Improved lifecycle efficiency with water lubricated stern tube solutions

BUSINESS WHITE PAPER

Finding a stern tube solution is one of the most critical elements to ensure a vessel's continuous operational capability.

Developments in technology have lowered the costs of the solutions, allowing industry decision makers to better consider their choice from financial, operational and environmental perspectives. Choosing a water lubricated stern tube solution instead of an oil lubricated one means that the shipowners are able to improve their lifecycle efficiency with lower operational costs, reduce risks to secure reliability of operations and future-proof their system to meet environmental regulations.

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Main market drivers

Reduced lifecycle costs, reliability and environmental compliance drive demand

When looking at the vessel's entire 20–30 years' operating horizon, it is clear that the ship owner may want to consider other aspects in addition to the initial investment made when purchasing the equipment. Reduced lifecycle costs, reliability of equipment and compliance with environmental regulations are important factors to consider.

To date, water lubricated stern tube solutions have mainly been used in naval vessels, fishing vessels and smaller ferries operating in archipelagos. The reasons for selecting water lubrication in these environments are clear: water lubrication is reliable and more suitable for these environments due to minimal risk of operational failure and no threat of oil spills from the system.

90% of the 90,000 commercial vessels operating in the world use oil as a propeller shaft lubricant. The somewhat lower initial investment required and a better short-term return on investment have favoured oil lubrication systems in the past. Today, however, there is increased interest in water lubrication within the cruise and merchant shipping markets.

The main drivers for this change are reduced costs over the whole lifecycle of the system. This is due to savings in the cost of oil, improved lifetime expectancy, a decrease in operational risks, reduced maintenance needs and the avoidance of costly accidents. A water lubricated system also ensures compliance with increasingly stringent environmental regulations. Water lubrication is preferable from an environmental point of view and in the eyes of legislators, since the risk of oil spills is non-existent.

Main market drivers in the marine new build market.

A brief history of propeller shaft stern tube solutions

- Seawater is the oldest lubricant for propeller shaft stern tube systems.
- Water lubrication was first challenged by oil systems in 1886 after which oil lubrication became the standard in the 1940s, the only exception was naval vessels.
- The primary reasons for selecting oil instead of water lubrication in the late 1880s was due to its improved capability of protecting the bearings and shaft from breaking, as well as shielding the shaft from corrosion with an oil bath.
- Current water lubrication systems, however, offer equal or even better qualities for protecting the shaft than oil lubrication systems. At the same time, they answer the need for an environmentally sound, reliable option for lubrication.
- Previously, regulations required frequent shaft withdrawal and repair every five years for vessels using water lubrication systems. Current systems being more reliable, regulators allow shaft withdrawal intervals as long as 15 years.

Risks associated with oil lubrication

The risks related to using oil lubrication concern system breakdowns if water enters the stern tube and oil leaks into the sea.

Risk reduction is one of the main drivers in the marine new build market and is also closely linked to environmental legislation. It is important to consider which risks are worth taking and which are avoidable. To understand the risks related to using oil lubrication in stern tube systems, we need to look at the sealing technology more closely. The performance of the seals in oil lubricated stern tube systems is crucial, as costs related to damage caused by seal malfunction can be substantial.

The sealing between the stern tube and the propeller shaft has an important role and it has to function efficiently and reliably under harsh and challenging conditions. The outboard propeller shaft seals in oil lubricated solutions serve two main purposes: the prevention of the oil leaking out and polluting the seas, as well as the avoidance of seawater from entering the stern tube system and contaminating the oil. If the outboard seal is damaged, water can enter the stern tube, which potentially can cause a risk of oil leakage or system breakdown. According to an analysis made by Lloyds Register, 43% of all system failures originate from the outboard seal. Bearings represent 14% of system failures.

Risk of system breakdown if water enters the stern tube
Outboard seals are frequently exposed to circumstantial outer damage. Entangled nylon ropes or fishing nets are the most common reason for a seal malfunction. When ropes or other objects enter the sealing system they disrupt the working symbiosis between the rotating and static parts of the seal.

If the outboard seal is a lip seal type arrangement, the cause of the fouling may damage or compromise the sealing lips and the shaft liner. In face type seals, it will “open up” the interface between the rotating and the static part, potentially damaging the face surfaces. The damaged outboard seal may allow water to enter the stern tube.

When water enters the stern tube it can create water pockets in the oil, or more commonly today with biodegradable oils, it can emulsify with the oil. This compromises the viscosity of the liquid film between the shaft’s running surface and the surface of the bearing. The water content in the oil increases and the load carrying capacity of the oil is reduced, consequently the bearing no longer operates hydro-dynamically and bearing failure occurs. When the film is compromised, the shaft will run on the white metal surface of the bearing, severely damaging both the shaft and bearings. It may overheat the white metal to the extent that its cohesion is affected and the lining is wiped off, causing even more catastrophic damage.

Risk of oil leakage related to oil lubrication
Rules recognised by all major classification societies reflect the importance of sealing performance in preventing major pollution or failures. Some clear cases, amongst others, are the recording of bearing weardown, oil temperatures and oil cleanliness. Ships’ staff samples the system oil frequently to monitor it in accordance with the attributed class rules (normally varying between the maximum limitations of 1% to 2%, if specified).

In some basic oil sealing systems, in order to prevent water from penetrating through and contaminating the system oil, the pressure inside the stern tube has to be greater than the differential pressure outside of it, i.e. in the sea. This means that there will always be a consumption of oil in any oil lubricated propeller shaft bearing system.

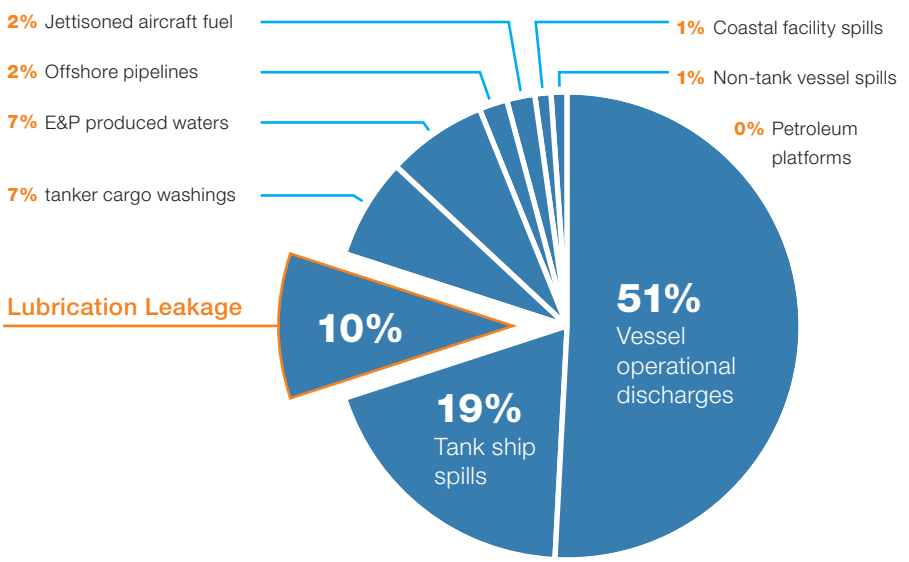
Whether the oil consumption is manifested as an oil leakage to the sea depends on the design of the sealing system. There are products in the market today that minimise this otherwise constant pollution.

Marine pollution

Another added risk, and the indirect result of a sealing device failure, is the oil pollution of the sea and loss of oil due to leakage. The amount of operational leakage depends on many factors, such as the age of the seals, the condition of the bearing, vibration and shaft movement. It is estimated that approximately 4 litres of oil can leak out of oil lubricated systems per day. There are around 90,000 commercial vessels operating in the world, of which up to 90% are operated with an oil lubricated propeller shaft stern tube solution. Thus, it can be estimated that up to 324,000 litres of oil can leak from oil lubricated stern tube systems per day.

Leakage from oil lubricated propeller shaft stern tubes may not be the largest contributor to marine pollution, but stern tube leaks are easily monitored and can therefore lead to sanctions by port authorities. Vessels can be impounded for polluting. Non-compliant vessels that are in breach of charter can be restricted from operating in certain areas. In the worst case, criminal charges may be brought against the operators. This shows that there is a strong link between legislation and cost when risk turns into reality.

Annual oil losses into the marine environment



National Research Council 2003

Eliminating oil leakages

There are primarily three options available to a ship operator to eliminate harmful oil leakages:

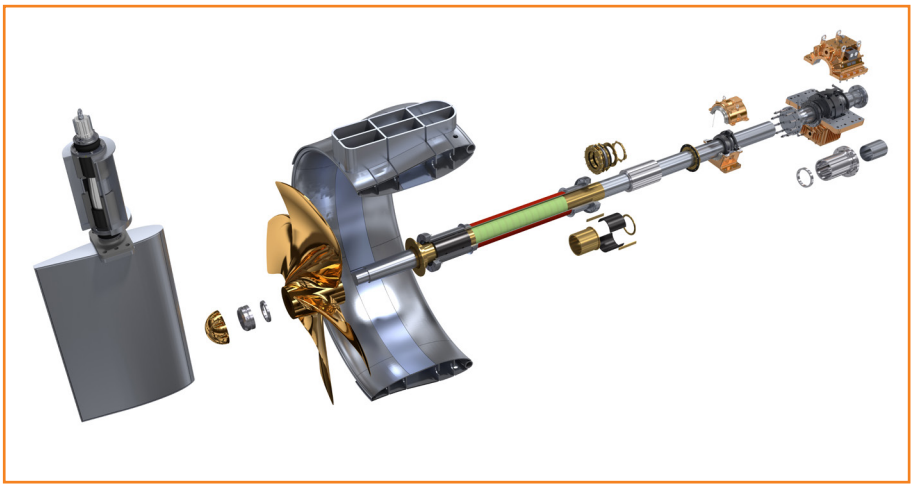
1) Remove the oil from the system completely and select a propeller shaft stern tube system using seawater lubrication.
2) Stop operational oil loss and use an anti-pollution seal system.
3) Reduce the impact of leaking oil to the environment and use Environmentaly Approved Lubricants (EAL) to replace mineral oil.

Seawater lubricated systems

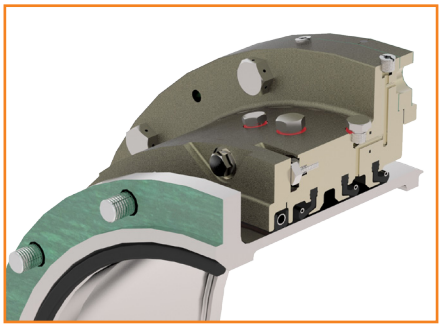
A seawater lubricated stern tube system is the most attractive of these options, should the main consideration be ultimate environmental protection and the elimination of any risk of oil loss. With no oil in the system, there is zero risk of oil leaking into the sea.

The normal adaptation of a water lubricated stern tube system includes a corrosion protected steel stern tube assembly fitted with aft and forward composite plain bearings. Fitted between the bearings and the shaft are bronze shaft liners, or journals. The shaft between the journals is protected, normally with a glass fibre coating (unless a fully stainless steel shaft is utilised, but this is only feasible for small vessels). The innermost part of this open loop water lubricated system is an inboard seal. No outboard seal is required unless the vessel is operating in environments with high turbidity or very cold conditions. If an outboard seal is fitted, it is called a closed loop water lubricated system.

In addition to this, an operator may choose to install a Water Quality System (WQS) to the flushing water supply in order to ensure optimum wear life for the bearings. Using an advanced WQS that monitors water flow, pressure and temperatures together with wear down gauges, operators are able to extend shaft withdrawal periods to an equivalent timeframe to that of vessels using oil as lubricant. This may mean that shaft withdrawal periods could be extended up to 15 years, thus resulting in savings in maintenance costs.



Example of water lubricated propeller shaft line.



Example of air seal.

Anti-pollution seal systems

There are two basic types of anti-pollution seal system, the air seal and the void space seal. Both these sealing solutions may operate on mineral oil lubricated stern tubes, whilst maintaining an oil free environment under normal operating conditions.

With the air seal, the system creates a pressurised air barrier between the oil and water. Any oil leakage is collected inboard in the drain collection unit, avoiding any pollution to the sea. The single biggest factor in lip type seal life is load, i.e. differential pressure. The system controls the pressure in all cavities, creating the optimum running conditions for the lip seals. This ensures a long seal life.

The void space seal incorporates a simple drained and vented space between the oil and water seals, which is connected inboard to a collection tank. This means that no oil pollution to the sea is possible under normal operating conditions. The robust outboard seal design gives long life between overhauls even in gritty water conditions (high turbidity).

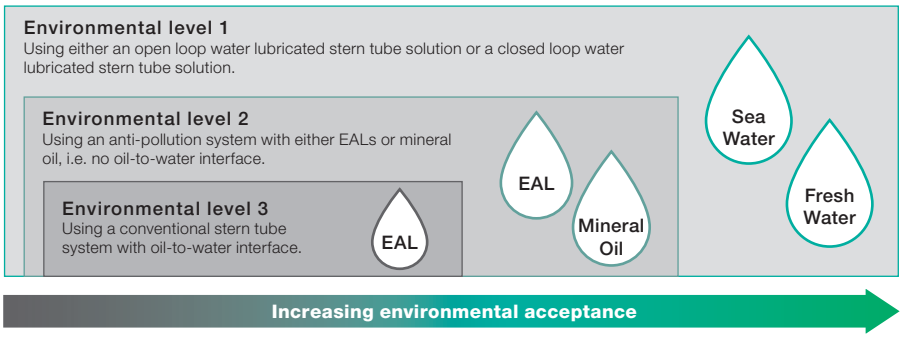
EAL lubricated stern tube systems

By using an Environmentally Acceptable Lubricant (EAL, also called biodegradable oil) instead of traditional mineral oil, the environmental risks can be reduced. EALs emulsify with water and only produce a slight sheen, and therefore have a smaller negative impact on the environment. However, careful selection of a lubricant which is compatible with both the stern tube bearings and seals is essential to ensure a long lifetime for the equipment.

Particular attention needs to be given to the seal's elastomer compatibility, as the EALs can be aggressive to many of the elastomers traditionally used in stern tube seals. Invariably, to ensure a reasonably long life, the seal elastomers and in some cases, the seal itself need to be changed for items specifically developed for use with these lubricants.

Categorisation of environmentally sustainable solutions

The graph below summarises how environmentally sustainable solutions can be categorised based on the technology used, system type and lubricant. The level of environmental acceptance increases when water lubrication is in use, since there is zero risk of oil leaking into the sea. This makes water lubricated systems also preferable in the eyes of legislators.



*Wärtsila internal categorisation - not industry standard.

Benefits of water lubrication

Cost savings when using water lubrication:

70,000 €

to

200,000 €

When selecting a water lubricated stern tube solution, ship owners and operators are able to improve their lifecycle efficiency with lower operational costs, reduce risks to secure reliability of operations and future-proof their system to meet any future environmental regulations.

Improving lifecycle efficiency with lower operational costs
Ship owners and operators are increasingly looking at advanced solutions that help them reduce their operational costs over the entire 20–30 year lifecycle of their vessels. Fuel efficiency, oil costs and freight rates are on top of the agenda, but maintenance costs and the cost of spare parts are also significant factors.

Advanced water lubricated systems justify their expense by the elimination of oil costs, the reduction of maintenance and spare parts, and the removal of the risk of leakage penalties.

The cost of oil alone, regardless of whether it is a mineral oil or an EAL, makes the oil system more expensive to operate than a water lubricated system. In a water lubricated system, there are simply no oil costs, since water has replaced oil as the system lubricant. By removing the outboard seal and converting to an open loop water system, the vessel will never have to disrupt its charter as a result of a seal failure. If the inboard seal malfunctions, it could be repaired or overhauled afloat.

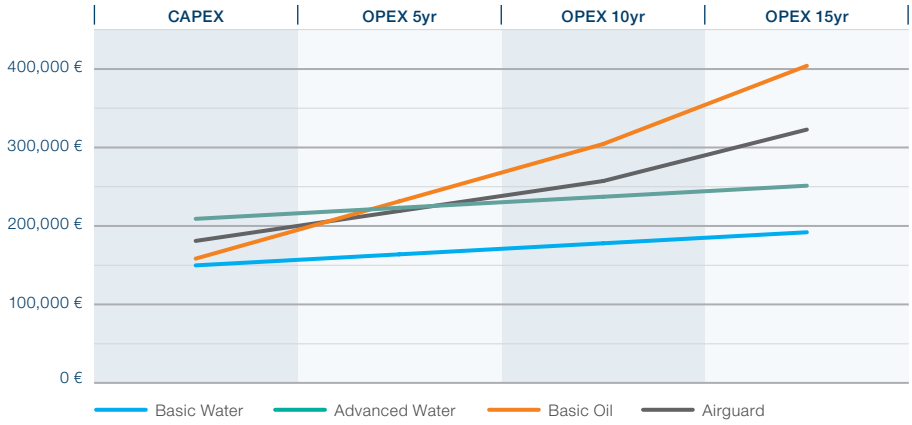
Additionally, the continuous monitoring of the water lubricated system provides real time data to prevent any system complications. The condition monitoring system measures water flow, flush temperature, shaft vibrations, bearing temperatures, bearing wear and shaft speed. This real-time data can be used to plan maintenance operations based on the actual condition of the system, rather than based on a calendar, thus minimising dry docking time as well as the work and spare parts required during dry docking.

Example of cost savings when using water lubrication
The table below illustrates the difference between the cumulative total costs for water and oil lubricated systems over an operating time of 15 years. Depending on a notation issued by a third party, a vessel using an advanced water lubricated system with an open loop water system can have a 15-year shaft withdrawal period, similar to an oil lubricated system (named advanced water system in the graph). A basic closed water system requires withdrawal of the shaft in dry dock every 5 years, which increases maintenance costs.

The difference between the oil lubricated systems is that biodegradable oil is approximately 5 times more expensive than mineral oil. Both bio and mineral oil systems in the comparison are VGP compliant*. Oil spillage from the systems is evaluated to be 2 litres in this calculation, but it can be even higher (3-6 litres). The initial oil intake and the replacing of oil every 5 years are included in the calculations.

*According to the VGP 2013 rule, vessels operating in US waters are not allowed to have sealing systems with an oil-to-water interface if the oil is a mineral oil.

Cumulative total cost over 15 years



Legend:

Basic water: stern tube, composite bearings, fwd seal, shaft journals & shaft coating

Adwanced water: stern tube, composite bearings, fwd seal, shaft journals, shaft coating, water quality system & wear down tool

Basic oil: stern tube, white metal bearings, aft seal incl. Tank, fwd seal inl. Tank, oil pump & filteration system

Airguard: stern tube, white metal bearings, aft seal incl. Air control, drain, flowpet, tank, fwd seal incl. Tank & oil pump

Disclaimer:
the scope in each solution represents necessary equipment required, it does not imply that wärtsilä will supply all items

- Initial filling of lubricant included in CAPEX, lubricant replaced every 5 years.
- Installation costs not included.
- The example illustrates a typical shipping vessel with a medium long propeller shaft and a shaft diameter between 550 mm to 650 mm.

The cost savings ship owners and operators are able to accumulate when using water lubrication systems vary from EUR 70,000 to over EUR 200,000 over 15 years.

Risk reduction boosts operational efficiency

Safe and reliable operations are a major concern for marine operators. Ensuring the long-term reliability of equipment and reducing unexpected disruptions are crucial to securing operational efficiency. The stern tube solution is one of the most critical components keeping the vessel operational. There are many operational risks related to using oil lubricated propeller shaft stern tube systems. There is no doubt that oil has better tribology than water, which affects the lifetime of the shaft and the bearing system. However, the new generation of water lubricated systems provide an equally robust solution if the water in the system is managed properly. In addition, water lubricated systems eliminate the potential environmental risks caused by oil leaks.

The most common cause of system failure in an oil lubricated stern tube arrangement is the failure of the outboard seal. If the outboard seal malfunctions, there is a risk that the bearing system will break down as water may enter the system and compromise the oil film between the shaft and the bearing surface, as described earlier in this paper.

In open loop water lubricated systems the outboard seal is not needed, which reduces risks and improves operational reliability. In a closed loop water system, sea water flushing is substituted for the closed loop lubricant (fresh water and 50% glycol arrangement) protecting the shaft and the bearings. A pump circulation system is still required to maintain flow through the sterntube to remove heat from the bearing.

Using a water lubricated system can ensure the bearing always operates in optimum conditions, reducing the risk of breakdown.

Technical outlook:
All types of rotating shafts require bearings inside the stern tube, predominantly to support the weight of the shaft. This makes bearings one of the most critical components of the system. If the bearing breaks down, the shaft and bearings may be damaged and oil may leak out to the sea. In practice, this means that the vessel is not operational and may be required to go into dry dock to fix the problem. When using water lubrication, a water quality system pumps water into the stern tube, creating optimal flow and temperature for a film between the bearing surface and the shaft. The control of flow ensures constant bearing temperatures within the system, while maintaining the fluid film between the shaft and the bearing. Thus the bearing always operates in optimal conditions, reducing the risk of breakdown.

A film of oil or water is always needed between the shaft and the bearing to keep the shaft from touching the bearing (hydrodynamic lift). In an oil lubricated system, the environment is controlled through pumps, heat exchangers and filtration. This ensures a balance within the system. A ship operator can monitor the conditions using temperature sensors, flow monitoring, pressure sensors, low oil level alarms and seal monitoring tanks.

Reducing risks with Wärtsilä water lubricated stern tube solutions

- Wärtsilä offers complete stern tubes, shaft alignment and portable condition measurement systems that can carry out health checks of equipment while the vessel is in operation.
- In addition, Wärtsilä is able to monitor the performance and condition of shaft bearings and seals in real time. This gives visibility to the actual condition of the equipment, increases predictability and helps in preventing incidents.
- Wärtsilä has recently expanded the warranty period for stern tube bearings in water lubricated applications to 25 years.

Legislators prefer water lubrication and steer towards it since it eliminates oil leaks in the sea.

Future-proofing the systems to meet environmental regulations
Ship operators are interested in reducing lifecycle costs and preventing operational risks, but legislation and regulations are also significant factors driving the market towards water lubricated solutions. Simply put, legislators prefer water lubrication and steer towards it due to it eliminating potential oil contamination into the sea. Regulatory compliance is also possible with biodegradable oils, but they are not considered the best choice as they still have a negative impact on the environment. Biodegradable oils dissolve in water. This reduces the negative impact, but does not fully eliminate it. Cost is also a factor to consider: biodegradable oils are four to five times more expensive than mineral oils.

United States Environmental Protection Agency (EPA) announced new rules in 2013, including a prohibition for vessels from operating in US waters unless using Environmentally Acceptable Lubricants (EALs), such as biodegradable oil. These rules also apply to other propulsion systems that use oil lubricated seals and bearings and have a direct oil-to-sea-water interface.

It is expected that worldwide environmental legislation regarding oil pollution will become even stricter. The EU maritime policy specifies the elimination of all vessel discharges into the marine environment by 2020, and it is believed that the EPA will release new legislation within the coming years to further drive the environmental trends of the marine market.

1972 Clean Water Act
1983 IMO Marpol 73/78
1987 Water Quality Act
2005 Major US court ruling
2008 EPA issues first VPG
2013 EPA issues VPG

Regulatory environment

1972 Clean Water Act (CWA)
Basic structure for regulating the waters of the United States. Makes it unlawful to discharge any pollutant from a point source into navigable waters without a permit.

1983 International Convention for the Prevention of Pollution from Ships (MARPOL 73/78)
IMO's bid to minimise pollution of the oceans and accidental spillage of oil and other harmful substances. Applicable to all ships flagged under countries that are signatories.

1987 Water Quality Act (WQA)
Restores and maintains the chemical, physical, and biological integrity of the waters of the United States. Prevents point and nonpoint pollution sources.

2005 MARPOL 1997 Protocol
Amendments to the 1973 convention. Includes Annex VI of MARPOL, which sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts.

2008 and 2013 Vessel General Permit (VGP)
EPA's National Pollutant Discharge Elimination System allows for incidental discharges into waters of the United States from larger vessels. VGP of 2013 calls for the use of environmentally acceptable lubricants for various marine applications such as propulsion systems using oil lubricated seals and bearings.

Summary

Ship owners' and operators' primary interests in today's business environment are operating costs, risk reduction and future-proofing their operations. The stern tube solution is one of the most critical components keeping a vessel operational, and considering different solution alternatives is of great importance.

The risks related to using oil lubricated stern tube solutions concern system breakdowns if water enters the stern tube and oil leaks into the sea. These risks can be avoided with sustainable equipment options: seawater lubricated systems with no oil in the system and lower risk for operational breakdowns, anti-pollution seal systems with no direct oil-to sea surface or EAL lubricated stern tube systems that use biodegradable oils as system lubricants.

By selecting a water lubricated stern tube solution, ship owners and operators are able to improve their lifecycle efficiency with lower operational costs, reduce risks to secure reliability of operations, and future-proof their system to meet environmental regulations.

There are around 90,000 commercial vessels operating in the world, of which 90% are operated with an oil lubricated propeller shaft stern tube solution. Water lubrication is the norm in naval vessels, fishing vessels and smaller ferries operating in archipelagos – all requiring a reliable and oil-free system. Today, however, there is revived interest in water lubrication within the cruise and ferry and merchant shipping market as well. This is based on the reduced costs over the lifecycle of the equipment, the reliability of water lubricated systems and their ability to meet current and potential future demands set by environmental regulations and legislation.

Summary of benefits received when using a water lubricated stern tube system

Reduced lifecycle costs
- Minimal spare parts
- Minimal maintenance, serviceable afloat
- No cost of lubricant and lubricant maintenance
- No emergency dockings
- No risk of leakage penalties

Reliability
- Control over the working environment of the bearings
- Minimal risk of bearing failures
- No risk of oil spillages
- Maximised availability for staying on schedule

Environmental compliance
- Future-proofing to meet tightening regulations
- Securing eco-friendly company image
- Complete removal of oil-related risks

Wärtsilä Seals & Bearings Services in brief

Wärtsilä provides integrated seals and bearings systems, packages and products that offer lifecycle efficiency, reduced risks through reliability and are environmentally sustainable.

As a truly global organisation, Wärtsilä has a broad product and services portfolio covering the whole lifecycle of the vessel. Looking ahead, Wärtsilä's continuing development and technological leadership can ensure customers an environmentally sound solution that always complies with the latest regulations.

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