The Multiple Criteria Assessment on the selected vegetable oils for the lubricating engine

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Abstract. Vegetable oils are considered to be an alternative and environmentally friendly resource of lubricants. Suitable for almost all industrial applications. They are obtained from natural raw materials, which are renewable and non-toxic to humans, living organisms, and the environment. Chemically, green oils are triacylglycerols with varying fatty acids compositions depending on the plant or seed, the crop, the growing conditions and the season, etc. The conducted research concerning matching the proper of type of vegetable oil to lubrication of the engine. The main objectives of engine oil have been drawn to the attention. To project of assessment has selected four roles of engine oil: lubrication, cooling, corrosion protection, and others (including oxidative stability, ash content, saponification value, and foam property). Each objective is described by a couple of detailed parameters of lubricants (for example viscosity index, coefficient of friction, wear scar diameter, pour point, cloud point, melting point, smoke point, flash point, iodine value, thermal conductivity, specific heat capacity, density, water content, acid number, anti-corrosion properties, etc.). In the evaluation process, AHP (Analytic Hierarchy Process) methods were used to determine the weights of individual criteria. Everything creates multiple criteria assessment of green oil. As a result of the multi-criteria assessment, most high scores have soybean oil, linseed oil, cottonseed oil, and olive.

1 Introduction

Lubricating oils are commonly used in automotive, industrial, process, and marine applications. In order to reduce consumption of energy by means of minimizing friction and wear of moving surfaces, cooling of elements, and extend the service life of mechanical devices [1]. In general, lubricants are composed of base oils and adjusted additives. Currently, a lot of bases are mineral oils derived from crude oil. However, the crude reserve is depleting and the environmental concern about the damaging impact of mineral oil is growing. There is a diligent demand for promising alternatives for mineral base stocks, which may be vegetable oils [2].

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The use of lubricants derived from natural raw (seeds, plants) has been in practice for many years. However, this idea was neglected due to the discovery of the aforementioned crude oil and the availability of low-cost mineral oils. Green oils are a quite good solution for commercial lubricants, since they retain a lot of technical properties of mineral oils.

The most important attributes of natural lubricants are non-toxicity, non-mutagenic, biodegradability. They have good lubricity properties, high lubricity index, and high flash point, etc. [3,4].

They are recommended for lubrication of the engine: soybean, olive, and coconut oil [1,5]. However, there is no broad explanation for such choices. This paper used multi-criteria assessment to select the best green oil from 9 popular in Poland types of bio-oils (rapeseed oil, castor oil, soybean oil, sunflower oil, linseed oil, palm oil coconut oil, and olive). On the basis of the main roles of lubricants in the engine, and selected 24 detailed parameters.

2 Vegetable oil

The vegetable oils are called green oils, natural oils, bio-oils, plant oils, or natural esters [6]. Bio-lubricant is defined as a lubricant obtained from natural raw materials, which are renewable and non-toxic for humans, living organisms, and environment. From a technical point of view, natural esters display very good physicochemical properties, such as high viscosity indexes and flash points as well as good resistance to shear [1].

Chemically, plant oils are completely different from commercial mineral or synthetic oils. The major element of plant oils (approximately 98%) is triacylglycerols with varying fatty acids composition depending on the plant or seed, the crop, the growing conditions and the season, etc. The rest components of green oils are diacylglycerols, monoacylglycerols, fatty acids, sterols, and tocopherols. Most of these minor elements are deleted in processing, and some are valuable by products [4,7].

The variety of plant oils allows them to be used in different industrial applications, including as biofuels, transmission fluids, metal casting, printing, inks, paints, coatings, disinfectants, greases, hydraulic fluids, etc.In table 1 shows the selected popular type of green oils with possible industrial applications.

Table 1. Selected vegetable oils developed for industry applications [1,5].

No.	Type of oil	Application
1.	Rapeseed oil	Chain saw bar lubricants, air compressor-farm equipment, greases, hydraulic fluids
2.	Castor oil	Gear lubricants, greases
3.	Soybean oil	Engine oils, transmission fluids, biodiesel fuel, metal casting/working, printing inks, paints, coatings, disinfectants, plasticisers, hydraulic oils
4.	Sunflower oil	Greases, diesel fuelsubstitutes
5.	Linseed oil	Coating, paints, lacquers, varnishes, Stains
6.	Palm oil	Rolling lubricant,-steel industry, grease
7.	Coconut oil	Engine oils, Gas engine oils
8.	Cottonseed oil	Bio fuels

9.	Olive	Engine oils, Automotive lubricants

According to the authors of the cited table 1 [1,5] for engine applications, the best choice may be soybean, olive, coconut oil. However, there is no broad explanation for such choices. In the next part of the paper, the multiple criteria assessment of vegetable oils is based on the most important objectives of engine oil.

However, the use of green oil to make lubricants is problematic, since most connect with the food chain, thereby causing speculation regarding the costs of natural oils and producing social imbalances and strong growth prices [1].

3 ENGINE OIL

Lubricating oil plays a key role in engines by diminishing friction and wear of moving pieces, inhibiting corrosion of the engine system, improving sealing, and cooling the engine [8]. In engine systems, lubricants must operate under variable pressure and temperature conditions and have to be stable to prolonged exposure to contaminating acids, which can cause progressive deterioration of the lubricant [1,9].

In general, a good lubricant should have high viscosity index (VI), high flash point, low pour point, high oxidation, and thermal stability, etc., as shown in Fig. 1.

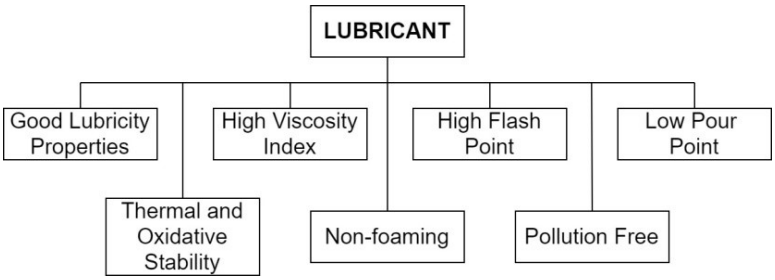

Fig. 1. Properties of good engine oil.

Listed in figure 1, the properties of good engine oil have been divided into 4 main objectives that motor oil should fulfill:

1. Lubrication,
2. Cooling,
3. Corrosion protection,
4. Other (incl. oxidation stability, resistance to foaming, contents of pollutants, etc.).

4 MULTIPLECRITERIA ASSESMENT OF VEGATABEL OIL

According to the division presented in point 3, criteria have been designed on the basis of which selected engine oils will be assessed (table 2). Each of the functions has been assigned appropriate detailed parameters that characterize the selected roles. In the evaluation process, AHP (Analytic Hierarchy Process) methods were used to determine the weights of individual criteria [10].

Table 2. The criterion weight for individual objectives.

No.	**Objective**	**Criterion Weight by AHP**

1.	Lubrication	0,5068
2.	Cooling	0,2641
3.	Corrosion Protection	0,1428
4.	Others	0,0863

4.1 Lubrication

The basic role of engine oil is to lubricate the surface of engine moving parts, which are in friction. It thus reduces friction, which tends to increase wear and tear of engine elements. In order to evaluate this role have been used: viscosity index, viscosity at 40 and 100 degrees Celsius, coefficient of friction, wear scar diameter, pour point, cloud point, melting point, smoke point, flash point, and iodine value (table 3).

Table 3. The criterion weight for parameters describing lubricating properties.

No.	Parameter	Unit	Criterion Weight by AHP	Comment
1.	Viscosity index (VI)	-	0,2555	Viscosity is the most important property of oil.It defined as the resistance of oil to flow. The possible range of VI [1]: VI < 35 – low, 35 < VI < 80 – medium, 80 < VI < 110 – high, VI > 110 –very high.
2.	Viscosity at 40°C	cSt or mm^2/s or Pa*s	0,1390	
3.	Viscosity at 100°C	cSt or mm^2/s or Pa*s		
4.	Coefficient of friction	-	0,0961	The tribological properties of lubricants could be evaluated by a lot of values. However, the most popular are wear scar diameter and coefficient of friction, using a four-ball tester.
5.	Wear scar diameter	mm	0,0961	
6.	Pour point	°C or K	0,0465	The lubrication process has to take place in the entire operating temperature range of the engine, therefore it is important to determine the low (pour, cloud, and melting point) and high temperature (smoke and flash point) properties.
7.	Cloud point	°C or K	0,0465	
8.	Melting point	°C or K	0,0465	
9.	Smoke point	°C or K	0,0465	
10.	Flash point	°C or K	0,1994	
11.	Iodine value (IV)	gI/100g	0,027618	Indicator of the number of unsaturation in the triglyceride.This parameter gives an indication of green oil ability to dry in the presence of oxygen in the air. The possible range of IV [11]: IV < 110 – non-drying oil, 110 < IV < 150 – semi-drying oil, IV > 150 – drying oil.

4.2 Cooling

The energy is lost through combustion, and the friction between parts causes the engine temperature to rise. The lubrication provided by the engine oil helps to release the heat through the lubrication system. It supports the coolant, which only cools certain elements of the engine. The parameters describing the ability to cool are thermal conductivity, specific heat capacity, viscosity at the lowest known temperature, pour point, density (table 4).

Table 4. The criterion weight for parameters describing cooling properties.

No.	Parameter	Unit	Criterion Weight	Comment
12.	Thermalconductivity	W/m*K	0,1667	These values significantly affect the transfer of heat, which is crucial from the point of view of heat dissipation to the environment. Information on the viscosity at different temperatures (especially low). The high viscosity leads to a decrease in cooling efficiency.
13.	Specific heat capacity	J/kg*K	0,1667	
14.	Viscosity at lowest known temperature	cSt or mm^2/s or Pa*s	0,1667	
15.	Pour point	^oC or K	0,1667	
16.	Density	kg/m^3or g/cm^3	0,1667	High density enables use as a storage medium.

4.3 Corrosion Protection

Fuel combustion generates corrosive acid that can damage the metal surfaces in the engine. With the special additives added to lubricants, corrosion is delayed. Over time, and in contact with oxygen, engine oil may oxidize and no longer play its corrosion inhibiting role. In order to evaluate this role have been used: water content, acid number, anti-corrosion properties, iodine value (table 5).

Table 5. The criterion weight for parameters describing corrosion protection properties.

No.	Parameter	Unit	Criterion Weight	Comment
17.	Water content	% or ppm	0,2064	The presence of water can increase the oxidation rate. The water contained in the oils is considered a highly hazardous pollutant.
18.	Acid number	mg KOH/g	0,3642	The acidity makes bio-oil very corrosive and extremely severe at high temperature.
19.	Anti-corrosion properties	-	0,3642	The most popular (and easy) method to test this parameter is copper strip corrosion. The range of results test [12]: 1a, 1b – slight tarnish, 2a – 2e – moderate tarnish, 3a, 3b – dark tarnish, 4a – 4d – corrosion.
20.	Iodinevalue (IV)	gI/100g	0,0652	This parameter gives an indication of green oil ability to dry in the presence of oxygen in the air.

4.4 Others

This group listed four parameters. Surface tension, describing the ability to build foam. Next oxidation stability, ash content and saponification value – specific number for vegetable oils.

Table 6. The criterion weight for parameters describing others important properties of engine oils.

No.	Parameter	Unit	Criterion Weight	Comment
21.	Surface tension at 20°C	mN/m	0,2785	The high surface tension is responsible for the formation of foam [13].
22.	Ash content	% or ppm	0,1312	The presence of ash in oil can cause erosion, corrosion, and formation of hard deposits.
23.	Saponification value	mg KOH/g	0,0656	A higher value for a given oil specifies a larger amount of smaller molecular weight fatty acids [14].
24.	Oxidation stability, 110°C	h	0,5247	Oxidative stability depends on the vegetable oil composition and the conditions the sample is subjected to. Resulting in chemical, and physical properties changes [15].

5 ASSESSMENT OF THE SELECTED VEGETABLE OILS

In compliance with the criterion weights for four groups describing the main roles of lubricants in the engine, presented in point 4. Selected nine green oils (rapeseed oil, castor oil, soybean oil, sunflower oil, linseed oil, palm oil coconut oil, and olive) were evaluated. These green oils are popular and commonly used in Poland. Parameter values have been collected from many papers of other authors [1,7,9,13,16-24] and own research [4,6].

At the same time, it should be remembered that the main criterion for assessing individual oils is their performance in the context of the most important operating parameters, which should be the basis for their classification [25-41].

Based on the detailed calculations, the results for each objective are listed in table 7 and 8. The sum of the results from the 4 roles gives the overall score for the multiple criteria assessment. Analyzing the obtained scores, soybean oil has the best lubrication properties. Castor oil turned out to be top for cooling. Linseed oil will protect the engine from corrosion. Coconut oil is most appropriate in terms of oxidative stability and ash content.

Table 7. The finale calculation of multi-criteria assessment for rapeseed oil, castor oil, soybean oil and sunflower oil.

	Weight	Rapeseed oil		Castor oil		Soybean oil		Sunflower oil	
Lubrication	0,5068	4,3266	2	5,174	4	6,379	9	5,666	6
Cooling	0,2641	3,3336	3	6,167	9	3,834	5	3,000	2
Corrosion Protection	0,1428	6,1898	9	2,663	3	5,227	7	4,859	6
Others	0,0863	6,296	7	3,296	3	4,900	5	3,016	2
		3,695		**5,0915**		**7,31**		**4,5982**	

Table 8. The finale calculation of multi-criteria assessment for linseed oil, palm oil, coconut oil, cottonseed oil and olive.

	Weight	Linseed oil		Palm oil		Coconut oil		Cottonseed oil		Olive	
Lubrication	0,5068	5,497	5	4,400	3,000	3,677	1	6,360	8	5,673	7
Cooling	0,2641	6,167	9	2,000	1,000	5,167	7	3,500	4	5,000	5
Corrosion Protection	0,1428	5,244	8	2,522	2,000	3,744	5	3,636	4	1,495	1
Others	0,0863	3,753	4	5,427	6,000	7,360	9	2,525	1	6,491	8
		6,399		**2,588**		**3,85**		**5,768**		**5,701**	

According to the multi-criteria assessment of green oils (table 7 and table 8), soybean oil with a score of 7.31, the best will fulfill the function of engine oil. The second-place has a linseed oil with a score of 6.399. The last place was taken by two cottonseed oil and olive, with very similar results (5.768 and 5.701 respectively). The general scores of mentioned four green lubricants are marked with gray.

Palm oil received the lowest score, 2.588. Coconut oil (presented in table 1 as a possible solution for engine oil) could have obtained much better results, but a high pour point causes a strong reduction in the overall rating. The high value of the pour point is crucial for the engine starting in winter conditions.

6 CONCLUSION

The crude reserve is depleting and the environmental concern about the damaging impact of mineral oil is growing. There is a diligent demand for alternatives for mineral base stocks, which may be vegetable oils. There are many types of vegetable oils, and they differ in chemical composition. The question remains, which of these a lot of types will be the most suitable for engine lubrication.

The paper shows a multiple criteria assessment of selected popular green oils. This assessment paid attention to four main roles of engine oil, they are lubrication, cooling, corrosion protection, and others (including oxidative stability, ash content, saponification value, and foam property). The author's assessment contains 24 detailed parameters of oils. The based on the collected values of parameters from own and other authors' research. Evaluated nine popular oils: rapeseed oil, castor oil, soybean oil, sunflower oil, linseed oil, palm oil coconut oil, and olive.

As a result of multi-criteria assessment it turned out that the most high scores have soybean oil, linseed oil, cottonseed oil and olive. The soybean and olive oils were known as prospective engine oils. The quite good result of linseed and cottonseed oil is surprising. Moreover, they have inedible sources. It is important due to social imbalances involved with deficiencies of food.

Therefore, it is recommended a make wide own research usability this type of oils (linseed oil and cottonseed oil) to application for lubrication of the engine. It is also will allow to grade quality of prepared multi-criteria assessment.

This investigation is significant in the present context of increasing global environmental pollution and decreasing crude sources. The crucial benefits of green lubricants are their high

biodegradability, renewable resource, and low toxicity. On the other hand, they are more expensive than mineral oils and some of them have edible sources. However, it should be research conducted possibility of replace the traditional mineral oils with bio-based oil. Especially need to pay attention to two aspects, economy and ecology.

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