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Assessment of properties and life cycle of biosynthetic oil

Aistė Feiferytė, M.Sc. degree [a], Jolanta Dvarionienė [a,*], Milda Gumbytė [b]

[a] Institute of Environmental Engineering, Kaunas University of Technology, Donelaičio str. 20, 44239 Kaunas, Lithuania
[b] Institute of Environment and Ecology, Aleksandras Stulginskis University, Studentu 11, Akademija, LT-53361 Kaunas, Lithuania

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ABSTRACT

This article contains the analysis of the possibilities of biosynthetic oils selection scheme. The properties of the newly produced biosynthetic oils (enzymatic production method) and their impact on the environment were analyzed. The assessment of the life cycle was made and the results obtained with biosynthetic oils (chemical production method) and mineral oils were compared.

For the process of oleic acid esterification with 1.2-propanediol, the following biocatalysts were applied: Lipolase 100 L, Lipex 100 L, Resinase A, Lipozyme TL IM, Novozym 435 and Lipozyme RM IM. The analysis of biotechnological esterification indicated that the enzyme preparation Lipolase 100L was the most effective during the esterification reaction. The following optimal conditions of 1.2-propanediol oleate during biotechnological production were determined: the molar ratio of oleic acid and 1.2-propanediol – 1:3.72, the amount of Lipolase 100L–1.84% (of oleic acid quantity), temperature – 33 °C, duration – 4 h. The obtained lubricant 1.2-propanediol oleate was characterized by a low coefficient of friction. The results obtained after the completion of the life cycle assessment in accordance with the methodologies of Environmental Design of Industrial Products 2003 and Impact 2002+ indicated that enzymatic production of 1 ton of biosynthetic oils (using 1.2-propanediol, oleic acid and biological catalyst), 1.2-propanediol oleate causes the least impact on the environment in the categories of global warming, ozone layer depletion, eutrophication, acidification, etc., in comparison with biosynthetic oils (when the amounts of raw materials of methanol, rapeseed oil, trimethylolpropane and catalyst NaOH are used) of trimethylolpropane oleate and mineral oils.

1. Introduction

The accelerating pace of globalization, growing economy and expanding production have a direct impact on the increasing use of natural resources and the extent of environmental pollution. Recently, the increasing environment pollution with traditional lubricants has become a serious problem in the environmental protection. The annual global market share of lubricants is equal to approximately 37–40 million metric tons (12% of this market share consist of synthetic lubricants), the majority of which (50%) enter the environment (Rudnick, 2013; www.freedoniagroup.com).

In order to reduce the negative impact on the environment and human health, it is appropriate to replace synthetic lubricants by biological lubricants that are produced on the basis of green products (based on canola, sunflower, soy oils) and animal products (fish, wool – lanolin). The increasing environmental requirements and the growing concern of the society and authorities have led to a search of alternatives in lubricant production. Vegetable oils and animal fats could replace the lubricants produced on the basis of minerals (Menezes et al., 2012). Biological lubricants produced on the basis of green and animal products are characterized by rapid biodegradability, low toxicity on humans and the environment, moreover, the oil can be easily recycled. However, the lubricants produced on the basis of biological products are not thermally stable, they are characterized by low oxidative, hydrolytic stability, their quality depending on the harvest, therefore their usage is limited (Sharma and Dalai, 2013).

Production of biosynthetic oils may be a promising activity aimed at reducing the environmental pollution and the increased energy consumption. The biotechnological production process, when chemical catalysts are replaced with biocatalysts (lipases), allows us to obtain a simplified technology of lubricant production. Production of biosynthetic oils, when biotechnological methods are applied, takes place in the organic environment, and the synthesis

* Corresponding author. Tel.: +370 37 300767; fax: +370 37 209372.
E-mail addresses: aiste.feiferyte@stud.ktu.lt (A. Feiferytė), jolanta.dvarioniene@ktu.lt (J. Dvarionienė), milda.gumbyte@asu.lt (M. Gumbytė).

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List of abbreviations

LCA	Life Cycle Assessment
CFC-11	Trichlorofluoromethane
NPG	Neopentyl glycol
PE	Pentaerythritol
TMP	Trimethylolpropane
SAE	Society of Automotive Engineers
EDIP	Environmental Design of Industrial Products
KOH	Potassium hydroxide
NaOH	Sodium hydroxide
CO_2	Carbon dioxide
PO_4	Phosphate
P-lim	Phosphorus limited factor
SO_2	Sulfur dioxide
C_2H_3	ClVinyl chloride
1.2- PO	1.2-propanediol oleate
CFC-11	Trichlorofluoromethane
N	Nitrogen
FU	Functional unit
RSM	Response Surface Methodology
Eq	Equivalent
CTU	Comparative Toxicity Unit

of esters is carried out by using catalysed lipases. Synthetic esters are derived from alcohol and acids (monocarboxylic, dicarboxylic, polycarbonic) (Šinkūnienė, 2014).

Scientists claim that the esterification reaction depends on the type of alcohol, mole alcohol and the ratio of acids and fats, the sort and amount of a catalyst, the duration and the temperature of the reaction (Gumbytė, 2011; Sivakumar et al., 2011). In the article "Bio-oil Valorization: a Review", Jacobson et al. (2013) state that esterification reaction is used as an effective way to replace an unwanted acid found in biolubricant with an ester. Meanwhile, a catalyst is used for increasing the speed and productivity of the reaction (Sivakumar et al., 2011; Jacobson et al., 2013).

According to Bornadel (2013), the following esters can be used for esterification reactions: 1.2-propanediol, neopentyl glycol (NPG), pentaerythritol (PE), trimethylolpropane (TMP), isopropanol, oleyl alcohol, 2.3-butanediol and other alcohols (Yao, 2009). The most commonly used fatty acids found in the part of synthetic ester are those that are derived from green (rapeseed, soybean, sunflower, corn, etc.) and animal products (animal fats and tallow). Thanks to their natural lubricating properties, these acids perfectly separate lubricated surfaces and protect them against intensive friction (Kupčinskas, 2013). Therefore, the lubricant obtained is characterized by better lubricating properties, lower attrition, solidification temperature, biodegradation, good viscosity and resistance to aging when compared with mineral oil (Bornadel, 2013; Nagendramma et al., 2012).

When seeking to develop more efficient environmental performance measures, researchers have looked for solutions during a biosynthetic oil study by taking into account the environmental impact during the product life cycle, i.e., by applying a life cycle approach. Ekman and Börjesson (2011) performed a life cycle assessment according to standards ISO 14040:2006 and ISO 14044:2006. They assessed a life cycle of synthetic ester-based trimethylolpropane oleate and mineral-based oils. The results of the study revealed that in case of mineral-based oils, the consumption of primary energy quantity was 27 MJ/m^3, while in case of trimethylolpropane oleate – 16 MJ/m^3. It confirms that production costs of bio-synthetic oil are lower. The analysis also demonstrated that mineral oil has a higher impact on global warming potential than bio-synthetic oil, in particular during the production and waste management stages (Ekman and Börjesson, 2011).

The particular information reveals that 90% of existing lubricants can be replaced with biolubricants (Florea et al., 2004). Some European countries (Germany, France, Austria) have taken the lead in making substantial efforts in the field of biological lubricant production (Chowdhury et al., 2013). 100,000 tons of biological lubricants were produced in Europe in 2011: half of this amount, i.e. 50,000 tons, were produced in Germany, 23,000 tons were produced in Scandinavian countries, and 1000 tons in France (Guillot, 2011). Germany and Scandinavian countries are the major consumers of biolubricants (Petran et al., 2008). It is forecasted that in the nearest future gross consumption of biological lubricants in Europe will increase and 240,000 tons will be produced in 2014, especially if states will support their production (Jose, 2012). It is believed that development of biosynthetic oil production based on the biotechnological method, practical application of foreign scientists' projects and research are the factors that will lead to the replacement of the products derived from oil with biolubricants in the future (Menezes et al., 2012).

The present analysis aims at studying the possibilities of using biosynthetic oil materials 1.2-propanediol and oleic acid and forming a technological scheme. It also analyzes the properties of the newly produced biosynthetic oil (enzymatic production method) and its impact on the environment. The assessment of the life cycle shall be performed and the results obtained shall be compared with biosynthetic oils (chemical production method) and mineral oil.

2. Methods

2.1. Materials

The following materials were used for the processes of esterification reactions of 1.2-propanediol and oleic acid:

- Oleic acid (analytically pure, Ekros);
- 1.2-propanediol 99% (Acros Organics, Belgium);
- 0.1 N KOH (fixanal);
- Ethanol (>96.3%, Joint stock company "Stumbras", Lithuania);
- Ether (Sigma–Aldrich, USA);
- Phenolphthalein (Sigma–Aldrich).

During the esterification processes the following lipases acquired from the private company „Biopolis" were used as biocatalysts:

- Lipolase 100L (lipase derived from Thermomyces lanuginosus, produced by Danish company Novozymes A/S);
- Lipex 100 L; (lipase derived from Thermomyces lanuginosus, produced by Danish company Novozymes A/S);
- Resinase A; (derived from Candida rugosa, produced by Danish company Novozymes A/S);
- Lipozyme TL IM (lipase derived from Thermomyces lanuginosus, produced by Danish company Novozymes A/S);
- Novozym 435 (lipase derived from Candida antarctica, produced by Danish company Novozymes A/S);
- Lipozyme RM IM (lipase derived from Rhizomucor miehei, produced by Danish company Novozymes A/S).

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