Çukurova Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 33(3), ss. 177-186, Eylül 2018
Çukurova University Journal of the Faculty of Engineering and Architecture, 33(3), pp. 177-186, September 2018

Using Analytic Hierarchy Process for Evaluating Different Biodiesels as an Alternative Fuel

Aslı ABDULVAHİTOĞLU[*1]

[1] *Adana Bilim ve Teknoloji Üniversitesi, Mühendislik Fakültesi, Makine Mühendisliği Bölümü, Adana*

Geliş tarihi: 27.04.2018 *Kabul tarihi: 15.10.2018*

Abstract

The industrialization that develops with the increasing population causes an increase in demand for fossil fuels in the world, which affects the supply-demand balance. This imbalance also causes a rise in prices. Therefore, increased oil prices and oil dependency lead the countries to the production and use of new energy resources. At this point, countries are evaluating biomass for biofuel production to generate energy, thus increasing the share of biofuels in total energy consumption. In this study, Analytic Hierarchy Process (AHP) is used to structure the decision problem and to attribute weights to criteria. Among the evaluated physicochemical fuel properties, the most important one is calculated as heating value and also the Cottonseed Fame is determined as the most suitable biodiesel in terms of fuel properties among the evaluated biodiesels.

Keywords: Biodiesel, Analytic hierarchy process (AHP), Fuel property

Analitik Hiyerarşi Proses Kullanarak Farklı Biyodizellerin Alternatif Yakıt Olarak Değerlendirilmesi

Öz

Artan nüfusla birlikte gelişen sanayileşme, dünyadaki fosil yakıtlara olan talebin artmasına neden olarak arz talep dengesini etkilemektedir. Bu dengesizlik fiyatlarda da artışa neden olmaktadır. Bu nedenle, artan petrol fiyatları ve petrol bağımlılığı, ülkeleri yeni enerji kaynaklarının üretimine ve kullanımına yönlendirmektedir. Bu noktada, ülkeler, biyoyakıt üretimi için biyokütleyi enerji üretecek şekilde değerlendirmekte ve böylece biyoyakıtların toplam enerji tüketimindeki payını arttırmaktadır. Bu çalışmada Analitik Hiyerarşi Süreci (AHP) karar problemini yapılandırmak ve ağırlıkları kriterlere atfetmek için kullanılmıştır. Değerlendirilen fizikokimyasal yakıt özellikleri arasında en önemlisi ısıl değer olarak hesaplanmış ve aynı zamanda pamuk yağı metil esterinin değerlendirilen biyodizeller arasında yakıt özellikleri açısından en uygun biyodizel olduğu tespit edilmiştir.

Anahtar Kelimeler: Biyodizel, Analitik hiyerarşi süreci (AHP), Yakıt özelliği

[*]Sorumlu Yazar (Corresponding author): Aslı ABDULVAHİTOĞLU, *aabdulvahitoglu@adanabtu.edu.tr*

1. INTRODUCTION

One of the biggest problems that we have come up with in this century is the increase in energy demand due to industrialization, urbanization and rapid population growth. Searching for alternatives is the primary energy source that we have to do in this century. Fossil-based fuels are basically used to meet the needs of growing world population. With this usage, climate change and environmental problems caused by fossil fuels are confronted as irrefutable facts. Fossil fuels have been major sources of energy for couple of decades. Since it is a consumable energy source, and the demands of the people increase, this fact somehow pushes the scientists and governments towards the renewable energy sources.

Biofuels are produced from many raw organic materials and biodiesel is one of the most promising biofuels among all. Oils which are an important part of human nutrition produced from oil plants. Hence the biodiesel is produced from oilseeds the production of biodiesel has an impact on vegetable oil prices. So scientists have concerns about the increase in food prices and the scarcity of food, and also the destruction of forests in order to expand biofuels production facilities, which would have harmful effects on the environment. However, with the conversion of non-renewable fats to biodiesel, both the increase in food prices and the need for fuel are partially hindered in this way. In particular, biofuels are at the forefront of these sources as they do not lead to an increase in carbon dioxide in the world. In order to increase the demand for these products, countries apply new policies and support the production of the alternative fuels. Research on biodiesel, a sustainable energy source, is being undertaken as an alternative to fossil fuels.

Biodiesel is considered an important source of renewable energy not only because of its potential to meet energy demand but also to reduce greenhouse gases [1]. Biodiesel, which is defined as an alternative to diesel, can be produced from methyl or ethyl esters of vegetable or animal oils [2]. The selection of the most suitable biodiesel source and proper mixing of biodiesel play an important role in the generation alternative energy production [3].

Following the energy crisis in the world in the 1970s, the shift to alternative fuels led to various investigations [4]. Biodiesel is one of the sources that can play an important role in future energy, especially as an alternative to diesel fuel in the transport sector [5].

Biodiesel, which has characteristics similar to fossil fuels, can be a potential alternative fuel [6,7]. It is a less toxic and renewable fuel than traditional petrodiesel [8-12]. The fuel mixture, which contains 20% biodiesel and 80% diesel in volume and is called B20, can be used without diesel engine modification. However, as the amount of biodiesel in the mixture exceeds 20% by volume, several engine modifications are required [13-16]. Biodiesel is produced in the presence of a catalyst by transesterification of vegetable oils or fats with alcohol, usually methanol [7,11,17].

It has been observed that, unlike fossil fuel, the physicochemical properties of biodiesel differ from the biodiesel raw material depending on the type of fuel used, which has a significant effect on the dynamic performance of the engine and the potential performance of the engine during its use. On the other hand, the use of biodiesel as fuel has often been observed to cause a significant increase in fuel consumption, carbon monoxide, unburned hydrocarbons, particulate matter and NOx emissions [18]. Despite the fact that biodiesel has better properties than crude vegetable oils, the main disadvantages encountered with biodiesel are high viscosity, low volatility, poor spray characteristics, low energy content, increased nitrogen oxide (NOx) emissions, high clouding and pour point when compared to diesel [18].

Currently, fossil fuels especially diesel which is used as the transportation fuel in Turkey (according to the Turkish Statistics Agency 2017 data, there are 11,102,943 diesel vehicles in Turkey which is equivalent to 50% of the total vehicles [19]; that causes not only numerous environmental problems but also strategic negative consequences. Diversification of fuel for the transport sector in Turkey will be possible with the evaluation of various alternative fuels. Therefore, a long-term strategic energy program should be formed to ensure national energy security in the 21st century. Hence, the Analytic Hierarchy Process (AHP) can be used to determine the best option among a number of alternatives.

The AHP is a decision-making method first introduced by Saaty in the 1970s. Each element in every level is compared bi-directionally with respect to a target element [20]. When selecting the best choice among the alternatives, there should be a number of criteria. For each criterion, a weighted value should be calculated to show their importance. The alternatives are then given a performance score. The total performance score of an alternative is the sum of the scores of the alternative for a particular criterion multiplied by the weight of the relevant criterion. The best alternative is the one with the highest overall performance score [20].

Sehatpoura et al evaluated various fuels (CNG, LPG, diesel, M85, E85, biodiesel, biogas and hydrogen) with AHP and found that compressed natural gas and liquid petroleum gas for light commercial vehicles in Iran is the most suitable alternative fuel when compared to other alternative renewable fuels [21]. Grasman and Sadashivam have done prioritization with AHP by using Biodiesel as a fuel in fleets [22]. Colak and Kaya proposed a Multi-Criteria Decision Model (MCDM) integrated model based on fuzzy sets in renewable energy alternatives in Turkey. The proposed fuzzy MCDM model combines the AHP based on interval type-2 fuzzy clusters and unresolved fuzzy TOPSIS methods. In addition, a sensitivity analysis was performed to examine the effects of the main criteria weights in the sequence [23]. Tasri and Susilawati have developed a selection methodology based on AHP for alternative renewable energy sources suitable for Indonesian power generation [24].

The purpose of this study is to select the most suitable biodiesel among the six different biodiesel for using as an alternative fuel. AHP was used for selecting the suitable biodiesel which is regarded as a multi-criteria decision-making problem. Literature studies have shown that, although there is a lot of work on biodiesel in our country, there is not any study on evaluation of biodiesel by using decision support systems. So this study will be a novel work in this area. The main difference of this study is using AHP to evaluate the physicochemical properties of six different biodiesels.

2. MATERIAL AND METHOD

The physicochemical characterized the properties of biodiesel. Some of these properties are heating value, Cetane number, density, viscosity, cloud and pour points, flash point, acid value, ash content, copper corrosion, carbon residue, water content and sediment, distillation range, sulfur content, glycerin, phosphorus and oxidation stability [24]. Among the stated physicochemical properties heating value, Cetane number, density, viscosity, pour point and flash point were chosen as indicating characteristics. Therefore, the objective of this paper is to decide the most suitable biodiesel among the evaluated six different biodiesels which meets the criteria according to the importance ratings determined by the experts.

Experimental values of six different kinds of biodiesel were taken from literature [25-32] and Table 1 is formed.

Table 1. Fuel properties of different kinds of biodiesel

Fuel Property	Peanut FAME	Rapeseed FAME	Camelina S. FAME	Jatropha FAME	Madhuca FAME	Cottonseed FAME	DIN 14214
Heating Value (MJ/kg)	40,1	37	39,05	38,5-42	39,4-39,91	39,5	35*
Cetane Number	53,59	54,4	51	46-55	51-52	41,2-59,5	>51
Viscosity (cSt)	4,42	4,44	4,38	3,7-5,8	3,98-5,8	4-4,9	3,5-5,0
Density (kg/m³)	848,5	882	886	864-880	904-916	874-911	860-890
Flashpoint (°C)	166	170	140	163-238	127-129	210-243	>120
Pour Point (°C)	-8	-12	-10	5-6	1-6	-10 to -15	-

* The heating value is defined in EN 14213 as 35 MJ/kg [25].

In this study, the Analytic Hierarchy Process (AHP) is attribute weights to criteria. Figure 1 shows the hierarchy model for biodiesel type selection and Table 2 shows the Importance scale values and definitions.

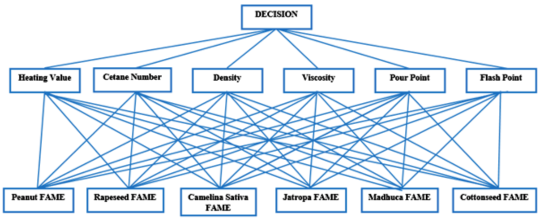

Figure 1. Hierarchy model for biodiesel selection

Table 2. Importance scale values and definitions [20]

Numerical scale	Verbal Scale
1	Equal Importance
3	Moderate Importance
7	Very Strong Importance
9	Extreme Importance
2,4,6 and 8	Intermediate Values

AHP was assessed using mathematical formulas given below. For the components stated below the diagonal, the formula 1 was used [33].

$$A = \begin{bmatrix} a_{12} & a_{12} & . & . & a_{1n} \\ a_{21} & a_{22} & . & . & a_{2n} \\ \dots & . & . & . & . \\ \dots & . & . & . & . \\ a_{n1} & a_{n2} & . & \dots & a_{nn} \end{bmatrix} \qquad a_{ji} = \frac{1}{a_{ji}} \qquad (1)$$

In order to determine the significance levels of the factors, the matrix is calculated by using the normalization method with the formula 2 [34].

$$B_i = \begin{bmatrix} b_{11} \\ b_{21} \\ .. \\ .. \\ b_{n1} \end{bmatrix} \qquad bi_j = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \qquad (2)$$

Subsequently, the matrix C which is constructed by combining the B column vectors as many as the number of factors in a matrix format. The arithmetic mean of the row components forming the matrix C is taken from the column vector W, which is named as Priority Vector and showing significance values, is obtained (3).

$$C = \begin{bmatrix} c_{11} & c_{12} & .. & .. & c_{1n} \\ c_{21} & c_{22} & .. & .. & c_{2n} \\ .. & .. & .. & .. & .. \\ .. & .. & .. & .. & .. \\ c_{n1} & c_{n2} & .. & .. & c_{nn} \end{bmatrix} \quad W = \begin{bmatrix} w_1 \\ w_2 \\ .. \\ .. \\ w_n \end{bmatrix} \quad w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n} \qquad (3)$$

Consistency Ratio (CR) is obtained by comparing the number of factors and a coefficient (λ) called Eigen Value. For the calculation of (λ), firstly A the comparison matrix is compared with the priority vector W to obtain the D column vector.

$$D = \begin{bmatrix} a_{11} & a_{12} & .. & .. & a_{1n} \\ a_{21} & a_{22} & .. & .. & a_{2n} \\ .. & .. & .. & .. & \dots \\ .. & .. & .. & .. & .. \\ a_{n1} & a_{n2} & \dots & .. & a_{nn} \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ .. \\ . \\ w_n \end{bmatrix} \qquad (4)$$

E is calculated from equation (5) and taking the arithmetic mean value (6) will give the eigen value λ.

$$E_i = \frac{d_i}{w_i} \qquad (i=1,2,....n) \qquad (5)$$

$$\lambda = \frac{\sum_{i=1}^{n} E_i}{n} \qquad (6)$$

Once the λ is calculated the Consistency Indicator (CI) can be determined by the formula (7). Also, Consistency Ratio (CR) can be determent by dividing the calculated with the formula (8), the value of CI to Random Consistency Index (RI) which is tabulated in Table 3.

$$CI = \frac{\lambda - n}{n - 1} \qquad (7)$$

$$CR = \frac{CI}{RI} \qquad (8)$$

Table 3. Random consistency index values [35].

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The consistency test is completed when the CR is numerically calculated. If CR <10 % then the achieved data is consistent which means the comparison matrix is consistent. If CR ≥10 % then the achieved data is inconsistent, so the comparison matrix should be revised [36].

3. RESULTS AND DISCUSSION

In this section, a binary comparison matrix was prepared with the aim of evaluating the properties of biodiesel obtained from different vegetable oil and used as fuel by comparing them with AHP.

3.1. Fuel Property Evaluation

It has been determined that the following evaluation points are the most important properties in the fuel; Cetane number, density, viscosity, flash point, pour point, heating value. In order to form the comparison matrix specialists were asked to answer the priority chart. The comparison matrix is formed as shown in Table 4.

Table 4. Comparison matrix of main criteria

Comparison Matrix	Cetane Number	Density	Viscosity	Flash Point	Pour Point	Heating Value
Cetane Number	1.00	1.93	1.18	3.33	4.38	0.62
Density	0.52	1.00	0.71	2.75	2.63	0.30
Viscosity	0.85	1.41	1.00	2.58	3.75	0.63
Flash Point	0.30	0.36	0.39	1.00	0.99	0.26
Pour Point	0.23	0.38	0.27	1.01	1.00	0.24
Heating Value	1.62	3.31	1.60	3.89	4.24	1.00

Table 5. Weighted values of main criteria

Importance levels of Main Criteria	Weight (W)
Heating Value	0.32
Cetane Number	0.23
Viscosity	0.19
Density	0.14
Flash Point	0.07
Pour Point	0.06

Normalization was done according to the formulas 2 and 3 then the priority vector was obtained as follows.

Table 6. Consistency ratio for fuel properties.

Name	Result
Maximum Eigen Value λ_{max}	6.1
Random Consistency Indicator (RI)	1.24
Consistency Indicator (CI)	0.019
Consistency Ratio (CR)	0.0154

Consistency Ratio for fuel properties equals to 0.0154 which is smaller than 0,1 then the comparison is consistent. According to calculated weighted main criteria are ranked in the following order: Heating value, Cetane Number, Viscosity, Density, Flash Point and Pour Point, respectively.

3.2. Evaluation of Different FAMEs

There are six different FAME for evaluation. For each fuel quality property, a matrix was formed by using importance scale values. The scale values were given according to DIN 14214. Normalization was done according to the formulas 2 and 3 then the priority vector was obtained.

3.2.1. Cetane Number

The **Cetane number (C)** is the indication of ignition characteristics or the ability of the fuel to auto-ignite quickly after being injected. Better ignition quality of the fuel is always associated with higher CN value. A higher CN indicates the shorter time between the ignition and the initiation of fuel injection into the combustion chamber [37].

Table 7. Comparison matrix for subcriteria cetane number

Cetane Number	Peanut FAME	Rapeseed FAME	Camelina S. FAME	Jatropha FAME	Madhuca FAME	Cottonseed FAME
Peanut FAME	1	1/3	3	1/5	1/3	1/6
Rapeseed FAME	3	1	5	1/2	4	1/5
Camelina S. FAME	1/3	1/5	1	1/7	1/2	1/9
Jatropha FAME	5	2	7	1	4	1/4
Madhuca FAME	3	1/4	2	1/4	1	1/8
Cottonseed FAME	6	5	9	4	8	1

Table 8. Weighted values of cetane number (CW)

Importance levels of Subcriteria Cetane Number	Weight (W)
Madhuca FAME	0.071791
Rapeseed FAME	0.146164
Cottonseed FAME	0.479117
Peanut FAME	0.057513
Jatropha FAME	0.213841
Camelina Sativa FAME	0.031574

Table 9. Consistency ratio for cetane number

Name	**Result**
Maximum Eigen Value λ_{max}	6.46999
Random Consistency Indicator (RI)	1.24
Consistency Indicator (CI)	0.093998
Consistency Ratio (CR)	0.075805

Consistency Ratio of Cetane Number equals to 0.075805 which is smaller than 0.1 then the comparison is consistent. The subcriteria of Cetane Number of six biodiesels are ranked in the following order: Cottonseed FAME, Jatropha FAME, Rapeseed FAME, Madhuca FAME, Peanut FAME, Camelina Sativa FAME, respectively.

3.2.2. Heating Value

Heating value (H) is the amount of heating energy released by the combustion of a unit value of the fuel [38].

Table 10. Comparison matrix for subcriteria heating value

Heating Value	Peanut FAME	Rapeseed FAME	Camelina S. FAME	Jatropha FAME	Madhuca FAME	Cottonseed FAME
Peanut FAME	1	9	4	5	3	2
Rapeseed FAME	1/9	1	1/4	1/4	1/5	1/5
Camelina S.FAME	1/4	4	1	1/2	1/3	1/2
Jatropha FAME	1/5	4	2	1	1/4	1/4
Madhuca FAME	1/3	5	3	4	1	1/3
Cottonseed FAME	1/2	5	2	4	3	1

Table 11. Weighted values of heating value (HW)

Importance levels of Subcriteria Heating Value	**Weight (W)**
Cottonseed FAME	0.240124
Peanut FAME	0.376157
Jatropha FAME	0.091322
Camelina Sativa FAME	0.087059
Rapeseed FAME	0.031977
Madhuca FAME	0.173361

Table 12. Consistency ratio for heating value

Name	**Result**
Maximum Eigen Value λ_{max}	6.468974
Random Consistency Indicator (RI)	1.24
Consistency Indicator (CI)	0.093795
Consistency Ratio (CR)	0.075641

Consistency Ratio of heating value equals to 0.075641 which is smaller than 0.1 then the comparison is consistent. The subcriteria of the Heating value of six biodiesels are ranked in the following order: Peanut FAME, Cottonseed FAME, Madhuca FAME, Jatropha FAME, Camelina Sativa FAME, Rapeseed FAME, respectively.

3.2.3. Density

Density is the weight per unit volume. Oils that are denser contain more energy [38].

Table 13. Comparison matrix for subcriteria density

Density	Peanut FAME	Rapeseed FAME	Camelina S. FAME	Jatropha FAME	Madhuca FAME	Cottonseed FAME
Peanut FAME	1	1/7	1/5	1/3	1/2	1/5
Rapeseed FAME	5	1	3	4	9	2
Camelina S. FAME	5	1/3	1	4	7	3
Jatropha FAME	3	1/4	1/4	1	3	1/4
Madhuca FAME	2	1/9	1/7	1/3	1	1/8
Cottonseed FAME	5	1/2	1/3	4	8	1

Table 14. Weighted values of density (DW)

Importance levels of Subcriteria Density	**Weight (W)**
Rapeseed FAME	0.364597
Camelina Sativa FAME	0.263046
Peanut FAME	0.036949
Jatropha FAME	0.086171
Cottonseed FAME	0.207526
Madhuca FAME	0.41711

Table 15. Consistency ratio for density

Name	**Result**
Maximum Eigen Value λ_{max}	6.435087
Random Consistency Indicator (RI)	1.24
Consistency Indicator (CI)	0.087017
Consistency Ratio (CR)	0.070175

Consistency Ratio of density equals to 0.070175 which is smaller than 0.1 then the comparison is consistent. The subcriteria of the density of six biodiesels are ranked in the following order: Rapeseed FAME, Jatropha FAME, Cottonseed FAME, Camelina Sativa FAME, Madhuca FAME, Peanut FAME, respectively.

3.2.4. Viscosity

Viscosity (V) is one the most important property of any fuel as it is the measure of resistance to flow. It affects the operation of the fuel injection equipment and sprays atomization, particularly at low temperatures when the increase in viscosity affects the fluidity of the fuel [25,39].

Table 16. Comparison matrix for subcriteria viscosity

Viscosity	Peanut FAME	Rapeseed FAME	Camelina S. FAME	Jatropha FAME	Madhuca FAME	Cottonseed FAME
Peanut FAME	1	2	1/2	5	3	1/5
Rapeseed FAME	1/2	1	1/2	5	3	1/5
Camelina S. FAME	2	2	1	6	2	1/4
Jatropha FAME	1/5	1/5	1/6	1	1/3	1/9
Madhuca FAME	1/3	1/3	1/2	3	1	1/3
Cottonseed FAME	5	5	4	9	3	1

Table 17. Weighted values of viscosity (VW)

Importance levels of Subcriteria Viscosity	Weight (W)
Camelina Sativa FAME	0.174950
Peanut FAME	0.147787
Rapeseed FAME	0.122739
Cottonseed FAME	0.443205
Madhuca FAME	0.081204
Jatropha FAME	0.030115

Table 18. Consistency ratio of viscosity

Name	Result
Maximum Eigen Value λ_{max}	6.444353
Random Consistency Indicator (RI)	1.24
Consistency Indicator (CI)	0.081204
Consistency Ratio (CR)	0.07167

Consistency Ratio of Viscosity equals to 0.07167 which is smaller than 0.1 then the comparison is consistent. The subcriteria of viscosity of six biodiesels are ranked in the following order: Cottonseed FAME, Camelina Sativa FAME, Peanut FAME, Rapeseed FAME, Madhuca FAME, Jatropha FAME, respectively.

3.2.5. Flashpoint

Flashpoint (F) is the temperature at which the fuel ignite when it exposed to a flame or a spark. It varies with the volatility of fuel. Since the flash point of biodiesel is higher than the diesel fuel it is safe for to transport, handling and storage [40].

Table 19. Comparison matrix for subcriteria flash point

Flashpoint	Peanut FAME	Rapeseed FAME	Camelina S.FAME	Jatropha FAME	Madhuca FAME	Cottonseed FAME
Peanut FAME	1	1/2	6	7	1/5	4
Rapeseed FAME	2	1	7	8	1/4	4
Camelina S. FAME	1/6	1/7	1	2	1/8	1/3
Jatropha FAME	1/7	1/8	1/2	1	1/9	1/3
Madhuca FAME	5	4	8	9	1	6
Cottonseed FAME	1/4	1/4	3	3	1/6	1

Table 20. Weighted values of flash point (FW)

Importance levels of Subcriteria Flash Point	Weight (W)
Madhuca FAME	0.464211
Rapeseed FAME	0.221876
Peanut FAME	0.171968
Cottonseed FAME	0.073697
Camelina Sativa FAME	0.039639
Jatropha FAME	0.028608

Table 21. Consistency ratio for flash point

Name	Result
Maximum Eigen Value λ_{max}	6,413561
Random Consistency Indicator (RI)	1,24
Consistency Indicator (CI)	0,082712
Consistency Ratio (CR)	0,066703

Consistency Ratio of Flash Point equals to 0.066703 which is smaller than 0.1 then the comparison is consistent. The subcriteria of flash point of six biodiesels are ranked in the following order: Madhuca FAME, Rapeseed FAME, Peanut FAME, Cottonseed FAME, Camelina Sativa FAME, Jatropha FAME, respectively.

3.2.6. Pour Point

Pour point (P) is the temperature at which the amount of wax out of solution is sufficient to gel the fuel, thus it is the lowest temperature at which the fuel can flow. The behaviour of biodiesel at low temperature is an important quality criterion. This is because partial or full solidification of the fuel may cause blockage of the fuel lines and filters, leading to fuel starvation, problems of starting, driving and engine damage due to inadequate lubrication [25].

Table 22. Comparison matrix for subcriteria pour point

Pour Point	Peanut FAME	Rapeseed FAME	Camelina S. FAME	Jatropha FAME	Madhuca FAME	Cottonseed FAME
Peanut FAME	1	1/3	1/2	4	5	1/4
Rapeseed FAME	3	1	2	8	9	3
Camelina S. FAME	2	1/2	1	5	6	1
Jatropha FAME	1/4	1/8	1/5	1	4	1/6
Madhuca FAME	1/5	1/9	1/6	1/4	1	1/9
Cottonseed FAME	4	1/3	1	6	9	1

Table 23. Weighted values of pour point (WP)

Importance levels of Subcriteria Pour Point	**Weight (W)**
Rapeseed FAME	0.375257
Camelina Sativa FAME	0.194753
Peanut FAME	0.115733
Jatropha FAME	0.051013
Cottonseed FAME	0.236669
Madhuca FAME	0.026575

Table 24. Consistency ratio for pour point

Name	**Result**
Maximum Eigen Value λ_{max}	6.378289
Random Consistency Indicator (RI)	1.24
Consistency Indicator (CI)	0.075658
Consistency Ratio (CR)	0.061014

Consistency Ratio of Pour Point equals to 0.061014 which is smaller than 0.1 then the comparison is consistent. The subcriteria of pour point of six biodiesels are ranked in the following order: Rapeseed FAME, Cottonseed FAME, Camelina Sativa FAME, Peanut FAME, Jatropha FAME, Madhuca FAME, respectively.

Once the calculations were done for each physicochemical property. The weighted formula then formed for each FAME as follows:

$$Weighted\ FAME = W_{1.1} * CW_{1.1} + W_{1.2} * DW_{1.1} + W_{1.3} * VW_{1.1} + W_{1.4} * FW_{1.1} + W_{1.5} * PW_{1.1} + W_{1.6} * HW_{1.1} \quad (9)$$

By using the above formula weighted result was calculated. The results are tabulated in Table 25.

Cottonseed FAME seems the best choice for producing biodiesel, on the other hand, Jatropha FAME seems the least preferred choice.

Table 25. Ranked results of biodiesels

Result	**Name**
0,31712	Cottonseed FAME
0,12518	Madhuca FAME
0,18449	Peanut FAME
0,11819	Camelina Sativa FAME
0,15428	Rapeseed FAME
0,10074	Jatropha FAME

4. CONCLUSION

The increase in global warming threatens the ecological balance of the world. Starting from the droughts in the fuels, researchers have been pushing to make assessments on fuels based on criteria such as renewability, environmental impact, and cost-effectiveness. Recently, the use of biodiesel as fuel has become a centre of attraction among researchers as it is renewable, biodegradable, non-harmful, environmentally friendly and sustainable.

In this study, the physicochemical properties of six different biodiesel (Cottonseed, Madhuca, Peanut, Camelina Sativa, Rapeseed, Jatropha) were evaluated by using the analytical hierarchy process. During this evaluation, 6 different fuel properties (heating value, Cetane number, viscosity, density, pour point and flash point) and 6 different biodiesels were compared. According to calculated weighted results by using AHP, the importance of fuel properties is listed as heating value, Cetane number, viscosity, density, pour point and flash point, respectively. From this point, the evaluation of six different by AHP method showed that Cottonseed FAME has the most suitable fuel properties and the Jatropha FAME has the least preferable results among the evaluated biodiesels. In the future, evaluation of engine performance characteristics and emission values with AHP and evaluation of new additives such as nanoparticles [41,42] will be appropriate for the future studies.

5. REFERENCES

1. Mofijur M., Atabani A.E., Masjuki H.H., Kalam M.A., Masum B.M., 2013. A Study on the Effects of Promising Edible and Non-edible

Biodiesel Feedstocks on Engine Performance and Emissions Production: A Comparative Evaluation, Renewable and Sustainable Energy Reviews 23, 391–404.

2. Xue J., Grift T.E., Hansen A.C., 2011. Effect of Biodiesel on Engine Performances and Emissions, Renewable and Sustainable Energy Reviews, 15, 1098–1116.

3. Sakthivel G., Sivakumar R., Saravanan N., Ikua W.B., 2017. A Decision Support System to Evaluate the Optimum Fuel Blend in an IC Engine to Enhance the Energy Efficiency and Energy Management. Energy, 140, 566-583.

4. Knothe G., Razon L.F., 2017. Biodiesel Fuels Progress in Energy and Combustion Science, 58, 36–59.

5. Thapa S., Natarianto I., Prakashbhai R.B., 2018. An Overview on Fuel Properties and Prospects of Jatropha Biodiesel as Fuel for Engines. Environmental Technology & Innovation, 9, 210–219.

6. Freedman, B., Pryde, E., Mounts, T. 1984. Variables Affecting the Yields of Fatty Esters from Transesterified Vegetable Oils. Journal of the American Oil Chemists Society, 61, 1638–1643.

7. Van Gerpen, J., 2005. Biodiesel Processing and Production. Fuel Processing Technology, 86 1097–1107.

8. Al-Zuhair, S., 2007. Production of Biodiesel: Possibilities and Challenges. Biofuels, Bioproducts and Biorefining, 1, 57–66.

9. Bozbas, K., 2008. Biodiesel as an Alternative Motor Fuel: Production and Policies in the European Union. Renewable and Sustainable Energy Reviews, 12, 542–552.

10. Knothe, G., Sharp, C.A., Ryan, T.W., 2006. Exhaust Emissions of Biodiesel, Petrodiesel, Neat Methyl Esters, and Alkanes in a New Technology Engine. Energy & Fuels, 20, 403–408.

11. Tiwari A., Rajesh V.M., Yadav S., 2018. Biodiesel Production in Micro-reactors: A Review Energy for Sustainable Development 43, 143–161.

12. Meher, L., Vidyasagar, D., Naik, S., 2006. Technical Aspects of Biodiesel Production by Transesterification-A Review. Renewable and Sustainable Energy Reviews, 10, 248–268.

13. Canakci M., Erdil A., Arcaklioğlu E., 2006. Performance and Exhaust Emissions of a Biodiesel Engine. Applied Energy, 83, 594–605.

14. Sharma, Y.C., Singh, B., Upadhyay, S.N., 2008. Advancements in Development and Characterization of Biodiesel: A Review. Fuel, 87, 2355–2373.

15. Van Gerpen, J., 2005. The Basics of Diesel Engines and Diesel Fuels. In The Biodiesel Handbook; Knothe, G., Van Gerpen, J., Krahl, J., Eds; AOCS Press: Urbana, IL, 17–25.

16. Xue J., Grift T.E., Hansen, A.C., 2011. Effect of Biodiesel on Engine Performances and Emissions. Renewable and Sustainable Energy Reviews, 15, 1098–1116.

17. Demirbaş, A., 2003. Biodiesel Fuels from Vegetable Oils Via Catalytic and Non-catalytic Supercritical Alcohol Transesterifications and Other Methods: A Survey. Energy Conversion and Management, 44, 2093–2109.

18. Sakthivela, R., Ramesh, K., Purnachandrana, R., Shameera, P.M., 2018. A Review on the Properties, Performance and Emission Aspects of the Third Generation Biodiesels. Renewable and Sustainable Energy Reviews, 82, 2970–2992.

19. www.tuik.gov.tr cited 11.9.2018.

20. Ishizaka, A., Labib, A., 2011 Review of the Main Developments in the Analytic Hierarchy Process. Expert Systems with Applications, 38, 14336–14345.

21. Sehatpoura, M., Kazemia, A., Sehatpourb, H., 2017. Evaluation of Alternative Fuels for Light-duty Vehicles in Iran using a Multicriteria Approach. Renewable and Sustainable Energy Reviews, 72, 295–310.

22. Grasman, S.E., Sundaresan, S., 2012. Implementation Policy Considerations for Achieving Year Round Operability of Biodiesel Programs Biomass and Bioenergy, 39, 439-448.

23. Çolak, M., Kaya, İ., 2017. Prioritization of Renewable Energy Alternatives by using an Integrated Fuzzy MCDM Model: A Real Case Application for Turkey, Renewable and Sustainable Energy Reviews, 80, 840–853.

24. Tasri A., Susilawati A., 2014. Selection Among Renewable Energy Alternatives Based on a Fuzzy Analytic Hierarchy Process in Indonesia. Sustainable Energy Technologies and Assessments, 7, 34–44.

25. Atabani, A.E., Silitonga, A.S., Badruddin, I.A., Mahlia, T.M.I., Masjuki, H.H., Mekhile, S., 2012. A Comprehensive Review on Biodiesel as an Alternative Energy Resource and its Characteristics. Renewable and Sustainable Energy Reviews, 16, 2070– 2093.

26. Rashid, U., Anwar, F., Knothe, G., 2009. Evaluation of Biodiesel Obtained from Cottonseed Oil. Fuel Process Technology; 90 (9), 1157–1163.

27. Yaşar, A., Keskin, A., Yıldızhan, Ş., 2016. Evaluation of Performance and Emission Characteristics of a VCR Diesel Engine Fuelled with Diesel Fuel and Diesel-Biodiesel-Alcohol Blends. Çukurova University Journal of the Faculty of Engineering and Architecture 31(1), 263-271.

28. Ramos, M.J., Fernández, C.M., Casas, A., Lourdes, R., Pérez, Á., 2009. Influence of Fatty Acid Composition of Raw Materials on Biodiesel Properties, Bioresource Technology 100, 261–268.

29. Ashraful, A.M., Masjuki, H.H., Kalam, M.A., Rizwanul Fattah, I.M., Imtenan, S., Shahir, S.A., Mobarak H.M., 2014. Production and Comparison of Fuel Properties, Engine Performance and Emission Characteristics of Biodiesel from Various Non-edible Vegetable Oils: A Review Energy Conversion and Management 80, 202–228.

30. Raheman, H., Ghadge, S.V., 2007. Performance of Compression Ignition Engine with Mahua (Madhuca Indica) Biodiesel Fuel 86, 2568–2573.

31. Kaya, C., Hamamci, C., Baysal, A., Akba, O., Erdogan, S., Saydut, A., 2009. Methyl Ester of Peanut (Arachis hypogea L.) Seed Oil as a Potential Feedstock for Biodiesel Production Renewable Energy 34, 1257–1260.

32. Thapa, S., Indrawan, N., Bhoi Pr. R., 2018. An Overview on Fuel Properties and Prospects of Jatropha Biodiesel as Fuel for Engines Environmental Technology & Innovation 9, 210–219.

33. Alonso, J.A., Lamata, M.T., 2006. Consistency in the Analytic Hierarchy Process: A New Approach. Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, 14(4), 445-459.

34. Davras, G.M., Karaatlı, M., 2014. Otel İşletmelerinde Tedarikçi Seçimi Sürecinde AHP ve BAHP Yöntemlerinin Uygulaması H.Ü. İktisadi ve İdari Bilimler Fakültesi Dergisi, 32(1), 87-112.

35. Awasthi, A., Satyaveer S. Chauhan., 2011. Using AHP and Dempster Shafer Theory for Evaluating Sustainable Transport Solutions Environmental Modelling & Software 26, 787-796.

36. Göksu, A., 2008. Bulanık Analitik Hiyerarşik Proses ve Üniversite Tercih Sıralanmasında Uygulanması. Süleyman Demirel Üniversitesi, Sosyal Bilimler Enstitüsü, İşletme Ana Bilim Dalı, Doktora Tezi, 128.

37. Filemon, J., 2010. Biofuels from Plant Oils. http://www.aseanfoundation.org/documents/books/biofuel. pdf; [cited 16.04.2018].

38. Atadashi, I.M., Aroua, M.K., Abdul Aziz, A., 2010. High Quality Biodiesel and its Diesel Engine Application: A Review. Renewable and Sustainable Energy Reviews;14(7), 1999-2008.

39. https://www.nrel.gov/docs/fy04osti/36244.pdf cited 14.8.2018

40. Lapuerta, M., Armas, O., Rodriguez-Fernandez, J., 2008. Effect of Biodiesel Fuels on Diesel Engine Emissions. Progress in Energy and Combustion Science; 34(2), 198-223.

41. Kilic, M., Ali, H.M., 2018. Numerical Investigation of Combined Effect of Nanofluids and Multiple Impinging Jets on Heat Transfer, Thermal Science 2018 On Line-First Issue 00, Pages: 94-94 doi.org/10.2298/TSCI171204094K.

42. Kilic, M., 2018. Askeri Sistemlerde Nanoakışkan Uygulamalarının Sayısal İncelemesi, The Journal of Defense Sciences, 17, 101-130, 10.17134/khosbd.427050.