WMTC ID No. F171126-021

Seawater for Propeller Shaft Lubrication in Merchant Ships – Environmental, Operational, Legal and Shipbuilding Considerations

Author names:
Mr. Craig D. Carter (SNAME Associate Member) [1] (AM)

1. Director of Marketing & Customer Service, Thordon Bearings Inc; MBA

Less than 5% of the world merchant fleet uses an open seawater lubricated propeller shaft bearing system. An open seawater lubricated propeller shaft system uses seawater as the lubrication medium in place of oil. Proven materials and new designs of non-metallic bearings now offer performance similar to oil lubricated metal shaft bearings with open seawater installations of more than 600 merchant vessels, ranging from cruise ships to tankers and containerships to workboats. This paper will look at the growing uptake of open seawater lubricated propeller shaft systems considering environmental, operational, regulatory and shipbuilding issues.

KEY WORDS: ships; bearings; seals; propeller shaft; seawater lubrication; sterntube; oil pollution; EAL; polymer bearings

CURRENT PROPULSION USED – CONVENTIONAL SHAFTLINES

On the majority of merchant ships, there are two types of shaftline arrangements – a) a sealed oil-lubricated system, used by approximately 95% of the commercial shipping fleet and b) an open seawater-lubricated system. The propeller shaft and bearing lubrication arrangement and sealing plays a vital part in the ship's operation. And depending on the trading profile of the ship, ship owners may have to upgrade, change or build new vessels with a shaftline lubrication that meets the regulations of the trading nation.

In a typical sealed oil-lubricated stern tube system, the metallic bearing(s) supporting the propeller shaft are usually lubricated with mineral oil (oil-based lubricant) that is sealed with a lip type seal at each end - AFT (outboard) and FWD (inboard) as shown in Figure 1. Typically, the stern tube contains 1,500 to 3,000 litres of oil depending on ship size. The oil/lubricant system requires frequent oil sampling to monitor ingress of seawater, maintaining oil operating levels, and a need for storage and disposal of oil.

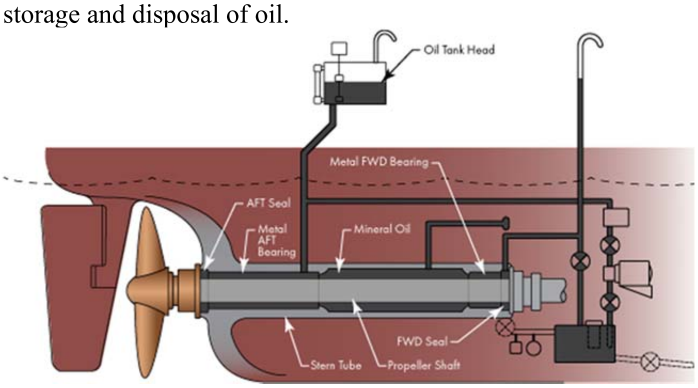

Fig. 1. Typical oil lubricated propeller shaft

The AFT propeller shaft seal is the only barrier between the oil and the sea. "Under optimal conditions the seals can work perfectly, no water enters the ship and no oil is lost to the marine environment. However, because sealing element harden over time, they wear down; consequently, the seal begins to leak oil. [*FN - Shipping and the Environment Dr. Karin Anderson of Chalmers University in Sweden 2016*] And this doesn't get fixed until the next drydocking. Ship owners know this as when the oil is lost to the sea, the crew must top up the oil head tanks to ensure the propeller shaft remains lubricated. But rather than being considered a closed system, as it is designed to be, lubricating oil is commonly viewed as a consumable, with shipowners accepting stern tube propeller shaft seal oil leakage as "normal operational consumption" and acceptable practice.

The aft shaft seal is the weak point of the oil lubricated stern tube, as besides the daily operational leakages, rope or fishing nets can catch on the propeller, damaging the sealing elements allowing oil to leak to the ocean or seawater to ingress, contaminating the oil. An emergency seal repair in situ can cost a ship owner US$200,000 to $400,000.

The propeller shaft seal industry has responded with the development of more complicated seals to prevent oil from leaking out and seawater from leaking in. "Air seals" or void space double seals, when properly maintained and sufficiently emptied, may completely eliminate oil drips or leakage into surrounding waters since the leakage is captured in the void space and then drained internally and captured by the vessel. However, seal manufacturers do not guarantee that their seals would completely eliminate the discharge. Shafts and seals do not operate in a perfect lab environment.

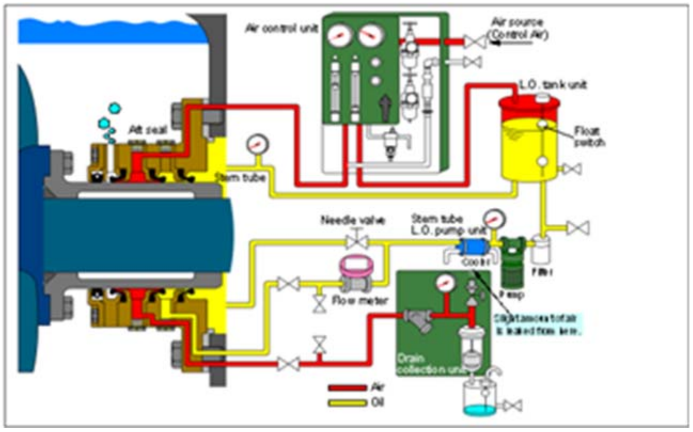

Fig. 2. Oil lubricated system with Typical AFT air seal

The level of potential pollution from oil-lubricated propeller shafts was brought into focus by Etkin, Dagmar Schmidt in the Environmental Research Consulting report Worldwide Analysis of In-Port Vessel Operational Lubricant. They stated: "The total annual inputs of lubricating oil worldwide from propeller shaft leakage into port waters is estimated to be between 37 million to nearly 61 million litres. If the same rates of discharge occur at sea as they do in port, the estimated worldwide annual inputs of lubricants to marine waters both in ports and harbours and at sea might be estimated to be about four times the port estimate. Thus, total worldwide use of propeller shaft lubricants from operational leaks and discharges would then be about 130 million to 244 million litres annually." [*FN Etkin*] This is equivalent to five *Exxon Valdez* oil spills.

Other statistics indicate that much of this pollution stems from seal failures -the aft stern gland (seal) and forward stern gland (seal) represent 43% and 24% of failures respectively.[*FN LR*] These mechanical failures together with external disturbances and the radial movement of the shaft, suggests it is practically impossible to make an oil-lubricated stern tube oil-tight.

More recently, for vessels trading in U.S. waters, the U.S. Environmental Protection Agency (EPA) rules require that vessel operators document their use of Environmentally Acceptable Lubricants (EAL's) in all oil-to-sea interfaces such as propeller shafts in official reports. The U.S. EPA defines these lubricants as being "biodegradable" and "minimally-toxic," and are "not bio accumulative". Four major types of propeller shaft lubricants can meet all the necessary required criteria as defined by the U.S. EPA: 1) vegetable oils 2) synthetic esters 3) polyethylene glycols [PAGs] and 4) seawater.

However, there have been industry concerns with the first three types of EAL's listed above. The design aspects include load carrying capacity – viscosity vs. pressure, viscosity vs. temperature, viscosity vs. shear rate and oil film/lift off speed. The operational aspects include: hydrolysis (effect of water ingress), oxidation stability/aging, wear rates (bearings and seals) and change over procedures. DNV-GL, in conjunction with marine insurers The Swedish Club, Norwegian Hull Club and Gard & Skuld, have recently announced the launch of a test program of EAL's at the University of Sheffield (UoS), U.K. The testing will focus on EAL lubrication performance in stern tube bearings and could influence future Class Society rules. [*FN – DNV-GL press release DNV GL launches new JDP to test biodegradable lubricants Jan. 16, 2018*]

Another concern that has been raised with the introduction of EAL's is the cost for these lubricants. Biodegradable lubricants can cost significantly more than mineral oil as shown in Figure 3.

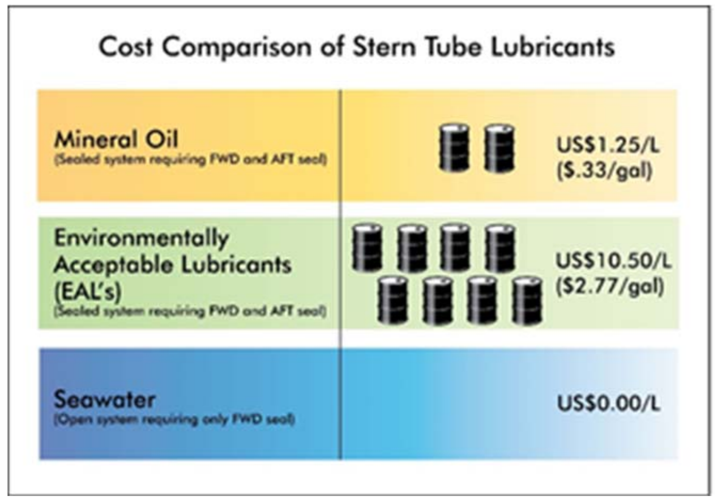

Fig. 3. Cost comparisons of stern tube lubricants

A RETURN TO SEAWATER LUBRICATED PROPELLER SHAFTS

Although there has been an increase in the number of vessels opting for seawater lubricated propeller shaft systems in recent years, many may consider the concept a relatively new development to meet shipowners' ocean sustainability goals. In fact, the concept dates to 1843, with its first application aboard Isambard Kingdom Brunel's iron-hulled *SS Great Britain*. Ships operated with open systems - wooden bearings lubricated by seawater, with *Lignum Vitae* wood used to support the propeller shaft. Stuffing boxes around the wood bearings acted as the seal to prevent seawater from entering the engine room, but these tended to score the bronze shaft liner and created more repair work. The wooden bearings lacked reliable wear life limits much beyond five years, so propeller shafts had to be withdrawn and the bearings replaced - an expensive task for the owner.

In the 1950s shaft seals were developed to enable oil lubrication with white metal bearings supporting the propeller shaft. The seal technology created a controlled environment for the bearings, extended shaft withdrawal periods and increased bearing life spans. Developments in sealed oil-based stern tube systems continued throughout the 1960s and 70s and, in line with shipowners demands for increased reliability, classification societies established rules for extended 15-year shaft withdrawal periods. The weakness of the sealed oil system however has always been the effectiveness of the seals, which must leak oil in operation for cooling, resulting in pollution. Seawater leakage in the other direction, into the stern tube, causes oil emulsion and often catastrophic bearing failure. Today, 95% of the world fleet operates with this system but we know that ships do not operate in a perfect environment and accidents can and do happen.

Today, better designs, modern materials and monitoring systems have brought a return to the open seawater lubricated propeller shaft system. The open system eliminates oil from the stern tube, using seawater as the lubrication medium and non-metallic polymer bearings in place of oil and white metal bearings. The seawater is taken from the sea, pumped through the bearings and returns to the sea. The seawater enters the forward section of the stern tube just aft of the seal. The seawater passes through the forward and then aft bearing prior to re-entering the sea. The open system eliminates the aft seal and the oil lubricant, as well as the storage, sampling and disposal of oil.

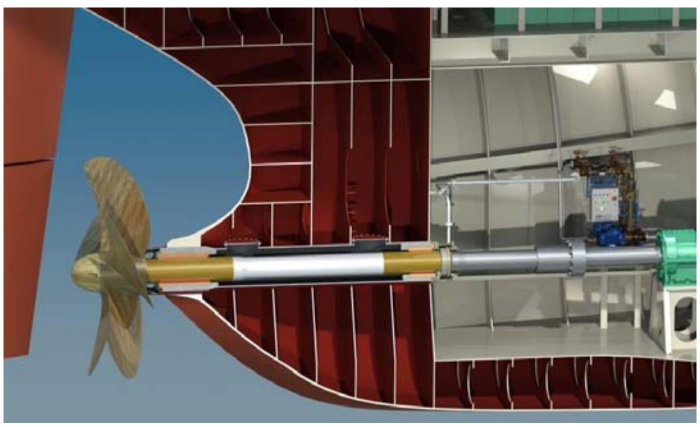

Fig. 4. Typical seawater lubricated propeller shaft bearing system

Polymer bearings and new designs were introduced over 25 years ago and performance to date shows bearing wear life expectations to be 18 years or longer creating similar technical equivalence to an metallic bearing operating in oil. The quality of the seawater supplied to the bearings is critical in ensuring long predictable bearing wear life. With this factor in mind, developments in seawater conditioning/filtering and monitoring packages ensure that an adequate supply of clean water is consistently being delivered to both the forward seal and the bearings.

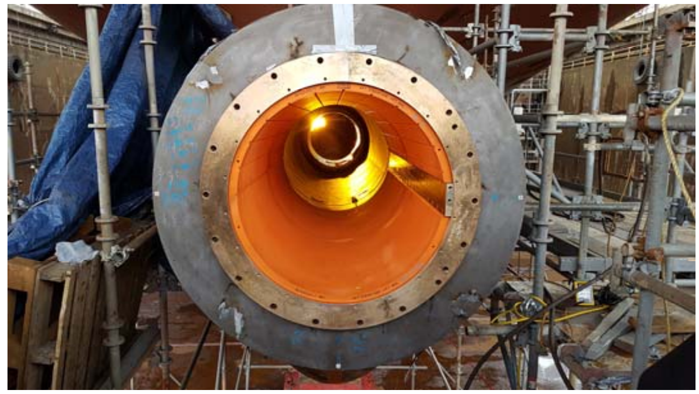

Fig. 5. Installed seawater lubricated polymer bearing

Another key difference between the oil and seawater lubricated system is that the latter technology requires a system to protect the propeller shaft against seawater corrosion. To prevent this corrosion - bronze, Inconel® or stainless steel liners are generally placed over the shaft in way of the bearings. Between the liners a waterproof flexible coating is typically fitted to protect the shaft.

Shaft coating technologies have significantly improved over the past 15 years. Today, flexible shaft coatings have been developed to prevent corrosion and permit extended shaft withdrawals. The coating for a seawater lubricated propeller shaft has always been a major issue for ship owners. Historically, according to Class rules for open water lubricated systems, the propeller shaft had to be removed for inspection every five years and this led to the much wider uptake of the oil lubricated system. Given the improvements in shaft coating and shaft inspection and monitoring methods, most Class Societies have revised their rules related open systems. Under the new rules, if the conditions are met for an open system, the propeller shaft does not need to be withdrawn.

Fig. 6. New 2-part epoxy corrosion resistant propeller shaft coating

In an open seawater lubricated system, only one shaft seal is required to prevent seawater from entering the engine room. There are several mechanical face and lip seals on the market that can meet this requirement.

With modern bearing materials, corrosion protection and improved inspection methods, many ship owners have decided to build their new ships with open seawater lubricated propeller shaft systems. Currently, there are over 600 commercial ships using this open system. Ship owners include Princess Cruises, BP Shipping, Matson Inc., Carisbrooke Shipping Ltd., Seacor Marine, ConocoPhillips, Canada Steamship Lines, Carnival Corp., COSCO, Staten Island Ferries, Scanscot, BC Ferries, Lomar Shipping, Grimaldi Group, Flinter Group, Viking Cruise Lines, Tidewater Corp., Erik Thun Group, American Commercial Lines, Inc., China Offshore Oil Engineering Co., Ltd., Algoma Corp. and Tropical Shipping. Yet still the vast majority of the global commercial fleet continues to operate with an outdated technology that is costly to maintain and operate and can be detrimental to the environment and corporate reputations.

Recent wear data on the performance of seawater lubricated bearings have shown bearing life to be in excess of 18 years and trending to be over 25 years as seen in Figure 7.

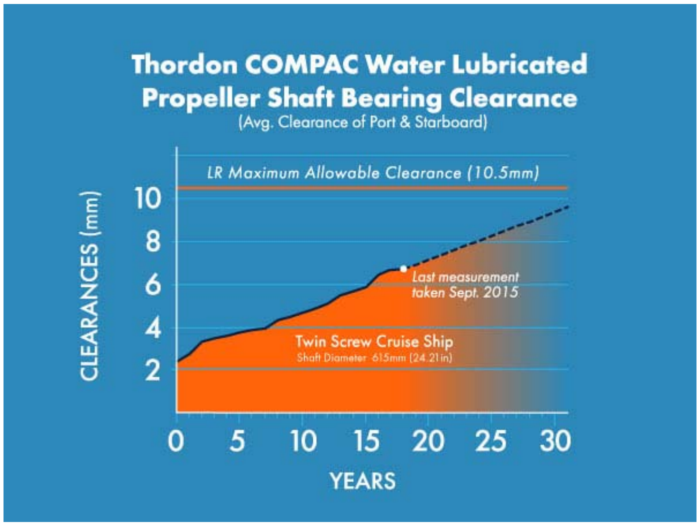

Fig. 7. Bearing clearances for a cruise ship operating with open seawater lubricated propeller shaft bearings since 1998

WHY USE SEAWATER?

To reduce ship operational costs, meet all pollution regulations preventing oil pollution, and to reduce or simplify installation and maintenance procedures, shipowners can now adopt an alternative oil/EAL-free propeller shaft bearing lubricating system that uses seawater as the lubricating medium eliminating oil/EAL/s.

Environmental Considerations

During the last few decades, the pollution of the world's oceans has become a matter of increasing international concern. Zero tolerance for any kind of ship source pollution is now becoming the norm and international regulations are becoming more and more stringent.

There are no completely reliable estimates or methodologies for estimation of stern tube oil discharges. Generally, propeller shaft seals are the only barrier between the oil in the stern tube and the marine environment. Discharges may depend on vessel type, condition, age, and maintenance. Theoretically, with a closed stern tube system there should be no leakage, but observations and reports of oil leakage indicate that there is "rarely a perfectly sealed system" and that there is always some small amount of leakage. Lloyd's Register provided Type Approvals for seals in 2005, that typically allowed 6-12 litres/oil leakage per day depending on the shaft diameter or the type of seal used.

According to the International Tanker Owners Pollution Federation (ITOPF) (2014), oil can affect marine organisms in several ways: by physically smothering, arresting physiological functions; as a toxic chemical; by destroying habitats and therefore resulting in the loss of keystone species.

In the U.S.A., under the Vessel General Permit (VGP), the U.S. EPA now regulates many ship discharges, specifically oil lubrication discharges from oil/sea interfaces such as stern tubes. It creates new reporting requirements and carries extensive civil and criminal penalties for violations, including jail time.

Effective Jan. 1, 2017, the International Maritime Organization (IMO) Polar Code includes a ban on "any discharge into the sea of oil and oily mixtures" so there can be no oil discharges from the propeller shaft system.

With an open seawater lubricated system, there is no possibility of oil discharges meaning zero impact on seabirds and aquatic life (compared to mineral and biodegradable oils/Environmentally Acceptable Lubricants).

Operational Considerations

An open seawater lubricated system is much less complex to install and operate than an oil lubricated system with a compressed air seal. Some of the differences between a current oil lubricated propeller shaft with an aft air seal and a seawater lubricated propeller shaft bearing system with no aft seal are:

- Only one shaft seal (there is no aft seal) with oil lubrication
- No header tank with water lubrication
- Typically 8-10 less pipe runs for water lubrication than with an air seal
- No controlled air equipment with water lubrication
- Less wiring compared to installing an air seal with water lubrication
- Heat sink surrounding the stern tube is not required on certain ships with water lubrication
- Shaft corrosion protection required with water lubrication

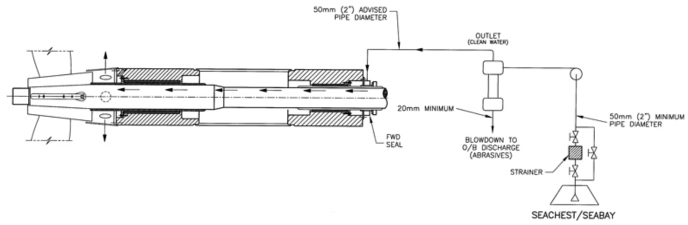

Fig. 8. A typical piping system for a seawater lubricated propeller shaft system

To operate a seawater lubricated bearing system, there is no oil/EAL replenishment required; no AFT seal lip replacement; no AFT liner adjustments, machining or replacement; no oil sampling, processing or record keeping; and no oil or oily water disposal. The concerns of oil discharges and any pollution risk are eliminated. The water lubricated shaft line is a simple solution and not complicated by the oil system's compressed air multi-lip seal system with different storage tanks for onshore disposal of oil. Typically, aft seals require maintenance every 3 to five-years. Even if they are not damaged, the rubber sealing elements wear down quickly as operating hours increase and seals start to leak oil. A typical closed oil lubricated system contains 1500 to 3000 litres of mineral oil. And when they do leak it not only gives rise to environmental concerns, but seawater passing into the stern tube closed system can emulsify the oil, leading to shaft bearing failure.

Research presented at the 2007 RINA (Royal Institute of Naval Architects) conference noted the benefits of water lubricated propeller shaft bearings. The presenters from Fincantieri, a large shipyard in Italy, stated that, "Traditionally, the shaft line is oil lubricated, and located inside the tube case with a diameter larger than the shaft itself. An alternative solution is presented with water lubrication, which offers some consequent benefits. First of all, the inflow water meets a smaller diameter and so the wake peaks on the propeller plane are reduced. Furthermore, the water through frictional effect is trailed in rotation towards the propeller with a significant benefit for propulsion efficiency (about 2%). The water lubricated shaft line is also practically maintenance free and represents a 'green' solution as the risk of oil leakage is avoided."

A major development in seawater-lubricated bearing technology, and one that many consider to be the primary factor in attracting commercial shipowners to the concept, is the change in classification rules for seawater lubricated propeller shafts withdrawal inspections providing extended shaft withdrawals on par with oil systems.

DNV-GL, Lloyds Register (LR), China Class Society (CCS) and Bureau Veritas (BV) have now modified rules for seawater lubricated propeller shaft systems, meaning the shaft does not have to be withdrawn for inspection for 15 years or longer from the date of build if certain monitoring condition criteria are met. This is equal to an oil lubricated propeller shaft and removes a major obstacle that shipowners had with water-based propeller shaft bearing systems.

Another issue that may prompt more commercial ship owners to consider seawater-lubricated shafts is the steep rise in bearing and seal failures on ships with conventional closed propeller shaft systems where environmentally acceptable lubricants (EAL) have been used. This is such a concern that DNV-GL recently established a working group to study performance and compatibility of EALs on conventional metal bearings. The classification society also suggested that the introduction of new propulsion system designs, such as single stern tube bearing installations and larger and heavier propellers operating at lower RPM, also had a negative impact on the oil-lubricated propeller shaft bearing.

Legal Considerations

When it comes to discharges from a ship's propeller shaft system, ships operating in US waters must be mindful of the regulations set forth by the U.S. Environmental Protection Agency Vessel General Permit, the environmental consequences, and operating costs when selecting a propeller shaft lubricant. While Environmentally Acceptable Lubricants (EALs) are a viable option, they do have many limitations and do not necessarily avoid the ship from needing an upgrade or replacement of parts. In 2017, the newly adopted Polar Code states that any discharge into the sea of oil from any ship shall be prohibited.

As many countries are investigating or setting targets for zero ship discharges to the environment, the use of seawater lubricated bearings already meet this objective.

Shipbuilding Considerations

The cost to build a new ship with an open seawater lubricated bearing system is typically 15-20% higher than an oil lubricated system. The higher cost is related to the corrosion protection of the shaft and stern tube. Shaft liners are usually the most expensive part of a shipowner's decision to use a seawater lubricated system at the newbuild stage. Bronze liners are used in way of the bearings although welded cladding and Inconel® have also been used. Costs to install an open seawater system at a newbuild stage rather than having to convert a ship mid-life are much lower. The conversion of the shaft system on existing vessels requires dry-docking, but can be coordinated with planned drydocks.

One of the primary reasons for the industry's slow adoption of open seawater systems lay, unfortunately, with the shipyard. While shipowners drive any equipment decision, shipbuilders' unfamiliarity with the technology is placing an unnecessary premium on the newbuild or retrofit cost of a seawater-lubricated alternative. In fact, when shipowners have enquired about it, they have been discouraged by shipbuilders unwilling to contemplate a new technique that ultimately is less complex and time consuming to install than the oil-based system. Parallel with shipyards' discouragement due to unfamiliarity with seawater-lubricated propeller shaft technologies is the perceived financial risk that some shipyards will be left liable for repair and maintenance cost if the technology fails.

The industry will need to provide further education to the shipyards that building a ship with seawater-lubricated propeller shafts bearings actually takes less time to build and has fewer components than a ship with an oil lubricated system. Of the 600 commercial ships built to date with open seawater lubricated propeller shafts, there was no evidence to date to show technology failure.

CONCLUSION

Today, an open seawater lubricated propeller shaft system offers considerable advantages to ship owners, not only in bearing wear life predictability and reliability, but they are also cheaper to maintain, easier to install and are future compliant. There has been substantial growth in the newbuild market for seawater lubricated propeller shaft systems, with references on more than 600 vessels, ranging from cruise ships to tankers and containerships to workboats. And this sustainable shipping solution eliminates another source of pollution from the world's oceans and seas.

REFERENCES

Etkin, Dagmar Schmidt. Environmental Research Consulting. (2010). "Worldwide Analysis of In-Port Vessel Operational Lubricant Discharges and Leakages" pg 14.

Smith, Andrew. Lloyd's Register Global Technology Leader-Engineering Systems. "Shaft Alignment Problems Analyzed," Marine Engineers Review, April 2009, pg.16

Britannia P&I Club RiskWatch, January 2017. https://www.britanniapandi.com/assets/Uploads/documents/Risk-Watch-Vol-24-No-1.pdf

Lloyds Register Type Approvals Part lA Subject: Main Propulsion Shaft Line Product: Sterntube Seals LR 2005. Retrieved from Web June 8, 2006 http://www.cdlive.lr.org/information/

U.S. EPA National Pollutant Discharge Elimination System (NPDES). Vessels - Frequent Questions: If an equipment manufacturer indicates that the working life of a conventional seal is reduced when used with EALs, is it possible to use a non-EAL lubricant based on technical infeasibility? Retrieved from Web Jan. 10, 2017 https://www.epa.gov/npdes/vessels-frequent-questions