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# The Performance, Wear, And Environmental Impact of Lubrication Systems Used in Marine Engines

DEGREE PROGRAMME IN MARINE ENGINEERING
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ABSTRACT

Alfred Uanekee: The Performance, Wear, And Environmental Impact of Lubrication Systems Used in Marine Engines
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The objective of this thesis is to examine the efficiency, durability, and ecological consequences of lubricating methods employed in marine engines. The maritime industry has played a role, in promoting unity through international trade. Considering the role of trade in the world’s economies it is important to prioritize the upkeep of ships.

Numerous studies have extensively examined the lubrication system of engines as a factor influencing the shipping sector. Failing to prioritize lubrication practices, like inspections and maintenance has resulted in engine failures, within marine systems ultimately reducing their efficiency and causing breakdowns of ships.

This research investigates lubricants that could be used for ships, at sea and has also found the lubricant for marine engine systems. Sampling and analysis methods to ensure the accuracy of our results. It's important to develop protocols, for producing lubricants to protect marine ecosystems and enhance the performance of ships.

Keywords: Maritime system, Lube Oil, Total Base Number, Total Acid Number, Lubricants, Marine Engine System, International Maritime Organization, International Convention for the Prevention of Pollution from Ships, Standards of Training, Certification, and Watchkeeping.

CONTENTS

# LIST OF TERMS AND ABBREVIATIONS

| | |
|---|---|
| SOLAS | Safety of Life at Sea |
| TBN | Total Base Number |
| TAC | Total Acid Number |
| IMO | International Maritime Organization |
| STCW | Standards of Training, Certification, and Watchkeeping |
| MARPOL | International Convention for the Prevention of Pollution from Ships |
| ECR | Engine Control Room |
| LED | Light Emitting Diode |
| Al | Aluminium |
| Fe | Iron |
| Ni | Nickel |
| Cu | Copper |
| Pb | Lead |
| V | Vanadium |
| Cr | Chromium |
| M/S | Motor Ship |
| P | Phosphorus |

# 1 INTRODUCTION

The maritime sector, as a cornerstone of global trade, has demonstrated its profound impact on the world economy, facilitating international trade and creating numerous employment opportunities (Kosowska-Stamirowska, 2020; Ducruet & Guerrero, 2022). However, the sustainability of this sector hinges on the efficiency and environmental friendliness of its operations, particularly in marine engines. The performance and wear of lubrication systems in these engines are critical yet often overlooked aspects that demand thorough examination. Despite some studies addressing marine engine lubrication, a comprehensive investigation that encapsulates performance, wear, and environmental impact is conspicuously absent.

This thesis aims to bridge this gap by systematically evaluating lubrication systems in marine engines, assessing their operational performance, wear characteristics, and consequent environmental ramifications. Employing a combination of experimental analysis and literature review, this study targets to provide insights valuable for ship operators, environmentalists, and policymakers.

The anticipated outcome is a set of recommendations that could revolutionize lubrication practices in the maritime industry, contributing to both economic efficiency and environmental sustainability. Given the reports on the maritime industry's importance to commerce, it is crucial to prioritize the protection of ships at sea.

Figure 1 illustrates that the marine industry in the United States significantly contributed to trade growth in 2018, surpassing other transportation sectors such as air, pipeline, track, and rail with a 41.8% increase.

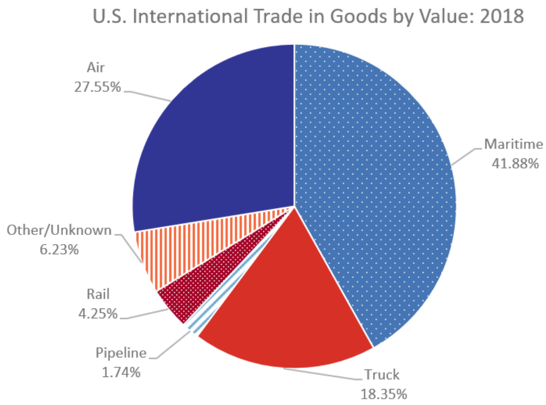


Figure 1: The United States' international trade in goods by value 2018. (International Trade Administration website, 2023)

The marine sector has proved to provide employment opportunities to diverse professionals, from marine engineers, shipbuilders, sailors, port workers, and researchers, thus significantly contributing to the economies of maritime nations and coastal regions. However, scientific exploration has been one of the major inventions of the marine industry. For instance, the marine industry has been on the frontline in supporting scientific research, which has made it possible to explore the world's marine ecosystems and oceans. Through this research, it has been possible to provide reliable insights into aspects of climatic change as well as the management of natural resources and biodiversity. This has made it possible for the marine sectors to contribute significantly to environmental conservation matters with an increased focus on sustainability technologies and practices with the objective of reducing the environmental impact of the marine industry. (Michalopoulou, 2021.)
The continuing efforts and research are aimed at reducing pollution, protecting the marine ecosystem, and promoting conservation, which is aimed at protecting lives.

The contributions of the marine industry to human life can, therefore, be attributed to proper management of the entire marine system, including the ships. Maintaining the ships guarantees the safety of both the personnel in the marine industry and also promotes the lifespan of the machinery involved in daily marine activities. Combined efforts are required from the marine team to ensure that the sea vessels are well protected and maintained to continue serving people, uniting nations and promoting relations through facilitating trade activities. (Elliott et al., 2020.)
Promoting and protecting the maritime industry means safeguarding the interests of the nations as well as protecting livelihoods that may arise from the issues of marine safety.

## 1.1 Research objectives

This research aims to investigate the effects of various lubrication systems on the operational performance, wear characteristics, and environmental sustainability of marine engines, framed within the maritime industry's regulatory frameworks and ecological challenges. The research question aimed for this thesis is: How do different lubrication systems impact the operational performance, wear characteristics, and environmental sustainability of marine engines in the context of the maritime industry's regulatory frameworks and ecological challenges?

Lubrication systems in marine systems have proven to play an important role in increasing the lifespan of marine vessels. On the same note, the lubrication of marine systems plays a critical role in reducing the friction between the moving parts, which is critical in reducing wear and tear. The working principle of the engine lubrication system is founded on distributing oil to the moving parts with the objective of reducing the friction between surfaces. Through this principle, it is therefore clear that lubrication plays an important role in increasing the life expectancy of an automotive engine of the marine system. The lubrication of the engine of a marine system plays a critical role in preventing the engine from succumbing to overheating and seizing quickly, which may endanger the lives of the personnel as well as damage the cargo in transit, which may result in increased losses. (Abbas & Shafiee, 2020.) Proper lubrication of marine system engine contributes to cleaning the internal parts of the engine, provides cushioning effects as a result of the engine's vibration, reduces wear and tear of engine moving parts and also contributes to minimizing power loss, which is mainly caused by the friction of the moving parts of the engine.

## 1.2 Scope and Limitation

The study was limited to the maritime industry. The generalization will, therefore, be confined to the maritime industry only and not any other transport sector. The study encountered challenges related to the ample time required to investigate and document the performance of various types of lubricants used in maritime engine systems. The study also required important resources to finance the entire process, which therefore resulted in the need for adequate finances and time to facilitate the achievement of the best outcome. The study is limited to the maritime industry, and it was, again, not possible to cover all the different types of lubricants used within the transport industry.

## 1.3 Thesis Organization

Chapter one of this thesis outlines the introduction to the marine system engine systems and the importance of the marine industry to the general global trade. Chapter two illustrates the literature review, which discusses the history and evaluation of marine engine lubrication. Chapter three highlights the methodology used to collect the data as well as the analysis of the gathered data from the field. Chapters four to six generalize the available lubrication systems for marine engines, the criteria for selecting the best lubricants, and the importance of conducting regular maintenance and inspection. Chapter seven outlines the environmental and also regulatory considerations of the marine engine lubrication system. Chapters eight and nine will discuss the findings from the research and conclude by summarizing the key points as well as outlining the significance of the study. Lastly, the last chapter will recommend the most appropriate and effective lubricants to the marine industry.

# 2 LITERATURE REVIEW

## 2.1 History and Evolution of Marine Engine Lubrication

Lubrication was invented by Elijah McCoy way back in 1872. In the early years, unlike modern days, the engines used to be stopped for lubrication to be applied. Through the invention of Elijah McCoy, it was possible to pally engine lubrication while the engine was still running, which played an important role in saving time and money. The evidence of lubrication can be traced back to ancient Egypt, where, within the industry, the wheels were treated with tallow animal fat that made it possible for moving parts to rotate easily, which made it possible to transport heavy loads. (Arnold, 2022.) The ancient Chinese, however, used a mixture of vegetable oils and lead that acted as lubricants in machinery to facilitate easy movement. The utilization of vegetable oils and animal fats continued until the 8$^{th}$ century when whale oil was introduced and applied in lubricating ladders, rudders and pulleys in marine vessels, especially ships; among the majorly used commodities included naphtha, which is a distilled hydrocarbon-based flammable oil which is like modern day lighter fuel and was mostly used by shipbuilders. The ever-growing need for lubricants in the automotive industry saw the lubricant manufacturers dig more into manufacturing petroleum-based lubricants to enhance and improve performance. (Pranav et al., 2021.)

The introduction of additives in the 1940s played a significant role in inhibiting oxidation, improving viscosity and resisting corrosion within the internal system of marine engines. However, the scientific knowledge behind additives in lubricants continued to evolve with a design to prolong the performance and service the life of automotive engine oils, which made it possible for the lubricants to provide more reliable services. (Tan et al., 2021.)

Sharma et al. (2020) argue that the demand of the marine industry drove the introduction of Synthetic lubricants in the early 1950s, and aerospace transformed engine lubrication as they were more effective and reliable. The evolution of modern lubricants, especially in the marine industry, continues as advanced products are evolving, all aimed at meeting the increasing demand for modern maritime systems with an objective of enhancing productivity, energy efficiency, and reliability, as well as ensuring environmental responsibility.

## 2.2 Lubricants Principles and Functions

Lubrication is classified as one of the critical factors that determine the performance of marine engines. It is, however, important to note that the suitability of the lubricant and lubrication method has a significant dominance on bearing life. Modern marine engines are complex and becoming increasingly more powerful and more efficient, which has resulted in improved efficiency. However, the development of new marine engines demands high-quality lubrication and maintenance to perform effectively. Lubrication of engine moving parts is crucial towards enhancing engine performance and longevity. The lubrication oils are critical in helping reduce the friction between the components of marine system engines, separating the opposing surfaces as well as preventing contact between metallic surfaces. (Kass et al., 2019.)

However, it has been found that the condition of the applied lubricants deteriorates with use as a result of contamination and chemical activities with marine engine systems. The principles of lubricants include that the viscosity of the lubricant oil must remain within certain clearly outlined limits. Although lubricant viscosity increases during the operation of the engine, it should be noted that increased or decreased viscosity may result in improper lubrication and thermal distortion. (Chen et al., 2020.)

Another important principle is to ensure that the lubricating oil does not contain amounts of water or insoluble substances. The presence of particles and excess water can be detrimental, to the engine’s performance leading to mechanical damage and inadequate lubrication of the internal engine parts. Additionally, it is crucial for the lubricating oil to have properties, against corrosion caused by chemicals. This includes the ability to neutralize acidity levels, which is commonly referred to as Total Base Number (TBN). This is critical in controlling the wear and tear of internal parts of the engine. (Woma et al., 2019.) Lastly, lubricating oil should be able to maintain the flash point set by the manufacturer. A lower flash point that is specified may indicate the presence of lighter hydrocarbons, which may indicate the possible effect of diesel fuel in marine engine systems. (Woma et al., 2019.)

As already outlined earlier, the primary functions of lubricating oils include cooling the engine, thus acting as a heat transfer mechanism, offering protection to the engine that happens as a result of oxidation and corrosion. Also, the lubricants act as engine cleaning systems by holding the contaminants in suspension (Kass et al., 2019). It is, therefore, clear that lubricants play a crucial role in enhancing the lifespan of an engine as well as ensuring that the ships are able to offer services for a long time and serve the intended purpose.

## 2.3 Types of Lubricants

There are different types of lubricants used in marine systems. Among the common types of lubricants includes oils. For instance, the purpose of marine trunk piston engine oils is to lubricate the engine, control piston deposits, and protect the engine bearings, which are critical in providing and enhancing good antiwear performance. (Olsson, 2021.)

The other common lubricant applicable in marine engine systems is grease. The grease lubricants facilitate the creation of an oil layer between the moving parts of an engine that is critical in lessening the amount of friction and wear. In some marine engines, the grease lubricant is used as a coolant, and it is also used to clean the internal system of an engine. (Olsson, 2021.) The marine engine systems also utilize penetrating lubricants, which are, however, not long-lasting and are mostly used to infiltrate tiny cracks, which adds to lubrication and helps break up rust within engine systems. Figure 2 illustrates a typical lubrication system for Marine two stroke diesel engine.

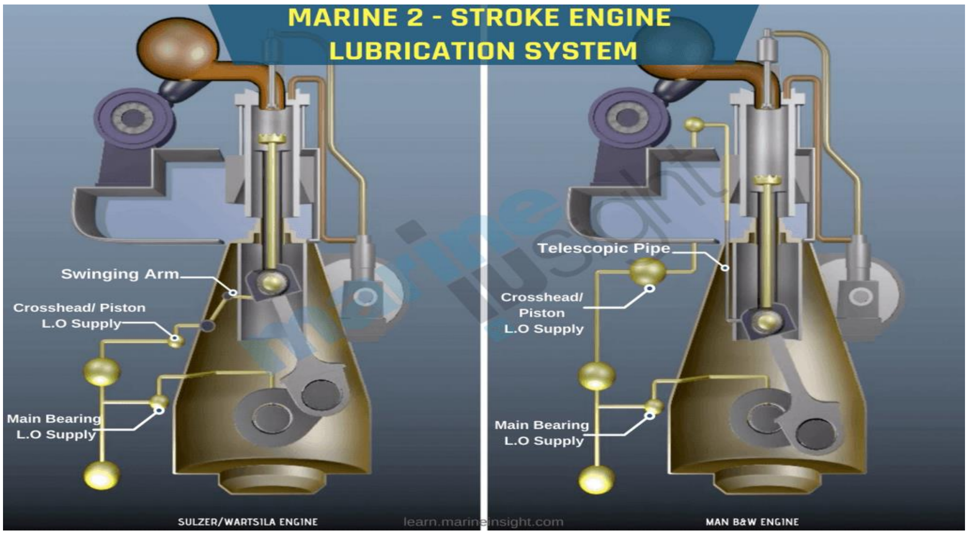


Figure 2: Ship's Main Engine Lubrication System. (Marine Insight website, 2019)

## 2.4 Components of Lubrication System

The engine's lubrication system plays a critical role in distributing oil within the engine system of a marine vessel with the objective of reducing the friction between the moving parts of the engine. Mainly, the distribution of oil to the engine facilitates the creation of an oil layer between the moving parts, which lessens the amount of friction and wear. (He et al., 2019.) Figure 3 illustrates an oil lubricating system for a marine diesel engine.

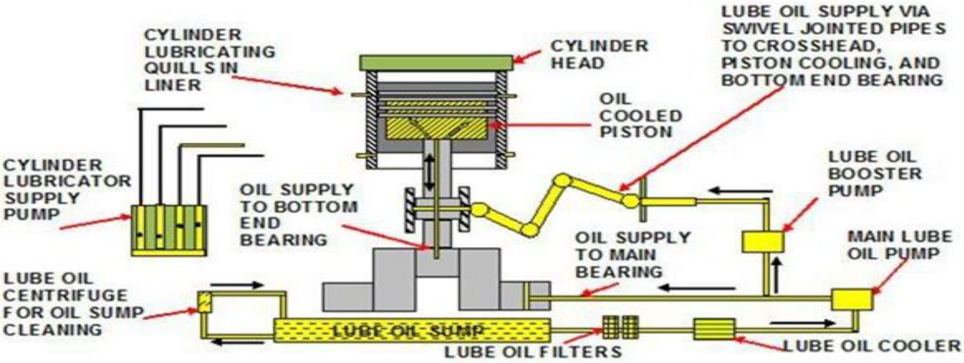


Figure 3: The lubricating oil system for marine diesel engine. (Marine Engineering website, 2019)

The lubricating oil is located at the bottom of the system, in a section referred to as the sump. The lubricating oil is drawn from the sump tank through the strainers to the filters. The oil goes through the cooler, where it is later forced into various parts of the engine. The branch pipes for the different cylinders are used to feed the main bearings with lubricating oil. The alarm fitted at the end of the distribution pipes plays a critical role in ensuring that the pump is able to maintain adequate pressures of the lubricants, making it possible to supply it to the entire engine system. After the engine oil has been used to flow back to the sump tank for reuse within the system. The level gauge in the sump gives the correct oil levels, which ensures the engine system is full of oil for lubrication. (Khanna et al., 2019.)

It is also important to note that the oil cooler is circulated by the seawater, which is always at a lower pressure than the oil. This, therefore, means that any leakage in the cooler may result in contamination of the oil by seawater. It is also important to note that an appropriate type of lubricant must be used for oil-lubricated pistons, which plays an important role in avoiding carbon deposits on the hotter sections of the engine systems. It is important to note that different types of ships engines have different lubrication systems, which, therefore, means the lubrication is carried out differently but still uses the same distribution principle of operation. (Olsson, 2021.)

## 2.5 Lubrication Challenges in Marine Engines

Like other industries, the maritime sector has not been left behind in issues of lubrication challenges. Among the major challenges that have been encountered in marine engine lubrication include improper sampling points and hardware. The research has reported that proper analysis of lubricant oils is critical. The analysis makes it possible to evaluate the health of the oil as well as the machine utilizing the lubricant. Obtaining all benefits of a particular lubricant requires obtaining the correct sample size and hardware. For instance, sampling through the use of oils with high concentrations of contaminants may make it difficult to establish wear and debris trends. (Kass et al., 2019.) As one of the sampling strategies, drop tube sampling has proven effective but requires the machine to be serviced frequently; failure to do so may result in particles settling at the bottom of the sump, which may prevent the collection of an appropriate sample.

The other lubrication challenge is the lack of clear procedures for the publication process of the marine engines. Clear documentation of lubrication procedures plays a crucial role in lessening the blow and also helping the involved individuals understand the proper procedures for applying the lubrication. Lastly, another common challenge that has been encountered during engine lubrication is over-greasing or overoiling, depending on the preferred lubricant—being a common problem, though unnoticeable, over-greasing results in premature bearing failure and higher operating temperatures that increase the risk for contaminant ingression. It is important to note that bearing requires a given level of lubrication for optimal and effective performance. (Ventikos et al., 2022.) There is, however, a popular formula used to determine the amount of lubrication required where the outside diameter of the section in question is multiplied by the width and then multiplied by 0.114 for all dimensions in inches.

# 3 RESEARCH AND METHODOLOGY

## 3.1 Data Collection Methods and Research Design

The research employed a systematic sampling research method that made it easy to apply while testing different lubricants used in marine systems engines. The reason, for choosing this sampling method is because it helps minimize any samples and improves the quality of survey reports. This research method is also important in preventing any manipulation of the collected data making it a reliable approach. The systematic sampling method is often seen as simple and easy to implement allowing for the inclusion of factors, in the gathered data. (Wang & Cheng 2020.)

The research was divided into two sections to analyze the results; the test and the spectrometry output. The standard test provided information, on viscosity, flash point, water content and solubility of CDX 30 and DURATEC HPL lubricants used in 2 stroke and 4 stroke engines. On the hand spectrometry measured the levels of elements, like iron, copper, lead, aluminium and more.

The utilization of data collection techniques ensured the reliability of the results. This allowed for the analysis of types of lubricants enabling testing of aspects related to their application, in marine systems. The instruments utilized in the study were also validated by the International Maritime Organization (IMO) confirming their suitability and further enhancing the credibility of the findings. Furthermore, it is worth mentioning that a single instrument was used consistently throughout the research to ensure uniformity in outcomes. A pilot test was conducted with the objective of familiarizing oneself with the procedures required in the data-collecting techniques.

## 3.2 Data Analysis Techniques

The research utilized reliable and effective data collection techniques, which necessitate the importance of employing quality data analysis techniques. As a result, the qualitative data analysis technique was utilized to analyze the results from the lubricants used in the data collection. The qualitative analysis techniques were used to explain the questions of how and why the data was analyzed in a particular manner. The results obtained from the laboratory utilized the latest analytical techniques as well as computer programming strategies with the objective of offering advanced analysis of the lubricants used in marine engine systems. The analysis of the results obtained was regarded as crucial, with an increased chance of employing the data by the relevant maintenance teams within the maritime industry to ensure the commendable lifespan of the ships. On the same note, the analysis of the data obtained was crucial towards helping the involved teams select the best lubricant for quality services depending on the engine type.

# 4 MARINE SYSTEM LUBRICATION OVERVIEW

## 4.1 Lubrication system diagram

Figure 5 represents a lubrication system of an engine that it is critical in supplying lubrication to various moving parts of a maritime engine system. The main function of this system is to form a film of oil between moving parts of an engine that is critical in reducing wear and friction, thus increasing the lifespan of the engine system. Marine propulsion systems rely on lubricants, for functions, such, as cooling and maintaining cleanliness. (Butrymowicz et al. 2021.)

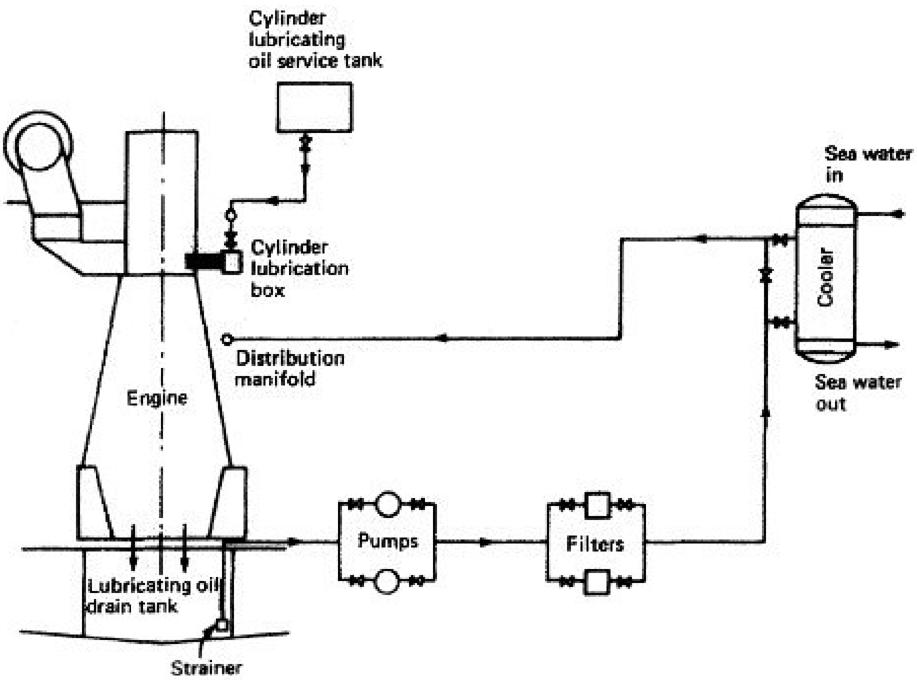


Figure 5: The lubrication system diagram. (Machinery Spaces Website, 2018)

The main oil system consists of six different parts, each with an individual system that makes it possible for the engine to function properly and offer quality services for a good duration. Without this section, the marine engine system may not perform effectively.

#### 4.1.1 The lube oil sump

The main function of this part is to store the lubricating oil used in the engine system. The part is located under the main engine, which makes it possible to supply oil to the other parts of the engine easily. It also has other critical components, such as the level gauge used to measure the quality of lubricant, the sounding and heating pipes, and the suction port. (Jiang et al., 2022.)

#### 4.1.2 The strainer

This is a special type of filter fitted at low pressure. The function of this part is to block the flow of large metallic particles into the engine system. This part is easy to clean and requires regular cleaning in order to maintain the system's pressure difference. (Holdmeyer, 2023.)

#### 4.1.3 The Main Engine Lubricating Oil Pump

This section comprises two screw pumps that are critical in delivering the lubricating oil to all engine parts. It should be understood that the pumps operate one at a time. The operational mechanism of the pump is that it takes suction from the engine and directs it to the distribution centre through the filter and the cooler. The distribution manifold makes it possible for the lube oil to reach the important areas that require lubrication, such as bearings, hydraulic power supply, under-piston space and guides. (Ventikos et al., 2022.) It should, however, be noted that the pumps are driven by an engine where low speed is required and a motor for increased speeds.

#### 4.1.4 The Lube Oil Filter

As the name suggests, the main function of this part is to prevent small foreign objects that may be present in the lubricant from getting into the engine system. The oil filters operate one at a time while the other remains on standby. Removing any metallic or foreign objects makes it possible to reduce any possible friction that may cause wear of critical engine components. (Holdmeyer, 2023.)

### 4.1.5 The Lubrication Oil Coolers

The Lubrication Oil Coolers serve the purpose of controlling the lubricating oil temperatures within the engine at around 45 degrees. Suppose the temperature goes beyond 60 degrees; an alarm will be raised, which will slow or stop the engine system. It should, however, be understood that a typical lubricant cooler passes through pipes with water to help cool it down. It should also be noted that a bypass valve is installed to control the quantity of lubricant flowing through the cooler. (Ventikos et al., 2022.) The coolers are also installed before the filters to help reduce any high pressures that may damage the lubrication system.

### 4.1.6 The Distribution Manifold

The Distribution Manifold helps distribute lubricants from the lube oil cooler to all the other parts of the engine. A significant part of the lube oil is directed towards the crosshead through the telescopic pipe and diverted to the under-piston space as well as crosshead bearings and through the telescopic pipes. The remaining lubricating oil goes through the thrust bearing, main bearings, vibration dampeners, and actuate exhaust valves, where it later drains back to the oil sump. (Jiang et al., 2022.)

### 4.1.7 A Technical Comparison of Two-Stroke and Four-Stroke Engines and Their Lubrication Demands

Basically, there are two types of marine engines, namely 2-stroke engines and 4-stroke engines. Each of these engines has unique lubrication needs, which are defined by the mode of operation. The main difference between the two types of engines is the amount of power developed. (Maree, 2020.)

### 4.1.8 Two-Stroke Marine Engine

The research conducted on different types of marine engines described the different lubrication needs required by different engines with different modes of operation. The research concluded that three important bearings require lubrication in two-stroke engines. Figure 6 illustrates the crosshead, crank-pin and main bearing as critical components of the two-stroke bearing that require lubrication for the engine system to operate effectively. The crankcase lubrication has been described as the best lubricant needed for the highlighted part. However, mist lubrication canals can be applied where the crankcase lubrication is not suitable. (Maree, 2020.) The section between the cylinder and the piston liner is also a special section that requires lubrication and is mainly achieved by using the cylinder oil for lubrication.

The research proved that crankcase lubricant is the most appropriate for two stroke engines, especially in bearing areas, which are circulated effectively by the main engine lube oil pump. This type of lubricant proved to be the most suitable as a result of its oil being less basic with TBN or around 6.

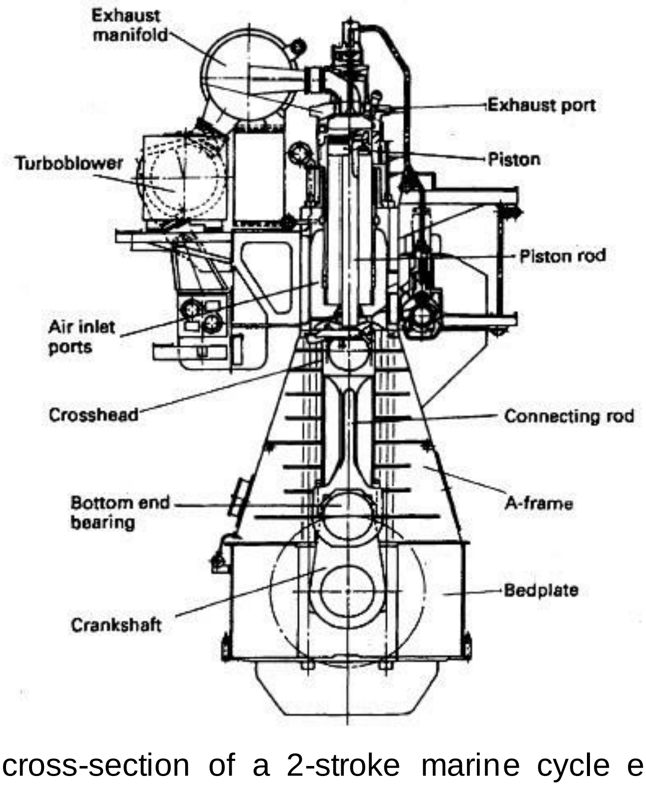


Figure 6: A cross-section of a 2-stroke marine cycle engine. (Machinery Spaces Website, 2018)

### 4.1.9 Four-Stroke Marine Engine

Figure 7 illustrates that contrary to a two-stroke engine that only requires its lubrication oil for critical internal components, a four-stroke engine requires circulating oil to all its moving parts. The study concluded that the two main systems of lubrication needed in a four-stroke engine. The splash lubrication of the pressurized lubrication pump system is the one used in the four-stroke engine to supply the lubricating oil to all of the engine parts. To achieve splash lubrication, the obscured crankshaft in the sump distributes oil to different parts of the engine. Wrist pins, cylinder walls and cam lobes are the few parts of the engine that receive engine oil from splash lubrication. The bearings of the cam, main, and rod receive lubricants from the pressurized system.

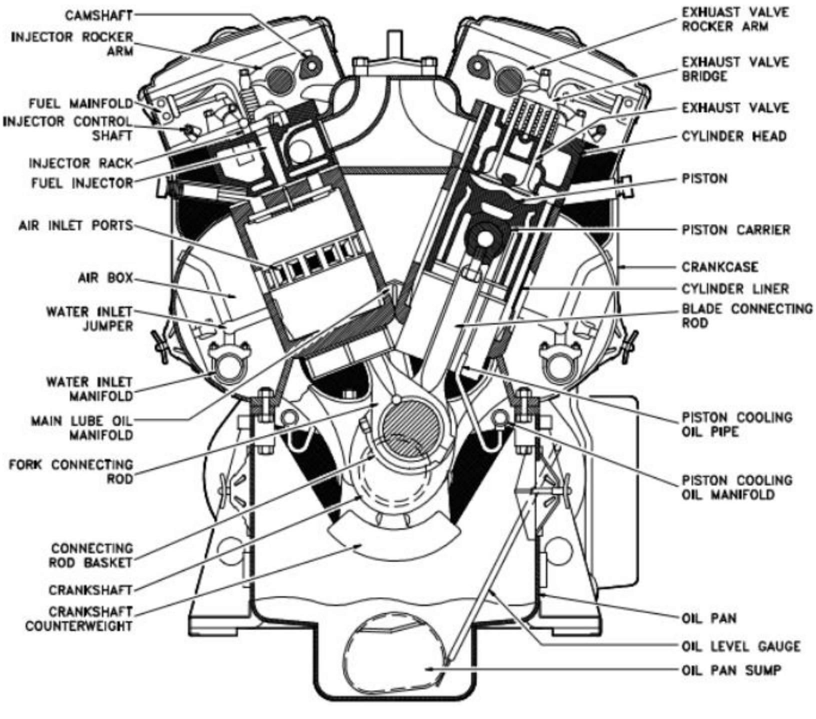


Figure 7: A cross-section of a 4-stroke marine cycle engine. (Machinery Spaces Website, 2018)

# 5 LUBRICATION SELECTION AND PROPERTIES

## 5.1 Strategic Selection of Marine Engine Lubricants

Different lubricants perform differently when applied to different types of marine engines. Selecting the best engine lubricants for certain types of marine engines results in quality performance and contributes to protecting marine life. (Hassanshahi et al., 2020.) Among the aspects to consider while selecting the appropriate lubricants for specific engine types include:

### 5.1.1 Ability to adhere to the surfaces (viscosity)

Quality lubricants must be able to protect critical engine parts from degradation. A good lubricant must, therefore, possess a high viscosity that contributes to the mechanical parts of an engine working better and ensures the protection of the entire system. Lubricants are essential, in engines as they create an oil film that adheres to the surfaces of engine parts effectively reducing friction. This helps prevent damage and deterioration of the engine components ensuring their operation. (Hassanshahi et al., 2020.)

### 5.1.2 Thermal stability

When it comes to selecting the lubricant, for engines stability is a factor to consider. It's important to choose a high-quality lubricant that offers stability in order to effectively dissipate heat and protect the engine from overheating. This guarantees that the engine runs optimally and properly with stable and consistent performance. The thermal stability helps to keep the engine components cool. This prevents decomposition and temperature changes of any sort. Also, it helps to predict any kind of chemical change in the marine engine system due to the change in temperature (Hassanshahi et al. 2020).

### 5.1.3 Demulsification

Selection of the lubricant used in the engine should be with the intention of demulsification i.e., separation of lubricant and water, and oil should not blend it. Lubricant blending with oil and water mixture will leave the other additives not to form, and hence one needs to add engine performance additive. Engine performance additive should be applied to the lubricating oil of the oil-water mixture in order to stop the additive from forming (Hassanshahi et al., 2020.)

### 5.1.4 Approval of the Original Equipment Manufacturer

Before any lubricant oil for an engine is bought and used for a boat, the approval of the lubricant oil from the engine manufacturer is inevitable. The engine will be properly taken care of and last longer when lubricant oil is approved by the manufacturer (Kass et al., 2019).

## 5.2 Viscosity and Temperature Considerations

When examining viscosity and temperature dependency, a vital study will be considered. It is necessary to understand the factors to be considered for the lubricants that will be selected on marine engine systems. It is a mandatory crucial factor to be found to ensure the engines work effectively (Kass et al., 2019.)

### 5.2.1 Importance of Viscosity

The test is about engine performance and lubricating property of an oil using a marine engine as a lubricant. This testing refers to the marine engine's result include water content, fuel consumption. Some tests include the specific fuel oil consumption, cylinder oil wear, piston ring wear and cylinder wear, and towards an engine room towards a general observation for the engine room. High Marine VIs have been proven to stabilize and shield the engine from fluctuations in temperature. (Kass et al. 2019). Marine engine oils with higher viscosity contribute to ensuring optimal lubrication of the engine system as well as ensuring the engine remains protected in different temperatures. Higher viscosity oil SAE 50 has been recommended for maintaining film strength even during warmer engine temperatures. Increasing the viscosity of the engine oil minimizes the chances of breaking down the film layer. It should, however, be noted that too high viscosity increases the viscous drag and may contribute to power loss. (Frost et al., 2023.) Appropriate oil films reduce friction and also contribute to marine engines starting quickly during cold weather.

### 5.2.2 Temperatures consideration

Temperature remains a critical consideration of engine oils for maximum and quality efficiency. The temperatures of the engine oils must be raised at least $90^{0}$ F prior to warming up the propulsion unit, as the oiliness of the oil at this temperature is important for quality lubrication. It should, however, be noted that low-temperature performance is appropriate for vessels that perform cold start. (Kass et al., 2019.) High-temperature stability is important for hot climates as well as continuous operations. The thermal stability of lubricants is essential in preventing the engine from overheating and cooling down the important parts of the engine, thus enhancing its durability and performance. Additionally, thermal stability also plays an important role in resisting decomposition that results due to temperature changes. (Frost et al., 2023.) Considering temperatures while applying lubricant to the engine system plays an essential role in not only protecting the engine by increasing its lifespan but also enhancing its performance.

## 5.3 Additives and their Functions

The research provided insights into the complex blend of additives contained in the engine oils with the objective of minimizing emissions and contributing to high-efficiency levels. As outlined before, the engine bearings in the engine system need lubrication to ensure maximum performance of the marine engine system. The oil film formed within the engine system prevents engine blow by controlling oil consumption, minimizing wear, reducing friction, and contributing to heat transfer within the engine system.

Engine oils have the highest percentage of additives, which include rust and oxidation inhibitors (Palani et al., 2022). Other additives include corrosion inhibitors, pourpoint depressants, foam inhibitors, viscosity index improvers, and antiwear additives. The research has concluded that additives have three major roles in engines, which revolve around enhancing existing base oil properties, especially with demulsifying agents, corrosion inhibitors and anti-foam agents. Also, additives suppress undesirable base oil properties with viscosity index improvers and pour points depressants. Lastly, the additives are also able to impart new properties to base oil, especially with extreme pressure additives, metal deactivators and tackiness agents. (Mohammed et al., 2023.)

# 6 LUBRICATION SYSTEM MAINTENANCE

## 6.1 Regular Inspection and Maintenance

The marine engine system is often considered the core component of any vessel. Taking care of the engine particularly when it comes to lubrication is crucial, for its operation. To ensure the engine lasts longer and operates efficiently it is important to stick to a schedule, for changing the engine oil and replacing filters. It's also crucial to inspect the cooling system for any signs of wear or leaks. If the inspections include cleaning the lubrication reservoirs, it proves to be an effective method. This particular step is important because it helps in getting rid of any particles that could affect the lubrication system of the engine. (Wakiru et al., 2020.)

The importance of inspecting the suction filters is such as cleaning them meticulously, checking for obstructions or impurities in the filter, and thus, removing them. It is imperative that to keep the oil running throughout the engine system, the oil strainer and filter should be thoroughly cleaned for any floating particles to disperse as early as possible to avoid damage to the different component parts of the lubrication system. This also helps in avoiding obstructions in the flow of the lubricant. You should look for any wear and tear in the lubrication system's pipework such as puncture holes, raptures, or any sort of ageing damage.

One helpful procedure of inspection would be to watch for modifications in the oil pressure in the lubrication system's work. This will enable an engine to carry oil accurately and circulate it all around the motor, keeping it safe. (Pourramezan et al., 2023.) Also, an examiner must hold checks and make sure that the chosen lubricants are flawless and that that suits the marine engine used for it. During inspection, it is possible to identify lubricants with additives that would clog the filters and possibly damage the engine and the lubrication system. Through regular inspection, it is possible to identify and follow the recommended lubricant storage and filling to reduce any chances of contamination that would result to damage of the lubrication system or the engine of the marine system. (Karatuğ & Arslanoğlu, 2022.) Regularly inspecting the engine system helps to ensure its protection and prolong the lifespan of the marine engine system.

## 6.2 Common Issues and Troubleshooting

Marine engine lubrication systems play a pivotal role in the operation and longevity of the vessel's power source. While these systems are designed to ensure optimal performance and reliability, they are not immune to challenges. These can be broadly categorized into issues arising during installation and commissioning, and operational malfunctions that occur during the engine's lifecycle. (Pimenov et al., 2021.)

### 6.2.2 Installation and Commissioning

The lubricating system of a marine engine must be configured for maximum efficiency throughout the installation and commissioning stages. Numerous difficulties could appear during this stage and jeopardize the dependability and efficiency of the system. The main focus of these difficulties is pressure problems in the system, which can be either excessively high or too low and have a number of root causes. (Pimenov et al., 2021.)

If the pump is not correctly primed during the initial oil loading into the reservoir, low pressure in the lubrication system may result. Low pressure can also be caused by the oil that remains in the engine as a result of evaporation or burning, which is frequently the result of worn-out pistons. This state may eventually result in less flow limitations and, consequently, lower lubricant flow pressures as the marine engine runs and wears. (Pimenov et al., 2021.)

Conversely, utilizing the wrong oil grade or contamination that happens during the assembly process are usually the causes of high pressure within the lubrication system. High lubricant pressures can result from blocked filters that are contaminated with dirt, gums, rust, or soot. These clogged filters can create resistance in the system. If these high-pressure situations are not handled right away, they may put stress on the lubricating system and perhaps damage engine parts. (Pimenov et al., 2021.)

### 6.2.3 System Malfunctions

During the normal operations of marine engine systems, various malfunctions can arise within the lubrication system, affecting its efficiency and the overall performance of the engine. These issues not only compromise the engine's reliability but can also lead to significant damage if not addressed promptly. (Polemis et al., 2023.) The following expands on the previously discussed common issues and introduces additional challenges:

#### 6.2.3.1 Reduced amount of lubricant dispensed

This issue may result in a change in the operating speed of the sea vessel and may be caused by a worn-out pump. The use of inappropriate lubricants and pump failure may also result in high evaporation rates that reduce the volume of lubricants applied to the lubrication system of an engine system. (Polemis et al., 2023.)

#### 6.2.3.2 Increased amount of lubricant dispensed

Among the main outlined causes of excess lubrication is deficient monitoring of the lubricant levels as a result of poor visibility conditions offered by the available lubricant gauges. Also, the incorrect flow of apportioning units contributes to increased volumes of lubricants in the lubrication system. (Polemis et al., 2023.)

## 6.3 Lubrication System Upkeep Best Practices

The lubrication system is regarded as one of the most critical components of the marine engine system, acting as the bloodstream of the engine by reducing friction, cooling engine components, and preventing wear and tear. Proper maintenance ensures optimal engine performance and longevity, safeguarding against operational failures that could lead to costly repairs or downtimes. (Wakiru et al., 2019.) Conducting best upkeep practices ensures the engine remains healthy and able to perform its tasks without any difficulties

### 6.3.1 Applying the appropriate lubrication oil

One of the most critical steps to ensure the lubrication system remains healthy includes being aware of the engine's critical parts that require lubrication. This step ensures that it is possible to apply the most appropriate lube oils for the marine system engines. On the same note, the practice contributes to ensuring the critical sections of the engines, such as the bearing, remain lubricated throughout the operations of the engine. Beyond just selecting the right oil, understanding when and how to apply lubricant considering the engine's workload, temperature ranges, and fuel type is essential. For instance, engines operating in colder climates may require lubricants with better low-temperature flow characteristics. (Wakiru et al., 2019.) To ensure that an individual is aware of critical engine systems that require frequent lubrication, it is always important to use the equipment manufacturer's manual for the best performance of both lubrication and the engine systems.

### 6.3.2 Maintain the lubrication system clean

The other lubrication best practice is always keeping the entire system clean. Before lubrication of the engine system, it is always important to ensure that all the lubrication areas have been cleaned by emptying the previously applied lubricant before putting the new oil. This involves not just draining old oil but also cleaning filters and strainers to remove debris. Techniques such as flushing the system can be employed to ensure thorough cleaning. Failure to clean the lubrication system may result in premature wear as a result of a mixture of dirt and lubrication oil. To some extent, failure to clean the lubrication system results in the blockage of the lubrication system, especially around the filters, results in unnecessary increased pressures, thus making it difficult to circulate oil within the lubrication and engine systems. Regular testing of the lubricant for the presence of water, particulate matter, and other contaminants can help determine the system's cleanliness and the effectiveness of cleaning protocols. (Wakiru et al., 2019.)

### 6.3.3 Cleaning lubrication reservoirs

Cleaning the lubrication reservoirs is essential in eliminating any contamination that may alter the functionality of the engine and lubrication system. This method is to examine if the reservoir has indications of corrosion or leaks which could introduce contaminants into the lubricant. A dirty reservoir may harm the surfaces and bearings which could lessen the service life of the engine and could on the other hand lead to unpredicted damages (McGuire et al., 2021.)

### 6.3.4 Regularly inspecting the lubrication system

It is a particular procedure for a lubrication system, not only for marine engine systems but also for other engine systems. Regular examination and inspection are necessary to identify any leakage or damage to the engine system and the lubrication system. It is essential to ensure if the flow rate and all the parts of the lubrication system are working properly. It is very essential to carry out testing to the lubrication oil to confirm the water content, contaminants and TBN. (Wakiru et al., 2020.) If we perform all these strategies then we can use the lubrication system for a long period of time and give quality and efficient timing to the engine for the appropriate duration.

### 6.3.5 Maintain the Lubricant Level and Quality

Maintaining the level and quality of the lubricant oil contributes to minimized maintenance and enhanced productivity. Keeping lubricant levels within recommended ranges prevents both overfilling, which can lead to leaks and inefficiency, and underfilling, which risks inadequate lubrication and increased wear. Maintaining the best quality of lube oil plays a critical role in extending the lifespan of the marine engine, reducing the cost of repairs and improving the overall efficiency of the lubrication and the engine system. (McGuire et al., 2021.)

# 7 CASE STUDY

## 7.1 Real examples of lubrication system challenges

In recent times. Ships have experienced challenges as a result of problems in the lubrication system. Some of the challenges have been fatal enough to cause deaths and destruction of property. Regular maintenance of the ships, especially the engine part, is crucial to ensure their continuity in serving the intended purpose. (Safety4Sea, 2020.) This chapter will address real examples that have been experienced before on matters connected to lubrication system challenges with respect to the marine sector. The chapter will also address solutions and outcomes to the highlighted issues.

### 7.1.1 Case study

This case illustrates a machinery failure as a result of contamination of the lubrication system, as reported by a Swedish club. According to the report linked to the incident, the ship was at the anchor awaiting further instructions as the weather deteriorated for seven days. Within no time, it was discovered that the vessel would steam around its area slowly. Within the next 24 hours, the pressure alarm system of the main engine lubrication sounded in the ECR. Upon scrutiny by the engineers present, it was found that there were particles of aluminium and other metals around the filter section of the lubrication system. On further scrutiny, metal particles were also discovered around the vessel's main engine crankcase. (Safety4Sea, 2020.)

Upon consulting the operating company of the vessel, it was decided that the vessel should be towed. Investigations were, however, conducted, which indicated that the metal particles discovered around the filter section and the crankcase of the main engine, as well as in the flowing oil, came from the piston ring and piston skirts. Three systems of the lubrication system were almost seized as a result of the challenge. The investigation also unveiled the extent to which the 6-cylinder medium type and the main engine were severely damaged following the lubrication issue in the vessel. Additionally, the piston rings, cylinder liners and bearings were also damaged by the problem. (Safety4Sea, 2020.) The turbocharger had also developed mechanical issues as a result of the nozzle ring being broken.

### 7.1.2 Case Findings

A thorough scrutiny was conducted with the objective of unveiling the real issue that resulted in the problem. The summary of the findings indicated that at the time of discovering the issue, the main engine and the turbo had been running for at least 7,300 hours since the previous major overhaul. It was also discovered that the overhaul had been conducted 18 months ago. However, the investigation proved that the system maintenance had been conducted as per the manufacturer's recommendations. It was also discovered that fuel oil analysis from the bunkering was within the prescribed specifications. Analysis of oil samples after the purifiers indicated that the purifiers were working as expected and as per the expectations. (Safety4Sea, 2020.) Several samples from the damaged pistons were also collected and taken to the laboratory for further scrutiny. It was discovered that the excessive wear of the pistons and the liners was not caused in any way by the catalytic fines. The testing of the cylinder liner lubrication system was examined and found to operate perfectly.

However, after reviewing the monthly main engine reports, the main engine exhaust temperatures, especially of the cylinder units, had increased by 30%-40% six months ago. Further investigations revealed that the turbocharger's revolution had dropped from 14,500 rpm to 12,000 rpm when at a load of 85%. As a result of high exhaust temperatures, the vessel engine was under high thermal temperatures and thus lacked thermal stability, which resulted in its breakdown. (Safety4Sea, 2020.)

The summary of the findings indicated that the vessel engine had been operated with a high thermal load for quite a long time, which affected the efficiency of the turbocharger. Additionally, the lube oil had been contaminated for a long time, resulting in the breakdown of the engine and the lubrication system. It was also found that the cylinder lubrication systems were clogged, and the cylinder lubrication had been inactive for some time. (Safety4Sea, 2020.) The hard impurities found in the oil lube system had deteriorated the oil lube system, making it difficult to operate.

### 7.1.3 Solutions and Outcomes

The problems were identified in the entire lubrication system as a result of irregular inspection. Regular inspection of the lubrication system would have helped the crew realize the maintenance needed in the vessel's lubrication system. Through maintenance, it would have been possible to realize clogged sections of the filters; unclogging these areas would have helped control the flow of lube oil and avoided unnecessary pressures. (Safety4Sea, 2020.) Regular maintenance of the lubrication oil system contributes to increasing the lifespan of not only the lubrication system but also the engine system, which also makes it possible to serve efficiently.

# 8 ENVIRONMENTAL AND REGULATORY CONSIDERATION

## 8.1 Impacts of the lubricants on the marine environment

The oil spill has had an impact on the marine environment and marine ecology. This occurs when lubricants leak from ships, particularly due to breakdowns in their lubrication systems. It can have harmful effects on both the marine ecosystem and its inhabitants. The toxicity of this impact is severe and takes significant time to manifest its inherent qualities fully. The event has an impact on the sea plankton and microorganisms, leading to their death and harm, which ultimately damages the environment. To address this effect, various techniques need to be employed to clean up the marine environment and ensure that ships are in good condition to protect marine life. (Zhang et al., 2019.)

However, some of these methods also have consequences. Considering the impact, it is crucial to prioritize efforts for recovery in order to protect what remains. An oil spill refers to the release of petroleum hydrocarbons into the environment, whether it occurs on land or in other settings. When oil is spilt on land, it poses a risk compared to when it contaminates water bodies. Cleaning up water pollution caused by oil spills is particularly challenging due to its difficulty. Petroleum, being a hydrocarbon, contains substances that can be harmful both directly and indirectly. Additionally, the characteristics of the spilt oil also play a role in the cleanup process. (Zhang et al., 2019.) Light and liquid oils mix quickly with water, while heavy and waxy oils take longer to disperse and require time for effective cleaning efforts.

### 8.1.1 Threat to sea animals

Depending on the circumstances, oil spillage can be dangerous, especially to marine life. Oil spillage affects marine life, such as fish, sea turtles and mammals that live in the waters. Oils have been reported to destroy the insulating ability of fur-bearing mammals that live in the sea, and the water-repelling abilities of the birds' feathers make their marine life more difficult by exposing them to such environments. Research conducted has proven that fish can digest oils which have negative effects on reproduction and may cause difficulties in growth rates and, to some extent, cause death. Contamination of sea waters by lubricants could also cause some species of fish to decline as a result of uncontrolled rates of death. Oil spillage in the sea also contributes to the blockage of oxygen flow, resulting in insufficient oxygen and low levels of oxygen, making it difficult for sea animals to survive. (Wallace et al., 2020.) The dangers, therefore, introduce the need to develop mechanisms that will help address the issue and ensure sea vessels are appropriately maintained to avoid such occurrences, which will play a crucial role in protecting marine life.

### 8.1.2 Threat aquatic plants

Oil spills have been reported to result in fouling, smothering, and poisoning, which endangers the life of aquatic plants and makes it difficult for them to survive in oily environments. The oil contamination of shoots has been reportedly interrupting the transportation of oxygen from the leaves to the roots, which makes the aquatic plants die. (Choudhary et al., 2021.) The absorption of petroleum hydrocarbons by aquatic plants makes it difficult for aquatic plants to survive, endangering their survival rates.

## 8.2 Regulations and Compliance in the Maritime Industry

The maritime sector functions, within a set of local rules that are designed to prioritize the safety of ships and the entire marine industry. These standards play significant roles in protecting the crew's welfare and the environment, as well as helping the shipping companies maintain the operational standards aimed at promoting safety. Among the regulatory landscapes in the marine industry is the International Maritime Organization (IMO), whose objective is to protect the oceans and, more particularly, sensitive sea areas. The IMO protects the biodiversity of marine mammals and prevents pollution by ships. Additionally, the Safety of Life at Sea (SOLAS) is also an international body that has been mandated to ensure that minimum standards are observed during ship manufacturing to promote safety in the maritime industry. (Joseph & Dalaklis 2021.) This strategy, therefore, ensures that ships promote the safety of the crew, the marine life and the surroundings of the sea industry.

The International Convention for the Prevention of Pollution from Ships, popularly known as MARPOL, has also been on the frontline in promoting safety within maritime operations. The main objective of this body is to implement regulations aimed at preventing as well as minimizing pollution caused by ships either from routine operations or accidents within the sea. Lastly, the Standards of Training, Certification, and Watchkeeping (STCW) is an international body whose roles include directing the knowledge and skills required by the mariners in order to perform their duties in a safer way to protect lives through enhancing safety measures. (Engtrø, 2022.)

Ship management companies are required to comply with all regulatory measures, which include safety management systems, crew training, satisfaction, and navigation safety. It should, however, be noted that compliance is not limited to international laws. Still, shipping companies are also required to observe the national laws and standards set by responsible ministries or government departments.

# 9 CASTROL LUBE OIL ANALYSIS AND DISCUSSION

## 9.1 Interpretation of the Findings

This chapter presents the results and discussion of the data gathered from the research conducted by Castrol Lab Check. The study used analytical techniques and computer programming to analyze all the data gathered. The two tools have proved to be valuable lubricant monitoring tools that are heavily relied on by the maintenance teams.

### 9.1.1 Characteristics of the products

The study utilized two different lubricants from Castro Energy that were used on the same vessel, M/S Haaga, a general cargo ship, to obtain results from the laboratory. The laboratory results analyzed different aspects of the lubricants to determine their content, which would determine their efficiency when applied to different sea vessel lubricants.

Table 1. CDX 30 Product Summary (Castrol Lab Check, August 6, 2022)

| | | | |
|---|---|---|---|
| **Customer** | ESL SHIPPING OY | **IMO number / Asset** | 9797632 |
| **Vessel / Asset** | HAAGA | **Sampling Point** | L.O. Inlet To Engine |
| **Machinery description** | MAIN ENGINE (CROSSHEAD DIESEL) 1 | **Sample Number** | 22126885 |
| **Customer sample point ID** | MEZZX1 | **Sample Label Ref.** | C 23250655 |
| **Manufacturer** | MAN Energy Solutions (2 Stroke) | **Model** | 5G45ME-C9.5 |
| **Product in Use Actual** | CDX 30 | **Product in Use UOA schedule** | CDX 30 |
| **Port landed** | HELSINKI | **Label Sampling Point** | LO INLET |
| **Castrol Contact email** | Are.Sletten@ec1.bp.com | **Diagnosed by** | Are Sletten |

CDX 30 is a lubricant product from Castrol Energies Company, which was tested on a M/S HAAGA cargo vessel. This type of lubricant oil is mainly used in lubricating the main engine of ship for the two-stroke type of engines.

Table 2. DURATEC HPL Product Summary (Castrol Lab Check, August 6, 2022)

| | | | |
|---|---|---|---|
| Customer | ESL SHIPPING OY | IMO number / Asset | 9797632 |
| Vessel / Asset | HAAGA | Sampling Point | L.O. Inlet To Engine |
| Machinery description | AUXY ENGINE 1 | Sample Number | 22179039 |
| Customer sample point ID | AEZZT1 | Sample Label Ref. | C 23516102 |
| Manufacturer | Man Energy Solutions (4 Stroke) | Model | 8L23/30DF |
| Product in Use Actual | DURATEC HPL | Product in Use UOA schedule | DURATEC HPL |
| Port landed | | Label Sampling Point | crankcase |
| Castrol Contact email | Are.Sletten@ec1.bp.com | Diagnosed by | Ruth Fusco |

Duratec HPL is the second product that was involved in the study, being a product of castrol energies and was used in the same vessel M/S HAAGA. The product was tested on an auxiliary engine manufactured by Man Energy Solutions, which is a four-stroke type of engine.

Table 3. Samples Summary on CDX 30 Product (Castrol Lab Check, August 6, 2022)

| **Sample number** | **22I26885** | 22G85996 | 22G31205 | 21Y21163 | 21Y04861 |
|---|---|---|---|---|---|
| Historic sample number | | | | | |
| Sampling Date | **29-Jun-22** | 14-Feb-22 | 05-Jan-22 | 02-Oct-21 | 31-Jul-21 |
| Date Received | **14-Jul-22** | 15-Mar-22 | 20-Jan-22 | 07-Oct-21 | 10-Aug-21 |
| Date Reported | **05-Aug-22** | 21-Mar-22 | 24-Jan-22 | 11-Oct-21 | 11-Aug-21 |
| Oil Life (Hrs) | **16186** | 14591 | 14054 | 13032 | 12105 |
| Equipment Life (Hrs) | **16186** | 14591 | 14054 | 13032 | 12105 |
| Status / Rating | √ | √ | √ | √ | √ |
| **Results** | | | | | |

Table 3 indices the number of trials done during the study as well as the sampling dates, the dates results were received as well as the date on which the data from the five samples were reported. The lubricant was applied and given sufficient time on the vessel in order to give reliable findings.

Table 4. Samples Summary on DURATEC HPL Product (Castrol Lab Check, September 6, 2022)

| **Sample number** | **22I79039** | 22I26888 | 22G85991 | 21Y29004 | 21Y04862 |
|---|---|---|---|---|---|
| Historic sample number | | | | | |
| Sampling Date | **23-Aug-22** | 29-Jun-22 | 19-Feb-22 | 06-Nov-21 | 31-Jul-21 |
| Date Received | **01-Sep-22** | 14-Jul-22 | 15-Mar-22 | 15-Nov-21 | 10-Aug-21 |
| Date Reported | **06-Sep-22** | 25-Jul-22 | 22-Mar-22 | 17-Nov-21 | 11-Aug-21 |
| Oil Life (Hrs) | **6254** | 5667 | 4561 | 3651 | 3071 |
| Equipment Life (Hrs) | **14035** | 13448 | 12342 | 11432 | 10852 |
| Status / Rating | √ | √ | √ | √ | √ |
| **Results** | | | | | |

Table 4 analyses the number of samples taken on DURATEC HPL during the study. The table also illustrates different dates on which the samples were taken, received and reported. The table also indicates the oil and equipment life in hours.

Table 5. Summary of CDX 30 Product Findings (Castrol Lab Check, September 6, 2022)

| Results | | | | | |
|---|---|---|---|---|---|
| **Standard Test** | | | | | |
| Free Water % | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Water content % | 0.08 | 0.07 | <0.05 | 0.07 | 0.06 |
| Flash point °C | >190 | >190 | >190 | >190 | >190 |
| Viscosity 100 °C mm²/s | 12.16 | 12.25 | 12.26 | 12.19 | 12.11 |
| Insolubles % | 0.27 | 0.12 | 0.11 | <0.15 | <0.15 |
| BN mg KOH/g | 9.3 | 8.7 | 8.5 | 6.7 | 6.7 |
| **Spectrometry** | | | | | |
| Al - Aluminium ppm | 1 | 1 | 1 | 1 | 1 |
| Ca - Calcium ppm | 3517 | 3621 | 3221 | 3217 | 3140 |
| Cr - Chromium ppm | 0 | 0 | 0 | 0 | 0 |
| Cu - Copper ppm | 2 | 3 | 3 | 33 | 10 |
| Fe - Iron ppm | 2 | 3 | 2 | 3 | 4 |
| Na - Sodium ppm | 2 | 2 | 2 | 2 | 2 |
| Ni - Nickel ppm | 0 | 0 | 0 | 0 | 0 |
| P - Phosphorus ppm | 240 | 259 | 250 | 246 | 260 |
| Pb - Lead ppm | 1 | 1 | 0 | 66 | 4 |
| Sb - Antimony ppm | 0 | 0 | 0 | 0 | 1 |
| Si - Silicon ppm | 4 | 4 | 4 | 4 | 4 |
| Sn - Tin ppm | 1 | 1 | 1 | 1 | 1 |
| V - Vanadium ppm | 0 | 0 | 0 | 1 | 1 |
| Zn - Zinc ppm | 347 | 338 | 358 | 319 | 327 |

Table 6 presents data from CDX 30 lubricant samples. It shows no free water and very low water content, which is ideal for lubricant integrity. The flash point is over 190°C, indicating no volatile contaminants. Viscosity at 100°C is consistent around 12, which is suitable for engine lubrication. Insolubles are very low, under 0.27%, suggesting minimal oil degradation. The Base Number (BN) shows significant reserve alkalinity, ranging from 6.7 to 9.3, to neutralize acids. Spectrometry indicates low wear metals like iron and copper but notable changes in phosphorus and zinc levels, which could relate to additive depletion or contamination. The high calcium suggests detergent additives presence, which is common in engine oils to keep surfaces clean.

Table 6. Summary of DURATEC HPL Product Findings (Castrol Lab Check, September 6, 2022)

This table illustrates the results obtained from the sampling carried out for the DURATEC HPL lubricant product. The table analyzes different outcomes conducted for different aspects of the lubricant oil.

| **Results** | | | | | |
|---|---|---|---|---|---|
| **Standard Test** | | | | | |
| Free Water % | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Water content % | 0.06 | 0.06 | 0.05 | 0.05 | <0.05 |
| Flash point °C | >190 | >190 | >190 | >190 | >190 |
| Viscosity 100 °C $mm^2/s$ | 12.62 | 13.01 | 12.88 | 12.76 | 12.77 |
| Insolubles % | 0.17 | 0.36 | 0.18 | 0.20 | 0.20 |
| Nitration A/cm | 0.0 | 0.0 | 0.5 | 1.5 | 1.4 |
| Oxidation A/cm | 12.7 | 13.1 | 13.8 | 12.2 | 13.3 |
| AN mg KOH/g | 2.42 | 3.15 | 2.32 | 1.96 | 2.18 |
| BN mg KOH/g | 3.7 | 4.0 | 3.2 | 3.4 | 3.3 |
| SAN mg KOH/g | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Spectrometry** | | | | | |
| Al - Aluminium ppm | 2 | 1 | 1 | 1 | 0 |
| Cr - Chromium ppm | 0 | 1 | 0 | 0 | 0 |
| Cu - Copper ppm | 11 | 6 | 4 | 3 | 3 |
| Fe - Iron ppm | 18 | 6 | 5 | 4 | 3 |
| Na - Sodium ppm | 6 | 3 | 1 | 1 | 2 |
| Ni - Nickel ppm | 1 | 1 | 0 | 0 | 0 |
| Pb - Lead ppm | 7 | 2 | 2 | 1 | 1 |
| Sb - Antimony ppm | 0 | 0 | 0 | 0 | 0 |
| Si - Silicon ppm | 2 | 2 | 1 | 1 | 1 |
| Sn - Tin ppm | 0 | 0 | 0 | 0 | 0 |
| V - Vanadium ppm | 0 | 0 | 0 | 0 | 0 |

The DURATEC HPL lubricant samples in table 6 shows excellent characteristics, with water content below 0.06%, ensuring negligible contamination. The flash point exceeds 190°C, negating fuel dilution concerns. Viscosity readings between 12.62 and 13.01 $mm^2/s$ at 100°C indicate stable flow properties and effective lubrication. Insoluble matter is minimal, between 0.17% and 0.36%, suggesting the oil remains clean. Nitration and oxidation values are low, AN (Acid Number) ranges from 1.96 to 3.15 mg KOH/g, and BN (Base Number) from 3.2 to 4.0 mg KOH/g, signifying limited oil degradation and good acid neutralization. Spectrometry results confirm low wear metal presence, with iron, copper, and lead well below critical levels, and negligible silicon, indicating effective filtration and minimal contamination ingress.

## 9.2 Implications for Marine Engine Efficiency

The results obtained from the study are critical for the marine system. The tests conducted introduced various elements that are rarely considered when it comes to lubrication needs for lubrication systems of ships. Low-speed operations for marine engines can result in various problems for the engine in terms of fuel consumption, more wear and tear, reduced output power and higher emissions. The higher the intake stroke pressure, the higher the efficiency of the marine system's engine system. Regular maintenance of the marine engine system contributes to ensuring the engine is able to function optimally, as well as ensuring that the engine can maintain its lubrication system, resulting in high levels of efficiency. Improving the turbocharger efficiency also has a higher chance of improving the reliability of the engine system as a result of introducing high charging pressures, which results in improving the engine efficiency.

## 9.3 Future Trends in Lubrication Systems

The global lubricants market is changing and growing fast. With the increased invention of new types of machinery, there has been a high demand for high-quality lubricants to improve the efficiency of the engine systems and maximize the performance of the engines. The introduction of the newest lubrication system in the progressive lubrication system is gradually changing the lubrication industry by introducing high reliability and efficiency of the engine system of not only marine engine systems but also other transport sectors.

The progressive lubrication system is a lubrication system that has been equipped with an LED controller and the progressive distributor that plays a critical role in gradually injecting the high-pressure lubricant based on the progressive type. This new type of lubrication system ensures continuous lubrication of the critical engine parts. Immediately after the pump stops on this new type of lubrication system, the pistons of the progressive metering device will stop at the current position and continue when the system is turned on.

The introduction of automatic lubrication systems is another trend in lubrication systems. Automatic lubrication systems are critical to heavy machinery such as marine engines. This type of lubrication system is unique in that it helps keep machinery at optimal performance, which means that engines experience less downtime. At the same time, this type of lubrication system plays an essential role in helping save time as well as ensuring that all engin e systems are well maintained for efficient operation.

# 10 CONCLUSION AND RECOMENDATIONS

## 10.1 Conclusion

According to the study’s findings it was concluded that lubricants play a role, in ensuring the functioning of marine engine systems. When applying lubricants to engines it is essential to take into account important factors that determine the most suitable lubricant for specific engine types. Regularly cleaning and inspecting the lubrication system of marine engines is vital, in enhancing both performance and efficiency of sea vessels. The research also concluded that adhering to the criteria for selecting lubricants is important towards ensuring that the most appropriate lubricant is used for the right engine to improve performance and productivity.

When choosing a lubricant, for types of engines it's crucial to consider factors like thermal conductivity and viscosity. These critical elements play a role, in determining the suitable lubricant. Understanding that different engine types have different lubrication needs will play an essential role in ensuring the selection of the most appropriate product for lubrication. Regular maintenance of the engine systems through inspection of the lubrication system will help in maintaining the health of the engine system by preventing wear and tear as well as contributing to promoting marine life by preserving the environment.

## 10.2 Contributions and Significance of the Study

This study will contribute positively to helping shipping companies select the most appropriate lubricants for sea vessels to improve the lifespan of their engines and service. Also, the study will help protect and promote marine life by helping the shipping companies observe measures that will help protect marine life. Informational regular inspection and maintenance of the lubrication system will largely contribute to reduced oil spillage in seas and oceans, thus contributing to protecting marine life.

## 10.3 Practical Recommendation for the Marine Industry

Based on the research conclusion, the researcher recommends that shipping companies should adhere to lubrication practices that will benefit not only sea vessels but also marine life. The regulation bodies linked to the sea sector should employ adequate measures and efforts that will ensure the manufactured lubricants meet the standards required for higher efficiencies. It would be important for the maritime industry to recommend measures that will promote the safety of marine life as well as contribute to preventing wear and tear through the manufacturing of quality lubricant products by the oil industries.

## 10.4 Areas for future research

More studies should be conducted on measures to develop high-quality lubricants that will protect the engine systems to prolong the lifespan of sea vessels and protect marine life. This would help develop comprehensive measures that would dictate the manufacturing standards that will ensure oil spillage has minimal effects on marine life and also protect the internal parts of the engine from wear and tear.

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