Emission estimates for diffuse sources
Netherlands Emission Inventory

Propeller shaft lubricant, inland navigation

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NETHERLANDS NATIONAL WATER BOARD - WATER UNIT
in cooperation with DELTARES and TNO

Propeller shaft lubricant, inland navigation

1 Description of emission source

A number of substances are released into surface water as a result of loss of propeller shaft lubricant from inland vessels.

On most vessels, the propeller shaft and the bearings are built into a tunnel running from the engine room to the ship's shell. Seals at the rear of this tunnel prevent outside water from working its way along the shaft into the ship and the engine room. The bearings and seals of propeller shaft systems are lubricated. The lubricant serves to lower friction resistance, and also cools the bearing housings and gaskets, keeps water out and helps stop corrosion. See figure 1 for a schematic of the principle of a greased propeller shaft seal.

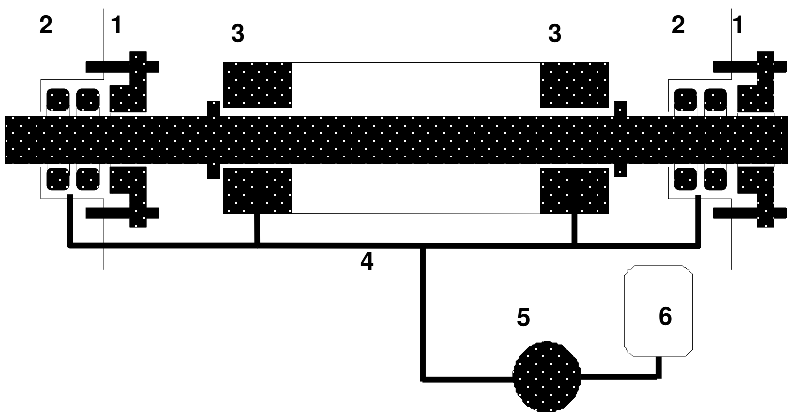

Figure 1: Greased propeller shaft seal [1]

Lubricant is applied between the bearings (1) and the sockets (2) through a grease channel (4).
The fore and aft seals (3) are supplied with lubricant via this same grease channel.
The grease pump (plunger pump) (5) provides a constant over-pressure and supply of new grease from the grease reservoir (6).

There are three types of grease systems in use in inland navigation for propeller shaft seals. The traditional greased systems are by far the most common system, but are now giving way to shaft seals with water or oil lubrication. The disadvantages of grease-lubricated propeller shaft bearings and seals are the generation of spent grease, the difficulty in refreshing the grease and the fact that a considerable portion of the grease ends up in surface waters.

This emission source is allocated to the governmental target sector “Transport” within the National Emission Inventory.

2 Explanation of calculation method

Emissions are calculated by a simple method that involves multiplying an activity rate (AR) - the transport performance on the inland routes - by an emission factor (EF) per substance, expressed in emission per AR unit.
The emission calculated in this way is referred to as the total emission. As it relates to direct discharge into surface waters, the total emission is the same as the net load of the surface water.
Emissions are calculated by a simple method that involves multiplying an activity rate (AR), in this case the transport performance of inland vessels in the Netherlands, by an emission factor (EF) per substance and per type of grease/lubricant, expressed in emission per unit of AR. The effects of the measures are processed as a degree of penetration in the incidence of various types of grease/lubricant.
Additionally, the derivation of the emission factors assumes a gradual improvement of the leak-tightness of the lubrication systems.

$$E_s = AR \times F_t \times EF_{t,,s}$$

Where:

E_s = Emission of substance (s), in kg
AR = Transport performance on Netherlands route, in tonne-km x 1,000,000
F_i = Degree of penetration of grease/lubricant type t (%)
$EF_{t,,s}$ = Emission factor for lubricant t and substance s, in kg /tonne-km x 1,000,000

3 Activity rates

The activity rate "transport performance in cargo-tonne-kilometres on Netherlands route" is assessed based on the number of tonne-kilometres sailed. This calculation relies on an annual series data of tonne-kilometres traversed for the period after 1996 based on data from Netherlands Statistics (CBS) [2], and for the period before 1996, calculated retroactively based on developments in transport capacity of inland navigation [3].

Table 1. Activity Rate: Transport performance of inland navigation on Netherlands route, cargo-tonne-kilometres (x 1,000,000).

Year	Transport performance on inland routes (tonne-km x 1,000,000)
1985	38,115*
1990	40,144
1995	36,744
2000	41,297
2005	43,066
2006	43,577

* Sailing intensity for these years is calculated from the sailing intensity registered for 1997, corrected for the transport capacity available in the Netherlands (number of ships * average tonnage).

4 Effects of policy measures

Grease-lubricated systems
Because some of the propeller shaft lubricant enters the surface water, suppliers have attempted to reduce the environmentally harmful nature of the greases. Lead, for example, has been virtually eliminated from greases in recent years, and a number of biodegradable products have appeared on the market. The present market share of these biodegradable products is unknown, but the two largest suppliers on the Dutch market [5, 6] expect that this share is certain to grow in the coming years. Ship environmental inspections by the department of Public Works & Water Management show that the percentage of organic propeller shaft lubricant has been increasing since 2002 [9].

Alternative systems: oil and water-lubricated shaft seals
In new ships, oil or water-lubricated shaft seals are becoming more and more common. Existing ships are also more frequently choosing to replace old grease-lubricated seals with "conversion systems" based on water or oil [7].

Oil-lubricated systems generally provide better sealing than grease-lubricated systems, lose little to no lubricant and keep virtually all water out. One disadvantage of this type of system, however, is their somewhat complicated construction. Closed oil-lubricated systems can often only be installed in new ships. Most oil-lubricated seals are difficult and expensive to install in existing ships [8].

Water-lubricated systems have the advantage that the lubricant, water, is environmentally friendly. A disadvantage is the fact that water is a less effective lubricant, so extra cooling is required. Additionally, water can introduce corrosion. Corrosion inhibitors and glycols enter the bilge water or contaminate the surface waters via the aft seal. Usually, this involves small quantities of leaking system water and low concentrations of additives, although these additives may be environmentally harmful. The risk of release of unknown quantities of additives into the environment will primarily be an issue at maintenance of the system.

Research [1] shows that since 1996, fewer and fewer traditional grease-lubricated shaft seals have been used, and that they are being replaced by water or oil-based systems.

5 Emission factors

Greases consist largely (80%) of mineral oil, which is combined with additives and soaps. According to manufacturers, no emissions of benzene and toluene are to be expected. The two largest manufacturers [5, 6] indicate that they no longer use lead in their greases. One other manufacturer claims that at this point it has eliminated lead in all but one annual batch for car engines. This means that emissions from lead should be marginal in comparison to the current estimate. Lead has been (and probably was before 1996) largely replaced by zinc/zinc naphthenate, or other components. With a few minor exceptions (such as lithium, which is used as a thickener in the soap component of the grease) there are no metals or heavy metals. According to the manufacturers, the propeller shaft lubricants contain no PAHs.

Correlating the quantity of propeller shaft lubricant discharged on the surface water with the activity rate "Transport performance of inland navigation on Netherlands route" requires the use of data from the SAB (Stichting Scheepsafvalstoffen Binnenvaart) [8]. According to SAB, in 2001 approximately 123 tonnes of lubricant were collected from inland vessels. Most likely, this figure is not only propeller shaft lubricant but also includes lubricant from the rudders (rudder hole sleeves). Additionally, the propeller shaft seals will not all be greased open shaft seals, but probably also include closed systems. Weekhout [7] estimated in 1996 a loss rate of 35% of the propeller shaft lubricant, which was probably released into the surface water. Previous calculations maintained a figure of 60% for this emission [4].

Because the loss rate has an impact on the emission factors, and this changes over time, a time series of emission factors is drafted. This involves producing use rates and multiplying them by the loss rates to derive the emission factors.

These use rates and loss rates are based on the total consumption of lubricant, which in turn is based on the quantity collected and the assumed quantity discharged. In 2001, 123,015 kg of lubricants were collected [8]. It is assumed that virtually all these lubricants consist of propeller shaft lubricant. With a loss rate of 35% [6] of the lubricant, this means that 66,239 kg of lubricant was discharged on surface waters, and the total consumption will have been 189,254 kg of lubricant.

Loss rates

In 2001, 35% of inland navigation was using the closed propeller shaft system [9]. 65% of inland navigation was responsible for the largest portion of the 66,239 kg of discharged lubricants. This means that each percentage of inland vessels without closed propeller shafts represents approximately 1,000 kg discharged. The collected quantities of lubricant from the SAB report [8] combined with the number of closed propeller shaft seals ascertained from ship environmental inspections [9] can be used to arrive at a rough calculation of the loss rate. These rates are shown in the table below. The loss rate calculated this way exhibits drops off somewhat drastically. For the trend calculation, a more gradual decrease was chosen. The last column shows the loss rate used in this fact sheet.

Table 2: Assessment of time series of loss percentage of propeller shaft lubricant

Year	Lubricant collected (kg) [8]	% closed propeller shaft [9]	Calculated loss (kg)	Produced lubricant (kg)	% loss calculated	% loss fact sheet
2001	123,015	35	65,000	188,015	35%	35%
2002	153,592	38	62,000	215,592	29%	34%
2003	138,519	39	61,000	199,519	31%	32%
2004	139,170	48	52,000	191,170	27%	31%
2005	115,567	50*	50,000	165,567	30%	30%
2006	108,295	54*	46,000	154,295	30%	29%

* = extrapolation from previous years

Use rates for zinc and zinc naphthenate:

For zinc and zinc naphthenate, an emission factor is calculated based on a formula provided by the manufacturer [5]. A batch of approx. 5,000 kg propeller shaft lubricant contains some 150 kg zinc naphthenate. The zinc content of this component is 10%, or 15 kg.

- The emission factor for zinc is 0.003 kg Zn/kg propeller shaft lubricant.
- The emission factor for zinc naphthenate is 0.03 kg ZnNaphthenate/kg propeller shaft lubricant.

In 2001, the transport performance was 41,927 million tonne-km [2], setting the use rate for Zinc naphthenate at:

Use rate, Zinc naphthenate	=	0.03 kg ZnNaphthenate/kg propeller shaft lubricant	x	189,254 kg lubricant	/	41,927 mil. tonne-km	=	0,.135 kg zinc naphthenate per tonne-km
Use rate, Zinc	=	0.003 kg Zn/kg propeller shaft lubricant	x	189,254 kg lubricant	/	41,927 mil. tonne-km	=	0.0135 kg zinc per tonne-km

Use rate for mineral oil
The estimated 66,239 kg of lubricant discharged for 2001 indicates that at a lubricant composition of 80% mineral oil, 52,991 kg of mineral oil was discharged into the surface water in the discharged lubricant. In 2001, the transport performance was 41,927 million tonne-km [2], meaning the emission factor for mineral oil is set at:

Use rate, mineral oil	=	80%	x	189,254 kg lubricant	/	41,927 mil. tonne-km	=	3.61 kg mineral oil per mil. tonne-km

Emission factor for lead:
Because only limited data is available for lead, no use rate can be assessed. Consequently, the emission factor for lead is based on the earlier emission estimate [4] for the year 1990, recalculated for the new activity rate "transport performance in cargo-tonne-kilometres."

Use rate for lead	=	Emission of lead in 1990	/	Transport performance in 1990		
	=	8041 kg lead	/	39,591 mil. tonne-km	=	0.20 kg lead per mil. tonne-km

For the emission factor for lead, the assumed loss rate of 60% in 1990 [4] is indexed and scaled at 100% with the loss rate assumed for the year under consideration.

The emission factors are then calculated by multiplying the loss rate for each year by the use rates.

Table 3: Time series of emission factors calculated with given loss rate, (kg/mil. tonne-km)

Year	Loss rate	Lead	Zinc	Zinc Naphthenate	Mineral oil
1985	60%	0.20	0.0081	0.081	2.2
1990	60%	0.20	0.0081	0.081	2.2
1995	40%	0.14	0.0054	0.054	1.4
2000	35%	-	0.0047	0.047	1.3
2005	30%	-	0.0041	0.041	1.3
2006	29%	-	0.0039	0.039	1.3

6 Emissions calculated

Calculation method

The emissions were calculated by multiplying the emission factors from section 5 by the activity rate shown in section 3, taking into account the elimination of lead from lubricants and the subsequent gradual replacement of the lubricants by biodegradable alternatives.

Lead
Because according to manufacturer claims [5, 6] it is known that lead was completely eliminated from propeller shaft lubricant by 1996, a linear drop-off in the three years from 1994 to 1996 is assumed, from 75% to 50% to 25%, being replaced by zinc naphthenate. Using the emission factor for lead, the emission of lead is then calculated with the assumed phase-out for the period 1992-1996.

Biodegradable propeller shaft lubricants
Biodegradable propeller shaft lubricants do not emit hazardous substances into the surface water. Although there is no way to estimate the percentage of biodegradable propeller shaft lubricants currently in use in the inland navigation sector, the mathematical method below shows how this effect can still be taken into account in the emission calculation. This relies on the assumption that since 1999, the percentage of biodegradable lubricants has been approximately 1% of all propeller shaft lubricants. For the years before 1998, the percentage of conventional lubricants is set at 100%. The ship environmental inspections by Public Works & Water Management [9] show that the percentage of organic propeller shaft lubricants is rising.

The percentages of propeller shaft lubricants are shown in table 4.

Table 4: Assumed loss rate and distribution of lead and zinc-based and biodegradable propeller shaft lubricants, inland vessels

Year	Percentage of lead-based lubricants	Percentage of zinc-based lubricants	Percentage of biodegradable lubricants
1985	100%	0%	0%
1990	100%	0%	0%
1995	50%	50%	0%
2000	0%	99%	1%
2005	0%	78%	22%
2006	0%	78%	22%*

* Percentage of biodegradable lubricants kept at 2005 level, no change in value prompted by consultation with manufacturer.

The emissions of lead, zinc, zinc naphthenate and mineral oil are then calculated with the assumed distribution of lead-based, zinc-based and biodegradable lubricants, the activity rate from section 3 and the emission factors from section 5.

The table below shows annual emissions for the various substances expressed in kg/year.

Table 5: Emissions to surface water by propeller shaft lubricant, inland vessels, (kg/year)

Year	Lead	Zinc	Zinc Naphthenate*	Mineral oil
1985	7,623	-	-	83,853
1990	7,918	-	-	87,100
1995	2,818	109	1,087	56,354
2000	-	193	1,932	53,149
2005	-	136	1,360	43,669
2006	-	133	1,331	44,187

* the emission Zinc naphthenate also includes the zinc component

We propose that the substance Zinc naphthenate be introduced into the Emission Inventory with a conversion of 10% m/m to zinc.

7 Release into environmental compartments

The full amount of the emissions identified here is discharged into the surface water. Emissions into the soil and air can be assumed to be negligible.

8 Description of emission pathways to water

The full amount of the emissions is discharged directly into the surface water. There are no emissions of this type into the sewer system.

9 Spatial allocation

The spatial allocation of emissions is assigned on the basis of a set of digital maps held by the Netherlands Environmental Assessment Agency (PBL). These maps present the spatial distribution of all kinds of parameters throughout the Netherlands, such as population density, traffic intensity, area of agricultural crops, etc. For the purposes of emission registration these maps are used as 'locators' to determine the spatial distribution of emissions. The range of possible locators is limited (see [11] for a list of available locators), as not every conceivable parameter can be used as a locator. In practice the locator judged to be the best proxy of the activity rate of the emission in question is applied for the distribution of emissions.
It is assumed that the distribution of emissions throughout the country is proportional to the national distribution of the locator.

The table below shows the locator used for the spatial allocation of the various emission sources.

Table 6: Summary of spatial allocation method

Element	Locators
Propeller shaft lubricant, inland navigation	Professional inland navigation

The method used to determine the locators is described in [11]:

Professional inland navigation
The allocation is determined by multiplying the number of vessels per shipping lane segment by the length of that segment (in kilometres). A distinction is made between push-towing and other inland navigation.
The latter category is in turn subdivided into two classes based on cargo capacity.
Data on numbers of inland vessels originate from the CBS; location and length of shipping lanes originate from the National Roads Database.

10 Comments and changes in regard to previous version

In previous years, emissions originating from propeller shaft lubricant from inland vessels were estimated using the method described in " Emissieschattingen Diffuse bronnen Schroefasvet binnenscheepvaart" version 1, RIZA 2002. This document uses the "number of active Dutch inland vessels" as activity rate. The activity rate is corrected with the assumption that 80% of inland vessels have a grease-lubricated system.

In previous estimates, the assumption used was that grease-lubricated open systems lose approximately 60% of the grease into surface water. The other 40% is contained in the engine room and transported to a processor. Research [7] showed that probably about 35% of the propeller shaft lubricant is emitted into the surface water. This makes the 60% loss rate estimate too high. The new loss rate is interpreted as the result of improvements in the technology. Regular updates of this loss rate are recommended. A figure of 35% is maintained for the years 1996-2000, gradually decreasing to 30% for the years 2000-2005.

Emissions of benzene and toluene are based on an incorrect assumption in previous calculations, and are therefore no longer included. The relatively large emission of lead is replaced by a smaller emission of zinc and zinc naphthenate. In addition, the quantity of discharged mineral oil is less than what was previously assumed.

11 Accuracy and indicated subjects for improvement

The method used in Emission Inventory publications has been followed as far as possible in classifying the quality of information [12]. It is based on the CORINAIR (CORe emission INventories AIR) methodology, which applies the following quality classifications:

A: a value based on a large number of measurements from representative sources;
B: a value based on a number of measurements from some of the sources that are representative of the sector;
C: a value based on a limited number of measurements, together with estimates based on technical knowledge of the process;
D: a value based on a small number of measurements, together with estimates based on assumptions;
E: a value based on a technical calculation on the basis of a number of assumptions.

The activity rate is updated by the CBS regularly, and can be classified under category B. In general, we can conclude that the emission factors are based on a limited number of measurements of several years ago, which have been extrapolated to the present based on certain assumptions. The current estimate takes into account the effects of measures in progress.

The use of quantity of lubricant collected for assessment of the emission factor produces a more precise picture than factors such as the amount of consumed or sold lubricant. Unknown factors are aspects such as quantities of foreign products used in the Netherlands and amounts of products that are used as propeller shaft lubricant, but not specifically produced for that purpose, or products produced as propeller shaft lubricant but not specifically used for that purpose.
This means that we can classify the emission factors in category C.

As far as the distribution of emissions among individual compartments and emission pathways is concerned, it is clear that all the emissions directly enter the surface water, so category A applies here. Finally, the spatial allocation of emissions is ultimately fairly reliable, so the reliability classification is B.

Element of emission calculation	Reliability class
Activity rates	B
Emission factors	C
Distribution among compartments	A
Emission pathways to water	A
Spatial allocation	B

The main areas where improvements could be made are:
- More elaborate inventory of lubricants (other substances) used;
- Periodic monitoring of current loss rates;
- The percentage of closed propeller shafts (table 2) has probably been on the high side in recent years. In a subsequent updated emission inventory, new estimates for this percentage could be made.

12 Request for reactions

Any questions or comments on this working document should be addressed to: Richard van Hoorn, Centre for Water Management, +31 (0)320-298491, email richard.van.hoorn@rws.nl or Joost van den Roovaart, Deltares, +31 (0)6-57315874, email joost.vandenroovaart@deltares.nl.

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