



PRELIMINARY PHYSICAL – CHEMICAL ANALYSES USED IN THE EVALUATION OF “IN SERVICE” MARINE DIESEL ENGINE LUBRICATING

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Lubricating oil performs lubrication, cleansing, cooling, and sealing duties while also possessing anti-wear, anti-rust, and anti-corrosion qualities. During use, oxidation reactions alter the physical-chemical properties of the lubricant, resulting in the formation of chemical compounds that degrade its quality. Analysis of used oil onboard is crucial as it is intended to enhance the reliability of the engine parts and provides valuable information on the quality of the oil during use and its compatibility for potential future use. To ensure good working

condition for marine engine, it is necessary to conduct oil analyses for density, viscosity, acid number, soot, and water content determination based on a regular preventive maintenance and monitoring program. Our paper aims to highlight the importance of these preliminary analyses onboard ships with a preventive role. They can be an important warning indicator, either to change the used oil immediately, or just to carry out further laboratory analysis.

ASSESSING LUBRICATING OIL PERFORMANCE



Acid Number
Density
Viscosity

Carbon mater
Soot
Water

SHIP MACHINERY



LABORATORY ANALYSIS



TEST KIT ANALYSIS



INTRODUCTION

Nowadays, the global market of marine lubricants is continuously growing, according to Polaris Market Research, with a growth of 2.4% over the forecast period 2021–2030. This growth is mainly due to low transport and maintenance costs and the presence of an increasing number of maritime industries. Added to these are the high performance, easy availability, and low costs of marine lubricants used. For efficient operation, the

machines on board ships need a certain type of lubrication, which is achieved by using various types of marine lubricating oils.¹

From the wide range of marine lubricating oils, the mineral ones have less applicability compared to the synthetic ones because their flow is slower through the engine circuits, which leads to high fuel consumption and degradation of their quality.²

Synthetic marine lubricants are mixtures of oil with additives, which are used in various equipment and installations on ships. This type of lubricating

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oils for diesel engines are designed to provide adequate lubrication under various operating conditions and different temperatures. The alkaline additives added to the lubricating oils play the role of protecting the engine against chemical corrosion due to the formed acidic combustion products. Moreover, these lubricants are more efficient than mineral ones because they have more characteristics that allow them to work even at extreme temperatures. This explains the increasing demand on the market for synthetic lubricants, which although they are more expensive, will lead in the near future to gradual elimination of lubricants based on mineral oil.³

Lube oils have anti-wear, anti-rust, and anti-corrosion properties to ensure proper lubrication, cooling and sealing characteristics. But oxidation reactions during use, cause physical and chemical stress for the lubricant with a negative impact on its quality. The quality of the oil determines the lifespan of the equipment. Thus, using low-quality oil will make it difficult to maintain the normal operation of the equipment, which will result in reduced efficiency and increased instability of the system's operation.⁴ At the same time, inadequate lubricant quality will cause a risk of high wear of moving parts in the device, high temperatures in the compressor, and even engine damage.⁴

For proper engine maintenance, analysing the used oil is crucial as it provides information about its current quality and suitability for future use. At the same time, this monitoring could also provide information about the condition of machines or oil-lubricated equipment.⁵

As is known, the lubricating oil has a limited period of operation, after which it must be renewed with a new batch. The physical-chemical properties of the lubricating oil, the type of machine for which it is used, and the use conditions are factors that decide its replacement.⁶ At the same time, apart from renewing the lubricant, after several hours of operation, it must be checked and tested during its use from the point of view of purity and quality.⁷

Different sources could change the acid concentration of the lubricant: acidic contaminants, depletion of alkaline reserve (due to additives) and oxidation by-products. Depending on the uses or applications of the lubricants, the types of contaminating acids are different.⁸ In recent years, a new term has occurred in association with lube oil quality, called oil stress, which may not be familiar to shipboard engineers in the front line of efficient engine operation.⁹

The aim of the study was to present the importance of monitoring the quality of marine lubricants as it has a decisive influence on the service cycle and equipment operating efficiency of ships. The analyses carried out were density, acidity index (AN) and viscosity. There are few data available in the literature on acidity determination of synthetic marine oils. Most studies are focused on the determination of the Total Basic Number (TBN). Numerous extensive investigations have demonstrated a correlation between the structural properties of lubricating oils, engine performance parameters (base number – BN), and the quantity of contaminants that develop in their volume as a result of engine component wear (wear and contaminant elements).¹⁰

In lubricating oils, the performance of engines is influenced by the presence of acidic chemical substances resulting from exhaustion of additives and oxidation reactions, which lead to corrosion and increased viscosity. AN-type analyses would more clearly indicate the real conditions of the engine's working environment, compared to TBN, which only indicates the amount of additive left.¹¹ A regular program of preventive maintenance and monitoring of the state of naval engines requires the establishment of a set of oil analyses, which would include analyses of density (d^{15}), viscosity, acidity index (AN), soot, and water content.

Different analyses of lube oils (density, acid number, and viscosity) were carried out in the chemistry laboratory at Romanian Naval Academy "Mircea cel Bătrân" using laboratory equipment and procedures. Also, because nowadays portable handheld oil analysis tools are widely available and most of the industry implements this rapid testing procedures, some analyses were carried out onboard using Geserco test kit for lubricating oil analysis.

RESULTS AND DISCUSSION

Both laboratory and test kit analyses were used to assess the condition of lubricating oil samples and results are presented in Table 1. Laboratory analyses provide information on the condition of the oil at the time of sampling, while analyses with portable test kits covers the monitoring of the condition of the oils between two sampling intervals or provide quick information on the quality of the oils on site.⁶ The results obtained can be correlated with the tables or guidelines of motor oil manufacturers, which link oil ageing, based on the values obtained for AN, soot accumulation and viscosity increase.

Table 1
Results and discussions for oil analysis

Sampling evidence ^{1*}	d ¹⁵ (kg/m ³)	AN, (mgKOH/g)	% change v40 (cSt)	Carbon matter ^{2*} (%)	Soot (%)	Water (%)	Discussions
Sa	858	2,15	+33	HL Cr	1.90	None	Oil viscosity is increased. Probable cause-soot. Consider changing oil. Critical carbon matter.
Sb	876	1.51	-7,3	LL	1.30	None	Oil viscosity is decreased. Consider change the oil type.
Sc	888	1.58	-6,4	LL	1.40	None	Oil viscosity is decreased. Consider change the oil type.
Sd	878	0.48	-0,9	LL	0.21	None	Oil & Equipment conditions are satisfactory
Se	882	0.53	0,0	LL	0.25	None	Oil & Equipment conditions are satisfactory
Sf	874	0.60	-4,5	LL	0.29	None	Oil viscosity is slightly decreased.
Sg	876	0.71 / Cr	0,0	LL	0.36	None	Oil & Equipment conditions are satisfactory
Sh	875	1.95	5,7	HL C	1.5	None	Oil viscosity is increased. Probable cause-soot. Consider further analysis after 100 RH. Severe carbon matter.
Si	878	1.80	8,5	HL C	1.1	None	None
RS1	874	0.41	–	NL	0	None	
RS2	875	0.41	–	NL	0	None	
RS3	857	0.12	–	NL	0	None	

Based on the results obtained, the degree of engine wear can be assessed, and oil changes can be revised accordingly.¹² Other preventive maintenance recommendations can also be developed to efficiently manage costs for ship operation. Correlated information, taking into consideration all analyses performed, are presented further.

Density analyses and acid number analysis results

Analysing the results from Fig. 1, it can be seen that the density values of the used oil samples are similar to those of the reference samples, so they are not influenced by the engine's operating time nor by the other physical-chemical characteristics of the oil (AN and viscosity).

In the analysis of oils and lubricants, dosing these acids by measuring acidity can provide insight into the net potential for oxidation and corrosion.

For most lubricant end users, Total Acidity Index (AN) is the most common measurement for this type of corrosion risk. The monitoring of the acidity index in lubricants will be carried out by regularly testing the batches of oil in use and comparing them with a new oil of the same type, which will be chosen as a reference.

An increased acidity index can have a negative impact on the operation of the engine, because it would produce:

- Serious corrosion of the components, especially in the presence of water found as impurity,
- An increase in viscosity that leads to pump losses,
- Deposits of tar and varnish on metal surfaces.

From a maintenance point of view, knowing the acidity index of the lubricants allows for the adjustment or optimization of oil change intervals and modification of the maintenance program to reduce the risk of corrosion.

^{1*} Sampling evidence: S (sample); RS (reference sample); a–i (numbering list).

^{2*} Carbon matter: LL (low level); NL (normal level); HL (high level); C (caution); Cr (critical).

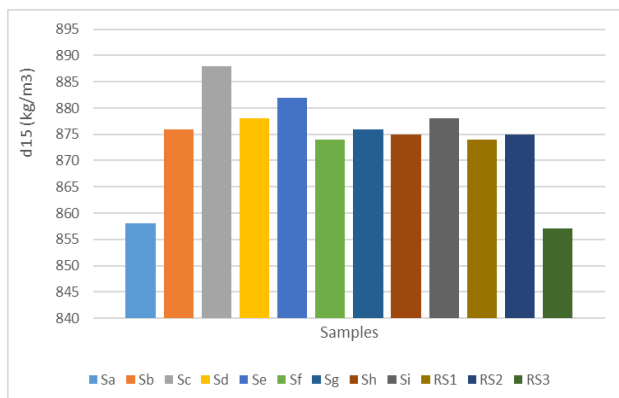


Fig. 1– Result for density analysis.

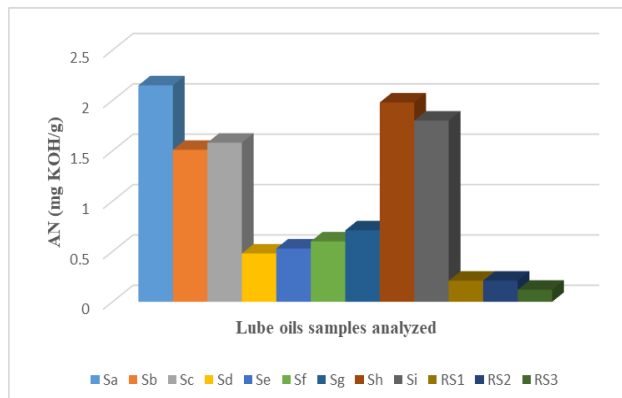


Fig. 2 – Results for AN analysis

According to C. Gay from Bureau Veritas, for evaluating the performance of industrial lubricants, when initial testing is limited, the acidity index can be considered the main factor for evaluating serviceability.¹³ Analysing the results of AN determination, presented in Fig. 2, the values for samples Sa, Sh and Si are very high. This indicates a higher concentration of acidic compounds in the oil sample analysed, caused by various factors such as oxidation, contamination, or degradation of additives, the high number of engine running hours since the last oil change. Generally, the AN value can be influenced by the nature of the acids present in lube oil, such as organic acids formed by oil oxidation in all general lubricants or sulfuric acids,

which are generally a result of sulphur present in diesel fuel oil. To further understand the cause of these high values, we need to check the viscosity and water contamination.

Viscosity analyses results

Because the viscosity of a new oil can vary as much as 20 % and stay within its designated ISO Viscosity Grade, the actual starting viscosity must be measured and recorded. In Table 2 are presented limits from the reference values, expressed in percentage, conventionally used for oils to easily interpret nonconforming results.¹⁴

Table 2

Viscosity limits for lubricating oil¹⁴

Limit	Crankcase oils (%)	Industrial oil (%)	Severe environment industrial oils (%)
Critical – upper	+20 %	+10 %	+7 %
Caution – upper	+10 %	+5 %	+4 %
Caution – lower	-5 %	-5 %	-5 %
Critical – lower	-10 %	-10 %	-10 %

It is better to measure the new lubricant's viscosity in the same way you plan to monitor the used oil's viscosity, using the same instruments, temperature, procedure, etc.¹⁵ The results for the Sa-Si oil samples are presented in Table 1 as percentage deviation from sample RS1, RS2 and RS3, chosen as reference samples. Most of the results for the sample collected from main engines onboard tugboats are below normal values but within the range limit. Except for the A – ship, where values are correlated with previous results, the possible reasons could be intensive running for long hours (at full speed)

or a mixing of different oils. Oil dilution with fuel is not a probable cause because the main engines have few running hours, and the component wear is low.

For diesel generators, there is an increase in viscosity, but within the caution upper limit. Additionally, an increase in viscosity, more than the critical upper limit, with a value of +33 % was on Sa. The high viscosity values are most likely due to carbon buildup in the crankcase (large soot content in the analysed sample), as provided next.

Carbon mater (blotter spot test) and soot content results

Soot contamination changes lubricating oil properties resulting a low-quality or cease function. These could lead to engine wear by increase in viscosity of the oil and pumping problems. Because only 29% of the soot produced when burning fuel oil enters the atmosphere through the exhaust system, the rest could form deposits on the cylinder

walls and piston bottoms, eventually ending up in the engine oil.¹⁶

For most of the samples, the blotter spot test has normal colour, radial distribution, easily identifiable circle limits, and clean edges. Therefore, the lubricating oils for main engines onboard tugboats are in good condition, with clean engines and no particle, water, or fuel contamination, similar to Sd spot from Fig. 3.

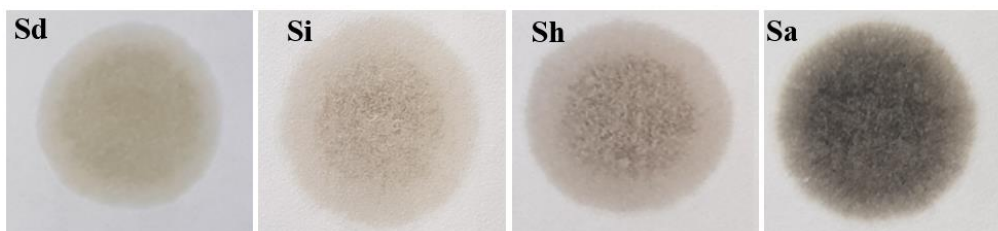


Fig. 3 – Results for spot analysis (sample Sd, Si, Sh, and Sa).

Analysing spots from sample Si, Sh and Sa some information about oil condition could be extracted:

- Si and Sh: the grey colour for the 2nd circle reveal that the lubricating oil is beginning to degrade (degradation is more visible for Sh, with marginal dispersion properties) but with low level of sediments;
- Sa: the lubricating oil is degraded, with increased soot particles causing the black color of the spot. The second circle is not clearly defined, indicating failing dispersion properties.

For this oil sample that presented abnormal characteristics on the blotter test, a soot content analysis was conducted. The values for samples Si, Sh and Sa are according to reference spot interpretation presented in Figure 6 and dispersion image of oil sample from Figure 3. Using optical reflectance (opacity) analysis, the Geserco Kit MT9080 quantified the soot concentration in lubricating oils subjected to analysis.

Water content analyses

The determination of the water content in the lubricating oil was carried out with the Rapid Oil Test Gauge, which operates by measuring the dielectric constant of the oil sample analyzed. Since water and oil have different dielectric constants, i.e. water has a higher dielectric constant at room temperature (about 70) compared to oil (about 2.1-2.4), as the water content in the oil increases, the dielectric constant of the mixture also increases.⁵

The difference in dielectric constant between new and used oil can provide information about the quality of the oil in terms of water content. The presence of water in lubricating oil can be in any of these three forms: dissolved, emulsified or separated. This may be due to either the ingress of sea water or fresh water through condensation or leakage from cooling or heating systems. The presence of water in lubricating oil is limited (max 0.2%), as it causes corrosion (rust) and damage to bearings and other engine parts. Furthermore, microorganisms can thrive in water, causing corrosion in pipes and storage tanks and potentially blocking filters.¹⁷ As shown in Table 3, all oil samples analysed based on the measured dielectric constant do not contain water. This information is crucial for preventive maintenance programs. In conclusion, the probable cause for high values for samples Si, Sh, and Sa in these tests indicates the degradation of lubricating properties, affecting engine performance. Based on these data, maintenance technicians need to identify issues and take action to reduce wear and prevent engine breakdowns.

EXPERIMENTAL

To evaluate the serviceability limit state (SLS) of lubricating oil, samples were collected from “Mircea” Tall Ship and three tugboats. The engine oil tested for this study was collected from a 4-stroke diesel engine installed onboard training ship “Mircea” (main engine) and three tugboats (main engines and auxiliary engines). The test material included 9 engine used oil samples and 3 new oil samples. Obtaining representative oil samples from

the lubricating system is essential for correct results. To obtain representative oil samples, a systematic sampling procedure was

ensured.¹⁸ The technical details of engines and oil samples are presented in Table 3.

Table 3
Oil sample coding and technical details for the equipment^{3*}

Equipment and LO details	Engine type / LO type	RH (from last oil change)	Remaining RH (MR)	Total RH (equipment)	Sampling code
Main engine (TS) / Castrol	MAK – 1100 hp	4362	638	28669	Sa
Main engine stbd (A-ship) / Castrol	VOLVO D16 MH – 600 hp	164	336	1662	Sb
Main engine port (A-ship) / Castrol	VOLVO D16 MH - 600 hp	164	336	1662	Sc
Main engine stbd (B-ship) / Castrol	VOLVO D16 MH - 600 hp	300	200	2175	Sd
Main engine port (B-ship) / Castrol	VOLVO D16 MH – 600 hp	300	200	2175	Se
Main engine stbd (C-ship) / Castrol	VOLVO D16 MH – 600 hp	248	252	1927	Sf
Main engine port (C-ship) / Castrol	VOLVO D16 MH – 600 hp	248	252	1927	Sg
Auxiliary engine (B-ship) / Divinol	CATERPILLAR C2.2 – 45 hp	168	332	2848	Sh
Auxiliary engine (C-ship) / Divinol	CATERPILLAR C2.2 – 45 hp	139	361	2560	Si
Main engine (Tall ship)	Castrol SAE 10w40	reference sample	–	–	RS1
Main engine (A, B, C ship)	Castrol Multi CRB 15W40	reference sample	–	–	RS2
Auxiliary engine (B, C ship)	Divinol 15W40	reference sample	–	–	RS3

All diesel engines are running on Castrol and Divinol marine lubricating oils, and their main characteristics are given in product data sheets.^{19,20}

The research focused on studying the structural characteristics of “in-service” lubricating oils in two stages:

- in a chemistry laboratory using special equipment and standard procedures,
- onboard ships using a portable test kit (Geserco Kit MT9080) with manufacturer instruction and recommendation.

In most shipping companies, these tests are now part of the condition monitoring maintenance program implemented onboard to extend oil drain intervals and reduce routine cost, without affecting the safety or causing unplanned downtime for equipment. In a recent study onboard a military ship, portable oil analysis instruments saved up to 15 hours per week, increasing the reliability and accuracy of the results and simplifying the process of measuring oil condition.²¹ Geserco Kit type MT9080 gives operators and maintenance personnel advance warning of potential machinery failures, through some very simple, rapid and cost-effective techniques.

Density analyses and acid number analyses

Density (d^{15}) analyses were carried out in duplicate according to ASTM D1298-12b (2017) using a glass hydrometer at room temperature and calculated.²² In order to determine the acid number (AN), an amount of potassium

hydroxide (KOH) base is required to neutralize the acid in one gram of oil sample.

The AN determination of engine oil is very important in a regular preventive maintenance program and condition monitoring of marine engines, being a major factor in corrosion, oxidation, nitration and increased viscosity. All these can be considered as drawbacks affecting the performance and not least the performance of the equipment. The determination of the acid number of lube samples is based on the extraction of the organic acids contained from the lube oil sample, in ethyl alcohol and their titration with an alcoholic KOH solution of 0.05 N concentration in the presence of phenolphthalein indicator until total neutralization by applying eq. (1). The standard unit of measure is mg KOH/g lube oil.²³

$$IA = \frac{v \cdot 2.805}{m} \text{ [mg KOH/g]}$$

where IA – acid number of lube oil; v – volume of the alcoholic KOH solution of concentration 0.05N used for the titration of the alcoholic supernatant from the analyzed oil sample [mL]; m – mass of lube oil subjected to analysis [g].

A manual Mohr burette with Schelbach stripe, pharmaceutical balance (ATZ 1200), digital vortex homogenizer with IR sensor (TX4 model), and Erlenmeyer flasks were used. Furthermore, for the preparation of solutions necessary for the analysis, ethanol (EtOH) (p.a) and KOH flakes purchased from Remed Prodimpex Roumania were used. The analyses were carried out at room temperature, in triplicate.

^{3*} Acronim: TS (Training ship “Mircea”); A,B,C (number list for tugboat); LO (lubricating oil); RH-running hours; MR-manufacturer recommendation.

Viscosity analyses

To determine the viscosity of the lube oils samples, a Geserco Kit MT9080 with Viscobille viscometer was used (Fig. 4a). Viscosity analyses of collected samples were measured using the ASTM D445 standard method to determine the viscosity at 40 °C. The results, reported in centistokes (cSt), can then be compared with the viscosity specifications of the reference sample. The significance of these results can indicate conditions such as oil thickening (an indicator of oxidation or nitration), increased contamination levels, and/or increase in the number of insoluble particles.²⁴

The Viscobille has two scales for monograde and multigrade engine oils. The test tube is filled with oil to be tasted, and the viscosimeter is placed in vertical position in order to bring the ball from the reference tube and the ball from the test tube to the start position. After that, the tester is placed in the horizontal position and tilted slightly so that the balls start falling in the oils (adjust the tilt angle on a range of 10° for fluid sample and 45° for viscous oil). Once one of the balls has reached the arrival line, return the Viscobille to the horizontal position in order to stop any movement and take the reading.²⁵ The main reasons for changing the viscosity are presented in Fig. 4b.



Fig. 4 – a) Geserco Kit MT9080; b) viscobille viscometer.

Carbon mater determination

The oil stain method is used for carbon matter determination. Viewing the stain that a drop of oil leaves on a paper filter²¹ provides information about unburnt matters originating from the combustion process and dispersive power of oil in use. Usually, a stain of used oil consists of three zones (Fig. 5).¹² For this type of

determination, the test uses a specialized type of filter paper designed to absorb oil but retain particulates, such as soot or carbon particles. The intensity of darkness exhibited by the oil on paper functions as a visual representative of the carbon concentration from the analysed sample. For collecting and applying the oil sample onto the test paper in a precise and controlled manner, glass or plastic pipettes were used.

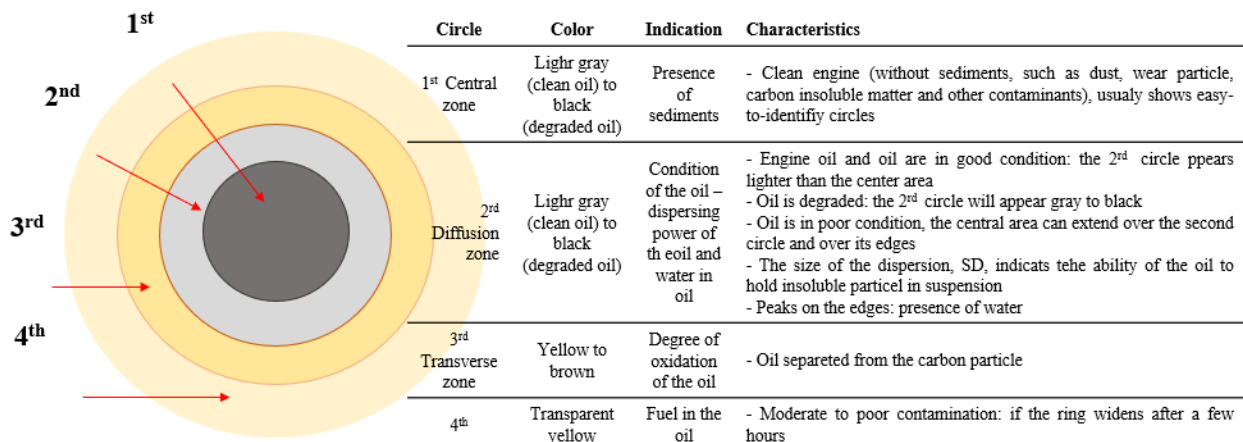


Fig. 5 – Oil strain structure.^{12,26}

A small quantity of used oil sample and the corresponding fresh oil are dropped on to a sheet of special filter paper and

allowed to spread. The size dispersion is calculated by applying relation (2).²¹

$$SD (\%) = \frac{d}{D} \cdot 100 \quad (2)$$

where d – diameter of central zone and
 D – S diameter of second circle.

The method is also known as the blotter spot test. The degree of diffusion of carbon matter particles gives information about the residual detergency of the oil, as is presented in Fig. 6. Satisfactory dispersive power corresponds to a low color change between the central part and edge of the spot.

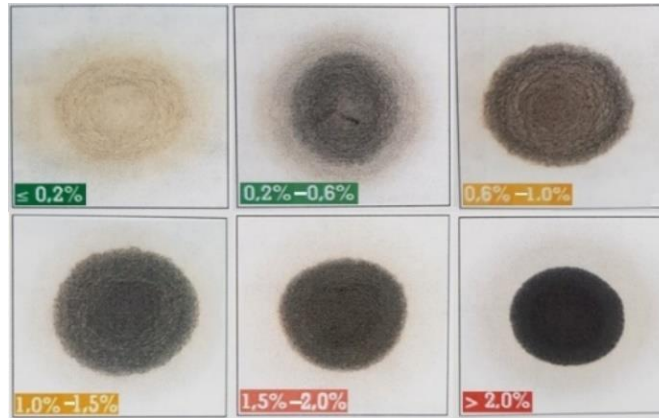


Fig. 6 – Reference spot for carbon matter and dispersion determination.²⁵

Soot content analyses

Soot is a by-product of diesel, a black carbonaceous particulate matter that does not dissolve in lubricating oil but can be suspended by the oil and removed during an oil change.¹⁷ As a dispersed solid phase, soot is kept in dispersion by dispersant-type additives introduced into engine oils, making its agglomeration to be difficult.¹⁷ Dispersants make up a significant

part of the engine oil additive package, hence, the effect of soot interaction with the dispersant is of particular importance.²⁷ The procedure involved an optical analysis to measure reflectance or opacity, providing a quick estimate of the soot content in the oil. Additional materials such as pipettes and vials are used for sample handling, and calibration standards are used to assist in the interpretation of the results. The analyses were carried out in duplicate at ambient temperature.



Fig. 7 – Soot content analyses for Sd sample.

Figure 7 presents the method for determining soot in oil using a rapid optical tester from the Geserco Kit MT9080. If soot is not well dispersed, it will cause the oil to thicken from its original viscosity grade. Additionally, soot can agglomerate to form particles large enough to initiate abrasive wear, and when the soot load of an oil gets too high, it settles out and forms sludge.¹²

Flask with 10 ml of solution, full sachet of reagent, and 5 ml oil sample



Close and tighten the flask on tester, press start button and shake to start the reaction



Fig. 8 – Water content analyses for Si sample.

Water content analyses

The presence of water is often overlooked as the primary root cause of machine problems after solid particles. Also, water is the most common contaminant in used lubricant oil samples. Excessive water contamination over a prolonged period of time

can lead to premature oil degradation, increased corrosion and increased wear.

Water contamination of used lubricating oils may originate from various sources such as temperature variations, moisture from humid combustion air, leaking cooling systems, poor filtering or separation. Additionally, determining water provides valuable information for establishing the source of water ingress (fresh or sea water). To detect the presence of water in the used oil sample, the Rapid Oil test Gauge was used, and the tests were carried out in duplicate. Also, for handling the samples subjected for analysis, a series of pipettes and glass beakers were used. The method is presented in Fig. 8.

CONCLUSIONS

Oil analysis is the most effective way to prolong the useful life of lubricants with a direct effect on equipment availability. This research shows some of the lubricating oil analysis methods available that should represent the baseline for any preventive or condition-monitoring maintenance program.

This study aimed to monitor the quality of marine lubricating oils to provide essential information for maintaining on-board equipment. The assessment of the engine wear degree could be determined based on the results obtained from both the laboratory and on-site tests of the oil samples collected. Thus, to effectively assess the quality of a marine lubricant, several key indicators were monitored, each with specific threshold values both to guide maintenance decisions and prevention and to ensure optimal, long-lasting engine performance. As a result, the main indicators characterizing the quality of a marine lubricating oil were analysed: density (d^{15}), acid number (AN), viscosity, soot content and water content. Based on the analyses carried-out, it was found that the values obtained can warn the personnel in charge of the equipment operation on board the ship about the quality of lubricating oils and the imposition of first preventive and protective measures. Thus, a density deviation of more than $\pm 2\%$ from the reference line suggests potential contamination or dilution of the oil. Variations beyond this limit indicate the need for immediate further testing. In the case of our samples, the values obtained for density (d^{15}) within the observed range (858–888 kg/m³) showed no critical deviations. When the AN value increases significantly, it can lead to corrosion and oil degradation. A value greater than 2 mgKOH/g indicates oxidation or severe contamination, requiring oil replacement. Samples with critical AN value obtained in the range of 1.95–2.15 mgKOH/g indicate degraded lube oils requiring immediate action. An increase in viscosity exceeding +20%

above the limit value for oils is considered critical, while a reduction of -10% indicates oil thinning or particle contamination. In our study, viscosity changes of up to +33% (example, Sa sample) were observed, which indicates considerable carbon matter or soot contamination, and oil thickening, necessitating rapid oil replacement. Soot values above 1.5% are considered high and values above 2% are considered critical for most marine diesel engines. High soot content can increase viscosity and lead to engine wear. The values obtained for Sa, Sh, and Si samples were in the range of 1.5%–1.9%, indicating critical soot levels, especially for the Sa sample. Water content less than 0.2% is acceptable in lubricating oils; levels above this threshold indicate serious contamination, possibly from condensation or system leaks, reduced lubrication efficiency, and requiring the oil change.

Other preventive maintenance recommendations can be developed, also to efficiently manage costs for ship operation. Correlated information taking into account all analyses performed were presented and recommendations were made for each equipment. These preliminary analyses are very important on shipboard with a preventive role. They can be an important warning indicator, either to change the used oil immediately, or just to carry out further laboratory analysis.

One of the limitations of the research is that oil samples were collected for only one replacement interval. To have a better understanding of the dependence between oil quality and engine performance, it is required that further samples be collected on each oil replacement. The authors consider that implementing the field and laboratory test oils for onboard engines would provide information to better assess maintenance decisions.

Finally, the methodology can be used for testing other onboard equipment that uses lubricating oil (compressors, emergency fire pump, emergency generator) or hydraulic oil (winches, capstans, cranes, and steering gear).

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