TUGNOLOGY '17

ROTTERDAM
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Day 2
Paper 8

Your Oil Is Talking, But Are You Listening? Controlling and Monitoring Oil Contaminants on Tugs

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SYNOPSIS

As modern tugs have evolved, so has the lubrication of these systems. Today, increasing demand is put upon lubricants in terms of operating temperatures, loads and performance. The oil film over components is only a few microns thick, invisible to the human eye, and it is therefore essential to control and monitor contamination effectively. It is well established that cleaner oil leads to longer component lifetimes and increased operational liability, but clean oil also means that an operator can detect small changes in both online and laboratory analysis, thereby often detecting abnormal wear before a breakdown.

INTRODUCTION

Any machine that uses oil for power transfer or lubrication is dependent on the condition of the oil. Oil comes into contact with all system components, and should be regarded as being as important as the blood in our bodies. The primary objective of keeping oil clean in a hydraulic or lubrication system is for protection of machine components to optimise reliability and function, as the consequential cost of a breakdown and loss of availability is very high. Malfunction of a thruster or hydraulic system can force a tug to come off-hire.

The secondary objective is to reduce running costs by extending the lifecycle of all system components, as well as the oil itself, which ensures optimum economic performance and return on investment. In most oil systems, you'll find silt particles of between 2-10 microns, with 1 micron (μm) equalling 1/1,000mm. In comparison, a human hair has a diameter of 70μm. Most particles are invisible to the naked eye, but can enter the oil system in large numbers via system openings, shaft seals, as well as inadequate air breathers.

Figure 1: Tug pushing cargo ship

Airborne particles are highly abrasive, as they get trapped in clearances in between gear teeth, valve plungers and housings, or between the piston and cylinder in a piston pump. The result is abrasive wear, known as seizing or grinding, which can give rates of wear 1,000 times greater than that anticipated by the machine manufacturer.

The same applies to the combustion of diesel and gas oil, where impurities in the form of particles and water accelerate wear on the fuel pump, needle valves in injectors, and other components. Modern common-rail systems with high injection pressures have very fine tolerances, typically 2-5μm, so they require very clean diesel.

Contamination control will result in increased operational availability and reliability, increased machine life due to reduced component wear, an extended oil life producing less waste oil and sludge, and a decreased carbon footprint and environmental impact.

CONTAMINANTS IN OIL

By definition, contaminants are anything which should not be in the oil, but most often we focus on three basic types: solid particles, water, and oil oxidation/degradation products (also referred to as 'varnish'). Reliable and optimally protected oil systems can only be realised if these contaminants are removed.

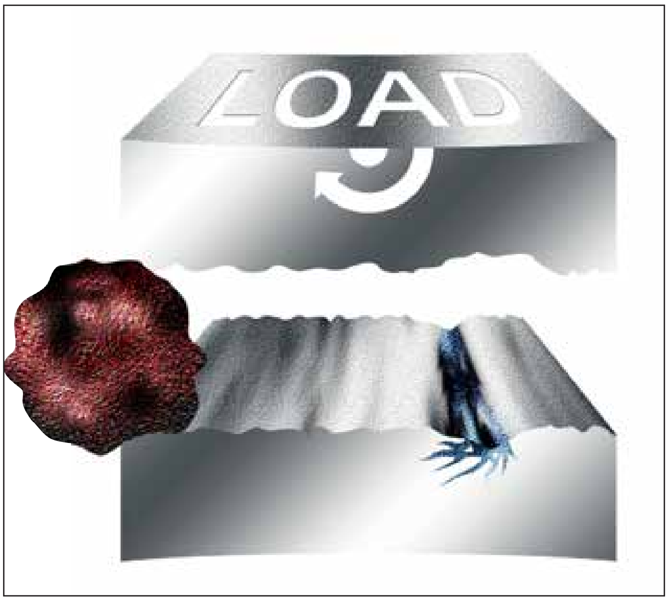

Figure 2: Solid contaminants

Solid particles *(Figure 2)* are extremely damaging, as they accelerate wear on pumps, valves, bearings and gears. Most particles are less than 10µm in size. Metals present in the oil will also act as catalysts to speed up the oil degradation process, resulting in varnish.

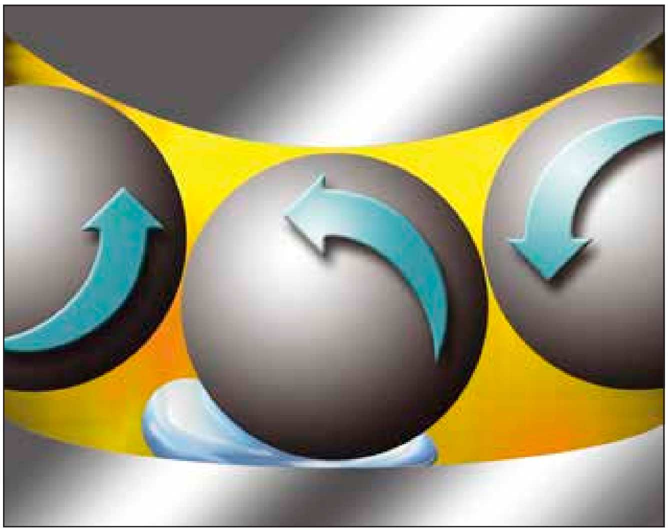

Figure 3: Water contaminant

Water present in oil *(Figure 3)* will cause damage such as micro-pitting and hydrogen embrittlement in pumps, gears and bearings, and is a catalyst for both rust and varnish. Water can also cause bacterial growth and sludge, particularly in diesel and stern tube oil.

Figure 4: Varnish

Oxidation caused by oil degradation reduces oil life considerably. The degradation process forms soft contaminants which fall out as varnish *(Figure 4)* and sludge in cold areas of the oil system, and will result in sticking valves, blocked heat-exchangers and accelerated wear due to the so-called 'sandpaper effect' of these products.

The most harmful particles are those of similar size or slightly bigger than the dynamic tolerance between the moving parts in the oil system. *Figure 5* below shows the distribution of particles by size in a medium loaded oil system. Only 10 per cent of all particles in the system are larger than 10µm, while about 70-80 per cent of the particles in the system are around 1-5µm, being quite difficult to capture in a normal pressure line filter.

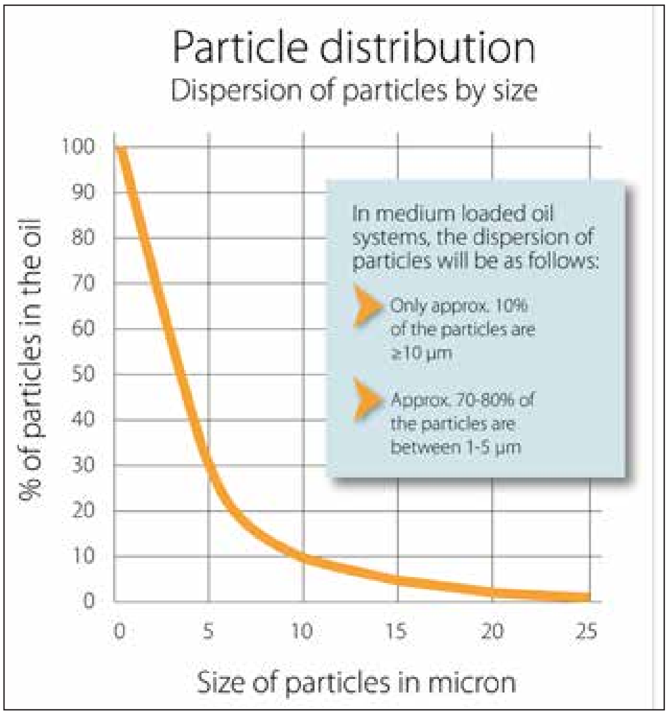

Figure 5: Particle distribution in oil

HOW TO ENSURE OIL CLEANLINESS

To ensure optimum oil and diesel cleanliness, you will need to limit ingression of contaminants, as well as remove particles and water already found in the oil. This is most effectively done by combining the follow elements:

- An air breather with a 3-10µm filter and silica gel for moisture absorption (desiccant). A hybrid version of this, including a bladder, will make the silica gel last longer;
- An inline pressure filter of 10-15µm with a capture efficiency above 99 per cent (B10 > 100);
- An offline depth filter *(Figure 6, overleaf)* capable of removing 3µm particles, bacteria, varnish and water. This should be connected to the most contaminated location, drawing oil from the bottom or drain and returning clean oil to the other end of the tank. A large dirt holding capacity will reduce filter operation cost.

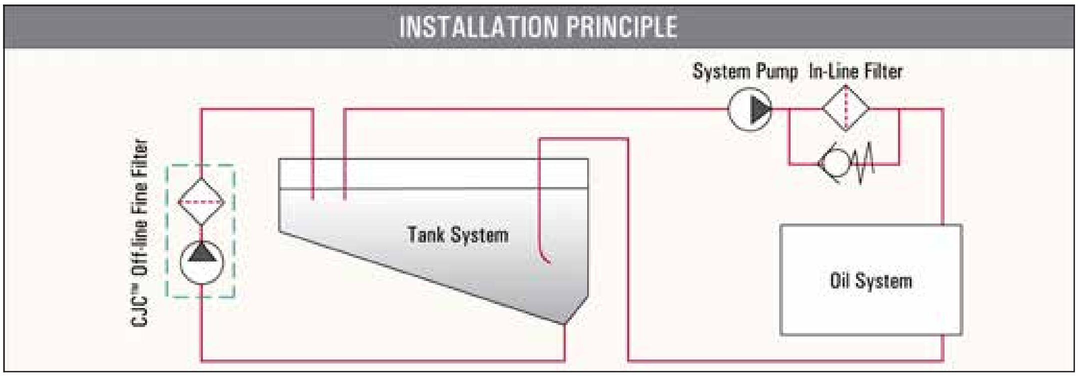

Figure 6: Installation principle of offline filter on lube oil and hydraulics

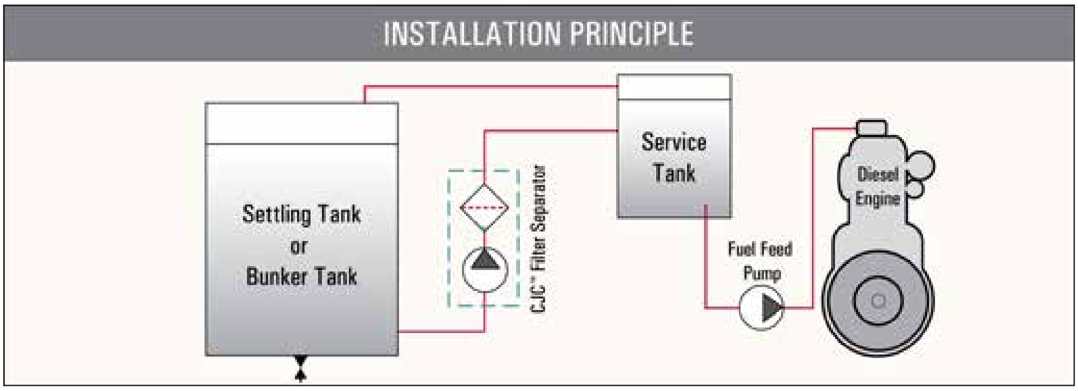

Figure 7: Installation principle of depth filter separator on diesel

In diesel engines, fuel cleanliness is of great importance, since the service life of fuel injectors and the pump depends on it. In common-rail systems, the high pressures require very tight tolerances, such as 2-5µm in the needle valve (found in injectors). A filter separator *(Figure 7)* capable of removing 3µm particles, bacteria and water will increase the life of the injector and pump, plus reduce the risk of diesel leakage into engine lubricant oil via worn injectors. Bacteria, also known as 'diesel pest', can be removed as well. The service tank will need to be clean, and the settling tank can over time be cleaned as well if a return line from the service tank is installed with approximately 10-20 per cent of the capacity returned.

MONITORING OIL CONTAMINATION

An effective contamination control programme should be introduced to regularly monitor the oil's condition, which will offer an insight into the condition of components and machines. Oil monitoring can be accomplished using on-site tests for systems of high criticality, but should also be verified by online sensors or laboratory tests. Oil sampling procedures should be carried out by trained personnel to ensure that representative samples during machinery operation are consistent, and to ensure a data trend (history) can be followed.

On tugs it is recommended to take oil samples at least every three months from the following systems:

- Main and auxiliary engines;
- Thrusters;
- Hydraulic systems;
- Gear/clutch;
- Stern tubes (if applicable).

An oil sample will reveal lots of information about the oil properties and system condition, even prior to shipping the results to a lab. The following onsite tools can help you translate information into corrective actions, and possibly avoid machine breakdown.

Visual inspection

Look at the oil colour *(Figure 8)*. Is it comparable to new oil? Oil oxidation changes the colour from amber to dark brown. Black oil is usually caused by soot from combustion by-products (engine lubricant oil) or micro-dieseling in hydraulic fluid due to entrained air in the suction of the pump.

Figure 8: Visual inspection

Can you see any large wear particles, exhibited as a black or shiny sediment? These are >100µm. Use a crackle test to show the water level above 1,000ppm (oil drop on hot plate). Look for cloudiness, emulsions, or free water – does water ingress into the oil system? Check the oil demulsibility by mixing oil with water at a ratio of 50/50 and time the separation. An emulsion of more than 5 per cent, or if the water takes more than 20 minutes to separate, means that the water separation efficiency, by coalescence or centrifugal forces, will be severely harmed. Engine oil, esters, glycols and most EAL fluids will keep the water in suspension, so will not show free water.

Blotter spot test

A drop of used lubricating oil on chromatographic paper will reveal soot, glycol and fuel dilution. Excessive soot contamination will cause the dispersant additives to deplete and the soot particles to agglomerate, forming larger particles and producing increased oil viscosity. On the blotter paper this will form a black spot *(Figure 9)*. Lubricating oil with good additives will lift soot particles easily and show a dark grey colour across the paper. Glycol can be located as black sticky paste with a sharp edged periphery, making the oil unable to travel on the paper. Fuel dilution can be detected when inspected under UV light, as a fluorescent ring will appear.

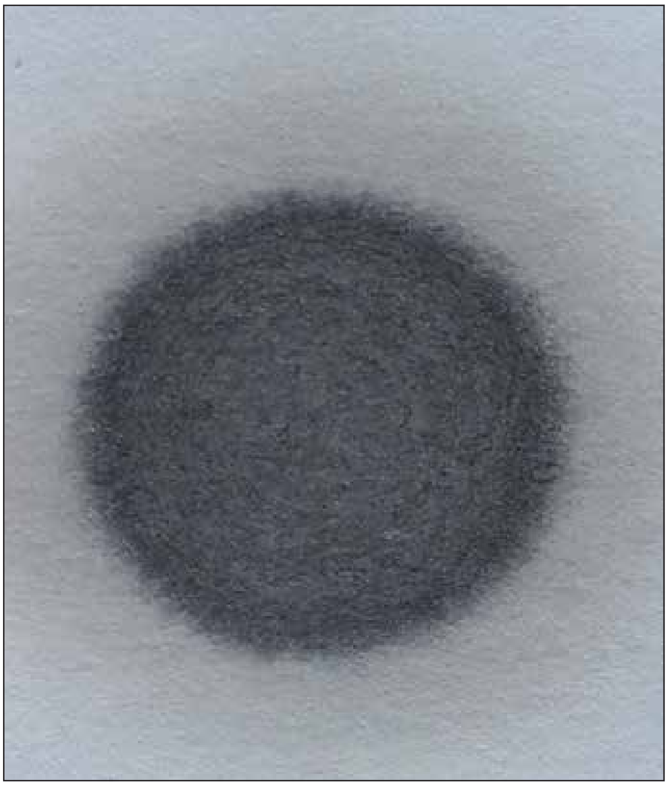

Figure 9: Blotter spot test

Inspecting the used filter element

To inspect this, examine a piece from a used filter element and look for shiny particles from metal wear, such as iron and brass. Iron wear particles are usually magnetic, so if a strong neodymium magnet can lift the material, then you have problems with machine wear. Note that iron particles can be black like soot, shiny/silver, or amber/brown like varnish *(see Figure 10)*.

Figure 10: Used filter element

If you can lift a piece of the filter, have an oil lab perform a WPC or PQ test. Using a USB microscope at a magnification of 200-400 times will reveal the colour, size, and shape of captured particles. Photos of magnified particles are more eloquent than a thousand words, and will help you to predict a wear situation.

CHANGING OIL

Oils are often changed because the lab report says so. This recommendation is usually based on a change in viscosity or acidity (TBN/TAN), or high levels of dirt, water, varnish or metal particles. Quite often the discarded oil is actually in chemically good condition, and could therefore have lasted much longer. The properties may still be intact, but the oil is just too dirty, the water content is too high, or the oxidation/varnish level has increased.

All of these contaminants can actually be removed from oil. If you spend five minutes reading the oil analysis report, you should see what the problem is. So instead of just replacing the oil, you might be able to clean it without having to replace it – and most importantly, to find out what the reason for the contamination is, and solve it, so it will not cause similar problems in the future.

ONLINE OIL ANALYSIS

Online oil analysis can help to predict if an oil change is really needed or if filtration is enough. Furthermore, it gives you access to historic data (the trend) and so can help you predict wear situations. Online technologies are becoming increasingly popular and for a good reason. The best condition monitoring of oil systems can be achieved by considering oil condition, water content and particle count in combination. Oil condition and water content sensors correlate to the oil's quality, and particle counters/sensors relate to equipment condition. Combining both enables optimum condition estimation for any oil system.

Obtaining the optimal installation point for the online sensors is vital to get the most representative data. It has been shown in tests that the offline circuit is an ideal place for online analysis, due to the constant homogeneous flow, stable temperature conditions and suction from the bottom of tank/sump. Optimal conditions are thereby present for evaluation and measurement of particles and general oil condition.

Oil condition sensors

Condition sensors typically measure the oil's quality by impedance spectroscopy, which correlates to oil degradation by oxidation, acidity, soot and water content. The sensors can be used to assess the oil properties and recommend actions such as top-up, filtration or full oil change. Monitoring enables you to take actions prior to severe degradation of the oil, or discover if general oil properties are out of specification.

Figure 11 shows results from a CJC oil condition sensor on a hydraulic system with increasing oxidation rates over a period of two months. The high level of oxidation/varnish in the oil warns the operator to schedule an oil change or to install a varnish removal equipment, such as an offline cellulose depth filter.

Oxidised oil can cause seizing of hydraulic valves as well as increased viscosity, which create problems such as increased friction and heat. In addition, the oil may be difficult to pump, leading to starvation. Oil oxidation and varnish can subsequently result in malfunction in the main winch, which can force the vessel to come off-hire.

Water in oil can be monitored by sensors giving an exact amount of moisture in ppm, but since these sensors are relatively expensive, more often systems use sensors giving humidity in a percentage related to the oil's saturation point, called %RS or %RH.

Water in oil

Water is often considered as the enemy of thruster lubrication oil. Water can be discovered in oil as:

- Dissolved water: the water molecules dispersed one-by-one throughout the oil, like humidity in air;
- Emulsified water: microscopic globules of water dispersed in stable suspension in the oil, like fog;
- Free water: water that readily settles to the tank/sump bottom; like rain.

The states of water in oil change depending on the base oil type, additives, pressure and temperature. When the water-state changes from dissolved into either emulsion or free water, we have passed 100 per cent of the saturation level (100%RS or %RH) at which the oil is able to hold at a given temperature and pressure.

A mineral-based hydraulic oil may have a saturation point of around 200ppm water in oil at 30 degrees C, but the same oil may dissolve up to 500ppm of water at 65 degrees C at 100 per cent saturation point. Therefore 50 %RS or %RH will correspond to around 250ppm at 65 degrees C. It is recommended to operate below 50 per cent of the saturation point at all times, to avoid free water or emulsions being formed when the oil system cools down.

A practical example for usage of an online oil humidity sensor could be on a thruster, where the sensor enables the operator to monitor water ingression and decide when to install a water separation filter.

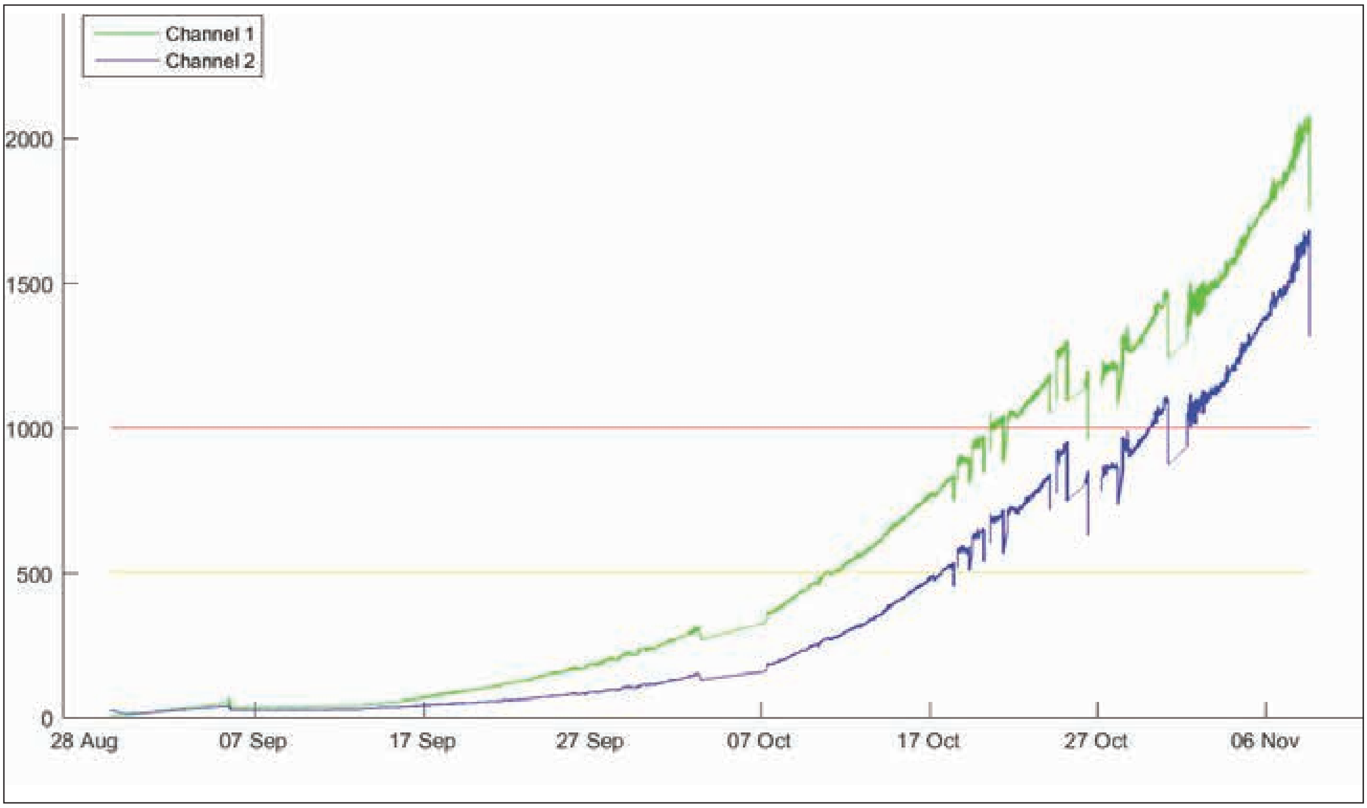

Figure 11: Oil condition sensor results

A well maintained thruster with good lubricating oil may show 10-30%RS during operation, but if this number increases, it indicates water ingression through worn seals etc. When the threshold of 60%RS at operation temperature has been passed, it is time to install a water separation equipment (thruster oil filter), to avoid free water falling out of oil solution, which will harm thruster gears and bearings severely *(Figure 12)*. A good thruster filter can remove water from the oil at the same rate as the ingression, so the tug can continue its job and schedule an inspection or docking for later.

An oil analysis will show the same trend of water in oil, but since oil samples are just taken every 3-6 months, the failure can progress during this period. An online humidity sensor *(Figure 13)* will detect the problem within hours and enable the operator to act fast.

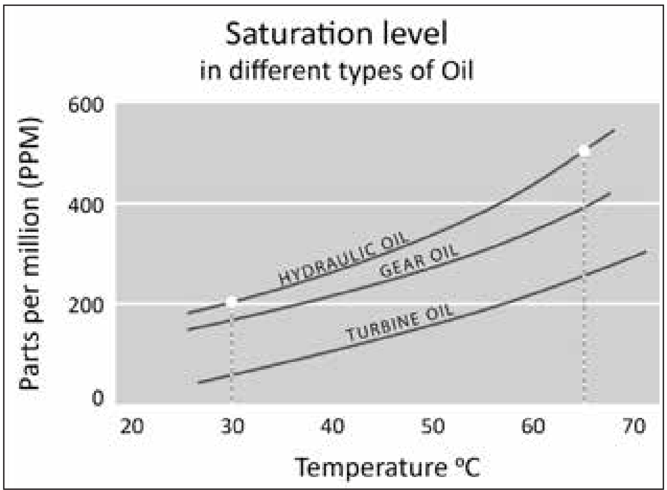

Figure 12: Saturation levels in different oil types
(Image: MP Filtri)

Figure 13: Oil condition monitor on HDU filter

Other oil types will have different saturation points, with SAE-standard engine lubricating oils and glycols having the highest, holding several thousand ppm water in solution. Furthermore, engine lubricating oils will create mainly emulsions and rarely free any water.

ONLINE PARTICLE COUNTING

Particles are always being created when machines are in operation, depending on load, rotational speed, oil temperature etc, but if the oil is kept free from contaminants then wear will be reduced to a minimum. Furthermore, it is much easier to discover abnormal wear when cleanliness is good, compared to a very dirty oil.

As an example, a worn bearing in a gear generates 50,000 particles larger than 4μm per 100ml of oil. If the oil's cleanliness is up to ISO 16/14/11 then it will contain a maximum of 64,000 particles above 4μm per 100ml, and thus the 50,000 extra wear particles will be easy to spot. On the other hand, this quantity would 'disappear' in dirty oil with 4 million particles per 100ml (ISO 22/20/17). Online particle counters continuously display information and will, in such cases, give you instant notification that something is wrong.

Benefits of online particle counting

- Early warning: if the trend rises, a worn bearing can be replaced in the gearbox instead of a total breakdown occurring
- Problems and schedule maintenance are foreseen based on the wear situation, again avoiding failure during hire
- Instant data and access to a history/trend can support more precise decision-making in case of overhauls, as well as improved maintenance practices and intervals

WEB-BASED VIEWER PLATFORMS

One of the available web-based platforms for online monitoring is the CJC™ Trender Tool, which receives data from the sensor package via a secure connection (GSM or Ethernet). The data can be shown on a webpage, but can also be provided directly to a surveillance system (SCADA system). Alarms can be sent out to the operator by email or text message when set thresholds have been passed.

Figure 14, opposite, shows sensors for water (in %RS), oxidation (varnish), an oil cleanliness code according to the ISO 4406 standard, filter inlet pressure and oil temperature. A useful load sensor can be incorporated as well. This screen enables the operator to see trends in quick overview, plus access to email updates.

The user can then choose to zoom in on one of the trends (eg, oil cleanliness) to look at the ISO codes or raw counts for specific dates. This is therefore a useful tool to support decision-making in case of increased particle counts *(Figure 15)*.

THE THRUSTER OIL FILTER

Many tug operators vouch for the performance of offline thruster oil filters, since they have experienced reduced maintenance costs after less than six months' operation. More importantly, a good thruster oil filter will

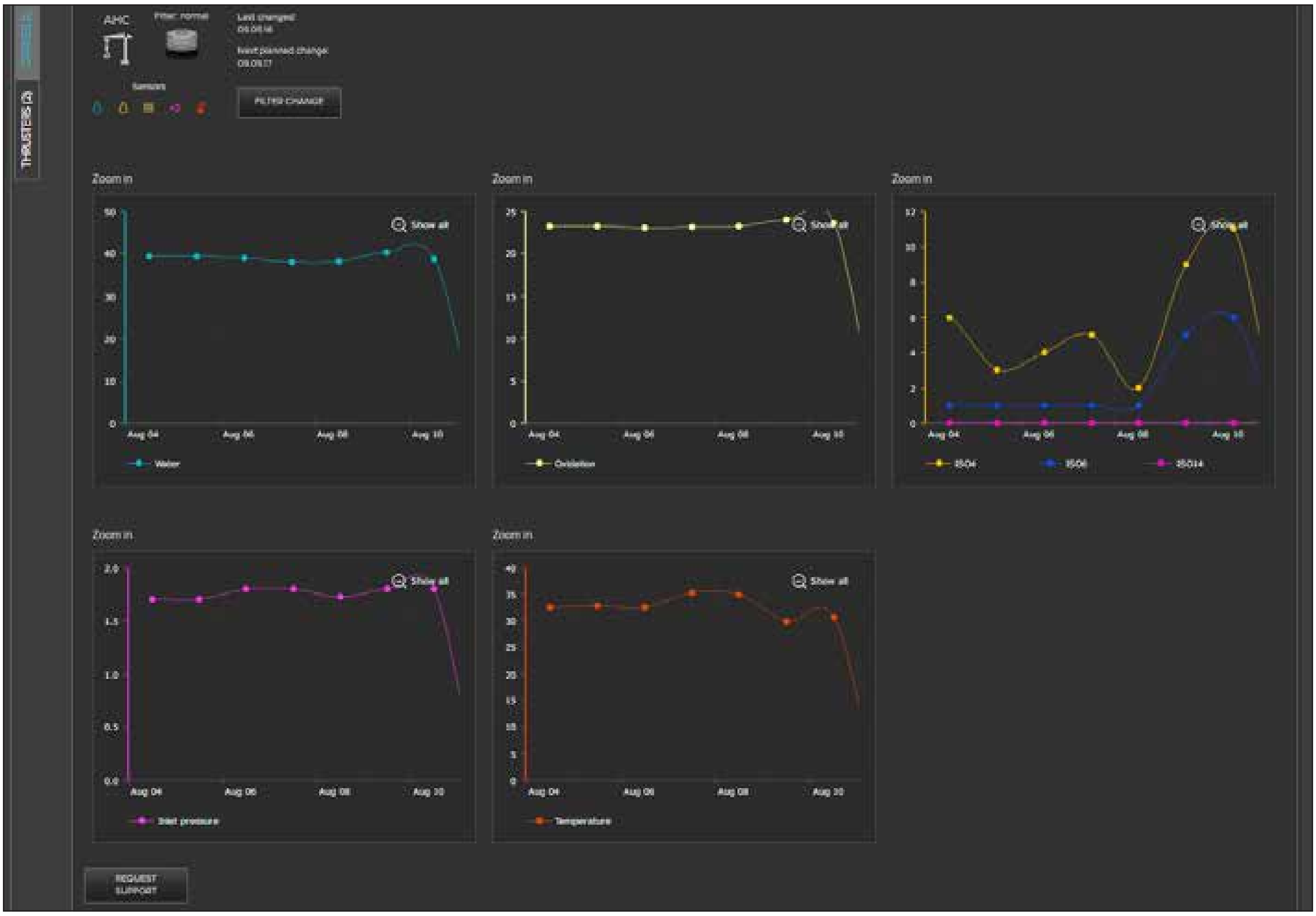

Figure 14: Trender tool overview screen

Figure 15: Trender tool zoom in details

allow a vessel to continue operation in spite of water ingress or excess amount of particles in the oil.

The optimal situation is to remove sea water continuously without the need for changing numerous water-logged filter inserts, and to avoid salt concentration building up in the oil, which can occur if evaporative equipment is utilised. Continuous water separation from thruster oil may be the factor needed to allow the vessel to continue working and defer docking to a later date.

Especially in the case of OSVs and anchor-handling tugs, this could mean being able to complete a delivery/contract without the need to come off-hire to fix the leak, as this usually means dry-docking the vessel. As an extra benefit, a good thruster oil filter will also take care of any particle and varnish contamination in the oil, extending the life of the oil, the shaft seal(s), the gears, bearings and all other components in the system.

CASE 1: PARTICLES PREDICTING A THRUSTER FAILURE

The following case is from a tug operating in the North Sea close to Denmark. The thrusters were equipped with online sensors for:

- Thruster load;
- Oil temperature;
- Water as percentage of the oils saturation point (%RS or %RH humidity);
- Wear particles larger than 100μm (Edi-current);
- Particles according to ISO 4406 (4μm, 6μm and 14μm).

Figure 16 below shows a normal correlation between thruster load and oil temperature. The water content is low at 10-15%RS, but the counts for larger metal particles show a clear upward going trend (green curve). Particles above 100μm are often related to a severe wear situation.

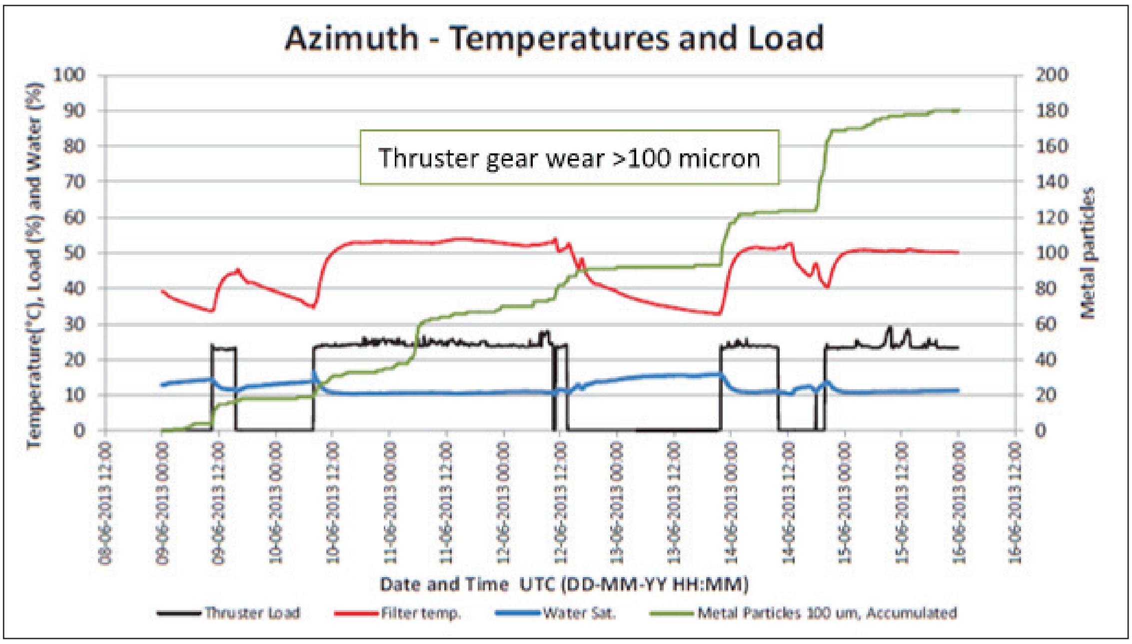

Figure 16: Normal correlation between thruster load and oil temperature[1]

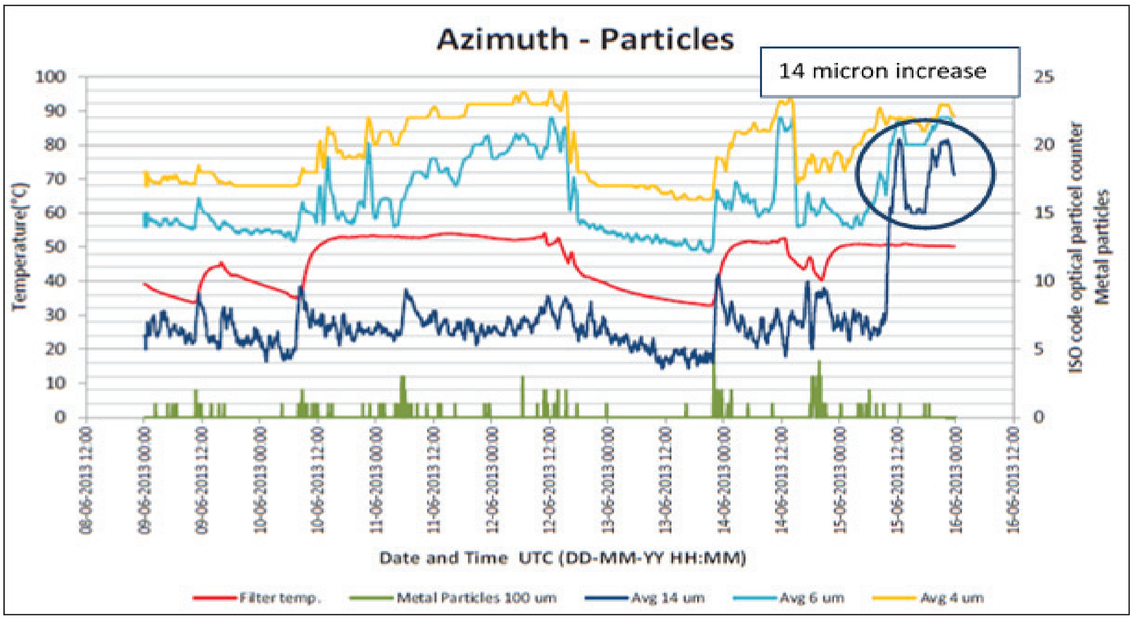

Figure 17: ISO codes, oil temperature and large metal particles[1]

Figure 17, previous page, shows ISO codes, oil temperature and large metal particles. While the amount of particles ≥4μm and ≥6μm fluctuate with temperature (load), it is easy to see that particles ≥14μm are increasing in number, again indicating a serious wear situation (shown in blue). In this case, the operators could now schedule docking and take the tug out of service before thruster breakdown.

CASE 2: EXTENDING LUBRICANT OIL LIFE IN A DIESEL ENGINE

Four-stroke trunk diesel engines often experience a short oil life due to a decreasing total base number (TBN) and increasing amount of insolubles, mostly soot. Dirty oil also results in premature wear and expensive engine overhauls.

The main reason for short oil life is related to combustion blow-by (soot, acids, etc) entering the engine sump, combined with high temperature and metal particles as catalysts. The insolubles and varnish can block filters, oil pipes and glaze cylinder linings with lacquer. An offline depth oil filter can remove varnish, abrasive particles and the insolubles/soot in order to stabilise the TBN value. Doing so will extend the life of the lubricant oil and components, enabling a longer interval between overhauls.

Bourbon Offshore in Norway had issues with short lubricant oil life (750 hours) and wanted to compare offline depth filters with centrifugal separators. An analysis was performed on the OSV ***MS Bourbon Mistral***, equipped with four Wärtsilä generator engines each of 1,665kW. Ever since they were new the engines have had quite high levels of insolubles (0.7 to 1.0 per cent weight), and the engines were getting very dirty inside. Two centrifugal separators were each connected to two engines, with 30 minutes changing interval. On Bourbon Offshore's own initiative, and with the blessing of Wärtsilä, a 3μm offline cellulose depth filter was installed on one of the engines, while the separator was disconnected.

After 18 days of operating the CJC offline filter and 70 hours of engine operation, an oil sample was sent to Castrol for analysis. The analysis showed that insolubles were reduced to 0.1 per cent weight and the TBN was stabilised *(Table 1)*. The lubricant oil now appeared like new, honey-coloured oil *(see Figures 18 and 19)*.

The lubricant oil was previously replaced every 750 hours, but with offline depth filters it is now only replaced every 4,500 operation hours – which is a six-fold extension.

Figure 18: Lubricant oil dip stick, centrifuge [2]

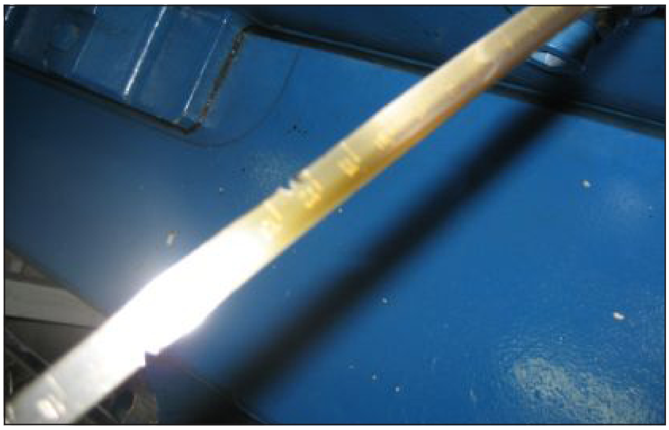

Figure 19: Lubricant oil dip stick, running 3 micron cellulose depth filter [2]

Figure 20 below shows two blotter spot test papers from the Danish ferry ***Tycho Brahe***, with four 2,460kW trunk engines running on marine gas oil (MGO). The first, with the dark spot, was taken when the engine had a centrifugal separator on the lubricating oil. The second was taken from the same engine and oil after one month using a CJC offline depth filter cleaning the oil. A gravimetric analysis showed 0.1 per cent weight of insolubles in the oil. The crew expect a four times longer lubricant oil life extension and at least 30,000 hours between engine overhauls.

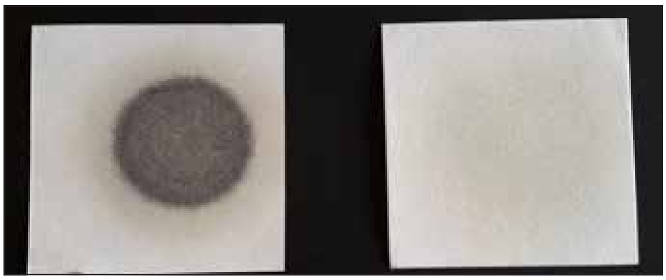

Figure 20: Blotter spot test on oil with centrifugal separator compared to cellulose depth filter[3]

Table 1: Results from **MS Bourbon Mistral**

	Before CJC filtration			After CJC filtration
	16 Jan	24 May	23 July	23 Sept
Insolubles/ soot	0.5% weight	0.6% weight	0.7% weight	0.1% weight

CONCLUSION

Are you listening to your oil? Controlling and monitoring oil contamination and making use of the available knowledge is certainly worth it. If you want to improve your oil cleanliness most effectively, it is done best with a combination of good breathers, in-line filters and off-line depth filters, while monitoring the oils' condition, water and particle content.

The benefits of improving and monitoring oil cleanliness are:

- Increased operational reliability, due to lower component wear;
- Fewer failures during hire/contract, due to problems and schedule maintenance being foreseen and based on the wear situation;
- Assistance with abnormal operation detection and correction, helping to find root causes more easily;
- Reduced oil consumption, thus less environmental impact.

Of course, filters and monitoring equipment come at a cost, but since the return on investment is typically less than 12 months, it is good business to install efficient contamination control equipment and to continuously monitor critical oil systems. For some critical systems, online monitoring and web-based platforms are needed for additional safety, and in order to have data readily available for interpretation.

In the future we will see more online monitoring of oil systems on tugs and workboats, because when operators act immediately it is often possible to avoid coming off-hire. This can be used as a competitive advantage. We may even see unmanned vessels being controlled solely by online sensors and computer systems, but that will be a few decades away.

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[1] Morten Henneberg, *Estimation of Condition and Wear Modes for Oil Lubricated Machinery in Ships*, PhD project, 2016

[2] ***MS Bourbon Mistral***, Bourbon Offshore, Norway

[3] ***Tycho Brahe***, Scandlines