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USED ENGINE OIL ANALYSIS – USER INTERPRETATION GUIDE



**The International Council
on Combustion Engines**

**Conseil International des
Machines à Combustion**



CIMAC was founded in Paris in 1951 where the first Congress took place. Originally CIMAC was organized as an industry event to discuss new ideas and developments within the engine and components industry together with institutes and universities.

It is supported by engine manufacturers, engine users, technical universities, research institutes, component suppliers, fuel and lubricating oil suppliers and several other interested parties.

The National Member Associations (NMAs), National Member Groups (NMGs) and Corporate Members (CMs) as well as previous CIMAC Recommendations are listed in the back of this publication.

This document has been elaborated by the CIMAC Working Group 'Marine Lubricants' in May 2011.

**CIMAC Central Secretariat
c/o VDMA e.V.
Lyoner Str. 18
60528 Frankfurt/Main
Germany**

Phone: +49 69 6603-1355
Fax: +49 69 5503-2355
E-mail: cimac@vdma.org
Web: <http://www.cimac.com>

FOREWORD BY THE PRESIDENT

Lubricating oil is as important for an engine as blood for a human. Today, a lot of information about human health can be obtained from blood tests.

And so it is for diesel engines. Used Oil Analysis is one of the important, and maybe the simplest, approaches to diagnosing the health of an engine. It is, however, not easy for engine users or engineers to understand and interpret each analysis parameter correctly and to assess the condition of the oil and the engine.

The CIMAC Working Group Marine Lubricants has developed the Recommendation for Used Oil Analysis. This CIMAC Recommendation describes the oil analysis process and gives information about each analysed parameter. With this information I believe that readers - users and engineers – gain useful knowledge about oil analysis, knowledge which contributes to the accurate assessment of the condition of lubricants and hence to the reliable operation of diesel engines.

The CIMAC Working Group Marine Lubricants comprises acknowledged experts from engine manufacturers, component and systems suppliers, oil companies, classification societies and ship operators/users. The new recommendation pursues the Working Group's ultimate target of proposing suitable measures in relation to lubricating oils and diesel engines, for use today and in the future.

I congratulate the Working Group for producing this remarkable Recommendation, a document which will long be useful to the large engine community all over the world.



Yasuhiro Itoh, CIMAC President
May 2011

USED ENGINE OIL ANALYSIS – USER INTERPRETATION GUIDE

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USED ENGINE OIL ANALYSIS – USER INTERPRETATION GUIDE

Abstract

Used oil analysis is an important part of engine maintenance. It provides information about the condition of the oil, its suitability for further use and to a certain extent information about the condition of the machinery lubricated by the oil. Precondition of a valuable oil analysis and its interpretation is a sample being taken according to a reliable procedure.

Besides routine methods used in all engine oil analyses, there are several advanced methods that provide additional information. Both routine and advanced methods are described and it is discussed how they can be interpreted for 4-stroke and 2-stroke engine applications.

The laboratory oil analysis is a snap-shot of oil condition at the time the oil sample was taken. Filling the gap between oil sampling can be done with on-line monitoring or with on-site analysis using portable test kits.

This recommendation no. 30 is intended to enable its reader to better understand the analysis of a used oil sample, to realise the limitations of some methods, to develop ideas on how to increase reliability and safety of the installation onboard as well as provide insight into used oil analysis as a trouble-shooting tool.

1 Why do we need used oil analysis?

The purpose of conducting used oil analysis is two-fold:

1. To assess the condition of the oil - to provide recommendations on its suitability for further use and optimisation of the oil change intervals.
2. To assess the condition of the engine - to enable the detection and thus prevention of issues which left unattended may impact the reliable operation of the engine.

This used Oil Analysis Guide and its recommendations can be used for the following lubricants & their applications:

- 2-stroke (system and cylinder oil) and 4-stroke engine oils in marine and power generation applications.
- Gas engine oils used for marine and power generation applications.

All these oils will be subjected to many different stresses when in service. Contamination by particles originating from wear and corrosion within the engine, contamination by combustion products, water and contamination from other sources occurs. The effects of these stresses combined with thermal degradation and additive depletion will cause an oil's properties to change in an undesirable way.

For example in low speed 2 stroke engines, the system oil is contaminated by cylinder oil due to leakage via the stuffing box gland seals between the crankcase and the scavenge space below each cylinder. In cylinder oils the Base Number additive in the lubricating oil is consumed by chemical reaction with sulphuric acid, originating from the sulphur in the fuel oil.

The system oil in large medium and low speed diesel engines is intended to be in use for a long time. The normal case is that the lubricating oil stays in the engine without replacement. Only the loss of oil, e.g. consumption during operation and loss of oil in the cleaning system, is compensated for by the topping up the volume with new oil. The consequence is that the average retention time of the oil in the system can be very long depending on the total oil volume in the system and the daily oil loss. This contrasts with the engine oil of high-speed engines and in some medium-speed engines which has to be drained regularly to keep the necessary performance.

As such engine oil drain intervals depend upon the engine type and design, the lubricating oil consumption, the engine oil quality, its conditioning, the operating conditions experienced by the oil and the type of fuel used. The oil drain intervals, to be effective, must be determined by oil analysis.

2 Procedure for used oil analysis

This chapter deals with oil analysis (routine and non-routine), key actions required for a correct analysis, oil sampling procedure, sample turnaround time, oil sampling intervals, and interpretation of oil diagnosis & test results.

2.1 Routine Analyses

The physical & chemical characteristics of an in-service oil are obviously linked back to the specific type of oil, its age and the conditions under which it operates. For engine oils, the tests carried out under "Routine Analyses" will typically include:

- 1) Viscosity
- 2) Water content
- 3) Base Number (BN) or Alkalinity reserve
- 4) Insolubles
- 5) Flash Point
- 6) Elements (measuring the concentration of additives and levels of wear metals, etc.)

These tests are typically carried out in highly automated specialised laboratories. Only a small volume of oil is needed- typically less than 250 ml for a full Routine Analysis, and fully automated equipment can be used. This makes Routine Analysis quick, easy & economical to run. Normally the test method used will be according to conventional ISO or ASTM standards but where in-house specialised test methods are used these can have the advantage that the tests are specifically designed for their relevance to 'used oil' based on many years field experience. In cases of a dispute the ISO or ASTM methods are used as the referee method.

Routine Analysis test kits, which contain all the equipment & containers necessary for taking the samples are delivered to the installations at regular intervals. Additionally, many kits now contain pre-labelled sample containers and pre-paid express mail postage bags. Most laboratories now operate on a 24 hour testing turnaround time from the time of sample receipt.

In cases where a high degree of test precision is needed standard Routine Analysis testing may not be suitable.

2.2 Non Routine Analyses

Sometimes more sophisticated testing is needed to investigate an ongoing problem or to obtain a better diagnosis of the condition of the engine or its components. These analyses are known as “Non Routine” analyses. Such tests can be carried out as part of an investigation or indeed be done as part of an oil based condition monitoring programme. Extended analysis suites can include tests carried out on engine deposits, debris & fuel samples as well as the oil samples themselves.

Non routine analyses typically require larger sample volumes (1 litre or so), and the analyses performed are chosen on a case by case basis with guidance from the oil supplier and / or engine manufacturer. Use of a different laboratory may also be required. It is necessary to provide specific and detailed information on the history of the engine & practical working details in order to determine which analysis is most useful to provide the most relevant diagnosis.

As such Non Routine analyses are more time consuming and specialised, they are also more costly so it is important to provide as much background information on the nature of the problem at the point of submitting the sample.

2.3 Key Actions required for a correct analysis

In order to enable a full and proper routine or non routine analysis it is essential that:

- The oil sample bottles are clean
- The oil sample taken is representative of the oil in service,
- All supporting details (e.g. sampling point, date, oil name and hours of service) are attached to the sample container and so are made available to the laboratory
- The sample is quickly dispatched to the laboratory

2.4 Sampling Procedure

How, when and where a sample is taken from within the lubrication system is very important. This is because only a very small amount of oil is taken during sampling. A 250 ml sample represents only a very small percentage of the total oil capacity which can be up to 100,000 litres. It goes without saying that it is essential to be sure that the sample taken is truly representative of the full oil volume and take the necessary precautions when sampling oils which may be hot and contained within pressurised systems, the use of gloves and face protection is advisory.

Some general, but key points regarding the acquisition of representative oil samples include:

- Sample when the machine is running at normal operating temperature, never when the equipment is stationary or cold, or after any significant addition of fresh oil.
- Sample from the main supply line of the engine, if necessary arrange to fit dedicated sampling valves that can be accessed easily and safely.
- Always sample from the same sampling point for any particular piece of equipment.
- Sample after flushing a small quantity of oil (0.5 - 1.0l) through the sampling point - and without operating the sampling valve between flushing and sampling.
- Whenever possible fill the sample directly into the sampling bottle to avoid any unnecessary contamination.
- Use only dedicated clean and dry sampling equipment intended for the sampling of used oils.

- To avoid leakage fill the sample bottle to 90% capacity and ensure it is properly sealed before despatch to the laboratory.

At this point the reader is referred to the CEC 1990 publication “Code of practice representative samples of engine lubricants on site ship (CEC M-12-T-91)” [1] or full details on how to observe the best sampling practices.

2.5 Good Sampling Locations

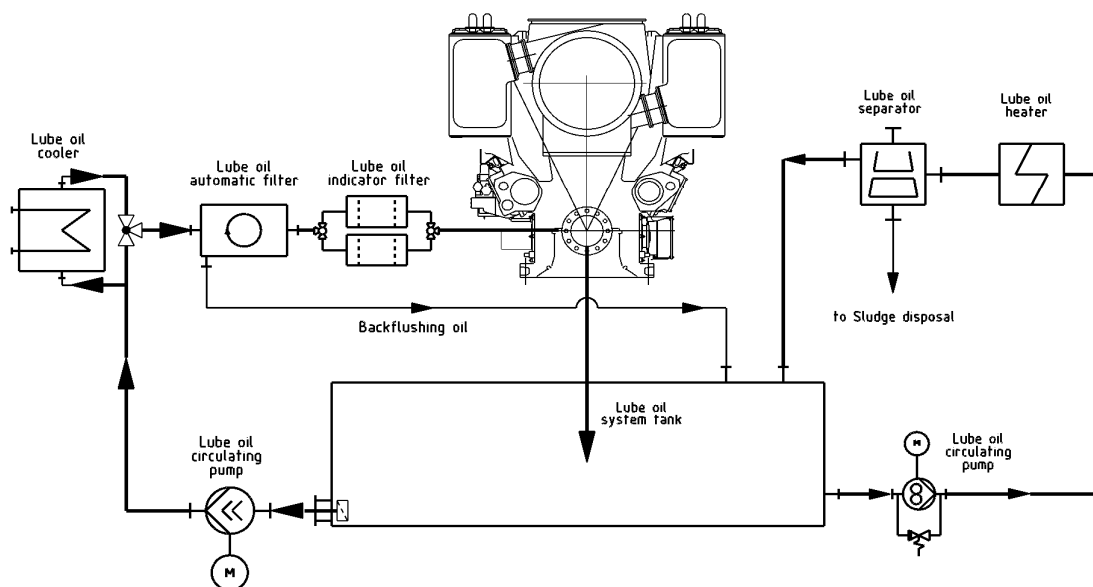


Figure 1: Typical oil system

System oil

Not all engines are equipped with sampling valves in the main lubricating oil system when delivered. It is therefore sometimes seen that the operator needs to remove e.g. a manometer before being able to take a sample of system oil. It is recommended that a dedicated sampling valve is placed in the circulating system before the engine entry.

The most representative sample of oil of the quality that the engine is exposed to, is taken from the lubricating oil system at the engine inlet. The sample should be taken at a location with a full flow condition to avoid getting the sample contaminated by precipitated sludge. In the case of horizontal piping with a low flow condition hence a risk of sludge forming in the bottom part of the pipe, it is recommended to place the sampling valve in the side or top of the pipe instead of in the bottom.

Centrifuges - Purifiers and clarifiers

Routine oil analysis cannot be used to assess the performance of centrifuges, purifiers and clarifiers as the tests normally offered cannot differentiate sufficiently between inlet and outlet conditions, therefore non-routine tests need to be employed which are based upon appropriate sampling and particle analysis techniques.

Scavenge drain oil (only 2-stroke engines)

Scavenge drain oil can be collected after each cylinder or in a common drain pipe collecting drain oil from all cylinder units.

Taking samples using the common drain pipe should be avoided as the effect of dilution and contamination between units reduces the opportunity of gaining a useful diagnosis of the effects of combustion and evidence of wear.

For two-stroke scavenge drain oil samples, a 250 ml sample may be difficult to achieve as the engine does not provide large amounts of scavenge drain oil. For this type of sample, 100 ml is usually sufficient. However it must be pointed out that the results of scavenge drain oil analysis are reliant upon the quality of the sampling procedure. In addition, it has been shown [2] that the results can be significantly influenced by contamination with system oil, fuel, partially pyrolysed fuel, water and inter-cylinder cross contamination, therefore any analysis and subsequent diagnosis must take this into account.

The scavenge drain piping is usually equipped with a closing valve and a sample valve branching off the vertical piping between the engine and the closing valve. The sample is drawn by closing the closing valve and waiting until the piping has filled up sufficiently so that a sample of drain oil can be collected. Unfortunately, it may take quite some time to fill up the piping until the point of the sampling valve is reached due to the relatively low flow rate of scavenge drain oil in the line.

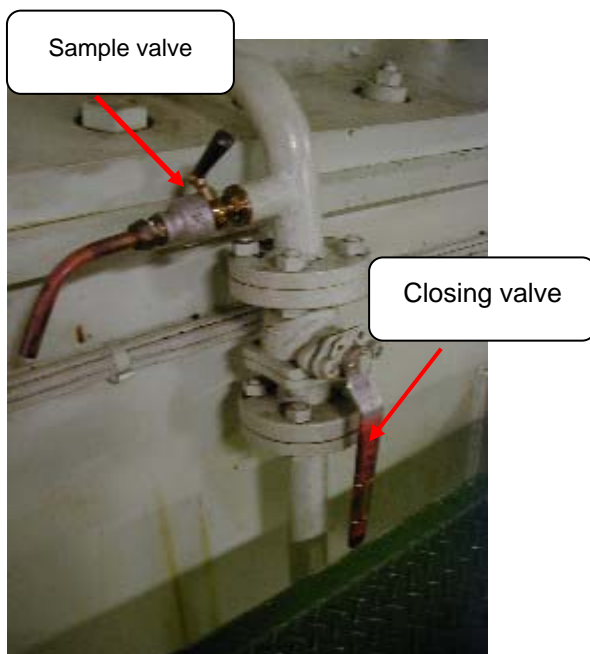


Figure 2: sampling location for scavenge drain oil

2.6 Sample Information

To guarantee that sample will be analysed without delay, it is vital that the label attached to the sample bottle is accurate and complete. Key information includes the name of the ship or power plant, the specific name of the engine, type of lubricant, type of engine, date of sampling and the number of hours of service. Omission or mistakes made in labelling may delay the analysis of the sample and make a correct assessment and recommendation impossible.

Analysis test kits are routinely delivered to ships and contain all the equipment & bottles necessary for taking the samples. Additionally, many kits now contain pre-labelled sample bottles and pre-paid express mail postage bags. Samples can be packaged and couriered to the nominated laboratory for testing, but care must be taken to ensure that they are labelled appropriately. Also it should be clearly stated that the package contains used oil samples for testing to destruction with a flash point greater than 60°C, otherwise it is possible that the samples could be held in transit due to transport safety concerns. Most laboratories can now operate on a 24hr testing turnaround time from the time of sample receipt if this is required. Though clearly such a fast turnaround would be unnecessary if samples have been held up in transit for many weeks prior to arrival at the laboratory.

Pre-labelling sample bottles considerably eases this process and reduces the number of errors that can be made. However, care must still be taken to ensure that the correct pre-labelled empty bottle is used and so therefore contains the oil from the correct sampling point.

It should be stressed that the interpretation of the used oil analysis results requires a precise knowledge of the equipment, its operating conditions and a range of other complimentary information in order to offer a diagnosis of machinery condition. This can include historical data from any known operating incidents that may have affected the equipment in service, plus environmental information and performance data. The value of having good additional information from the engineering staff is essential to making an appropriate diagnosis.

It is also important to realise that a full and proper diagnosis cannot be achieved from the results of just one analysis.

2.7 Sampling Intervals

Correct interpretation of the oil analyses results requires monitoring the individual test parameters as a function of time or operating hours. This allows graphs to be plotted which can be extrapolated to indicate the normal operating trends of a piece of equipment and therefore what future results would be called “normal”. Any significant deviation from these trends can be highlighted by the analyst so that on-site investigations (by the engine staff) can be carried out to find the cause. Any analysis made outside this context is very often difficult to interpret.

When sampling for oil based Condition Monitoring (CM) the sampling frequency for systems will vary according to the result of the risk assessment that is made when the maintenance review is carried out; however in the main it will most likely be prudent to take samples on a monthly basis until sufficient trends have been established to allow optimisation and thus adjusting the sampling frequency thereafter as appropriate. NB, Care must be taken however, to ensure that where a condition monitoring tool such as oil analysis is being used as a protective device, i.e. to highlight the development of a known failure condition, the sampling frequency must be shorter than the “mean time to failure”. Without this there will be failures which remain unprotected. Experience has shown that used oil analysis for CM is less effective where failure types have particularly short “mean time to failure” profiles, e.g. liner scuffing or bearing fractures.

So, in order to monitor results as a function of time it is vital to take the oil samples at regular intervals-typically these will be defined by the OEM (Original Equipment Manufacturer) or by the oil supplier, but will normally not be greater than 3 months apart.

2.8 Oil analysis, diagnosis & interpretation of results

For any given oil characteristic, “caution” and “action/urgent” threshold limits are typically set up for the oil used within a specific piece of equipment. These are warning values, which once reached or exceeded require investigation by the engine staff as they indicate a potential problem - if a ‘caution’ limit, or they can indicate a more serious specific problem - if an action/urgent limit in the equipment. In certain instances the laboratory may require further samples to be taken to monitor a condition. This will form part of their diagnosis and will be included within the oil analysis report.

The initial threshold limits can originate from the OEM and or the oil supplier. If OEM and oil supplier limits are different, at least during the engines’ warranty period, the OEM limits should be followed in the first place. These limits are based on the particular equipment technology and on many years of successful operating experience & ‘know-how’ in the field of used oil analysis.

For a full understanding of these limits the reader is directed to CIMAC Recommendation No.29 - “Guidelines for the lubrication of medium speed diesel engines” chapter 7 entitled “lubricating oil analysis and its significance” [3].

It should be noted that these limits are guidance and may be in certain instances overruled by oil experts, for example after taking into account other evidence such as the general trend of the test characteristics and supporting information coming from the staff.

It must be stressed that limits must be assessed and amended accordingly on a system by system basis and also periodically as the data set develops over time. The use of initial guidance limits should only be considered as part of the set-up process as reliance upon arbitrary limits offers a false security that by operating within such limits no issues will be forthcoming.

3 Oil characteristics

This chapter briefly summarizes the methods used for measuring the oil characteristics. The recommended methods for the main characteristics are listed in the document “CEC M-13-T-92: Recommended standard methods for analysis of used oil from large diesel engine”. A precise description how the characteristics are measured can be extracted from the respective standard method. This chapter does not only describe the recommended methods but also includes other methods that have been applied.

In addition this chapter describes the meaning of each characteristic and the influencing factors.

3.1 Main characteristics

Main characteristics are those measured by most oil analysis labs. They are the basic things that have to be measured and are detailed below.

3.1.1 Viscosity

The kinematic viscosity (kV) is commonly referred to as just ‘viscosity’ and is determined by measuring the time a fluid needs to flow through a defined capillary at a defined temperature. The viscosity describes the flow resistance of a fluid and is typically expressed as a kV@40 or kV@100 test result, where 40 or 100 denotes the test temperature used (°C).

The viscosity of lubricating oil is defined at 100°C according to the SAE J300 Industry Classification System and is expressed in $\text{mm}^2 \text{s}^{-1}$ or cSt (centistokes). In practice, this parameter is also measured at 40°C and many used oil analysis laboratories report the viscosity measurement at 40°C, 100°C or both. Kinematic viscosity is the absolute or dynamic viscosity in Pa. S divided by the fluid density.

Change to oil viscosity during operation is mainly influenced by oil contamination (Insolubles, fuel, soot, particles and water) and oxidation. In the case of a two stroke engine, the system oil could also be contaminated by the cylinder oil.

3.1.2 BN (Base Number)

The alkalinity of lubricating oil is defined as the quantity of hydrochloric acid or perchloric acid required to neutralize one gram of oil, expressed in terms of the equivalent number of milligrams of potassium hydroxide (mg KOH/g). The BN is measured by titration with acid.

The BN (formerly called TBN total base number) is a measure of the alkalinity reserve. It shows the potential of the lubricating oil to neutralize acids caused by combustion products condensing on the cylinder walls and elsewhere within the engine. For example sulphur in the fuel is converted to sulphur oxides during combustion - mainly SO_2 along with a small proportion of SO_3 . Together with the water formed during the combustion process, the sulphur oxides condense on the cylinder walls as sulphuric acid, this acid is then neutralized by the alkalinity of the lubricant.

BN depletion is mainly influenced by the sulphur content of the fuel used, the oil consumption of the engine and the operating conditions of the engine.

3.1.3 Water content

The water content of used oil is typically measured by Karl-Fischer titration or by infrared spectroscopy rather than by the more commonly referenced distillation method.

Water can originate from various sources and can cause fresh or sea water contamination of the oil. Water in lubricating oil is a pollutant and is potentially harmful to the engine even in low quantity. Unfortunately traces of water in used lubricating oil tend to be unavoidable - they can result from internal leakages (water jacket, coolers), build up of condensation, or, through use of an incorrectly set separator.

3.1.4 Flash Point

The temperature at which a spark or a flame can ignite the oil vapor is called the flash point. This is the lowest temperature, at which vapours from the oil can be ignited.

Change of flash point is mainly influenced by fuel contamination and to a certain extent by oil degradation.

There are different Industry flash point test methods including the "Open Cup" and "Closed Cup" type methods.

It must be noted that due to evaporation losses the result with the Closed Cup method is generally lower than the result with the Open Cup method. NB: Flash Point is NOT a measure of flammability.

3.1.5 Insolubles

Insolubles can be defined as solid material that can be isolated from the oil by filtration or by centrifugation after a solvent (pentane, heptane or toluene) has been added.

However it should be realised that this is not the amount of insoluble material (particles) in the oil! It's important to know that different insolubles analysis methods will generate different values and so only the analyses made by the same test method are reliably comparable with one another.

The amount of Insolubles is increased in case of oil contamination (e.g. fuel) and by degradation of additives.

3.1.6 Metallic elements

The metallic elements in the oil are measured by spectroscopic methods. This can be atomic emission, atomic absorption or X-ray fluorescence spectroscopy.

The elements measured include additive elements, wear metals, combustion products and external contaminants e.g. from cooling water or intake air. Therefore these values are influenced by the additive package of the oil, component wear and fuel combustion.

Mostly Plasma Emission Spectrometry (ICP - Inductively Coupled Plasma) is used to determine the metal contents of used lubricating oils. However particles bigger than 5 - 7 μm are not detected by this method as they are not fully vaporised in the plasma due to mass effects and so wear element concentration can be underestimated in cases of particularly high wear. Here non-routine analysis like x-ray fluorescence spectroscopy, ashing of the sample before ICP measurement (to collect 100% of the material within the sample), ferrography, ferrometry, PQ (Particle Quantifier) and similar methods can help.

It must be realised that - according to the type of apparatus and way of sample preparation, the results obtained can be very different. When comparing and plotting results for trend analysis, therefore, it is important to ensure that the data are generated by the same laboratory, the same apparatus and the same method.

The accuracy and lower detection limits of the methods have to be considered carefully before any alarm or alert condition is applied to the analysis- especially low values (below 5 ppm) should be interpreted with caution.

3.2 Advanced Lubricant Analysis

For advanced lubricant analysis other oil characteristics can be measured, typically such testing performed only by a few specialized labs upon specific request or for specific applications.

3.2.1 AN (Acid number)

The AN formerly called Total Acid Number (TAN) describes the amount of acidic components in the oil. It is measured by titration with a base such as Potassium Hydroxide (KOH). The acidity of a lubricant is measured by the amount of KOH required for neutralization and is expressed in mg KOH/g.

The AN is relevant for lower BN oil and mainly in engines operated on gas. It is influenced by oil degradation.

3.2.2 Oxidation

The oxidation is measured by infrared spectroscopy. Oxidation products within the oil have an absorption at 1710 cm^{-1} . The number reported is the absorption value at this wavelength.

Oxidation is a process in which oxygen reacts with hydrocarbon molecules to form insoluble carbonaceous residues and resins. The oxidation of an oil is influenced by temperature and contamination.

3.2.3 Nitration

The principle of measuring Nitration is very similar to oxidation but uses a different infrared wavelength (1620 cm^{-1}).

The nitration is influenced by oil degradation and results from the reaction of the oil with NO_x . This value is typically only measured for gas engine oils and high-speed engine oils.

3.2.4 Sulphation

Sulphation is measured at an infrared wavelength of 1150 cm^{-1} . Sulphate by-products are typically formed from the oxidation of Sulphur components of the additives or fuel contamination and results from the reaction of the oil with SO_2 . Typically as BN reduces, absorption peaks indicative of Sulphation increase.

For any or all of the above measurements a fresh oil sample is needed in order to create a baseline for determining the rate and degree of degradation that has subsequently occurred. Only the results from same laboratory and the same analysis method should be compared with each other in this respect.

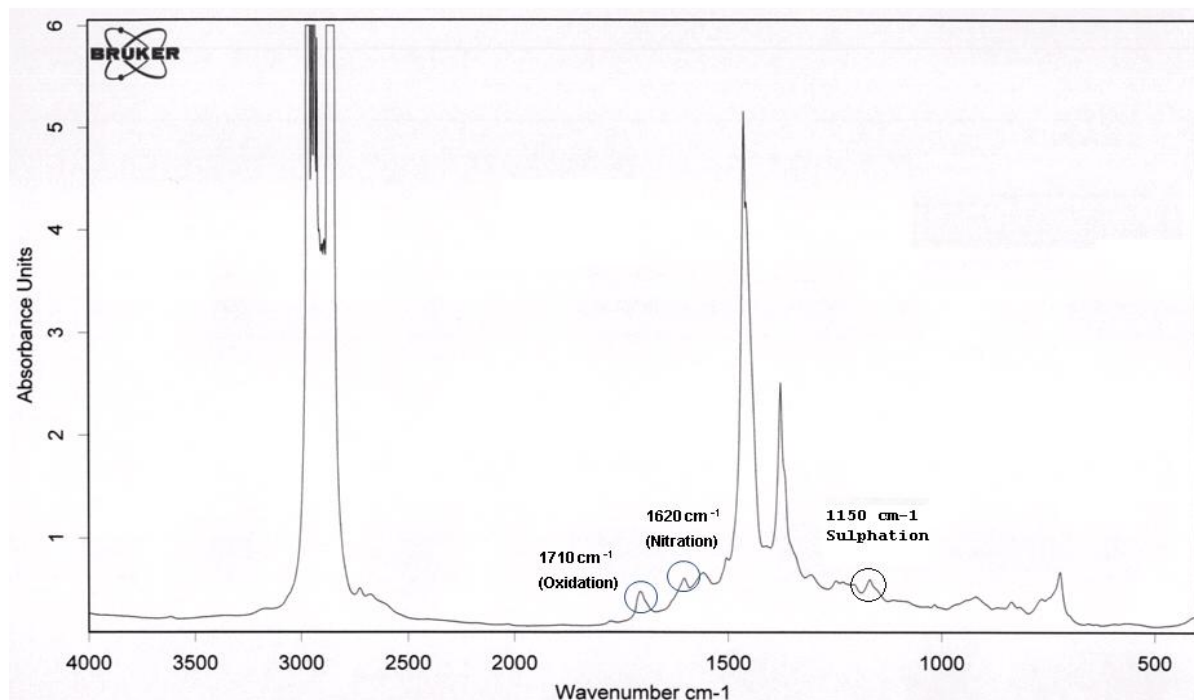


Figure 3: FT-IR spectra of a lubricating oil

3.2.5 Particle Count

Particle counting is done in order to determine and trend the level of particulate or dirt loading within an oil.

This can be determined by light obscuration or light scattering techniques or by image analysis of particles that have been filtered from the oil. The result is expressed as the amount of particles of different sizes.

Typically, the particle counting is done using optical evaluation using standard industry methods (like ISO 4406, NAS 1638). Basically, these methods were developed for hydraulic oils and are not very suitable for used engine lube oils which are much darker and as such more difficult to assess due to the presence of soot and pollution. This means that it is necessary to dilute the sample as much as 1:10, which will lead to significant variation in the results, as such this type of test is not routinely carried out for engine oils.

When it is necessary to determine the particle count within used lubricants a number of laboratories have developed in-house methods which are non-routine but are acceptable for determination of the particle population and size distribution. These methods will in time become acceptable standards as experience develops and confidence increases.

The size and amount of particles is influenced by wear condition, contamination of the oil with particles (e. g. through charge air), and products of combustion and of course by oil treatment.

3.2.6 VI (Viscosity Index)

The VI is calculated from the two measurements of viscosity at 100°C and 40°C and describes the viscosity-temperature relationship of the oil. A high VI indicates a small change of viscosity with temperature.

The VI is mainly defined by the base oil properties and by additives used.

A high VI is important for multi-grade oils where a restricted range of viscosity over a large temperature range is required to meet specification. Such a high VI enables optimum performance under varying temperature conditions.

3.2.7 Sulphated Ash

To measure sulphated ash content the oil is burned to remove the hydrocarbons and the remaining ash is converted into sulphates by reaction with sulphuric acid. The resulting sulphated ash represents the amount of ash building additives in the oil.

This technique measures the amount of detergent and anti-wear additives in new lubricating oil and so is not typically applied to used oils.

3.2.8 Soot

The amount of soot is measured by infrared absorption. The value is influenced by combustion, oil degradation and of course by the quality of the oil treatment.

3.2.9 Asphaltene Content

The asphaltene content can be measured by a chromatographic method, separating molecules according their molecular size [4].

Asphaltenes are heavy molecules originating from the heavy fuel oil. The asphaltene content represents the amount of unburned heavy fuel components. Such components can enter the oil through fuel leakages or as unburned fuel via the combustion chamber [5].

3.2.10 PQ (Particles Quantifier) Index

The PQ Index determines the relative quantity of ferrous metals in an oil sample as a function of the quantity of ferromagnetic debris in the sample. As the oil sample is brought into close proximity to the controlled magnetic flux field within the apparatus, this field will distort proportionally to the amount of ferromagnetic debris within the sample. The amount of distortion is expressed as the "PQ Index" and is independent of particle size. This value is then used in conjunction with spectrometric or other ferrographic analysis data.

Generally, as a wear situation deteriorates within a given system, more large particles tend to be generated. As a result, emission spectroscopy or atomic absorption test results which only capture data from particles typically less than 5-7 μm in size, will be seen to flatten or even reduce over time against an increasing PQ index value. The sensitivity of the PQ index is most effective where particles are in excess of approximately 20 μm , meaning that there is however a dip in sensitivity between 7 and 20 μm but wear debris under aggressive tribological conditions tends to produce a wear debris population over a wide size range up to and in excess of the critical clearance dimensions of interacting surfaces.

3.2.11 Ferrography

In Analytical Ferrography a ferrogram is created by either rotary particle deposition or by linear gravity slide. Both methods require the sample to move through a magnetic field which has the effect of aligning the ferrous particles in size order.

The resultant a ferrogram is then studied by an expert to quantify the type, concentration, size and morphology of ferrous particles. Here aspects such as the processes involved in the formation can be described such as cutting, fatigue, adhesion, fretting etc. thus giving further understanding of the wear situation within the machine.

It is extremely important to ensure that the experts dealing with the Ferrography are fully familiar with the type of equipment being assessed. The sump volumes of large engines can be significantly greater compared to smaller equivalents and a period of learning must be built into any relationship with a new oil analysis laboratory. Furthermore, trending of Ferrography is potentially misleading as the samples need to be extremely representative and taken in such a way as to ensure good repeatability and reproducibility.

3.2.12 Ferrometry

Ferrometry, a similar technique to the PQ Index, measures all the ferrous particles (100% efficient for particles size > 0.1 μm) of a fluid. The principle is to precipitate all magnetic particles by creating a strong magnetic field through a glass tube. A fibre optic bundle directs light at two locations where large (> 5 μm) and small particles are deposited by the magnet. The measure is obtained by a reduction of light, proportional to the quantity of particles captured. Two sets of readings are made: one for the large particles (L), one for the small particles (S). From these values, the following calculation can be made:

- Wear Particles Concentration (WPC) is derived by adding L+S, divided by the volume (V) of

$$\text{sample} \Rightarrow \frac{L+S}{V}$$

- Percentage of large Particles (PLP). When volume of sample is 1ml

- WPC = L+S and the PLP can be calculated as follows $\Rightarrow \text{PLP} = 100 \frac{L}{L+S}$

- Wear Severity Index $\Rightarrow \text{WSI} = \frac{L^2 + S^2}{V}$

3.2.13 Blotter Tests

There are a number of "Blotter" or "Patch" test methods which can be used to quickly reference the condition of used engine oil. They rely upon the relative density and film forming properties of the various constituents of the used lubricant. More specifically, as an oil ages and the dispersancy and detergency capabilities deteriorate, it is possible to detect these via the different types of pattern that are left behind.

A small quantity of used oil sample and the corresponding fresh oil is dropped onto a sheet of special filter paper and allowed to spread. For simple tests it is used purely for comparison. For the basic analysis the droplet will behave in a number of ways. Firstly the insolubles will separate from the oil thus allowing a basic comparison to be made. Quantification of this can be assessed by the trained

analyst but should not be quoted as there are no statistical qualitative or quantitative controls which apply in this regard.

For a more quantitative assessment of insolubles there is a more detailed analysis based upon a photometric measurement. After patch development is complete, the sheet is then transferred to a special photometer which has been adjusted to zero using the spot of the fresh oil. The absorbance of used oil spot is measured automatically over concentric zones. Absorbance in the central zone provides a measure of the amount of sooty insoluble material present in the used oil and the radial distribution of absorbance relates to the lubricant's dispersancy.

4 4-Stroke Diesel Engines: Interpretation of the characteristics of lubricating oil

Interpretation of the different characteristics of a lubricating oil sample is closely linked to the type of fuel burned by the engine namely distillate fuel, residual fuel, bio-fuel, gas or other.

The category of the engine - high or medium-speed (*) - has no great impact on the lubricating oil parameters which are routinely undertaken.

(*) By convention, Diesel engines running from around 300 Rpm up to approximately 1,200 rpm are called medium-speed engines.

The main difference between these two categories concerns the potential oil life duration:

- High speed engines are often drained on a regular basis (e.g. annually or after a predetermined period of service).
- Some medium-speed engine types do not require oil draining, except when the lubricating oil batch is accidentally polluted (e.g. by water or fuel) or it is considered to have degraded to a point where the analysis results indicate that the increased risk of damage is considered too high. Alternatively, for other engine types, replacement of the lubricating oil volume in whole or part may be advisory e.g. due to the small oil sump volume, low lubricating oil consumption or severe contamination.

In addition, the type of operation required of each engine, such as for base load or emergency generator operation or propulsive power and also the quality and performance of the lubricating oil treatment system (purification, separation and filtration) in use, will have an impact on the lubricating oil life.

4.1 Lubricating oil main characteristics

4.1.1 Viscosity

Viscosity is the most important property of lubricating oils. It determines not only the internal friction, but also the load carrying capability and the oil film thickness between bearing surfaces. Viscosity influences the bearing temperature, the oil quantity transported to the piston under crown for cooling and to the cylinder liners/piston rings. It also affects the oil's "spread-ability".

Viscosity of the lubricant in use varies in service, mainly due to contamination with soot produced by combustion of fuel and lubricating components, contamination with the fuel, oxidation, thermal degradation and water content.

Reasons for viscosity increase:

- **Low lubricating oil level.** This is of particular importance because of its impact on all other processes listed below. The lubricating oil volume should be kept at the level recommended by the engine manufacturer.
- **Oxidation.** This is a process that is very dependent on temperature, contamination and the availability of oxygen. It is aggravated when the lubricant is contaminated with raw fuel (e.g. containing unstable olefinic components). Furthermore, the catalytic activity of wear metals, such as copper and iron, can accelerate oxidation.
- **Nitration.** This occurs mainly due to high NO_x content of blow-by gases. This is more relevant to gas engine lubricating oil than diesel engine lubricating oil.
- **Sulphation.** Sulphation is inversely proportional to BN depletion and can be used to give an indication of the degree of degradation of the lubricant.
- **Contamination by residual fuel.** This occurs if coagulation of asphaltenes from residual fuel takes place within the lubricating oil in use and it is the main reason for viscosity increase of engines operating on heavy fuel oil (HFO).
- **Insolubles.** Significant increases of insolubles in used lubricating oil can result from poor combustion, faulty operation of purifiers, insufficient capacity of filters, and also ingress of sulphuric acid into the lubricating oil due to low cylinder liner temperature, poor mechanical condition of the engine, etc.
- **Soot.** Increase of sooty insolubles in the lubricating oil in use can be caused by high lubricating oil consumption that can lead to increased soot production from burnt lubricant in the combustion chamber. Also low-load operation in the engines equipped with conventional (jerk pump) fuel injection equipment can increase soot content in lubricating oil, since the combustion process is not so optimal due to low fuel injection pressures. Further, also worn fuel injection nozzles can result in increased soot content in used lubricating oil.
- **Water.** Contamination with water forming an emulsion will increase the lubricating oil viscosity.
- **Admixture with another lubricant.** Mixing with higher viscosity oil will cause an increase in the viscosity of the total oil charge.

Reasons for viscosity decrease:

Decrease in lubricant viscosity is potentially more harmful to the engine than an increase of viscosity. It will reduce lubricating oil film thickness with the risk of seizure, more particularly in bearings. The main cause of viscosity reduction is the dilution by light fuels, use of lower viscosity lubricating oil for topping up or by contamination with cleaning fluids.

4.1.2 BN (Base Number)

Typical depletion profiles for new oils are shown below. The BN of new lube oil drops sharply for a short while and then decreases more slowly to an equilibrium value. Thereafter, this equilibrium will continue indefinitely, provided the Sulphur content of the fuel and lubricating oil consumption remain stable.

If the alkalinity of the lube oil has dropped too much, there is a serious risk of corrosive wear of the cylinder liners, piston rings and bearings (anti-friction layer) as the oil has not enough potential to neutralise the sulphuric acid produced by fuel combustion. This neutralisation results in the formation of either calcium or magnesium sulphates (depending on the additive contained in the lube oil) which

inevitably become part of the insolubles carried by the lube oil when returning to the crankcase. The chart below shows that the rate of depletion in relation to operating hours and sulphur content

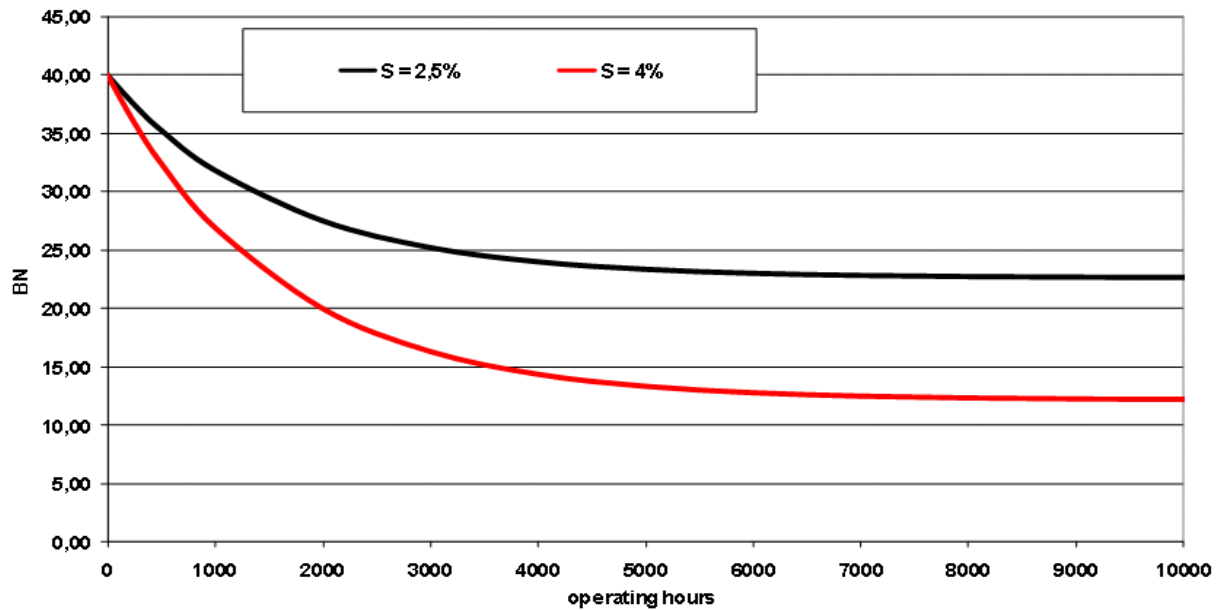


Figure 4: Typical BN depletion profiles

4.1.3 Water Content

Water affects the viscosity and lubricity of the lubricating oil and if not removed may form an emulsion with it. It is, therefore, desirable to keep the water content as low as possible by centrifuging (if installed). If the water content exceeds 0.2% (v/v), appropriate operation of the centrifuge should be carefully checked and if necessary adjusted to ensure optimum lubricating oil / water separation. In addition root causes of water contamination should be investigated and solved as soon as possible.

Some lubricants can form water-in-oil emulsions preventing the water from being removed by centrifuge alone. Such emulsion, if circulated, will reduce the load carrying capacity of the lubricating oil in bearings and may lead to failures. In some cases it is possible to drive off and thus reduce the water content by higher temperature purification at ~95°C, if this is not possible as a consequence, any emulsified lubricating oil should be replaced as soon as possible.

Alkaline and most other additives are sensitive to water content. If lubricating oil is contaminated by water, additive depletion could take place, which means, among other effects, a drop of BN. With water, additives form insolubles sludges which are disposed in the centrifuge. Used lubricating oils exhibit greater intolerance compared to the same lubricating oil when new.

Sea water is corrosive and potentially harmful. Whether corrosion will actually occur in the engine depends on a number of factors - for instance, how much salt is in the lubricating oil, how much water and strong acids are also present and whether the lubricating oil retains sufficient anti-corrosion performance capability.

4.1.4 Flash Point

A drop in the flash point normally indicates contamination of the lubricant by distillate fuel, although with residual fuel no significant change may be apparent. For guidance, it is advisable to check for fuel leakages when the flash point drops by 30°C or more.

A reduced Flash Point normally indicates that there is a fuel leakage into the lubrication system. A more precise test method for measuring fuel contamination in distillate fueled engine oil, which is commonly utilized in used oil analysis laboratories, is gas chromatography. However, in order to detect fuel leakages via the flash point, only results achieved with the same test method can be compared.

Crankcase Explosions

Temperature limits for safe/unsafe operation have been found unreliable because crankcase explosions have been reported where high flash points are measured. The current position is that two preconditions must exist for a crankcase explosion to occur

1. The presence of a flammable vapour atmosphere (ratio of oil droplet size to oxygen)
2. A heat source or "hot spot".

A hot spot can be a hot running bearing, a fire outside the engine or piston failure undetected by a defective or switched off oil mist detectors, etc.

4.1.5 Insolubles

The control of the insolubles level in used lubricating oil is important for satisfactory lubrication of an engine and long term engine reliability. It requires an integrated view of the engine, the lubricating oil quality being used, the used lubricating oil condition and the effectiveness of the lubricant maintenance system. This, in particular, is relevant in engines with low lubricating oil consumption and/or extended drain intervals.

A high insolubles result can occur for a number of different reasons. Although particles are included in the insolubles, the main fraction are contaminants and degradation products that are dissolved or dispersed in the oil and cannot be considered as particles. The content of insolubles is a composite parameter that reflects the degree of oil degradation and oil contamination.

Contaminants, as described above, can increase the viscosity of the lubricating oil and may lead to the formation of deposits on piston under-crowns and filters. Also, the heat transfer performance of lubricating oil coolers may be compromised.

4.1.6 Metallic Element Content

Additive Elements:

Ca, Si, Mg, P, Zn.

Their concentration can serve for the identification of the lubricant in use, or as an indicator that the lubricant analysed has been mixed or contaminated by another type of oil grade or brand.

Wear elements:

Al, Cr, Cu, Fe, Mo, Pb, Sb, Sn.

These may indicate wear of bearings, piston rings, cylinder liners and other engine components.

Component wear is directly influenced by the engine type i.e. the internal component technology, the mode of engine operation (speed, partial or full load profile, number of daily starts etc.).

Molybdenum (Mo) can also be an additive element contained within the lubricating oil and or cooling water. As a consequence limit values cannot be given.

The only way to appreciate the analysis results is to plot the different values and follow the trends using the same test method. A correct interpretation of the different metal contents can only be done if there is a significant historical feedback, either built up by the customer on similar engines or by the engine builder.

It has to be mentioned that the most often used method of metals analysis, ICP, is insensitive to particles above 5-7 μ m (see chapter 3.1.6).

Oil Contaminants:

Na, Ni, V, Al, Si, Cl, Mg, B, K.

K, Mg, B, Cl and Na derive from water based contaminants, condensate, sea water, coolant etc. Si may come from dust/sand (e.g. Aluminium Silicate) but is typically also contained in lubricating oil additives (anti-foam). V and Ni derive from fuel in case HFO is used. Na and K can derive from heavy fuel oil and diesel fuels containing biodiesel or can be present from additives used in the engine coolant.

4.2 Other lubricating oil characteristics

4.2.1 AN (Acid Number)

An increase in AN may indicate oxidation or contamination with some acidic products. Operation on bio-fuel can also increase the AN. Used lubricating oil, with a high AN, can be corrosive.

4.2.2 Oxidation

The higher the oxidation the more degraded the oil is and the poorer the lubricating properties. One measurable effect of oxidation is viscosity increase. Another can be an increase in acid number (AN).

4.2.3 Nitration

Nitration is caused by lubricating oil molecules reacting with nitrogen oxide. High nitration levels can result in additive depletion, viscosity increase and deposit formation.

This is particularly relevant for gas engines.

4.2.4 Sulphation

Sulphation is caused by the oxidation of sulphur compounds. Sulphation is inversely proportional to BN depletion and can be used to support the indication of degradation of the lubricant. Typically these compounds also increase the production of varnishes and sludges which degrade the performance of the lubricant.

4.2.5 Particle count

Hard particles are abrasive to engine components. Therefore the amount of particles, especially larger ones, should be kept at a minimum.

The amount and size of particles in the used oil sample can be used for investigation of the efficiency of lubricating oil treatment. It has to be mentioned that standard industry techniques for particle counting cannot be applied to darkly coloured engine oils.

4.2.6 VI (Viscosity Index)

When the VI of a used lubricating oil becomes significantly reduced the lubricating oil has probably deteriorated by mechanical shearing and/or thermal stress of the polymeric additives. This only applies to multi-grade oils containing VI improvers. However lubricating oil contamination with fuel can also decrease VI.

4.2.7 Sulphated ash

This value is only measured for fresh lubricating oils. It is relevant for gas engines where a high amount of ash can result in deposits causing misfiring of the engine.

4.2.8 Soot

There are several running conditions which will result in soot increase such as poor combustion (defective injection), lack of air (due to clogged air filter, defective supercharging), overloading, poor maintenance, etc.

An increase of soot also increases the viscosity of lubricating oil.

4.2.9 Asphaltenes

Asphaltenes are high molecular weight aromatic hydrocarbons present in residual fuel. In contact with the lubricant (which are typically paraffinic/aliphatic based), they can coagulate and form black sticky deposits on all metal surfaces of the engine. According to the situation, it may lead to oil scraper ring clogging and fuel injection pump blockage - for those equipped with oil sealing - and to piston under-crown deposits.

Asphaltenes content gives an indication on the proportion of fuel component present in used lubricating oil (i.e. fuel dilution) and can be related to viscosity increase of the latter.

4.2.10 PQ (Particles Quantifier) Index

PQ index is a good indicator of separator and filter efficiency (comparison upstream/downstream). It can also be used as a trend tool for wear conditions when measured on a regular basis.

4.2.11 Ferrography

With this method the particles dangerous to operation due to their size and hence their potential to increase the rate of wear can be determined and also to a certain extent their origin. It can be used to check the performance of the oil treatment system.

In case of engine damage it can provide useful information about the cause of the damage.

4.2.12 Ferrometry

As for PQ index, Ferrometry values are good indicators of separator and filter efficiency (comparison upstream/downstream). It can be also used as a trend tool for wear conditions when measuring it on a regular basis.

4.2.13 Blotter Test

This is a highly subjective analysis and as such no standards currently exist for the analysis of the patches. However, it has value as a very inexpensive and useful trending tool. The two main features are the amount of insolubles present and the condition of the dispersancy additive. If the oil is new, the patch will be uniform and exhibit no ring formation. As the oil ages then the patch will darken due to increased insoluble particulate, but may remain without rings due to the presence of sufficient dispersancy additive. As this additive weakens then rings start to form as the insolubles start to become less susceptible to the effects of the remaining dispersancy. However dispersancy characteristics will vary from a uniform light grey deposit where dispersancy is good to one of to a dark two phase deposit. At this point issues in future performance are of concern, because the deposits within the engine itself may not be able to be reabsorbed into the new charge or fresh top up. Other aspects that can be detected are fuel content, usually as a clear external ring and water which causes the insolubles to form uneven dropouts or spots.

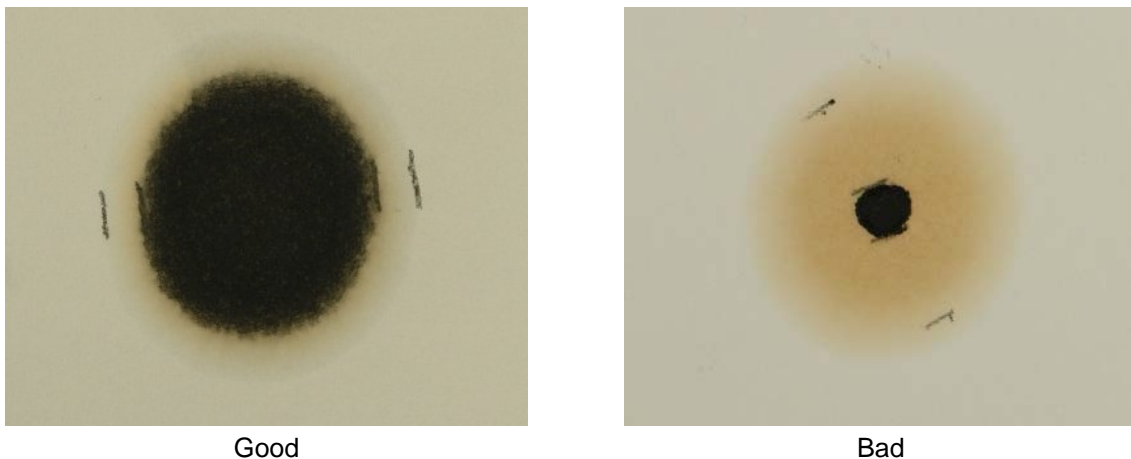


Figure 5: Example of a blotter test for a good and a bad oil sample

4.2.14 Limits for oil in use

Most OEM's have introduced their own specific oil test parameter limits and they publish action items and recommendations specific to these limits. As their recommendations are based on many years of successful operating experience they should always be used in the first instance to interpret the test oil's results.

Table 1 and 2 are intended for guidance only or in cases where limits are not available from the engine manufacturer themselves.

Table No.1 -

Typical limits for Mandatory Action for medium-speed engines

Extract from CIMAC Recommendation No. 29 “Guidelines for the lubrication of medium speed diesel engines” [2]

PROPERTY	METHOD	UNIT	PRECAUTIONARY ACTION	MANDATORY ACTION
Viscosity	ISO 3104	mm ² s ⁻¹ @ 40 °C	- 25% / + 25%	- 25% / + 45%
		mm ² s ⁻¹ @ 100 °C	- 15% / + 15%	- 20% / + 25%
Base Number	ISO 3771	mg KOH/g	-40%	-50%
Water content	ISO 3733	% v/v	> 0.2	> 0.4
Flash point	ISO 2719	°C	< 190	< 170
n-pentane insolubles	ASTM D 893B	% m/m	> 1.5	> 2.0

Table No. 2 -

Typical limits for used oil analyses for high-speed engines

Extract from CIMAC Recommendation No. 20 “Lubrication of large high speed diesel engines” [6]

Property	Method	Advisory	Mandatory
Viscosity 40 °C	ISO 3104	-20% / +25%	-25% / +30%
Viscosity 100 °C	ISO 3104	-20% / +20%	-25% / +25%
Flash point, PMCC, °C	ISO 2719	< 190	< 180
Total insolubles, %m	IP 316	2.0 - 3.0	> 3.0
BN, mg KOH/g	ISO 3771	< 60% of fresh oil	< 50% of fresh oil
TAN, mg KOH/g	ASTM D 664	> new oil + 1.5	> new oil + 3
Water, %v/v	ISO 3733	> 0.2	> 0.3
Oxidation, abs/cm	FTIR	> 15	> 25
Nitration, abs/cm	FTIR	> 15	> 25
Wear elements [mg/kg]	ASTM D 5185 (ICP-PES)	OEM to advise on elements and limits	OEM to advise on elements and limits

5 2-stroke diesel engines: Interpretation of the characteristics of lubricating oil

5.1 Introduction

In the two-stroke diesel engine, the combustion chamber is separated from the crankcase by a stuffing box, which acts as a seal between the crankcase and the under piston space.

The piston/ring/liner interface is lubricated by **cylinder oil** which has the following capabilities:

- Neutralisation
- Detergency
- Providing an oil film

The cylinder oil is a single use product that is not recycled within the system. The oil is injected at intervals appropriate to the lubrication needs of the engine and is scraped down so any excess oil remaining is collected in the scavenge drain. A mixture of used cylinder oil, combustion products and wear particles is formed in the scavenge space above the stuffing box. Where the stuffing box is not completely sealing off the crankcase-piston interface, (which is normal), this mixture can then contaminate the system oil in the crankcase. Conversely, some system oil can pass into to the scavenge space via the stuffing box.

Analysis of the scavenge space drain oil gives an indication of the cylinder condition as sudden changes in the wear metals can be a sign of abnormal wear taking place and as a witness to combustion the drain oil can yield useful information if the results of analysis are considered against the wider effects of dilution and contamination with other materials present.

The **system oil** has a variety of functions:

- Lubrication of bearing, camshaft driving gear and turbocharger
- Piston cooling and crank case cleanliness
- Serves as hydraulic oil in electronically controlled engines
- Operation of exhaust valve and torsional / axial damper

The system oil is refreshed by topping up and only on rare occasions will the entire sump need replacement. It follows that contamination of the system oil will gradually increase until equilibrium between the rate of contamination and topping up has been established.

Analysis of the system oil will give an indication of the system oil condition but also the general condition of the areas that the system oil is in contact with can be monitored through analysis.

Due to the size of sump volumes of marine 2-stroke system oils, the dilution of normal wear debris will be significant therefore modest changes in the levels of wear materials will need to be investigated to establish what is normal and what is not. Oil contaminants such as water and insolubles must be monitored closely and if indicated, purification parameters such as flow rate and temperature may require periodic adjustment to ensure that contaminants are kept at a minimum.

5.2 Scavenge drain oil

Many factors influence the metal and physio-chemical (e.g. BN and viscosity) characteristics of scavenge drain oil. Some of these factors are fuel sulphur level, cylinder oil BN and dosage, system oil contamination, operating profile etc. For this reason interpretation of scavenge drain oil analyses may be difficult for the untrained eye. Most major oil companies and some independent companies offer scavenge drain oil analysis and evaluation of the results.

It cannot be stated how much care must be taken when assessing scavenge drain oil as the potential for misinterpretation is significant. It is not possible to accurately compare these results, as without knowledge of dilution/contamination the oil collected in the scavenge drain has many unknowns. Unless some extensive form of dilution correction is undertaken based upon knowledge of the fuel oil, new and used system oil, feed rates and operational data collected from the engine at the time of sampling, use as a routine condition monitoring tool is limited to the measurement of significant changes issues such as high iron, water or BN change. Whilst these are useful care in interpretation must be exerted.

The most reliable results are obtained by lab measurements as this will give the most accurate analysis results. However, various onboard test equipment (most of these perform iron debris measurements only) are available on the market and have the benefit of providing instant results although equipment available for onboard analyses also has its deficiencies. Some do not measure iron originating from corrosion and the results could therefore give a false indication of the cylinder condition, for instance the iron level can look normal while the cylinders are suffering from acid attack. One of the key benefits of being able to test onboard is the frequency of sampling. For instance, scuffing is a wear process that usually occurs over a very short period of time, therefore routine - say 3 monthly analysis - is not an ideal choice as a protective device, as such a failure has a short duration between the point at which the failure is detectable and the point at which the failure occurs.

As with all oil analysis, when using scavenge drain oil as a tool it should be remembered that this is a trending tool only. The analysis of one single sample does not give sufficient indication of the actual cylinder condition as each engine will have its own baseline level of metals. As such, it is necessary to monitor the drain oil for a period to establish this baseline before full benefit can be achieved from these analyses.

Sudden changes in the analysis results might call for a closer investigation and this can potentially lead to the identification of minor scuffing incidents. However, due to the many influencing factors, experience is needed for a good interpretation of the data. Therefore, scavenge drain oil analysis should be conducted in parallel with scavenge port inspections to check the general engine condition.

BN (Base Number)

The BN of the drain oil is influenced by the fuel sulphur level, the cylinder oil BN and the cylinder oil feed rate. The higher the fuel sulphur level, the more sulphuric acid is formed during combustion. The acid formed condenses on the liner surface and the basicity (expressed as BN) provided by the cylinder oil will neutralize the acid.

From this it follows that the lower the fuel sulphur level and/or the higher the cylinder oil BN and feed rate, the higher the drain oil BN. Optimisation of the demand for neutralisation and the demand for the appropriate fluid film forming capability is a constant challenge for the engineer as the sulphur content of the fuel varies for each bunker and for differing areas of operation. With a fixed BN for the cylinder oil neutralisation demand can be met by adjusting the feed rate, however the required oil film properties are proportional to engine operation, therefore the best solution will likely be a compromise of some sorts.

Iron

Iron in Scavenge Drain Oil will usually be present as wear particles originating primarily from the cylinder liner and piston rings. It is influenced by the fuel composition and cleaning (wear particles such as cat fines), the fuel sulphur level (as corrosive acids formed during combustion), cylinder oil BN and feed rate (neutralization of acids).

Sudden increases in the baseline iron level may indicate increased liner and/or piston ring wear and call for further investigation.

Water

Water in the drain oil originates primarily from the scavenge air and thereby the ambient air. The amount of water in drain oil is typically below 1% although variations are widely seen.

Metals

Several metals are used in alloys of the various engine components. Sudden increases in these metals may indicate abnormal wear; however, the influencing factors are complicated due to the interactions between these factors. Interpretation of the resulting trends for the various metals is best done based on experience.

5.3 System oil

The system oil is continuously contaminated through the stuffing box by scavenge drain oil. Through topping-up with fresh system oil, a balance will be kept ensuring that the system oil maintains the correct properties. The system oil is cleaned by settling, filtering and centrifuging which to some extent will remove particles/impurities from the oil [7].

System oil should be analysed on a routine basis to ensure that its optimum condition is maintained.

BN (Base Number)

The BN of a fresh system oil is generally low (below 10 mg KOH/g) but the contamination by scavenge drain oil will lead to a BN increase. The system oil topping-up helps to balance this change and BN levels of 15-20 mg KOH/g are observed on average.

High BN levels may result in water separation problems for which reason the OEMs have a caution limit of BN 25, and recommend to replace a portion of the system oil at a BN level of 30.

Viscosity

The kinematic viscosity reflects the condition of the lubricant. A progressive increase can represent an indication of degradation of the lubricant.

Scavenge drain oil contamination contributes to a viscosity increase as cylinder oils are SAE 50 grade lubricants, while system oils are generally SAE 30 grade lubricants. As an example, kinematic viscosities of 160 to 180 mm²/s at 40°C can be considered as caution limits for SAE 30 grade lubricants.

Water

The water content has to be low to avoid bearing damage (displacement of the oil film by free water droplets) and can lead to an emulsification of the lubricant, which can cause cavitation inside engine bearings. It is commonly agreed to avoid water contents of more than 0.2%. High water content may also lead to corrosive attack on the bearings.

Unless emulsified into the system oil, centrifugation of the system oil will remove the water. As system oil is usually only analysed a few times a year, short periods of water contamination might never be discovered unless they result in bearing damage. For this reason, some engine manufacturers recommend to use online water analysis equipment.

Apart from a direct analytical determination of the water content, the measurement of chloride and of sodium also can give an indication of water contamination. (Note: the industry has recently recognized the need for standardization of the water determination of lubricants. This is currently being discussed by CIMAC and CEC working groups).

Metals

The metals content is an important parameter to follow as it shows, for example, the wear pattern of the bearings. This can be observed by checking soft metals such as copper, lead, tin, silver or molybdenum.

Fuel

Fuel might leak into the system oil through the stuffing box or through the leakages in the fuel pump. Indications of fuel contamination can be obtained by looking at vanadium and/or nickel levels, however, as both vanadium and nickel are present in the scavenge drain oil as combustion products, these components can only be used as rough indicators of fuel contamination. Asphaltenes give a better indication of fuel contamination.

Insolubles

The insolubles content is showing the efficiency of the purifier operation.

Table 3 is intended for guidance only or in case limits from the engine manufacturer are not available.

This table has been created based on the CIMAC recommendation no. 15 [8] considering latest modifications suggested by engine manufacturers.

PROPERTY	METHOD	UNIT	MANDATORY ACTION
Viscosity @ 100 °C	ISO 3104	mm ² s ⁻¹	max. 3.0 mm ² s ⁻¹ decrease
			max. 3.5 mm ² s ⁻¹ increase
Acid Number	ASTM D664	mg KOH/g	max. 2.0 mg KOH/g increase
Base Number	ISO 3771 / ASTM D2896	mg KOH/g	min. 3.0
			max. 30
Water Content	ISO 3733 / ASTM D1744	% v/v	max. 0.2
Flash Point	ISO 2719 / ASTM D3828	° C	min. 180
n-pentane and toluene insolubles	ASTM D893B	% m/m	max. 1.5

Table No. 3 - Limits for system oil in use

6 On-Line Condition Monitoring

Removal of an oil sample from equipment and evaluating its test parameters outside of the equipment is the most commonly adopted practice for establishing oil condition; a growing number of alternative technologies are now also emerging that permit some in-situ testing of oil condition – the ‘on-line’ evaluation of oil within its own operating environment. Currently the capabilities of on-line condition monitoring are limited to certain oil condition parameters and so whilst it can assist with standard testing practice it should not yet be viewed as a total replacement for it.

With the rapid developments being made within this field of technology it is not practical to provide a reference listing of the many different on-line sensor & equipment devices available. Instead this chapter explores the many aspects of using on-line condition monitoring, encompassing practical considerations, benefits & also potential problem areas that can be encountered when adopting it.

6.1 Background

The management of modern machinery requires engineering staff to identify and manage risks. Modern engines are equipped with a great many systems and devices to enable the engineer to do this, however it is only relatively recently that reliable oil parameter sensors have been seen in the market.

The demands for the observation of changes in real time, in order to be able to manage any increased risk, and the potential for cost improvement over the life of the installation, are the driving factors behind the move towards oil sensors.

Oil based condition monitoring using samples taken for analysis, suffers significantly from delays in transit and turnaround time, as a result this is becoming more and more unacceptable in the modern engineering environment.

6.2 Sensor Categories

What the engineer must know is the range of capability within which any sensor, or indeed sensor array, can operate accurately in order to programme in a specific response.

Sensor capability can be broken down into three categories:

1. Oil condition variables
2. Oil contaminant variables
3. Machinery wear debris variables

Oil condition variables: deterioration or change in the basic properties of the oil itself – e.g. changes in viscosity, reserve alkalinity, oxidation, nitration, additive levels.

Oil contaminant variables: externally generated contaminants - e.g. water, fuel, soot, abrasives and acids.

Machinery wear debris variables: internally generated debris - e.g. from gears, bearings, shafts, liners, rings, seals.

Alarms based upon rates of change, in addition to upper and lower limits, would ideally be considered for each individual installation.

Any specific sensor or sensor array might respond to changes in data within each of the above groups, however each signal must be separately identified.

6.3 Considerations

For any engine, the two most important aspects of oil condition and functional capability are its viscosity and reserve alkalinity. This applies especially to trunk piston engines where un-burned fuel and acidic combustion by-products can contaminate the oil.

The most likely contaminants are water from cooling jackets; scavenge air and general condensation, abrasive insolubles from un-burned fuel contaminants and in certain cases raw fuel from leaking injectors or fuel pump seals.

Wear debris will most likely originate from the ring/liner interface, various bearings, push rods and valves etc. The nature of this wear will normally be harmless, within normal limits, and the rate will be stable.

Any changes to normal equilibrium may forewarn a failure. Such failures could be very significant like a loss of propulsion, or relatively minor like a malfunction in an oil purification unit.

It is therefore important to select sensors that will detect significant changes in these failure indicators, such that real and effective responses can be carried out.

What should not happen is that sensors generate alarms when there is no risk. This can be the case if, for example, the variable being measured is not appropriate, or alarms have been incorrectly configured.

6.4 Sensor Technologies

There are numerous technologies available to indicate a change in oil condition; however care must be taken when making a selection as very often the output is not absolute. The sensor output may be in units which are not scientifically accepted.

For instance, there are sensors available which measure the change in dielectric constant via the use of a dual capacitance transducer. As the dielectric constant will vary due to such parameters as the presence of water, oil oxidation, and acidity, it is not possible to determine which variable is affecting the total signal value without further analysis.

6.4.1 Common sensors for water content

Water content can be measured in two ways – either as an absolute value (percent or ppm), or as the degree of maximum water saturation possible within the oil (the water activity). Different oil types have different saturation point and this point will change with temperature, relative humidity, contamination and oil ageing. These contamination and oil ageing effects may not necessarily render the method inaccurate, but they will have to be considered when developing a sensor based water analysing system.

6.4.2 Viscosity

Viscosity can be measured by using resonance meters or automatic capillary viscosity sensors. Temperature needs to be incorporated into algorithms for the viscosity variation.

6.4.3 Infrared Absorption Sensors

Discreet Attenuated Total Reflectance (ATR) Infrared sensors set at the required frequency, can detect water, soot, glycol, oxidation, sulphation, nitration and one typical additive from the lubricant, the zinc dialkyldithiophosphate (ZDDP).

6.4.4 Ferrous Debris Detectors

Most ferrous debris monitors work by measuring the modification of an inductive magnetic field that occurs when iron metal particles are present. Some iron oxides (e.g. magnetite, Fe_3O_4) can also be detected, but iron sulphate due to acid corrosion cannot. These are all key states of iron-containing contaminants in used engine oils.

Nickel metal (zero oxidation state) could be detected by such a monitor, however nickel from fuel (2+ oxidation state) that gets into the used oil cannot. The vast majority of the nickel in used oils is due to the latter case.

As the mass of the particle is directly proportional to its effect on the magnetic field, the degree of effect can be indicated. Various additional algorithms can be used to reduce errors and deduce a quantitative assessment, however these are open to scrutiny. That said, when used for trend analysis they can be useful, though the relationship between the particle mass and its residence time within the field of measurement will have an effect upon accuracy, and hence the flow rate across the sensor is critical and must also be known.

6.4.5 Oil Condition Sensors

Oil condition sensors do not measure any specific variable and are in reality capacitance or dielectric constant tools. They are however used as a first line of defence and will signal change when either water, oxidation or acidity changes occur. These have been developed primarily for the automotive sector as a means of improving the engine management protocol to alert the driver of the most appropriate servicing interval.

6.4.6 Selection Criteria

When making a decision to utilise a sensor to monitor oil or machinery condition, it is vital to ensure that the variable measured is a known pre-determination or a symptom of a known failure mode. In addition, detection should be within a sufficient time-frame to allow for a remedial action to be taken to reduce, remove or manage the increased risk. Oil sensors should be backed up with conventional oil analysis until confidence can be assured.

7 On site test kits

7.1 General

Monitoring the condition of a lubricant in-situ by the equipment operators provides an extremely cost effective and quick method of checking the oil condition. These in-situ checks can quickly confirm whether the oil is continuing to provide the optimum protection to the engine, or, if the oil is prematurely reaching the end of its lifetime. In this way they can alert equipment operator to potential problems within the oil systems. In this way on-site test kits identify potential problems before they become serious problems and can help decide if further more elaborate and accurate investigations (using an external laboratory) are required to investigate specific problems. In certain cases these test kits can identify the likely cause of a problem and result in greater engine reliability as the necessary corrective action can immediately be taken.

Test kits comprise of a boxed set of all the necessary reagents and solutions required to conduct the specific tests on the oil. The test kits can also include the necessary basic equipment used to both extract the oil samples with and the containers in which to perform the testing. The number of tests and the sophistication of the tests vary according to the specific test kit supplier.

7.2 Limitations of On-site Test Kits

The testing of oil using simple on-site test kits although clearly providing a useful and quick method for conducting routine evaluations in engines, should not be used as a replacement for the full laboratory analyses that are carried out as part of the full oil maintenance programme. Although it offers a faster and cheaper alternative to conducting a laboratory analysis the results are also less sophisticated and also less precise.

7.3 Oil Test Parameters

The following 5 test types represent the main oil test parameters (oil characteristics) typically used to verify the oil's condition:

- Viscosity
- Water Content
- Sea water Detection
- Alkalinity (Base Number)
- Insoluble Matter (Contamination)

7.4 Test Equipment Units

Various companies also now offer more specialised elaborate testing units, several of which have been developed in co-operation with Engine Manufacturers & Oil Marketers. Care has been made to maximise the automation of this equipment so that the equipment, although very specialised, is simple to operate and simple to interpret the results it gives - i.e. to understand what actions are necessary to take. This has been achieved so the equipment can be operated by the equipment operator without the need for specialised training.

OIL TEST PARAMETER	EQUIPMENT/TEST NAME	PRINCIPLE OF MEASUREMENT
Viscosity	Viscometer	kinematic viscosity measurement
	Inclined plate	visual comparison between fresh and used oil, go & no-go
Water	Crackle test	heat oil and it makes a 'crackle' noise if water present
	Pressure Measurement	a chemical reaction test, with pressure increase measured which is proportional to water content
Sea water	Colour indicator	a colour change of the stick or plate indicates presence of chloride ion from sea salt
Base Number	Pressure Measurement	The pressure increase due to a chemical reaction, proportional to the BN base number (Alkalinity) of the oil is measured
Contamination	Spot Test / Blotter Test	Oil Spot Test on filter paper

8 References

- [1] CEC M-12-T-91 "Representative sampling in-service of marine lubricants"
- [2] CIMAC paper no. 61, congress Vienna 2007
- [3] CIMAC Recommendation No. 29 "Guidelines for the lubrication of medium speed diesel engines 2nd update version 2008"
- [4] CEC test method L-94-10
- [5] Diesel+Gas Turbine Worldwide, June 2006, page 40
- [6] CIMAC Recommendation No. 20 "Guidelines for diesel engines lubrication - Lubrication of large high speed diesel engines, 2002"
- [7] CIMAC Recommendation No. 24 "Treatment of the System Oil in Medium Speed and Crosshead Diesel Engine Installations, 2005"
- [8] CIMAC Recommendation No. 15 "Guidelines for the Lubrication of two-stroke Crosshead Diesel Engines, 1997"

9 Appendix: Acknowledgement, Membership & Disclaimer

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Other CIMAC recommendations

(available in the CIMAC Technical Paper Database)

- No. 1 Recommendations for Diesel Engine Acceptance Tests, 1968
- No. 2 Recommendations for Gas Turbine Acceptance Test, 1968
- No. 3 Recommendations of Measurement for the Overall Noise of Reciprocating Engines, 1970
- No. 4 Recommendations for SI Units for Diesel Engines and Gas Turbines, 1975
- No. 5 Recommendations for Supercharged Diesel Engines, 1971
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- No. 8 Recommendations regarding Requirements for Heavy Fuels for Diesel Engines, 1986 (superseded by No. 11)
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- No. 13 Guidelines for the Lubrication of Medium Speed Diesel Engines, 1994
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- No. 15 Guidelines for the Lubrication of two-stroke Crosshead Diesel Engines, 1997
- No. 16 Guidelines for operation and/or maintenance contracts, 1999
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- No. 29 Guidelines for the Lubrication of Medium Speed Diesel Engines - 2nd updated version, 2008 (supersedes CIMAC Recommendation No. 13)

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