Experts in Oil Analysis

Covers:

- Lubricant Analysis
- Fuel Analysis
- Electrical Oil Anaysis
- New Oil Testing
- Condition Monitoring
- How to Read a Report
- Source Elements Guide

Introduction to Oil Analysis

Pocket essentials.

4th Edition

by Adam Cutler

Contents

About book – Make sure you have latest version

I started writing this book after clients started asking me could I provide some written material so they could learn more about oil analysis. It started as a 3 page summary guide, but as more information was requested it has grown in size.

The versions have been regularly updated as time went on, meaning there are some older versions out there that are not up to date.

Before continuing please visit my LinkedIn page where I always post the latest versions of this guide to ensure you have the latest addition. The world of oil analysis formulations, testing and technology is always changing, so I continually have to update the guide to take into account for these changes.

Section 1 – Oil Analysis Best Practices

Why Oil analysis

Oil analysis identifies early signs of contamination, fluid degradation and abnormal wear before they cause costly and permanent damage to equipment. Oil analysis determines when the properties of the lubricant have reached a point at which they are no longer serviceable. It helps in 3 main business areas: Maintenance, Management and Uptime.

Maintenance

- Identify contamination and wear and identify corrective actions such as lube/filter changes
- Reduce in service failures by improving equipment maintenance.
- Establish condition based lubricant drain intervals & maintenance actions.

Management

- Improve business reliability and productivity, hence profits.
- Improve manufactured products quality & reduce waste/spoilage.
- Reduce unnecessary maintenance such as time dependent component changes.
- Assist in product (e.g. lube oils, coolants, greases) selection to allow your assets to run most efficiently.

Uptime

- Reduce equipment downtime.
- Increase overall equipment usable life.
- Extend drain intervals, reduce oil consumption, reduce disposal costs and reduce environmental impact.

Oil Analysis Example benefits

1. **Identification of severe machine faults** – Allowing these to be corrected at an early stage to prevent a major failure.

2. **Reduce power/fuel consumption** – Identifying faults that lead to machine inefficiency / high fuel consumption e.g. a leaky fuel injector.

3. **Reduces Machinery unplanned downtime** - by helping ensure equipment is maintained in a good condition.
4. **Improves your reputation with clients** – if your equipment is running more efficiently then you are less likely to get behind in production / deliveries and hence the client will have a better experience of your service.

5. **Reduces unnecessary maintenance** – this ensures components / lube replacements only occur when needed
6. **Reduces wastage or build-up of intermediate production process items** – if the last stage of the process fails then you risk build-up of stock that may be perishable in the process.
7. **Improves safety** – Identify mechanical or chemical safety concerns with equipment before they cause hazards to others e.g. uncontrolled movements in hydraulics or fire risks.

How to sample (Drawing the sample)

Lube Trend

How to take a sample

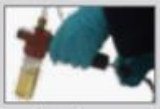
1

PPE must be worn.
Take Care - Oil may be hot / at high pressure

2

Machine should be running for at least 1 hour at operating temperature

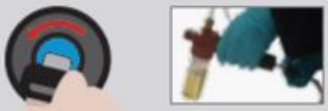
3a



Sample when machinery is on (if safe to do so)

or

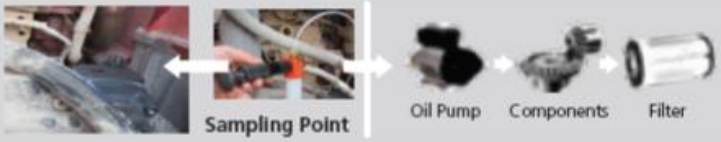
3b



Or within 15 minutes of Shutdown

3c

Sample at an approved sample point e.g. dipstick. Maintain consistency in use of this sampling point for trending purposes. Sample after oil has passed components, but before the filter



4

(A) Clean area around sampling point (e.g. A1) using lint free cloth

(B) Unscrew bottle cap and screw bottle securely to thief pump.

(C) i. Directly push front nozzle (C1) to machine if sampling point fitted (and go to step E),

or

ii. cut length of tubing to dipstick length / sufficient length to reach mid point of oil in sump.

(D) Push tubing through o-ring seal (D1) into bottle and close o-ring seal.

(E) Draw pump back (E1) until bottle is 50% filled and unscrew bottle to break vacuum and stop flow.

(F) Discard oil in bottle safely and within environmental legislation. Re fit bottle and refill to 90%.

(G) Unscrew bottle from sample & fix lid immediately. Discard tubing safely within environmental legislation.

www.lubetrend.com

ISO 17025, ISO 14001 & ISO 18436

Working with

Using the right Bottle is just as important as sampling right

Just as important as taking the sample in the correct manner, using a suitable container is just as important. It is surprising the number of times samples arrive in drinks bottles, urine specimen pots and various weird and wonderful sample container types not designed for sampling oil, fuel, coolant or Adblue.

Drinks bottles no matter how confident the sampler is that they rinsed the bottle and dried it properly always leaves in doubt if water is found in the sample was it from the machinery or from the residue in the bottle.

Likewise specimen pots despite being clean often have residues and chemicals to preserve or inhibit changes in bacterial content etc which are not suitable for condition monitoring type samples. Laboratory bottles for other industries are also not to be used as e.g. water testing samples may have nitric acid residues to help dissolve the sample for processing at an environmental or water lab, but this would give a tremendously high acid number when testing and could affect a machinery diagnosis.

Even within the oil analysis industry there is a huge variation in the types and quality of bottles used on the market. For instance many are designed with mineral oil in mind, but when used with synthetics the bottles become brittle after several hours meaning the bottle breaks when picked up – often feeling as fragile as an egg shell. Those that are not fully brittle are still etched meaning the particle count goes up as dissolved plastics are now in suspension in the oil, and the clarity of the bottle is impacted. Other bottles the issues are around thread durability and bottle resistance to expansion with fridge compressor bottles exploding even when significantly degassed before sealing. The rest tend to have bottles that are too thick or of the wrong material to be fully transparent to allow a complete visual inspection of the bottle.

The Lubetrend bottle range was designed with quality, safety, versatility, durability and practicality in mind. Some of our bottles took several years of design work to perfect before offering to clients involving trailing several plastics manufacturers and testing to destruction. Our most common two bottles of 100ml and 65ml plastic have been dropped, kicked, boiled, frozen, stamped, squeezed, shocked, tested with all major sample type groups and most of the lab solvent list so we know exactly what they can do. We also under promise and over-deliver with regards to what the bottle can do with for instance our maximum oil temperature quoted on the bottle is significantly beneath what we know the bottle can go to, but we have purposely stated it lower to give you that peace of mind when sampling.

We also care about the environment so we now offer the option to have more environmentally friendly cardboard packaging to ship sample bottles to clients that is made using recycled materials and is fully recyclable at no additional cost.

Lubetrend 65

Features:

Crystal clear optics allowing for early detection of metallic, water or debris ingress by analyst and with Lubetrend visual appearance camera rig.

Exceptionally durable and sample resistant

Reduced lubricant waste volume from oil sampling. Reduced shipping costs.

Volume: 65ml, 38mm thread.

Holds: Lubricating oils, Adblue, coolant, water, grease, diesel, fire resistant fluids, compressor oils, brake fluids & emulsions.

Suitable suites: All universal suites, some gold suites. Not sufficient volume for all platinum suites.

Weight for return shipping filled with sample*

83g (Without Mailer-'Bottle & Oil only)

108g (With Mailer)

*weights taken using a VG 32 mineral oil filled bottle. There will be slight variation depending on sample taken and how full bottle.

Lubetrend 100

Features:

Crystal clear optics allowing for early detection of metallic, water or debris ingress by analyst and with Lubetrend visual appearance camera rig.

Increased volume for enhanced suites.

Volume: 100ml , 38mm thread.

Holds: Lubricating oils, Adblue, coolant, water, grease, diesel, fire resistant fluids, compressor oils, brake fluids & emulsions.

Suitable suites: All universal suites, some gold suites. Not sufficient volume for all platinum suites.

Weight for return shipping filled with sample*

112g (Without Mailer-'Bottle & Oil only)

137g Grams (With Mailer)

*weights taken using a VG 32 mineral oil filled bottle. There will be slight variation depending on sample taken and how full bottle.

Also Available in 600ml and 1L options too.

Lubetrend Fuel Safe

Features:

Double seal to prevent fuel leaking consisting of an inner plastic bung and outer screw cap. Designed for carrying fuels where flashpoint is close to, but not less than minimum for shipping regulations.

Also available for high temperature sampling where fluid exceeds recommendations for plastic sample bottles.

Volume: 100ml , 600ml or 1L

Holds: Same as Lubetrend 100 and 65, high temperature fluids such as thermal oils, but should not be used to hold Adblue which can react with the metal over prolonged storage.

Suitable suites: All suites where a plastic sample container is not suitable. Size is dependent on suite required.

Weight for return shipping filled with sample*

100ml- 171 g
600ml- 717 g
1 litre- 1412 g

*weights taken using UK Road Diesel.

Lubetrend 1L

Features:

Higher density plastic for higher stability for shipping with larger volumes and operating at higher temperatures as seen in steam and gas turbines.

Handles nearly all suites offered.

Volume: 1L

Holds: Ideal for Steam / Gas turbine annual and monthly health checks or new oil testing.

Suitable suites: All popular suites offered.

Weight for return shipping filled with sample*: 902g

*weights taken using a VG 32 mineral oil filled bottle. There will be slight variation depending on sample taken and how full bottle.

Transcheck Bottle

Features:

Glass bottle with optics designed to allow for visualisation of normally invisible paper insulation fibres. Container designed for ideal seal of gases in sample for dissolved gas analysis.

More durable than commonly used gas syringes.

Volume: 500ml

Holds: Insulating oils

Suitable suites: All Transcheck suites.

Weight for return shipping filled with oil sample: 775g

Shipping Invoice & Declaration Lube samples (Shipped to UK)

Please print 1 copy of this page for each package of lubricant / insulating fluid samples sent to laboratory.

Commercial Invoice for Export

(Only to be used for return of Lubetrend Condition Monitoring Sampling)

Ship to: - ALcontrol Oil Laboratories, Unit 6, Parc Caer Seion, Conwy, LL32 8FA, UK

Company Reg. No: 4057291. VAT Number: 755 5048 20.

Contact Name: Adam Cutler.

Phone Number: (+44/0) 1492 574750. Email: oillab@alcontrol.com

Payment Terms: Cash. Currency: GBP.

Item	Full Description of Goods	QTY	Unit Price in £GBP	Total Value for Customs
A	Small package of lubricant/ insulating fluid samples for testing Flash point >200^{0}C Non Hazardous Not restricted. Complies fully with IATA restrictions No commercial value – samples will be tested to destruction on day of arrival at laboratory.	1	<1 GBP	<1 £GBP
Total Amount				<£1GBP
LESS THAN ONE POUND £GBP. SAMPLES OF NO COMMERCIAL VALUE				

ABOVE MENTIONED VALUE IS FOR CUSTOMS PURPOSE ONLY.

Declaration of contents of package

To whom it may concern,

The contents of the package are not of a dangerous nature (non-hazardous, non-flammable, non-toxic, non-explosive, non-infectious, non-corrosive and non-radioactive) for and on behalf of the below named company. It is being shipped to ALcontrol Laboratories UK for analysis purposes only. I assure that the contents are/is a non-restricted cargo & is not classified as dangerous goods under IATA Regulations & has a flash point of >200^{O}C. I confirm the material/contents are safe and acceptable commodity for air transport & do not reflect any hazard to the aircraft & to other environment. I declare that the above information is true and correct to best of our knowledge for samples shipped to the laboratory.

Name (please sign)…… **Company**……

Date: …DD……/…MM…/……YYYY……

Shipping Invoice & Declaration Fuel samples (Shipped to UK)

Please print 1 copy of this page for each package of fluid samples sent to laboratory.

Commercial Invoice for Export

(Only to be used for return of Lubetrend Condition Monitoring Sampling)

Ship to: - ALcontrol Oil Laboratories, Unit 6, Parc Caer Seion, Conwy, LL32 8FA, UK

Company Reg. No: 4057291. VAT Number: 755 5048 20.

Contact Name: Adam Cutler.

Phone Number: (+44/0) 1492 574750. Email: oillab@alcontrol.com

Payment Terms: Cash. Currency: GBP.

Item	Full Description of Goods	QTY	Unit Price in £GBP	Total Value for Customs
A	Small package of Diesel / Gas Oil/Biofuel sample samples for testing (UN 1202). Flash point >60.5^{O}C (MSDS attached with package). Not flammable at ambient temperatures. IMO: Not classified as dangerous IATA, IMO, DGR, ICAO, and IMDG: Not regarded as hazardous for transportation in small volumes and restrictions exempt in small quantities. NB: Liquid Volume less than 1L and within the limited quantities exemption for transport according to United Nations Economic Commission for Europe, IATA, IMO, DGR, IMDG, UK Government and US Government regulations (links to regulations on MSDS). No commercial value – samples will be tested to destruction on day of arrival at laboratory.	1	<1 GBP	<1 £GBP
Total Amount				<£1GBP
LESS THAN ONE POUND £GBP. SAMPLES OF NO COMMERCIAL VALUE				

ABOVE MENTIONED VALUE IS FOR CUSTOMS PURPOSE ONLY.

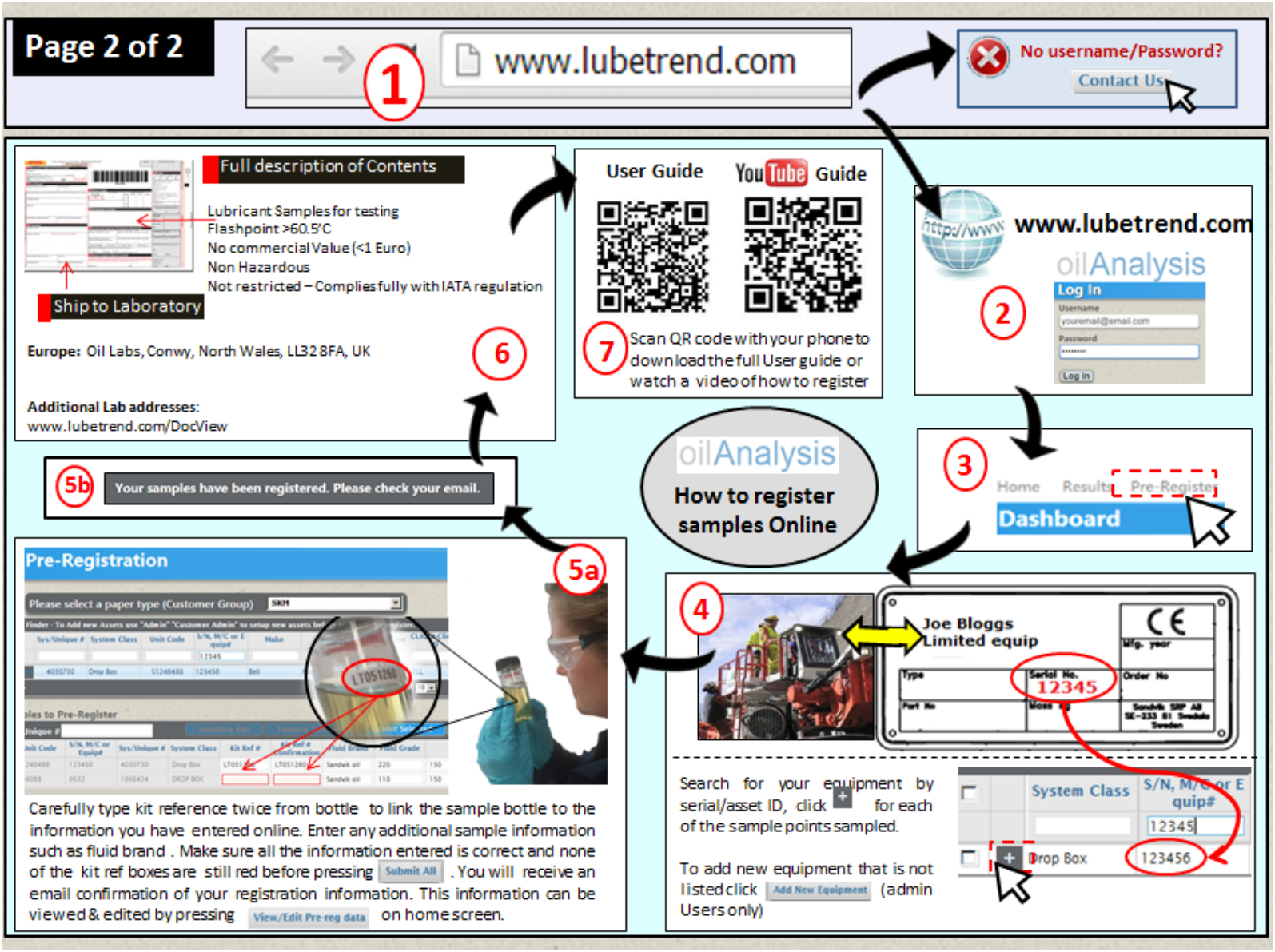
Declaration of contents of package

To whom it may concern, To the best of our knowledge, the package contains a small amount of diesel fuel/gas oil/biofuel for testing for and on behalf of the below named company. It is being shipped to ALcontrol Laboratories UK for analysis purposes only. I assure that the contents volume fall within the limited quantities exceptions as stated in UNECE regulations, as quantity is <1L & the product has a flash point of >60.5^{O}C making it not flammable at ambient temperatures expected during transport. I confirm that a suitable Laboratory approved Fuel Safe container has been used for transport and the packaging is double layered to reduce risk of contents spillage during transport. I enclose an MSDS sheet for the package to support this declaration.

Name (please sign)…… **Company**……

Date: …DD……/…MM…/……YYYY……

How to sample (taking a sample pre-register and shipping)

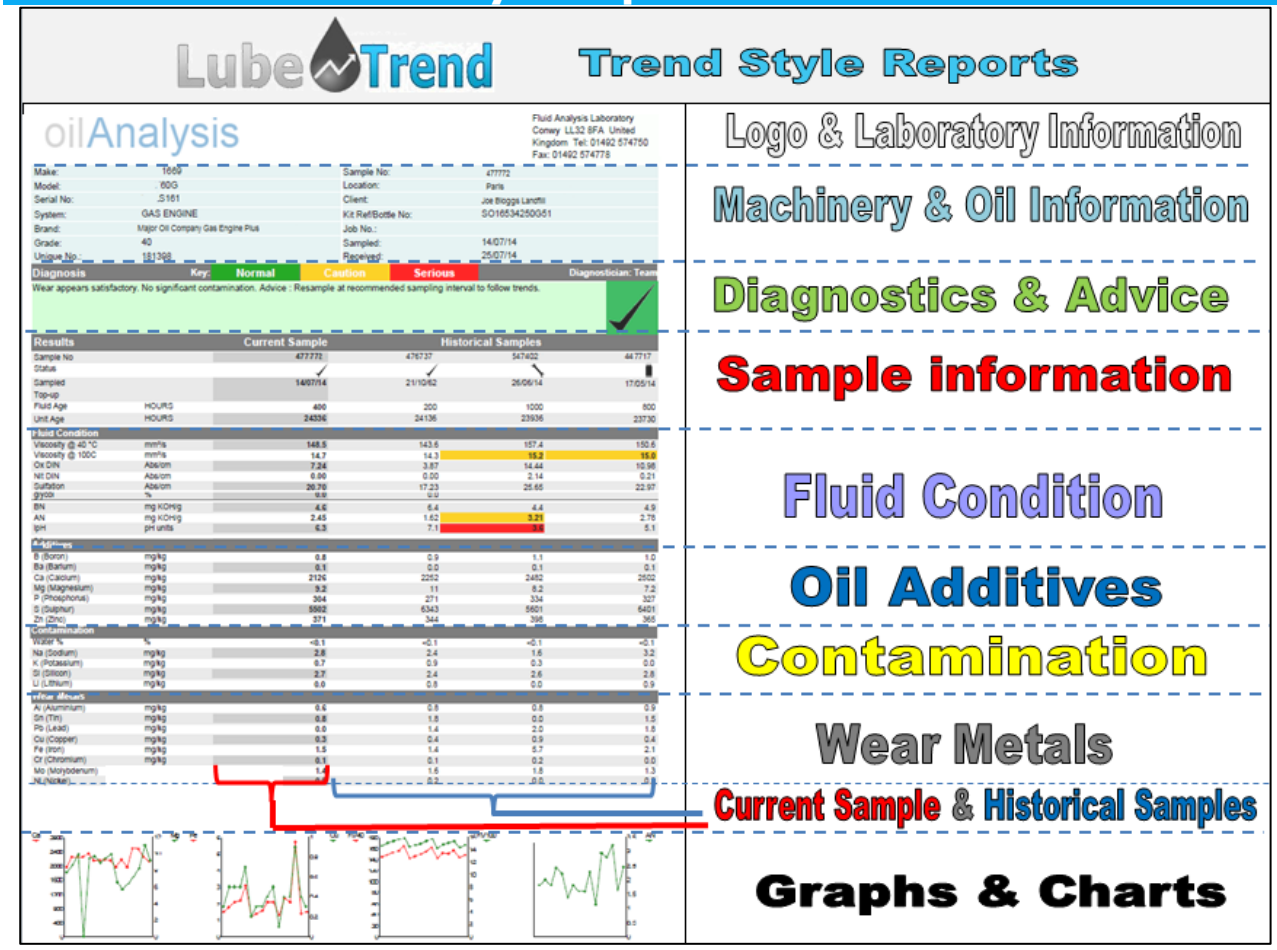


Section 2 – Routine Analysis Tests Lube Oils

Lubetrend reports introduction

Lubetrend offers several bespoke formats of report, but the most commonly used ones are the Trend style report, Specification style report and Multi-page Summary Reports. Below goes through these types of report.

Lubetrend Trend-Style reports.



This is by far the most common report style for lubricated machinery. The top section contains the logo and laboratory information, which can be rebranded on Key Client accounts.

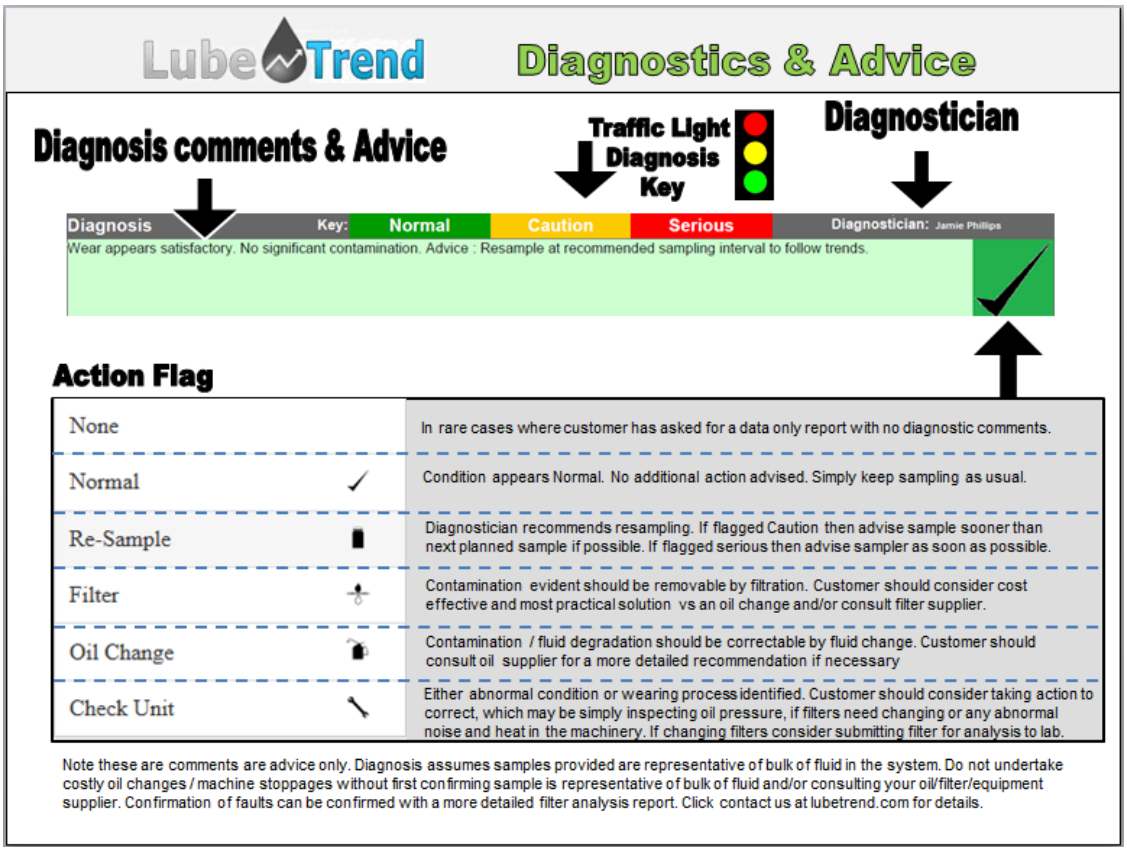
Machinery & Oil Information

This section contains the Machinery information, but does vary on certain customers reports. By default the order is:

- **Make** – This is the manufacturer of the equipment such as Volvo, MWM etc.
- **Model** – This is the equipment model.
- **Serial Number** – This is your unique name for the equipment which may be a fleet number, asset ID, Machine serial, Machine Registration or VIN Number. Essentially, this is however you wish to describe the equipment to allow the laboratory to uniquely identify it.
- **System** – This is the description of the system sampled e.g. Hydraulic Main tank, Engine oil sump etc.

- **Fluid Brand** – This is the brand and product name such as Fuchs, Mobil & Total.
- **Grade** - This is the viscosity Grade e.g. SAE 15W40 or ISO VG 32. A full explanation of Viscosity Grades is given later in this document.
- **Unique No / System ID**– This is the unique identifier the lab set to the system sampled that can be used for trending purposes. This avoids confusion with serial number where e.g. Engine No1 and Generator No1 may in fact be the same piece of equipment, but described differently by the sampler. Hence the unique number allows unique identification of a sample compartment.
- **Sample No** – This is the number the laboratory assign to the bottle on arrival for quality and auditing purposes.
- **Location** – This is the end client location.
- **Client** - This is used when e.g. the laboratory's customer has an end customer that they have sampled on their behalf.
- **Kit Ref/Bottle No**: This is an identifier given to every sample to allow the customer to track progress, identify if a sample has arrived yet and to register their samples online using pre-registration.
  To see how to pre-register your samples online try this link https://www.youtube.com/watch?v=KbGXonPenZ0
- **Job No** – This is a client Job reference / purchase order (if applicable.)
- **Sampled** – This is the date sampled by the client.
- **Received** – This is the date received by the laboratory.

Diagnostics & Advice



Traffic light system – Lubetrend uses a traffic light system of Normal, Caution and serious. Serious red reports should be given the most urgent attention by the engineer reading the reports, followed by the cautions and lastly by the normal samples.

Action Flag symbol – This is the diagnosis action flag to help assist the engineer of what to do next.

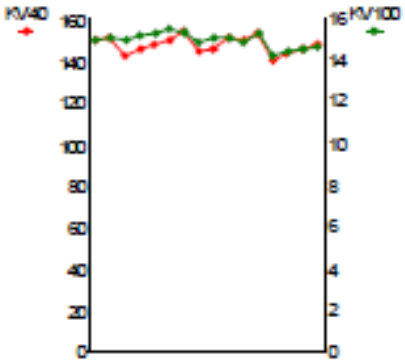
Sample information

- **Sample No** - This section contains current and historical sample numbers.
- **Status** - shows the current and historical Action flags
- **Sampled** – Dates sampled
- **Top-up** – Volume of oil topped up during sample period.
- **Fluid age** – Number of Hours, Miles or Kilometres oil has been in use since last complete oil change.
- **Unit age** – Number of Hours, Miles or Kilometres machine has been in use since machine build.

Fluid condition, Additives, Contamination and Wear metals - These contain the relevant sample data with the relevant units. See ***sections of Lubetrend report*** below for details.

Graphs and charts

These are charts that show on the bottom of the report to trend important aspects of the report. In the example on the right; Viscosity at 40^{O}C (KV40) vs 100^{O}C (KV100) are plotted on the left and right Y axis.



As a rough general rule, if a value is staying roughly the same and the graph is horizontal then there is no problem, but a sudden rise or fall can indicate a possible abnormal condition in the system. The graphs help graphically show this to the reader.

Sections of Lubetrend report

Fluid condition – These are physical properties of the oil such as the viscosity (how thick the oil is), Acid Number (how acidic) to determine if the fluid has degraded or is still serviceable.

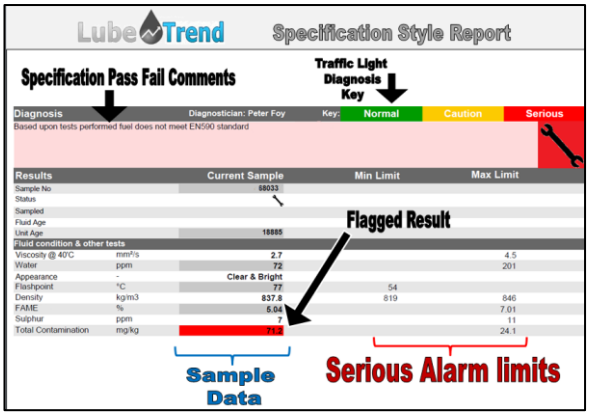
Contamination – This is where contaminates such as wrong oil, water, fuel and dirt are identified.

Additives – this is where metal additives such as detergent and dispersants and anti-wear additives are monitored.

Wear Metals – This is the most recognisable part of condition monitoring to most people and those with None destructive testing (NDT) backgrounds. As components wear in the system these are monitored for abnormal trends.

Units - This ensures the data is presented in a format that is understood. A value of 80 for water may look high if it is in percent, but if the value is in parts per million (move the decimal place 4 times = 0.008%) then this is very low. Hence the units used are important, especially if a customer has recently switched laboratory supplier.

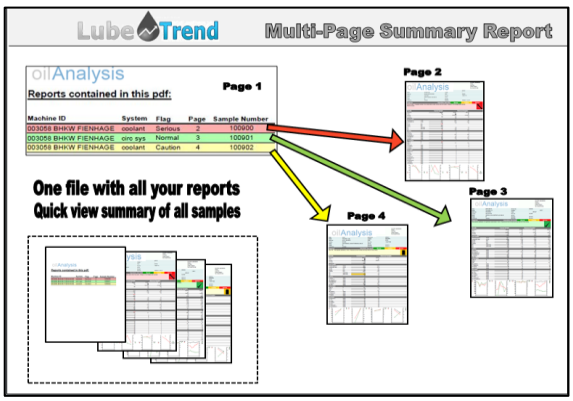
Specification style reports



Specification style reports are the same as the trend style reports except that rather than showing sample history they show minimum and maximum alarm limits. These are best for specification testing where a sample either passes or fails a standard e.g.

Fuel specification testing such as road diesel (EN590),off-road machinery (BS2869) and Marine fuels (ISO 8217).

Multi-page reports



The multi-page report is the same as the trend style report, but it batches all samples for a machine or location into one report with a quick view summary of the status of all the sampling points sampled.

Tests on Lubetrend report (Fluid Condition)

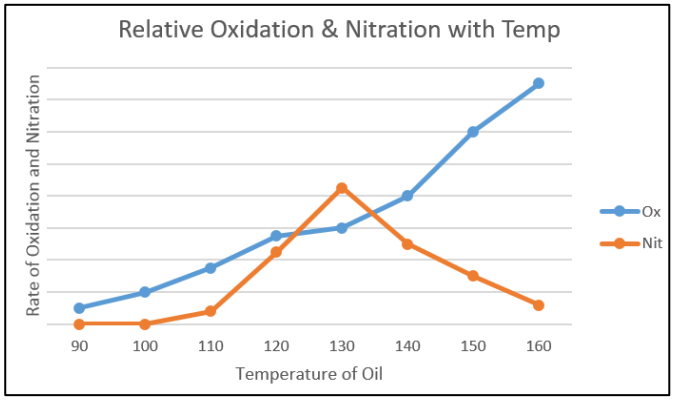
Viscosity (10ml)– This is defined as resistance to flow, or how thick an oil is.

It changes with temperature i.e. as you heat an oil it will begin to thin and as the oil is cooled it will begin to thicken. The importance of viscosity is that at high temperatures the lubricant film must be thick enough to separate the two surfaces, but thin enough to still be energy efficient. Many diesel engines are produced with a lower viscosity base oils with special Viscosity Index Improver additives so at low temperatures they are fuel efficient in cranking the engine, but at high operating temperatures still give sufficient film thickness to prevent wear. These oils are called multi-grades (e.g. 15W40, 5W30 etc). Viscosity is measured at two temperatures.

- Viscosity at 40'C – All lubricating fluids (as standard) are measured at this temperature and is the standard temperature to measure fluids for industrial applications with ISO Viscosity grade ratings.
- Viscosity at 100'C – This is performed on all multi-grade (denoted with a "W" in the grade, where **W** = **W**inter) and SAE grade fluids used in engines and automotive gear oils.

Oxidation (30ml) – high temperatures and oxygen (in air) increase the rate of oxidation of lubricants where the oxygen chemically bonds with the oil to form organic acids (measured by Acid Number) that can cause corrosion in machinery. Excessive oxidation can result in oil thickening, sludges and varnishes in machinery.

Nitration (30ml) – This is typically only starts at higher loads, and at prolonged temperatures >70C as the bonds of nitrogen (N_2) in air requires approximately twice as much energy to break as the bonds of Oxygen (O_2) in air. The rate of nitration formation increases up to a peak of ~130^{O}C, however, at extremely high temperatures (>150^{O}C) nitration products break down leading to a reduction in nitration formation (see graph to left).



It is heavily influenced by the air/fuel ratio, reduces when crankcase ventilation and oxygen improves. Like oxidation this can result in oil thickening and sludge formation. Additionally, when combined with water this can form nitric acid causing corrosion to components.

Sulphation (30ml)– Sulphur present in fuel or engine oil during combustion can combine with water produced during the combustion process to form sulphuric acid (battery acid) which can cause corrosion to engines. Engine oil lubricants are designed with an specialist antacid additives (Base Number) to neutralise the acids (Acid Number).

Acid Number (AN) (30ml)– This is the concentration of acid in the fluid. The new oil value may not be zero since some oil additives react similar to acids with the reagents used for testing. Hence it is important to monitor the trend in change of TAN from a baseline sample or new oil reference. In engine applications this can be used in conjunction with a Base number value with the crossover of the two values a common method of deciding when to change oil. However, always be guided by your lubricant provider and OEM recommendations.

Base Number (BN) (30ml)– This is the amount of alkali additive remaining in the engine lubricant. This is used in conjunction with an AN value and oil changes are typically either on a drop of 50% from a baseline sample or when the value becomes less than the AN. Again, always be guided by your lubricant provider and OEM recommendations.

Tests on Lubetrend report – (Contamination)

Understanding ISO cleanliness codes

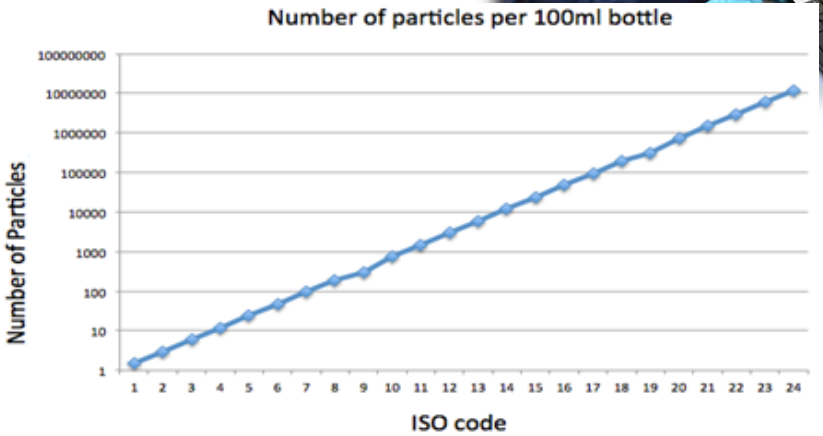
Particle counting techniques have been used to measure the cleanliness of fluids for many years. Once this practice was implemented, it soon became evident that fluids, which looked clear and bright, were often very dirty. Microscopic examinations would reveal many harmful abrasive particles, which could potentially have lead to an unexpected failure. In fact the number of particles present were often too unwieldy to comprehend and appreciate. Numbers, such as 14712586partides per 100 millilitre greater than 6 microns and 1275916 partides per 100 millilitre greater than 14 microns and so on.
The International Standards Organisation (ISO) considered this problem and devised a simple index system to rationalise these large numbers.

Some pre-2001 OEM guidelines used a 2 code system, which was later replaced with the 3 code system (table below). So 18/15 in the old system relates to the last 2 codes in the new system e.g. XX/18/15

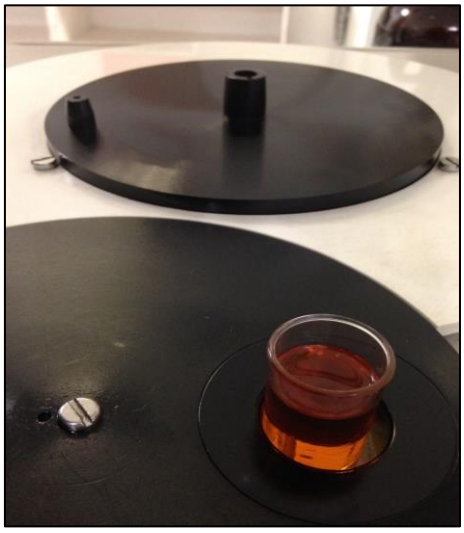
OLD SYSTEM MICRONS	NEW SYSTEM MICRONS
	4
5	6
15	14

ISO Particle count (60ml) – Particle counts measure the relative cleanliness of a fluid. This can be performed at different particle sizes from 4 microns all the way up to 70 microns. The most common cleanliness method is the ISO code system that measures the number of particles at 4, 6 and 14 microns. Traditional thinking suggests particles between 6 and 14 microns are the most damaging to equipment, but current thinking suggests smaller particle sizes such as 4 microns may also be damaging to systems with small machine tolerances, hence these are measured too. To easily express the cleanliness and allow comparison of large numbers. The code is expressed from smallest to largest from left to right, so a code of 20/19/15 means a code of 20 (500k to 1m particles in 100ml sample) greater than 4 microns, a code of 19 (250k to 500k) particles greater than 6 microns per 100ml sample and an iso code of 15 (16k to 32k) particles greater than 14 microns in a typical 100ml sample container.

Particle counts on reports are typically expressed per ml rather than 100ml since early 1990s, and the 100ml example above is just for simplicity to explain the number of particles in the sample bottle.



No of particles /ml	ISO cleanliness code
5M – 10M	**30**
2M – 5M	**29**
1.3M – 2M	**28**
640K – 1.3M	**27**
320K – 640K	**26**
160K – 320K	**25**
80k to 160k	**24**
40k to 80k	**23**
20k to 40k	**22**
10k to 20k	**21**
5k to 10k	**20**
2.5k to 5k	**19**
1.3k to 2.5k	**18**
640 to 1300	**17**
320 to 640	**16**
160 to 320	**15**
80 to 160	**14**
40 to 80	**13**
20 to 40	**12**
10 to 20	**11**
5 to 10	**10**
2.5 to 5	**9**
1.3 to 2.5	**8**



PQ – Ferrous debris (10ml) **–** This is a non-dimensional value indicating the amount of ferrous (i.e. Iron, Steel, Cobalt or Nickel - magnetic) material in the sample. Standard Iron results are performed by ICP (Inductively coupled plasma) and measures particles ideally less than 5 to 10µm (an explanation of the theory of ICP is available in our Youtube video (minutes 16 to 18). By comparison the width of a human hair is 80µm. Therefore large ferrous particles that can be seen by eye will be underestimated by ICP. Hence the PQ method detects small and large particles.

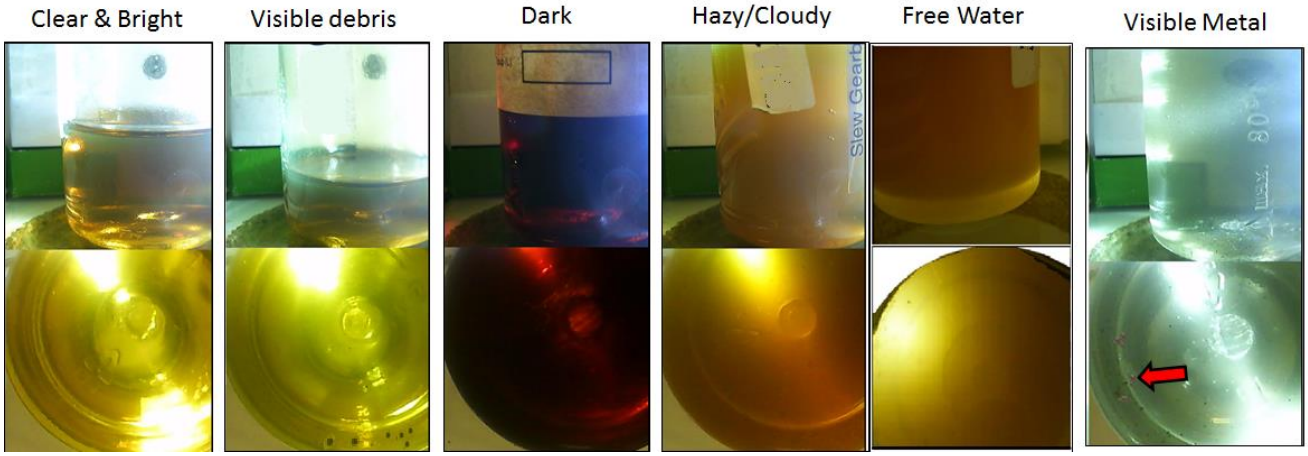
Soot (30ml)– This is a normal process of the fuel combustion process. This is a good indicator of combustion efficiency in the engine and should be monitored as part of any diesel engine analysis package.

Water (20ml) – Water content found in the system. This may be a freshwater source e.g. tap water, or saline water (with sodium), or coolant (with sodium and/or potassium and possibly glycol). In water based fluids, the water content needs to be within certain concentrations to maintain fire-resistance properties. If water is a contaminant in the system then it needs to be prevented from entering or removed after ingress (see Section on symptoms and corrective actions for details on how).

Glycol – this is an analysis linked to the water content. Glycol contamination suggests a coolant leak, incorrect sampling or use of a dirty top-up can.

Diesel Fuel (20ml) – This can be provided as a normal, caution or serious result based on flash point, or as a percentage dependent on your test suite type. Excessively high fuel dilution may also pose a fire risk. Diesel systems converted to run on biofuels such as B20, B80 and B100 the fuel dilution can be provided as a percentage FAME (Fatty-Acid-Methyl-Ester) content.

Appearance – This is a test performed on all fluid samples except diesel engines (as the oil is too black to see through). The sample is analysed visually for contamination or visible wear particles prior to testing. This is a qualitative test so does not differentiate between a little and a lot of dirt in a sample. It is a good confirmation test to confirm other diagnostic data.



ICP Wear Metals (Source Element guide)

Lubetrend Analysis Common Wear Metals

Element	Engines	Gear / Axles	Transmissions	Hydraulics / Turbines	Compressors
Aluminium (Al)	Pistons, Thrust Bearings, Turbo Bearings, Main/Rod, Bearings	Pumps, Thrust Washers, Aluminum Casting, Dirt (with Silicon), Torque converter.	Torque converter, Pumps, Thrust Washers, Aluminum Casting, Dirt (with Silicon)	Bearings, Thrust Plates, Pistons, pump motor housing.	Case Casting, Impellers/Screws
Cadmium (Cd)	Environmental Contaminant	Sometimes an Alloy Metal, Environmental Contaminant	Sometimes an Alloy Metal, Environmental Contaminant	Alloy with Aluminum (Bearings), Environmental Contaminant	Alloy with Aluminum (Bearings), Environmental Contaminant
Chrome (Cr)	Piston Rings, Liners, Exhaust Valves, Shaft Plating, Stainless Steel Alloy, Taper Bearings	Roller/Taper Bearings, Needle Bearings, Shafts	Roller Bearings, Needle Bearings, Shafts	Rods, Cylinders, Gears, Shafts, Pistons	Shafts, Bearings
Copper (Cu)	Main/Rod Bearings (Also look for Lead & Tin), Brass (with Zinc) / Bronze (with Tin) Bushings, Leaching (Oil Cooler - 1st 2000 hours). Governor, Wrist pin bushings, Valve train bushings, Thrust washers.	Bronze (with Copper) Bushings Cage Metal (with copper) from Roller Bearings, Leaching (Oil Cooler). Clutches, Steering discs, thrust washers.	Clutch Plates, Brass/ Bronze Bushings (Also Look for Tin and/or Lead & Zinc), Oil Cooler Core Tubing	Bearings, Bushings, Thrust Washers, Oil Cooler Tubing	Bearings, Bushings, Thrust Plate, Oil Cooler Tubing
Iron (Fe)	Liners, Valve Train, Gears, Crankshaft, Camshaft, Rods, Oil Pump, Wrist Pins	Gears, Shafts, Bearings, Cast Iron	Gears, Disks, Housing, Bearings, Brakes Bands, Shafts	Rods, Cylinders, Gears, Shafts, Pistons, bearings	Gears, Shafts, Bearings, Casting
Lead (Pb)	Main/Rod Bearings, Solder (old machines), Aftermarket Additive, Corrosion	Cage Metal from Roller Bearings, Oil Cooler Core Tubing	Clutch Plates, Brass/ Bronze Bushings (Also Look for Tin and/or Zinc)	Bearings, Bushings	Bearings, Bushings
Manganese (Mn)	Steel Alloy Metal in Gears, Some Shafts	Steel Alloy Metal in Gears, Some Shafts	Steel Alloy Metal in Gears, Some Shafts	Steel Alloy Metal in Gears, Some Shafts	Steel Alloy Metal in Gears, Some Shafts
Nickel (Ni)	Alloy in Valves, Crankshaft, Camshaft, Contaminant in Marine HFO Fuels (with Vanadium)	Steel Alloy from Bearings, Shafts	Steel Alloy form Bearings, Shafts	Valves, Spools, Shafts	Shafts, Bearings
Silver (Ag)	Silver in Wrist Pin Bushings (GM Electro-motive devision engines), Some Solder from Cooler Core Joints	Solder	Trace Element in some Needle Bearings, Solder form Oil Cooler Core Joints	Solder	Solder
Tin (Sn)	Bearings (with lead & Copper), Bronze (with Copper) Bushings, Flashing from Pistons, Tin-Lead Solder. Bearing overlay	Bearings, Bushings with Copper and Lead)) Solder from Tin-Lead Solder	Brass (with Zinc) / Bronze (with Tin) Bushings (Also Look for Tin and/or Lead & Zinc)	Bearings (with Lead & Copper), Bushings, Solder form Tin-Lead Solder	Bearings (with Lead and Copper), Bushings, Solder from Tin-Lead Solder

Lubetrend Analysis Common Contamination Elements					
Element	**Engines**	**Gear / Axles**	**Transmissions**	**Hydraulics / Turbines**	**Compressors**
Lithium (Li)	Lithium Based grease.	Lithium Based grease.	Lithium Based grease.	Lithium Based grease.	Lithium Based grease.
Potassium (K)	Sodium from Salt Water, Spray Wash, Anti-Freeze Inhibitor (Coolant Leak) Additive from Potassium Borate Gear Oil	Sodium from Salt Water, Spray Wash, Anti-Freeze Inhibitor, Additive from potassium Borate Gear Oil	Sodium from Salt Water, Spray Wash, Anti-Freeze Inhibitor (Coolant Leak) Additive from Potassium Borate Gear Oil	Environmental Contaminant from Pot Ash Mining, Water Contaminant, Anti- Freeze Inhibitor	Environmental Contaminant from Pot Ash Mining, Water Contaminant, Anti- Freeze Inhibitor
Silicon (Si)	Dirt (Silica), Silicone form Silicon based Synthetic, Silicone Sealants, Silicates from Anti-Freeze,	Dirt (Silica), Silicone form Silicon based Synthetic, Silicone Sealants, Silicates from Anti-Freeze	Dirt (Silica), Silicone form Silicon based Synthetic, Silicone Sealants, Silicates from Anti-Freeze	Dirt (Silica), Silicone form Silicon based Synthetic, Silicone Sealants, Silicates from Anti-Freeze	Dirt (Silica), Silicone form Silicon based Synthetic, Silicone Sealants, Silicates from Anti-Freeze
Sodium (Na)	Sodium from Salt Water, Spray Wash, Anti-Freeze Inhibitor (Coolant Leak)	Sodium from Salt Water, Spray Wash, Anti-Freeze Inhibitor	Sodium from Salt Water, Spray Wash, Anti-Freeze Inhibitor (Coolant Leak)	Sodium from Salt Water, Spray Wash, Anti-Freeze Inhibitor	Sodium from Salt Water, Spray Wash, Anti-Freeze Inhibitor

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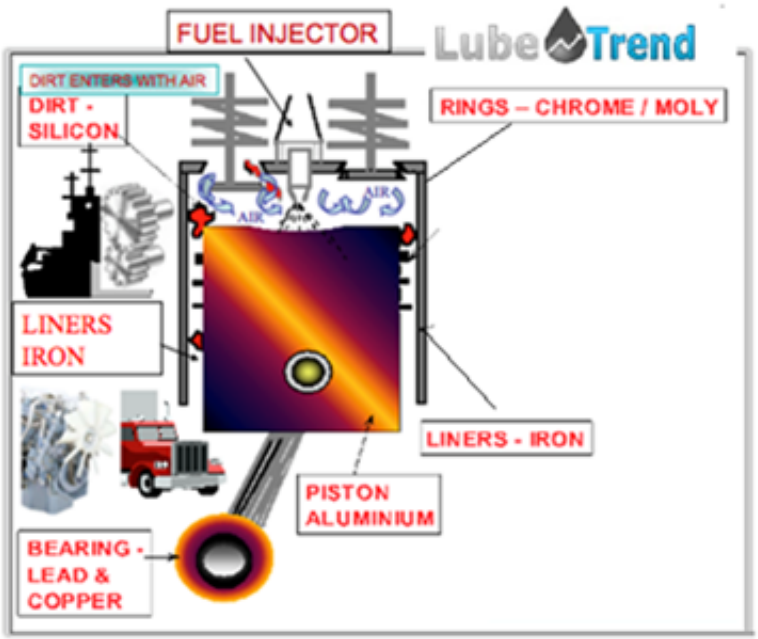
Lubetrend Analysis Multi-origin Elements					
Element	**Engines**	**Gear / Axles**	**Transmissions**	**Hydraulics / Turbines**	**Compressors**
Molybdenum (Mo)	Friction Modifier Additive in Oils, Grease Contamination, Molybdates from Some Coolants, Rings	Friction Modifier Additive in Oils, Grease Contamination,Molybdates from Some Coolants	Friction Modifier Additive in Oils, Grease Contamination,Molybdates from Some Coolants	Friction Modifier Additive in Oils, Grease Contamination, Molybdates from Some Coolants	Alloy or Plating from Rings, Retainer Pins, Friction Modifier Additive in Oils, Grease Contamination, Molybdates from Some Coolants
Nickel (Ni)	Alloy in Valves, Crankshaft, Camshaft, Contaminant in Marine HFO Fuels (with Vanadium)	Steel Alloy from Bearings, Shafts	Steel Alloy form Bearings, Shafts	Valves, Spools, Shafts	Shafts, Bearings
Titanium (Ti)	Valves, Piston Pins, Bearings, Shafts, Paint or coatings	Shafts, Gears, Bearings, Paint or Coatings	Shafts, Gears, Bearings, Paint or Coatings.	Valves, Piston Pins, Bearings, Shafts, Paint or coatings, turbine blades	Shafts, Gears, Bearings, Paint or Coatings
Vanadium (V)	Alloy Metal, Contaminant in Marine HFO Fuels (with Nickel)	Unlikely wear metal. Possibly contamination	Unlikely wear metal. Possibly contamination	Alloy Metal (turbine blades)	Alloy Metal (impellor)

Lubetrend Analysis Common Additive Elements					
Element	**Engines**	**Gear / Axles**	**Transmissions**	**Hydraulics / Turbines**	**Compressors**
Barium (Ba)	Very old detergent additive (decades old), Not Commonly found in Engine Oils, Contaminant in Drilling Applications	Demulsifying Agent, Additive Common in Compressor Oil, Some Transmission Fluids & Gear Oils, Contaminant in Drilling Applications	Very old detergent additive (decades old), Not Commonly found in Gear Oils, Contaminant in Drilling Applications	Demulsifying Agent, Additive Common in Compressor Oil, Some Transmission Fluids & Gear Oils, Contaminant in Drilling Applications	Demulsifying Agent, Additive Common in Compressor Oil, Some Transmission Fluids & Gear Oils, Contaminant in Drilling Applications
Boron (B)	Additive Common in Engine Oils & Some Gear Oils (synergistic effect with other Anti-wear additives)	Additive Common in Engine Oils & Some Gear Oils (synergistic effect with other Anti-wear additives)	Additive Common in Engine Oils & Some Gear Oils (synergistic effect with other Anti-wear additives)	Additive Common in Engine Oils & Some Gear Oils (synergistic effect with other Anti-wear additives)	Additive Common in Engine Oils & Some Gear Oils (synergistic effect with other Anti-wear additives)
Calcium (Ca)	Detergent/Dispersant Additive, Calcium from Water Contamination, Lime Dust	Detergent/Dispersant Additive, Calcium from Water Contamination, Lime Dust, Engine oil contamination	Detergent/Dispersant Additive, Calcium from Water Contamination, Lime Dust,	Detergent/Dispersant Additive, Calcium from Water Contamination, Lime Dust, Engine oil contamination	Detergent/Dispersant Additive, Calcium from Water Contamination, Lime Dust, Engine oil contamination
Magnesium (Mg)	Detergent/Dispersant Additive,Alloy, Environmental Contaminant, Hard water	Detergent/Dispersant Additive, Alloy, Environmental Contaminant, Engine oil contamination	Detergent/Dispersant Additive, Alloy, Environmental Contaminant	Detergent/Dispersant Additive,Alloy, Environmental Contaminant, Engine oil contamination	Detergent/Dispersant Additive, Alloy, Environmental Contaminant, Engine oil contamination
Phosphorus (P)	Anti-Wear Additive ZDDP (ZincDialkyl-DithioPhosphate), Phosphate Ester, Phosphate Inhibitor found in Coolants	EP Additive, Anti-Wear Additive ZDDP (Zinc-DialkylDithioPhos-phate), Phosphate Ester, Phosphate Inhibitor found in Coolants	Anti-Wear Additive ZDDP (ZincDialkyl-DithioPhosphate), Phosphate Ester, Phosphate Inhibitor found in Coolants	Anti-Wear Additive ZDDP (Zinc-DialkylDithioPhos-phate), Phosphate Ester, Phosphate Inhibitor found in Coolants	EP Additive,Anti-Wear Additive ZDDP (Zinc-DialkylDithioPhos-phate), Phosphate Ester, Phosphate Inhibitor found in Coolants
Zinc (Zn)	Alloy in Brass, Anti-Wear Additive ZDDP, Galvanized Steel from Filter Canisters	Alloy in Brass,Anti-Wear Additive ZDDP, Galvanized Steel from Filter Canisters	Alloy in Brass, Anti-Wear Additive ZDDP, Galvanized Steel from Filter Canisters	Alloy in Brass, Anti-Wear Additive ZDDP, Galvanized Steel from Filter Canisters	Alloy in Brass,Anti-Wear Additive ZDDP, Galvanized Steel from Filter Canisters

LubeTrend

BiteSize Diagnosis
Heavy Duty Diesel Engines

Sources of Engine Wear



Note many elements have multiple sources and limits are just a **general guide only** and should not be used alone as a basis to take action. The best diagnosis can only be obtained with a combination of trending and diagnostic experience. For assistance with reading your reports email techservice@alcontrol.com or call (+44/0) 1492 574750

Typical limits

Test	Units	Caution	Serious
Sodium	mg/kg	35	80
Silicon	mg/kg	20	40
Aluminium***	mg/kg	12	20
Chromium***	mg/kg	10	20
Copper***	mg/kg	35*	60*
Iron***	mg/kg	75	100
Lead***	mg/kg	30	40
Tin***	mg/kg	7	15
Molybdenum***	mg/kg	15**	30**
Soot***	%	>2.5%	>3.4%
Water	%	>0.2%	>0.2%
Fuel	%	>2%	>4.5%
Viscocity	mm2/s	>15% of unused	>20% of unused
PQ	-	20	>30

*Copper may be normal if leaching from copper based components e.g. cooler.

**Molybdenum may be normal as present in some oil additive packages

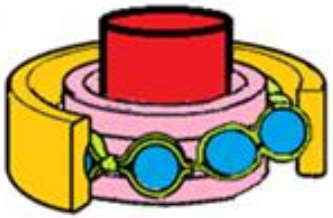
*** Parameters are assumed to be per 250 oil hours, 6000 miles or 10,000km

Bite-size Diagnosis (Gears)

LubeTrend Bite Size Diagnosis : Axle/Gear Applications

Gear Systems

Rolling Element
Inner Race
Outer Race
Cage. Shaft.



Gear Wear Sources

Silicon	Dirt (and Al), sealant, Sand, Oil additive & Synthetic Fluids
Aluminium	Pumps, White Metal Bearing, Thrust Washers & Torque Converters
Chromium	Roller Bearings, Needle Bearings, Shafts
Copper	Brass/Bronze, Cage Metal in Roller Element Bearings, Phosphorbronze gears
Iron	Gears, Shafts, Bearing, cast iron
Lead	Bushes, Bearings
Tin	Bronze / PhosphorBronze (with Copper), White Metal Bearings, Bushes
Lithium	Grease

Typical limits

Test	Units	Caution	Serious
Sodium	mg/kg	20	40
Silicon	mg/kg	40	60
Aluminium***	mg/kg	15	30
Chromium***	mg/kg	5	10
Copper***	mg/kg	20	40
Iron***	mg/kg	200	450
Lead***	mg/kg	10	20
Lithium	mg/kg	-	10
Tin***	mg/kg	10	20
Water	%	>0.24%	>0.6%
Viscocity	mm2/s	>15% of un-used	>20% of un-used
PQ	-	100	200

*** Parameters are assumed to be per 500 oil hours, 10,000 miles or 20,000km

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Bite-size Diagnosis (Hydraulics & Compressors)

LubeTrend Bite Size Diagnosis : Hydraulics & Compressors

Typical limits Compressors

Test	Units	Caution	Serious
Silicon	mg/kg	20	40
Aluminium***	mg/kg	10	15
Chromium***	mg/kg	4	10
Iron***	mg/kg	20	30
Lead***	mg/kg	5	10
Lithium	mg/kg	5	10
Tin***	mg/kg	5	10
Water	%	-	0.15
Viscocity	mm2/s	>15% of un-used	>20% of un-used
PQ	-	20	40

Typical limits Hydraulics

Test	Units	Caution	Serious
Silicon	mg/kg	20	40
Aluminium***	mg/kg	20	40
Chromium***	mg/kg	4	10
Iron***	mg/kg	25	50
Lead***	mg/kg	5	10
Lithium	mg/kg	-	10
Tin***	mg/kg	5	10
Water	%	-	0.15
Water (Biodegradable / ester based)	% Mg/kg	0.06 600	0.09 900
Viscocity	mm2/s	>15% of un-used	>20% of un-used

*** Parameters are assumed to be per 500 oil hours, 10,000 miles or 20,000km

Note many elements have multiple sources and limits are just a **general guide only** and should not be used alone as a basis to take action. The best diagnosis can only be obtained with a combination of trending and diagnostic experience. For assistance with reading your reports email techservice@alcontrol.com or call (+44/0) 1492 574750)

Section 3 - Specialist testing Lube oils, Electrical oils and Fuels

Specialist Lubricant Tests

In addition to routine oil analysis tests there are several specialist tests that are commonly performed as supplementary analysis or as part of an annual machinery health check.

Air release (250ml) is a test where air is blown through a lubricating fluid at a set temperature and pressure. The release of the 'trapped' air bubbles within the fluid is measured until no additional gas escapes. The time it takes to reach this point is called the air release and time is measured in minutes.

Tested On: Hydraulics, Compressors, Steam and Gas Turbines

Diagnostic significance: The air release should be as low as possible. Contamination and oxidation products can increase the air release time. Air is a poor lubricant and so if air is likely to become trapped for long periods in the lubricant the lubricant becomes less effective. In hydraulic applications the entrainment of air in a system poses many risks:-

1. Air can be compressed and this can lead to potential uncontrolled movement in machinery.
2. Air when compressed becomes very hot and can actual lead to thermal breakdown of the oil surrounding the bubbles. The principle is very similar to the combustion process in a diesel engine but instead of a hydrocarbon fuel being passed into air and then compressed, air is passed into a hydrocarbon fluid and then compressed.

Typical Diagnostic limit: 5 to 20. Typically ~10 minutes

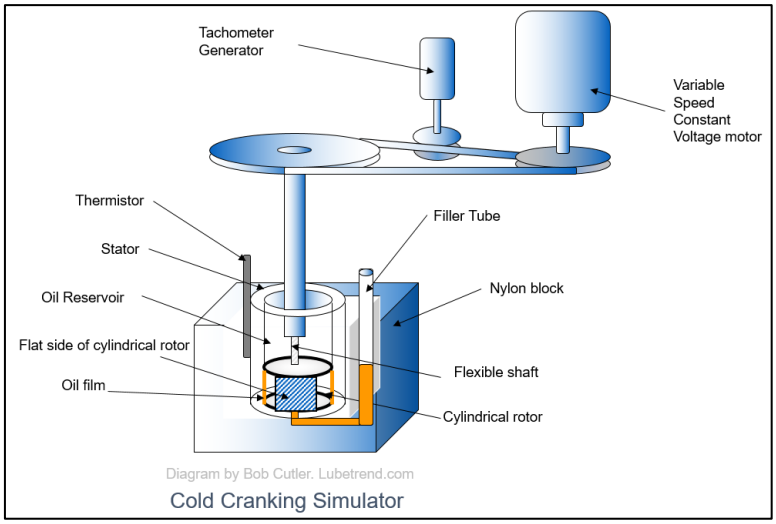
Colour (5ml) is a simple test where the colour of the fluid is compared to set standards of a given scale from 1 to 8 with increasing darkness.

Tested On: Usually Steam and Gas Turbines. However, any lubricant sample can potentially benefit from this test.

Diagnostic significance: As an oil oxidises the colour will begin to darken/change and a colour change can often be one of the first indicators of early oxidation. The absolute colour is not significant, but the trend compared to previous samples is measured. Increasing darkness usually indicates other investigative tests should be performed such as Acid Number and antioxidant testing by RULER or RPVOT. Colour change may not always be significant as a small increase in acid number can still cause a noticeable change in colour,

hence it should only be used in conjunction with other analysis data and not as the sole diagnostic flag.

Cold Cranking Simulator (120ml) **(Winter Grade Viscosities) –** Certain engine SAE lubricant grades have multiple grades denoted with a 'W' in the name e.g. 15W40, 5W30, 0W20 etc. W = Winter and denotes the viscosity grade at a low temperature. A 15W40 for instance is a SAE 15 grade oil with a viscosity improver additive that means when the temperature reaches 100^{O}C it acts like a SAE 40 oil. This allows for improved efficiency and fuel economy at lower temperatures. To confirm the fluid performs correctly at cold temperatures a cold-crank simulation is run where a piston is rotated within a static cylinder through the oil at very low temperatures (as low as -35^{O}C) to simulate cold cranking. A variation on this method exists called the **mini-rotary viscometer (MRV)** (25ml), which measures the cold pumping viscosity instead of cranking viscosity which is usually performed as part of specification testing.

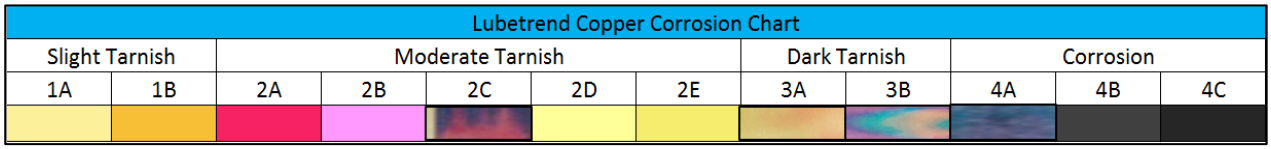


Tested On: Engine oils used in conjunction with viscosity at 100^{O}C and other tests. This is tested on all new products and any dispute resolution to confirm the grade used in warranty cases.

Diagnostic significance & Diagnostic limits: This is a specification testing limit set to ASTM 5293.

SAE Grade	Crank Temp (^{O}C) (CCS)	Max Cold cranking Viscosity (mPa.S) - CCS	Pump Temp (^{O}C) (MRV)	Max Cold Pumping Viscosity (mPa.S) - MRV
0W	-35	6200	-40	60 000
5W	30	6600	-35	60 000
10W	-25	7000	-30	60 000
15W	-20	7000	-25	60 000
20W	-15	9500	-15	60 000
25W	-10	13000		

Copper Corrosion (60ml) is a test where a finely polished and degreased copper strip is submerged in the sample fluid at a set temperature and duration. The tarnish / corrosion of the strip is determined using a reference of corrosion standards such as the below. The corrosion level is determined in an ascending scale from 1 to 4 each broken into between 2 and 5 letter categories.



Tested On: Any Mineral oil lubricant; typically turbines.

Diagnostic significance: Many lubricating systems use copper in e.g. coolers and connecting tubing as well as components such as bushes and bearings. Corrosion to these parts of a system can ultimately reduce the life of the equipment. It is usually used for compatibility testing of oil for suitability for systems containing copper. Reasons for increased copper corrosion are usually owing to contamination with high sulphur containing compounds or lubricating oils that increase the formation of copper-sulphur tarnish compounds.

Typical Diagnostic limit: 2A on turbine applications. On fuel systems Slight Tarnish (1A and 1B) are maximum allowed.

Cloud point, Pour point, CFPP, Channel point (60ml) **–** This is the point at which a fuel or low temperature lubricant form a wax causing clouding and eventually stop pouring. The cloud point is the point at which the fluid begins to crystallise. The pour point is considered the point $3^{O}C$ above the temperature at which the fluid did not pour for 5 seconds when the test tube is tipped on its side. The channel point is considered the point at which a channel can be formed in a lubricating fluid and it does not instantly fill in the gap behind an object passing through it. A CFPP (Cold-Filter Plugging Point) is used on fuels where fuel is passed through a special filter at low temperature eventually causing it to block (Plugging Point) – this is used in conjunction with a cloud point to determine the temperature at which a fuel could possibly begin to cause filter blockages.

Tested On: Predominantly fuels, but any low viscosity fluid can be tested.

Diagnostic significance & Typical Diagnostic limit: On certain fuels there are legislative limits used around the world for fuels depending on climate conditions. In lubricating systems, a cloud, pour or channel point value higher than the lowest temperature the machinery will be operating means the fluid may:

- Block filters with wax deposits (primarily on fuels)
- Be difficult or impossible to pump fuels or lubricants
- Result in wear as the points where a channel in the fluid is left (e.g. gear teeth passing through the lubricant) will have direct metal to metal contact.

Evaporation Loss (Noack) (75ml) **–** There are several alternative methods for this test, but the principle of the method includes heating the fluid to a high temperature and measuring the percentage mass loss of the sample after a set period of time.

Tested On: In service Engines and hydraulics, but usually any new lubricants too.

Diagnostic significance: A low result is ideal and a high result suggests the oil will thicken over time as the lighter fractions of the lubricant evaporate off at high temperature. This results in reduced useful life of the oil. Causes of a high result can be blends of light and heavy base oils or contamination/top-up with another product with a different boiling profile to the rest of the lubricant. If a

recently changed oil or new oil shows a high value then please consult your lubricant supplier for advice.

Typical Diagnostic limit: Varies dependent on machine OEMs and lubricant suppliers recommendations, but typically a result of 14% or greater would be seen as high. On engine specifications ACEA 2012 A1, B1, A3, B3, B4, C1, C2, C3, E4, E6, E7 and E9 the result must be less than or equal to 13%. ACEA 2012 C4 has a maximum limit of no greater than 11%.

Flash point (open (100ml) **and closed** (100ml)**) and firepoint.** Flashpoint and fire-point are important tests when determining safety of certain systems. It may come as a surprise that no liquid burns and it is in fact the vapours just above the liquid that actually burn. Hence performing a closed cup flashpoint (i.e. with a lid on the container the flashpoint is lower because the vapours are allowed to collect. Closed flashpoints are usually most important in systems where the vessel is closed such as fuel tanks and when transporting fluids. Open cup flashpoints are usually slightly higher because there is no lid to the container and the gases can escape, hence a higher temperature is needed for sufficient vapour to collect above the fluid to cause a flash. A flash is when a flame is placed just above the liquid the vapours ignite and then go out quickly in a 'flash'. If you continue heating the fluid past the open flash point, to a point at which the vapour ignites and stays lit because the fluid is at sufficiently high a temperature for more vapours to be produced to fuel the flame, then this is termed the fire point.

Tested On: Any product that has a Material Safety Data Sheet. Nearly every product has this as a new oil batch test and these are important safety tests. However, in condition monitoring it is mostly used in engines to detect fuel dilution, petroleum product drilling/mining equipment and seal oils to detect contaminating petroleum products such as natural gas, and in heat transfer / metal quenching systems to determine if product is safe for continued use.

Diagnostic significance & Typical Diagnostic limit: The limits used are often application specific and involve analysing the trends. However, diesel fuels closed flashpoints need to be over 56^{O}C, whilst lubricating oils need to be over 200^{O}C. In heat transfer systems the comparison of the gap between the open and closed flashpoint is important as it determines when the oil has degraded to a point in which small light end fractions of the oil have collected as a vapour in the system and run a significant fire risk.

HTHS (High Temperature High Shear) Viscosity (100ml) **-** this is a relatively new oil specification test used to determine how well oils perform under extreme conditions e.g. where the temperature and friction is highest. Low HTHS oils give the best fuel economy as the oil is thinner and provides less energy to rotate the bearing shaft, but provides least protection against wear. A high HTHS oil gives the best wear protection, but a poorer fuel efficiency. A table of the ACEA-2012 specification requirements is listed below. Traditionally, the test is performed at 150^{O}C, but some of the newer fuel efficiency testbed testing now measures at 100^{O}C as well.

Lubetrend Summary of ACEA 2012 HTHS data

Test	A1 / B1	A3/B3	A3 / B4	A5 / B5	C1	C2	C3	C4	E4	E6	E7	E9
Viscosity at 150^{O}C and 106 s^{-1} shear rate (mPa.s)	≥ 2.9 and ≤ 3.5; On XW20 ≥ 2.6	≥ 3.5		≥ 2.9 & ≤ 3.5	≥ 2.9		≥ 3.5		≥ 3.5			

MPC Varnish test (70ml) is a method for determining the tendency of an oil to varnish. Varnish is a build-up of oxidation products in a system and can coat components, block valves and filters and cause reduction in heat loss through oil cooler pathways. Overall, varnish is very difficult to remove without specialist filtration equipment or chemical cleaning/flushing once it forms and so the ideal situation is to avoid varnish build up and prevent it occurring in the first place. Hence the importance of monitoring MPC Varnish potential on a regular basis as part of an annual or biannual health check of the system. After an initial incubation period of up to 3 days, the MPC method involves a filtration with solvent through a 0.45 micron filter patch. The result is read using a colour spectro-photometer sensor to accurately determine the colour and hence level of varnish (i.e. the insoluble oil degradation products) in the sample.

Tested On: Hydraulics, Compressors, Steam turbines and Gas turbines.

Diagnostic significance & Typical Diagnostic limit: Below is an example of the varnish report graph. Serious is considered >40. <15 is considered normal. 15 and 30 are the two choices of caution limit popularly used depending on whether there is a previous varnish problem or based on OEM recommendations.

Sulphated Ash and SAPS (Sulphated Ash Phosphorus & Sulphur) (30ml)**–** In engines the lubricant coats the liner and rings to provide a fluid film between these and the piston. The piston rings function is to separate the combustion chamber from the lube oil, but no system is perfect and small quantities of lube oil over time come into contact with combustion gases and enter the combustion chamber. Lube oil when heated will burn to form the gases carbon dioxide and water as does the fuel, but the metal additives such as Calcium, Magnesium and Zinc which are important engine oil additives will form an ash rather than a gas. This ash has two related issues.

(1) It will be blown out of the exhaust and hence cause environmental pollution. These contribute to the particulates often measured when determining tax implications on cars and trucks.
(2) The ash remains hot even after the compression stroke has ended and can cause pre-ignition when the piston is not at top-dead-centre.

Tested On: SAPS on Engine oils and Sulphated Ash only on greases.

Diagnostic significance: This is important when confirming the correct specification of oil has been used. Sulphated ash is important for the particulate emissions standards, but this is part of the larger SAPS standards. The Phosphorus and Sulphur are important because these are catalytic converter poisons, leading to increased exhaust emissions. Lubetrend have

worked heavily with several Truck and agricultural OEMs researching this issue. Equally, the Sulphur promotes Sulphur Oxides (SO_x), which form acid raid. Therefore, the SAPS standards monitor the particulate emissions (sulphated ash), and exhaust emissions (Sulphur and Phosphorus) Lubricant manufacturers in low SAPS oils use ashless additives as substitutes.

Typical Diagnostic limit - A table of ACEA specification limits is listed below.

Lubetrend Summary of ACEA 2012 SAPS data												
Test	A1 / B1	A3/B3	A3 / B4	A5 / B5	C1	C2	C3	C4	E4	E6	E7	E9
Min Base Number (mg KOH/g)	8		10	8			6		12	7	9	7
Max Sulphur (ppm)					2000	3000	3000	2000		3000		4000
Phosphorus (ppm)					≤500	≤900	≥ 700 & ≤ 900	≤900		≤800		≤1200
Sulphated ash (%)	≤1.3	≥ 0.9 & ≤1.5	≥ 1.0 & ≤1.6	≤ 1.6	≤ 0.5	≤ 0.8		≤ 0.5	2	1	2	1

Routine Electrical Oil Testing

The following table summarises some of the routine electrical oil limits used typically by an electrical oil laboratory.

Fluid condition Electrical fluid limits						
Test Name	**TC**	**TB**	**TA**	**TO**	**TS**	**TP**
Full Name	**Category C Transformer (<72.5kV)**	**Category B Transformer (>72.5kV to <170kV)**	**Category A Transformer (>170kV to <400kV)**	**Category O Transformer (>400kV)**	**Switchgear**	**Tapchanger**
Dielectric Breakdown (kV) – Min (Non-Ester based synthetics)	30	40	50	50	Use TC, TB, TA or TO limit	Use TC, TB, TA or TO limit
Dielectric Breakdown (kV) – Min (Ester based synthetics)	45	45	50	50	Use TC, TB, TA or TO limit	Use TC, TB, TA or TO limit
Water / moisture (ppm) - max (Non-ester based synthetics)	30 (caution) 40 (serious)	20 (caution) 30 (serious)	10 (caution) 20 (serious)	10 (caution) 20 (serious)	Use TC, TB, TA or TO limit	Use TC, TB, TA or TO limit
Water / moisture (ppm) – max (Ester based synthetics)	400 (Serious if breakdown impaired)	400 (Serious if breakdown impaired)	400 (Serious if breakdown impaired)	400 (Serious if breakdown impaired)	Use TC, TB, TA or TO limit	Use TC, TB, TA or TO limit
Acidity (mg KOH/g) – max (Non-ester based synthetics)	0.1 (caution), 0.3 (serious)	0.1 (caution), 0.15 (serious)	0.1 (caution), 0.15 (serious)	0.1 (caution), 0.15 (serious)	0.07	Use TC, TB, TA or TO limit
Acidity (mg KOH/g) – max (Ester based synthetics)	2.0 (serious)	2.0 (serious)	2.0 (serious)	2.0 (serious)	Use TC, TB, TA or TO limit	Use TC, TB, TA or TO limit)
Colour – max ASTM Colour - Max	LIGHT 2	LIGHT 2	LIGHT 2	LIGHT 2	LIGHT 2	LIGHT 2
Contamination - Max	LIGHT	LIGHT	LIGHT	LIGHT	NIL	LIGHT
Particle count (ISO code) Max	20/18/15 (caution)	20/18/15 (caution)	20/18/15 (caution)	20/18/15 (caution)	20/18/15 (serious)	20/18/15 (caution)
Total Furans (FFA) and individual FFA counts – Max	1	1	1	1	1	1 (if paper used)
Est. Degree of Polymerisation (DP) - Min	Caution <600 or <50% of new oil value. Serious <300	Caution <600 or <50% of new oil value. Serious <300	Caution <600 or <50% of new oil value. Serious <300	Caution <600 or <50% of new oil value. Serious <300	Caution <600 or <50% of new oil value. Serious <300	Caution <600 or <50% of new oil value. Serious <300 (if paper used)
Interfacial Tension (IFT mN/m) - Min	Caution (28) Serious (22 or 18 dependent on trends)	Caution (28) Serious (22 or 18 dependent on trends)	Caution (28) Serious (22 or 18 dependent on trends)	Caution (28) Serious (22 or 18 dependent on trends)	Caution (28) Serious (22 or 18 dependent on trends)	Caution (28) Serious (22 or 18 dependent on trends)
Power Factor @ 90°C - Max	1	1	0.2	0.2	Use TC, TB, TA or TO limit	Use TC, TB, TA or TO limit
Dielectric Dissipation Factor (DDF) / Tan Delta @ 90°C - Max	0.1 (caution) 0.5 (serious)	0.1 (caution) 0.5 (serious)	0.1 (caution) 0.5 (serious)	0.1 (caution) 0.5 (serious)	0.1 (caution) 0.5 (serious)	0.1 (caution) 0.5 (serious)
Resistivity at 90°C Giga ohms metres - Min	3 (caution) 0.2 (serious)	3 (caution) 0.2 (serious)	10 (caution) 3 (serious)	10 (caution) 3 (serious)	Use TC, TB, TA or TO limit	Use TC, TB, TA or TO limit
Corrosive Sulphur - Max	Non corrosive	Non corrosive	Non corrosive	Non corrosive	Non corrosive	Non corrosive
Flash Point (OC) Max % Drop from new oil / first sample	10%	10%	10%	10%	10%	10%

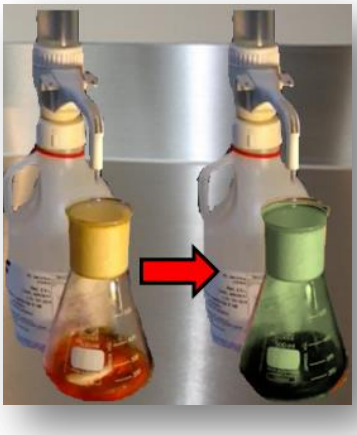
These are LubeTrend general guidelines. Note Trending may be used by the lab to over-rule these general limits. Additional electrical oil diagnosis information sources are available from: BS EN60422:2013.

Dielectric breakdown (250ml) – of the two main functions of the insulating fluid, one of them is to provide an electrical insulation. The dielectric breakdown is the voltage at which the insulator no longer prevents an electrical discharge across (arrowed red to right) two electrical contacts submerged into the fluid. The method involves submerging the two electrical contacts in the fluid and gradually increasing the voltage until the insulating properties are over-come termed the breakdown voltage. The test is repeated several times and an average breakdown voltage is obtained.

Diagnostic significance: Presence of contamination such as long fibres, water, dirt and oxidation products can all contribute a low dielectric breakdown. The breakdown voltage is an excellent overall indicator of contamination in the fluid as the contaminants will have conducting properties.

Moisture – This is a measure of the water in the sample. The maximum allowable content of water/moisture in electrical oil is much less than a lubricated system. This is owing to the significance of water in hindering the ability of the insulating oil to perform its function in being an electrical insulator. Owing to the difference in solubility of water in the insulating fluid at very low concentrations temperature becomes far more significant to determine the water content. This is often referred to as a temperature adjusted water. Temperature adjusted water takes into consideration the temperature of the water measured in the laboratory as well as the temperature of the oil at time of sampling provided by the sampler to adjust the laboratory measured water to the water measured in a transformer.

Diagnostic significance: Presence of water contamination can contribute to increased oxidation and contribute to a low dielectric breakdown. Water can enter the transformer via atmospheric air through a breather, or through degradation of the cellulose paper insulation. Water can also contribute to paper insulation breakdown as the water breaks down the paper insulation.



Acidity – Excessive temperature and the presence of oxygen in air causes the oil to oxidise forming organic acids. This is accelerated in the presence of metallic catalysts such as the metallic windings. Acidity is measured by titration with an alkali using a coloured indicator to identify the concentration of alkali needed to neutralise the acid changing the indicator from orange to green as identified to the left.

Diagnostic significance: Acidity build up can lead to varnish formation and catalyse the breakdown

of cellulose within the paper insulation. Acid products can increase the solubility of the moisture in the oil.

Dissolved Gas Analysis (DGA)

Dissolved gas analysis is the study of fault gases in transformer oil to predict transformer faults. This is different to the fluid condition analysis as it specifically identifies the condition of the electrical system and the faults within it. DGA analysis can predict fault gases up to 4 years in advance of a failure

Typical Fault Gas alarm limits					
Test Name	**Example Fault type**	**Temperature Range**	**Transformers**	**Switchgears**	**TapChanger**
Hydrogen (ppm)	Arcing corona / start-up	Low (100 °C to 300°C)	100	100	4000+
Methane (ppm)	Sparking	Low (100 °C to 300°C)	100	100	2000
Ethane (ppm)	Local overheating	Mid (300 °C to 700 °C)	100	100	4000
Ethylene (ppm)	Severe overheating	High (>700 °C)	30	30	2000
Acetylene (ppm)	Arcing	High (>700 °C)	12	12	4000
Carbon Monoxide (ppm)	Paper insulation / severe overloading	n/a	500	500	100

meaning significant plans can be made to take corrective action on the system.

Note Trending may be used by the lab to over-rule these general limits.

Ratios Methods (80ml) - Although, the method of determining faults by DGA includes alarm limits in fault detection, it is the ratio of the gases to one another that determines the fault diagnosis. There are many different methods each with their own merits for use in electrical oil diagnosis. Examples of which include:

- Rogers Ratios
- Duval's Triangle
- IEC Ratios
- IEEE Conditions
- Key Gases

All of these methods above are used by the LubeTrend laboratory in electrical fault diagnosis, but our default diagnostic method is the Rogers ratios method followed by Duval's triangle where confirmation is needed.

Did you know the inventor of Rogers Ratios worked for Lubetrend?

The reason our default method is the Rogers' ratios is Ron Rogers who invented the system and was one of the first to publish a method for DGA Ratios fault gas interpretation, worked for Bob Cutler at his laboratory in the 1980s to 1990s and trained our diagnosticians in this method of interpretation. Some of our diagnosticians were personally trained by Ron Rogers, whilst the remainder (including myself) were trained by Ken Lewis who spent most of his early career learning electrical oil diagnostics at the side of Ron Rogers at our laboratory.

Diesel Fuel Testing – Routine Testing

Note – Fuel regulations are constantly changing and also vary by country. The threshold values used in this document are based on latest information as of point of writing based on UK regulations, but if in doubt some limits may be outdated please contact the laboratory (+44 (0) 1492 574750) / techservice@alcontrol.com if you have any questions. Additionally, ask for if there have been any updates to this guide to reflect any new regulation limit changes.

Much of the testing is performed to confirm the fuel meets specification at the point of the refinery. There are often complex transportation and supplier chains before the product finally meets the client and the product can be held in bulk storage where contamination can occur over time. Hence, in addition to the standard refinery testing to specification that is performed there are additional places where fuel testing can be performed.

- **Specification testing** - testing to full standard specification of fuel – commonly a mandatory requirement. Examples include:
    - **Point of sale to client** – confirmation product meets requirement at point of delivery.
    - **Periodic spot checks** – usually annual, especially on critical pieces of equipment, or where more than one fuel type is used on site to confirm no cross-contamination.
- **Condition Testing** - confirmation fuel has not been contaminated during bulk storage. These are generally more condensed suites to look for contamination such as dirt, water and microbes. Examples include:
    - **Bulk storage tank checks** to confirm no water, dirt or microbial growth. Usually performed 3 monthly, or post tank cleaning. Bulk tank testing is usually performed in two locations:
        - **Bottom of tank –** To identify sediment, water and sludges that require drain off.
        - **Centre of tank** – to identify overall condition of the bulk of the tank.
-
- **Warranty Testing** - confirmation correct fuel has been used in the machinery for warranty purposes. This is commonly requested by OEMs to confirm if a failed machine is covered by warranty and if the warranty has been invalidated by mis-fuelling. Examples include:
    - **Any machine failures** where suspected fuel faults.
    - **Suspected mis-fuelling** e.g. Petrol in diesel.

Elemental Analysis - See our YouTube video (minutes 16 to 18) for principles of how this test is performed.

Diagnostic significance: This is usually used to test for presence of lubricating oil contamination (calcium, Magnesium, Phosphorus or Zinc), as well as Iron corrosion in bulk storage tanks and the sulphur is within specification. In marine applications Vanadium and Nickel are also good indicators of cross contamination with heavy fuel oil products.

Elemental Analysis – Sulphur (30ml)

This is the most commonly monitored fuel property on diesel across all industries. This is because regulations have continuously lowered the level of allowable sulphur to be used owing to its environmental implications and its link to emission gases causing acid rain. Additionally, sulphur in the presence of water (produced in the combustion process) forms sulphuric acid – battery acid, which means more acidic by-products causing corrosion to engine parts (see earlier sections "Tests on Lubetrend report" - Acid number and Base number). Finally, sulphur in the form of active sulphur can lead to corrosion of injection system components (see copper corrosion). This has meant that, for example, some fuel regulations have reduced sulphur content from 1000ppm to as low as 10ppm over the space of a decade.

Sulphur maximum limits are also variable by industry and application with a fuel acceptable for off-highway standby generators not acceptable for combustion in a road operating vehicle. In addition, in the marine industry bunkering in one location with different regulations for fuel, can mean although the sulphur is acceptable in one location, it cannot be burnt in another location – hence the need to monitor every batch of fuel, even if the fuel met specification at point of sale. One of the problems in lowering the sulphur is that despite its obvious disadvantages, sulphur is an excellent lubricant and so the constant lowering of sulphur content causes headaches for both OEMs in operating more fuel efficient fuel injection rail systems with tighter tolerances as well as fuel suppliers in supplying fuel with sufficient lubricity properties to prevent injectors seizing.

Water Content (20ml)

Water is a poor lubricant, causes corrosion, promotes microbial growth and also is not combustible, so its content needs to be tightly monitored to ensure efficient operation of the machinery. It additionally is not taxable, so in transport chains its content needs to be monitored closely to determine if 50000L of bulk delivery fuel is indeed that or if 500L of it are water for instance. In a market where exceptionally large quantities of bulk fuel storage fuel are bought and sold each day, and profit margins in the industries buying the fuel are quite small, any additional expense that should not be incurred can have a big impact on the businesses involved.

Diagnostic significance: The cause of water is usually due to fuel storage conditions in that tanks 'breathe' – i.e. the air temperature in the day and night changes meaning there is a constant circulation of air – usually through breathers – into the tank. At night this cool air condenses on tank walls and

over time there can be a large build-up of water content in the storage tanks. Additionally, tanks tend to be drained or pumped from the bottom meaning if the tank has not been disturbed for a long time water sinks to the bottom of the tank because water is denser than fuel. This means that even low water contents overall, are found in high concentrations when drawing from the tank bottom.

Microbial Growth (10ml)

Microbial growth is usually only present when water is also present in the system as all known cellular life requires liquid water to thrive. Hence, minimising water content is an excellent way of reducing microbial growth. The reason microbial growth is so important is that they tend to get filtered out by the filtration system in addition to water and the filters act as an excellent breeding ground for microbial growth. This growth can completely block filters meaning insufficient fuel reaches the injector rail and the engine stops.

There are two main ways of detecting microbial growth. One is to measure as a culture, where the microbes are incubated for sometimes several days or even weeks to identify the number that grow per volume, termed Colony Forming units (CFU/ml). This is useful for determining the microbe type e.g. bacteria/fungi or yeast/mould so that a suitable biocide may be used. However, please note local regulations vary on the use of biocides in fuel systems – so please check with your local authority if you can use them. The use of tank cleaning services where the tanks are flushed and cleaned is becoming more common – in these cases the particular organism is not as significant and the speed of testing becomes more relevant. In these situations, fast turnaround test kits are quite popular. These can produce results in just a few hours of microbial activity by biochemistry as opposed to microbiology. cATP looks at the presence of life by life-presence confirming biochemical reactions as opposed to culturing and growth. The testing is usually more expensive than performing standard culture methods, but does give a faster result, which in critical equipment is usually something that is worth the extra cost.

Diagnostic significance: The viscosity is an important physical property. Causes for high viscosity include: too high biofuel, lubricating oil or heavy fuel oil contamination, whilst too low viscosity can be caused by solvent or petrol contamination.

Fuel (Diesel) – Typical Specification Limits used

Limits based on EN590: 2009 for Road vehicles / coastal vessels, BS2869: 2010 for off-road highway vehicles and stationary applications, and ISO 8217 for marine applications (none-costal). Regulations change by country, so consult your local authorities to for regional differences.

		Road (EN590: 2009)		Offroad (BS2869: 2010)				Marine (ISO 8217: 2010)							
		Automotive		Off-road mobile		Off-road Stationary		DMX		DMA		DMZ		DMB	
Test	**Units**	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Viscosity @ 40C	*mm2/s*	2.0	4.5	2.0	5.0	1.5	5.0	1.4	5.5	2.0	6.0	3.0	6.0	2.0	11.0
Density @ 15C	*Kg/m^3*	820	845	820		820					890		890		900
Calc. Cetane Index	-	46		45			45	45		40		40		35	
Carbon residue (10% bot.)	*%*		0.3		0.3		0.3								0.3
Dist. Recovery @ 250C	*%*		65		65		65								
Dist. Recovery @ 350C	*%*	85		85		85									
95% recovered at	*^oC*		360												
Flash Point (closed)	*^oC*	55		56		56		43		60		60		60	
Sulphur	*mg/kg*		10		**10** (at Manufacture) **20** (at distribution)		1000		10000		15000		15000		20000
Ash content	*%*		0.01		0.01		0.01		0.01		0.01		0.01		0
Water content	*mg/kg*		200		200		200								3000
Contamination/Sediment	*mg/kg*		24		24		24								
Oxidation Stability	*g/m3*		25		25		25		25		25		25		25
Copper corrosion (3h @ 50C)	*rating*		1		1		1								
FAME	*%*		**7** (in UK)		**7** (in UK)		**7** (in UK)								
Lubricity wear scar at 60C	*µm*		460		460		460								
CFPP			**-4** (UK Mar to Nov) **-12** (UK Nov to Mar)		**-4** (UK Mar to Nov) **-12** (UK Nov to Mar)										
Pour point	*^oC*										-6 (winter) 0 (Summer)		-6 (winter) 0 (Summer)		0 (winter) 6 (Summer)
Cloud point	*^oC*								-16						
Strong Acid number	*mgKOH/g*				None		None								
Hydrogen Sulphide	*mg/kg*								2		2		2		2
Acid Number	*mgKOH/g*								0.5		0.5		0.5		0.5
Sediment (hot oil filtration)	*%*														0.1
Appearance	-							Clear & Bright							

Section 4 - Specialist testing – filters and forensic failure analysis

Lubetrend Filter Debris Analysis (LFDA)

OIL FILTERS are designed to capture:

- Wear metals
- Solid debris
- Water
- Spent Additives

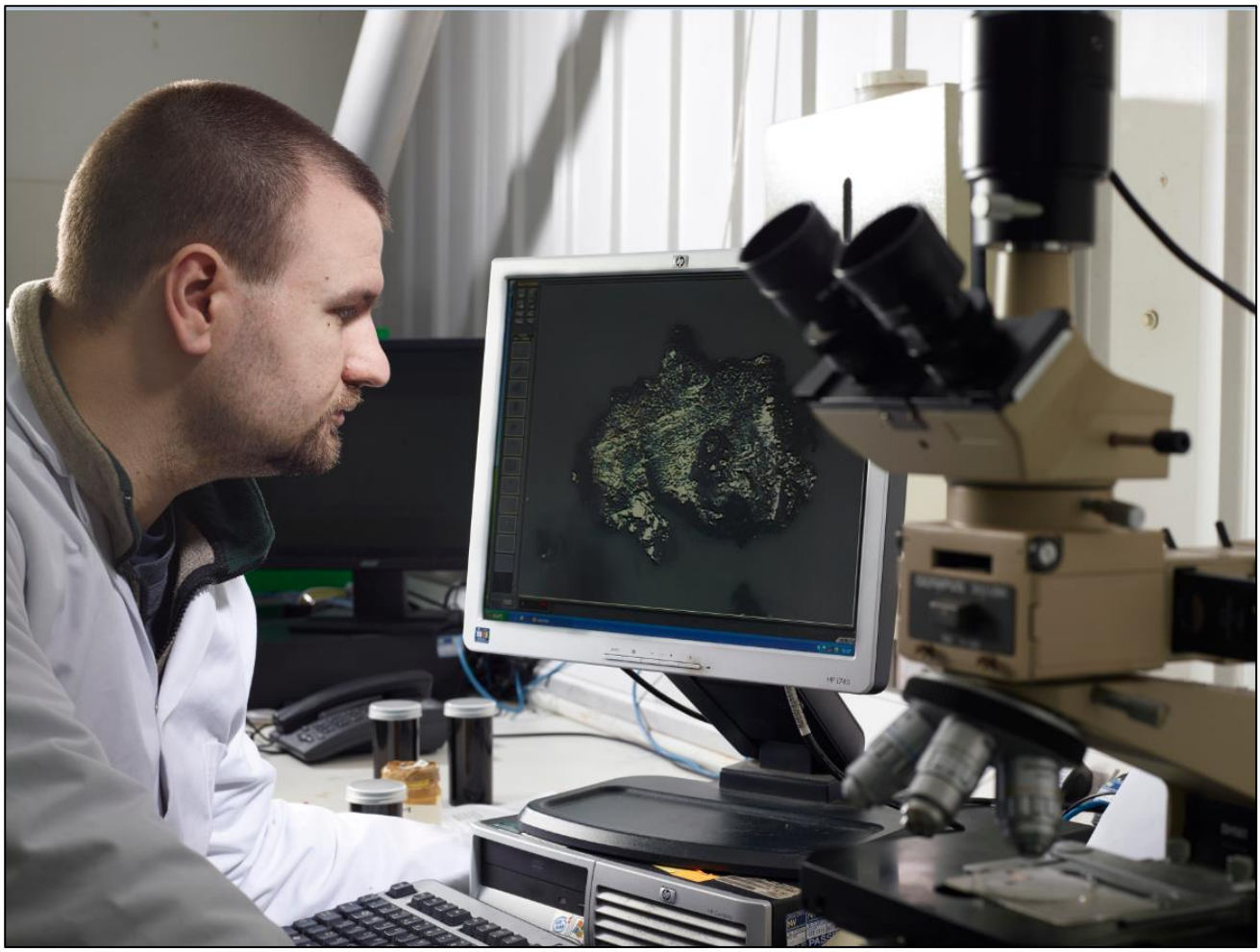
Hence show historical evidence of wear patterns & contamination –

Making them a valuable receptacle of information to perform Root Cause Analyses (aka Machine Post Mortems) through Analytical Ferrography

Standard Filter Analysis programmes detect stages of component failure through Standard Analytical Ferrography providing valuable information concerning:

- Early Stages of abnormal wear
- Large Wear particles - indicative of serious wear
- Small Wear particles - by Fine filtration preventing detection by regular Condition Monitoring atomic emission spectroscopy
- Wear mechanisms & Failure Modes
- Root Cause Analysis – but not organic material contamination

However, the Lubetrend Filter Debris Analysis (LFDA) Programme is a full Root Cause Analysis programme including Standard Ferrography **and far more**. Indeed Alcontrol trains customers and their competition in the art and techniques of Standard Ferrography, through their accredited British Institute of Non-Destructive Testing (BINDT) courses, held within their impressive, well equipped Lubricant Condition Monitoring Laboratories.



Ferrography is a proven technique to identify the mode of failure by studying the morphology (shapes & texture) of the wear debris found in a used oil filter, offered by many laboratories. However, the Alcontrol Full Filter Analysis programme is far more - it recognises Filters also show evidence of both organic & inorganic debris leading to failure modes not evident by standard Ferrography techniques alone.

Lubetrend recognises and understands that filters rarely fail owing to wear debris alone – but recognises filters block due to minute inorganic particles, immiscible fluids, oxidised oil debris, spent additives compounds and insoluble organic chemical contaminants not miscible with lubricants, which together with normal wear debris and environmental dirt, blind the filter medium pores, causing the demand for repeated early filter changes and potentially complete machine failure.

The Alcontrol Filter Analysis Programme (LFDA) includes both Analytical Ferrography and their specially designed Chemical analysis programme to identify chemical species found in most used filters.

Staffed by highly motivated oil chemists and diagnosticians with decades of experience in oil analysis and lubricant formulations, the Alcontrol Filter Analysis Programme (LFDA) is able to identify the chemical structure of organic and inorganic materials present in filters - using Atomic Emission & FTIR spectroscopy, XRF, Laser Net Fines (LNF), Microscopy, Gas Chromatography and wet chemical techniques.

Then Alcontrol reports this valuable diagnostic and prognostic information in clear - user friendly terms - giving recommendations & advice on what action to take to overcome the problems identified by (LFDA).

Section 5- Training Courses – get further information

Training Courses (ISO 18436 certification)

If you have enjoyed this introductory guide and would be interested in attending one of our formal training courses please let us know at techservice@alcontrol.com

Coming soon in next version of this guide

If you would like to offer suggestions for other topics to cover please message me on LinkedIn

These pages are for additional notes

Want to Learn More? Please Attend Our Courses

BINDT

LubeTrend

Experts in Oil Analysis

Course Content: Level 1

- Introduction to lubricants
- Maintenance of lubrication devices and equipment
- Storage, handling, dispensing of lubricants
- Lubricant selection
- Oil Sampling
- On Site testing of lubricants
- Common laboratory tests
- Verification of collected data and interpretation
- Input of laboratory data into spreadsheets/database
- Maintain Oil analysis program/database
- Undertake basic machine inspections/audits
- Demonstrate basic quality knowledge in accordance with laboratory practises (ISO 17025)

Course Content: Level 2

- Overview of Level 1 course
- Setting up of machinery specific test-suites
- Establish Lubricant Monitoring Programs
- Failure Mode & Criticality Analysis
- Management Reporting
- Operate & Identify wear debris particle instruments
- Preparation of reports & corrective actions on machines condition
- Manage & Trend analysis databases
- Use of other CM Techniques (VA, Thermography)

ISO 18436 - British Institute of non destructive testing (BINDT) training programme conducted at Alcontrol, Conwy Oil Analysis Levels I, II, & III