initial equipment registration is easily accomplished by furnishing the laboratory with a consolidated equipment list based on a thorough survey of the machines and systems to be sampled or by completing an individual registration form the first time each unit is sampled. In either case, the sampling point ID and current operating data is sent with each sample. To complete our sample processing forms and sample container labels completely and accurately, the following data is crucial for the laboratory to provide an accurate analysis of the test results and reliable maintenance recommendations:

- **Unit ID**

  The Unit ID is a reference number for an entire unit. Examples include a company asset or inventory identification number or vehicle serial number.

- **Unit Manufacturer & Model**

  Manufacturer & Model allows an analyst to identify specific component metallurgies and confirm wear metals present in the sample.

- **Component**

  Component represents the type of oil-wetted system being sampled – engine, hydraulic, gearbox. Our forms also provide designations for common sampling positions – left, number 3, rear – or an actual description of the component's use – fan drive, winch, swing – for clear, more precise identification.

  NOTE: In industrial applications, "unit" and "component" often refer to the same mechanical system. In these cases, the description of the sampled system should be recorded as the "unit."

- **Time Since New or Last Overhaul**

  Since normal wear rates change over the lifetime of a component and break-in may resemble abnormal wear, the operating hours or miles since the component was first put into service or since the last overhaul or rebuild can greatly affect interpretation of the test results. This data may be obtained from the component's service meter or from general operating records.

- **Time Since Last Oil Change**

  This is the number of hours or miles of component use between the time the oil was last changed and the time the sample was taken and is essential to time-based trend analysis.

- **Oil Type**

  The manufacturer, complete product name and viscosity grade for the oil sampled is important for proper interpretation.

- **Oil Consumption or Make-Up Oil**

  Complete oil changes should not be reported as make-up oil or identified as "new oil." Consumption or make-up oil is the amount of oil added to maintain a correct oil-fill level in the sampled component.

A sample may not be processed immediately if the client name, unit and component identification or sample date are not provided with the sample. Having sampled the unit before does not ensure that the unit and component identifications match the information provided with previous samples submitted for that unit. Testing could be delayed until this information is obtained or the results may not be filed correctly with other samples from that unit.

Any recent maintenance, changes in performance or unusual operating conditions pertaining to the unit should be included with the sample as well as any information collected during other routine maintenance and servicing activities.

Program Personnel

All personnel involved in implementing and maintaining an oil analysis program as part of any maintenance initiative should be trained on each of these important aspects which are vital to a program's continued success:

- Taking representative samples
- Recording consistent, complete and accurate oil and component information for sample processing
- Sending samples to the laboratory as soon as they are collected
- Using any online data management tools provided by the laboratory for optimal equipment management and to achieve maximum machine performance and reliability

Understand Data Interpretation & Maintenance Recommendations

Our interpretation and evaluation of laboratory test results typically separates the overall component and fluid condition – as relative to the severity of contamination and wear – into four main classifications:

NORMAL

Physical properties of the fluid are within acceptable limits and no signs of excessive wear or contamination are present.

MONITOR

Specific test results are outside acceptable ranges yet are not considered serious enough to justify diagnostic action. However, caution is advised as the initial stages of an abnormality often show the same pattern of results as do temporary conditions, such as extended usage or overloading.

ABNORMAL

Physical properties, contamination and/or component wear are clearly unsatisfactory but not critical. A confirming sample is recommended. Additional diagnostics may be necessary to confirm all sample conditions and corrective actions could be necessary to prevent reduced service life or overall loss of performance.

CRITICAL

Lubricant physical properties, contamination and/or component wear is clearly serious enough to require immediate diagnostic and/or corrective action to prevent major long-term loss of performance or component failure – short-term loss of performance may already be present. Operating hazards are likely to increase and large-scale repairs may be required. Recommendations may include removing the unit from service until a re-sample or other recommended diagnostics confirm that repairs are necessary.

Clients are contacted immediately by phone on all samples the laboratory classifies as “critical.” LOAMS users can designate within the application to have reports at specific severity levels emailed to them which include recommendations from our experienced data analysts for taking immediate maintenance action to correct both the problem and the cause.

NOTE: Sample severity assessments are relative and are assigned using both trend analysis and condemning limits.

In the trend analysis of wear elements, threshold values are developed to identify the boundary areas between normal and abnormal results. These values can vary by component type, application, length of service and manufacturer/model and don’t provide sharp lines of “normal/abnormal” interpretations. Instead, they indicate ranges of increased probability for a developing issue.

Generally, the lubricant and component condition can be considered “normal” as long as the wear, contamination and lubricant deterioration levels remain within established “normal” ranges. Regardless of threshold values, any sharp increase in wear metals or major shift in physical properties can signal the beginning of a problem. Therefore, threshold values cannot be used as “go/no go” criteria and should not be developed or applied without a great deal of caution, judgment, experience and client input.

REMEMBER:

- Always request clarification of the test results or data analysis if you don’t understand them
- Familiarize yourself with the laboratory’s severity classifications so that you know which units you can continue to monitor and which units need immediate maintenance attention
- Establish alarm limits specific to your equipment needs, if necessary
- Review test reports and act on maintenance recommendations in a timely manner

Provide The Laboratory With Feedback

The accuracy of the laboratory's interpretation guidelines is verified by the comparison between laboratory maintenance recommendations and the actual conditions confirmed by the customer's diagnostic inspection. While these data interpretations are continually refined by practical experience, the following customer feedback is extremely helpful when included on the sample information form:

- Suspect abnormal lubricant or component conditions
- Findings of any inspection performed as a result of oil analysis program recommendations
- Discovery of abnormal machine conditions that were not previously indicated by oil analysis
- Notification of servicing and/or maintenance performed
- Information concerning operating environment or equipment application changes

Measure Program Cost Effectiveness

Routine oil analysis can achieve substantial savings in maintenance and repair costs by detecting small problems before they develop into serious or catastrophic maintenance events. The economic savings from oil analysis may not show clearly on the "bottom line" because they represent the cost maintenance events that were prevented. However, many of these savings can be calculated by comparing the cost of a testing program to:

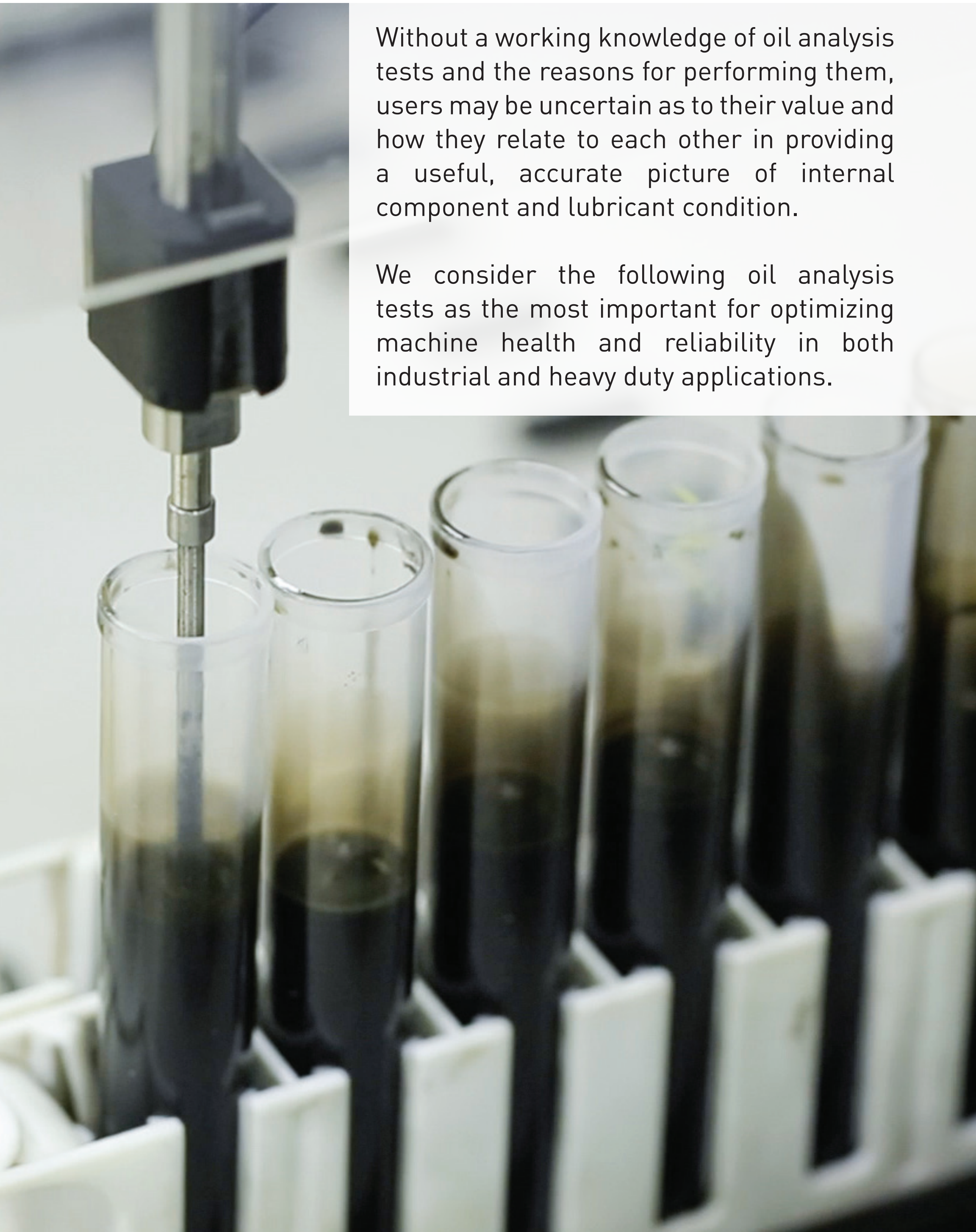
- Parts and labor expenses for component repair, overhaul or replacement
- Losses in revenue during downtime
- Reductions in consumable items, such as lubricants or fuels
- Increases in productivity levels

Because a well-run oil analysis program is deeply integrated within a company's overall maintenance program, program managers must establish a strong platform for measuring, documenting and distributing to upper management the contribution oil analysis makes to profitability.

TESTS AND THEIR SIGNIFICANCE

Without a working knowledge of oil analysis tests and the reasons for performing them, users may be uncertain as to their value and how they relate to each other in providing a useful, accurate picture of internal component and lubricant condition.

We consider the following oil analysis tests as the most important for optimizing machine health and reliability in both industrial and heavy duty applications.



Spectrochemical Analysis

Wear, contaminant and additive elements present as dissolved solids and microscopic particles suspended in the fluid are identified and measured in parts per million by weight. The analyzed elements are grouped into three main categories:

Wear

Relative motion between lubricated parts is always accompanied by friction between the opposing part surfaces. Despite the fact that these surfaces are usually coated with an oil film, friction wears them away. Some of the wear particles produced are small enough to remain suspended in the circulating oil. Since these wear products are composed of the same materials as the surfaces from which they originated, the level of each wear metal remaining in the used oil indicates the relative wear rate of the lubricated parts.

- **Adhesive / Rubbing Wear**

  Adhesive or rubbing wear occurs when the oil film does not separate the roughest points of the opposing moving surfaces allowing those surfaces to touch each other. This type of wear occurs normally during both break-in and routine service intervals as the moving parts wear slightly to maintain alignment. If severe adhesion occurs due to load, speed or temperature conditions, scuffing and scoring may result. Metal may be torn from part surfaces or transferred from one part to another with eventual seizure of the affected parts likely. During normal service, adhesive wear is controlled with anti-wear additives formulated to bond with lubricated surfaces reducing direct part-to-part contact.

- **Abrasive Wear**

  Abrasive wear results from a cutting or etching motion caused by circulating hard particles or hard-surface projections wearing away softer surfaces. Abrasive wear sources typically include contaminants, such as dirt, that have entered a component's oil system and the resulting wear metal particles.

- **Fatigue Wear**

  Fatigue wear occurs when cyclic or repeated load stress causes cracking, spalling or pitting of component part surfaces. Fatigue wear is more commonly associated with ball/roller element bearings and gears where the component surfaces "roll" past each other.

- **Corrosive (Chemical) Wear**

  Corrosive, or chemical, wear results when chemical reactions cause the corrosion or oxidation of part surfaces and part movement or fluid pressure dislodges material from part surfaces. This type of wear is associated with the presence of rust-promoting conditions, corrosive contaminants and/or excessively high levels of chemically active additives.

- **Cavitation Wear**

  Cavitation wear occurs when metal is removed from parts by the impact of collapsing cavitation bubbles on part surfaces. Cavitation itself is associated with partial vacuums formed in a liquid by sudden changes in pressure and may be caused by vibration, reduced or uneven liquid flow or other factors involving certain component shapes and movements.

Contaminants

Depending upon the circumstances, many substances can be classified as contaminants. Silicon, in the form of silicon dioxide (sand), is one of the most common contaminants monitored by spectrochemical analysis. Similarly, grease contamination in an oil system may be indicative of increases in aluminum or barium if the grease contains metallic soaps. Although the term contamination is commonly associated with substances entering a component's oil system from an external source, wear metals themselves are also a form of contaminant.

Additives

Additives are chemical compounds added to oils, fuels and coolants to provide specific beneficial properties to the finished product. Examples include anti-wear, anti-oxidant, detergency and dispersant additives. These additives create new fluid properties, enhance fluid properties already present and/or reduce the rate at which undesirable changes take place in a fluid during service.

Wear & Contaminant Elements					
Element	**Engines**	**Transmissions**	**Gear Systems**	**Hydraulics**	**Compressors**
SILICON	Silicon is typically associated with dirt contamination. This contamination can result from any condition that allows dirt to enter a component oil system. Other sources of silicon include seals, oil and coolant additives and greases.				
IRON *alloying element or cast metal*	Gears and shafts, block, cylinder liners, valve train, connecting rods, rings and oil pump, some bearings, pumps, housings, some pistons, some accessory systems	Gears and shafts, bearings, brakes and disks, pumps and shift spools, PTO, housing	Shafts and gears, bearings, housing	Rotors, vanes, pistons and rods, housing and bores, gears and shafts, valves	Gears and shafts, case, valves, cylinder liners, crossheads, rings and screws or turbines, bearings, some oil cooler tubing
COPPER *alloying element*	Bearings, wrist pin and valve train bushings, some main and accessory bearing retainers, other bushings and thrust washers, oil-cooler tubing; also may be present as an oil additive or a crossover contaminant from a leaking transmission seal, some oil-control valves	Discs, bearings, bushings and thrust washers, retainers and separators, oil cooler tubing	Bearings, bushings, retainers and thrust washers, oil cooler tubing	Bearings and bushings, swash plate cups, valves, some pistons, some pump cylinders, oil cooler tubing	Bearings, bushings, thrust washers and retainers, oil cooler tubing
ALUMINUM *alloying element or cast metal*	Aluminum oxides present in the environment are typically associated with silicon (dirt) contamination.				
	Pistons, bearings, bushings, blocks, main and accessory cases and housings, some oil cooler tubing, some retainers, seals, baffles	Some cases, impellers, bushings and retainers	Bearings, bushings, retainers and thrust washers, oil cooler tubing	Some pump housings	Cases, impellers, some pistons and crossheads, retainers
CHROMIUM *alloying element or plating*	Liners and rings, shafts, valve train, bearings, shafts and gears, seals		Bearings, shafts, seals	Rods, valves	Liners and rings, shafts, valve train
LEAD & TIN *alloying or flashing*	Bearings, some pistons, bushings and thrust washers		Bearings, shafts, seals	Pump thrust plate, bushings	Bearings, bushings
	Lead may still be found (rarely) in industrial paints and primers. Tin may be present as an oil additive, usually in conjunction with lubricants containing molybdenum compounds.				

Element	Engines	Transmissions	Gear Systems	Hydraulics	Compressors
NICKEL *alloying element or plating*	Gears and shafts, valve train, bearings		Gears and shafts, bearings	Gears and shafts, bearings	
SILVER *plating or tracer*	Silver is also occasionally used as a physical "tracer" to indicate that wear has progressed to a certain point. In this application, silver is either plated directly onto a part surface or incorporated into a layer under the surface. The wear condition of the part can then be related to the amount of the tracer deposited in the oil. This usage is most often found in aerospace applications. Some bearings and bushings, oil cooler solder, seals				
MOLYBDENUM *plating or tracer*	Molybdenum is typically found only in certain aerospace and heavy duty commercial or industrial steels. It may also be present in fuels as heavy crude residual material.				
MAGNESIUM *alloying element*	Cases and housings				
TITANIUM *alloying element*	Titanium is typically found only in certain aerospace and heavy duty commercial or industrial steels. Some shafts, bearings, and gears				
ANTIMONY *alloying element*	Certain types of journal bearing overlays				
ZINC *alloying element*	Brass fittings (with copper), galvanized surfaces				
VANADIUM *alloying element*	Vanadium is typically found only in certain aerospace and heavy duty commercial or industrial steels. It may also be present in fuels as heavy crude residual material.				

Additive Elements

Element	Engines	Transmissions	Gear Systems	Hydraulics	Compressors
MOLYBDENUM	Extreme pressure additive or solid lubricant in specialty oils and greases; corrosion inhibitor in some conventional coolants or supplemental additives				
MAGNESIUM	Detergent, dispersant, alkalinity increaser				
SODIUM	Corrosion inhibitor in oils and coolants				
BORON	Detergent, dispersant; anti-oxidant in oils and coolants				
BARIUM	Corrosion and rust inhibitors, detergent, anti-smoke additive in fuels				
PHOSPHORUS	Anti-wear, combustion chamber deposit reducer; corrosion inhibitor in coolants				
POTASSIUM	Corrosion inhibitor, trace element in fuels, also found as a mineral salt in sea water (marine cooling systems)				
CALCIUM	Detergent, dispersant, alkalinity increaser				
ZINC	Anti-wear, anti-oxidant, corrosion inhibitor				

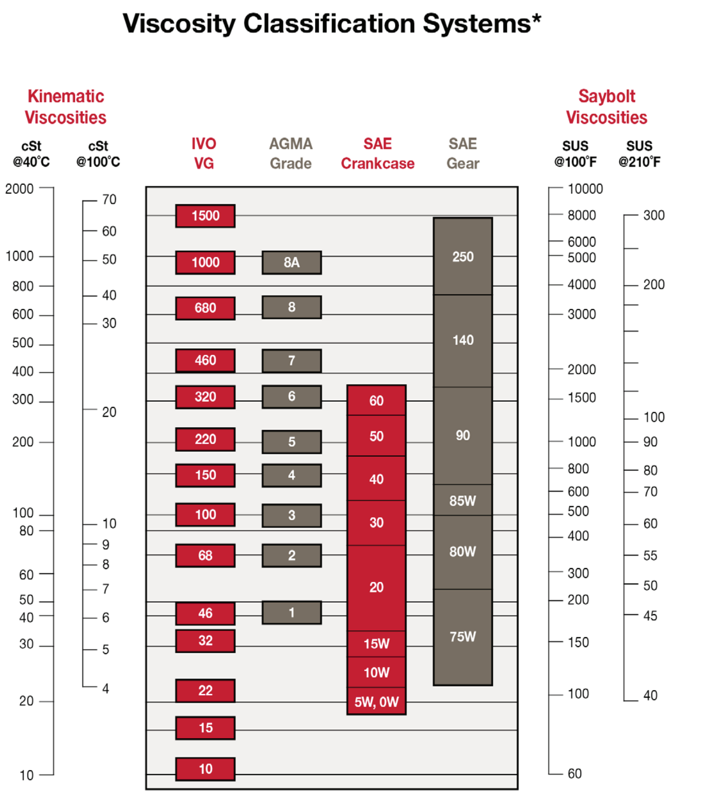
Physical analysis concentrates on measuring the degradation of certain lubricant characteristics.

Viscosity

Considered to be an oil's single most important physical property, viscosity is a lubricant's internal resistance to flow at a given temperature in relation to time. Changes in viscosity can indicate improper servicing, contamination or lubricant breakdown.

Viscosity is measured at 40°C for industrial applications and at 100°C for engine oil applications. It is most commonly determined using a kinematic method with results reported in centistokes (cSt – 1 Centistoke (cSt) = 1 square millimeter per second). In addition to the viscosity result, the crankcase oil viscosity class of an engine lubricant may also be expressed as an SAE grade.

Viscosity classification systems provide a uniform and common basis for designating lubricants. The grade comparison chart below is a general guide that applies to viscosity at several different reference temperatures but does not evaluate total lubricant quality. These comparisons are based on a 95 VI product.



*This grade comparison is a general guide that applies to viscosity at several different reference temperatures but does not evaluate total lubricant quality. These comparisons are based on a 95 VI product.

Water

The presence of water in a non-water-based fluid indicates contamination from condensation or an outside source. Excessive levels of water promote lubricant breakdown and component corrosion. The presence of water can be identified by a "crackle" test and reported in % volume. In applications where extremely low levels of water must be maintained, the Karl Fischer titration method is used to report water content in parts per million (ppm).

Fuel Soot

Fuel Soot is an indication of an engine's combustion efficiency. An excessive concentration of soot promotes oil gelling and sludge in the engine, which leads to poor oil circulation. Fuel injector efficiency and timing, the integrity of ring piston seal, oil consumption and load all have an effect on fuel soot concentrations. Results are reported in weight %.

Fuel Dilution

Fuel dilution is the amount of unburned fuel present in an engine lubricant. Most commonly associated with clogged or malfunctioning fuel injectors or fuel system assemblies, excessive fuel dilution reduces lubricity, lowers lubricant load-carrying capacities and increases the probability of a crankcase fire and/or explosion. Fuel dilution is most accurately measured by gas chromatography and is reported in % volume.

Glycol

A positive result indicates the presence of glycol contamination, most commonly associated with a leak between the crankcase and the engine's cooling system. Glycol contamination promotes wear, corrosion, lubricant breakdown and sludging. When oil analysis indicates water ingression or the presence of coolant additives, additional chemical tests are recommended to confirm the glycol contamination.

Infrared Analysis (FTIR)

When organic compounds, such as lubricating oils, are exposed to infrared light, substances present within the compound will absorb the light at specific wavelengths. The amount of absorbance at a particular wavelength is related to both the type and quantity of absorbing material. In this way, certain contaminants and physical changes in the lubricant can be directly measured according to a molecular spectrum. Glycol (coolant) contamination, sulfates, acid and base changes, as well as certain additives, may also be detected, along with an extremely wide range of organic compounds.

Oxidation

Oxidation is the result of a series of chemical reactions involving oxygen and elevated temperatures resulting in compounds that contribute to the acidity of the oil and depletion of the basic additives. The degree of oxidation is a good indicator of oil degradation and a rapid increase in oxidation may indicate abnormal operating conditions, internal overheating or an over-extended oil drain interval. Test results are reported in the absorbance scale.

Nitration

Nitration is the result of the oxidation of atmospheric nitrogen during the combustion process. A high nitration value can indicate an improper air/fuel ratio, excessive loads or piston ring "blow-by." Test results are reported on an absorbance scale.

Neutralization Number

Both the acidic and alkaline content of a lubricant may be measured and expressed as a neutralization number obtained from an acid/base titration.

Acid Number (AN or TAN – Total Acid Number)

Acid Number measures the total amount of acidic material present in the lubricant. An increase in AN above that of the new product indicates oil oxidation, or mixing with a more acidic product or contaminant. The results are expressed as a numeric value corresponding to the amount of potassium hydroxide required to neutralize the acid per one gram of sample.

Base Number (BN or TBN – Total Base Number)

Base Number measures the total alkaline content present in the lubricant. Many of the additives used in engine oils contain alkaline (basic) materials intended to neutralize the acid-forming processes of aging and fuel combustion. A relatively high BN is associated with increased protection against ring and cylinder liner corrosion and damage to "yellow" metals, such as copper and bronze. Abnormal decreases in BN indicate a reduced acid-neutralizing capacity and/or a depleted additive package. The test first determines the amount of acid required to neutralize the alkaline content of the sample. The final result is then expressed as an equivalent amount of potassium hydroxide per gram of sample.

Particle Count

Particle counting is a valuable part of any oil analysis program as the use of clean oil can not be emphasized enough. This test employs a laser particle count instrument that counts the number of particles in a specific size range per a given volume of sample.

Particle count calibration techniques and the reporting of results standards have been developed to assist in obtaining consistent results and meeting targeted cleanliness levels. ISO 11171 defines the proper techniques for instrument calibration while ISO 4406 simplifies the reporting of particle count data by assigning cleanliness codes based on the total number of particles in three given size ranges - for example 22/20/16.

The first cleanliness code corresponds to the number of particles greater than 4um, the second cleanliness code corresponds to the number of particles greater than 6um and the third to particles greater than 14um. Abnormal particle contamination levels are associated with increased wear, fluid contamination or degradation and loss of filter efficiency.

The ISO Cleanliness Code for Particle Distribution

These particle count results have been assigned an ISO Cleanliness Code of 22/20/15.

ISO 22/20/15

31167
>4µ to >70µ
The code number 22 represents 31,167 particles measuring >4µ.

6650
>6µ to >70µ
The second code number 20 represents 6,650 particles measuring >6µ.

316
>14µ to >70µ
The third code number 15 represents 316 particles >14µ in size.

ISO Code	particle/1ml
30	10,000,000
29	5,000,000
28	2,500,000
27	1,300,000
26	640,000
25	320,000
24	160,000
23	80,000
22	40,000
21	20,000
20	10,000
19	5,000
18	2,500
17	1,300
16	640
15	320
14	160
13	80
12	40
11	20
10	10
9	5
8	2.5
7	1.3
6	0.64
5	0.32
4	0.16
3	0.08
2	0.04
1	0.02
0.9	0.01
0.8	0.005
0.7	0.0025

Particle count results are assigned three ISO code numbers based on the total number of particles equal to or greater than a given size range.

An increase from one code number to the next generally indicates that the particle contamination level has doubled.

Particle Quantifying

PQ exposes samples to a magnetic field where the ferrous debris in the sample distorts the field and the amount of distortion is represented as the PQ Index. This is an arbitrary number specific to the technique. However, as the determination of iron by ICP is dependent on particle size where detection is typically limited to < 10 microns, the PQ offers superior detection when larger particles are present. As no single laboratory test completely represents the amount of ferrous wear present in an oil sample and most wear trends start with smaller sized particles that eventually lead to larger particles, including PQ in your fluid analysis program helps in obtaining a complete assessment of current wear conditions.

Careful monitoring of ICP iron concentrations and trends in PQ Indexes provides a means of triggering an Analytical Ferrography Analysis to qualify the type and severity of the wear. Analytical Ferrography is a powerful tool when used in conjunction with other analysis results and allows data analysts to provide users with a well-defined course of action to remedy the current adverse condition(s).

Ferrography

Ferrography is an analytical technique in which wear metals and contaminant particles are magnetically and gravimetrically separated from a lubricant and arranged according to size and composition for further examination. It is widely used in oil analysis to determine component condition through direct examination of wear metal particles.

Complete ferrographic analysis consists of three parts:

- Direct Reading (DR) ferrographical analysis
- Creation and examination of an analytical ferrogram
- Interpretation and reporting of the results of an analytical ferrogram

DR ferrography precipitates the wear particles from a sample and electronically determines the quantity of "large" (over 5 microns) and "small" (1 to 2 microns) particles present in the sample. Wear calculations from these results indicate the rate, intensity and severity of wear occurring in the sampled machine. In cases where the DR ferrography wear trends indicate an abnormal or critical wear condition, analytical ferrography can reveal the specific wear type and probable source of the wear condition.

Analytical ferrography uses the Ferrograph Fluid Analyzer to concentrate and distribute particles directly onto a microscopic ferrogram slide by drawing the oil sample across a glass or plastic plate in the presence of a strong magnetic field. An experienced evaluator then examines the ferrogram to determine the composition and sources of the particles and the type of wear debris present.

An analytical ferrography report includes specific type and quantity classifications of the metallic and non-metallic debris present on the slide, a color photomicrograph of the ferrogram, an assessment of the sampled machine's overall wear status and a detailed interpretation of the ferrography results.

Specialty Testing

While much of this reference guide has focused on routine testing, test slates for certain industrial systems, greases, fuels, coolants or other special investigations often include non-routine or ASTM specification tests. Bureau Veritas laboratories are fully equipped to provide customers with a wide scope of testing capabilities and specially designed analysis programs for many applications and sample types.

In addition to the testing offered through the Oil Condition Monitoring program, other advanced and specialty testing capabilities are available through the Bureau Veritas Oil & Petrochemicals business line, which offers services that can be customized to meet your exact requirements, whether they are for a comprehensive laboratory program or the testing of individual samples.

Capabilities include:

- Laboratory outsourcing and management
- Product quality control
- Research and development projects
- Routine laboratory testing
- Consultancy utilizing our highly trained experts

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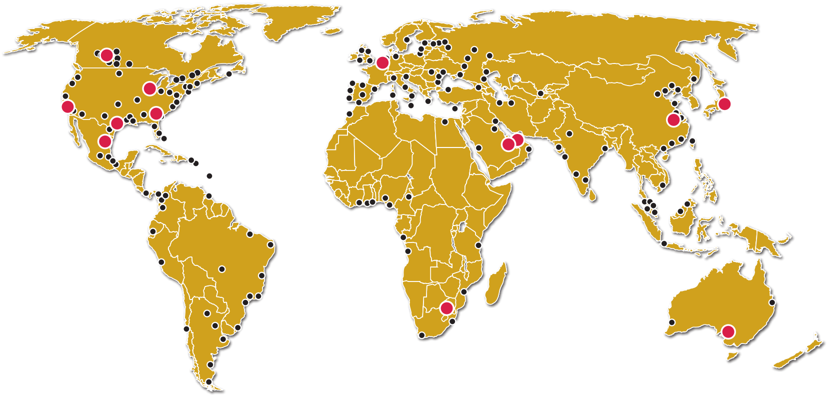

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- Oil & Petrochemical Locations

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