RESEARCH ON LUBRICATION PROPERTIES OF SELECTED RAW PLANT AND ANIMAL MATERIALS

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Abstract. The article presents the results of research on lubrication properties of rapeseed oil, methyl esters of rapeseed oil, as well as esters with goose fat. Rapeseed oil has a better lubrication properties in relation to methyl esters of rapeseed oil. Addition of goose fat to esters negatively affected their lubrication properties. The presented results confirm a relationship between the degree of unsaturated and lubricated properties. Among the tested compounds with oxygen groups (COOH, COOCH₃, C = O), the oleic acid (with a COOH group) characterised the best lubricity. The fat goose, which contains the least amount of unsaturated fatty acid esters, proved to be ineffective addition lubricity between the factor lubricants analysis.

Keywords: biodiesel, rapeseed oil, methyl esters of the fatty acids of rapeseed oil, lubricity, wear testing.

Notations

C – carbon;
C16:0 – 16 carbon atoms and 0 double bond between carbon atoms;
C18:0 – 18 carbon atoms and 0 double bond between carbon atoms;
C18:1 – 18 carbon atoms and 1 double bond between carbon atoms;
C18:2 – 18 carbon atoms and 2 double bond between carbon atoms;
C18:3 – 18 carbon atoms and 3 double bond between carbon atoms;
COOH – carboxyl group;
DMC – dimethyl carbonate;
H – hydrogen;
HFRR – high frequency reciprocating rig;
KOH – potassium hydroxide (caustic potash);
O – oxygen;
OH – hydroxyl group;
RME – rapeseed oil methyl esters.

Introduction

The availability of adequate amount of conventional fossil fuel for internal combustion engines and the associated effects of global warming and other environmental issues arising due to the combustion of fossil fuels are the two most threatening problems of our present civilization (Datta, Mandal 2016). The fossil fuels are finite resources and their mass consumption has significant impacts on our environment and society (Sugami et al. 2016). Automotive sector has a big impact on the natural environment (Marczuk et al. 2015). Energy intensity of the vehicle can be determined on the basis of a driving simulation based on driving cycles for fuel consumption and harmful emissions measuring (Barta, Mruezek 2014). A growing awareness of the impoverishment of the fossil fuels has lead to an intensive search for renewable fuels (Gustavsson et al. 2012). Scientists from different corners of the world are making sincere attempts to find out the suitable alternative fuels (Datta, Mandal 2016; Sugami et al. 2016; Kobus et al. 2015; Mickevičius et al. 2014; Myczko, Golimowska 2011; Szlachta 2002; Nazimek et al. 2015) and can be found many researches of engine operational conditions (Barta, Mruezek 2014; Figlus, Liščák 2014; Drożdziel, Krzywonos 2009; Macián et al. 2016; Mikulski et al. 2016; Panneer Selvam, Vadivel 2012; Lin, Li 2009) and diagnostics (Figlus 2015; Glowacz 2010, 2015; Jedliński et al. 2015; Armas et al. 2013).

The article presents the results of the tests of rapeseed oil lubricity, RME and RME with addition of goose fat.
1. Biofuels for diesel engines

Selection of raw material for the production of biofuels depends mainly on the geographical region. This can be edible and nonedible vegetable oils, produced from rapeseed, soybean, sunflower seed, rice bran, tobacco, cotton, as well as animal fats and waste fats (Myczko, Golimowska 2011). The first place in the world in production takes soybean oil, obtained in a moderate climate and palm oil, obtained in hot climate. In Poland, the main raw material for the production of biofuels is rapeseed oil (Szlachta 2002).

Using inedible material and fat material considered to be waste raises no controversy on unethical applications of food sources, but makes it possible to, at least partially, satisfy the demand for renewable energy, thus enabling environmentally friendly disposal of material that is considered to be a waste product (Macián et al. 2016). Most authors (Sugami et al. 2016; Kobus et al. 2015; Mickevičius et al. 2014; Szlachta 2002; Zdziennicka et al. 2015), focus on the use of biofuels of plant origin. Studies on the use of fuels of animal origin are significantly less frequent (Mikulski et al. 2016; Panneer Selvam, Vadivel 2012; Lin, Li 2009; Armas et al. 2013; Sakthivel et al. 2014; Barrios et al. 2014; Öner, Altun 2009; Behçet 2011).

Poland is, along with Hungary, in the leading position in breeding goose in Europe. About 24 thousand tons of goose meat is produced per year, of which approximately 93% is exported. 100 g of goose meat contains 32 g of fat, i.e. per year in Poland is produced about 7680 tons of goose fat (Szczepańska-Piszcz 2010). Poultry fat is a production waste in meat industry. This is a low-cost raw material, usually not used in food and non-food products (Kostecka 2008).

Of the biodiesel, vegetable oils canola oil is especially frequently used (Zdziennicka et al. 2015). Vegetable oils and animal fats are composed primarily of triglycerides, which by the chemical nature are esters of fatty acids and glycerol. One glycerol molecule is connected with three, most often different ones, chains of the fatty acids (Myczko, Golimowska 2011), containing from 14 to 24 carbon atoms. Between carbon atoms is a different number of double bonds, focusing on the extent saturated fatty acids. The greater the number of double bonds in fatty acid, the greater the inastiability of acid. In a natural rapeseed oil is about 95...98% of the triglycerides, which are dominated by esters of unsaturated: oleic, linoleic and linolenic acids (Szlachta 2002). Goose fat contains little amount of saturated acids compared to mammals fat (Kostecka, Kowalski 2002). Goose fat contains little amount of saturated acids compared to mammals fat (Kostecka, Kowalski 2002).

During the rapeseed oil transesterification occurs rebuilding of triglycerides, i.e. molecules of methanol (ethanol or butanol) create along with fatty acid residue molecules fatty acid methyl esters molecules of rapeseed oil, and glycerol (Szlachta 2002). However, free fatty acids react with alkalis, and the resulting soap and water are removed during purification of esters (Myczko, Golimowska 2011).

An alternative for methanol in transesterification process is DMC, which may solve the problem of the large amount of glycerol resulting in this process (Sun et al. 2014).

Triglycerides of vegetable oils and animal fats contain functional group C = O. At the end of the hydrocarbon chain of the free fatty acid there is COOH, while in the ester of the free fatty acid is COOCH3.

In research by Knothe and Steidley (2005) is described lubricity test, carried out with the friction apparatus HFRR and using oxygenates, containing 10 carbon atoms. The following order of oxygen groups was received, increasing lubrication properties: COOH > CHO > OH > COOCH3 > C = O > C-O-C. Fuel with a low lubricity with the addition of free fatty acids has been also examined, receiving a significant improvement of lubricity, which is confirmed by previous studies (Kajdas, Majzner 2001a, 2001b; Kensey, Ecker 2003). Biodiesel from castor oil increases the lubricity due to the presence of contaminants as free fatty acids or glycerol, which have been observed to behave as lubricity imparting moieties (Agarwal et al. 2013; Knothe 2005; Cvengroš et al. 2006; Meneghetti et al. 2006a, 2006b; Scholz, Da Silva 2008; Canoira et al. 2010).

Initial correlation between the degree of unsaturation and lubricity was presented by Geller and Goodrum (2004). Examined fatty acid methyl esters, ester of stearic acid (C18:0), ester of oleic acid (C18:1), ester of linoleic acid (C18:2) and linolenic acid ester (C18:3) show improvement of lubricity, together with the increase of unsaturation, i.e. the number of double bonds between carbon atoms. Therefore, among the tested esters, the ester of stearic acid in the smallest extent affected such properties, meanwhile the ester of linolenic acid effectively improved lubricity.

Liquid film occurs very often in industrial applications with thicknesses that may range from below 10 μm to above 5 mm (Cui et al. 2014). Engine tribology has been always an important subject of study in the automotive industry (Macián et al. 2016). Some tribological components in automotive engines operate in direct contact with the fuel, under severe conditions (Gustavsson et al. 2012). This includes fuel system, injection pumps and plungers.

2. Materials and methods

The tests have been carried out on the test bench, as described in detail in the research by Gardyński (2005) and shown in Figure 1.

They based on simultaneous abrading of three samples in the form of cone bearing rollers (diameter ∅ = 5 mm) on a rotating flat counter sample in form of a longitudinal bearing race, in conditions of lubrication by lubrication
factor at temperature of 333 K, pressure of 29.43 kN and total path of friction approximately $2 \times 10^4$ m. The lubricating agent, in quantities of 30 dm³ circulated in the closed circuit and was filtered, and temperature stabilized. The lubricity was evaluated by loss of mass and surface of samples and by the coefficient of friction.

Rapeseed oil, RME and RME with goose fat were tested. The share of fatty acids in selected vegetable oils and goose fat is shown in Table 1, the acid numbers are shown in Table 2.

### 3. Results and discussion

Figure 2 shows macroscopic images of footprint area of cooperation of friction samples while lubricating by use of rapeseed oil, RME and RME with goose fat.

The smallest footprint area of cooperation was observed for samples lubricated with rapeseed oil. For samples lubricated with RME was found larger footprint area of cooperation, while the footprint area of cooperation of samples after conducted lubrication with RME with goose fat is the largest, which is confirmed by quantitative results of lubricity factors of tested agents presented in Figure 3, as well as described in research by Gardyński and Kaldonek (2013).

Quantitative results of research RME and RME with goose fat are in Figure 3.

Addition of goose fat to methyl esters of rapeseed oil has resulted in an increase in mass loss of samples and the footprint area of cooperation and its equivalent diameter, when using this lubricant.

The previous studies described in research by Gardyński and Kaldonek (2013), indicate that the best lubrication properties of tested vegetable oils had soybean oil, i.e. oil containing the largest number of unsaturated acid esters, which is in line with earlier dependence.

As far as the tests outlined in research by Kiernicki et al. (2007), the addition of oleic acid – CH$_3$(CH$_2$)$_7$CH=CH(CH$_2$)$_7$COOH, i.e. acid containing one double bond between carbon atoms and the COOH to methyl esters of rapeseed oil contributes positively to their lubrication properties.

Acid number of vegetable oil is higher than the acid number of methyl esters of rapeseed oil. According to sequence of oxygen groups, the COOH strongly affects the lubrication properties. For the lubrication properties of the methyl esters is mainly responsible group COOCH$_3$, while group C = O, i.e. triglycerides group of vegetable oils and animal fats occurs in further place of the listed sequence.

![Figure 1. The test bench to determine lubrication and resistance of materials to wear: 1 – the shield of friction node; 2 – the base and the drive of friction machine; 3 – measuring system of the friction moment; 4 – weighing arm; 5 – temperature stabilization system of the tested lubricant; 6 – circulation system and lubricant filtration (Gardyński 2005)](image-url)

![Figure 2. Macroscopic images of footprint area of cooperation of friction samples while lubricating by use of rapeseed oil, RME and RME with goose fat.](image-url)

### Table 1. The content of the fatty acids in vegetable oils (Baczewski, Kaldoński 2008) and goose fat [\% of mass]

| The name of oil | C18:1 oleic acid | C18:2 linoleic acid | C18:3 linolenic acid | C16:0 palmitic acid | C18:0 stearic acid |
|----------------|------------------|--------------------|---------------------|-------------------|------------------|
| Rapeseed oil   | 60...73          | 19...22            | 9...10              | 2...4.8           | 1.2...2          |
| Soybean oil    | 22...34          | 53...60            | 2...10, 8***        | 7...11            | 2.1...6          |
| Sunflower oil  | 17...18, 22***   | 71...74, 66***     | 0.5                 | 6...7             | 2.9...4          |
| Corn oil       | 30...50, 28***   | 34...56, 58***     | 1.0                 | 11...12           | 1.5...4          |
| Peanut oil     | 48...48.5        | 32...34            | 0.9...1.0           | 11...14           | 2...2.4          |
| Rice oil       | 42.5             | 39.1               | 1.1                 | 5                 | 1.9              |
| Goose fat      | 52.9             | 11.2               | 0.54                | 23.3              | 8                |

Sources: *Śliwki robaczywki (2013); **Pomianowski and Dajnowiec (2009); ***Szlachta (2002).
Addition of goose fat to methyl esters of rapeseed oil, i.e. fat containing more than 30% of saturated esters, and therefore less unsaturated acid esters in relation to vegetable oils, affected negatively the lubrication properties of esters. Despite the higher number of goose fat than acid number of methyl esters of rapeseed oil, the increased consumption of samples lubricated with fuel containing this additive was observed. The content of esters of saturated acids in goose fat and the presence of C = O responsible for lubricity had a decisive influence on the results of the tests.

Conclusions
Based on the results of tests carried out the following conclusions were drawn:
- the obtained results of the studies are in accordance with the presented, reported in the literature sequence of oxygen groups improving lubricity;
- the content of esters of saturated acids negatively affects the lubrication properties of goose fat, which reduces the possibility of implementation of this post-production waste in test form in biofuels;
- further attempts to use goose fat as a component of a biofuels should be carried out on the processed material with an increased participation of unsaturated fatty acids in relation to saturated ones.

Figure 2. The image of friction samples in lubrication conditions:

a – using rapeseed oil; b – RME; c – RME with goose fat (dark area represents a track of cooperation)

Figure 3. The results of the lubricants features of RME with goose fat: a – mass loss of samples; b – the footprint area of cooperation; c – the diameter of an equivalent wheel; d – the average value of coefficient of friction
Contribution
Leszek Gardyński was responsible for the concept of the article and study, supervised all stages of the study, participated in possession of the materials, collection and interpretation of data, and writing the manuscript.
Jolanta Kaldonек provided the test bench and interpretation of data, supervised all stages of the study and writing the manuscript.
Both authors have read and approved the manuscript.

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