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# TOPSIS Multi-Criteria Decision Modeling Approach for Biolubricant Selection for Two-Stroke Petrol Engines

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**Abstract:** Exhaust pollutants from two-stroke petrol engines are a problem for the environment. Biolubricants are a new generation of renewable and eco-friendly vegetable-based lubricants, which have attracted a lot of attention in recent years. In this paper, the applicability of the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method to support the process of building the scoring system for selecting an appropriate two-stroke lubricant has been analyzed. For this purpose, biolubricants (TMP-triesters) based on castor oil, palm oil, and waste cooking oil were produced and then utilized in a 200 cc two-stroke gasoline engine to investigate their effects on its performance and exhaust emissions. The results obtained from the use of the entropy technique in the TOPSIS algorithm showed that palm oil-based lubricant took up the greatest distance from the Negative Ideal Solution (NIS) and was selected as the most optimal lubricant for these types of engines.

**Keywords:** two-stroke; biolubricant; technique for order of preference by similarity to ideal solution (TOPSIS); engine oil

## 1. Introduction

In the present century, internal combustion engines constitute a major portion of the crude oil resource consumption, and have become one of the largest consumers of energy. Therefore, it is necessary to pay attention to the methods of reducing the fuel consumption of these engines. Since about one third of the energy loss of internal combustion engines belongs to frictional losses, it is possible to easily perceive that the proper lubrication of different parts of the engine with the aim of friction decrease in its moving parts has a great impact on reducing energy losses and fuel consumption. Generally, engine oil is one of the vital fluids in engines and by lubricating different parts, it plays the role of blood in the body's circulatory system. On the other hand, unfortunately this important liquid also has a petroleum-based origin like the fuels used in the engine and depends upon the perishable and expensive oil resources meaning one cannot rely on them for long. In addition, millions of tons of lubricants are used and the resultant oils are spread in the natural environment and cause environmental pollution every year [1]. This is one issue, while the other independent issue is the environmental pollution that appears as a result of the mixed burning of the lubricants and engine fuels. Therefore, the production of lubricants through renewable and environmentally friendly resources such as vegetable oils has received unprecedented attention today. Vegetable oil-based lubricants, which are called biolubricants, do not pollute the environment due to their desired biodegradation in addition to their renewable nature because of their dependence on plant sources. Biolubricants, which are derived from the chemical modification of vegetable oils, are free of the disadvantages to vegetable oils such as high pour point and low oxidation stability, and they show great potential to replace petroleum-based lubricants [2]. Figure 1 shows the life cycle of biolubricants.

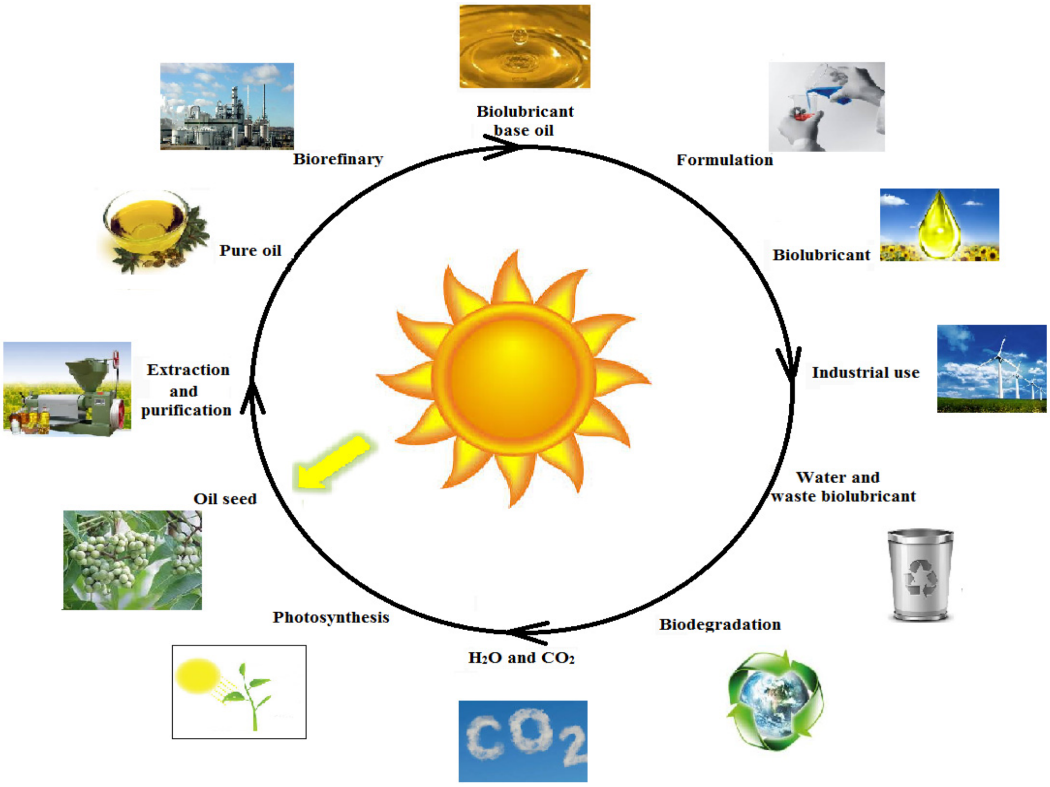



**Figure 1.** Biolubricants LCA.

A two-stroke engine is a type of internal combustion engine, which completes one engine cycle in each revolution of the crankshaft (two courses) and has the potential for the two-foldpower production of similar four-stroke engines. Four-stroke engines have replaced them in automobiles due to lower emissions, longer life, and lower fuel consumption [3]. However, these engines are still in demand because of their simple design, light weight, high power generation, good cold start behavior, and relatively low cost and are used as a well-known power source in two-wheel tractors, cut-tree motor saws, lawn mowers, small power generation engines, motor boats, motorcycles, *etc.* [3]. Since two-stroke engines do not have a closed crankcase like four-stroke engines, as they use the crankcase as part of the induction tract, oil must be mixed with the gasoline for distribution throughout the engine for lubrication (Figure 2). Therefore, in this type of engine, some petroleum-based engine oil is mixed with fuel (diesel and gasoline) for lubrication purposes and is then burned in the combustion process, which leads to an increase in exhaust emissions. These emissions cause the outbreak of a variety of human diseases such as respiratory diseases, eye irritation, cancer, poisoning, anemia, *etc.* in addition to harmful environmental effects such as acid rain, greenhouse effects, and damage to plants. This has led to growing concerns about toxic contaminants in two-stroke engines, which are being replaced by four-stroke engines due to the existing problems despite the doubled generation power and other benefits. There are over eight million motorcycles in Iran containing two-stroke-engines a main part.

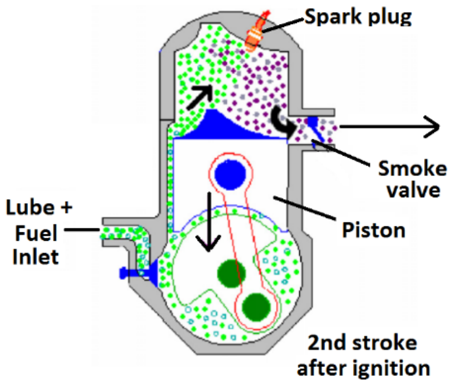



**Figure 2.** Lubrication with the help of the crank chamber in two-stroke engines and creation of smoke.

This issue requires proper scientific research and solutions. One of these solutions can be the use of vegetable-based lubricants or biolubricants instead of petroleum-based lubricants. To this end, some research has also been done on the impact of biolubricants on internal combustion engines across the world. Sivasankaran (1988) produced mixtures of two-stroke engine oil based on jojoba vegetable oil, and examined the chemical and physical characteristics, fatigue, and wear of engines, as well as the deposit formation in the engines. The results showed that the performance of jojoba vegetable oil in two-stroke petrol engines was equal to that in commercial engine oils [4]. Zhou and Ye (1998) tested two types of new two-stroke engine oil, in which oxygen-containing additives and catalysts had been used, on two-stroke engines of scooters and examined exhaust particles via a gas chromatography method. The results showed that the use of these two engine oils reduced exhaust particles of the scooter engines from 33 to 36 percent [5]. Singh (2011) produced two-stroke engine oil from castor plant oil through the epoxidation method and came to the conclusion that this engine oil reduced smoke by more than 50 percent and also decreased fuel consumption compared with mineral two-stroke engine oil [6]. The use of biolubricants in internal combustion engines has not been limited only to the engine oil and encompasses a wide range of vehicles. Figure 3 shows an overview of different applications of biolubricants in a car [7]. Studies show that there is no comprehensive study to investigate and compare different aspects of using biolubricants in two-stroke engines and to select the best choice between them using decision making methods. The present study is therefore focusing on this goal.

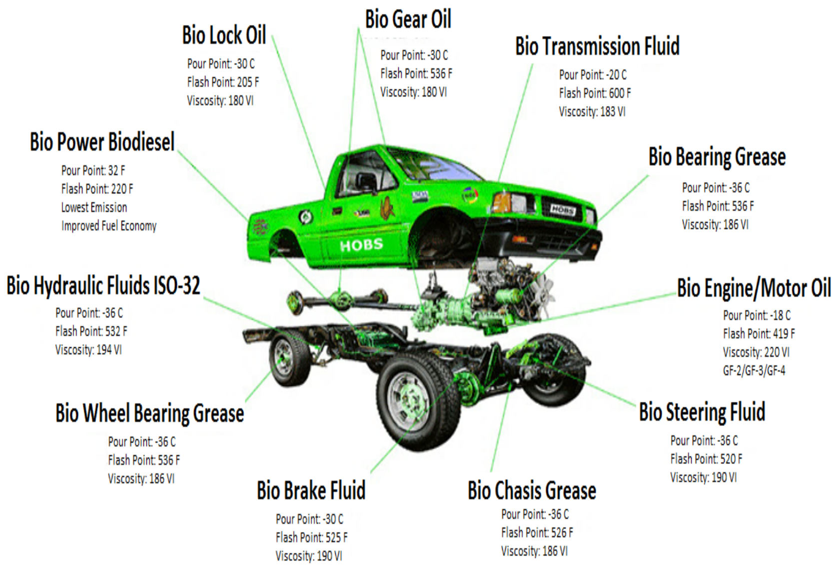



**Figure 3.** Different usages of biolubricants in various parts of a vehicle.

## 2. Materials and Methods

### 2.1. Test Setup

The biolubricants used in this study were produced out of castor oil (CO), palm oil (PO), and waste edible oil (WCO) via the transesterification method along with trimethylolpropane in renewable energy laboratories of Tarbiat Modares University (TMU). The process of biolubricant laboratory synthesis is shown in Figure 4. The produced biolubricants are depicted in Figure 5. The technical specifications of each produced biolubricant and the two-stroke engine oil that was used in this study as the control sample are shown in Table 1.

**Table 1.** Physical properties of the lubricants applied in the engine test.

| Details | Density at 15 °C | Viscosity index (VI) | Viscosity at 100 °C | Viscosity at 40 °C |
|---|---|---|---|---|
| Test Standard (ASTM) | D1298 | D2270 | D445 | D445 |
| Unit | gr/cm$^3$ | - | cSt | cSt |
| Two-stroke engine oil (2T) | 0.883 | 95 | 9 | 71.73 |
| Castor oil based Biolubricant (COB) | 0.953 | 82 | 8.67 | 75.82 |
| Palm oil based Biolubricant (POB) | 0.9058 | 390 | 4.90 | 12.67 |
| Waste cooking oil biolubricant (WCOB) | 0.8316 | 166 | 2.67 | 8.04 |

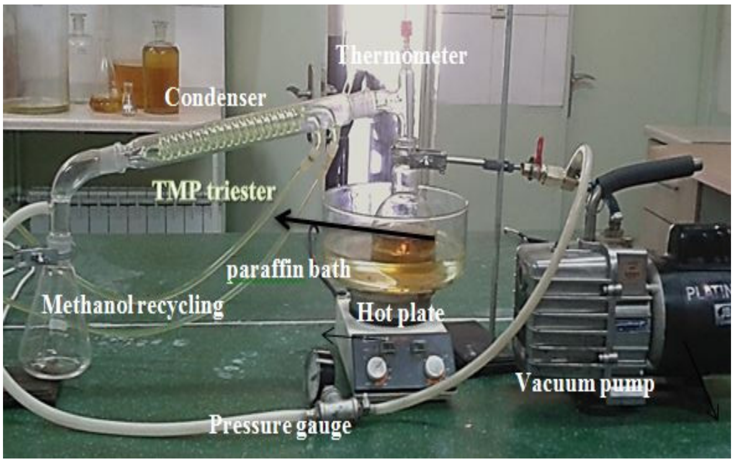



**Figure 4.** Biolubricant synthesis process by transesterification method.

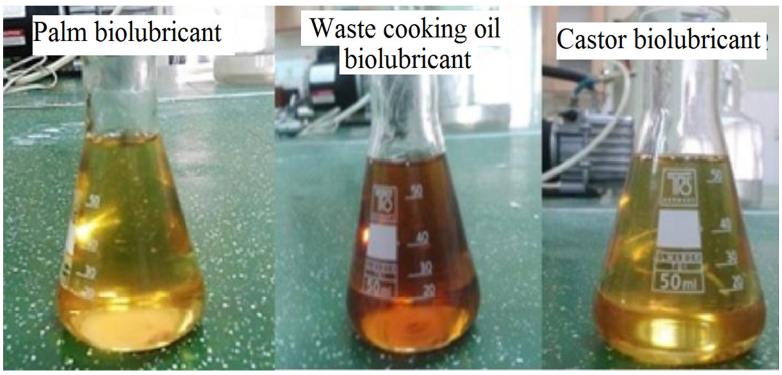



**Figure 5.** The biolubricants used in the engine test process.

The two-stroke engine tested in this study was a 200 cc Vespa motorcycle whose technical specifications are presented in Table 2.

**Table 2.** The two-stroke engine's technical specification.

| Engine Type | Two-Stroke Vespa with Three Orifices |
|---|---|
| Number of cylinders | Single-cylinder |
| Manufacturer | Niroomoharrekeh |
| Engine size | 200 cc |
| Cooling system | Air cooling |
| Lubrication system | Mixed with fuel |
| Ignition system | CDI |
| Motorcycle class | Scooter |

To measure the performance parameters of the engine, an eddy current dynamometer with the power of 15 kW was used (Figure 6). Similarly, in order to measure the brake specific fuel consumption (BSFC), a Flowtronic 205 fuel gauge system was applied. This equipment had been connected to an auxiliary fuel tank containing biolubricant and gasoline with the mixing ratio of 1:20 (5% biolubricant). This mixing ratio was selected in consultation with experts in the laboratory and from the standard range of gasoline and lubricant mixing ratio. Measurements of exhaust emissions from the engine exhaust were carried out by the exhaust emission analyzer MGT5 (Table 3).

**Table 3.** Technical specification of emission analyzer.

| Emissions | $NO_x$ | $O_2$ | HC | $CO_2$ | CO |
|---|---|---|---|---|---|
| Range | 0–5000 ppm | (0–25) Vol.% | 0–4000 ppm | (0–20) Vol.% | (0–15) Vol.% |
| Accuracy | 120 ppm | 0.1% | 10 ppm | 0.5% | 0.03% |
| Measurement Technique | Electrochemical | Electrochemical | Infrared | Infrared | Infrared |

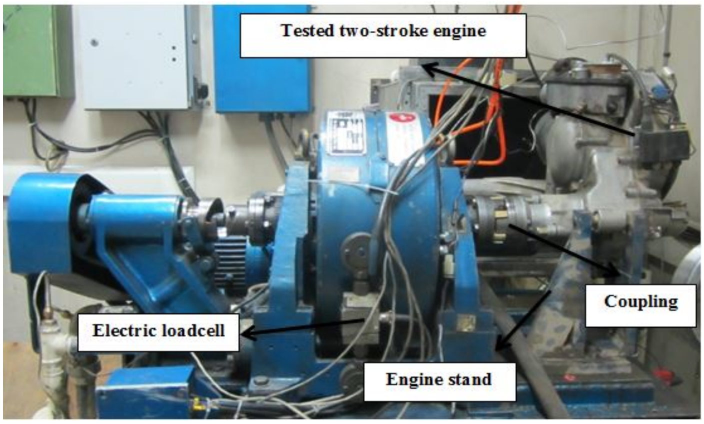



**Figure 6.** Engine test stand and the applied dynamometer.

The range of engine speeds was selected between 5000 and 7500 rpm, which were the maximum and minimum available engine speeds for stable working.

### 2.2. TOPSIS Method

One of the problems in evaluating the results of this research work was the difficulty in selecting the best alternative choice amongst the options due to the strength of some biolubricants in some parameters and their weakness in the other parameters. Therefore, the TOPSIS multi-criteria decision-making algorithm was used for choosing the best alternative from the available biolubricants. Decision making is the study of identifying and selecting alternatives based on the values and preferences of the decision maker. A decision making matrix is applied as one of the powerful tools for the decision making process, and is designed based on a rectangular array of elements, arranged in rows and columns [8].

TOPSIS (Technique for Order Preferences by Similarity to Ideal Solution) is one of the methods used for solving multiple criteria decisions or problems. The main idea of TOPSIS is to evaluate the alternatives by simultaneously measuring their distances to the Positive Ideal Solution (PIS) and to the Negative Ideal Solution (NIS). PIS is an alternative that is most preferred by the decision maker (DM), *i.e.*, maximizes the benefit criteria and minimizes the cost criteria, whereas NIS is the least preferred solution, *i.e.*, it maximizes the cost criteria and minimizes the benefits. The preference order is then built according to the relative closeness of the alternatives to PIS, which is a scalar criterion that combines these two distance measures. The traditional TOPSIS method assumes that the evaluation criteria, criteria weights, alternatives, and their resolution levels are precisely defined, namely that the problem is defined in the form of a decision matrix filled with crisp data. In other words, it requires the decision or problem to be well structured. The TOPSIS algorithm steps can be classified as follows [9–11]:

First step:

Change of the decision-making matrix into a dimensionless matrix by the following formula:

$$n_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^{m} r_{ij}^2}} \quad (1)$$

Second step:

Creation of a weighted dimensionless matrix with W vector assumed as an input to the algorithm. This means:

$W = \{W_1, W_2, ..., W_n\} \approx$ (assumed from DM)

$$\text{Dimensionless weighted matrix} = V = N_D \times W_{n\times n} = \begin{bmatrix} V_{11} & \cdots V_{1j} & V_{1n} \\ \vdots & \ddots & \vdots \\ V_{m1} & V_{mj} \cdots & V_{mn} \end{bmatrix} \quad (2)$$

$N_D$ is a matrix wherein the rates of the indices are dimensionless and comparable, and $W_{n\times n}$ is a diagonal matrix wherein only the elements of its original diameter will be non-zero.

Third step:

The positive ideal solution and the negative ideal solution are defined as follows:

$$\text{PIS} = \{ (\max V_{ij} \mid j \in J), (\min V_{ij} \mid j \in J') \mid i = 1,2,\ldots m\} = \{V_1^+, V_2^+, \ldots V_j^+, \ldots, V_n^+\} \quad (3)$$

$$\text{NIS} = \{ (\min V_{ij} \mid j \in J), (\max V_{ij} \mid j \in J') \mid i = 1,2,\ldots m\} = \{V_1^-, V_2^-, \ldots V_j^-, \ldots, V_n^-\} \quad (4)$$

Fourth step:

In this step the values of distances from PIS and NIS is calculated. The distance of the alternative from ideal solutions using the Euclidean method is as follows:

$$d_{i+} = \{ \sum_{j=1}^{n} (V_{ij} - V_j^+)^2 \}^{0.5} \; ; i = 1,2,\ldots..m \quad (5)$$

$$d_{i-} = \{ \sum_{j=1}^{n} (V_{ij} - V_j^-)^2 \}^{0.5} \; ; i = 1,2,\ldots..m \quad (6)$$

Fifth step:

Calculating the relative closeness to the ideal solution which is defined as follows:

$$\text{cl}_{i+} = \frac{di-}{((di+) + (di-))}; 0 \leqslant \text{cl}_{i+} \leqslant 1; \; i = 1,2,\ldots, m \quad (7)$$

It is observed that if $A_i$ = PIS, then $d_{i+}$ = 0 and $cl_{i+}$ = 1, but if $A_i$ = NIS, then $d_{i-}$ = 0 and $cl_{i+}$ = 0. Therefore, as the size of $A_i$ is closer to the PIS, the value of $cl_{i+}$ will be closer to 1.

Sixth step:

The available alternatives can be ranked based on the downside order of $cl_{i+}$.

Entropy Technique

In multi criteria decision-making problems, especially multi-index decision-making problems, the availability and knowledge of the relative weights of the existing indices is an effective step in the process of problem solving. Amongst the methods of determining the weights of indicators, one can refer to the use of experts' opinions, least squares, the eigenvector technique, Shannon entropy, *etc.* [8,12].

Entropy in information theory is expressed as a measure of the uncertainty by a discrete probability distribution (Pi), which is described as follows: (First, a value shown by the symbol E is calculated) (Equations (8) and (9)):

$$E=-K\sum_{i=1}^{n}\left[p_i \times Lnp_i\right] \tag{8}$$

$$E= -K\sum_{i=1}^{n}\left[p_i \times Lnp_i\right] = -K\left\{\left(Ln\frac{1}{n}\right)\left(\frac{n}{n}\right)\right\} = -kLn\frac{1}{n} \tag{9}$$

where k is a positive constant and 1 > E > 0 will be possible from the probability distribution of $P_i$, based on the statistical calculated mechanism, and its value will be at the maximum in case of the equality of $P_i$s. A decision-making matrix contains information that entropy can use as a criterion for evaluation. Table 4 shows the decision-making matrix.

**Table 4.** General Model of a decision-making matrix.

| | $X_1$ | $X_2$ | ... | $X_n$ |
|---|---|---|---|---|
| $A_1$ | $r_{11}$ | $r_{12}$ | ... | $r_{1n}$ |
| $A_2$ | $r_{21}$ | $r_{22}$ | ... | $r_{2n}$ |
| ... | ... | ... | ... | ... |
| ... | ... | ... | ... | ... |
| ... | ... | ... | ... | ... |
| $A_m$ | $r_{m1}$ | $r_{m2}$ | ... | $r_{mn}$ |

In the matrix 4, $A_i$s are the choices, which should be ranked. Also the alternatives are evaluated based on indices of $X_j$.

In this matrix, $r_{ij}$ is the value of each index proportional to each of the alternatives. The information content of this matrix is initially as $P_{ij}$ and the following formula holds true for $E_j$ from $P_{ij}$:

$$P_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}};\ \forall\ i,j \tag{10}$$

## 3. Results and Discussion

In the engine test procedure, the engine was set at the wide open throttle state (WOT) and the engine speed was varied from 5000 to 7500 rpm. As the engine starts to work and accede the stable status, each of lubricant tests commenced respectively by changing the peripheral fuel/lubricant mixture tank. Figures 7 and 8 show the average amounts of test variables related to both engine performance and exhaust emissions in different engine speeds.

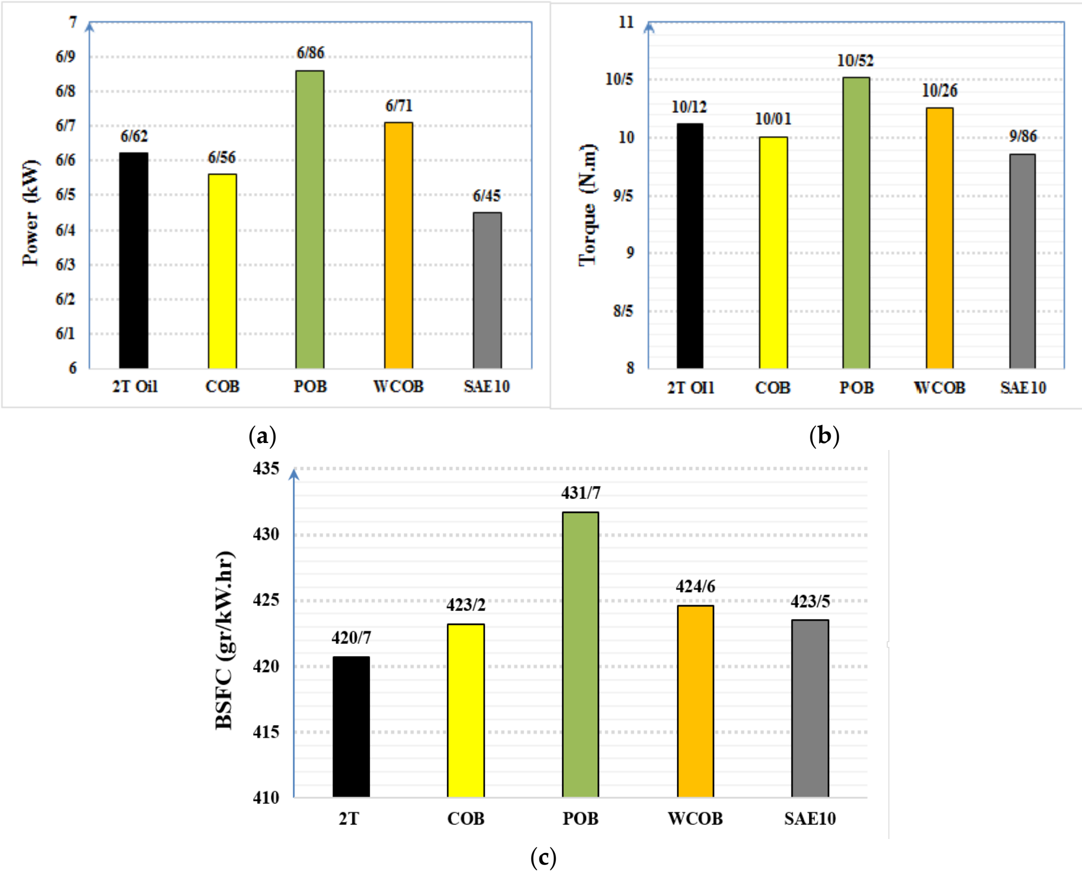



**Figure 7.** Mean values of engine performance test in different lubricant applications: (**a**) Brake power; (**b**) Torque; (**c**) BSFC.

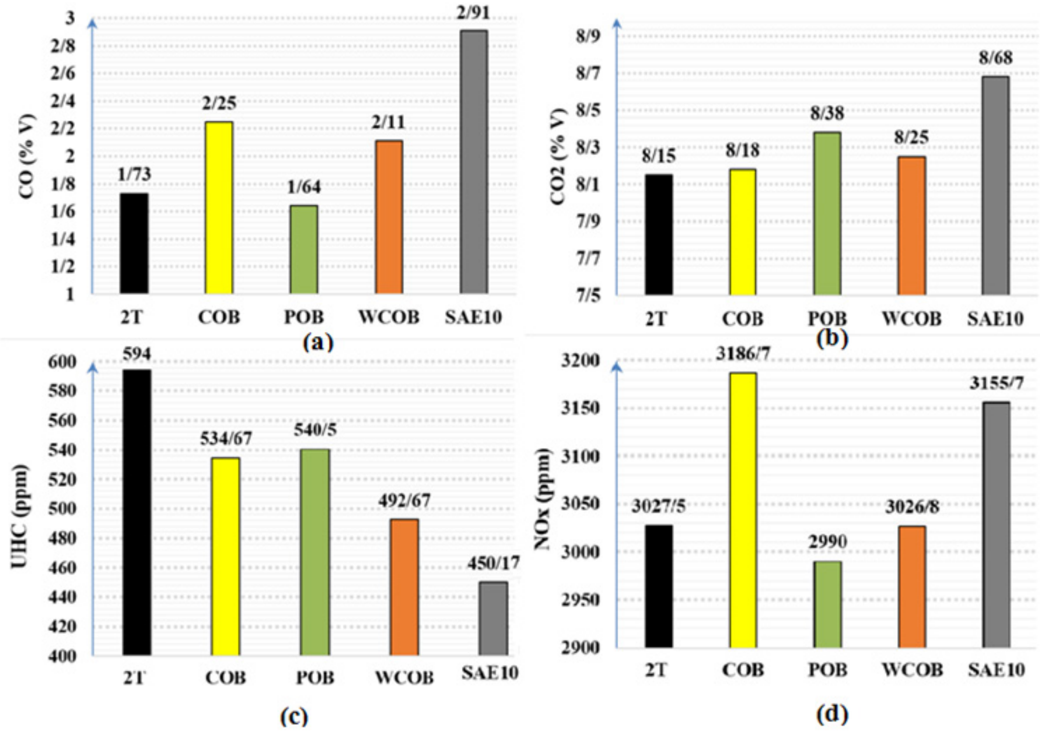
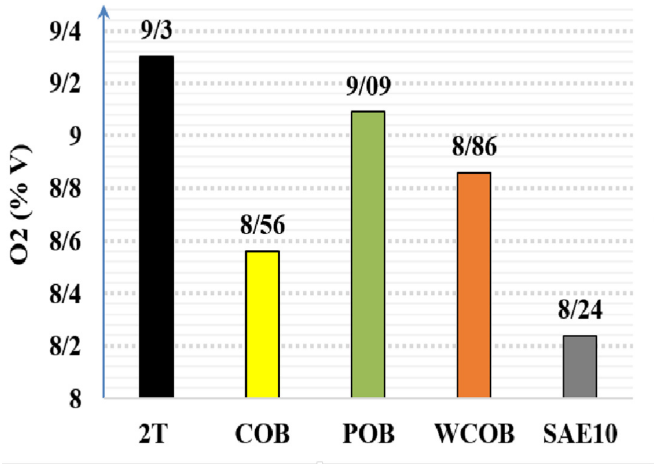



**Figure 8.** *Cont.*




(**e**)

**Figure 8.** Mean values of engine emissions tests in different lubricant applications: (**a**) CO; (**b**) $CO_2$; (**c**) UHC; (**d**) $NO_X$; (**e**) $O_2$.

As it can be seen from the above illustrations, there are both positive and negative points for each of lubricants which make it perplexing to judge between them and choose the ideal one. According to the above-mentioned points, firstly the decision-making matrix (Table 5) was formed to select a suitable lubricant (step 1) and then a dimensionless matrix is formed using the Equation (1) in second step (Table 6).

**Table 5.** Decision-making matrix.

| | Power | Torque | BSFC | CO | $CO_2$ | UHC | $NO_X$ | $O_2$ |
|---|---|---|---|---|---|---|---|---|
| 2T Oil | 6.62 | 10.12 | 420.7 | 1.73 | 8.15 | 3027.5 | 594 | 9.3 |
| COB | 6.56 | 10.01 | 423.2 | 2.25 | 8.18 | 3186.7 | 534.67 | 8.56 |
| POB | 6.86 | 10.52 | 431.7 | 1.64 | 8.38 | 2990 | 540.5 | 9.09 |
| WCOB | 6.71 | 10.26 | 424.6 | 2.11 | 8.25 | 3026.8 | 492.67 | 8.86 |
| SAE10 | 6.45 | 9.86 | 423.5 | 2.91 | 8.68 | 3155.7 | 450.17 | 8.24 |

**Table 6.** The dimensionless decision matrix.

| | Power | Torque | BSFC | CO | $CO_2$ | UHC | $NO_X$ | $O_2$ |
|---|---|---|---|---|---|---|---|---|
| 2T Oil | 0.445769314 | 0.445606574 | 0.442942968 | 0.35562396 | 0.437537495 | 0.439827742 | 0.506339398 | 0.471656713 |
| COB | 0.441729109 | 0.440763025 | 0.445575146 | 0.462516711 | 0.439148062 | 0.462955926 | 0.455765128 | 0.434127039 |
| POB | 0.461930135 | 0.463219482 | 0.454524552 | 0.337123291 | 0.449885178 | 0.434379834 | 0.460734755 | 0.4610064 |
| WCOB | 0.451829622 | 0.451771092 | 0.447049166 | 0.433737893 | 0.442906053 | 0.439726047 | 0.419963352 | 0.449341772 |
| SAE10 | 0.434322066 | 0.434158184 | 0.445891008 | 0.598188279 | 0.465990853 | 0.458452322 | 0.383735365 | 0.417897991 |

Next, the weight matrix was developed based on the entropy technique. Values shown in Tables 7 and 8 are related to the weighted dimensionless decision matrix, and PIS and NIS values for each dependent variable of the engine test respectively were obtained by accomplishing second and third steps.

**Table 7.** The weighted dimensionless decision matrix.

| | Power | Torque | BSFC | CO | $CO_2$ | UHC | $NO_X$ | $O_2$ |
|---|---|---|---|---|---|---|---|---|
| 2T Oil | 0.003423085 | 0.003859484 | 0.000594557 | 0.277654666 | 0.004158 | 0.005033537 | 0.007530365 | 0.015043 |
| COB | 0.00339206 | 0.003817533 | 0.000598091 | 0.36111156 | 0.004173 | 0.005298224 | 0.006778216 | 0.013846 |
| POB | 0.003547185 | 0.004012033 | 0.000610103 | 0.263210204 | 0.004275 | 0.00497119 | 0.006852125 | 0.014704 |
| WCOB | 0.003469622 | 0.003912876 | 0.000600069 | 0.338642396 | 0.004209 | 0.005032374 | 0.006245766 | 0.014332 |
| SAE10 | 0.003335181 | 0.003760327 | 0.000598515 | 0.467037618 | 0.004428 | 0.005246683 | 0.005706977 | 0.013329 |

**Table 8.** Positive ideal solution (PIS) and negative ideal solution (NIS) values for each dependent variable of engine test.

| | Power | Torque | BSFC | CO | $CO_2$ | UHC | $NO_X$ | $O_2$ |
|---|---|---|---|---|---|---|---|---|
| PIS | 0.003547185 | 0.004012033 | 0.000594557 | 0.263210204 | 0.004158 | 0.00497119 | 0.005706977 | 0.013329 |
| NIS | 0.003335181 | 0.003760327 | 0.000610103 | 0.467037618 | 0.004428 | 0.005298224 | 0.007530365 | 0.015043 |

Finally, the relative closeness of $A_i$s to the ideal solutions (Table 9) was determined after the determination of the positive and negative ideal solutions and the Euclidean distance of the $i_{th}$ alternative from the ideals.

**Table 9.** Distance of $A_i$ from the positive and negative ideal solutions.

| Lubricant | Distance of $A_i$ |
|---|---|
| 2T engine oil | 0.99404258 |
| Castor oil biolubricants | 0.539313915 |
| Palm oil biolubricants | 0.999922603 |
| Waste cooking oil biolubricant | 0.743390679 |
| SAE 10 lubricant | 0.000150834 |

The obtained $A_i$s for each of the lubricants used in this study were arranged in descending order. According to the explanation given by the TOPSIS algorithm, the lubricant with the higher numerical value of $A_i$ will have more desirability. It was observed that the palm biolubricant took up a higher value of $A_i$ after the rating of each of the lubricant alternatives and, consequently, it enjoys higher desirability.

## 4. Conclusions

The following conclusions can be drawn from the present research work:

1 The results obtained from the use of the TOPSIS algorithm showed that palm oil-based lubricant is the most favorable biolubricant compared to the other lubricants used in the test. Each of the physical and chemical characteristics of the biolubricants used in the test, such as lubricity power, flash point, the percentage of different fatty acids in the structure of vegetable oils, pour point, oxidation stability, thermal stability of oil, and other parameters are involved in the combustion process of the lubricant with gasoline and is effectivenessin terms of its importance. It is noteworthy that addressing the role of each of the characteristics of the oils needs precise experiments, complex devices, and separate research that form the subject of tribology.

2 Due to the fact that the biolubricants were used in this study without any additives for improving the physical and chemical properties of engine oil and they showed even better performance than the mineral two-stroke lubricants (2T oils) in some cases.

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**Author Contributions:** All the authors contributed to this work. Masoud Dehghani Soufi designed the study, performed the experiments, and wrote the first draft of the paper. Barat Ghobadian and Gholamhassan Najafi contributed to the conceptual approach and thoroughly revised the paper. Mohammad Reza Sabzimaleki contributed to developing the mathematical analyses.

**Conflicts of Interest:** The authors declare no conflict of interest.

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