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APPLICATION NOTE

Residual Cylinder Oil Base Number (BN) Measurement with Portable IR Analysis for Shipboard Use

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Synopsis

Today, BN measurement of the piston underside oil is typically measured offsite at oil analysis labs or onboard using a shaker test kit. A new analyzer, FluidScan Q1200, eliminates the need for hazardous chemicals and operator interpretation of the results to reduce the cost and time involved in shipboard Base Number cylinder oil analysis.



Figure 1: The effects of cold corrosion can be seen on this cylinder liner. The surface has uneven pock marks; these enable severe sliding wear to occur.

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Recommended piston underside residual BN

Value	Description
> 25 mgKOH/g	**Safe** corrected piston underside residual BN to avoid piston ring and liner corrosion.
about 15 mgKOH/g	**Alert** corrected limit for piston underside residual BN to avoid excessive corrosion.
< 10 mgKOH/g	**Danger** corrected limit for piston underside residual BN and is likely to lead to excessive corrosion and rapid piston ring and liner wear if not corrected.

Figure 2: Wartsila's recommended limits for BN in residual cylinder oil for two-stroke engines.

Introduction

Due to the effects of over-capacity and reduced freight rates in the aftermath of the recent recession, ship operators have implemented "slow steaming" operations to reduce costs. Operating two-stroke engines in slow steaming mode results in dramatically lower fuel bills but it also increases the risk of developing cylinder cold corrosion if cylinder lubrication is not carefully managed. Avoiding cold corrosion on cylinder liners is a major challenge for ship owners practicing slow steaming. All marine engine suppliers have issued technical bulletins discussing the problems (Fig 1).

In addition, the expansion of low Sulfur Emission Control Areas (SECA) on global trade routes and future limits on sulfur in fuel are changing normal practice. There is greater use of dual fuel handling, which requires switching between high and intermediate BN lubricants based on the fuel used. Since different fuels have different sulfur contents, the BN provided by the lubrication oil must be changed depending on the fuel used. This means that modifying cylinder lubrication oil feed rates becomes a daily task. This optimization requires daily monitoring of residual drain oil BN. Current approaches are not suitable for this monitoring frequency as it can take several hours to measure each cylinder. A new handheld BN analyzer was developed in close cooperation with Winterthur Gas & Diesel (WinGD) and Wärtsilä Services providing ship owners with a fast, accurate way to measure BN to optimize cylinder lubrication. This paper outlines the challenges of the traditional laboratory and field methods for measuring BN, and it presents a new IR approach using a handheld infrared analyzer.

Background

Wärtsilä Services and Winterthur Gas & Diesel, as well as MAN Turbo and major lubricant suppliers, stress the need for more frequent piston underside oil analysis on their two-stroke engines and provide specific recommendations for slow steaming operating conditions. (Ref 2,4,5,6,7)

In addition to monitoring residual BN by measuring the piston underside drain oil, the designers also recommend measuring the inlet (fresh) cylinder oil BN, particularly if the ship operator is blending on board. The piston underside oil BN measurement should typically be above 25 mgKOH/g based on the technical bulletin recommendations (Fig 2). Keeping the residual oil BN within these guidelines requires frequent direct monitoring onboard.

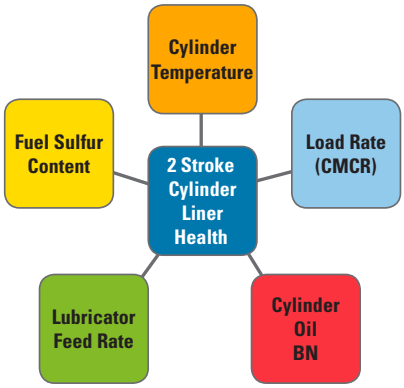


Figure 3: Many variables affect cylinder health. Direct measurement of all these variables is needed to ensure proper engine health.

Understanding Cylinder Lubrication

Ship owners want to avoid premature cylinder liner failure. Reliable operation is achieved when all the major variables are in control and balanced (Fig 3). The major variables are cylinder temperature, load rate, cylinder oil BN, lubricator feed rate, and fuel sulfur content. All these factors are interdependent. For example, if the sulfur content of the fuel increases, then BN and feed rates need to change accordingly. Also, when steaming, the ship engineer can change the cylinder lube oil feed rate (LOFR) to compensate for change in these variables based on engine control system data or BN measurement (Fig 4).

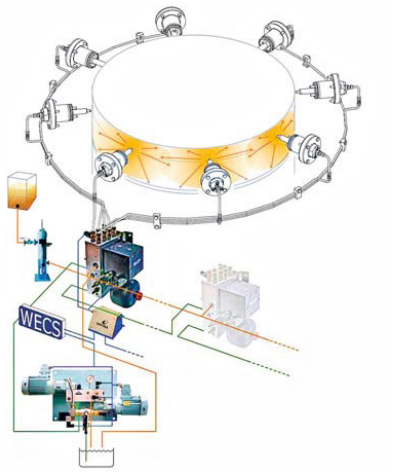


Figure 4: Wartsila Pulse Lubrication System allows for tighter control of cylinder lubrication.

Most cylinder lubricating systems are essentially feed forward systems, as there is no feedback to the engine control system based on piston running conditions. For this reason, it is easy to lag behind on changing the lubricator spray settings when fuel sulfur concentrations (transition from HFO to MGO) change. This change can be gradual and take up to 72 hours. This lag can lead to either under lubrication or over lubrication. Under lubrication can cause cold corrosion and sliding wear. Over lubrication can cause wastage of good cylinder oil and bore polishing/hydraulic lock.

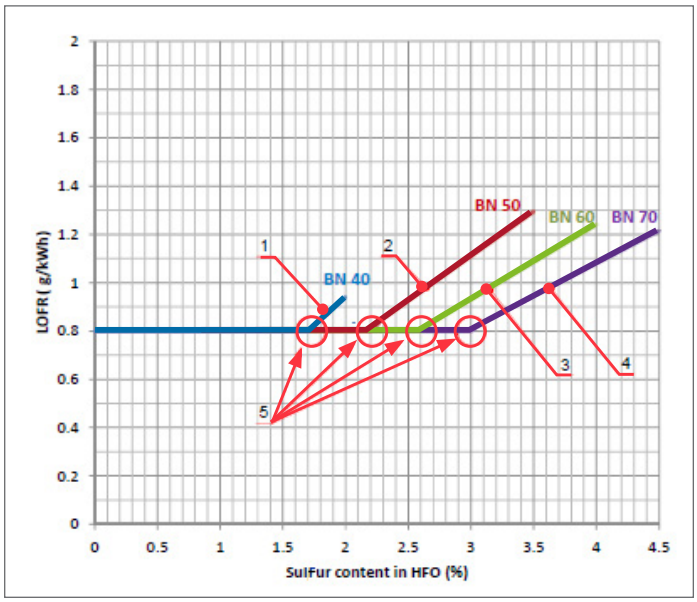


Figure 5: Lube oil feed rate chart based on the sulfur content of the fuel being used.[6]

Traditionally, cylinder feed rate charts that engineers rely on have the fuel sulfur content as the variable across an assumed BN range based on the new oil values (Fig 5).

These guides were originally designed for long cruises where the high sulfur fuel oil (HFO) composition was known and there were few changes. With sulfur rates changing hourly as ships enter SECA zones and BN oil being switched also, it becomes a delicate balance to avoid cold corrosion.

The BN of the piston underside oil is an ideal metric for feed rate control (Fig 6). Traditionally it has not been employed in this way, predominantly because of the difficulty in quickly obtaining a BN result that was accurate and reliable enough. By providing this information in real time, LOFR (lube oil feed rate) settings can be adjusted precisely up to the hour.

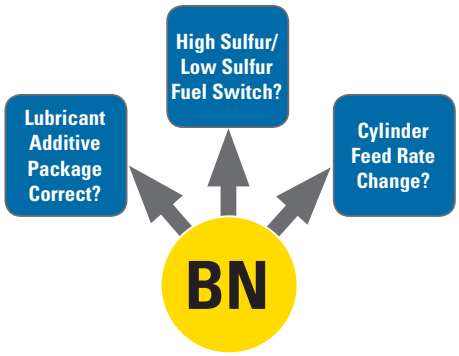


Figure 6: BN results answer many questions for both engine health and lubrication considerations.

Understanding BN measurement

Base Number (BN or neutralization number) is a measure of a lubricant's alkalinity reserve. Most modern cylinder oils qualified for marine engines use detergents such as calcium, barium, or magnesium carbonates and sulfonates, as well as calcium phenates and salicylates, applied in formulations designed to address the extremely corrosive environment. Potentiometric titration techniques, where acidic titrant is added to the lubricant in a tri-solvent designed to facilitate dissolution, are the referee methods in use by testing facilities worldwide. Cylinder oil BN analysis has traditionally used a perchloric acid (HCLO4) titrant in a glacial acetic



Figure 7: Titration apparatus used in laboratories. Many now employ an autosampler as BN measurement can take 20 to 30 minutes per test. (Ref: Mitsubishi)

acid solvent mix (ASTM D 2896), chosen because of its ability to neutralize both strong and weak basic additives in cylinder oils. Another widely used method ASTM D4739 is commonly specified for system or four-stroke engine applications consuming low sulfur fuels. It employs hydrochloric acid (HCL) as a titrant and is the preferred method for trending BN on engines over time, particularly when wear debris is present. Existing referee methods are designed to be performed in a laboratory with trained technicians who understand the test (all require experience) and the proper infrastructure for handling hazardous chemicals, glassware, and ventilation (Fig 7). In particular, ASTM D2896 requires additional infrastructure specifications with duct work because perchloric acid fumes are extremely corrosive. Proper titration of a high BN oil sample can take over 30 minutes to determine an end point, so most labs today employ some automation to the titrators. Though these procedures remain official methods, they are not at all suitable for onboard monitoring.

Infrared Spectrum Analysis

Infrared (IR) spectroscopy, as applied to cylinder oil analysis, describes a technique whereby infrared energy is transmitted through an oil sample of a known pathlength and the resultant spectrum is analyzed. Absorption of infrared energy depends on the molecular vibrations present in a sample. These vibrational modes interact only with specific and reproducible frequencies (or wavelengths) of IR radiation and produce a distinctive pattern in the absorption spectrum which can be analyzed for quantitative chemical information about the oil sample. The mid-IR region is most commonly used (4000 to 400 wavenumbers). Both the alkaline reserve additives in cylinder oils, and the acid build up as those reserves are depleted, can be seen as changes in the infrared spectrum of a sample.

Infrared spectroscopy has been used to determine TAN or TBN of lubricant samples in laboratory settings as a way to cut down on the time to arrive at a value and to avoid high chemical costs on routine samples. Directly probing the lubricant "as-is" allows for trending of the change in acid or base content of the sample even though the actual value may not be known. Using multivariate methods to correlate a change in the infrared spectrum to a titrated TAN or TBN value has been successful with unique calibrations dependent on fluid type; however, these methods can be sensitive to fluid contamination, type mix-ups, and changes in the formulation.

Due to the challenges involved in the transfer of those calibrations to unknown samples, these methods never progressed much outside of the experimental laboratory until the development of the FluidScan® Infrared Analyzer in 2009. The FluidScan analyzer was the product of a multi-year effort to meet an extended oil drain and fluid condition assessment requirement for a US military cost reduction and environmental improvement initiative. It is a self-contained handheld analyzer that delivers instant fluid condition assessment to the user. It eliminates sample preparation and time-consuming cleanup using a patented flip top sampling cell for easy and rapid field analysis.

At the core of the FluidScan is a patented, mid-infrared spectrometer with no moving parts. The spectrometer collects the infrared light transmitted through the fluid in the flip top cell into a waveguide as illustrated in Figure 8. The FluidScan design maximizes optical throughput and spectral resolution in a hand held device. Consequently, it provides more than

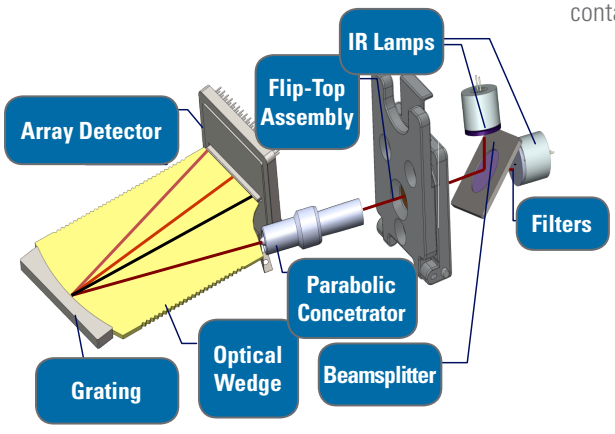


Figure 8: Optical schematic for the FluidScan IR grating spectrometer. IR energy is passed through the sample in the flip top cell, concentrated and diffracted towards a tuned detector. The signal is then processed on board to provide usable data quickly.

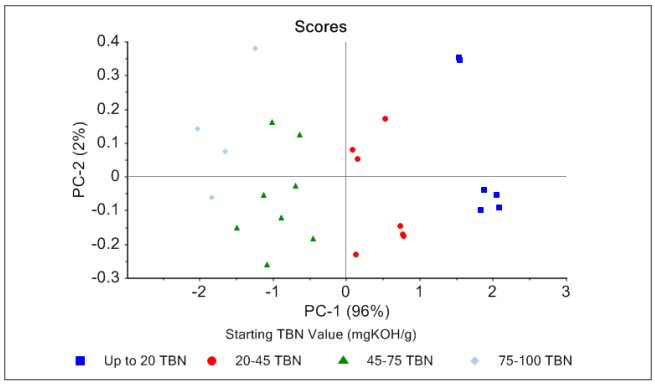


Figure 9: Principal Component Analysis (PCA) of the new oil dataset shows good correlation of PC1 with the new oil BN per D2896.

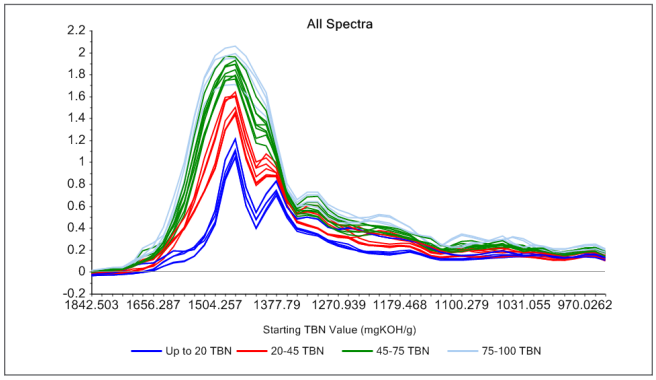


Figure 10: IR Spectra of dozens of cylinder oils show the peaks, due to additives, that closely follow each other in the 1000 to 1700 cm^{-1} range.

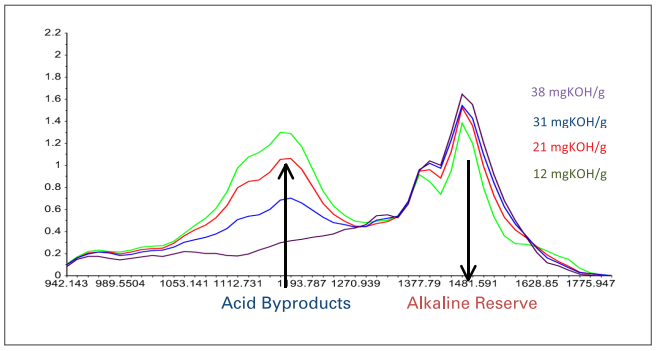


Figure 11: The IR spectra for oils with BN in the range of 12 to 38 mgKOH show depletion of the alkaline reserve and accumulation of acidic byproducts.

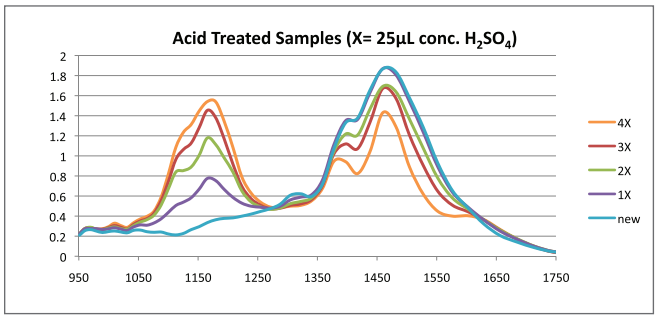


Figure 12: Strong sulfuric acid was added to cylinder base oils to model corrosion effects. The spectral changes were consistent with real world samples.

adequate spectral range, resolution and signal-to-noise ratio for the rapid analysis of in-service lubricants. This unique technology has been optimized for low power consumption, enabling the production of a rugged, highly accurate analyzer that operates on Li-Ion batteries for up to eight hours.

Developing a Cylinder BN Application on the FluidScan

Even though the additive chemistry used in cylinder oil varies, there are distinct spectral characteristics present in the infrared spectrum that can be correlated to TBN value. To develop the application, several dozen new and residual cylinder oils were collected. Each sample was tested with both an IR spectrometer and a titrator to develop a database containing IR spectra and titration results (both ASTM D4739 and D2896) for each sample.

The spectra of new lubricants were qualitatively examined to investigate the various additive formulations present. A principal component analysis (PCA) was performed on the infrared spectra of several new cylinder lubricants of various brands and additive formulations. As shown in Figure 9, there is a strong correlation along the first principal component with the BN value of the new lubricant as determined by ASTM D2896. Such a strong correlation supports the development of a universal calibration for BN for all of these oils.

This can be visualized most clearly in the spectral region between 1000 cm^{-1} and 1700 cm^{-1}. The peak intensity and profile of a given base number range is distinct regardless of the oil brand or blend (Fig 10).

The spectra of residual oils were analyzed over a range of intermediate BN (Fig 11). An obvious evolution of the peaks with a change in BN occurs which corresponds to the depletion of the alkaline additive package and the buildup of byproducts from the reaction of acids with the BN package. The transformation is common for every cylinder oil type examined in this study, which is promising for a universal calibration for BN by infrared spectroscopy.

In order to look at the correlation between base number and infrared spectroscopy, eight new oils were randomly selected consisting of two oil types in each starting base number range. They were titrated with concentrated sulfuric acid (97%) to synthetically create samples spanning the range of BN values from new to 10 mgKOH/g (Fig 12). The samples were stirred overnight and then analyzed by infrared spectroscopy and titration.

This data was used to develop a universal cylinder BN calibration without regard to the specific oil type or additive package of the sample. A three factor partial least squares (PLS) regression model (RMSEC = 6.2 mgKOH/g) was successfully created tailored to a frequency region of about 1320 cm^{-1} to 1850 cm^{-1} over the

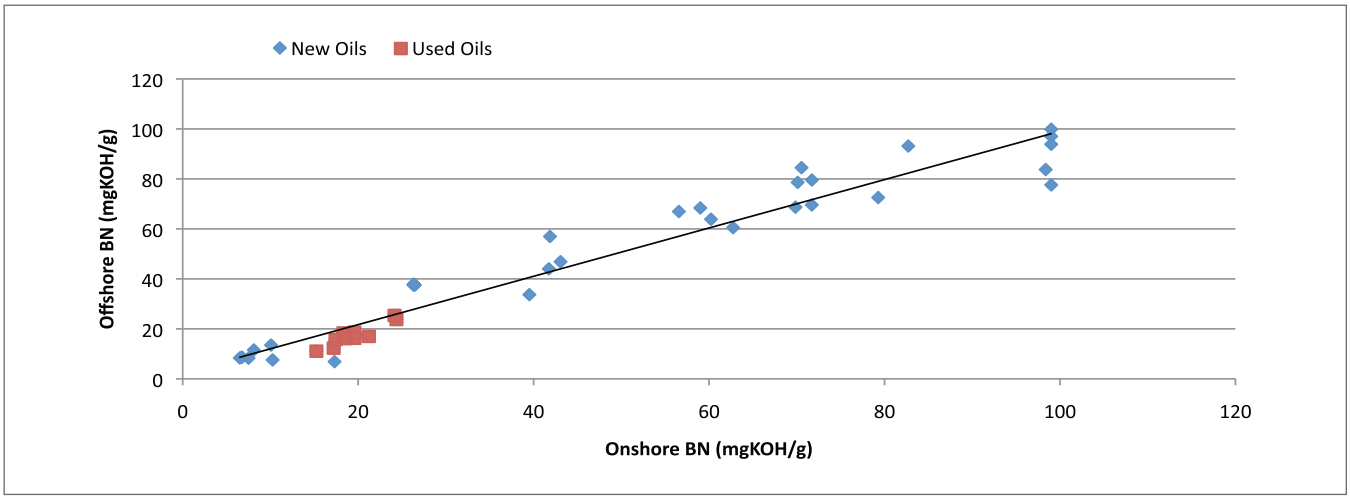


Figure 13: The predicted onshore infrared calibration correlates well with the offshore D2896 laboratory result for BN (mgkOH/g).

- R^2 (new and used) = 0.9407
- RMSEP (used) = 2.87
- Average Absolute Error (used) = 2.36

SELECTION OF USED SAMPLES

TEST SAMPLES	PRED BN (mgKOH/g)	LAB BN (mgKOH/g)
w508	7.77	10.98
w507	8.99	12.82
w503	14.38	14.37
w512	12.08	14.46
w531	12.67	15.00
w548	12.48	15.43
w533	14.75	15.66
w547	13.43	16.82
w527	20.94	19.35
w539	19.48	20.04
new	57.16	62.70

Figure 14

entire BN range of 2 to 102 mgKOH/g. The calibration shows good correlation (R^2 = 0.94) with D2896 base number titration results upon validation with both new and used oils (Fig 13). On an authentic sample set of residual oil in the critical range of 10 mgKOH/g to 25 mgKOH/g, the average absolute error of the IR result compared to D2896 titration value was about 2 mgKOH/g (Fig 14).

Discussion

Currently BN measurement of the piston underside oil is measured offsite at oil analysis labs or increasingly onboard using a shaker test kit. Onboard shaker kits are time consuming, need bench space, involve hazardous chemicals, and require the sample to be brought to the kit. The effort is so involved that frequently only one TBN test is performed on board daily – on the common drain. Extra effort and cost is needed to look at the drain oil from each piston to calibrate the lubricating system per cylinder instead of the damage and wastage resulting from simply adjusting the feed rate.

BN measurement is ideal in conjunction with new cylinder lubrication systems which have much more precise feed rate and cylinder spray patterns that reduce cylinder lubricant usage. Other indirect methods such as scrapedown oil analysis focus on the iron content which is the aftermath of poor control techniques. Real time BN measurement can dramatically alter the onboard feed rate instructions, so the result is integral to the decision making rather than a historical observation.

FUEL TYPE IS...	ONBOARD BN RESULT IS...	FEED RATE SETTING SHOULD...	WHY?
HFO	<15	Increase	Under lubrication-scuffing risk
HFO	>25	Decrease	Over lubrication hydraulic lock/chemical bore polish risk
MGO	>25	Decrease	Over lubrication mechanical bore polish risk
MGO	<15	Increase	Under lubrication risk

Summary

A new analyzer eliminates the need for hazardous chemicals and operator interpretation of the results to substantially reduce the cost and time involved in shipboard Base Number cylinder oil analysis. The portability of the new instrument makes it possible to carry the device and walk from cylinder to cylinder. BN test results are obtained in only one minute which saves substantial amounts of scarce shipboard manpower. Only a few drops of oil are required for an analysis which dramatically reduces the waste stream. The instrument simplifies the process of measuring oil conditions and does not require any interpretation by operators for results that are more accurate and repeatable. The instruments store test results and provide automatic alarming, so the need for manual logging is eliminated.

The FluidScan® 1200 is a rugged, handheld infrared oil analyzer that measures marine cylinder oil Base Number using a universal calibration. The operator only needs to introduce a sample for measurement and a BN is returned. It does not require the brand of oil. The Fluidscan 1200 has been calibrated for a range of 5 to 100 BN, and the results correlate well with lab titration systems.

In addition to BN testing, the analyzer comes equipped with on-board software enabling ship owners to test a range of key oil condition parameters in synthetic and petroleum-based lubricants found in other shipboard machinery ranging from system oil, hydraulic and gear oil and lubricants from other auxiliary equipment. The device determines lubrication contamination, degradation and cross-contamination, at the point of use, by measuring key oil condition parameters and helps operators make maintenance decisions quickly. The technology works by first identifying and classifying the fluid via its infrared spectrum into its general chemical family. From this information, the instrument selects the appropriate set of chemometric algorithms to analyze the fluid and provide quantitative total base number (TBN), total acid number (TAN), oxidation, nitration, sulfation, additive depletion, water, glycol and soot. A distinct advantage in using an infrared oil analyzer is the additional ability to identify unknown new oils from a built-in library of fluids. This enables the onboard operators to determine oil mixups or incoming quality control for new lubricants in the storage area, thus reducing the risk of equipment problems due to the use of incorrect oil.



The last few years have been particularly challenging, thanks to a slow steaming and the burden of having to have to rely on shipboard equipment to survive. The cost of cylinder oil, at $2500 per tonne, means that having the right measurement tools to determine just the right amount of oil at the right time is critical. Base number (BN) has always been recognized as a powerful measurement to monitor proper cylinder lubrication, but the delivery of this data was too inconvenient. The new BN analyzer makes it so easy to acquire BN data, it is now possible for ship engineers to make fast decisions to lower costs in real time.

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