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Thrusters

An Environmentally Preferable Lubricant for Tunnel and Azimuth Thrusters

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ABSTRACT

Ocean-going vessels use oil lubrication in the tunnel thrusters. Offshore vessels also use oil lubrication in the azimuth thrusters. Oil leakage from the thrusters is a serious environmental issue in these vessels. In this paper, a water-soluble, environmentally preferable lubricant newly developed for such thrusters is outlined. Properties required for a thruster lubricant and a suitable base fluid are discussed. Environmental compatibility (biodegradability, low toxicity and no sheen or sludge formation), viscosity, lubricity, oxidation stability, rust prevention and seal compatibility of the new lubricant are described. These properties show that for tunnel and azimuth thrusters the new lubricant can improve not only their environmental compatibility but also their seawater tolerance. Field experience of the thruster lubricant is also presented.

1. INTRODUCTION

Medium and large ocean-going vessels use oil lubrication in the propulsors for the sterntube bearings and the tunnel thrusters. Offshore vessels also use oil lubrication in the propulsors for the azimuth thrusters. Recently the requirements for the environmental compatibility of vessels have increased.

Governments around the world are looking at vessel pollution sources with an eye towards increasing regulations and penalties. The public supports increased regulations of vessels operating in their waters. In 2009, in the United States, the US Environmental Protection Agency published the National Pollution Discharge Elimination System Vessel General Permit rules. Propulsion equipment was specifically stated in the rules in section 2.2.9:

“The protective seals on controllable pitch propellers, azimuth thrusters, propulsion pods, rudder bearings, or any other oil to sea interfaces must be maintained in good operating order to minimize the leaking of hydraulic oil or other oils. The vessel owner/operator must not discharge oil in quantities that may be harmful as defined in 40 CFR Part 110 from any oil to sea interface.” [US EPA – NPDES VGP 2009]

Severe crackdowns against vessels with oil leakage have been carried out. Oil leakage can result in heavy fines or imprisonment. Therefore, oil leakage from the propulsors is a serious environmental issue for these vessels.

Tunnel and azimuth thrusters have a drive shaft, a propeller shaft, gears transmitting power from the drive shaft to the propeller shaft, rolling bearings supporting the shafts, an oil lubrication of the shafts, the bearings and the gears, and a propeller shaft seal preventing oil leakage. The lubricant presently used is industrial gear oil with high lubricity. A typical tunnel thruster is schematically outlined in Figure 1. The seal used is

Figure 1 Typical Tunnel Thruster

a basic design because the thruster does not have enough space available for a more sophisticated design. Therefore, it is very difficult to seal the thruster oil perfectly.

One of the solutions that is attracting keen interest in minimizing oil leakage issues are biodegradable oils. Biodegradable oils, which are decomposed rapidly to carbon dioxide and water in the marine environment, are environmentally friendly. Some biodegradable oils have already been used in sterntube applications [Wholley 2005]. Existing biodegradable oils, however, do not satisfy all the properties required for propulsor lubricants.

Table 1 Comparison of Potential Base Fluids

	No Sheen or Sludge Formation	Water Tolerance	Seal Compatibility
Triglyceride	Poor	Weak, hydrolysis can occur.	Fair
Synthetic Ester	Poor	Weak, hydrolysis can occur.	Fair
Polyalkylene Glycol	Good	Good	Poor, high swelling

Table 2 Tested Lubricants

	Type	Base Fluid	Viscosity @40°C mm^2/s	Specific Gravity @15°C
TH	Thruster Lubricant	Polyethylene Glycol	99	1.12
ST	Sterntube Lubricant	Polyethylene Glycol	76	1.12
MG	Gear Oil (AGMA 3EP)	Mineral Oil	99	0.89
MT	Turbine Oil	Mineral Oil	69	0.88

One of the authors presented a newly developed, environmentally preferable sterntube lubricant, which is based on polyethylene glycol, a type of polyalkylene glycol [Sada 2006]. The lubricant is water-soluble, and forms no sheen on seawater surface or sludge below seawater surface. From the viewpoints of marine lubrication applications and rust prevention, the lubricant can tolerate 10% seawater, while conventional mineral based lubricants cannot tolerate 5% seawater. Application in marine hydraulic systems, such as controllable pitch propellers and stabilizers, is another promising area for this lubricant [Sada 2008]. The new sterntube lubricant, however, does not provide the high lubricity required in thruster applications.

In this paper, a polyethylene-glycol-based, water-soluble, environmentally preferable lubricant for tunnel and azimuth thrusters is outlined. The environmental compatibility and the viscosity are described. Concerning the lubricity, the scuffing load capacity in FZG gear test, the extreme-pressure parameters in four-ball test, and the wear property in translatory oscillation test are described. Additionally, the oxidation stability, the rust prevention, and the seal compatibility are described. Finally, field experience is presented.

2. NEW THRUSTER LUBRICANT

2.1. Base Fluid

The following properties are required for environmentally preferable propulsor lubricants:

- No sheen or sludge formation
- Biodegradability
- Low toxicity
- High viscosity
- Water tolerance
- Seal compatibility

Triglyceride and synthetic ester form surface sheen because they are not very soluble. At high temperature, hydrolysis can occur in these fluids with water contamination. Polyalkylene glycol forms no surface sheen or sludge and tolerates water well because of its water-solubility.

From the viewpoints of biodegradability, low toxicity and high viscosity, triglyceride, synthetic ester and polyalkylene glycol were selected as potential base fluids. Triglyceride is natural ester, and includes vegetable oils. A comparison of these fluids is given in Table 1.

The TH-100 fluid has a minor drawback in that it causes excessive swelling at high temperatures of the most common seal material, a fluoro-elastomer. Poor solubility and hydrolysis are essential fluid properties, and they cannot be easily changed. The seal compatibility, however, can be solved by modifying the seal material. In conclusion, polyalkylene glycol is the most suitable base fluid for a propulsor lubricant.

2.2. New Thruster Lubricant

As a sterntube lubricant, turbine oil of a viscosity grade of 68 or 100 is generally used. As a thruster lubricant, industrial gear oil of a viscosity grade of 100 or 150 is generally used. Their base fluid is mineral oil. For thruster lubrication, higher viscosity and lubricity are required.

An environmentally preferable thruster lubricant has been developed. Its base fluid is polyethylene glycol, a type of polyalkylene glycol, which is the most suitable base fluid for propulsor lubrication. Its viscosity grade is the same as that of standard thruster

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oil. The lubrication performance is equivalent to that of standard thruster oil.

2.3. Comparison of Properties

In this paper, the properties of the new thruster lubricant (TH) are compared to those of three lubricants, polyethylene-glycol-based sterntube lubricant (ST), mineral-oil-based industrial gear oil (MG) and mineral-oil-based turbine oil (MT). MG is standard oil for thrusters and MT for stern tubes. The lubricants tested are outlined in Table 2.

3. ENVIRONMENTAL COMPATIBILITY

3.1. Biodegradability

Biodegradability means that a lubricant is decomposed rapidly to carbon dioxide and water in the marine environment. The biodegradation process is shown in Figure 2.

For biodegradation testing, the CO_2 evolution test [OECD 301B] and the O_2 uptake test [OECD 301C] are commonly applied. For the development of new lubricant, the O_2 uptake test was applied, because it is more stringent and severe than the CO_2 evolution test [Batterby 2005]. When a test substance has greater than 60% biodegradation after 28 days in the test, it is defined as readily biodegradable.

Figure 3 shows the biodegradation curves of TH, ST, MG and MT. The biodegradation of TH and ST reached the pass level of 60% after 14 days. The biodegradation after 28 days for TH and ST was 69% and 83%, respectively. These lubricants are readily biodegradable. TH is less biodegradable than ST, because TH is thicker than ST. MG and MT had less than 20% biodegradation after 28 days.

MG and MT were tested with emulsification by ultrasonication because of its poor solubility. Biodegradation of poorly soluble substances is very dependent on the emulsification level applied in the test. In one case, a poorly soluble substance had 88% biodegradation with full emulsification and 18% biodegradation with no emulsification [Batterby 2000]. Because TH and ST are water-soluble, they need no emulsification in the biodegradation test. The biodegradability of TH and ST in the field is expected to be much higher than that of a poorly soluble lubricant even if these lubricants have the same biodegradation in the O_2 uptake test.

Table 3 Acute Toxicity to Fish

	96h-LC50 ppm
TH	> 100
ST	> 100

$$C, H + O_2 \xrightarrow[\text{Bacteria}\\ \text{Water}]{} CO_2 + H_2O$$

Figure 2 Biodegradation Process

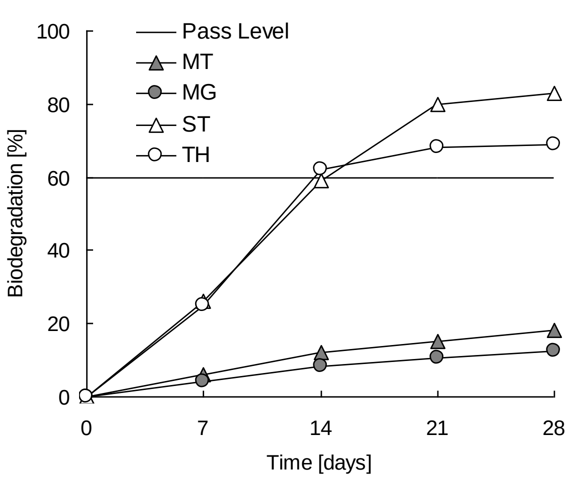

Figure 3 Biodegradation vs. Time

3.2. Low Toxicity

Polyethylene glycol, which is the base fluid of TH and ST, is a well-known non-toxic material. It is generally used as a base material for cosmetics and medicines, often noted as PEG in the ingredient list. The toxicity of TH and ST was evaluated by the acute fish toxicity test [OECD 203]. The results for 50% lethal concentration after 96 hours, 96h-LC50, are given in Table 3. The toxicity parameter for TH and ST exceeded 100 ppm. Both TH and ST are classified as practically non-toxic according to the United Nations definition [UN GHS].

3.3. No Sheen or Sludge Formation

In the USA, the Code of Federal Regulations state: "<u>§ 110.3 Discharge of oil in such quantities as ''may be harmful'' pursuant to section 311 (b) (4) of the Act (Clean Water Act).</u> For purposes of section 311(b)(4) of the Act, discharges of oil in such quantities that the Administrator has determined may be harmful to the public health or welfare or the environment of the United States include discharges of oil that:

(a) Violate applicable water quality standards; or

(b) Cause a film or sheen upon or dis-coloration of the surface of the water or adjoining shorelines or cause a sludge or emulsion to be deposited beneath the surface of the water or upon adjoining shorelines. " (40CFR Ch. 1)

The base fluid of TH and ST, polyethylene glycol, is water-soluble. Since the additives, such as the rust inhibitor, are also water-soluble, TH and ST are completely water-soluble. The environmental impact of surface sheen and sludge cannot be neglected. Both TH and ST form no sheen on seawater surface or sludge under seawater surface because of their water-solubility. They are more environmentally friendly than poorly soluble, biodegradable lubricants.

4. VISCOSITY

4.1. Viscosity-Temperature Relationship

Figure 4 shows the relationships of kinematic viscosity and temperature for TH, ST, MG and MT. At 40 ^{o}C TH is as thick as MG, but the curve of TH is flatter. The curve of ST is also flatter than that of MT. TH and ST have superior temperature-related viscosity characteristics.

4.2. Water Contamination Viscosity

Because mineral oil is poorly water-soluble, water contamination in mineral oil becomes free water. The free water causes a considerable decrease in lubrication performance. On the other hand, water contaminated in TH and ST does not become free water because they are water-soluble. Therefore, the lubricity under water contamination does not decrease dramatically.

For TH and ST, the relationships of kinematic viscosity at 40 ^{o}C and water content are shown in Figure 5. The viscosity decreases as the water content increases, but the relationship is nearly linear. No sudden drop occurs.

5. LUBRICITY

5.1. FZG Gear Test

The scuffing load capacity was evaluated through the FZG gear test [DIN 51354]. The test rig is shown in Figure 6. Test gears of type A with high sliding at the pinion tooth tip were used. A pitch line velocity of 8.3 m/s and a lubricant temperature of 90 ^{o}C were applied. Loads were increased in stages 1 to 12. For industrial gear oil, scuffing load stage of 12 or more is required [AGMA 9005].

The scuffing load stage results are given in Table 4. At the maximum load stage of 12, no scuffing occurred for both TH and MG. For ST and MT, scuffing occurred at stage 9 and stage 8, respectively. TH satisfies the scuffing performance required for industrial gear oil.

Figure 7 shows the torque applied at the scuffing load stages. The scuffing torque was greater than 535 N·m for TH and MG, while it was 302 N·m for ST and 239 N·m for MT. Concerning scuffing load, the capacity of TH and MG is at least 1.8 times larger than that of ST.

5.2. Four-Ball EP Test

The four-ball extreme-pressure (EP) test [ASTM D2783] was carried out to evaluate the EP parameters. The test method is schematically outlined in Figure 8. Bearing steel balls (diameter: 12.7 mm, material: JIS SUJ2) were immersed in a test lubricant. A ball rotation speed of 1760 rpm, a test temperature of 25 ^{o}C, and a test period of 10 seconds were applied. The following EP parameters were derived from the test:

- Weld load (WL)

Table 4 Scuffing Load Capacity

	TH	ST	MG	MT
Scuffing Load Stage (A/8.3/90)	12+	9	12+	8

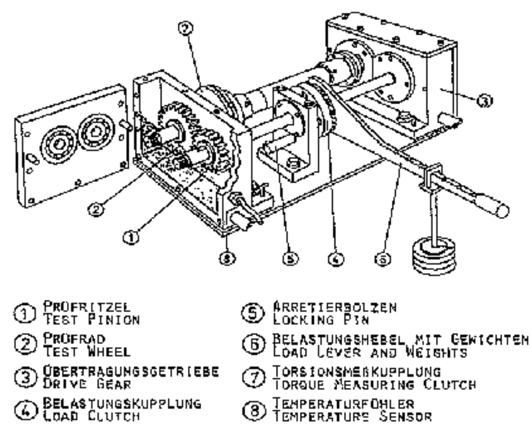

Figure 6 FZG Gear Test

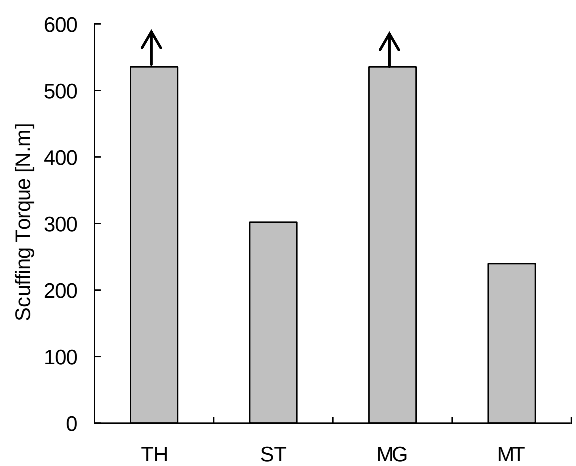

Figure 7 Scuffing Torque

- Last non-scoring load (LNL)
- Load wear index (LWI)

For TH, ST, MG and MT, the relationships of wear scar diameter and normal load are shown in Figure 9. The wear scar diameters at LNL to WL are shown. The curve of TH is considerably different from that of MG. TH has much higher LNL. The curve of ST is similar to that of MT.

Figure 10 shows the comparison of EP parameters. Compared to MG, TH had lower WL, and higher LNL and LWI. The difference in WL was very small. The EP parameters for ST are similar to those for MT. TH has high EP performance equivalent to standard thruster oil.

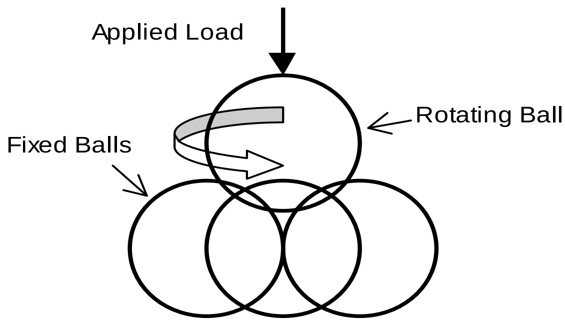

Figure 8 Four-Ball EP Test

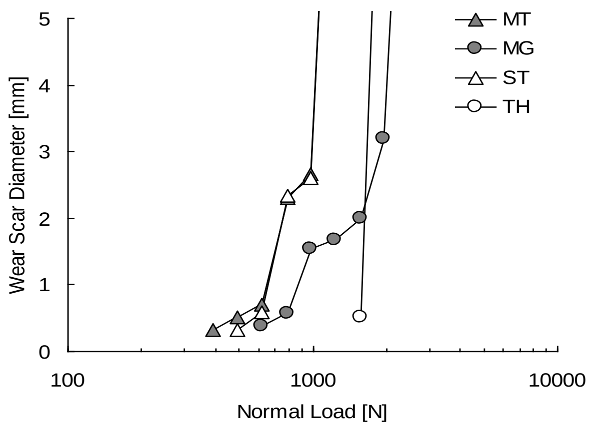

Figure 9 Wear Scar Diameter vs. Normal Load

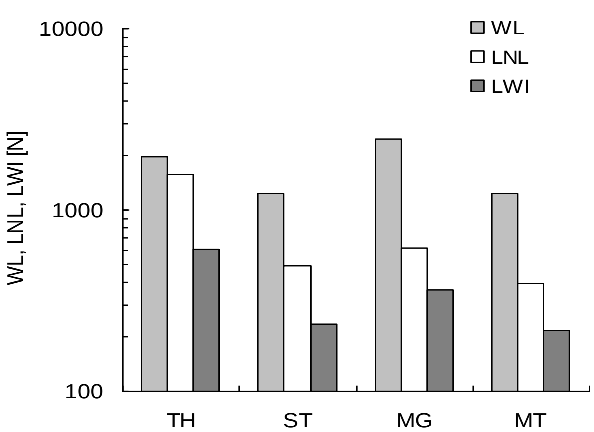

Figure 10 EP Performance

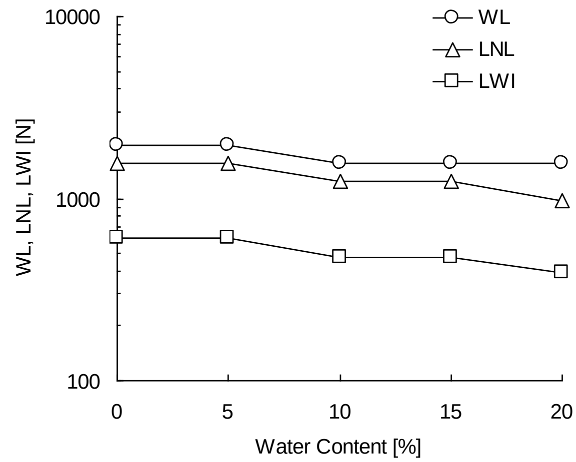

Figure 11 EP Parameters vs. Water Content

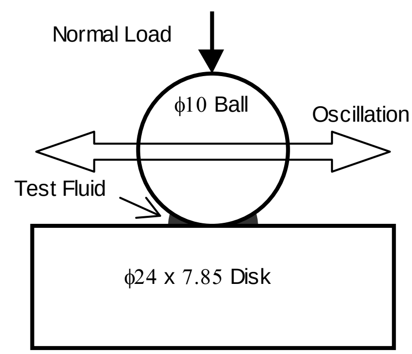

Figure 12 Translatory Oscillation Test

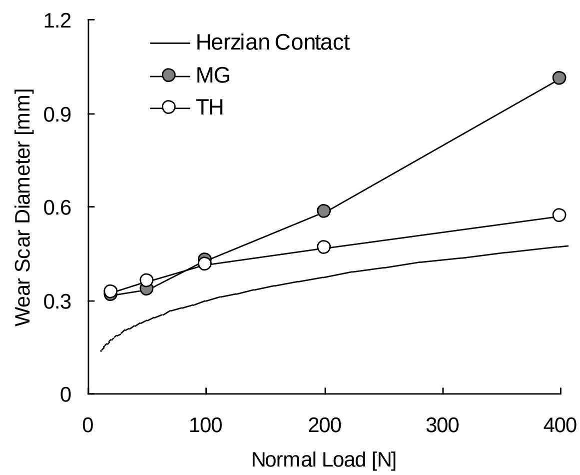

Figure 13 Anti-Wear Performance

For TH, the lubricity under water contamination was evaluated through the four-ball EP test. The relationship of EP parameters and water content is shown in Figure 11. The EP parameters decreased as the water content increased, but the EP parameters for TH with 5% water are the same as those for neat TH. The water contamination allowable for standard thruster oil is very low. It is generally recommended as 0.1%. TH can tolerate much higher water contamination.

5.3. Translatory Oscillation Wear Test

The translatory oscillation test [DIN 51834], a type of ball-on-plate sliding test, was carried out to evaluate the anti-wear performance. A bearing steel ball (diameter: 10 mm, material: JIS SUJ2) and a bearing steel disk (diameter: 24 mm, thickness: 7.85 mm, material: JIS SUJ2) were used. The lubricants of 0.03 mL were supplied at the contact point of the ball and the disk. The test method is schematically outlined in Figure 12. A frequency of 50 Hz, an amplitude of 2 mm, an ambient temperature of 80 ^{o}C, a test period of 10 minutes were applied. The normal loads applied were 20 N, 50 N, 100 N, 200 N and 400 N.

Figure 13 shows the diameters of the wear scars on the balls for TH and MG. Contact diameters derived from Herzian theory are also shown in the figure. The contact diameters are baseline to evaluate anti-wear performance for this test. The wear scar diameters increased with increasing normal load. The diameters for TH were nearly equal to those for MG at the normal loads of 100 N or less, but they were smaller than those for MG at the normal loads of 200 N or more. The curve for TH is nearly parallel to the baseline, even when the load is high. TH has excellent anti-wear performance.

Table 5 Anti-Rust Performance

Seawater %	TH	ST	MG	MT
5	rust-free	rust-free	rust-free	rust-free
10	rust-free	rust-free	rust-free	rusted
15	rust-free	rust-free	rust-free	rusted
20	rust-free	rusted	rusted	rusted

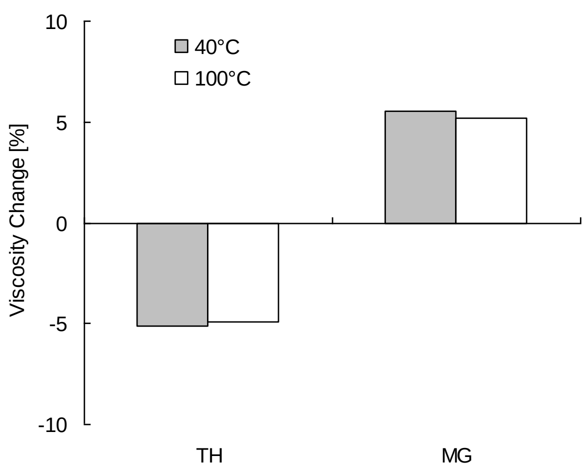

Figure 14 Anti-Oxidation Performance

6. OXIDATION STABILITY

For TH and MG, the oxidation stability was evaluated through the standard test for industrial gear oil [ASTM D2893]. A test temperature of 121 ^{o}C, a test period of 312 hours (13 days) were applied. Dry air with a flow rate of 10 L/h was delivered to a test lubricant of 300 mL during the test. For industrial gear oil, viscosity change at 100 ^{o}C is required to be 6% or less [AGMA 9005].

The viscosity change results are shown in Figure 14. The viscosity of TH decreased, but the viscosity of MG increased. The changes in TH and MG were approximately 5%, and were less than the requirement of 6%. TH has sufficient anti-oxidation performance as a thruster lubricant.

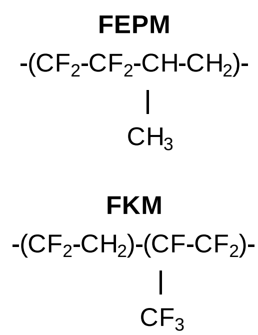

Figure 15 Fluoro-Elastomers

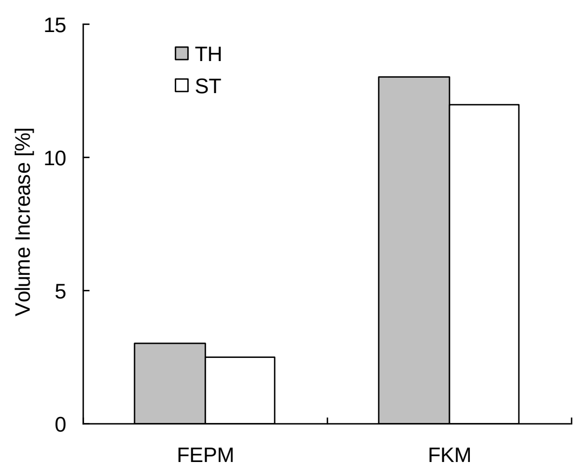

Figure 16 Swelling of Fluoro-Elastomers

7. RUST PREVENTION

For TH, ST, MG and MT, the rust prevention under seawater contamination was evaluated according to the anti-rust test method [JIS K2510]. The test metal was 0.2% carbon steel (JIS S20C). The test temperature and the test period were 60 ^{o}C and 72 hours (3 days), respectively. Synthetic seawater with 3.5% sodium chloride was used.

The test results are given in Table 5. The test metal was not rusted in TH with 20% seawater, but was rusted in MG with 20% seawater. In ST with 15% seawater the test metal was not rusted, but in MT with 10% seawater the test metal was rusted. TH has sufficient anti-rust performance as a thruster lubricant.

8. SEAL COMPATIBILITY

A new seal material was developed for polyethylene-glycol-based lubricants, because polyethylene glycol, which is the base fluid of TH and ST, causes excessive swelling in commonly used seal material, such as a fluoro-elastomer of vinylidene fluoride and hexafluoro-propylene (FKM), under high temperature condition. The new seal material is a fluoro-elastomer of tetrafluoro-ethylene and propylene (FEPM). FEPM has excellent resistance to chemicals. The structures of FEPM and FKM are shown in Figure 15.

The volume change results for the seal compatibility test are shown in Figure 16. The seal material test specimens were immersed in the test lubricants. The test temperature and the test period were 150 ^{o}C and 70 hours, respectively. The results clearly show that both TH and ST have a low swelling effect on the new seal material.

Table 6 Anti-Scuffing Performance

	Scuffing Load Stage (A/8.3/90)
Neat MG	12+
MG + 10% TH	12+

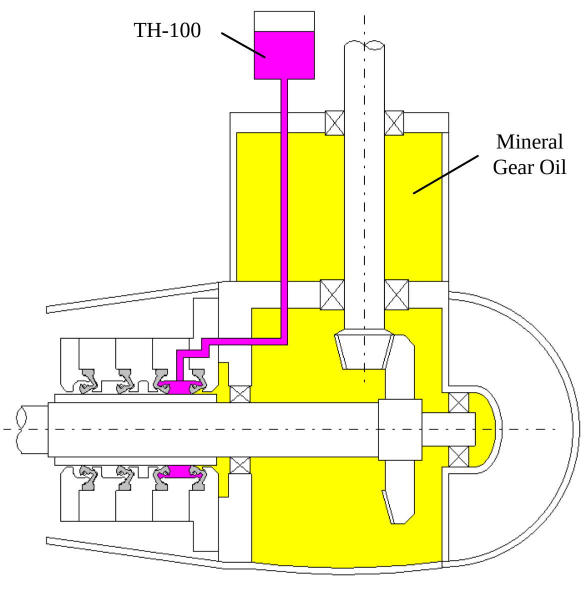

Figure 17 Barrier Thruster Seal

9. FIELD EXPERIENCE

The new sterntube lubricant was named KEMEL ST-77. The first trial in sterntube application began in November 2005 on a fishing boat. Totally the sterntube lubricant has been applied to more than 40 vessels. This has included large container carriers.

In July 2008, ST-77 had been applied to a controllable pitch propeller system of a vessel operating in an environmentally sensitive area. This is the first trial in marine hydraulic system application.

The new thruster lubricant was named KEMEL TH-100. Firstly the lubricant had been applied to propeller shaft seals of azimuth thrusters of a tugboat in October 2008. For the lubrication of the gears and bearings, conventional gear oil had been applied. The application is schematically explained in Figure 17. The seal with TH-100 is a barrier to prevent the gear oil leakage.

Prior to the application, effect of mixture of mineral gear oil and TH-100 was evaluated through the FZG gear test aforementioned. In the test, MG and TH outlined in Table 2 were used. As given in Table 6, no scuffing occurred for MG with 10% TH at the stage 12. Mineral gear oil provides good lubrication even when it contains 10% TH-100.

10. CONCLUSIONS

A water-soluble, environmentally preferable lubricant for tunnel and azimuth thrusters was developed. The lubricant has excellent environmental compatibility (biodegradability, low toxicity and no sheen or sludge formation), and high lubricity equivalent to industrial gear oil. In addition, it provides good water contamination lubrication, which is essential for thruster lubricants.

ACKNOWLEDGEMENTS

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REFERENCES

AGMA 9005, Industrial Gear Lubrication - D94, American Gear Manufacturers Association

ASTM D2783, Standard Test Method for Extreme-Pressure Properties of Lubricating Fluids

(Four-Ball Method)
ASTM D2893, Standard Test Method for Oxidation Characteristics of Extreme-Pressure Lubricating Oils
Batterby, N. S. "The Biodegradability and Microbial Toxicity Testing of Lubricants - Some Recommendations." Chemosphere, 41-7 (2000)
Batterby, N. S. "Biodegradable Lubricants: What Does 'Biodegradable' Really Mean?." Journal of Synthetic Lubrication, 22-1 (2005)
DIN 51354, Testing of Lubricants – FZG Back-to-Back Gear Test Rig: Test Method A/8.3/90 for Gear Lubricants, Part 2
DIN 51834, Tribological Test in the Translatory Oscillation Apparatus
JIS K2510, Testing Method for Rust-Preventing Characteristics of Lubricating Oil
OECD 203, Test Guideline on Acute Fish Toxicity, Organization for Economic Co-operation and Development
OECD 301, Test Guideline on Ready Biodegradability, Organization for Economic Co-operation and Development
Sada, H., Yamajo, S., Hawkins, D. W., and Kawazoe, T. "An Environmentally Compatible Lubricant for Sterntube Shafting and Bearing Systems." 11th Propellers/Shafting Symposium of the Society of Naval Architects and Marine Engineers, Williamsburg (2006)
Sada, H., Yamajo, S., and Hawkins, D. W. "An Environmentally Compatible Lubricant for Sterntubes and Marine Hydraulic Systems." Advanced Naval Propulsion Symposium of the American Society of Naval Engineers, Arlington (2008)
UN GHS, Globally Harmonized System of Classification and Labeling of Chemicals, United Nations
Wholley, C. "Development of an Environmentally Adapted Sterntube Lubricant." 7th International Symposium on Marine Engineering, Tokyo (2005)
