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Condition monitoring and diagnostics of machine systems — Tribology-based monitoring and diagnostics —

Part 1:
General requirements and guidelines

Surveillance et diagnostic de l'état des systèmes de machines — Surveillance et diagnostic basés sur la tribologie —

Partie 1: Exigences et lignes directrices générales

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 5, *Condition monitoring and diagnostics of machine systems*.

A list of all parts in the ISO 14830 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Tribology and lubricant-based monitoring is a broad field comprising the activities of monitoring, reporting and responding to information obtained from the analysis of lubricating oils, hydraulic fluids and greases. Common terms used to describe this practice are "oil analysis", "lubricant" and "wear debris". Because it also encompasses the analysis of used hydraulic fluids and greases, this document generically refers to the entire practice as "lubricant analysis".

Lubricants are used in a wide range of machine types, including stationary industrial equipment and mobile equipment used in transportation, construction and mining. Examples of machine types include gearboxes, pumps, hydraulic systems, turbines, compressors, engines and transmissions. Many different condition types can be analysed and reported in the practice of lubricant and wear debris, including:

a) quality and condition of new oil deliveries;

b) state of lubricants during storage and dispensing;

c) distressed, degraded or non-compliant in-service lubricant properties;

d) lubricant contamination;

e) wear particle composition and physical characteristics;

f) abnormal failure root causes or stressing conditions.

The methods of gathering and analysing fluid properties and conditions vary widely and evolve directly from which conditions listed above will be reported. Often instruments and procedures are employed in a laboratory to analyse lubricant samples. Similar instruments can be used remotely in the field or plant. In certain cases, instruments or sensors can be used in real time, including on-line particle analysis, dedicated to a specific machine and fluid.

This document for lubricant condition monitoring, also known as tribodiagnostics, forms a vital component of asset management and as such will form one of the platform condition monitoring knowledge base documents required for the application of ISO 55000, ISO 55001 and ISO 55002 (asset management International Standards) to machines which establishes the management system requirements for performance monitoring.

Using lubricant and wear debris to monitor condition and diagnose faults in machinery is a key activity in predictive maintenance programmes for most industries. In certain cases, instruments or sensors can be used in real time, including on-line debris analysis, dedicated to a specific machine and fluid types. Other non-intrusive technologies including thermography, vibration analysis, acoustic emission and motor current analysis are used as complementary condition analysis tools. Those in the manufacturing industry who have diligently and consistently applied these techniques have experienced a return on investment far exceeding their expectations. However, the effectiveness of these programmes depends on the capabilities of individuals who perform the measurements and analyse the data.

This document contains general requirements and guidelines for activities relating to monitoring of physical and chemical properties of lubricants, lubricant contamination and wear particle suspended in lubricants. The monitoring objective is to assess tribological health and condition of machine system surfaces, as well as condition of the lubricant itself, to provide information on the operating condition of the machine for protection and predictive maintenance.

The accuracy and repeatability of lubricant analysis results are dependent upon both sample acquisition techniques and analyst's competence. The competence requirements for both are detailed in ISO 18436-4 and ISO 18436-5.

Condition monitoring and diagnostics of machine systems — Tribology-based monitoring and diagnostics —

Part 1:
General requirements and guidelines

1 Scope

This document specifies requirements and guidelines for the analysis of lubricating oils, hydraulic fluids, synthetic fluids and greases.

Tests for electrical insulating oils and heat transfer oil are outside the scope of this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13372, *Condition monitoring and diagnostics of machines — Vocabulary*

ISO 13379 (all parts), *Condition monitoring and diagnostics of machines — Data interpretation and diagnostics techniques*

ISO 13381-1, *Condition monitoring and diagnostics of machines — Prognostics — Part 1: General guidelines*

ISO 17359, *Condition monitoring and diagnostics of machines — General guidelines*

3 Terms and definitions

For the purposes of this document, the terms and definitions given ISO 13372 and the following apply:

ISO and IEC maintain terminological databases for use in standardisation at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

3.1
analytical ferrography
magnetic precipitation and subsequent analysis of wear particles from a fluid sample

3.2
contamination control
set of planning, organizing, managing and implementing activities for the purpose of achieving and maintaining a specific contamination level

3.4
tribology
science and technology of interacting surfaces in relative motion, and of related subjects and practices including lubrication, friction and wear

4 Symbols (and abbreviated terms)

cSt	centistoke (1 cSt = 1 mm^2/s)
L	litre
µm	micron, micrometre
ppm	parts per million, generally by weight (1 ppm = 10^{-6}, 10 000 ppm = 1 %)

5 Lubricant and wear particle analysis

5.1 Asset management

Lubricant and wear debris analysis is one of the key methodologies required for the monitoring of machinery asset performance and condition. The overarching management system for condition monitoring should be in accordance with ISO 55001, which establishes the management system requirements for performance monitoring and enables the achievement of the asset management principles contained in ISO 55000.

5.2 Strategies

5.2.1 Before failure onset (as a proactive strategy tool)

Before the lubricant is used and prior to the onset of failure, lubricant, contamination and wear debris analysis can confirm that the lubricant is physically and chemically fit for service and compatible prior to use and that the machine contains the correct lubricant. It also confirms that contamination levels are within acceptable limits. Lubricant and wear debris can be an important tool in efforts to assure quality of new lubricant deliveries and fitness for service, storage and dispensing effectiveness, and reclamation activities. These are proactive applications of the practice that have the potential to extend machinery life.

5.2.2 During failure development (as a predictive strategy tool)

When a machine fails, wear particles, contaminants and lubricant property changes are often produced prior to any observable operational deterioration. Lubricant, contamination and wear particle analysis provides early detection and diagnosis of problems. Failure prognostics, the process of estimating residual machine or lubricant life, can also be performed. Prognostic forecasts are improved when multiple data parameters are measured and defined. This process can include comparison with benchmarking and manufacturer's data.

5.2.3 Following machine failure (as a reactive strategy tool)

Users can analyse lubricant properties, wear particles and contaminants from a failed machine to diagnose problems and design solutions to prevent recurrence.

5.2.4 Other benefits

Lubricant and wear debris can be used to avoid unnecessary oil changes or extend drain intervals, resulting in reduced lubricant consumption and associated costs. In certain hazardous applications, it can help ensure safety of machinery. Lubricant and wear debris can also be used to optimize lubricant selection, potentially resulting in reduced energy consumption.

Machine criticality, probability of failure and operating environment (temperature, contamination, etc.) are other factors that influence the selection of lubricant and wear debris type and sampling frequency.

5.3 Information to be gained through lubricant and wear debris

5.3.1 Lubricant properties

This category of analysis deals with the assessment of chemical, physical and additive properties of a lubricant, to confirm its identity and that it complies with specified requirements.

5.3.2 Lubricant contamination

External contaminants of various types can be either externally ingested or internally generated. They can enter systems and lubricants during manufacture or servicing, or from the environment or internal generation. It can also include microbiological inclusive of bacteria, fungus and yeast organisms requiring specialised testing.

Contamination compromises machine reliability and promotes lubricant failure. Lubricant analysis targeting contamination can help ensure goal-driven targets for contamination control are maintained.

5.3.3 Machine wear

When friction surfaces wear, they generate wear particles that enter the lubricant. Monitoring and analysis of internally generated wear particles enable the detection and evaluation of abnormal conditions, which assists in directing necessary remedial actions.

6 Measurement parameters

6.1 Lubricant and wear debris parameters

Commonly measured used lubricant and wear debris parameters are summarised in Annex A.

Many parameters have multiple test methodologies or instruments, each with specific limitations of detection, accuracy, repeatability and reproducibility. The lubricant and wear debris program strategies and objectives determine the most appropriate test method(s) to employ.

Test method modifications can vary between laboratories, resulting in differences in results. Sometimes, results cannot be comparable between instruments due to variances in test method and instrumentation. Tests are also susceptible to human and method error.

The valve arrangement for sampling can also give a great variation in results, due to the narrow passages of the valve, which has an increasing influence as system pressure increases.

Many commonly used ISO, ASTM and equivalent test methods are designed for testing new lubricants. The properties of used lubricants can cause variation of test results.

6.2 Lubricant test suites

Single lubricant tests cannot usually satisfy all analysis objectives, particularly for routine condition monitoring. For this reason, a suite of tests is normally performed to measure all parameters of interest. Test selection criteria include machine and lubricant type, likely failure modes and symptoms, and technique sensitivity, accuracy and feasibility.

Typical test suites for common lubricant types and applications are shown in the tables of Annex B. Also shown are exception tests that may be applied when investigating particular problems.

The same suite of tests should generally be used for each lubricant type and application. Variables that typically change are frequency of testing and parameter alarm levels.

6.3 Sampling frequency

FMSA analysis, which shall be carried out in accordance with ISO 13379-1, is recommended to determine initial sampling and inspection periods. These should be short to allow creation of a baseline for each machine. The tables in Annex B also show typical frequencies for common tests and lubricant types. Similar practices can be employed to determine magnetic particle detector inspection periods.

Sampling and inspection intervals can be optimised by taking into account the following machine and application-specific conditions:

a) Criticality: safety, environmental, downtime, repair and business interruption failure consequences.

b) Operational and fluid environment conditions: these influence frequency and rate of machine and lubricant failure. They include pressure, load, temperature, speed, contaminant ingression rate, wear rate and duty cycle severity.

c) Lubricant age: problems often occur immediately after lubricants are serviced (drains, refills and top-ups) due to contamination by incorrect and/or incompatible lubricants. Lubricants approaching the end of their useful life are also at high risk due to depleted additives, incipient oxidation and high levels of various contaminants.

d) Machine age and maintenance factors: the chances of failure for most machines are greater during break-in and after major repairs, rebuilds or extended downtime; or machine modifications. Risks can also increase as a machine approaches the end of its expected life.

e) Failure behaviour: known and expected failure modes, including historical P-F intervals (as defined in IEC 60300-3-11) for failure mode and measurement technique combinations.

f) Machine condition: whenever abnormal condition reports are received, sampling frequency should be increased to improve diagnosis and prognosis confidence.

Computer based software is available to manage lubricant and wear particle sampling intervals, based on condition analysis results obtained. This makes use of cumulative distribution and probability density functions, suitably adjusted for time intervals, condition status and cost/risk potential. As a further step, when combined with costs of inspection and failure, the software can determine the economically optimum point to undertake inspection.

7 Sampling

7.1 Objectives

Analysis results interpretation is only valid if samples are representative of the lubricant under operating conditions. Errors in obtaining samples impair all further analytical efforts. Example procedures are given in Annex C.

The primary goals of sampling are:

a) Maximizing data density: information contained per sample unit volume.

b) Minimizing data disturbance: information is uniform, consistent and unaltered by the process. Ensure samples are not contaminated; this can distort the data, making it difficult to distinguish between contaminants and what was originally in the lubricant.

When selecting and locating sample points, inclusive of wear particle and contamination detectors, the following applies:

i) Sampling points shall provide safe acquisition of the sample during dynamic operating conditions if required.

ii) Points should provide representative and repeatable samples, be easy to use, minimize leaks or spills and be self-sealing if appropriate. They should be located in areas with minimal contamination that are easily and safely accessible during normal machine operation.

iii) Sample points shall be compatible with the fluid, operating pressure, external environment, sampling procedure and analysis type used.

iv) Point design should minimize areas where contaminants can settle out when not in use, minimize generation of internal contaminants and permit self-flushing. They should be easily cleanable externally and not allow any of the sampling equipment to come into contact with contamination during use.

v) Fit dedicated points to each compartment or system intended for routine sampling. Also fit them to other large compartments if a suitable location for suction or similar sampling is not available.

vi) Not all locations produce the same data concentration. Some machines can require multiple sampling locations for complex or multiple component systems.

vii) Distribution of large or heavy particles is not always uniform in a system. Detecting such particles can require a specific strategy to extract samples from areas immediately adjacent to components, low flow or historical settling areas. For critical or high failure rate machines, observation of particle settling areas is important to ensure effective sampling. Provide secondary sample points, such as on either side of filters, individual component return lines and separate reservoir compartments, where they are likely to be required for problem investigation or ad hoc sampling.

viii) Sample points should be labelled with their purpose, with interchangeable labels used on rotable components.

7.2 Pressurized sample points

The type of points used for sampling from pressurized, flowing lines ("dynamic sampling") are dependent upon, and shall be rated for, system maximum operating pressures:

a) Points should be located to permit dynamic sampling wherever possible from main fluid lines in a section where turbulent flow conditions exist, or have some means of inducing turbulence.

b) Extraction points should be clear of pipe boundary flow layers. The sampler axis should be approximately perpendicular to flow, entering the pipe from top or side. Fluid exit points should be directed vertically down.

c) Points shall permit on/off valving of sample flow and have the ability to reduce system pressure to atmospheric pressure at a minimum flow rate of 100 ml/min (preferably 500 ml/min) in the open position, without altering oil contamination levels or distribution.

d) Where lines operate at atmospheric pressure, it can be necessary to extract samples using a vacuum pump, particularly if oil viscosity is high.

e) Locations chosen should be downstream from components of interest, away from contaminant ingression points and upstream of filters, separators, dehydrators, settling tanks, etc.

f) Where an oil circulation system has an accessible combined return line to the reservoir from lubricated components, this is the preferred primary sample point, before any return line filter.

g) Where this is not feasible, a sample point between the oil supply pump and any pressure line filter should be used.

h) If neither of the above is practicable and a system is fitted with permanent off line (kidney loop) filtration, an alternative sample point is between the circulation pump and filter. Lines that only contain static pressure, such as instrument lines, should not be used unless they can be adequately flushed prior to sampling.

i) Sample points on high-pressure lines should have a label warning of a high-pressure jet hazard and be shielded.

j) Sample points specifically installed for the purposes of particle acquisition should include a self-sealing function in order to minimize system contamination and leakage.

k) For pressurized systems, a closed loop technique may be used. This in line sampling method minimizes the variation in result between laboratories and can improve sample accuracy and repeatability. A closed loop system can also reduce the health risk for people taking samples from high pressure systems.

l) If the sampling bottle is integrated in the circulation system for fluid sampling, the influence of the sampling bottle cleanliness can also be reduced.

m) Magnetic particle detectors should be installed in self-sealing valve housings to facilitate safe removal under dynamic conditions.

7.3 Static sample points

Static sampling from reservoirs, sumps, etc. may be used when dynamic sampling is not practicable, e.g. splash lubricated gearboxes and pumps:

a) Samples should be extracted from centralised areas in compartments where fluid is in motion, as close as possible to any oil return line and away from quiescent areas caused by corners and baffles. Fittings used should be well clear of moving parts and not interfere with compartment design flows.

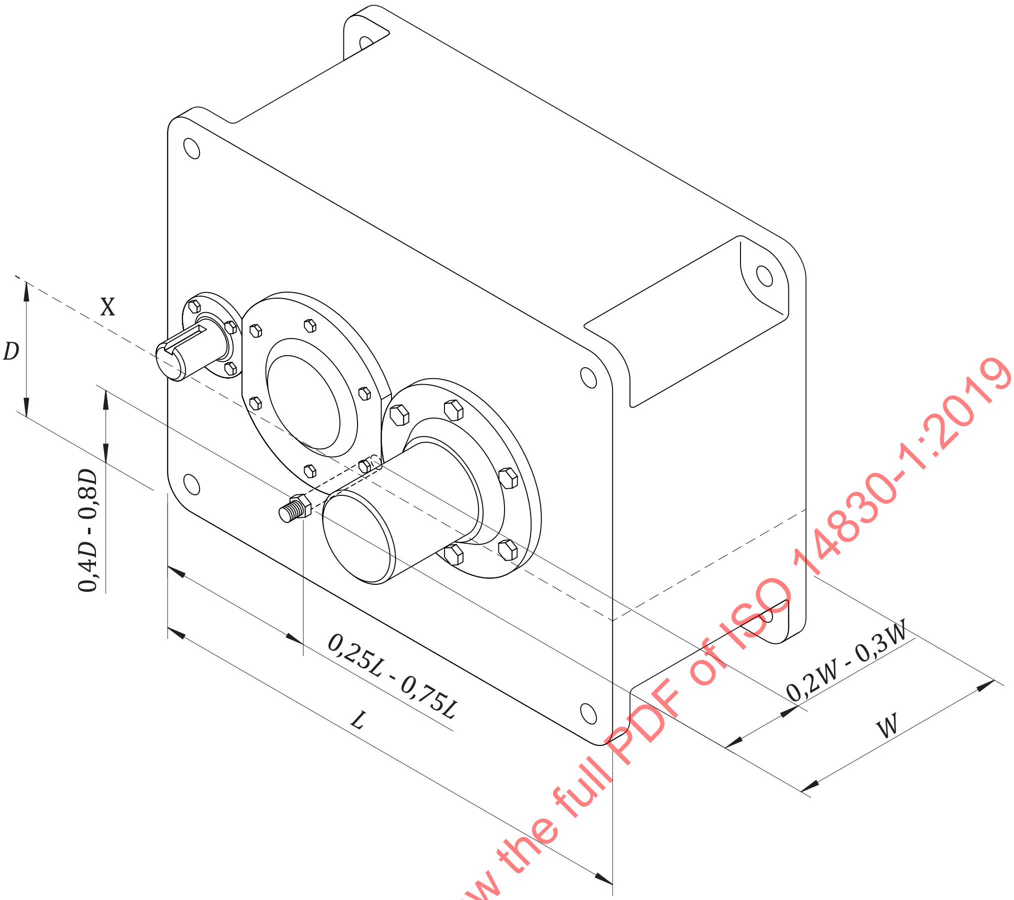
b) Dedicated static sampling points are preferred. These include extension tubes inserted into the fluid bath from above and used with a vacuum pump, or valves inserted below fluid level.

c) Sample extraction using the vacuum pump and drop tube method is acceptable provided correct procedures are followed, inclusive of angled tube cutting and preservation of bottle cleanliness during sample extraction, and point locations comply with the other requirements of this document.

d) Points on level indicators and the like should only be used if they can be adequately (10 times the dead space) flushed prior to sampling.

e) The use of drain ports for sampling is discouraged, unless the analysis objectives can still be met.

f) Figure 1 gives guidelines for sample point location in a typical splash lubricated gearbox casing. Similar dimensions apply to hydraulic and lubrication system reservoirs, etc. Sample points will often need to be custom built or modified to achieve the requirements of this document for a particular compartment.



Key

D	depth
L	length
W	width

Figure 1 — Guidelines for static sample point location

7.4 On-line and in-line sampling

On-line sampling can be performed in situ, utilising testing hardware situated in a sampling loop attached to the lubricant circulation system or situated in the main lubricant flow path.

Only a limited range of tests is available for on-line and in-line sampling, compared to off-line analysis. The choice of method is based on analysis objectives, practicality and economics.

7.5 Magnetic plug sampling

Sampling or removal of magnetic particles from magnetic plugs can be achieved by careful removal of particles into a clean container. An applicable method uses Zinc free adhesive tape to remove the particles from the device followed by transferal of the particles to plain white card for recording and analysis. Weighing of magnetic plugs before and after particle removal can also provide useful data for trending particle generation rate. Typically, this method gives indication of failure at a very late stage. However, the fittings can also be used as oil sample points allowing for direct comparison.

7.6 Grease sampling

The objectives of grease sampling remain to maximize data density and minimize data disturbance:

a) Samples should be representative of grease at component load zones.

b) Multiple sample locations can be required, particularly if components are large, or load zone location or wear characteristics vary.

c) Sampling should be carried out at identical locations, using identical methods to reduce variation.

8 Fluid sampling equipment

8.1 General

Equipment used to extract samples should not disturb their quality. It should be easy to use, clean, rugged and cost-effective.

8.2 Sample containers

Container cleanliness should conform to ISO 3722 to ensure representative samples are obtained, as summarised in Table 1.

Table 1 — Sample bottle cleanliness requirements

Sample bottle cleanliness class (ISO 3722)	Max. no. of particles >10 µm/ml	Sample bottle cleanliness target (ISO 4406)	Lowest compartment cleanliness target (ISO 4406)
Clean	100	16/14/11	18/16/13
Superclean	10	13/11/8	15/13/10
Ultraclean	1	9/7/4	11/9/6

Container volume shall provide a sufficient sample amount for the range of analysis tests to be performed, plus ullage space to allow for agitation. Materials used shall be compatible with the chemicals and temperatures likely to be encountered and not create additional hazards.

8.3 Sample tubing

Sample tubing should be clean and used only once. Flexible, clear, plastic derived material that is compatible with the chemicals and temperatures likely to be encountered is recommended.

Tubing diameter shall correspond to the sampling hardware and procedures used. It should be cut at a 45° angle, to the shortest length practicable for the application.

8.4 Manually operated hand held sample pumps

Manually operated hand held vacuum sample pumps should be designed for the purpose and kept clean internally and externally. If they become contaminated, dismantle and flush with clean white spirits or kerosene, filtered to the same cleanliness target as sample bottles they are used with. Do NOT use solvents or degreasers for flushing.

An area where sampling tools and equipment can be kept clean and in good working order should be designated.

8.5 Other equipment

The following additional equipment can be useful during lubricant sampling:

a) Previous analysis reports, sample route details, notebook and pens.

b) Pre-printed labels, felt tip pens or barcoded labels to mark/record samples.

c) Clean sample bottles and plastic tubing in individual zip lock bags.

d) Vacuum sample pump and sampling fittings in plastic bags.

e) Small torch, tape measure, plastic ties or electrical tape.

f) Tube cutter, multi tool, pocket knife or scissors. Shifting spanner.

g) Lint-free cloth, dust brush, scraper and cleaning solvent.

h) New clean lubricant for top-ups.

i) Container for waste flushing oil and used tubes, appropriately labelled.

j) Gloves and required personal protective equipment.

k) Bag, toolbox, trolley, etc. for carrying equipment.

Sampling of particles from magnetic plugs can be achieved by careful de-greasing and removal of particles using a non-metallic scraper into a clean container. Particle sampling can also be achieved by using Zinc free adhesive tape to remove the particles from the plug and then transferring the tape to plain white card.

8.6 Sample transport

All sample storage equipment shall be sealed from external contamination during transport and storage, protected from external environment and provided with secondary leak containment. The required sample accompanying documentation is given by country regulations for transport as applicable**.**

9 Sample analysis

9.1 General

Collected samples shall be analysed using predefined test suites, to provide measurements of desired lubricant and machine condition parameters. The process followed depends upon available analysis options.

9.2 On-site analysis

Testing may be performed using on-site facilities if available. Some on-site instruments use dielectric spectroscopy, voltammetry or infrared spectroscopy to detect changes in base oil and additive chemistry. Other on-site devices include portable sensors for moisture monitoring, contamination and wear particles analysis inclusive of morphology and image analysis. Commonly applied tests are discussed further in Annexes A and B.

On-site instruments and small workbench laboratories provide flexibility and convenience when instant information is needed. They typically cannot perform the full battery of tests that some complex situations require. However, bench level and portable instruments are important enabling technologies that offer time-critical information such as fluid contamination and wear particles analysis.

On-site analysis is frequently used for first-pass testing, with results in exception forwarded to an off-site laboratory for further analysis. For some organizations, this can provide significant and practical benefits, including:

a) perceived commitment to lubricant and wear debris;

b) lubricant and wear debris is visible and tangible;

c) greater control over quality;

d) faster analysis turnaround;

e) better customization of tests;

f) analysts familiar with equipment in which lubricants are used;

g) greater on-site knowledge and understanding of lubricant and wear debris.

9.3 Off-site analysis

Testing may be performed using off-site laboratories when on-site facilities are unavailable or lack capabilities. These typically offer a wide range of routine and exception tests for various lubricant types. Commonly applied tests are discussed further in Annexes A and B.

Most such laboratories offer their services on a commercial basis. General guidelines for laboratory selection are contained in Annex D. The laboratory is a partner in analysis program success and its role cannot be understated. Primary laboratory and site contact personnel should be nominated and responsible for maintaining the relationship. Regular contact between these personnel should take place to keep them informed of developments and quickly resolve any issues.

9.4 Sample documentation

Annex E details requirements for laboratory registration of sample points and documentation of samples.

10 Alarm criteria

To accurately monitor an item of plant, it is important to predefine alarm levels, above which some form of remedial action is required to prevent breakdown. These may be expressed in the following ways:

a) Absolute: a fixed figure for a parameter, i.e. a limit provided by a machine manufacturer.

b) Relative: a positive and/or negative variation relative to some reference point for the parameter (such as a mean, baseline or nominal value). The variation amount itself may be an absolute figure, percentage, standard deviation, etc.

c) Trending: amount and direction of changes in a parameter over time.

d) Comparison: comparison of a parameter with a known or reference standard. Normally used for qualitative type test results.

e) Statistical: limits set based on mean and standard deviation as well as historical behaviour.

Each test parameter should be compared against its target figures to identify parameters in alarm and assess their severity. Comparison should also be made with associated parameters and historical results to detect any trends of concern. If no faults are identified, the task is usually complete. Where faults are present, the diagnosis process should be initiated.

Initial alarm levels need to be set utilising experience, history and OEM guidelines and shall utilise the methodologies outlined in ISO 13379 (all parts), ISO 13381-1 and ISO 17359. Target and alarm guidelines for routine lubricant tests are given in Annex F.

These list the methods for determining levels for each parameter, lubricant type and application. The severity levels should be interpreted as follows:

Nominal	Target, new lubricant baseline or nominal figure.
Warning	Failure initiators/indications exist. An interim solution can be required.
Severe	Failure initiators/indicators in severe condition. Maintenance action is required.

These figures are intended to provide initial levels for equipment. They should be regularly reviewed and adjusted to take into account individual machine design, size, criticality, operating state, operating environment, condition, fault history, etc. as well as any changes to lubricant formulation or test methods.

i) Where sufficient historical data exists, alarm limits may be set using statistical analysis and should include rate of change alarm limits.

ii) Elemental analysis levels should be based on variation from baseline for additives (elements present in new lubricant formulation) and statistical analysis for contaminants and wear metals (elements that should not be present). Some elements (e.g. silicon, zinc) can be an additive, contaminant and/or wear metal depending upon application and lubricant formulation.

iii) New samples of all lubricants monitored should be analysed for baseline data prior to testing used lubricants. This reference data should be updated regularly.

iv) Alarm levels should also be incorporated into analysis results interpretation and reporting systems, and be kept updated for any changes.

v) Alarm levels should be developed in conjunction with other condition monitoring technologies where applicable.

11 Diagnosis and prognosis

This section details typical actions performed when one or more lubricant test results triggers an alarm. The tables in Annex G describe each parameter measured and available options for action. Diagnosis shall be carried out in accordance with ISO 13379 (all parts) in order to identify existing fault(s) and cause(s). Prognosis shall be carried out in accordance with ISO 13381-1 in order to predict future progression, time to failure and risk of fault(s). A guideline table of metal sources is contained in Annex G.

a) If doubt exists over quality of a sample or analysis results, a retest should be arranged prior to taking any action. Confirmation testing is always recommended where the impact of an incorrect decision can be significant.

b) Often there is sufficient information in current and historical analysis results to allow recommendations to be made for any faults present. However, thorough diagnosis and prognosis can require additional testing or data gathering to be performed.

c) Determinations cannot usually be made on single test results. Relative levels and trends of all measured parameters shall be considered. Tests in Annexes B, F and G are correlated with others that can have a bearing on their interpretation.

d) The testing strategy may also include analysing the differences between lubricant inlet and outlet locations and comparison with the results from other locations for the same machine as well as other similar machines.

e) Wear particle analysis can be useful to qualify types and origins of solid particles. This should be carried out automatically and reported with routine test results, which requires off-site laboratories to be notified of trigger test parameters and levels.

f) Numerous other test methods are available for specific applications, problems, lubricant types, etc. as well as the full range of condition monitoring methodologies. Suitably qualified and experienced personnel as per ISO 18436-4 or ISO 18436-5 should be consulted on a case by case basis as needed.

g) The available alternative actions to address a lubricant fault are usually:

   1) do nothing,

   2) filter lubricant to remove solid particles,

   3) purify lubricant to remove water,

   4) replenish additives, or

   5) drain, flush and fill the compartment with new lubricant.

The degree and speed of reaction are dictated by alarm level severity, equipment criticality, access limitations, etc.

h) Frequency of monitoring should be increased until an identified fault is corrected. As a guide, monitoring at no more than ½ normal interval for severe conditions, based on overall machine condition assessment, is recommended.

i) Any data likely to be required for subsequent root cause failure analyses should be captured and stored. This includes retaining critical samples for retesting.

j) After remedial action is complete, repeat testing to confirm it was successful and gather new baseline data.

12 Results reporting

All analysis results should be recorded and easily retrievable for future reference and trending purposes. Reports for identified fault conditions should include information in accordance with ISO 13381, ISO 13379 (all parts) and ISO 13374.

13 Personnel qualifications

13.1 Field analysts

Personnel involved in on-site lubricant sampling and analysis should be qualified and assessed in accordance with ISO 18436-4.

13.2 Laboratory analysts

Personnel involved in laboratory lubricant analysis should be qualified and assessed in accordance with ISO 18436-5.

Annex A
(informative)

Common lubricant and wear debris parameters

A.1 Lubricant properties

A.1.1 Viscosity

A.1.1.1 Viscometry (ASTM D445/ISO 3104)

Kinematic viscosity is a measure of a fluid's internal resistance to flow under gravitational forces. Kinematic viscosity has standard units of centistokes (cSt). Viscosity reporting is only valid when the temperature at which the test was conducted is reported, e.g. 32 cSt @ 40 °C. Specified test temperatures are 40 °C and 100 °C depending on lubricant type and application. Some viscometry test methods can produce inaccurate results due to contamination from water, dissolved gasses, fluids and particulates.

A.1.1.2 Viscosity index (ASTM D2270/ISO 2909)

The viscosity index is a widely used and accepted measure of the variation in kinematic viscosity due to changes in the temperature of a petroleum product between 40 °C and 100 °C. A higher viscosity index indicates a smaller decrease in kinematic viscosity with increasing temperature of the lubricant. The viscosity index is used in practice as a single number indicating temperature dependence of kinematic viscosity. It is sometimes used to characterize base oils for purposes of establishing engine testing requirements for engine oil performance categories.

A.1.2 Neutralisation number

A.1.2.1 Acid number (AN) (ASTM D664, ASTM D974, ISO 6618, ISO 6619)

Applied to industrial oils (non diesel or gasoline engine crankcase lubricants), the acid number (AN) is a measure of the acid concentration of the oil. The AN test result is expressed as the volume (milligrams) of potassium hydroxide (KOH) required to neutralize the acidic components in one gram of sample oil. The reported unit is mg KOH/gm of oil. AN can be quantified by either colorimetric (ISO 6618) or potentiometric (ISO 6619) titration methods although for dark coloured oils the latter method should be used.

Some of the oil's additives, i.e. anti-rust and anti-wear additives, can produce a high initial AN value due to these compounds containing weak acids. Initially, the acid number can decrease slightly as additives deplete and subsequently as the oil ages and oxidizes, small amounts of acidic by-products are often formed in the oil causing the AN to then increase.

A.1.2.2 Total base number (TBN) (ASTM D2896, D4739, ISO 6618, ISO 3771)

A TBN titration is used to determine the reserve alkalinity of a lubricant. The TBN is generally accepted as an indicator of the ability of the oil to neutralize harmful acidic by-products of engine combustion. Crankcase oils are continuously monitored for TBN particularly in marine and residual gas engine applications where the quality of the fuel is suspect. High sulphur fuels quickly deplete the reserve alkalinity of the crankcase oil that is then unable to neutralize the harmful acids formed as a result of the combustion process.

The BN test is usually performed by potentiometric titration due to the darkness of engine oil. In the case of BN, the alkaline oil is neutralized with hydrochloric or perchloric acid. Results are reported in mg

KOH/gram of oil, same as the AN. The purpose of this is synchronization, i.e. one unit of BN neutralizes one unit of AN. BN numbers trend steadily downward over time as the oil's reserve alkalinity is depleted by combustion and oxidative acids. Results between different test methods are not comparable. Results also differ between using hydrochloric and perchloric acid test methods due to the effects of additives and wear metals.

A.1.3 Oxidation level

A.1.3.1 Colour

Darkening of light coloured oils can signify oxidation or contamination with dark coloured products. Used oils from gasoline and diesel engines can show a variety of colours ranging from light brown through red-brown to black. Colour assessment in these cases are not particularly reliable, although an intense brown colour can be indicative of lacquer and a clear black colour indicative of soot rich oils. Black colouring of oils can also often come from partially oxidized iron debris. Analysts should be aware that oil cosmetics from the manufacturer are sometimes used giving a bright colour to the oil.

A.1.3.2 Odour

An acrid smell with dark colouring and thickening of the lubricant indicates serious oxidation.

A.1.3.3 Dielectric constant

The electro-chemical properties of an oil change during its use. Dielectric testing detects, measures and indicates the total effect of lubricant degradation and contamination on the dielectric constant of the oil. It is a comparative test and requires a calibration against a sample of new unused oil of similar type. It is particularly responsive to contamination effects due to oxidation, water, acids, antifreeze, metal particles, fuel dilution, dirt, soot and sludge.

Dielectric measurements are used to measure insulating properties and the presence of organic acids, water and oxides.

A.1.3.4 Infrared spectrometry (ASTM E169, ASTM D7418, ASTM D7214, ASTM D7412, ASTM D7414)

Fourier transform infrared (FTIR) spectroscopy provides a rapid means to monitor several oil parameters simultaneously. Numerous oil properties, additives and contaminants absorb infrared energy at characteristic frequencies and are reported. The spectrum of the used oil is usually compared to the baseline of an identical new oil for analysis of contaminants such as soot, water, glycol, fuel, chemical solvents, anti-wear and oxidation inhibiting additives, and lubricant degradation caused by oxidation, nitration and sulphation.

Many laboratories do not consider FTIR results to be sufficiently conclusive by themselves. This is due, in part, to the various constituents of used oils that can mask or interfere with test precision. For the best use of this test method, a baseline of the new oil shall be obtained from the same lubricant manufacturer, type, grade and batch. High levels of contaminants can also affect test results by masking element signatures or skewing results.

A.1.3.5 Insolubles (ASTM D893)

The insolubles in virgin oil are from the normal oxidation process of the oil, which leaves free carbon in suspension when oxygen forms with hydrogen (oil is a hydrocarbon). The insolubles test is a centrifuge method. A measured volume of oil is mixed with a heated solvent, agitated and spun at high speed.

A.1.3.6 Ultracentrifuge

This is used to estimate the concentration of varnish-producing oxide insolubles and similar suspension.

A.1.3.7 Surface tension or interfacial tension

This provides an indication of polar impurity, oxidation insolubles and other contaminants.

A.1.4 Oxidation resistance

A.1.4.1 Cyclic voltammetry (ASTM D6971)

This is used to determine the remaining useful life of certain additives and to estimate AN and BN.

A.1.4.2 Oxidation stability testing (ASTM D2272)

A widely deployed test method to determine oxidation stability is the rotating pressure vessel oxidation test (RPVOT), also known as the rotating bomb oxidation test (RBOT). This test method utilizes an oxygen-pressured vessel to evaluate the oxidation stability of the sample oil at high temperatures in the presence of water and a copper catalyst coil. The number of minutes required to reach a specific drop in gauge pressure (signifying the onset of oxidation) for a particular sample of used oil is compared to the reference number of minutes required for a new oil.

A significant change between the new and used oil relates to a corresponding change in an oil's oxidation stability and remaining useful life. For the best use of this test method, a baseline of the new oil shall be obtained from the same lubricant manufacturer, type, grade and batch.

Because the RPVOT test is often costly and time consuming to conduct, an assortment of other test methods is sometimes used instead. These methods have been found to relatively good correlation to RPVOT and include cyclic voltammetry, differential scanning calorimetry and interfacial tension.

A.1.5 Water resistance

A.1.5.1 Demulsibility and separability (ASTM D1401, ASTM D2711, ISO 6614)

This is used to assess the presence of polar impurities that influence an oil's ability to separate from free water.

A.1.5.2 Rust test (ASTM D665)

The rust preventing characteristics test (ASTM D665) is designed to measure the ability of industrial oils to prevent rusting under conditions of water contamination. The test can be performed with either distilled water or synthetic seawater.

A.1.6 Aeration resistance

A.1.6.1 Foam stability (ASTM D892/ISO 6247)

The tendency of oils to foam can be a serious problem in systems such as high-speed gearing, high-volume pumping and splash lubrication. Inadequate lubrication, cavitation and overflow loss of lubricant can lead to mechanical failure. This test method is used in the evaluation of oils for such operating conditions. It covers the determination of the foaming characteristics of lubricating oils at 24 °C and 93,5 °C. Means of empirically rating the foaming tendency and the stability of the foam are described.

A.1.6.2 Air release (ASTM D3427/ISO 9120)

Agitation of lubricating oil with air in equipment, such as bearings, couplings, gears, pumps and oil return lines, can produce a dispersion of finely divided air bubbles in the oil. If the residence time in the reservoir is too short to allow the air bubbles to rise to the oil surface, a mixture of air and oil circulates through the lubricating oil system. This can result in an inability to maintain oil pressure (particularly with centrifugal pumps), incomplete oil films in bearings and gears, and poor hydraulic system performance or failure.

This test method measures the time for the entrained air content to fall to the relatively low value of 0,2 % volume under a standardized set of test conditions and hence permits the comparison of the ability of oils to separate entrained air under conditions where a separation time is available. The significance of this test method has not been fully established. However, entrained air can cause sponginess and lack of sensitivity of the control of turbine and hydraulic systems. It is possible that this test is not be suitable for ranking oils in applications where residence times are short and gas contents are high.

A.1.7 Elemental spectroscopy by ICP (ASTM D5185), RDE (ASTM D6595) or XRF

Elemental spectroscopy quantifies the presence of dissolved and some undissolved inorganic materials by element in the lubricant (both oil and grease). Most ICP elemental spectrometers used today for lubricant and wear debris are the atomic emission type, either inductive coupled plasma or rotating disc electrode. These instruments work by exposing the sample to extreme temperatures generated by an arcing electrode or by an argon plasma torch. The extreme heat vaporizes the atoms causing them to emit energy in the form of light. Each atomic element emits light at specific and characteristic frequencies. The spectrometer quantifies the amount of light generated at each frequency and calculates the concentration of each element (iron, lead, tin, etc.) in parts per million (ppm) based on calibration curves.

Most elemental spectrometers report the concentration of 15 or more elements. The elements reported can provide an indication of increased generation of wear particles, ingression of various types of contamination or depletion of certain additive elements. The accuracy of this instrument is influenced by a number of factors including the fact that it is particle-size limited. Dissolved metals and suspended particles up to approximately two microns are detected with high accuracy. The accuracy diminishes as particle size increases up to five microns beyond which ICP particle detection becomes unusable.

RDE test method identifies the metals and their concentration so that trends relative to time or distance can be established and corrective action can be taken prior to more serious or catastrophic failure. This test method uses oil-soluble metals for calibration and does not purport to relate quantitatively the values determined as insoluble particles to the dissolved metals. In an RDE spectrometer, also sometimes referred to as an “Arc-Spark” instrument, the oil is vaporized and excited using a high voltage discharge between an electrode and a rotating carbon disc. Analytical results are particle size dependent and low results can be obtained for those elements present in used oil samples as large particles. The test method is capable of detecting and quantifying elements resulting from wear and contamination ranging from dissolved materials to particles approximately 10 µm in size.

XRF spectroscopy is similar to atomic emission spectroscopy (AES) which has been commonly used in oil analysis for decades. Both techniques require the excitation of atoms followed by an analysis of the emitted light (UV-visible or x-rays). The rotrode AES method, however, excites the outer electron shells of the atoms using an electrical discharge to create a plasma, causing thermal emission, like the extreme temperatures of an argon plasma torch. As the atoms return to the normal state, the excess energy is emitted as light. Each element emits light at different frequencies on the electromagnetic spectrum. The amount of light emitted at a given frequency corresponds to the concentration of the element present in the sample.

Conceptually, XRF works in the same way as ICP. The difference is that XRF excites the atoms with a bombardment of X-rays. In return, the atoms emit X-rays characteristic of the chemical element at an amplitude that corresponds to the mass of the chemical element in the sample. XRF spectrometers are commonly calibrated to report the concentrations of the reported elements present in parts per million (ppm).

A.2 Lubricant contamination

A.2.1 Appearance

Simple sensory tests such as appearance, colour and smell can provide an indication of the lubricant condition. Sensory tests are very subjective and can easily lead to misinterpretations. A comparison should be made using either a glass bottle or test tube between the used oil and a sample of the original unused oil. Water or refrigerant contamination can cause the oil to appear hazy.

A.2.2 Particles

A.2.2.1 Particle counting (ASTM D7596, ASTM D7647, ASTM D6786, ISO 4406, ISO 4407, ISO 17500, ISO 11500, SAE AS 4057D)

The particle count test gives the number of particles above specified size ranges (in microns) per fluid volume (usually per ml or 100 ml). The size ranges are greater than 4 µm, 6 µm and 14 µm. Also, particle concentration and distribution data may be expressed in terms of ISO 4406 cleanliness codes or by other less frequently used codification systems.

Particles can be counted manually using optical microscopy (ISO 4407) or automatically using either optical (ISO 17500) or pore-blockage type particle counting methods. Optical particle counters (ISO 11500) can produce inaccurate results due to sensitivity to entrained air and water.

Pore blockage test method does not have an ASTM test standard to comply to. The other limitation of this test method is that results are extrapolated for some size ranges. Regardless of the method used, it is recommended that the same method be always used to ensure that results are consistent and repeatable.

For wear debris analysis and trending, the SAE AS 4057D method can provide additional information for particles of larger sizes up to 100 µm.

A.2.2.2 Filter inspection

Examination of the system filter is another simple test that is overlooked. The debris trapped by the filter is a historical accumulation of the debris generated by the system. Debris on the filter can be washed with petroleum spirit and examined using a low powered magnifying glass. Identification of the debris provides valuable information concerning the operation of that equipment. A visual examination as to colour and hardness often suffices to identify the metal particles. Positive identification of the metals present can be determined by a few simple tests performed with a permanent magnet, soldering iron and, if available, hydrochloric acid, nitric acid, chromic acid, sodium or potassium hydroxide.

A.2.3 Water

A.2.3.1 Water concentration tests (ASTM E2412, ASTM D6304, ASTM D95, ISO 3733, ISO 10337 + ISO 12937)

There are three widely used test methods to determine water concentration in lubricating oils: crackle test, FTIR (ASTM E2412) and Karl Fischer (ASTM D6304, ISO 10337 + ISO 12937).

A crackle test consists in a drop of oil being placed on a hot surface above 150 °C (typically 160 °C). The sample bubbles or crackles for water contents greater than 0,05 % or 500 ppm.

In the reagent test method, a known volume of oil is placed in a sealed container with a known amount of calcium hydride. The container is shaken vigorously causing the water in the oil to react with the calcium hydride, producing hydrogen gas. This chemical reaction is as follows:

CaH2 + 2 H2O → Ca(OH)2 + 2 H2

The calcium hydroxide [Ca(OH)2] product is a solid and precipitates out, while the H2 is hydrogen gas and its pressure is measured using a manometer. This reaction is stoichiometric, so one mole of water in solution produces one mole of hydrogen gas. Therefore, measuring the pressure of the gas resulting from the reaction indicates how much water was contained in the oil sample.

The FTIR method is as described previously with a reporting limit for water of 0,1 % below which results are generally not reported.

Karl Fischer (KF) reports water content in concentration units such as percentage or parts per million (ppm) of the “total” water (free, emulsified and dissolved) in the oil sample. The accuracy of the test is affected by the presence of sulphur containing contaminants and additives such as anti-wear agents, rust-inhibitors and EP anti-scuffing agents. The KF oven method should be used for non-dielectric oils in order to avoid additive interference. For dielectric oil, such as transformer oils, where there are no additive interferences, the standard KF technique should be used.

Co-distillation (ASTM D95/ISO 3733): a knowledge of the water content of petroleum products is important in the refining, purchase, sale and transfer of products. The amount of water as determined by this test method (to the nearest 0,05 % or 0,1 % volume fraction, depending on the trap size used) may be used to correct the volume involved in the custody transfer of petroleum products and bituminous materials. The allowable amount of water may be specified in contracts. This test method covers the determination of water in the range from 0 % to 25 % volume fraction in petroleum products, tars and other bituminous materials by the distillation method.

A.2.4 Soot

A.2.4.1 Blotter spot tests

This is used to measure soft insoluble suspension in oil, including soot, oxides and glycol contamination. This test is particularly useful for testing engine crankcase lubricants. A drop of oil on a piece of blotting paper shows a distinct ring when dry. A ring of light debris on the outer circumference of the circular spot indicates that the oil has retained its dispersancy properties. A black central spot indicates sludge and the loss of dispersancy. A brown or yellow stain on the blotter spot indicates oxidation.

A.2.4.2 Soot by FTIR

An increase in soot material can lead to increased wear, filter plugging and viscosity, which is usually a consideration for diesel engines, although it can also be an indicator of carburettor or injector problems in other fuel systems. Monitoring of soot is therefore an important parameter in determining overall machinery health and should be considered in conjunction with data from other tests such as atomic emission (AE) and atomic absorption (AA) spectroscopy for wear metal analysis (test method ASTM D5185), physical property tests (test methods ASTM D445, ASTM D6304 and ASTM D2896), and other FT-IR oil analysis methods for oxidation (test method D7414), sulfate by-products (test method D7415), nitration (test method D7624), additive depletion (test method D7412), and breakdown products and external contaminants (practice E2412), which also assess elements of the oil’s condition .

A.2.4.3 Thermogravimetric analysis (ASTM D5967)

Thermogravimetric analysis (TGA) primarily heats and continuously weighs the sample, drawing a graph of the weight change against temperature as the test progresses. TGA is the recognised standard technique for measuring soot in engine oils and is used to produce calibration fluids for other techniques, e.g. FTIR. It involves adding a drop of oil to the balance pan, which in turn is lowered into a closed heating chamber, then filled with nitrogen to remove the air (oxygen). The unit heats the sample from room temperature up to 1 000 °C and weighs the sample continuously, drawing a graph of weight loss against temperature. As the maximum temperature is reached, oxygen is flushed through the chamber, which immediately turns the soot to carbon dioxide. The change in weight at this temperature is a measure of the soot content.

A.2.5 Glycol

A.2.5.1 Schiff’s reagent (ASTM D2982)

Schiff’s test is used to determine the presence of antifreeze in lubricants. It gives a positive purple colour if “1, 2 – diols” compounds are present. Ethylene and propylene glycols are 1, 2 – diols. The test is sensitive only above 1 000 ppm. Its drawbacks are that new uncontaminated oils can give a false positive reading, owing to the additives present in the lube oil and also give false negatives, if the 1, 2 – diol compound (antifreeze) in the used oil has oxidized to one of its derivatives. Some transmission oils must not contain any amount of glycol, so a test with a LOD of 1 000 ppm is unsuitable in these cases. Hence the test should only be carried out by experienced laboratory staff.

A.2.6 Fuel contamination

A.2.6.1 Flash point test (ASTM D92, ASTM D93, ASTM 3828, ISO 2592, ISO 2719, ISO 1523 + ISO 3679 + ISO 13736)

A lubricant's flash point is the lowest temperature at which an ignition source causes the vapours of the lubricant and its contaminants to ignite under specified conditions. This test is important for heat transfer fluids and diesel engine oils as it estimates the amount of volatiles produced by cracking and for fuel dilution in the oil respectively. The oil is said to have "flashed" when a flame appears and instantaneously propagates itself over the entire surface. The flash point identifies the presence of volatile molecules from fuel and other flammable contaminants.

A.2.6.2 Gas chromatography (ASTM D3524, ASTM D3525)

This is used to measure low concentrations of glycol (coolant), fuel dilution and solvents.

A.3 Machine wear

A.3.1 Wear particles

A.3.1.1 Analytical ferrogram and filtergram patch tests (ASTM D7670, ASTM D7684, ASTM D7690, ASTM D7919)

Both of these tests are methods of separating particles from the oil sample and laying them out in a configuration that can be analysed under a microscope. Both tests allow the particles to be analysed under a microscope in order to identify the size, shape, metallurgy, morphology and surface texture of the particles, all leading to an assessment of the wear mechanism and severity.

The ferrogram uses a magnetic separation technique that causes primarily ferrous particles to be deposited in a monolayer on a glass substrate, segregated generally by size, in linear strings of particles.

The filtergram method in comparison provides a random distribution of all particles. The filtergram test is normally used when the combination of the particle quantifier, particle count or spectrometer shows that primarily non-ferrous metals are present.

Analysis of particle morphology (shape), colour, size, reflectivity, surface appearance, edge detail, angularity, elemental content and relative concentration provides the analyst with clues about the nature, severity and root cause of a wearing problem.

As previously stated, spectrometers are only capable of measuring the size of particles less than 5 µm to 10 µm. Various "techniques" such as "ferrography", "filtergram" and the "particle quantifier" have been developed to overcome this particle size shortcoming. For example, the particle quantifier (PQ) measures the total amount of ferrous debris in a sample of oil or grease, the PQ index, and can be either portable or laboratory based.

A.3.2 Ferrous particles

A.3.2.1 Particle quantifier (PQ)

The unit functions on the principle that a distortion of a magnetic flux field occurs when a ferromagnetic sample is placed within the field. The unbalanced condition is measured and digitally displayed as a PQ index. Experience shows that the readings obtained are influenced by factors such as particle size and concentration.

A.3.2.2 Direct reading ferrograph (DRF)

DR ferrography (DRF) is a technique that magnetically separates, classifies and counts wear particles from lubricating oils. Oil samples are siphoned through a precipitator tube and subjected to a strong magnetic field causing the particles to deposit according to size. By means of light obscuration, the density of wear particles is sensed at two locations. All particles larger than 5 µm deposit within a few millimetres of entering the magnetic field at the first sensor location (D_l). The smaller particles travel a greater distance to the second sensor location. These remaining particles are deposited and sensed at the second sensor where they are displayed as D_s.

There are several useful relationships to be obtained from these two readings, as the underlying principle of ferrography is to observe the behaviour of both D_l and D_s, relative to each other. Severity of wear indices have been developed from these readings and these can be trended also. Some of the more common methods in use are: large particle count: D_l; small particle count: D_s; total particle count: $D_l + D_s$; difference in counts: $D_l - D_s$; ratio of counts: D_l / D_s; wear severity index : $(D_l + D_s)$ $(D_l - D_s)$; and percent large particles (PLP).

A limitation of this test method is that is does not directly measure non-ferrous particle density. Dark samples can also affect readings due to light obscuration. High levels of ferrous contaminants can totally obscure the light source and subsequently require further sample dilution. Water contamination can also preclude the use of this test.

A.3.2.3 Optical image analysis

The images of wear particles are monitored with a video camera and particles are classified and counted into sizes, image type and type of wear. This method can be used for particle sizes from 4 µm to 100 µm. The particles for image analysis are shown between 20 µm and 100 µm.

A.4 Other tests for the analysis of lubricating oils

A.4.1 General

Because lubricant and wear debris is a diverse field with many different analytical objectives, there are many different tests and test procedures used by laboratories. Not all can be included in a general guideline. However, the following few tests are worth mentioning and are described by the property they measure.

A.4.2 Rotrode filter spectroscopy (RFS)

A microscopic inspection of the carbon disc electrodes used in rotating disc electrode (RDE) spectrometers reveal they are porous. Rotrode filter spectroscopy (RFS) makes use of this fact, and a funnel-based fixture is used to clamp the discs; therefore, used oil samples can be drawn through the outer circumference of the disc when a vacuum is applied. The filtering process captures the particles in the oil. The oil is then washed away with solvent and the disc is allowed to dry. The particles are left on the outer circumference of the disc electrode so they are vaporized and can be detected on the RDE spectrometer.

A.4.3 Varnish potential (ASTM D7843)

This test method extracts insoluble contaminants from a sample of in-service turbine oil onto a patch and the colour of the membrane patch is analysed by a spectrophotometer. The results are reported as a ΔE value, within the CIE LAB scale. This test method is not appropriate for turbine oils with dyes.

A.5 Grease specific tests (ASTM D128)

A.5.1 General

Many lubricant and wear debris test methods can also be used for grease. These include microscopic wear particle identification (analytical ferrography), FTIR, Karl Fischer, elemental spectroscopy, ferrous density analysis and oxidation stability testing.

ASTM D128 discusses a number of applicable grease testing methods. The test methods for analysis cover greases of the conventional type, which consist essentially of petroleum oil and soap. The constituents that can be determined are soap, unsaponifiable matter (petroleum oil, and so forth), water, free alkalinity, free fatty acid, fat, glycerin and insolubles.

A.5.2 Penetrometer

This is used to identify changes in grease consistency due to cross-contamination with an incompatible grease, thermal or oxidative failure, or contamination. It is also used to test the quality of new grease deliveries.

A.5.3 Thermal gravimetric analysis

This widely accepted technique provides the most accurate estimate of the concentration of soot as a percent by weight. The test involves progressively heating the sample in a nitrogen-rich atmosphere over time to vaporize volatile fractions until the weight of the sample levels off, typically occurring at around 600 °C. Then, the nitrogen environment is replaced by air and the temperature is further raised allowing the oil to oxidize until the weight again stabilizes. Soot concentration is then calculated by subtracting the weight of the volatile ash components from the weight of the original sample.

A.5.4 Differential scanning calorimetry (ASTM D5483)

This test method covers the determination of oxidation induction time of lubricating greases subjected to oxygen at 3,5 MPa (500 psig) and temperatures between 155 °C and 210 °C.

A.5.5 Dropping point (ASTM D566)

This is used to test the quality of new grease deliveries and loss of high temperature consistency in used grease.

A.5.6 Grease compatibility (ASTM D6185)

The compatibility of greases can be important for users of grease-lubricated equipment. It is well known that the mixing of two greases can produce a substance markedly inferior to either of its constituent materials. One or more of the following can occur. A mixture of incompatible greases most often softens, sometimes excessively. Occasionally, it can harden. In extreme cases, the thickener and liquid lubricant completely separate. Bleeding can be so severe that the mixed grease runs out of an operating bearing. Excessive syneresis can occur, forming pools of liquid lubricant separated from the grease. Dropping points can be reduced to the extent that grease or separated oil runs out of bearings at elevated operating temperatures. Such events can lead to catastrophic lubrication failures.

A.5.7 Oil separation (ASTM D4425)

The ASTM D4425 test method is useful in evaluating the degree to which a grease would separate into fluid and solid components when subjected to high centrifugal forces. Flexible shaft couplings, universal joints and rolling element thrust bearings are examples of machinery which subject lubricating greases to large and prolonged centrifugal forces. This test method has been found to give results that correlate well with results from actual service.

Annex B
(informative)

Typical lubricant test suites and frequencies

Table B.1 — On site tests
(H=hours, M=months, E=exception, R=routine)

Parameter classified by primary area of application, but may apply to more than one!		*Test*		*New Oil*	Industrial Machines							Mobile Equipment				*Grease*
		ISO	*ASTM*		*Industrial Gear Oil*	*Industrial Hydraulic Fluid*	*Steam Turbine Oil*	*Gas Turbine Oil*	*Paper Machine Oil*	*Refrigeration Compressor Oil*	*Air & Gas Compressor Oil*	*Diesel Engine Oil*	*Transmission Fluid*	*Automotive Gear Oil*	*Mobile Hydraulic Fluid*	
Lubricant Properties																
Viscosity	@ 40 °C	3104	D341 D445	R	R	R	R	R	R	R	R	R	R	R	R	
Neutralisation Number	Acid No. (AN)	6618 6619	D974 D664	R	R	R	R	R	R	R	R		R	R	R	
	Base No. (BN)	3771 6618	D2896 D974 D4739	R (Engine oil)								R				
Oxidation level	Colour		D1500	R	R	R	R	R	R	R	R		R	R	R	R
	Odour			R	R	R	R	R	R	R	R	R	R	R	R	R
Lubricant Contamination																
Appearance			D4176	R	R	R	R	R	R	R	R	R	R	R	R	R
Particles	4\6\14	4406 11171 11500		R	R	R	R	R	R	R	R	R	R	R	R	
	Filter inspection			E	E	E	E	E	E	E	E	E	E	E	E	
Water	Crackle test			R	R	R	R	R	R	R	R	R	R	R	R	
	% saturation			R	R	R	R	R	R	R	R	R	R	R	R	
	Reagent test			E	E	E	E	E	E	E	E	E	E	E	E	
Soot	Blotter Spot			R (Engine oil)								R				
Glycol (coolant)	Schiff's Reagent		D2982									E				
Machine Wear																
Wear debris	Filtergram/Ferrography		D7690	E	E	E	E	E	E	E	E	E	E	E	E	
Ferrous debris	Magnetic plug				R	R	R	R	R	R	R	R	R	R	R	

Table B.2 — Off site tests

(H=hours, M=months, E=exception, R=routine)

Parameter classified by primary area of application, but may apply to more than one!		*Test*		*New Oil*	**Industrial Machines**							**Mobile Equipment**				*Grease*
		ISO	*ASTM*		*Industrial Gear Oil*	*Industrial Hydraulic Fluid*	*Steam Turbine Oil*	*Gas Turbine Oil*	*Paper Machine Oil*	*Refrigeration Compressor Oil*	*Air & Gas Compressor Oil*	*Diesel Engine Oil*	*Transmission Fluid*	*Automotive Gear Oil*	*Mobile Hydraulic Fluid*	
Lubricant Properties																
Viscosity	@ 40 °C	3104	D445	12M	3M	3M	3M	3M	3M	3M	3M	500H	500H	500H	500H	
	@ 100 °C	3104	D445	12M (Engine & VI Improver oil)	E	E	E	E	E	E	E	500H	E	E	E	
	Index	2909	D2270	12M (Engine & VI Improver oil)	E	E	E	E	E	E	E	500H	E	E	E	
Neutralisation Number	Acid No. (AN)	6618 6619	D974 D664	12M	3M	3M	3M	3M	3M	3M	3M		500H	500H	500H	
	Base No. (BN)	3771 6618	D2896 D974 D4739	12M (Engine oil)								500H				
Oxidation level	Colour		D1500	12M	3M	3M	3M	3M	3M	3M	3M		500H	500H	500H	R
	FTIR		D7418 E2412	12M	3M	3M	3M	3M	3M	3M	3M	500H	500H	500H	500H	R
	Insolubles		D893				6M	6M								
	Ultra Centrifuge		Mobil				6M	6M								
Nitration	FTIR		D7418 E2412	12M (Engine oil)								500H				
Sulphation	FTIR		D7418 E2412	12M (Engine oil)								500H				
Oxidation resistance	FTIR		D7418 E2412	12M	3M	3M	3M	3M	3M	3M	3M	500H	500H	500H	500H	
	Cyclic Voltammetry		D6971	12M			3M	3M			E					
	RPVOT		D2272	Once (Turbine oil)			12M	12M			E					
	TOST	4263														
Water resistance	Demulsability	6614	D1401 D2711	Once (Turbine oil)			6M				E					
	Rust Test		D665				6M				E					
Aeration resistance	Foam Stability (Sequence I)	6247	D892	Once (Turbine oil)	E	E	6M	6M			E					
	Air Release	9120	D3427	Once (Turbine oil)		E	6M	6M								
Additive Elements	Ba, B, Ca, Mg, Mo, P, Zn		D4951 D5185 D6595	12M	3M	3M	3M	3M	3M	3M	3M	500H	500H	500H	500H	R

Table B.2 *(continued)*

Parameter classified by primary area of application, but may apply to more than one!		*Test*		*New Oil*	**Industrial Machines**							**Mobile Equipment**				*Grease*
		ISO	*ASTM*		*Industrial Gear Oil*	*Industrial Hydraulic Fluid*	*Steam Turbine Oil*	*Gas Turbine Oil*	*Paper Machine Oil*	*Refrigeration Compressor Oil*	*Air & Gas Compressor Oil*	*Diesel Engine Oil*	*Transmission Fluid*	*Automotive Gear Oil*	*Mobile Hydraulic Fluid*	
Lubricant Contamination																
Particles	4\6\14 count	4406 11171 11500		12M	3M	3M	3M	3M	3M	3M	3M	500H	500H	500H	500H	
Water	FTIR		D7418 E2412	12M	3M	3M	3M	3M	3M	3M	3M	500H	500H	500H	500H	R
	Karl Fischer	10337 12937	D6304	12M	3M	3M	3M	3M	3M	3M	3M		500H	500H	500H	R
	Co-distillation	3733	D95	E	E	E	E	E	E	E	E	E	E	E	E	
Soot	FTIR		D7418 E2412	12M (Engine oil)								500H				
	TGA		D5967									E				
Glycol (coolant)	FTIR		D7418 E2412	12M (Engine oil)								500H				
Fuel Dilution	FTIR		D7418 E2412	12M (Engine oil)								500H				
	Flash Point	2592 2719 1523, 3679, 13736	D92 D93 D3828	12M (Engine oil)				E			E	E				
	Gas Chromatography		D3524 D3525	12M (Engine oil)				E			E	E				
Contaminant Elements	K, Si, Na		D4951 D5185 D6595	12M	3M	3M	3M	3M	3M	3M	3M	500H	500H	500H	500H	R
Machine Wear																
Wear debris	Filtergram	4407		E	E	E	E	E	E	E	E	E	E	E	E	
Ferrous debris	PQ Index				3M	3M	3M	3M	3M	3M	3M	500H	500H	500H	500H	
	Direct Reading Ferrography			E	E	E	E	E	E	E	E	E	E	E	E	
	Ferrogram			E	E	E	E	E	E	E	E	E	E	E	E	
Wear Metal Elements	Ag, Al, Cd, Cr, Cu Fe, Mn, Ni, Pb, Sn, Ti, V		D4951 D5185 D6595	12M	3M	3M	3M	3M	3M	3M	3M	500H	500H	500H	500H	R

Annex C
(informative)

Sampling procedure examples

C.1 Preparation

The steps below should be followed before every sampling task, regardless of the sample point type and location:

a) Follow all applicable safe work and access procedures.

WARNING — LUBRICANT SAMPLING HAZARDS INCLUDE HIGH PRESSURE FLUIDS AND POTENTIAL TOXICITY.

b) Review sampling work order and gather necessary equipment.

c) Verify that pre-printed sample labels contain the correct information for each sample.

d) Ensure all necessary information is available (Annex E).

e) Proceed to sample point locations in turn. Confirm point labels correspond to task details.

f) Take samples during normal machine operation, to avoid errors due to particulate settling. Machines should be operating for at least 30 minutes prior to sampling.

g) Samples should be taken within 15 minutes of the machine being shut down.

h) Do not take samples immediately after disturbance of the lubrication system, including topping up with new lubricant, changing filter elements, internal cleaning or component replacement. Allow time for contaminant levels to evenly distribute first.

i) Remove contamination from sample point fittings using clean solvent and lint free cloth.

j) Connect sampling equipment and flush to remove any debris. Flushing volume should be at least 500 ml and not less than 5 times volume of lines, valves, fittings, etc. Table C.1 gives guidance on flushing volumes:

Table C.1 — Flushing volume per 100 mm of common sampling tubes

Tube type	Nominal size	Internal diameter (mm)	Flush volume (ml/100 mm)
Sch.40 pipe	0,5”	15,8	100
	0,75”	21,3	180
	1”	26,6	280
	1,5”	40,2	640
	2”	52,5	1 080
Steel tubing	0,25”	3,9	6
	0,375”	7	20
	0,5”	10,2	40
Minimess[a] tube		2,0	2

[a] This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named.

Table C.1 *(continued)*

Tube type	Nominal size	Internal diameter (mm)	Flush volume (ml/100 mm)
Sample tube	0,25"	4,5	8
[a] This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named.			

k) Ensure the system lubricant volume is adequate to remove flushing amount. Capture flushed oil for appropriate disposal; DO NOT return to compartment. Take note of obvious problem symptoms such as large particles, haziness or free water.

l) Do not uncap bottles until ready to collect sample. Ensure lid is kept in a clean location during sampling. Only fill bottles to around 75 % full to allow room for agitation. Recap immediately after sampling.

C.2 Pressurized system sampling

This method involves sampling from dedicated fittings in pressurized, flowing lines and is preferred in most cases.

a) Perform the previous preparation steps.

b) Ensure fluid discharge point is directed into a waste container and away from personnel. Activate flow slowly to avoid a high pressure jet; be careful if system pressure is very high. Adjust fluid flow rate to about 500 ml/minute, 100 ml/minute minimum.

c) Allow required flushing volume to drain off. Leave the flow running and place the sample bottle under the stream, taking care to avoid touching the fitting.

d) If the compartment cleanliness target is 15/13/10 or below, the following additional steps are required:

   1) Approximately half fill the sample bottle. Leave the fluid running into waste container.

   2) Recap the bottle firmly and shake vigorously for a count of ten. Dispose of fluid into waste container.

   3) Once bottle is well drained, collect sample by holding it under the oil stream.

e) Shut off fluid flow and perform follow up steps.

C.3 Manual vacuum pump sampling

This method is for manually sampling compartments not equipped with dedicated fittings. Samples may be drawn through suitable openings, such as a fill point, breather or dipstick hole, using flexible tube and a vacuum sampling pump.

a) Perform the previous preparation steps.

b) Clean around sample point. Remove plug, fill point, breather, dipstick, etc. and place in a location where it will not get contaminated or damaged.

c) Cut a new section of sample tube to length. If necessary, attach a clean "splint" to tube to control insertion. Ensure that the sample end of the tube is cut at 45°.

d) Insert the tube into the vacuum sampling pump, ensuring the end goes all the way through and emerges at least 10 mm from body.

e) Take samples while the machine is running if possible, although this is not recommended for compartments which contain moving parts such as gearboxes or engines. Sample these compartment types within 15 minutes of the machine being turned off unless a guide tube is fitted.

f) Insert the tube into compartment the desired amount, ideally to half fluid depth. Try not to allow end to touch compartment sides or opening. Ensure the sample will be extracted from a compartment central area where fluid is in motion, as close as possible to any oil return line and away from quiescent areas caused by corners and baffles.

g) Fit a bottle to pump and draw off required flushing volume, then remove and empty oil into waste container. Repeat as necessary until required volume is drawn through sample point and tube. Be careful to hold pump and bottle upright and keep fluid from contacting pump.

h) Attach a new, clean sample bottle to pump. The previously used bottle may be kept for flushing other points but should not be used for sampling.

i) If the compartment cleanliness target is 15/13/10 or below, the following additional steps are required:

   1) Approximately half fill the sample bottle with pump.

   2) Remove the bottle, cap firmly and shake vigorously for a count of ten. Dispose of fluid into waste container.

   3) Once bottle is well drained, reattach it to pump.

j) After taking sample, clean any fluid off pump and store it in a sealed bag or container then perform follow up steps.

C.4 Drain point sampling

This method is for sampling compartments not equipped with dedicated fittings or permitting use of the vacuum pump method. Samples are obtained from a drain valve or plug.

a) Perform the previous preparation steps.

b) Where there are risks of excessive fluid loss, take drain samples with machine turned off and within 30 minutes of shutdown. They are often taken during fluid changes.

c) Estimate volume of fluid required to provide a representative sample based on compartment size, design, level of sediment in bottom, drain fitting location, etc. Carefully remove drain plug or open valve and allow this amount to flow into a waste container of sufficient volume.

d) Leave flow running and place an uncapped sample bottle under the stream, taking care to avoid touching any part of the fitting. Observe the following additional cautions:

   1) Do NOT take sample as fluid starts to drain.

   2) Do NOT take sample as fluid finishes draining.

   3) Do NOT take sample from fluid collected in another container.

   4) During fluid changes, sample when compartment is approximately half drained.

e) Replace drain plug or close valve and clean up area. Refill or top up the compartment as necessary then perform follow up steps.

C.5 Grease sampling

Collection of grease samples is different from normal sampling. The usual aim is to identify and quantify any abnormal operating wear particles. It is therefore important to obtain samples from as close as possible to component wearing surfaces. It does not really matter if the machine is at operational temperature, and there are no time restraints.

a) Collect grease samples in standard sample bottles. These should be cleaned to ISO 3722 Superclean class and approximately half filled if possible. Do not use plastic bags to collect samples.

b) Clean away external surface contaminants prior to accessing components. Stiff and/or hard grease is usually old grease and should be discarded unless there is a valid reason for examining it.

c) Use one of the following methods to collect samples, or develop techniques appropriate to particular applications:

    1) Fit a clean, large diameter plastic tube to an available component opening (such as an unused grease point or fill plug). Grease component as normal with machine running. Remove tube after sufficient grease has purged into it, cut off an appropriate length and place into sample bottle.

    2) Thoroughly clean around usual component purge point (e.g. shaft seal). Grease component as normal with machine shut down. Collect exuded grease using a clean spatula and place into the sample bottle.

    3) With machine shut down, insert a clean, large diameter plastic tube into grease cavity and plunge into grease near wearing surfaces. A vacuum sampling pump with suitable adaptor may be used to draw grease into tube if necessary. Withdraw grease filled tube, cut off an appropriate length and place into the sample bottle.

    4) Disassemble or open component. Remove grease sample from as close as possible to wearing surfaces using a clean spatula and place into the sample bottle.

    5) There are many grease supply and discharge designs. These should to be considered when deciding if sampling is truly representative of wear conditions. Bearings fitted with retaining seals are often difficult to sample and can sometimes be considered as sealed for life.

C.6 Follow up

The steps below should be followed after every sampling task, regardless of the sample point type and location:

a) Dismantle sampling equipment, clean up any spills and recap sampling points.

b) Immediately label each bottle with sample details using a permanent marker. Pre-printed labels greatly assist in this task. They can be applied to bottles prior to, during or after sampling, depending on user preference. Labels should contain the information listed in Annex E.

c) Top up sampled compartment with new clean lubricant if necessary.

d) Clean up sampling area and dispose of waste sampling materials, rags, flushing lubricant, etc. in accordance with environmental requirements.

e) Complete the sampling work order. Note any samples not taken and reasons why to enable rescheduling.

f) Check filled sample bottles. Any samples that are obviously contaminated, insufficient, incorrectly labelled, etc. should be retaken. Label the remainder and forward for analysis.

g) If mailing samples, appropriately package them to avoid leakage. Related requirements are given in postal regulations. Aim to send them within 24 hours of being taken, arriving within the week they are taken.

WARNING — FLAMMABLE LIQUIDS (I.E. FUEL SAMPLES) SHALL NOT BE POSTED.

Annex D
(informative)

Commercial laboratory selection guidelines

In selecting an off-site analysis laboratory, it is best to begin with a detailed description of tasks they are to perform. Leave as little to chance as possible: the more detailed and specific the work scope, the more satisfied users will be with the service. The following specific parameters should be considered:

a) Location: where should the laboratory be located? Many organizations prefer it to be geographically close to their plant so they can “run over” a sample if required. However, it can be just as efficient to express ship samples across the country as sending them across town. There is some benefit to having the laboratory in the same time zone when questions arise. Still, for most users, location is relatively low on the list of selection priorities.

b) Industry orientation: many laboratories specialize in certain industries or industry segments. For instance, some specialize in locomotives, aviation, trucking, off-road equipment, nuclear power plants, rotating equipment, hydraulic systems or the steel industry. Most laboratories advertise general, full-service capabilities but a closer look can reveal a distinct area of speciality. This impacts on the detail and depth of results interpretation provided.

c) Turnaround time: a fault detected too late cannot be corrected in time to save a machine. It is important that a laboratory commits to a reasonable turnaround time as requested by the customer. The turnaround commitment is often reflected in the price charged. It is not unusual for a laboratory guaranteeing 48-hour routine sample turnaround to charge considerably more than one with no guarantee. 24-hour turnaround can be required for exception samples.

d) Test capability: there are many differences between laboratories in the area of capability. Some offer a wide array of performance testing capabilities, while others emphasize a narrow group of tests targeted at equipment reliability and lubricant health. Refer to the recommended test suites in Annex B to ensure a laboratory can meet minimum requirements.

e) Flexible testing: many laboratories do not let customers design their own test suites for machine types, nor provide flexibility for exception testing. This can be necessary in order to develop appropriate test bundles for routine or exception testing.

f) Targets and limits: certain laboratories permit customers to set limits for equipment, while others do not. Requiring a customer to conform to a rigid set of limits can reduce analysis program overall effectiveness.

g) Report style: analysis reports need to conform to customer needs. There should be both tabular and graphical presentation of data. Customer limits and targets need to be visible, and new lubricant baseline data shown next to used lubricant data. Exception results, condition and recommendations should be clearly displayed.

h) Quality assurance: test accuracy is one of the most common customer complaints about commercial analysis laboratories. Presently, there is no independent control or verification of used lubricant analysis quality, nor is there a licensing body for such laboratories. Therefore, it is important to look at what a laboratory is doing to monitor itself. Here are some questions to ask:

    1) Is the laboratory accredited to ISO/IEC 17025? Does it meet the requirements of 10 CFR 50 Appendix B (nuclear qualified)?

    2) Does the laboratory have an ISO 9001 certified quality management system?

    3) Does it perform daily instrument calibration verification?

    4) Are blind control samples processed to assess accuracy and performance?

    5) Are control charts maintained for each instrument, showing test frequency and precision of calibration tests?

    6) What quality assurance procedures have been put in place to manage quality?

i) Personnel qualifications — laboratory personnel should receive initial and on-going training to keep skills current. Personnel involved with testing and interpreting analytical data should actively participate in professional trade associations that provide basic and advanced industry related training and instruction, and offer certification programs reflecting real knowledge in all aspects of lubrication, machinery components, tribology, quality control and maintenance best practices. Personnel should be competent and be assessed in accordance with the appropriate category of ISO 18436-5.

j) Electronic data service: modern lubricant analysis programs are generally paperless. It is far more efficient to only spend time troubleshooting and examining data from non-conforming machines. Sophisticated lubricant analysis software programs are widely available that interface to commercial laboratory services. Appropriate communication technologies should be used to transmit routine and exception results.

k) Price: from a practical standpoint, this should not be the most important selection consideration. Quality and effectiveness of analysis services influence the overall effectiveness of the program and benefits received. Customers should expect to pay a fair price for timely and high quality services.

Once a work scope has been developed, the process below is used to make the final selection:

i) Send out bid requests to several laboratories that are likely to meet requirements.

ii) Interview laboratories that submit acceptable responses by phone.

iii) Select top two or three laboratories and ask them to submit references.

iv) Select top choice and an alternate.

v) Visit top choice to see operation and meet people. If acceptable, award the contract.

Annex E
(informative)

Sample documentation requirements

E.1 Sample point registration

The initial machine registration process provides background information needed by the laboratory and data analysts to define which routine and exception tests are to be performed. It is also useful for creating data presentation formats and setting initial limits and alarms on monitored properties. Registration should include information such as:

a) location details: company, division, site, area, system, contacts;

b) machine details: identification number, name, type, make, model;

c) compartment details: name, location, function, volume, filtration;

d) lubricant details: supplier, type, grade.

Any other relevant details such as performance specifications, maintenance history, operating environment, application information, standard test regime, target and alarm levels and sample volume required should also be included. Registration data should be updated when changes affecting analysis results or interpretation occur.

E.2 Sample documentation

The accompanying documentation identifies key information about a sample, machine and required tests, including any special testing instructions. Minimum requirements for information to be supplied with each sample include:

a) machine and compartment identification, as registered;

b) date sample was taken;

c) name of sampling person;

d) sampling location description and ID number;

e) information required for sample bottle label;

f) sampling method and equipment to be used;

g) information on whether sample was taken during normal operation, a shutdown, lubricant change or other relevant sampling conditions;

h) date of last lubricant change and flush;

i) lubricant supplier, type and grade if changed from when machine was registered;

j) sample bottle cleanliness class;

k) sampling tube length (if applicable);

l) flushing volume;

m) sample volume;

n) access limitations and safety precautions;

o) any other tests or observations required;

p) applicable standards, specifications, procedures and guidelines.

Additional information that can be required with a sample includes:

i) total machine hours or service period, since installation or last major overhaul;

ii) lubricant service period or approximate level of machine usage since last sampled;

iii) last lubricant replenishment date;

iv) total volume of lubricant added since last sampled or changed;

v) last filter change date;

vi) any machine or lubricant abnormalities observed during operation.

Further sampling information requirements are given by country regulations i.e. MSDS, Commercial invoice, customs, or Global harmonized codes.

Annex F
(informative)

Alarm criteria guidelines

Table F.1 — On site test alarm criteria

Parameter - classified by primary area of application, but may apply to more than one!		Units	New Oil		Industrial Machines																				
					Industrial Gear Oil			Industrial Hydraulic Fluid			Steam Turbine Oil			Gas Turbine Oil			Paper Machine Oil			Refrigeration Compressor Oil			Air & Gas Compressor Oil		
			Nominal	Reject	Nominal	Warning	Severe	Nominal	Warning	Severe	Nominal	Warning	Severe	Nominal	Warning	Severe	Nominal	Warning	Severe	Nominal	Warning	Severe	Nominal	Warning	Severe
Lubricant Properties																									
Viscosity	@ 40 °C	cSt	Grade	Nom. ± 5%	New oil	Nom. ± 5%	Nom. ± 10%	New oil	Nom. ± 5%	Nom. ± 10%	New oil	Nom. ± 5%	Nom. ± 10%	New oil	Nom. ± 5%	Nom. ± 10%	New oil	Nom. ± 5%	Nom. ± 10%				New oil	Nom. ± 5%	Nom. ± 10%
Neutralisation Number	Acid No. (AN)	mgKOH/g	Baseline		New oil	Nom. + 0.2	Nom. + 0.7	New oil	Nom. + 0.2	Nom. + 0.7	New oil	Nom. + 0.1	Nom. + 0.2	New oil	Nom. + 0.1	Nom. + 0.2	New oil	Nom. + 0.2	Nom. + 0.7				New oil	Nom. + 0.2	Nom. + 0.7
	Base No. (BN)	mgKOH/g	Baseline																						
Oxidation level	Colour	colour	Baseline		New oil		Unusual darkening	New oil		Unusual darkening	< 0.5	3	5	< 0.5	3	5	New oil		Unusual darkening	New oil		Unusual darkening	New oil		Unusual darkening
	Odour	unitless	Baseline		New oil		Burnt, pungent, unusual	New oil		Burnt, pungent, unusual	New oil		Burnt, pungent, unusual	New oil		Burnt, pungent, unusual	New oil		Burnt, pungent, unusual	New oil		Burnt, pungent, unusual	New oil		Burnt, pungent, unusual
Lubricant Contamination																									
Appearance		unitless	Baseline		Clear & bright		Hazy, milky, free water, debris	Clear & bright		Hazy, milky, free water, debris	Clear & bright		Hazy, milky, free water, debris	Clear & bright		Hazy, milky, free water, debris	Clear & bright		Hazy, milky, free water, debris	Clear & bright		Hazy, milky, free water, debris	Clear & bright		Hazy, milky, free water, debris
Particles	4\6\14	µm	Lube type target + 1 (received) - 1 (dispensed)		17\15\12	19\17\14	21\19\16	16\14\11	18\16\13	20\18\15	16\14\11	18\16\13	20\18\15	16\14\11	18\16\13	20\18\15	17\15\12	19\17\14	21\19\16	16\14\11	18\16\13	20\18\15	16\14\11	18\16\13	20\18\15
	Filter inspection				Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination
Water	Crackle test	% vol.	0	0,05	0	0,05	0,1	0	0,05	0,1	0	0,05	0,1	0	0,05	0,1	0	0,05	0,1	0	0,05	0,1	0	0,05	0,1
	% saturation	% sat.	0	40	0	40	80	0	40	80	0	40	80	0	40	80	0	40	80	0	40	80	0	40	80
	Reagent test	% vol.	0	40% sat.	0	250	500	0	200	400	0	200	400	0	200	400	0	250	500				0	200	400
Soot	Blotter Spot	%	Baseline																						
Glycol (coolant)	Schiff's Reagent	ppm																							
Machine Wear																									
Wear debris	Filtergram	unitless			Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination
Ferrous debris	Magnetic plug	unitless			Normal wear		Abnormal wear	Normal wear		Abnormal wear	Normal wear		Abnormal wear	Normal wear		Abnormal wear	Normal wear		Abnormal wear	Normal wear		Abnormal wear	Normal wear		Abnormal wear

All figures given are initial starting points only. They shall be adjusted with experience, further data, individual circumstances, test types, etc.

Nominal	= New oil or target figure.
Warning	= Failure mode/s exist & maintenance action is required. An interim solution may be acceptable.
Severe	= Failure mode/s in severe condition, catastrophic failure or significant damage imminent. Immediate maintenance action (full solution) is required.

a)

Table F.1 *(continued)*

Parameter - classified by primary area of application, but may apply to more than one!		*Units*	**Mobile Equipment**												*Grease*		
			Diesel Engine Oil			*Transmission Fluid*			*Automotive Gear Oil*			*Mobile Hydraulic Fluid*					
			Nominal	*Warning*	*Severe*	*Nominal*	*Warning*	*Severe*	*Nominal*	*Warning*	*Severe*	*Nominal*	*Warning*	*Severe*	*Nominal*	*Warning*	*Severe*
Lubricant Properties																	
Viscosity	@ 40 °C	cSt	New oil	Nom. +10 /-5%	Nom. +20 /-10%	New oil	Nom. ± 5%	Nom. ± 10%	New oil	Nom. ± 5%	Nom. ± 10%	New oil	Nom. ± 5%	Nom. ± 10%			
Neutralisation Number	Acid No. (AN)	mgKOH/g				New oil	Nom. + 0.2	Nom. + 0.7	New oil	Nom. + 0.2	Nom. + 0.7	New oil	Nom. + 0.2	Nom. + 0.7			
	Base No. (BN)	mgKOH/g	New oil	Nom. - 25%	Nom. - 50%												
Oxidation level	Colour	colour				New oil		Unusual darkening	New oil		Unusual darkening	New oil		Unusual darkening	New grease		Darkening, colour change
	Odour	unitless	New oil		Burnt, pungent, unusual	New oil		Burnt, pungent, unusual	New oil		Burnt, pungent, unusual	New oil		Burnt, pungent, unusual	New oil		Burnt, pungent, unusual
Lubricant Contamination																	
Appearance		unitless	Clear & bright		Hazy, milky, free water, debris	Clear & bright		Hazy, milky, free water, debris	Clear & bright		Hazy, milky, free water, debris	Clear & bright		Hazy, milky, free water, debris	Clear & bright		Hazy, milky, free water, debris
Particles	4\6\14	µm	17\15\12	19\17\14	21\19\16	17\15\12	19\17\14	21\19\16	17\15\12	19\17\14	21\19\16	16\14\11	18\16\13	20\18\15			
	Filter inspection		Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination			
Water	Crackle test	% vol.	0	0,1	0,2	0	0,05	0,1	0	0,05	0,1	0	0,05	0,1			
	% saturation	% sat.				0	40	80	0	40	80	0	40	80			
	Reagent test	% vol.				0	250	500	0	250	500	0	200	400			
Soot	Blotter Spot	%															
Glycol (coolant)	Schiff's Reagent	ppm	0	200	400												
Machine Wear																	
Wear debris	Filtergram	unitless	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination			
Ferrous debris	Magnetic plug	unitless	Normal wear		Abnormal wear	Normal wear		Abnormal wear	Normal wear		Abnormal wear	Normal wear		Abnormal wear			

All figures given are initial starting points only. They shall be adjusted with experience, further data, individual circumstances, test types, etc.

Nominal	= New oil or target figure.
Warning	= Failure mode/s exist & maintenance action is required. An interim solution may be acceptable.
Severe	= Failure mode/s in severe condition, catastrophic failure or significant damage imminent. Immediate maintenance action (full solution) is required.

b)

Table F.2 — Off site tests alarm criteria

Parameter - classified by primary area of application, but may apply to more than one!		Units	New Oil		Industrial Machines																	
					Industrial Gear Oil			Industrial Hydraulic Fluid			Steam Turbine Oil			Gas Turbine Oil			Paper Machine Oil			Refrigeration Compressor Oil			Air & Gas Compressor Oil		
			Nominal	Reject	Nominal	Warning	Severe	Nominal	Warning	Severe	Nominal	Warning	Severe	Nominal	Warning	Severe	Nominal	Warning	Severe	Nominal	Warning	Severe	Nominal	Warning	Severe
Lubricant Properties																									
Viscosity	@ 40 °C	cSt	Grade	Nom. ± 5%	New oil	Nom. ± 5%	Nom. ± 10%	New oil	Nom. ± 5%	Nom. ± 10%	New oil	Nom. ± 5%	Nom. ± 10%	New oil	Nom. ± 5%	Nom. ± 10%	New oil	Nom. ± 5%	Nom. ± 10%				New oil	Nom. ± 5%	Nom. ± 10%
	@ 100 °C	cSt	Grade	Nom. ± 5%																					
	Index	unitless	Baseline																						
Neutralisation Number	Acid No. (AN)	mgKOH/g	Baseline		New oil	Nom. + 0.2	Nom. + 0.7	New oil	Nom. + 0.2	Nom. + 0.7	New oil	Nom. + 0.1	Nom. + 0.2	New oil	Nom. + 0.1	Nom. + 0.2	New oil	Nom. + 0.2	Nom. + 0.7				New oil	Nom. + 0.2	Nom. + 0.7
	Base No. (BN)	mgKOH/g	Baseline																						
Oxidation level	Colour	colour	Baseline		New oil		Unusual darkening	New oil		Unusual darkening	< 0.5	3	5	< 0.5	3	5	New oil		Unusual darkening	New oil		Unusual darkening	New oil		Unusual darkening
	FTIR	au	Baseline		New oil	Nom. + 6	Nom. + 12	New oil	Nom. + 6	Nom. + 12	New oil	Nom. + 6	Nom. + 12	New oil	Nom. + 6	Nom. + 12	New oil	Nom. + 6	Nom. + 12				New oil	Nom. + 6	Nom. + 12
	Insolubles	% wt.									0	0,05	0,1	0	0,05	0,1									
	Ultra Centrifuge	unitless									0	2	3	0	2	3									
Nitration	FTIR	au	Baseline																						
Sulphation	FTIR	au	Baseline																						
Oxidation resistance	FTIR		Baseline																						
	Cyclic Voltammetry	% wt.	Baseline								New oil	Nom. - 50%	Nom. - 75%	New oil	Nom. - 50%	Nom. - 75%							New oil	Nom. - 50%	Nom. - 75%
	RPVOT	minutes	Baseline								New oil	Nom. - 50%	Nom. - 75%	New oil	Nom. - 50%	Nom. - 75%							New oil	Nom. - 50%	Nom. - 75%
Water resistance	Demulsibility	minutes	Baseline								< 15	15	30												
	Rust Test	unitless									Pass		Light fail										Pass		Light fail
Aeration resistance	Foam Stability (Sequence I)	ml	Baseline		30/0		450/0	30/0		450/0	30/0		450/0	30/0		450/0							30/0		450/0
	Air Release	minutes	Baseline					4	6	8	4	6	8	4	6	8									
Additive Elements	Ba, B, Ca, Mg, Mo, P, Zn	ppm	Baseline		New oil (or 0)	Nom. ± 10% (or +1 SD)	Nom. ± 20% (or +2 SD)	New oil (or 0)	Nom. ± 10% (or +1 SD)	Nom. ± 20% (or +2 SD)	New oil (or 0)	Nom. ± 10% (or +1 SD)	Nom. ± 20% (or +2 SD)	New oil (or 0)	Nom. ± 10% (or +1 SD)	Nom. ± 20% (or +2 SD)	New oil (or 0)	Nom. ± 10% (or +1 SD)	Nom. ± 20% (or +2 SD)	New oil (or 0)	Nom. ± 10% (or +1 SD)	Nom. ± 20% (or +2 SD)	New oil (or 0)	Nom. ± 10% (or +1 SD)	Nom. ± 20% (or +2 SD)
Lubricant Contamination																									
Particles	4\6\14 count	µm	Lube type target + 1 (received)		17\15\12	19\17\14	21\19\16	16\14\11	18\16\13	20\18\15	16\14\11	18\16\13	20\18\15	16\14\11	18\16\13	20\18\15	17\15\12	19\17\14	21\19\16	16\14\11	18\16\13	20\18\15	16\14\11	18\16\13	20\18\15
Water	FTIR	% vol.	0	0,1	0		0,1	0		0,1	0		0,1	0		0,1	0		0,1	0		0,1	0		0,1
	Karl Fischer	ppm	0	40% sat.	0	250 (40% sat.)	500 (80% sat.)	0	150 (40% sat.)	250 (80% sat.)	0	100 (40% sat.)	200 (80% sat.)	0	100 (40% sat.)	200 (80% sat.)	0	250 (40% sat.)	500 (80% sat.)				0	150 (40% sat.)	250 (80% sat.)
	Co-distillation	% vol.	0	0,05	0	0,05	0,1	0	0,05	0,1	0	0,05	0,1	0	0,05	0,1	0	0,05	0,1	0	0,05	0,1	0	0,05	0,1
Soot	FTIR	% wt.	Baseline																						
	TGA	% wt.																							
Glycol (coolant)	FTIR	% wt.	Baseline																						
Fuel Dilution	FTIR	% wt.	Baseline																						
	Flash Point	°C	Baseline																						
	Gas Chromatography	% wt.	Baseline																						
Contaminant Elements	K, Si, Na	ppm	Baseline		0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD
Machine Wear																									
Wear debris	Filtergram	unitless			Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination
Ferrous debris	PQ Index	unitless			0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD
	Ferrogram	unitless			Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination
Wear Metal Elements	Ag, Al, Cd, Cr, Cu Fe, Mn, Ni, Pb, Sn, Ti, V	ppm	Baseline		0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD

All figures given are initial starting points only. They shall be adjusted with experience, further data, individual circumstances, test types, etc.

Statistical values should be based on 30 or more data sets

Elemental analysis levels should be based on variation in nominal levels for additives & SD (Standard Deviation) increases for contaminants

Nominal = New oil or target figure.

Warning = Failure mode/s exist & maintenance action is required. An interim solution may be acceptable.

Severe = Failure mode/s in severe condition, catastrophic failure or significant damage imminent. Immediate maintenance action (full solution) is required.

a)

Table F.2 *(continued)*

Parameter - classified by primary area of application, but may apply to more than one!		*Units*	**Mobile Equipment**															*Grease*		
			Diesel Engine Oil			*Transmission Fluid*			*Automotive Gear Oil*			*Mobile Hydraulic Fluid*					
			Nominal	*Warning*	*Severe*	*Nominal*	*Warning*	*Severe*	*Nominal*	*Warning*	*Severe*	*Nominal*	*Warning*	*Severe*	*Nominal*	*Warning*	*Severe*
Lubricant Properties																	
Viscosity	@ 40 °C	cSt	New oil	Nom. +10 /-5%	Nom. +20 /-10%	New oil	Nom. ± 5%	Nom. ± 10%	New oil	Nom. ± 5%	Nom. ± 10%	New oil	Nom. ± 5%	Nom. ± 10%			
	@ 100 °C	cSt	New oil	Nom. +8 /-4%	Nom. +15 /-8%												
	Index	unitless															
Neutralisation Number	Acid No. (AN)	mgKOH/g				New oil	Nom. + 0.2	Nom. + 0.7	New oil	Nom. + 0.2	Nom. + 0.7	New oil	Nom. + 0.2	Nom. + 0.7			
	Base No. (BN)	mgKOH/g	New oil	Nom. - 25%	Nom. - 50%												
Oxidation level	Colour	colour				New oil		Unusual darkening	New oil		Unusual darkening	New oil		Unusual darkening	New grease		Darkening, colour change
	FTIR	au				New oil	Nom. + 6	Nom. + 12	New oil	Nom. + 6	Nom. + 12	New oil	Nom. + 6	Nom. + 12			
	Insolubles	% wt.															
	Ultra Centrifuge	unitless															
Nitration	FTIR	au															
Sulphation	FTIR	au															
Oxidation resistance	FTIR																
	Cyclic Voltammetry	% wt.															
	RPVOT	minutes															
Water resistance	Demulsability	minutes															
	Rust Test	unitless															
Aeration resistance	Foam Stability (Sequence I)	ml															
	Air Release	minutes															
Additive Elements	Ba, B, Ca, Mg, Mo, P, Zn	ppm	New oil (or 0)	Nom. ± 10% (or +1 SD)	Nom. ± 20% (or +2 SD)	New oil (or 0)	Nom. ± 10% (or +1 SD)	Nom. ± 20% (or +2 SD)	New oil (or 0)	Nom. ± 10% (or +1 SD)	Nom. ± 20% (or +2 SD)	New oil (or 0)	Nom. ± 10% (or +1 SD)	Nom. ± 20% (or +2 SD)	New oil (or 0)	Nom. ± 10% (or +1 SD)	Nom. ± 20% (or +2 SD)
Lubricant Contamination																	
Particles	4\6\14 count	µm	17\15\12	19\17\14	21\19\16	17\15\12	19\17\14	21\19\16	17\15\12	19\17\14	21\19\16	16\14\11	18\16\13	20\18\15			
Water	FTIR	% vol.	0	0,1	0,2	0		0,1	0		0,1	0		0,1	0		0,1
	Karl Fischer	ppm				0	250 (40% sat.)	500 (80% sat.)	0	250 (40% sat.)	500 (80% sat.)	0	150 (40% sat.)	250 (80% sat.)	0	250	500
	Co-distillation	% vol.	0	0,1	0,2	0	0,05	0,1	0	0,05	0,1	0	0,05	0,1			
Soot	FTIR	% wt.	0	4	8												
	TGA	% wt.															
Glycol (coolant)	FTIR	% wt.	0		0,1												
Fuel Dilution	FTIR	% wt.	0	2	4												
	Flash Point	°C	New oil	Nom. - 20	Nom. - 40												
	Gas Chromatography	% wt.	0	2	4												
Contaminant Elements	K, Si, Na	ppm	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD
Machine Wear																	
Wear debris	Filtergram	unitless	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination			
Ferrous debris	PQ Index	unitless	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD			
	Ferrogram	unitless	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination	Normal wear		Abnormal wear, contamination			
Wear Metal Elements	Ag, Al, Cd, Cr, Cu Fe, Mn, Ni, Pb, Sn, Ti, V	ppm	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD	0	Mean +1 SD	Mean +2 SD

All figures given are initial starting points only. They shall be adjusted with experience, further data, individual circumstances, test types, etc.

Statistical values should be based on 30 or more data sets

Elemental analysis levels should be based on variation in nominal levels for additives & SD (Standard Deviation) increases for contaminants

Nominal = New oil or target figure.

Warning = Failure mode/s exist & maintenance action is required. An interim solution may be acceptable.

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b)

Annex G
(informative)

Diagnosis and prognosis guidelines

G.1 Lubricant properties

G.1.1 Viscosity

Viscosity testing can be applied to oil (Table G.1) and can increase or decrease for a number of reasons.

In industrial oils, an increase in viscosity can indicate oxidation, thermal failure, water/glycol contamination, soot loading, contamination with dirt or water or an addition of a higher viscosity oil to the system. Insoluble levels in excess of 5 % weight in diesel engines can cause the oil to become extremely viscous and cause difficulty in starting, blocked filters and oil starvation leading to mechanical failure.

It is seldom that the viscosity of an industrial oil decreases in use. If this occurs, it suggests contamination with a solvent or lower viscosity oil, fuel dilution in engine oils, VI improver (additive) shear-down, base oil shear-down and base oil cracking.

Table G.1 — Viscosity

Sampling strategy	From active fluid zones
Machine inspections	Operating temperature
Onsite tests	Onsite viscometer
Primary tests	Kinematic or absolute viscosity
Alarming strategy	Percent plus/minus from new oil baseline, typically 10 %
Exception, supporting or confirming tests	AN, FTIR, elemental spectroscopy, oxidation stability, flash point
Confirming companion technologies	None

Viscosity affects oil film thickness and film strength, which impact wear rate, heat generation and energy consumption, among other things. Therefore, controlling viscosity within a known range is important as is identifying sudden and significant viscosity excursions. These excursions are often symptomatic of abnormal conditions such as wrong oil, degraded oil or contamination. The specific condition that was the cause of a viscosity change is more precisely revealed by looking at other lubricant test properties.

Sometimes measuring viscosity at two temperatures (usually at 100 °C and 40 °C) is important, and a viscosity index (VI) is calculated and reported. VI is an indication of how the viscosity of the oil varies with temperature, and is called for when the machine needs to operate over a wide temperature range.

G.1.2 Neutralisation number

G.1.2.1 Total acid number (TAN or neutralization value) (ASTM D664, ASTM D974)

The degree to which TAN has increased over and above the new oil's baseline should be monitored. TAN is an indication of the extent to which the oil has degraded. A high or rising TAN typically indicates the oil's antioxidants have expired and it needs to be changed. TAN above 4,0 are generally considered corrosive and have the potential to attack bearing materials and other metal surfaces. This risk is increased in the presence of water contamination which strengthens the corrosive potential of acids.