



Lubricants based on renewable resources – an environmentally compatible alternative to mineral oil products

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Abstract

The development of lubricants like, e.g. engine and hydraulic oils was traditionally based on mineral oil as a base fluid. This fact is related to the good technical properties and the reasonable price of mineral oils. The Report to the Club of Rome (W.W. Behrens III, D.H. Meadows, D.I. Meadows, J. Randers, The limits of growth, A Report to the Club of Rome, 1972) and the two oil crises of 1979 and 1983, however, elucidated that mineral oil is on principle a limited resource. In addition, environmental problems associated with the production and use of chemicals and the limited capacity of nature to tolerate pollution became obvious (G.H. Brundtland, et al., in: Hauff, Volker (Ed.), World Commission on Environment and Development (WCED), Report of the Brundtland-Commission, Oxford, UK, 1987), and the critical discussion included besides acid rain, smog, heavy metals, and pesticides also mineral oil (especially oil spills like the case Exxon Valdes). A disadvantage of mineral oil is its poor biodegradability and thus its potential for long-term pollution of the environment. From the early development of lubricants for special applications (e.g. turbojet engine oils) it was known, that fatty acid polyol esters have comparable or even better technical properties than mineral oil. Subsequently, innumerable synthetic esters have been synthesized by systematic variation of the fatty acid and the alcohol components. Whereas the alcohol moiety of the synthetic esters are usually of petrochemical origin, the fatty acids are almost exclusively based on renewable resources. The physico-chemical properties of oleochemical esters can cover the complete spectrum of technical requirements for the development of high-performance industrial oils and lubricants (e.g. excellent lubricating properties, good heat stability, high viscosity index, low volatility and superior shear stability). For a comprehensive review of their technical properties see F. Bongardt, in: Jahrbuch für Praktiker, H. Ziolkowsky (Ed.), Verlag für chemische Industrie GmbH, 1996, pp. 348–361. This article will focus on the ecological properties of oleochemical (synthetic) esters. The environmental relevance of oleochemicals in comparison to petrochemicals is discussed, and then the principles of an ecological assessment are described. The ecotoxicological properties and the biodegradability of oleochemical esters are presented. Finally, the ecological properties of the oleochemical esters are discussed with regard to existing environmental classification and labeling systems. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Biodegradation; Ecotoxicity; Environmental classification; Oleochemicals; Petrochemicals; Renewable resources; Sustainability

1. Market situation for oleochemical lubricants in Germany

The total market for lubricants in Germany is about 1 million t per year (1998). By far the biggest market segment are engine and gear oils for automotive with about 450 000 t/a. The second biggest market segment are hydraulic oils with about 150 000 t/a, and about

400 000 t/a oils and fats are used for other industrial applications like grease and metal working fluids. The market share of lubricants that are (mainly) derived from renewable resources is only 2.5%, i.e. 25 000 t/a (Heine). From a positive point of view this means that bioproducts still have an enormous market potential. However, reality looks different. Although the bioproducts are available on the market since at least five

years, they have struggled from the beginning to compete with the well-established mineral oil-based products for two reasons. The first reason is their image as “trouble makers”. This is because in the early days mineral oils were simply substituted by bioproducts without taking into account their special properties (Peschke, 1993). This led to a couple of highly recognized damages on hydraulic equipment, because either the fluids (namely the triglycerides) were not suited to cope with the pertaining frame conditions (higher temperatures, moisture content), or because the fluids were not compatible with the washer materials built in. These early problems, however, have been overcome and today for almost all applications a suitable oleochemical lubricant can be found (Völtz, 1995). The second and most severe reason is the higher price of oleochemical lubricants. Compared to mineral oil-based products oleochemical base fluids are 2–5-fold more expensive (Wallis). The higher price of oleochemical esters is caused by the costly multi-step synthesis of these chemicals and, thus, is inevitable. For lubricants that are derived from renewable resources to compete with mineral oil-based products, there must be other advantages besides price and technical performance and these are their superior ecological properties.

2. Sustainability of the use of chemicals

The sustainability of the use of chemicals (and raw materials in general) can be divided in two aspects. The

first aspect regards the origin of the resources. Mineral oil is a fossil raw material. It was formed million years ago from ancient forests when the plant biomass became covered by sediments. Under conditions of high pressure and elevated temperatures the biomass then very slowly was converted to bitumen and mineral oil (Follmann, 1981). This process took thousands of years. Therefore, the deposits of mineral oil can in no way be replenished on the same time-scale as they are used up. Although the original scenario of the Club of Rome from 1985 had turned out to have been over-pessimistic, mineral oil is a finite resource. In addition, the availability of mineral oil is highly dependent on political considerations. Therefore, even existing deposits do not guarantee that mineral oil will be available to us in the future, at least not at the current price. Synthetic esters on the other hand are (mainly) derived from animal fats and plant oils as raw materials, and are thus renewable raw materials par excellence. The second aspect regards the pollution of our natural environment associated with the use and discharge of chemicals. This aspect can be divided in two sub-aspects: direct and indirect pollution. In Fig. 1 the lifecycle of oleochemicals is shown. In the first enzymatically catalyzed reaction, the organic carbon leading to the oleochemicals is synthesized in the leaves of green plants via the photosynthetic assimilation of atmospheric carbon dioxide. A surplus of energy-rich organic molecules is stored in the plants as carbohydrates (starch) or as fat. Fats are esters of fatty acids with the trifunctional alcohol glycerol. The plant biomass then can either be directly used for the extraction of the tri-

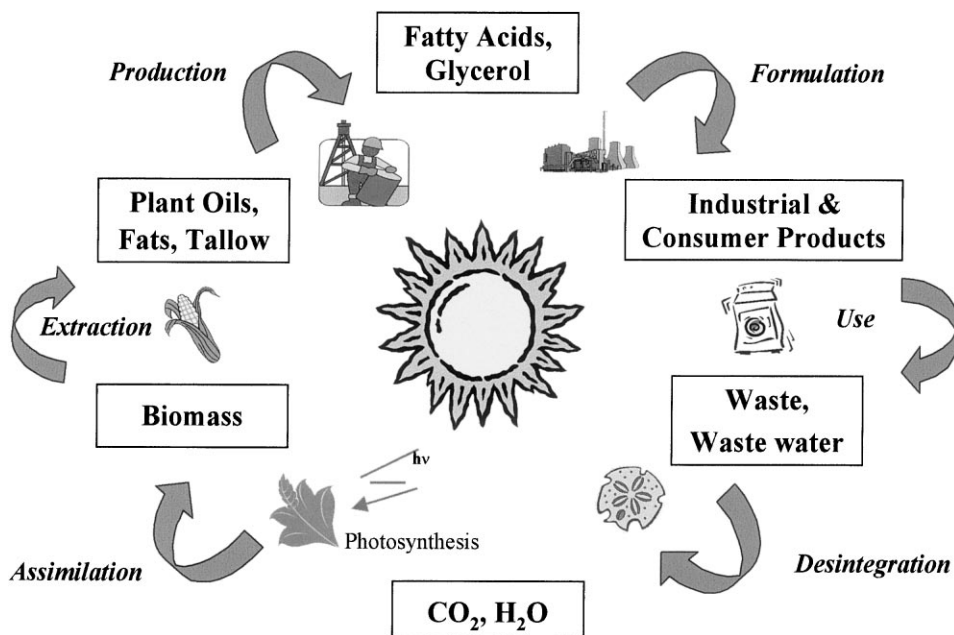


Fig. 1. Life cycle of chemical products based on renewable resources.

glycerols or, e.g. in case of carbohydrate-rich biomass, be used as a feedstock for cattle. The extracted triglycerols are then subjected to a fat-splitting reaction, where the ester bonds are hydrolytically cleaved. Reaction products are the free fatty acids and the alcohol glycerol. Both can either be used as such or can be further processed by means of oleochemical methods (Umbach, 1996). The fatty acids, for example, are usually reduced to the corresponding fatty alcohols, which are valuable raw materials, e.g. for the production of surface-active substances (surfactants). The resulting oleochemicals are then used as raw materials for the formulation of industrial (technical) or consumer products. After their use, the products are discharged, the majority via wastewater. A small fraction ends up in landfills, and an even smaller fraction of waste is energetically used (burned). Regardless of the pathway of discharge, at the end of their lifespan the organic chemicals are disintegrated into carbon dioxide and water, either by microorganisms present in wastewater treatment plants or in landfills, or by incineration. In the case of oleochemicals, the carbon dioxide liberated equals the amount of carbon dioxide that was originally taken up by the plants from the atmosphere. Thus, with regard to the carbon dioxide balance of the atmosphere oleochemicals in general and, with regard to the scope of this article, synthetic esters in special have zero effect. In contrary to oleochemicals the carbon cycle of petrochemicals is not closed, but open. Mineral oil-based products lead to an increase of atmospheric carbon dioxide and thus contribute to global warming. This effect is referred to as indirect or secondary environmental pollution. Direct or primary pollution of the environment is caused by the direct exposition of a chemical to the environment. In case of lubricants there are two different types of applications, i.e. open systems and closed systems (Table 1). In open systems the lubricant is used as a loss lubricant. Thus, over time the lubricant is quantitatively lost to the environment. Examples for open applications are given in Table 1. In closed systems the lubricant ideally is not exposed to the environment. However, in reality the situation is quite different. Using

the percentage of used lubricants that are yearly collected and recycled (60%), it can be estimated that about 40%, i.e. 400 000 t/a, end up annually in the environment (Schütte, 1999). Thus, lubricants are chemicals with high environmental relevance. Therefore, it is highly desirable that environmentally compatible lubricants should be used wherever possible.

3. Ecological assessment of chemicals – basic aspects

The intention of an ecological (risk)assessment is to answer the question, if the use of the substance under consideration is environmentally compatible or not. Therefore, any ecological assessment has to cover the following two aspects: the inherent ecotoxicological properties of a substance (hazard) and the environmental fate of the substance (exposure scenario). A comprehensive discussion of the systematics of an ecological safety assessment can be found in Steber (1995).

3.1. Ecotoxicity

Ecotoxicity data describe the toxic effects of chemicals towards organisms in the environment. Because it is not feasible to investigate all the different wildlife species in the laboratory, it has been generally agreed to evaluate the ecotoxicity of a substance by testing only certain standard species which represent the different levels of the natural food chain (Fig. 2). For the aquatic compartment the fish, daphnia, algae and bacteria are the most relevant test organisms, and standardized test methods, such as laid down, for example, in the OECD “Green pages”, i.e. OECD methods 201–210 (OECD, 1995), have been established for these end-points (Table 2). The ecotoxicological tests can be divided into two groups: acute tests investigate the effects of high concentrations of a chemical during a relatively short time of exposure (determination of lethality = LC_{50} -value or of other relevant effects = EC_{50} -value), whereas subchronic and chronic tests investigate long-term effects at sub-lethal concentrations (determination of the

Table 1
Exposure scenarios of direct pollution of the environment by lubricants

	Exposure to the environment	Area of use	Example
Open systems	Continuous “Loss lubrication”	Forestry	Power saw chain oils
		Traffic	Switch lubricants
		Construction	Slab oils
		Oil production	Drilling fluids
Closed systems	Only in case of accident “Blown pipe” “Leakage” “Human error”	Forestry	Hydraulic of harvesters
		Traffic	Engine, gear oils
		Construction	Hydraulic oils
		Metal industry	Metal working fluids

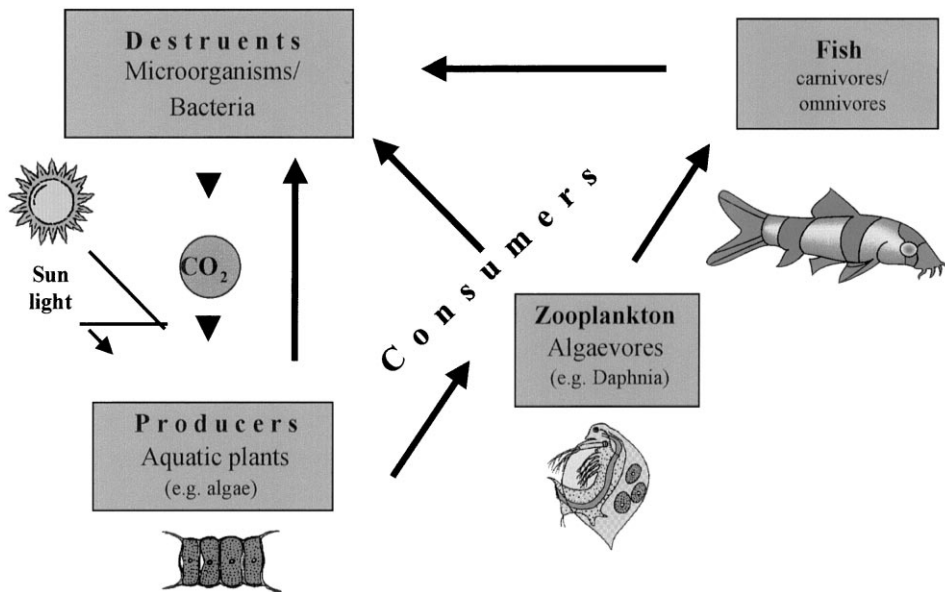


Fig. 2. The aquatic food chain and the representative lead organisms algae, daphnia, fish and bacteria.

Table 2
Internationally standardized ecotoxicological test methods

Test type	Test species	Test method
Acute tests (short-time effects, parameter: LC ₅₀ /EC ₅₀)	Algae (72 h)	OECD 201
	Daphnia (48 h)	OECD 202/1
	Fish (96 h)	OECD 203
	Bacteria (30 min)	OECD 209
Chronic tests (long-time effects, parameter: NOEC)	Daphnia (21 d)	OECD 202/2
	Fish (>4 w)	OECD 210

No Observed Effect Concentration = NOEC). The environmental classification of substances is usually based on data from acute tests. If a substance is readily biodegradable and acute test data do not indicate an increased ecotoxicity, there is generally no need to conduct the more costly chronic tests. On the other hand, for high volume chemicals that are foreseen to be quantitatively discharged into the wastewater (like, e.g. detergent components) determination of chronic data is necessary to conduct a reliable risk assessment.

3.2. Environmental fate

The most important aspect with regard to the environmental fate of a substance is its biodegradability. A comprehensive review can be found by (Gerike (1987)). Biodegradability means that a substance is susceptible to biochemical breakdown by the action of microorganisms (Fig. 3). The first breakdown step (i.e. the disappearance of the original molecule) is called primary degradation. Determination of primary degradability is

□ Primary degradation:

Substance A → B

(determination of the disappearance of the parent substance by substance (group)-specific analysis)

➤ **of relevance primarily for surfactants**

□ Total degradation (ultimate biodegradability):

Substance A → B → ... → CO₂ + H₂O (+ biomass)
(complete mineralisation of the organic material)

➤ **of relevance for all organic substances**

Fig. 3. Biodegradation: definition of the different types of determination methods.

of main relevance for surfactants due to specific legal requirements (detergent law). Of considerably more general importance is the determination of the ultimate degradability (mineralization) of substances to CO₂ and H₂O (and, at the same time, the formation of biomass). A very special test is the so-called CEC test, originally

Table 3
Internationally standardized test systems for the determination of the biodegradability of organic substances

Test type	Name of the test	Analytical parameter	Methods
OECD screening Tests	- DDAT	DOC	OECD 301 A
	- Sturm test	CO ₂	OECD 301 B
	- MITI test	DOC	OECD 301 C
	- Closed Bottle test	BOD/COD	OECD 301 D
	- MOST	DOC	OECD 301 E
	- Sapromat	BOD/COD	OECD 301 F
“Semi-official” screening test	- BODIS test	BOD/COD	ISO 10708
	- CO ₂ -headspace test	CO ₂	ISO 14593
Other test systems	- CEC test	Infrared spectrum	CEC L-33-T93

developed for two-stroke engine oils, because it does not clearly differentiate between primary and ultimate degradations (Battersby et al., 1992, 1999; Ablitt et al., 1994). Nowadays the CEC test is of relevance only for the German environmental label “Blauer Engel”, but will be replaced in the near future by tests for true ultimate biodegradability. Ultimate biodegradability guarantees the safe reintegration of the organic material in the natural carbon cycle. Simple but rather stringent standardized test methods have been established for the investigation of ultimate biodegradability (Table 3). They are laid down, for example, in the OECD “Yellow pages”, i.e. OECD methods 301 A-F (OECD, 1995), or ISO standard methods, e.g. ISO 10708 (biological oxygen demand for insoluble substances – BODIS test (Richterich et al., 1998)) and 14593 (CO₂-Headspace test (Battersby et al., 1999)). Substances that surpass in these tests the biodegradation limit values for “ready biodegradability” (i.e. 60% of CO₂-evolution or oxygen consumption (BOD/COD) or 70% removal of dissolved organic carbon (DOC), and fulfilling the 10-day time window criteria) are regarded as fast and ultimately biodegradable in the environment. The evaluation if a substance is readily biodegradable or not is very important for its environmental classification, and the determination of its water hazard class. For some applications, e.g. drilling fluids for off-shore oil production, degradability under anaerobic conditions, as encountered on the seafloor, is also highly desirable. In addition to the biodegradability, the bioaccumulation behavior (i.e. the potential of a chemical to concentrate in animal tissues) is important with regard to the evaluation of a possible long-lasting adverse impact to biota.¹ However, the ester linkage of the oleochemical esters is susceptible to enzymatic cleavage, and the lib-

erated natural fatty acid and alcohol components can be metabolized. Therefore, oleochemical esters are not expected to bioaccumulate in biota despite their log Pow² $\gg 3$.

3.3. Ecological risk assessment

Ecotoxicity as well as biodegradability tests determine the environmentally relevant substance-inherent properties of a chemical and do not include the aspect “exposure”. Thus, the fact that a substance is toxic to aquatic organisms or that it is poorly biodegradable does not mean per se that this substance actually exerts adverse effects to the environment. To address this question a risk assessment has to be conducted. A schematic view of the elements of an ecological risk assessment is shown in Table 4. Simply speaking, an ecological risk assessment compares the predicted environmental concentration (PEC) of the chemical under consideration with the predicted ecotoxicological limit concentration (PNEC) that is expected to be tolerated even by the most sensitive aquatic organisms without adverse effects. If the quotient PEC/PNEC is lower than 1, the use of such a substance is considered to be environmentally compatible (Steber, 1995).

4. Testing of water-insoluble substances

The experimental investigation and the assessment of the ecological properties of water-insoluble substances (like most oleochemicals) are not trivial. However, the problems associated have been overlooked for a long time. Testing of poorly water-soluble substances re-

¹ biota = all living organisms, i.e. animals, plants and microorganisms.

² Pow = partition coefficient of a substance between an octanol and a water phase.

Table 4
Principal steps of an environmental risk assessment

Step	Environmental fate	Ecotoxicity
I. Substance-inherent properties (hazard assessment)	Determination of biodegradability e.g. by OECD 301 A-F	Evaluation of ecotoxicity under standardized laboratory conditions e.g. OECD 201-203
II. Environmental frame conditions	Exposure scenario Production volume Type of application Effluent disposal	Extrapolation of the laboratory data to the real environment Safety factors
III. Risk assessment	Assessment of exposure Predicted environmental concentration (PEC) Comparison : PEC vs. PNEC If PEC < PNEC, the use of a substance does not cause concern	Assessment of the ecotoxicological potential Predicted no effect concentration (PNEC)

quires special knowledge and experimental skills (Gerike, 1984). The first difficulty is to get the necessary information about the water solubility of a test substance. Usually water solubilities are not determined very precisely (e.g. in mg/l). Instead, verbal descriptions are given in the Safety Data Sheet like “insoluble” or “of low solubility”. Whereas the statement “insoluble” could still mean a solubility of 0.1% (i.e. of 1000 mg/l), determination of the real water solubility of substances described as “of low solubility” could yield values in the range <20 µg/l. Thus, if there is any uncertainty about the water solubility of a test substance it is advisable to determine this parameter experimentally or, in the case of degradation tests, determine at least the total organic carbon/dissolved organic carbon (TOC/DOC) ratio. Whereas it is rather trivial that degradation tests which are based analytically on the DOC-parameter are not suitable for the investigation of insoluble substances, the proper choice between the other available test systems is not easy. The situation is even more complicated with respect to ecotoxicity testing. Especially the determination of EC₅₀-values for algae and daphnia can be biased by insoluble portions of the test substance floating on the surface of the test media. If these small test organisms get to the surface, they can be physically trapped in the organic layer. This phenomenon is in fact hardly distinguishable from immobilization caused by systemic toxicity of the test substance. Thus, an overestimation of the toxicity may be the result. To avoid such misleading results industry and the German Environmental Protection Agency (UBA) have agreed on a special test protocol for water-insoluble substances (Steinhäuser, 1992). It is based on testing of water accommodated fractions (WAF) (Willing, 1999). WAFs are prepared by stirring the test substance for at least 24 h in water, and subsequently removing the insoluble portions by an appropriate method, e.g. by filtration. If it has been shown that WAFs up to a loading of 100 mg/l are not

toxic, an EC₅₀ > 100 mg/l can be used for environmental classification. However, with regard to WGK 0 it has to be shown that even up to a loading of 10 000 mg/l the resulting WAF is not toxic.

5. Ecological properties of lubricants from oleochemical esters³

5.1. Aquatic toxicity

The structure of oleochemical esters is characterized by one or more carbon ester bonds in the molecule and by alkyl chains originating from oils and fats, i.e. the energy storage molecules of plants and animals. A typical animal fat is tallow (less common, fish oil). Plant oils are produced mainly from coconuts, palm and palm kernel, rape seeds, soybeans and sunflowers. Due to their biochemical synthesis the corresponding fatty acids and their derivatives (e.g. the fatty alcohols) have even numbered, linear alkyl chains that range from 8 to 22 carbon atoms (C₈–C₂₂). The specific structure of their alkyl chains determines to a great extent the physico-chemical as well as the ecological properties of the oleochemical esters. Almost all synthetic esters have a rather low water solubility, i.e. <<1 mg/l. Therefore, their ecotoxicity is usually determined with water accommodated fractions. Because of their great economic

³ Abbreviations: BOD = biological oxygen demand, BODIS = biological oxygen demand (test) for insoluble substances, COD = chemical oxygen demand, DDAT = DOC die away test, DOC = dissolved organic carbon, MITI = Japanese Ministry of International Trade and Industry, MOST = modified OECD screening test, OECD = Organization for Economic Cooperation and Development.

Table 5
Comparison of the aquatic toxicity of typical lubricants from renewable resources with mineral oil

Type of lubricant	Substance (example)	Fish-toxicity (LC ₅₀) (mg/l)	Daphnia-toxicity (EC ₅₀)	Bacteria-toxicity (EC ₀) (mg/l)
Native ester	Glycerol-trioleate	10.000	≫Water-solubility ^a	10.000
Synthetic ester	2-Ethylhexylcocoate	10.000	≫Water-solubility ^a	10.000
Synthetic ester	Trimethylolpropane-trioleate	5.500	>1.000 mg/l	10.000
Mineral oil	C ₁₁ –C ₂₁ n-Alkane	500	>1.000 mg/l	>1.000

^a Water accommodated fractions (WAF) of the substance were tested after removal of insoluble material.

Table 6
Comparison of the aerobic and anaerobic biodegradability of typical lubricants from renewable resources with mineral oil

Type of lubricant	Substance (example)	Aerobic biodegradability (%)	Anaerobic biodegradability (%)
Native ester	Glycerol-trioleate	100	86 ^a
Synthetic ester	2-Ethylhexylcocoate	95	77 ^a
Synthetic ester	Trimethylolpropane-trioleate	86	75 ^a
Mineral oil	C ₁₁ –C ₂₁ -alkane	23–63 ^b	Not degradable under anaerobic conditions

^a Formation of CH₄ + CO₂ after 42 days in the ECETOC test.

^b 10d-window or even limit value for ready biodegradability not fulfilled.

importance which is due to their excellent technical performance, the ecological properties of these substances have been extensively investigated (Willing, 1999) (i.e. data for additional aquatic species like algae and/or chronic toxicity studies are available too (IUC-LID; Hall et al., in preparation)). Against the usual test organisms (fish, daphnia and bacteria) the synthetic esters are only scarcely or not toxic (LC/EC₅₀-values in the range of 1000–10 000 mg/l), certainly due to their very low water solubility (Table 5). If the ecotoxicity of mineral oil is compared with the ecotoxicity of the synthetic esters, it shows that mineral oil has slightly less favorable ecotoxicological properties.

5.2. Biodegradability

In the 301 A-F OECD tests for ready biodegradability (OECD, 1995), or comparable stringent ISO tests (e.g. the BODIS-test, ISO 10708 (Richterich et al., 1998)), oleochemical esters exhibit high degradation rates, generally exceeding the pass level for ready biodegradability (Willing, 1999) (Table 6). This result might be a surprise for those expecting poor biodegradability of such insoluble substances. Although degradation of water insoluble substances is, compared to homogeneously distributed soluble substances, certainly rendered more difficult due to the limited bioavailability of the test substance, these results show that biodegradability is mainly determined by the chemical structure and less by the water solubility. Mineral oils are degraded under these conditions to only 20–60% BOD/COD.

Taking into consideration that the classification as readily biodegradable according to the OECD definition requires the fulfillment of an additional kinetic criteria, i.e. the so-called 10-day window (Fig. 4), mineral oils cannot be regarded as readily biodegradable (The 10d-window requires that the degradation pass level, e.g. 60% BOD/COD, is reached within 10 days after the onset of degradation. The onset of degradation is defined as 10% degradation.). In addition to their excellent aerobic biodegradability, lubricants based on renewable resources are easily biodegradable under anaerobic conditions, whereas mineral oils are not (Herold et al., 1995).

% degradation (BOD/COD)

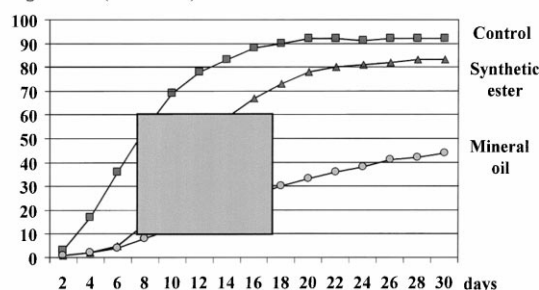


Fig. 4. Ultimate biodegradability: OECD criteria for ready biodegradability in the tests OECD 301 A-F. The duration of the OECD screening tests is 28 days. The limit value of 60% (CO₂ resp. BOD/COR) or 70% (DOC) must be reached within 10 days after the onset of the degradation reaction.

6. Environmental classification and labeling of oleochemical esters

6.1. Dangerous for the environment

Whereas the EU Dangerous Preparation Directive requires for many years to indicate dangerous toxicological (e.g. X_i , irritating) and physico-chemical (e.g. F, flammable) properties of substances on the package, a corresponding environmental labeling was not required until 1994. However, since May 1994 chemical substances (raw materials, but not formulations) have to be environmentally classified in Germany on the basis of their aquatic toxicity (fish, daphnia and algae), their biodegradability and their bioaccumulation potential (Commission Directive, 1992). Substances classified as dangerous for the environment have to be labeled with *N*, and the pictogram “dead fish, dead tree”. However, oleochemical esters are not “dangerous for the environment” due to their low aquatic toxicity (LC/EC_{50} -values $\gg 100$ mg/l), their ready biodegradability and their low bioaccumulation potential. With regard to the EU Dangerous Substance Directive no classification and labeling are required.

6.2. Water hazard class

In 1986, as a result of a great fire in a Sandoz storage facility, large amounts of chemicals were flushed into the river Rhine by the fire fighting measures and caused a tremendous fish-dying (“Fischsterben”). To avoid such environmental disasters in the future it is required that all chemical products (raw materials and formulations) produced or marketed in Germany are to be classified in the so-called water hazard classes (WGK) depending on their water endangering properties (Steinhäuser, 1996). The criteria on how to classify the water endangering properties are laid down in the specific German regulation the Verwaltungsvorschrift wassergefährdender Stoffe (VwVwS) (Bundesministerium und Naturschutz, 1999). This classification has to be stated in Chapter 15 of the EU Safety Data Sheet, and it gives an indication

of the possible environmental impact that may result in case of a spill or an accident. Depending on the WGK classification, more or less severe (costly) precautionary measures are required for handling and storage facilities. Because the original VwVwS had several drawbacks (rather complex regulation, inherent uncertainties, e.g. when to give a Bonus/Malus and, most importantly, it is considered as a trade barrier by other countries), in May 1999 the WGK-classification scheme has been put on a new basis in as far as the classification now is based on the risk phrases (“R-Sätze”) of the Dangerous Substance Directive (the national German legislation is the “Gefahrstoffverordnung”). This harmonization with the EU-classification makes the scheme easier to use, more transparent, and opens the possibility for other countries to adopt this scheme, too. Due to the drop of the former WGK 0 the new scheme has only three water hazard classes, i.e. WGK 1 (weakly water endangering), WGK 2 (water endangering), and WGK 3 (strongly water endangering). In addition, substances that do not have any water endangering potential are regarded as not water endangering (NWG). NWG are regarded as the only substances that are not water soluble, that do not have any dangerous properties (R-phrases) and that are readily biodegradable. It is the responsibility of the producer or importer of a chemical to determine the WGK according to the new scheme. The proper classification including the underlying data set (identity of the substance, R-phases, etc.) has to be submitted to the authorities, i.e. to the Kommission zur Bewertung wassergefährdender Stoffe (KBwS). The KBwS then publishes the WGK classification on its home page in the internet (www.umweltbundesamt.de/wgs/wgs-index.htm). For formulations (which are not published in the internet) the WGK usually is calculated on the basis of the WKGs of their components according to the mixing rule (“Mischungsregel”). However, the new VwVwS now has opened the possibility for a classification of formulations based on a direct experimental determination of the relevant ecotoxicological properties of the formulation. In such cases the classification has to be approved by the KBwS.

Table 7

Comparison of the ecological properties and the classification of lubricants from renewable resources with mineral oil-based lubricants (base fluids without additives)

	Lubricants from renewable resources	Lubricants based on mineral oil
Biodegradability (aerobic)	+	o
Anaerobic biodegradability	+	–
Ecotoxicity	+	+
Environmental classification (EU)	Not necessary	Not necessary
Water hazard class (Germany)	Not water polluting (nwg)	Weakly water polluting (WGK 1)
Compatible with ecolables (e.g. Blue Angel)		No

6.3. Ecolabels

Whereas the EU environmental classification scheme has the intention to indicate dangerous properties, ecolabels work just the opposite way. They indicate to the consumer that a certain product is, from an ecological point of view, better than others. Ideally, as a consequence of an increased consumer demand for these “greener” products, the whole market will shift to more environmentally compatible products. In the application field of lubricants there are two ecolabels that are of general importance. The first to mention is the German “Blauer Engel” which is issued for biodegradable hydraulic fluids, biodegradable loss lubricants and slab oils and biodegradable power saw chain lubricants (Deutsches Institut für Gütesicherung und Kennzeichnung e.V., 1998). Secondly, there is the Swedish “Clean Lubricants” label, also for hydraulic oils. Both labels require that the base oils are readily biodegradable, and that the products, i.e. base oils plus additives, are not harmful for aquatic organisms. In addition, the “Clean Lubricants” label requires for products to be classified in the best category, that the products originate – at least partly – from renewable resources. Oleochemical esters in general fulfill the requirements of these ecolabels, whereas mineral oil does not. However, the additives necessary to achieve the required technical performance are often the limiting components.

7. Conclusion

Due to the increasing market relevance of environmental labeled products, the ecological properties of oleochemical esters have been intensively studied within the last couple of years. In general, their aquatic toxicity is very low or almost negligible and they are in most cases readily biodegradable (Table 7). They are not to be labeled as “Dangerous for the environment” according to the EU Dangerous Substance Directive. Their origin from renewable resources results in the protection of the natural resources of the earth, and in lower net CO₂-emissions (“global warming”) compared to petrochemical products. Not many other lubricants have such a rather positive ecological profile. Thus, most of them are classified in the most favorable German water hazard classes, i.e. in WGK 1 or even as not water polluting (NWG). In addition, they fulfill the requirements of several European environmental labels, e.g. the “Blauer Engel”. These favorable ecological properties together with their well-established technical performance recommend the oleochemical esters as suitable base oils for the development of high performance “green” oil and lubricant products.

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