



marine lubricants information bulletin 18

# onboard & onshore drip oil analysis for two-stroke marine engines



Reliable, accurate analysis of drip oil conducted onboard, supported by in-depth laboratory diagnostics, remains important following the widespread shift to lower sulfur fuels since the introduction of IMO 2020 marine fuel emissions legislation.

## Introduction

With the general move from high sulfur fuel oils to fuels with a sulfur content of lower than 0.5% from 1st January 2020, ship operators might have assumed that problematic corrosive wear within marine two-stroke engines would disappear. As a result, some may believe it is not necessary to measure for non-magnetic iron particles often interpreted to be indicative for corrosive wear, only the for larger, magnetic iron particles that are often connected to immediately damaging abrasive and adhesive wear. Chevron's experience indicates that this is not the case and required further exploration.

As long as there is sulfur in fuel there is the risk of cold corrosion, particularly with modern engines operating at a slow speed with a very long stroke. Many newer engines are still at risk of corrosion and it is important to continue monitoring this corrosion when operating on very low sulfur fuel oil (VLSFO). Furthermore, the presence of larger, magnetic iron particles is not in itself enough to confirm that cylinders are suffering from abrasive or adhesive wear. It can also indicate high levels of corrosive wear.

For these reasons, Chevron Marine Lubricants believes that monitoring of total iron content is the best way to monitor engine wear via regular testing with the DOT.FAST® onboard kit. Further, deeper analysis using DOT.FAST laboratory services can deliver even more accuracy and can distinguish between iron particles (as well as other metals) in the drip oil to predict or diagnose problematic wear.

## Drip oil

Drip oil — sometimes called scrape-down oil — is used cylinder oil collected from the scavenge space of marine two-stroke engine cylinder liners. Analyzed on a regular basis, drip oil samples can track cylinder condition and identify trends that may necessitate remedial action on the part of the engine operator.

The two key parameters in drip oil are:

- Remaining alkalinity (or residual BN): The combustion of fuel containing sulfur forms acids which, untreated, can cause excessive corrosive wear. The cylinder oil's alkalinity reserve, represented by the base number (BN), counters this effect. Too low remaining alkalinity suggests there may not initially have been enough alkalinity to tackle acid formation effectively.
- Iron content: The presence of iron in drip oil indicates the level of wear taking place in the cylinder, and whether the wear is acceptable or could lead to cylinder condition challenges. Both the amount and the type of iron in drip oil needs to be analyzed to fully understand the state of the cylinder.

## Cylinder wear

The most relevant types of wear in marine engine cylinders are chemical or corrosive wear and mechanical wear, which can be caused by adhesion or abrasion.

- Corrosive wear: Caused by acid — usually sulfuric acid arising from the fuel sulfur content — attacking the mechanical parts in the combustion space. Mild

corrosion will result in the formation of mainly iron oxides and salts, which actually help to maintain the cylinder condition by providing a liner surface structure that promotes a stable lubricating oil film. Excessive corrosion will release larger iron particles, also known as ferrous magnetic debris, wearing the liners and piston rings down quickly.

- Abrasive wear: Occurs when hard particles (such as cat fines) larger than the oil film thickness get trapped between cylinder liner surface and piston rings. The softer surfaces will be scored and both small (soluble) and large (insoluble) iron particles will be generated.
- Adhesive wear: Caused by hard contact between cylinder liner surface and piston rings due to a lack of oil film. In the absence of a protective coating on the cast iron metal surface, the piston ring will weld to the cylinder liner under the high pressure and temperature occurring in the combustion chamber. This weld will tear off as the piston moves, resulting in heavy damage to both the cylinder liner surface and the piston ring, with both small and large iron particles being released.

#### Iron content

From the description of wear above, it is clear that corrosive and adhesive/abrasive wear are associated with different types of iron particles.

- Small particles (soluble and non-magnetic): These include iron oxides and salts and are more often associated with corrosive wear.
- Large particles (insoluble and magnetic): These particles are predominantly associated with abrasive and adhesive wear, as well as with an excessive amount of corrosive wear.

**Figure 1: Excessive alkalinity caused by overfeeding**



**Figure 2: Excessive corrosion**



Despite this association, it is important to note that the type of wear cannot always be neatly identified from these particles alone. For example, high corrosive wear can result in large particles in the cylinder oil, while abrasive or adhesive wear will generate small particles often associated with corrosive wear as well. These ambiguities make rigorous analysis essential to correctly identify the primary type of wear in engine cylinders.

The sweep test provides an example of the challenges low-sulfur fuels can pose for conventional drip oil analysis. The sweep test determines the optimal cylinder oil feed rate relative to the sulfur content in the fuel. This engine and operation-specific ‘feed rate factor’ can then be used to recalculate the optimal feed rate when switching to fuels with different sulfur content.

#### Sweep test

The sweep test is normally performed while operating on high-sulfur fuel. Starting at a high feed rate, operators progressively reduce the feed rate each day until the engine manufacturer’s minimum recommended rate is reached. At high feed rates, drip oil analysis shows high residual BN — the oil has an excess of alkalinity to neutralize any acids formed in the engine during the combustion. As well as using an excessive amount of cylinder oil, alkalinity overfeeding can lead to the formation of deposits on the piston top and ring lands. The optimal feed rate will show enough remaining BN to indicate that there was sufficient alkalinity originally to neutralize acids, but not so much as to cause these deposits.

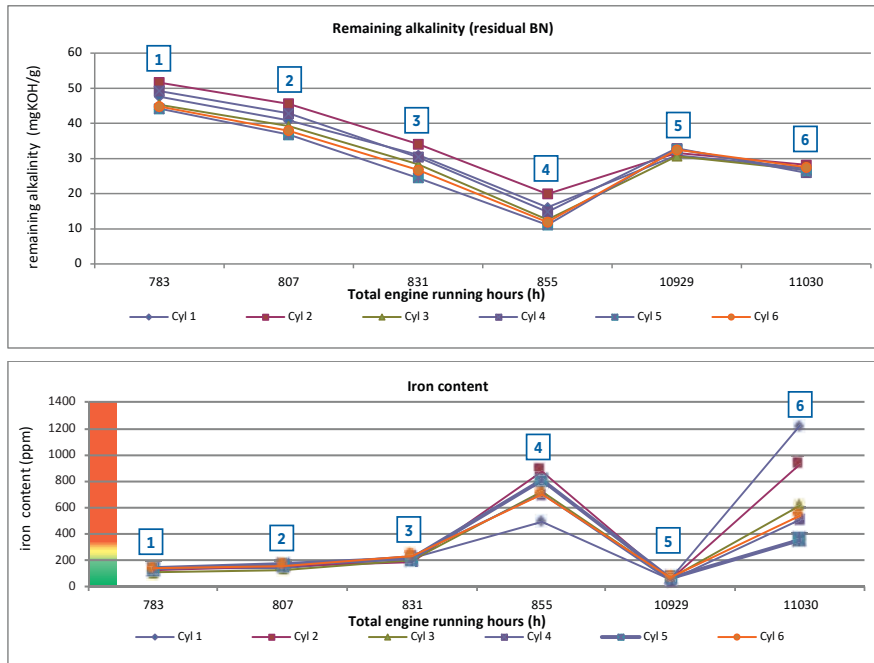
As the feed rate is lowered, more of the alkalinity reserve is consumed and the residual BN decreases until a point is reached where the cylinder oil does not adequately protect the liner from corrosion. At this stage, corrosion will occur and the iron content in the drip oil sample will increase. A low level of corrosion is acceptable, and the ideal feed rate lies within this range. The optimal feed rate factor therefore sits on the curve between too much residual BN and too much iron content in the drip oil.

As vessels without scrubbers have not been allowed to carry high sulfur oil since March 2020, very low sulfur fuel oil is increasingly used for sweep tests. But the optimal feed rate factor can be more challenging to determine on low-sulfur fuel. While with high sulfur fuel there are two parameters that can be used to determine the optimal cylinder oil feed rate — iron content and residual BN — when running the test with low sulfur fuel, iron content is the focus. This is because the alkalinity reserve in the cylinder oil depletes far less and residual BN remains closer to that of the fresh cylinder oil. Further, the feed rate can be reduced significantly without getting an early warning that corrosion has started, and the cylinder can enter boundary lubrication conditions as the feed rate drops below a point where the oil film between the piston ring pack and liner is inadequate.

#### Onboard analysis

The DOT.FAST® onboard test kit provides an accurate way to identify the point at which iron particles in the cylinder

**Figure 3: Sweep test on MAN ES 6S50ME-B9.3 using HSFO and early experience using VLSFO**



Points 1–4 show sweep test results with HSFO in combination with Taro Ultra 100 (100 BN). While the residual BN in the drip oil samples decreases steadily as the cylinder oil feed rate is lowered, the iron content increases due to the increased level of corrosion occurring in the cylinders. At point 4 the alkalinity reserve in the cylinder oil is depleted and the wear level is excessively high. Point 2 shows the optimal 'cylinder oil feed rate factor', with both the residual BN and the iron content at optimum levels.

Points 5–6 show cylinder oil feed rate optimization using VLSFO in combination with Taro Ultra 40 (40 BN). At point 5 the residual BN is at acceptable level and the iron content indicates optimized conditions at the given cylinder oil feed rate, however the reduction of the feed rate at point 6 results in excessive wear without a significant drop of the residual BN.

The graphs above illustrate the importance of accurate tools to monitor the iron content in drip oil samples (using onboard & onshore analysis). They demonstrate that the residual BN can no longer be used to determine the optimal cylinder oil feed rate where low sulfur fuels are in use.

\* Cylinder oil feed rate factor: cylinder oil feed rate (g/kWh) relative to the sulfur content in the fuel.

oil start to rise, even with VLSFO in use in combination with low BN cylinder oils.

Some of the other onboard test kits commercially available focus on large iron particles that are generated in case of excessively high cylinder wear — often associated with 'abrasive' wear. These kits are typically based on inductive sensor technology and detect the presence of ferrous magnetic debris in the oil sample. Other kits focus on the small particles — soluble and non-magnetic iron — often associated with 'corrosive' wear. These small particles are generated both in case of high wear and as an early indication of increased wear. X-ray technology can detect both the large particles and the smaller, soluble iron, but can be significantly more expensive to implement. However, although these alternative devices can distinguish between different types of iron, as per above they do not distinguish between types of wear.

While it is desirable to understand the mechanism, it is impossible to determine from the type of iron only, and needs to be arrived at in combination with other data. Chevron Marine Lubricants' DOT.FAST® kit uses wet chemistry to measure the total iron content, picking up both the large particle ferrous magnetic debris as well as the soluble, non-magnetic iron. This enables early detection of increased wear of any type, even before any large iron particles are generated.

The DOT.FAST onboard test kit is designed to make the analysis easy to perform without training. Reagents are provided in the required quantities and the engineer

needs only to transfer some drip oil by means of a pipette with a fixed volume into the vial, then break the inner vials to release the reagents. After filtering out any debris and other contaminants, the vials are then placed in the Chevron Drip Oil Analyzer, which uses photometric reading to determine the total iron content expressed in parts per million (ppm).

The use of onboard test kits enables crew to take immediate corrective action in many cases, but the interpretation of results may require additional expertise. For this reason, it is recommended to combine onboard analysis with onshore verification, especially in cases of sweep testing and cylinder oil feed rate optimization.

### Onshore analysis

The addition of onshore analysis enables an in-depth evaluation of the drip oil samples, and the reports contain actionable comments generated by technical experts.

As well as the residual BN and the total iron content, additional parameters are measured with laboratory accuracy. Not only does the laboratory distinguish between small, non-magnetic iron particles and larger ferrous magnetic debris, but other wear metals such as copper, chromium and aluminum are also evaluated. High copper content can indicate running-in conditions for example, which results in high iron content as well, where there is no issue. Aluminum potentially indicates the presence of cat fines in the fuel, which will translate as abrasive wear and excessively high iron content in the drip oil samples accordingly.

**Figure 4: Chevron's proprietary DOT.FAST® kit and Disporack™**



*Drip Oil Analyzer and MicroMan® Pipette*

*DispoRack™ with 12 ITUs (Iron Testing Units)*

**Features and benefits:**

<p><b>DOT.FAST Onboard Test Kit</b></p> <ul style="list-style-type: none"> <li>• Chemical testing with the Disporack™ unique in the industry</li> <li>• Iron measured for soluble and insoluble particles (total iron content)</li> <li>• Individual vials keep the chemistry free from contamination and maintain quality</li> <li>• Minimize human error with fixed quantities</li> <li>• Robust design for a long service life</li> </ul>	<p><b>DOT.FAST Onshore Analysis</b></p> <ul style="list-style-type: none"> <li>• Analysis in specialized, ISO certified laboratories</li> <li>• Total iron content and system oil dilution taken into account</li> <li>• Expertly reviewed analysis</li> <li>• Easy to interpret report with actionable recommendations</li> <li>• Fast turnaround</li> <li>• Historical reference data maintained on secure website</li> </ul>
--	---

**Accurate onboard testing:**



1. Collect drip oil samples from scavenge sampling valves.



2. Prepare the samples using the DispoRack and ITUs.



3. Test the prepared samples using the Drip Oil Analyzer.

Next to that, the amount of system oil in the drip oil samples is determined, which is key for proper interpretation of the test results. System oil normally has a very low wear metal content and BN, and when it breaches the stuffing box between the crankcase and the cylinders to mix with the drip oil, this will dilute the results for all parameters. As such, a drip oil sample containing an acceptable concentration of iron by measurement may still reveal high cylinder wear if this sample happens to be highly diluted with system oil. For this, it is important to determine the 'system oil dilution factor'.

Engine oil samples are sent for onshore analysis using the FAST™ fluid analysis sample kit. This sample kit contains everything needed to deliver the samples, including standard sized sample bottles, labels and pre-addressed envelopes for Chevron's global laboratories. Analysis is conducted at ISO-certified laboratories and customers

receive feedback in a FAST report within 24–48 hours of receipt of the final sample batch.

**Conclusion**

Analysis of all drip oil parameters remains important after IMO 2020 and the widespread move to low sulfur fuels. Onshore laboratory analysis is needed to distinguish between excess corrosion and abrasive/adhesive wear, regardless of whether the operator's onboard kit measures magnetic iron, iron oxides and salts ("soluble") iron or the total iron content. The difference is that equipment that determines the total iron content — such as the Chevron DOT.FAST® onboard test kit — enables operators to track corrosion and wear of any type at low levels. This is critical for modern two-stroke engines that may still be prone to cold corrosion even when using low-sulfur fuels, and for identifying other forms of wear that are not related to fuel sulfur. ■