CIMAC
INTERNATIONAL COUNCIL
ON COMBUSTION ENGINES

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# CIMAC Guideline

## Used engine oil analysis

# Content

# 1 Reasons for doing used oil analysis

The key reason for doing USED OIL ANALYSIS (UOA) is to ensure machinery condition is effectively monitored over time thereby avoiding expensive machinery failures. Machinery failures at sea can be disastrous and USED OIL ANALYSIS is critical tool in helping ensure machinery provides continuous reliable service. USED OIL ANALYSIS can be likened to a health check for machinery. It allows early detection of wear and the condition of the lubricant and its suitability for continued service.

Oil analysis can monitor equipment condition before damage occurs. This includes the ability to monitor lubricant condition and the presence of contaminants and moisture. A huge benefit of oil analysis is to detect problems in both the oil and the machine. The many benefits of routine used oil analysis include:

- Longer equipment life. Oil analysis ensures machinery is being optimally lubricated while also monitoring issues such as wear and contamination
- Extend lubricant life. Oil analysis yields a clear picture of the condition of the lubricant so that it does not have to be changed prematurely
- Reduce equipment downtime. Oil analysis gives maintenance personnel the opportunity to detect and correct issues before a failure or breakdown occurs, thereby reducing the potential for serious disruptions in operations

# 2 What, when, and how to sample

The following table lists typical ship board equipment that can benefit from Used Oil Analysis monitoring:

Table 1: Marine Applications for UOA

| **Typical marine application for Used Oil Analysis** | |
|---|---|
| Main Engines | Purifiers |
| Auxiliary engines | Reduction Gears |
| Cam shaft systems | Slow-speed engines system oil |
| Compressors (air/refrigeration/cargo) | Steering gear hydraulic gears |
| Deck gear drives | Control Pitch Propeller (CPP) System |
| Deck hydraulics | Thrusters |
| Gas Turbines | Stern tube |
| Thermal Oil system | |

**NOTE: The scope of this paper is limited to Used Engine Oil Analysis**

## 2.1 When to sample

The goal of sample frequency is to achieve a regular pattern of sampling. This establishes a credible historical trend of machine and oil performance.
• Follow OEM-recommended sample intervals for your equipment.
• Follow classification societies' guidelines, such as DNV, Lloyd's Register and ABS.
• In the absence of OEM guidelines, refer to the recommendations below for general guidance in establishing initial sample frequency.

- Low Speed Engine system oil…. (1000 to 2000 hours)
- Low Speed Engine scrape down oil…. after reaching high load, after every fuel change, and after changing oil feed rate setting. Refer to OEM recommendation
- Medium Speed Engine….. (500 to 1000 hours).
- High Speed Engine….. (250 to 500 hours)

## 2.2 How to sample

Each sample has to be representative.

To obtain accurate analysis:

- Always flush sampling point before taking sample.
- Sample at consistent intervals from the correct sample location using proper sampling techniques[1]. In addition, periodic sampling should be done from the same location and in the same procedure.
- Sample at operating temperature through a sampling valve, vacuum pump or sampling tube. Be safe, use caution when oil is above 120°F (50°C). Use protective gear recommended in the Safety Data Sheet for the lubricant.
- Use clean sample bottles and sampling point. The sampling should be carried out in a clean environment and the bottle should be sealed and labelled immediately after filling.
- Record equipment and sample details. Document this data to improve interpretation and establish an analysis trend.
- Obtain fresh oil sample for a baseline
- Drain and fill sample must be taken

# 3 Interpretation of results and actions to take

Interpreting the results from Used Oil Analysis is key. The following sections provide guidance with respect to different machinery types.

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[1] Refer to CIMAC Recommendation 30 for details of sampling best practices.
Refer to OEM literature for recommended sample points, frequency, and technique.

## 3.1 4-stroke engine – used engine oil analysis

Interpretation of the used oil analysis is closely linked to the following variables:

- Type of fuel burned by the engine, namely, E.g. distillate fuel, residual fuel, bio-fuel, gas or other.
- The quality and performance of the lubricating oil and it’s treatment system (purification, separation – temperature setting, and filtration – absolute mesh size)
- Engine design, for example, the following conditions increase oil stress… increased firing pressure, increased engine or oil temperature, reduced oil capacity and low oil consumption.
- Operating variables such as how long oil has been in service, high or low load engine operation.

The following table is a guide showing suggested parameters to measure in 4-Stroke Engine Oil Analysis and a brief interpretation of the results.

Table 2: 4 Stroke Engine Oil Analysis Interpretation

| **Parameter** | **Change** | **Possible Reason** | **Potential Risk** |
|---|---|---|---|
| ***Primary*** | | | |
| Viscosity | Increase | Residual fuel ingress<br>Asphaltenes<br>Oil ageing / Oxidation<br>Contamination<br>Additive degradation<br>Inadequate purifier operation<br>High soot<br>Incorrect oil grade used<br>Emulsion (water) | Increase in friction<br>Temperature rise<br>Bearing damages<br>Deposits |
| Viscosity | Decrease | Distillate fuel dilution<br>Oil shear<br>Incorrect oil grade used | Bearing damages |
| BN | Increase | Top up with high BN oil | Increased piston top land and exhaust valve deposits |
| BN | Decrease | High Sulphur fuel impact<br>(Neutralizing acids) | Cylinder component corrosion<br>Deposits |
| Water Content | Increase | Cooling water leakage<br>Condensation<br>Incorrect purifier setting | Corrosion<br>Bearing damage<br>Sludge deposits |

| | | | |
|---|---|---|---|
| | | | Filter blockage |
| Flash Point | Decrease | Distillate fuel dilution | Reduction in viscosity bearing damage |
| Insolubles | Increase | Residual fuel ingress<br>Asphaltenes<br>Oil ageing / Oxidation<br>Contamination<br>Wear debris<br>Extended oil drain interval<br>Inadequate purifier operation | Viscosity increase causing increased friction<br>Bearing damage<br>Accelerated Wear<br>Filter blockage<br>Deposits<br>Formation of sludge |
| ***More Detail*** | | | |
| Soot | Increase | Poor combustion<br>Oil ageing<br>Insufficient purification or filtration | Increased engine wear<br>Deposits or sludge |
| Asphaltenes | Increase | Combustion residue (residual fuels)<br>Residual fuel leakage | Deposits<br>Sludge formation<br>Viscosity increase |
| Oxidation | Increase | Oil ageing<br>Overheating<br>Blow by | Viscosity increase<br>Deposits<br>BN reduction<br>Insoluble increase<br>Oil filter blockage<br>Corrosion of metal parts and increased component wear |
| Nitration | Increase | High temperature NOx production and reaction with oil | Viscosity increase and deposits |
| TAN | Increase | Oil ageing<br>Oil oxidation<br>Contamination | Accelerated oil ageing<br>Corrosion of metallic components<br>Additive depletion<br>Viscosity increase |
| Wear elements *<br>Fe, Cr, Al, Pb, Sn, Cu | Increase | Wear of bearings, piston rings, cylinder liners | Damage to respective engine components depending on the wear elements found |

| | | | |
|---|---|---|---|
| | | and other engine components | |
| Common additive elements<br>Ca, Si, P, Zn, Mg | Decrease | Some consumption of additives is acceptable<br>Dilution with incorrect oil grade | Only for trending |
| Contamination **<br>Na, Ni, V, Al, Si, Cl, Mg, B, K | Increase | Sea water ingress<br>Cooling water ingress<br>Fuel ingress | Only for trending |

* Trending the oil analysis results with historical data is a very effective way of interpreting the results. For example, minor presence of Fe or Cu may not be a cause of concern if the presence is consistent with the history of previous analyses.

** K, Mg, B, Cl and Na derive from water-based contaminants, condensate, sea water, coolant etc. Si may come from dust/sand (e.g. Aluminum Silicate) but is typically also contained in lubricating oil additives (anti-foam). Presence of V and Ni are derived from residual fuel and is indicative of fuel oil contamination. 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.

NOTE: It's the trend in the above measurements that is most important. Any change in trend has to be investigated. Failure to do this investigation completely negates the value of used oil analysis.

*The above guide is just a brief summary. For more detailed information on 4-stroke engine oil analysis and interpretation, see CIMAC Recommendation 29 for medium speed engines and CIMAC Recommendation 20 for high-speed engines.*

## 3.2 2-stroke engine – used system oil analysis

System oils provide the following functions: bearing lubrication, piston cooling, gear lubrication, and serve as a hydraulic fluid.

System oils should not form an emulsion because this will prevent the centrifuge from removing water.

Performance of the lubricating oil treatment system (purification, separation, and filtration) will have a big impact on the suitability of the lubricating oil.

Issues that deteriorate system oil performance include: High leakage of scrape down oil through piston rod stuffing box, water contamination, and contamination with fuel.
*More detailed information on system oil analysis and interpretation can be found in CIMAC Recommendations 30 and 31.*

The following table is a guide to which parameters to measure in 2-Stroke System Oil Analysis and a brief interpretation of the results

Table 3: Two Stroke Engine Oil Analysis Interpretation

| **Parameter** | **Change** | **Possible Reason** | **Potential Risk** |
|---|---|---|---|
| ***Primary*** | | | |
| Viscosity | Increase | Stuffing Box leakage<br>Oil ageing / Oxidation<br>Residual fuel contamination<br>Inadequate purifier operation<br>Incorrect oil grade used | Increased bearing friction<br>Deposits (piston cooling space, bearings) |
| | Decrease | Stuffing box leakage<br>Distillate fuel contamination | Bearing failure |
| BN | Increase | Stuffing box leakage<br>Different oil grade added | Impacts water separation |
| BN | Decrease | Incorrect oil grade used | Corrosion<br>Crankcase deposits |
| Water Content | Increase | Cooling water leakage<br>Water ingress (FW/SW)<br>Condensation<br>Inadequate purifier operation | Corrosion<br>Acid formation<br>Reduce additive effectiveness<br>Bearing damage<br>Sludge deposits<br>Hydraulic system failure<br>Filter blockage |
| Flash Point | Decrease | Distillate fuel dilution from leaky fuel pumps | Viscosity decrease<br>Poor lubrication<br>Crankcase explosion |
| Insolubles | Increase | Residual fuel ingress<br>Wear debris<br>Oil degradation<br>Inadequate purifier operation | Viscosity increase<br>Accelerated wear<br>Filter blockage<br>Deposits<br>Sludge |
| ***More Detail*** | | | |

| | | | |
|---|---|---|---|
| Particle Count | Increase | Stuffing box seal leakage<br>Wrong/incorrect sampling procedure/location<br>Inadequate purification<br>Wear particles<br>Fuel contamination<br>Fresh oil top up | Increased wear of bearings, etc.<br>Damage to hydraulic system components |
| *Wear elements<br>Fe, Cr, Al, Pb, Sn, Cu | Increase | Wear of bearings, journals, gears, stuffing boxes, and other engine components | Look for wear of respective engine components based on trend analysis for wear elements |
| **Common additive elements<br>Ca, Si, P, Zn, B, Mg | Decrease or Increase | Different oil added<br>Stuffing box leakage<br>Extended oil usage causes depletion<br>Inadequate purifier operation | Follow trends. The additives are used to enhance oil properties such as anti-wear, corrosion inhibiter, detergent, rust inhibitor, anti-friction, and antioxidants |
| **Contamination<br>Ni, V, Na, K, Mg, B, Cl | Increase | Sea water ingress<br>Cooling water ingress<br>Fuel ingress | Follow trend |

* Trending the oil analysis results with historical data is a very effective way of interpreting the results. For example, minor presence of Fe or Cu may not be a cause of concern if the presence is consistent with the history of previous analyses.

** K, Mg, B, Cl and Na derive from water-based contaminants, condensate, sea water, coolant etc. Si may come from dust/sand (e.g. Aluminum Silicate) but is typically also contained in lubricating oil additives (anti-foam). Presence of V and Ni are derived from residual fuel and is indicative of fuel oil contamination. 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.

NOTE: **It’s the trend in the above measurements that is most important.** Any change in trend has to be investigated. Failure to do this investigation completely negates the value of used oil analysis.

Best practice involves establishing a historical baseline and watching for a significant change or trend. Plotting the results is the best way to see changes and gauge their significance. A correct interpretation is based on your historical database or the recommendations of the engine builder.

## 3.3 2-stroke engine – scrape down oil analysis

The following table is a guide to which parameters to measure in 2-Stroke Scrape-Down Oil Analysis and a brief interpretation of the results

Table 4: 2 stroke engine scrape down oil sample interpretation

| **Parameter** | **Change** | **Possible Reason** | **Potential Risk** |
|---|---|---|---|
| ***Primary*** | | | |
| BN | Too Low | Cylinder oil BN or feed rate too low for fuel sulfur content | Cold corrosion/wear<br>Increased ring land and pack deposits |
| | Too high | Cylinder oil BN or feed rate too high for fuel sulfur content | Increased piston top land and crown deposits<br>Possible liner polish<br>Possible scuffing<br>Deposits on Exhaust systems |
| Water Content | Increase | Inefficient water catchers<br>Cooling water leakage | Corrosive wear |
| Wear elements<br>Fe, total iron | Over OEM limit | Corrosive and mechanical wear of rings and liner<br>Low cylinder oil feed rate | Abnormally high wear<br>See notes below* |
| Fe, metal particles | Increase | Mechanical wear of rings and liner<br>Low cylinder oil feed rate | Abnormally high wear<br>See notes below* |
| Cr, Mo, Cu, Al, Si, Va | Increase | Stuffing box wear<br>Ring wear<br>Wear of piston skirt<br>Cat fines from fuel<br>Poor combustion | Abnormally high wear |

* Concentration of ferrous iron in the scrape down oil is indicative of engine liner wear due to abrasion. The level of iron salts in the sample is an indication of engine liner wear due to corrosion.

Scrape Down oil sample composition can vary greatly from cylinder-to-cylinder and over time. As a result, a database of many past samples is required before you can interpret present results. Expect changes in fuel Sulphur level and load to have big effects.

A Sweep Test or Piston Underside Drain Oil Analysis Test should be carried out to optimize the cylinder oil feed rate based on the iron and BN levels. Refer to individual OEM latest guidelines for details of method.

Obtaining a representative sample is key criteria for attaining correct analysis and interpretation.

*[Reference: Study of the relationship between cylinder lubricant drain condition and performance parameters of 2-stroke cross-head engines. (Congress 2001, Hamburg)]*

*[Reference: Investigations into abrasive and corrosive wear mechanisms of pistons and liners in large bore 2-stroke diesel engine cylinders. (Paper no. 14: CIMAC Congress 2004, Kyoto)]*

# 4 Shore laboratory based analysis versus ship board analysis methods

There are currently many test kits, methods, and on-line sensors available for analyzing used oil on board the vessel. They are continually being developed and refined and this paper does not attempt to catalog them or compare them. Instead, the operator can compare and utilize shipboard analyses along with laboratory analysis.

Shore laboratory analyses benefit from very sophisticated equipment, highly trained analysts, and elaborate ways of checking the accuracy. This is impossible to duplicate in ship board analysis methods. On the other hand, a shore laboratory analysis can at times suffer delay due to the time required to get samples from the ship to a shore laboratory. The advantage of the onboard test is that it can give quick results allowing the ship staff to take immediate action…. before the shore results become available. The onboard tests, especially when the results are abnormal, should be backed up with shore analysis.

The operator must develop trust in a shipboard analysis. This can be done by running analyses of duplicate samples, one at the shore lab, and the other using the shipboard analysis. The results can be used to develop a comparison database and then periodically carrying out the duplicate analyses will demonstrate the credibility of the shipboard analysis. The methods used by the shore laboratory are different as compared to the shipboard analysis and there is bound to be some variances. Such variances have to be recorded. Armed with this information, the operator can use the shipboard analysis for routine or quick checks and have a good idea of how far the results may differ from the shore lab results.

Decisions on machinery and oil maintenance should always be made with regard to the observed trend of UOA results.

# 5 ACKNOWLEDGEMENT

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