1. Background

As awareness of shipping’s impact on the environment grows, increasing attention is being paid to “operational lubricant discharges”. Such leakage of lubricating oil, in the course of normal operations, may occur both from underwater equipment (sterntubes, controllable pitch propellers, thrusters and pods, steering gear, stabilisers) and from above the waterline equipment (such as cranes, davits, passenger & cargo access ramps & doors, hatch covers and winches) as listed in Fig. 1.

The amount of lubricant discharge in aggregate may be substantial. One recent study[1] estimated that between 37 million and 61 million litres per annum of lubricant may be discharged from vessels in port, whilst another[2] suggested that operational lubricant discharges from sterntubes alone (at sea as well as in port) may amount to 60 million litres per annum. Indeed, sterntubes are considered to be one of the chief sources of operational lubricant discharge[3]. Modern sterntube shaft seals are intended to prevent leakage but all seals can malfunction through a variety of causes: vibration; shaft or seal misalignment; seal or liner wear; variation in pressure differential between the oil and water sides of the seal; and damage from debris such as fishing lines.

“Environmentally Acceptable Lubricants” (EALs) (sometimes described as “biodegradable lubricants” or “bio-lubes”) have been developed in response to such operational lubricant discharges. When properly formulated, EALs have been shown to provide a practical alternative to conventional mineral based lubricants, which cause more damage to the environment when they are lost into the water.

*Received December 24, 2012
** Vickers Oils, UK
The benefits of using EALs, and the confidence which has been gained in their performance, is already recognised by the appearance of a growing number of regulatory requirements and commercial initiatives mandating or incentivising the adoption of EALs. These include:

- **IMO Guidelines for Ships Operating in Arctic Ice-Covered Waters**[^4]: “Sterntube bearings, seals and main propulsion components located outside the hull should not leak pollutants. Non-toxic, biodegradable lubricants are not considered to be pollutants.”

- **DNV Environmental Class - Clean Design notation**[^5]: authorises the use of biodegradable lubricant (under controlled conditions) in the sterntube bearing.

- **RINA additional Class Notation Green Plus**[^6]: requires use of “biodegradable” lubricants.

- **Clean Shipping Index**[^7]: measures the environmental profile of vessels, and awards more points for use of environmentally acceptable lubricants in sterntubes, external hydraulics, thrusters and CP propellers.

- **Baltic Sea Position**[^8]: “Biologically degradable oil is an alternative to conventional mineral based oil”.

- **US Environmental Protection Agency (EPA) – Vessel General Permit (VGP)**[^9]: the current (2008) VGP advises that vessel “owners/operators should use an environmentally preferable lubricant” but also asserts that the use of such products does not “authorise the discharge of any lubricant in a quantity that may be defined as harmful as defined in 40 CFR Part 110.”

However, the draft 2013 VGP (published 30 November 2011) proposes the mandatory use of “environmentally acceptable lubricants” (which meet certain defined ecological criteria) in all oil-to-sea interfaces with effect from 19 December 2013. This would be without exception for new vessels; applications for existing vessels would be excluded only if it would be “technically infeasible” to use EALs. Coincidentally, it is also proposed to extend the provisions of the VGP system to smaller vessels (less than 79 feet) through a parallel “sVGP”. This also mandates the use of EALs.

If approved, the revised VGP and proposed sVGP would almost certainly lead to a substantial increase in the use of EALs. However, at the time of writing (December 2012), the VGP remains a draft. Publication of the final version, which will set out exactly what the rules must be, has been postponed until March 2013.

In any event, EALs are already being used in appropriate applications by a substantial number of commercial operators who recognise that, despite their higher unit price as compared with conventional mineral oils, the overall cost is fairly modest given the relatively small quantities of lubricant involved and the possibility of extended change out intervals.

For such vessel operators EALs offer four distinct benefits.

- The best EALs can offer superior performance compared to conventional lubricants, particularly with regard to fluid life and operating temperature range.

- EALs have been used by some operators as evidence of continuous improvement for compliance programmes such as ISO 14001 and (in the case of tankers) TMSA. In most applications the introduction of EALs is a relatively straightforward process, so their use is a simple step to support ISO 14001.

- Introducing EALs has been used as a means of enhancing corporate reputation; and also of demonstrating operators’ Corporate Social Responsibility and commitment to sustainability. This has been particularly true for sections of the marine industry which operate under the closest public scrutiny.

- There are documented cases where the use of EALs has been regarded by enforcement authorities as a mitigating factor in some cases of accidental leakage, which has resulted in lesser penalties being imposed.

The increasing use of EALs must be matched by growing understanding that EALs are high performance, premium products which need careful management by the user, accompanied by clear guidance from both lubricant suppliers and equipment manufacturers. The following discussion will be illustrated by reference to Vickers Oils’ experience of supplying EALs to more than 1,250 vessels over the last fifteen years. (Vickers Oils’ EALs all use ester based technology and so the discussion below considers only ester based EALs).

2. **Definition**

There are several international standards for land based EALs. Among these are the Blue Angel, European Eco-label, Nordic Swan and Swedish Standard SS 155470 labelling programmes. However, EALs for marine applications have no internationally agreed and accepted
standard definition. Although there are some regional, industry-specific regulations (such as the OSPAR HMCS standards for the North Sea offshore oil & gas industry), there are no regulatory criteria which define what is an environmentally acceptable lubricant for the wider marine market. (The US EPA Draft 2013 VGP does propose such criteria which, if introduced, may become the default international criteria.)

Unfortunately the lack of agreed definition to date has allowed some suppliers to use misleading statements and meaningless performance claims for products that are not as “environmentally-friendly” as the claims suggest.

To prevent confusion and to avoid misunderstanding, end-users should ask their EAL suppliers for details of the specific test standards used as the basis of the ecological claims. EAL suppliers should also be asked for independent laboratory test results to validate any claims made.

Moreover, some of the terminology has been confused. Some products have been promoted as “non-sheen” but actually have limited biodegradability and may be toxic. Other products, such as some food-grade lubricants, are assumed to be EALs but are actually based on mineral oil and are neither biodegradable nor renewable.

Vickers Oils has so far adopted the two key criteria that form the core of all international definitions of environmental performance, namely biodegradability and low toxicity.

**Biodegradability** is the measure of the rate at which a product will break down within the marine environment. Biodegradation of a lubricant is the breakdown of a product, by micro-organisms, into simpler substances such as carbon dioxide, water and ammonia. For it to occur, oxygen, water and nutrients are generally required.

In order to be accepted as “biodegradable”, a lubricant should be at least 60%* biodegradable within 28 days by one of the international tests for ultimate biodegradability, OECD 301 A-F or OECD 306 (*70% for OECD 301 A & E). OECD 301 B is preferred.

**Low Toxicity**: The toxicity of a lubricant is at least as important as its biodegradability. The aquatic food chain is made up of three types of organism: plants, vertebrate (e.g. fish) and invertebrate (e.g. shrimp). It is important that toxicity to all three is considered to maintain the environmental balance. Plant life, such as algae, is at the base of the food chain and any toxic effects here may have a negative impact on organisms that feed directly or indirectly on it. It has been shown by Weyers et al.\(^{10} \) that tests on algae are often the most telling, due to its high sensitivity towards toxic substances.

Therefore we believe it is essential that toxicity testing should include algae; results that do not include algae should be regarded as incomplete.

In order to be acceptable, a lubricant should achieve a level of “Practically Non-Toxic” to plant, vertebrate and invertebrate according to OECD 201, 202, 203 Acute Toxicity tests.

Space does not permit full consideration of these and other eco-criteria and of their various test methods\(^{10} \). But it is worth noting as a general rule that the degree of biodegradability and renewability of the complete formulation tend to be dependent on the base fluids. The toxicity of the formulation is heavily affected by the additives which may be used to improve performance in such areas as thermal stability (oxidation resistance), load-carrying and wear protection, and resistance to corrosion.

Additionally, of course, any EAL should be fit for purpose and approved or at least accepted by equipment manufacturers.

### 3. Fitness for Purpose

The greatest concern regarding environmentally acceptable lubricants has been about their performance and “fitness for purpose” in comparison to conventional mineral oils which have been in use for decades and for which there is a good deal of actual user data. In particular, Original Equipment Manufacturers (OEMs) have been reluctant to approve and give a warranty for the use of environmentally acceptable lubricants in their machinery until they have seen sufficient actual user data over a long period. Conversely, customers are reluctant to adopt the use of environmentally acceptable lubricants without such OEM endorsement. Fortunately, through long term R&D programmes, carefully monitored trials over the last 15 years, often arranged in partnership with OEMs, Vickers Oils has accumulated a substantial body of user data and gained approvals for its own range of marine EALs from many of the major marine equipment manufacturers around the world.

The lubrication performance of EALs can be easily established through industry standard tests in the relevant ISO and national (e.g. JIS, ASTM and DIN) standards. For the sake of space, this paper will assume that all serious EALs can demonstrate that they comply with these normal requirements, which often form the basis of OEM specifications and which apply to all lubricants, regardless of base oil.
Both OEMs and users of marine equipment have concentrated on four additional questions which apply to EALs:

- Is the EAL compatible with the system (in particular, with seals)?
- What is the effect of temperature, both high and low, on the environmentally acceptable lubricant?
- What is the effect of water on the environmentally acceptable lubricant?
- How does the fluid lifetime of the environmentally acceptable lubricant compare to that of conventional oils?

Answers to these questions depend very heavily on both the general type and specific formulation of the EAL under evaluation, as will be seen below.

But in general, these concerns can be addressed through a three-way approach with responsibility shared between the OEM, the EAL supplier and the end user.

EALs are different from mineral oils and may not have the same compatibility with other materials such as elastomers. Therefore it is the OEM’s responsibility, working in collaboration with the EAL supplier, to recommend and use appropriate elastomers, paints and other components. Some OEMs have already begun to use elastomers which have better compatibility with (certain types of) EAL as standard in all their products. This is by far the easiest approach to adopt as it prevents confusion and helps in-service introduction of EALs. Other OEMs will fit EAL compatible components on request from an owner/yard. This can usually be done only at new-build or at a major overhaul.

Sterntube seal manufacturers are seeking to improve the compatibility of their materials with ester based biodegradable fluids, and are developing increasingly sophisticated rig tests in order to predict long-term behaviour in extreme conditions. Currently sterntube seal manufacturers apply restrictions and conditions to the use of biodegradable fluids. One aim for both seal and fluid manufacturers is to enable biodegradable fluids to be used as freely as mineral oils.

The EAL supplier must fully understand each particular application and the various “what - ifs” that can apply in each case. Such understanding can only be gained through many years’ practical experience and knowledge of marine equipment. The EAL supplier must then apply that understanding, along with an equal knowledge of the raw materials that are available, to the process of selecting the base oils and additives for the environmentally acceptable lubricant. The purpose is to ensure that there are, in practise, no adverse effects.

As noted above, the “fitness for purpose” of a marine EAL depends on its formulation as well as the intended application. There are several different types of ester based EAL. The simplest products are those based on natural oils such as rape (and other seeds) or tallow. These are highly biodegradable, are completely renewable and have good compatibility. But whilst the higher quality natural oils can be suitable for less demanding applications, they can suffer from poor performance in both cold and hot conditions or in the presence of water.

In general terms, high-performance “saturated synthetic esters” are required for the most demanding applications such as pressurised hydraulic systems; gear lubricants; Extreme Pressure (EP) greases; and/or any product that is required to work under high temperature conditions especially where water may be present. Such high-performance base oils can have very good resistance to oxidation (thermal degradation) and to hydrolysis (breakdown by water at high temperature) as well as good low-temperature properties. Carefully selected saturated synthetic esters provide the best combination of performance and compatibility for base oils.

However lower cost formulations can perform adequately depending on severity of the operating considerations. Additive performance is also critical. Most additive packages are designed for mineral base oils but new raw material technologies for EALs continue to be developed.

Crucially – and sometimes overlooked – the end user/customer also has a responsibility for the successful on-board management of EALs. In a few cases, such careful attention has not been given to the EALs in use which has had unfortunate consequences. Proper management of EALs is described in the next section.

### 4. On-Board Management of EALs

EALs are high performance, premium products that deserve proper maintenance to ensure a good return on the investment. EALs should be treated differently to ordinary mineral oils. Proper procedures need to be followed, as suggested in the “Instructions for Use” typically offered by EAL suppliers. These may include:

- If changing over to a new EAL, fully drain out the existing oil, or, if this is not possible, flush the system. Carry-over of the existing fluid ideally should not exceed 5% of the total system capacity.
• When introducing EAL hydraulic oil, it should be filtered in accordance with equipment makers’ recommendations to remove any contamination that may occur once the packaging is open.
• After filling, the system should also be filtered to achieve the required system cleanliness.
• All system filters should be renewed.
• Only top up with the same EAL – avoid mixing different types because of possible incompatibilities.
• EALs should be stored indoors in their original drums, sealed, until they are introduced into the system. Where possible, do not store in a reserve storage tank (because of the possible risk of contamination and/or microbial infection).
• If lubricants must be stored outside, they should be laid on their sides with the bungs horizontal, to minimise the risk of moisture contamination in the drums.
• EALs should be regularly checked under an oil condition monitoring (OCM) programme that complies with the requirements of Classification Societies. The OCM test should include additional tests appropriate for EALs. As always, end users should pay close attention to the recommendations written in the OCM report.
• In high pressure, high temperature applications (such as some thruster gears and some hydraulic systems), EALs could break down if water enters the system. Therefore water content should be controlled to 1,000 ppm (0.1%) through regular sampling and the use of a suitable separator or purifier. Hygroscopic breathers are recommended to absorb airborne moisture.

5. User Experience

Ester based EALs have been delivered by the author’s company to more than 1,250 vessels since sea trials commenced in 1997, and currently are used in sterntubes, CPPs, thrusters, rudder stocks, fin stabilisers, cranes, davits, hatchcovers, shell doors, side & stern ramps and winches. The experience of using EALs has been extremely positive in the vast majority of cases. EALs are in use on a wide variety of vessel types and locations, including Ice Class 1A bulkers in the Arctic and cruise liners in the Caribbean.

• The longest continuous use of EALs in one vessel is now more than 10 years (since delivery in 2002). An emulsifiable EAL is used in the twin sterntubes of this cruise liner, fitted with a face seal, and the bearings have run well, despite occasional occurrences of water entry through the seal.
• A fleet of short-sea car carriers make frequent port calls in sandy waters, which increase the risk of stern tube shaft seal damage and oil leakage. Therefore the owner has chosen to use EALs in the sterntubes to reduce the environmental impact in case of leaks.
• A ferry owner in the Baltic decided to use EAL hydraulic fluid to operate stern ramps on a new-built ferry. The vessel has worked satisfactorily for several years through winter temperatures as low as -35°C.
• Conventional mineral hydraulic fluid in the cranes for a self-unloading bulker became unfit for use after 350 to 450 hours. Pump failure followed, resulting in repairs and increased costs because the cargo then had to be loaded and unloaded by dockside cranes. The use of saturated synthetic ester based hydraulic fluid has extended fluid life by a multiple of at least four. The same crane unit has been operating continuously now for approximately 2,000 hours. This has greatly improved operational efficiency and has reduced costs.
• Leakage of grease from rudder stocks has been reduced by using EAL grease which has greater resistance to “wash-off” than conventional mineral oil based grease.

Long term sea trials in several other applications are continuing to run for up to five years and seem to be performing well. Recently a five year sea trial with a new type of elastomeric seal was successfully concluded. This experience shows that, when high quality EALs are used and are properly maintained, they perform well even in difficult conditions.

6. Conclusion

Leaks of lubricating oil into the marine environment rightly attract more attention than ever before. These oil leaks may come from below-the-waterline equipment, especially sterntubes and thrusters, or from deck equipment including cranes and ramps.

There are some incentives to encourage, and some proposed regulations to enforce, the use of “Environmentally Acceptable Lubricants” (EALs) which cause less environmental damage if accidental leakage happens. Properly formulated EALs can meet demanding standards of environmental acceptability whilst also offering a high standard of operational performance. Certain of them can offer benefits over conventional mineral oils in terms of performance and service life.
Equipment makers, EAL suppliers and users have a shared responsibility for the successful use of EALs which should be carefully maintained and managed on board. Actual experience gained over the last 15 years shows that EALs are a practical alternative to conventional mineral oils.

Acknowledgements

The author thanks all his co-workers at Vickers Oils, in particular Mr. C.J. Wholley. The author also thanks the Royal Institute of Naval Architects for permission to base some aspects on an earlier paper, “Environmentally Acceptable Lubricants – the Future in Marine”, presented at the Royal Institute of Naval Architects, London, February 2012 (© RINA).

References

[3] Etkin, op. cit, calculates that 4.6 million to 28.6 million litres of the estimated total are lost through the sterntube.
[4] IMO MSC/Circ.1056 MEPC/Circ.399 23 December 2002, clause 7.2.3
[5] DNV Rules for Classification of Ships; Newbuildings; Special Equipment and Systems; Additional Class. January 2011 Part 6, Chapter 12: Section 2 – page 17 (clause C 1000) and Section 3-page 23 (clause C 1100), as modified 1st January 2013
[6] RINA Rules for Classification of Ships – Additional Class Notation Green Plus 2009 – Appendix 2, Clause 1.1.18

Author

Peter Vickers is Chairman & Managing Director of Benjn. R. Vickers & Sons Ltd (“Vickers Oils”) which is an independent, specialist manufacturer of high performance lubricants. He is the fifth generation of his family to work in the business (which was established in 1828), which he has done since graduating from Oxford University. He held a variety of roles in the company, including sales and technical service, before taking on his present responsibilities.