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Marine Slow-Speed Engines’ Cylinder Oil Lubrication Feed Rate Optimization in Real Operational Conditions

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Abstract: The paper presents results of research performed to find the most suitable cylinder-liner-lubricating-oil feed rates for lubrication of long-stroke, slow-speed marine engines to reduce cylinder oil consumption and reduce engines’ maintenance costs. Obtained research data can be used to increase engines’ reliability, reduce operational costs of the vessels, and improve energy efficiency on board ships. Using analysis of under-piston scavenge drain oil, research has been performed to find the relationship between various engines’ operational factors and the wear intensity of cylinder liners and piston rings. Prediction models of the most suitable cylinder oil feed rates depend on the brand of cylinder oil and fuel actually in use, and the sulfur content in the fuel oil. Verified in operation, the presented practical model can be used by engines’ operators to set up cylinder oil feed rates with satisfactory cylinder liner and piston ring wear rates and cylinder oil consumption. It is underlined that analysis of scavenge drain oil properties gives an answer whether reduction of the cylinder oil lubricating feed rate is possible, information about the quality of lubrication of cylinder liners and piston rings, and can be used as a maintenance tool to maintain the serviceability and reliability of marine slow-speed engines.

Keywords: cylinder liner wear; piston rings wear; scavenge drain oil; cylinder oil feed rate; maintenance; reliability

1. Introduction

In the operation of marine slow-speed engines, one of the important operational issues is proper lubrication of piston rings and the cylinder liner (PR-CL) to reduce mechanical friction between the CL and PR and the total energy consumed [1]. The PR-CL assembly, in many cases that have been observed in the operation of marine slow-speed engines, causes a decrease in the sealing/tightness of the engine’s combustion chamber, and this in turn affects the overall efficiency of the engine and the “environmental performance” of engine operation [2–4]. Over recent years, cylinder lubricant feed rates have been reduced from the previous “normal” level of 1.6 [g/kWh] to current engine manufacturer recommendations in the range of 0.7–1.34 [g/kWh] [2,4–6]. Performed during engines’ operation, the analysis of scavenge drain oil (ASDO) properties is providing some information regarding the quality of lubrication of the PR-CL, but it depends on various engine operational parameters [6–9]. Interpretation of the results of ASDO requires considering the whole “picture” of engine condition, the combustion process, and many other operational parameters of the engine.

2. Lubrication of Cylinder Liners of Marine Slow-Speed Engines

The cylinder liners (CL) in a slow-speed, two-long-stroke, crosshead engine are lubricated by a separate system. Fresh lubricating oil is directly supplied to the cylinders by an injection system specifically designed to provide lubrication for the liners, pistons, and piston rings. Oil is injected through a number of holes drilled in the liner, usually six or eight of these displaced circumferentially around the liner at a chosen vertical position.
within the piston stroke. Oil is supplied by pressure pulses from positive displacement lubricators driven from the engine camshaft or by a separate hydraulic system, and it is regulated to deliver oil at a given rate. Lubricator quills are connected to each oil hole and contain a non-return valve to prevent blowback of combustion gases. A special type of oil is used which is not recovered after use. Used cylinder oil is scraped by piston rings (PR) to an under-piston scavenge space. The idea of cylinder lubrication for a marine slow-speed engine is shown in Figure 1. The generic purposes of a cylinder lubricant are to protect the cylinder liners, pistons, and piston rings from the harmful effects of combustion by-products and to provide an oil film between piston rings and cylinder liners. To achieve this, the cylinder lubricant is required to [5,10,11]:

- Spread uniformly over the cylinder liner surface and form a stable oil film;
- Provide a gas seal between the liner and the piston rings;
- Neutralize acids formed from the products of the combustion process;
- Minimize deposit formation on piston surfaces and ring grooves;
- Flush out particles formed during combustion from the combustion chamber and wear particles of liners and piston rings;
- Prevent a build-up of deposits in the piston ring grooves which can lead to ring sticking or breakage;
- Prevent corrosion of the cylinder liner and other combustion chamber components while the engine is stopped;
- Be compatible with the different methods used by engine manufacturers to introduce lubricant into the combustion chamber.

One of the most important abilities of cylinder lubricating oil is to neutralize acids formed from the products of the combustion process in order to reduce corrosive wear of cylinder liners and piston rings. For this reason, cylinder lubricating oil has alkaline additives which give oil the ability to neutralize acids that are produced during fuel combustion. This ability is expressed by the BN, or Base Number, of the oil. Recently, in the shipping industry, cylinder lubricating oils are being used with BN 40, 50, 57, 70, or 100. For example, a BN of 70 for a typical slow-speed engine cylinder oil means that a quantity of acid equivalent to 70 milligrams of potassium hydroxide is required to neutralize the alkaline additives present in one gram of this oil. The higher the Base Number of the engine oil, the more acid it will be able to neutralize during use. Correct engine operation ensures that the optimum supply of the cylinder lubricant to the critical ring/liner interface is maintained. Five factors determine the lubricating oil feed rate:

- Sulphur content in the fuel oil;
- Alkali content in the cylinder lube oil (BN);
- Engine history;
- Engine load;
- Operation environment.

Detailed advice on oil feed rates and maintenance to ensure the necessary protection of the engine is given in the engine manufacturers’ instruction manuals [2,9,12,13]. Engine makers never give strict instructions to optimize cylinder lubricating oil (CLO) consumption. They rather give recommendations in instruction manuals and makers’ service letters to protect the engine without optimization of cylinder oil consumption. Engine operators would like to have simple, strict instructions regarding setting up the cylinder oil feed rate (COFR) to operate engines with acceptable PR-CL wear rates and reasonable daily cylinder oil consumption. It can improve energy efficiency, reduce daily cylinder oil consumption, reduce costs of maintenance, and improve the overall reliability of engines as the prime movers of ships. Ships’ managers and operators are very much concerned with the process of increasing ships’ reliability and energy efficiency. The used cylinder lubricating oil is partly burned and partly drained from the bottom of the cylinder liners and discharged. A too high COFR causes:
➢ High emissions of unburnt harmful cylinder oil additives and hydrocarbons into the atmosphere;
➢ Higher wear rates of PR-CL due to accumulation of abrasive deposits in the combustion chamber;
➢ High accumulation of waste cylinder oil drained from scavenge spaces, which has to be utilized on board in incinerators or discharged to shore facilities. Utilization of waste cylinder oil in incinerators causes emissions of harmful substances into the atmosphere.

It is noticed that marine engine makers tend to reduce the COFR in their instructions and recommendations due to commercial competition without taking into account recent engine condition, environment, substandard fuels used, and many other factors important for engines’ safe operation. All operators of vessels tend to reduce the COFR to reduce the costs of lubricants [14–17].

Analysis of Scavenge Drain (ASDO) Monitoring

The cylinder drain oil composition is formed from used cylinder oil scraped by piston rings (PR), PR-CL assembly wear particles, water, unburnt fuel oil, and system oil that has entered into scavenge spaces through stuffing boxes’ sealing rings with wear particles from engine bearings and cross contaminants. Percentages of each contaminant in scavenge drain oil depends on the technical conditions of the engine during operation, quality of fuel used, applied COFR, and the brand of cylinder oil. Analysis of used cylinder oil taken from the engine through the scavenge spaces’ bottom drains can be used for evaluation of engines’ CL-PR wear intensity and evaluation of wear trends. The idea of sampling for ASDO is shown in Figure 1. All the benefits of ASDO have been described by many authors and presented in their scientific papers [4–6,8,16]. Analysis of scavenge drain oil (ASDO) data can be used for:

➢ Monitoring of CL condition;
➢ Optimization of cylinder oil feed rate;
➢ Extending time between overhauls;
➢ Reduction of waste oil burned on board in ships’ incinerators;
➢ Reduction of emissions into the environment from the fumes of unburnt oil.

With this appreciation of the possible goals and data of the analysis of scavenge drain oil, we have to take into account that:

➢ ASDO results are influenced by many parameters (operating conditions);
➢ ASDO is a helpful tool but not sufficient to evaluate the CL-PR condition alone;
➢ Engine inspections are necessary as well, and ASDO is not an early warning tool to detect sudden or severe wear.

One of the most important goals of performing an analysis of scavenge drain oil properties is getting an answer to whether reduction of the COFR is possible, or if it is necessary to increase it. Analysis can be used as a maintenance tool with the support of visual inspections of the liners’ and piston rings’ condition to maintain the serviceability of engines. Experience and the consequent advice provided by authors [4,6–8] had suggested that “good practice” required reserve alkalinity of the cylinder drain oil to be maintained in the range of 20–30 BN to provide adequate protection against corrosive wear, and in order to ensure that iron, as the indicator of wear, is maintained below 150 ppm. Many instances have been noted where ASDO shows iron content increasing, and alkaline reserve reducing, as a consequence of increased acid condensation during combustion. Analysis of the lubricant drain oil is considered by many operators as adequate to show whether the engine is over- or under-lubricated [9,12,13]. It is, however, insufficient to rely only on measurement of the alkaline reserve and iron content of the drain oil. A reliable interpretation depends on taking into account the characteristics of the fuel in use, the engine’s maintenance status, the condition of the engine, and performance data. An
unsuitable COFR can have serious consequences for the operation of vessels, people on board, and the environment [18–22].

Figure 1. Schematic drawing of scavenge drain oil samples for analysis [17].

3. Research Tests to Find Out the Most Efficient Cylinder Oil Feed Rate during Normal Operation of Engines

In scientific papers [18,19,23,24], we are able to find many research results dedicated to cylinder liners’ lubrication, but it is difficult to find research results which solved the practical issues.

The purpose of the performed tests was to find out the most efficient cylinder oil feed rate for engines in operation depending on:

- The various BNs of the fresh cylinder oils used;
- The sulphur content in the used residual fuel oil.

Scavenge drain oil samples drawn during the performed scientific experiments have been tested for:

- Iron particle content using a portable analyzer on board the research vessels. Results have been confirmed by shore laboratory analysis according to ASTM D5185-09. The obtained precise tests resulted in 98% accuracy.
- Compensated residual Base Number using a portable analyzer on board the research vessels. Results have been confirmed by shore laboratory analysis according to ISO 3771:2011(E). The obtained precise tests resulted in 98.7% accuracy.
Scavenge drain oil analysis has been performed for samples taken from each engine’s cylinder to evaluate the cross contamination between each unit. Tests have been performed on engines in normal operation, installed on ships as the prime movers, and engaged in worldwide trade. All tests have been performed at engines’ steady load of 83-85% MCR during normal operating condition of engines installed for ships’ propulsion [2,5,6]. It means after completed running in process of PR-CLs, in the range of 1500–18,000 working hours after overhauling of PR-CL assembly Marine slow speed engines PR-CLs assembly are usually overhauled after 12,000 to 18,000 engine working hours. Recently the time between CL-PR assembly overhauls is many times extended to even to 20,000 wh due to economical reasons. Cylinder oil feed rates have been changed from 1.54 through 1.40; 1.26; 1.05; 0.91; and up to 0.81 [g/kWh]. COFRs have been changed and adjusted on the HMI (human–machine interface) of the cylinder lubrication control system. During 24 h of testing at a specified cylinder oil feed rate, two series of samples have been taken from all engines’ cylinders and analyzed. The first series has been taken after 12 h and the second one after 24 h of testing. Samples were analyzed to obtain the iron (Fe) particles content measured in [mg/kg] and the residual BN [mg KOH/g].

This way, we obtained one average result for the testing of each particular cylinder oil feed rate for all test engine cylinders. The duration of each test was 6 days.

3.1. Research Performed on the Test Engine No. 1

Research tests have been performed on an engine (MCR 27160kW at 74 rpm, seven cylinders) operated with fresh CLO-57 BN [mg KOH/g]. Figures 2–4 present results obtained while performing the described research tests for operation of this test engine on various brands of fuels. Due to limited space in the paper, averages of the values of acquired test results are presented by the authors.

Figure 2. Scavenge drain oil analysis results versus cylinder oil feed rate for fresh cylinder oil BN 57 [mg KOH/g] in operation on residual fuel RMG 380-3.05% S.
Obtained research data show that the most suitable and efficient cylinder oil feed rate for operation of the engine on fuel with 3.05% S is set up on HMI value 1.09 [g/kWh]. This value of COFR has been set up permanently for operation of the engine using the mentioned brand of fuel and brand of CLO. It applies for all the engine’s cylinders. Effects of engine operation with the mentioned most suitable COFR for PR and CL condition have been evaluated during visual inspections of the PRs and CLs of all the engine’s units through under-piston scavenge spaces. Using expert knowledge, the condition of all inspected PRs and CLs have been rated as “good” to “very good” following an inspection guide recommended by the engine’s maker [5,6] after 659 and 1830 engine working hours.
Obtained research data show that the most suitable and efficient cylinder oil feed rate for operation of the engine on fuel with 2.31% S is set up on HMI value 1.05 [g/kWh]. This value of COFR has been set up permanently for operation of the engine using the mentioned brand of fuel and brand of CLO. It applied for all the engine’s cylinders. Results of engine operation with the mentioned most suitable COFR for PR and CL condition have been evaluated during visual inspections of the PRs and CLs of all the engine’s units through under-piston scavenge spaces. Using expert knowledge, the condition of all inspected PRs and CLs have been rated as “good” to “very good” after 1100 and 2300 engine working hours.

Obtained research data show that the most suitable and efficient cylinder oil feed rate for operation of the engine on fuel with 0.033% S is set up on HMI value 1.0 [g/kWh]. This value of COFR has been set up for forthcoming operation of the engine using the mentioned brand of fuel. Effects of engine operation with the mentioned most suitable COFR for PR and CL condition have been evaluated during visual inspections of all the engine’s units through under-piston scavenge spaces. Using expert knowledge, the condition of all inspected PRs and CLs have been rated as “good” to “very good” after 978 and 2350 engine working hours.

3.2. Research Performed on the Test Engine No. 2

Research tests have been performed on Test Engine No.2 similar to those for Test Engine No.1 (MCR-27160 kW at 74 rpm, seven cylinders), but operated with another brand of fresh CLO-70 BN [mg KOH/g]. Figures 5–7 present results obtained while performing the described research tests for operation of the test engine on various brands of fuels. Due to limited space in the paper, average values of acquired test results are presented by the authors.

Figure 5. Scavenge drain oil analysis results versus cylinder oil feed rate for fresh cylinder oil BN 70 [mg KOH/g] in operation on residual fuel RMG 380-3.38% S.
Obtained research data show that the most suitable and efficient cylinder oil feed rate for operation of the engine on fuel with 3.38% S is set up on HMI value 1.13 [g/kWh]. This value of COFR has been set up permanently for operation of the engine using the mentioned brand of fuel and brand of CLO. It applied for all the engine’s cylinders. The results of engine operation with the mentioned most suitable COFR for PR and CL condition have been evaluated during visual inspections of PRs and CLs of all the engine’s units through under-piston scavenge spaces. Using expert knowledge, the condition of all inspected PRs and CLs have been rated as “good” to “very good” after 790 and 1870 engine working hours.

Obtained research data show that the most suitable and efficient cylinder oil feed rate for operation of the engine on fuel with 2.45% S is set up on HMI value 1.04 [g/kWh]. This value of COFR has been set up permanently for operation of the engine using the mentioned brand of fuel and brand of CLO. It applied for all the engine’s cylinders. The results of engine operation with the mentioned most suitable COFR for PR and CL condition have been evaluated during visual inspections of PRs and CLs of all the engine’s units through under-piston scavenge spaces. Using expert knowledge, the condition of all inspected PRs and CLs have been rated as “good” to “very good” after 790 and 1870 engine working hours.

Obtained research data show that the most suitable and efficient cylinder oil feed rate for operation of the engine on fuel with 0.042% S is set up on HMI value 1.02 [g/kWh]. This value of COFR has been set up permanently for operation of the engine using the mentioned brand of fuel and brand of CLO. It applied for all the engine’s cylinders. The results of engine operation with the mentioned most suitable COFR for PR and CL condition have been evaluated during visual inspections of PRs and CLs of all the engine’s units through under-piston scavenge spaces. Using expert knowledge, the condition of all inspected PRs and CLs have been rated as “good” to “very good” after 790 and 1870 engine working hours.

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piston scavenge spaces. Using expert knowledge, the condition of all inspected PRs and CLs have been rated as “good” to “very good” after 995 and 1780 engine working hours.

Obtained research data show that the most suitable and efficient cylinder oil feed rate for operation of the engine on fuel with 0.042% S is set up on HMI value 1.02 [g/kWh]. This value of COFR has been set up permanently for operation of the engine using the mentioned brand of fuel and brand of CLO. It applied for all the engine’s cylinders. The results of engine operation with the mentioned most suitable COFR for PR and CL condition have been evaluated during visual inspections of PRs and CLs of all the engine’s units through under-piston scavenge spaces. Using expert knowledge, the condition of all inspected PRs and CLs have been rated as “good” to “very good” after 760 and 1720 engine working hours.

3.3. Research Performed on the Test Engine No. 3

Research tests have been performed on Test Engine No. 3 similar to those for Test Engines No. 1 and 2 (MCR-27160 kW at 72 rpm, seven cylinders). Engine No. 3 was operated using another brand of fresh CLO-100 BN [mg KOH/g]. Figures 8–10 present results obtained while performing the described research tests for operation of the test engine on various brands of fuels. Due to limited space in the paper, averages of the values of acquired test results are presented by the authors.

Figure 8. Scavenge drain oil analysis results versus cylinder oil feed rate for fresh cylinder oil BN 100 [mg KOH/g] in operation on residual fuel RMG 380-3.47% S.
Figure 8. Scavenge drain oil analysis results versus cylinder oil feed rate for fresh cylinder oil BN 100 [mg KOH/g] in operation on residual fuel RMG 380-2.53% S.

Figure 9. Scavenge drain oil analysis results versus cylinder oil feed rate for fresh cylinder oil BN 100 [mg KOH/g] in operation on distillate fuel DMA-0.055% S.

Figure 10. Scavenge drain oil analysis results versus cylinder oil feed rate for fresh cylinder oil BN 100 [mg KOH/g] in operation on distillate fuel DMA-0.055% S.

Obtained research data show that the most suitable and efficient cylinder oil feed rate for operation of the engine on fuel with 3.47% S is set up on HMI value 1.11 [g/kWh]. This value of COFR has been set up permanently for the operation of the engine using the mentioned brand of fuel and brand of CLO. It applied for all the engine’s cylinders. The results of engine operation with the mentioned most suitable COFR for PR and CL condition have been evaluated during visual inspections of PRs and CLs of all the engine’s units through under-piston scavenge spaces. Using expert knowledge, the condition of all inspected PRs and CLs have been rated as “good” to “very good” after 580 and 1230 engine working hours.
Obtained research data show that the most suitable and efficient cylinder oil feed rate for operation of the engine on fuel with 2.53% S is set up on HMI value 1.03 [g/kWh]. This value of COFR has been set up permanently for operation of the engine using the mentioned brand of fuel and brand of CLO. It applied for all the engine’s cylinders.

Obtained research data show that the most suitable and efficient cylinder oil feed rate for operation of the engine on fuel with 0.055% S is set up on HMI value 0.98 [g/kWh]. This value of COFR has been set up permanently for operation of the engine using the mentioned brand of fuel and brand of CLO. It applied for all the engine’s cylinders.

The effects of engine operation with the mentioned most suitable COFR for PR and CL condition have been evaluated during visual inspections of the PRs and CLs of all the engine’s units through under-piston scavenge spaces. Using expert knowledge, the condition of all inspected PRs and CLs have been rated as “good” to “very good” after 854 and 1589 engine working hours.

4. Prediction Model as an Aid to Set up the Most Suitable COFR in Real Engine Operation Conditions

All data obtained during the research performed on research Engines No. 1 and No. 2 and No. 3 to find the most suitable cylinder oil feed rates in various operational engine conditions was used as data for the program STATISTICA, license JPZ009K288211FAACD-Q. The program STATISTICA was used for regression analysis to find a prediction model to calculate the COFR that should be set up on an engine in operation depending on the sulphur content in used fuel (S-%) and the brand of CLO (BN [mg KOH/g]). The same program was used to draw a 3D diagram of COFR versus sulphur content in used fuel and the BN of the CLO in use. It is presented in Figure 11.

![Figure 11. COFR versus sulphur content in used fuel and BN of CLO.](image-url)

The STATISTICA prediction model of the COFR calculation required to be set up for a marine slow-speed engine in operation is as follows:
\[ \text{COFR} = 1.042 + (0.035S) - (0.0004BN) \]  

\[ R^2 = 0.88, \text{ Standard Est. Error} = 0.026 \]

where:
- \( S \)—fuel’s sulphur content [%].
- \( BN \)—fresh CLO Base Number in use [mg KOH/g].

Setting up the calculated COFR using the prediction model depending on the sulphur content in fuel used (S-%) and the brand of CLO (BN [mg KOH/g]) should preserve satisfactory wear ratios of the PR-CL assembly with the required reserve alkalinity of the SDO in the range higher than 20–30 BN and iron content below 150 ppm. Validation and verification of the presented model was confirmed during the performed series of tests on the engines in normal operation.

5. Verification of Prediction Model

To confirm and validate the prediction model described in Section 4 for calculation of the most suitable COFR, a series of verification tests have been performed during normal, real engine operation. Verification tests have been carried out on two engines (MCR-27160 kW at 74 rpm). During the tests, the first engine was operated using CLO with BN 80 [mg KOH/g]. The second engine was operated using CLO with BN 60 [mg KOH/g]. Engines were operated at 83–85% MCR. Verification tests were performed during operation of the engines on fuels with various sulphur content. The effects of engine operation with various COFRs on PR and CL condition calculated using prediction model (1) have been confirmed during visual inspections of PRs and CLs of all the engines’ units through underpiston scavenge spaces. Table 1 presents ASDO results obtained after set-up of COFR using the prediction model. Verification tests confirmed the applicability of the prediction model to set up the most suitable COFR to optimize cylinder oil consumption and operation of the engine’s CL-PR with reasonable wear rates.

### Table 1. ASDO results obtained after set-up of COFR using prediction model.

<table>
<thead>
<tr>
<th>CLO BN [mgKOH/g]</th>
<th>Fuel Sulphur Content [%]</th>
<th>Calculated COFR Using Prediction Model [g/kWh]</th>
<th>Set-up COFR on HMI [g/kWh]</th>
<th>Engine’s WH in Operation with Set-Up COFR [h]</th>
<th>Average Iron Content in SDO at Engine 83–85% MCR [ppm]</th>
<th>Average Residual BN in SDO at Engine 83–85% MCR [mg KOH/g]</th>
<th>Evaluation of Results of PR and CL Visual Inspection to Confirm Effects of Engine Operation with Set-Up COFR [-]</th>
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<td>555</td>
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<td>865</td>
<td>70</td>
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</table>

6. Discussion

Tests results performed to optimize cylinder oil consumption and obtain satisfactory CL-PR cylinder wear rates for selected engines are described above. The results of these observations and analytical assessments are summarized below:

- It is necessary to adjust the specific COFR depending on the fuel sulfur content and the brand of CLO used. Makers of engines are giving recommendations for adjustment of the COFR, but wear rates of the CL-PR are omitted.
- Engine operators can make an initial calculation of the COFR using the prediction model whenever sulfur content in the fuel in use changes or the BN of the cylinder lubricating oil in operation is changed. Operators should obtain satisfactory wear
ratios for the PR-CL assembly with the required reserve alkalinity of the SDO in the range higher than 20–30 BN and iron content below 150 ppm.

- Application of presented research results gave excellent results for CL-PR wear rates in practical operation of engines. Calculation of the COFR using the prediction model can be easily applied by engine operators. There is a lack of such a simple aid tool in the operation of marine long-stroke engines.

- Results of engine operation with the calculated COFR for the condition of PRs and CLs have been confirmed during visual inspection of PRs and CLs of all the engine’s units through under-piston scavenge spaces. Verification tests confirmed the applicability of the prediction model.

- The prediction model applies to normal operation conditions for engines operating at loads of 80–85% MCR (maximum continuous rating). However, some engines' lubricators have load dependent modes, in which case the COFR calculated using the formula can be used in the full range of loads on the engine.

- Results of ASDO give an answer to whether a reduction of the cylinder lubricating oil feed rate is possible, inform about the quality of the lubrication of liners and piston rings, and include many other engine operational data. ASDO can be used as a maintenance tool with the support of visual inspections of liners’ and piston rings’ condition to maintain the serviceability of engines. An unsuitable COFR can cause serious consequences for the operation of vessels, the people on board, and the environment.

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**Abbreviations**

- PR: Engine’s piston rings
- CL: Cylinder liner
- PR-CL: Piston rings and cylinder liner assembly
- CLO: Cylinder lubricating oil
- COFR: Cylinder oil feed rate [g/kWh]
- MCR: Engine maximum continuous rate [kW]
- SDO: Scavenge drain oil
- ASDO: Analysis of scavenge drain oil
- BN: Base Number of cylinder lubricating oil [mg KOH/g]
- MCR: Maximum continuous rating of engine [kW]
- rpm: Revolutions per minute [1/60s]
- % S: Sulfur content in used fuel [%]
- ppm: Parts per million [mg/kg]
- wh: Working hours, number of hours in operation [h]
- HMI: Human–machine interface

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