INTERNATIONAL JOURNAL OF AUTOMOTIVE SCIENCE AND TECHNOLOGY

2024, VOL. 8, NO: 4, 457-466

www.ijastech.org

e-ISSN: 2587-0963

Selection of Optimal Waste Cooking Soybean Oil Biodiesel Blends for Emission Reduction in CI Diesel Engines Under Variable Loads: A Combined Analytic Hierarchy Process (AHP)-Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) Analysis

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Research Article

Abstract

Globalization has significantly heightened the demand for fossil fuels, resulting in a notable increase in ozone pollution levels. This heightened environmental awareness has spurred researchers to delve into the exploration of diverse renewable energy sources. In the course of extensive investigation, this study investigates the emission characteristics of a diesel engine fueled by waste-cooking Soybean oil biodiesel and diesel blends. A single-cylinder, four-stroke CI engine was utilized to experiment with various biodiesel blends, assessing major regulated pollutants at 25%, 50%, 75%, and 100% loads. Different Blends like B10WCO, B20WCO, B30WCO, B40WCO, B50WCO, and B0 Diesel Blends were prepared and ranked using an AHP-TOPSIS hybrid MCDM approach to determine the optimal fuel. AHP was employed to assess each criterion's importance, while TOPSIS ranked the alternatives. NOx emerged as the most significant criterion, with a 30% Waste Cooking Soybean oil biodiesel and 70% diesel blend identified as the best option at 75% and 100 % engine loads. Policymakers can use this integrated analysis technique to develop new business models aimed at reducing exhaust emissions and fossil fuel reliance. This research contributes to the study of renewable energy sources, particularly Waste cooking Soybean biodiesel blends, in automotive usage, providing insights for more efficient and environmentally balanced alternatives.

Keywords: Waste Cooking Biodiesel, MCDM, AHP-TOPSIS, NOx Reduction.

History
Received 15.09.2024
Revised 28.10.2024
Accepted 25.11.2024

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***To cite this paper*: :** Kajale,T., Pawar, A., Hole, J., Dubal, S. Selection of Optimal Waste Cooking Soybean Oil Biodiesel Blends for Emission Reduction in CI Diesel Engines Under Variable Loads: A Combined Analytic Hierarchy Process (AHP)-Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) Analysis. International Journal of Automotive Science and Technology. 2024; 8 (4) 457-466. http://dx.doi.org/10.29228/ijastech..1550536

1. Introduction

The demand for high-efficiency engines, energy regulations, and environmental concerns are driving the rapid expansion of alternative fuel research. [1,2]. Biodiesel is a promising solution that surpasses traditional diesel in terms of meeting stringent regulations concerning fuel efficiency and emissions. It provides a cleaner chemical energy source [3]. Originating from sustainable sources such as used cooking oil, fats from animals, and oils made from vegetables, biodiesel not only reduces carbon footprints but also mitigates environmental disasters and global warming [4,5]. However, the proliferation of crops used for the generation of biodiesel threatens agricultural productivity and the availability of food [6]. Improper disposal of waste cooking oil exacerbates these challenges, leading to water contamination and adverse effects on ecosystems and public health [6]. The world is facing an imminent energy crisis, and as fossil fuel stocks diminish, switching to alternate alternatives must happen quickly [7]. To secure a sustainable energy future, research is continuously focused on improving performance and lowering emissions related to biofuels, particularly blends of biodiesel. These biofuels present a viable path.

To solve environmental and financial issues, it is crucial to use used cooking oil as biodiesel in diesel engines [8]. Biodiesel may be produced from an extensive selection of feedstocks, comprising waste oils, microbial oils, algal oils, and a variety of vegetable and animal fats [9]. The elements carbon monoxide (CO), sulphur dioxide (SO2), and nitrogen oxides (NOx) are examples of gases that lead to a "greenhouse effect" in the Earth's atmosphere. Global warming results from this heat-trapping. We need cleaner diesel engine alternatives to fight this. Low-emission renewable fuels are one viable approach [10,11]. It appears that biodiesel is a strong option for this. It comes from renewable sources, can be easily obtained in large amounts, and has several positive environmental effects. Biodiesel is oxygenated, non-toxic, biodegradable, and not harmful to the environment. [12].Waste Cooking oil, which is usually thrown away by companies and households, may be converted into biodiesel, providing a sustainable substitute for conventional fossil fuels. [13]. By processing this waste into a useful energy source, we reduce our need for finite fossil fuel sources and reduce the environmental damage that waste disposal incorrectly generates [14]. Furthermore, utilizing waste cooking oil as biodiesel promotes circular economy principles by transforming a waste stream into a valuable resource [15]. Usually in diesel engines, biodiesel produced from waste cooking oil performs similarly to regular Diesel but releases less hazardous pollutants, improving air quality and lowering greenhouse gas emissions. Utilizing waste cooking oil as a feedstock for biodiesel helps to solve waste management issues and promotes a more environmentally friendly and sustainable energy landscape, which has a advantages for the natural environment as well as society [16,17]. The utilization of different feedstocks, their composition, and impurities limit the waste oil or waste cooking oil's large-scale productivity [12]. According to reports, waste cooking oil biodiesel may reduce CO emissions by up to 20%.[18].   Studies by various researchers [19–25] reveal significant similarities in the characteristics of diesel and biodiesel in terms of their physical as well as chemical composition. Moreover, biodiesel holds several advantages over diesel. Pre-planning and analysis of potential alternative fuel alternatives can be done in several ways, Decision-makers have to consequently consider several factors [26]. Multi-criteria decision-making (MCDM) methods serve as indispensable decision support tools, facilitating the sorting and evaluation of alternatives based on predefined criteria. These methods, such as Multi-criteria decision-making procedures benefit greatly from the use of TOPSIS, WPM, ANP, and AHP (Analytic Hierarchy Process) [27].

This study aims to evaluate the emission characteristics of diesel engines fueled with waste-cooking soybean oil biodiesel blends in comparison to conventional diesel. Through a combined AHP-TOPSIS methodology, the research identifies the optimal biodiesel blend for emission reduction across varying loads, providing valuable insights to support sustainable fuel alternatives and reduce reliance on fossil fuels.

2. Material and Procedures

The objective of the investigation was to assess the efficiency and emission characteristics of an internal combustion engine that operates on a blend of diesel and soybean waste cooking oil biodiesel. The soybean oil used in this study was purchased from the market, utilized by a hotel, and subsequently collected for further processing. The acid value of raw waste cooking soybean oil was measured at 2.3 mg KOH/g, per ASTM D6751 standards, exceeding the permissible limit for biodiesel production. To mitigate the elevated acidity, sulphuric acid was used as a catalyst in transesterification. After the transesterification process, the acid value was markedly diminished to 1.26 mg KOH/g. The engine was operated at 1500 rpm under a consistent compression ratio of 18. The injection pressure was maintained at 60 MPa and the injection timing was maintained at 16 degrees before TDC. Maintaining a speed of 1500 rpm while operating under varying loads of 25%, 50%, 75%, and 100%. To assess the efficacy of various blends, we examined emission parameters, including CO, HC, CO2, O2, NOx, and smoke. The optimal blend was determined by the biodiesel blend's capacity to reduce emissions. We employed a multi-criteria decision-making approach to address the challenges associated with selecting a biodiesel blend and to identify and recommend the ideal blend for engine operation.

2.1 Experimental Setup

In this investigation, we used a diesel engine that stood out for its air-cooled design, four-stroke operation, vertical orientation, and rapid speed. The engine was loaded using an electrical eddy current dynamometer. Engine parameters are precisely specified in Table 1. Our test setup included equipment that monitored air intake and fuel consumption. Furthermore, the proportional intensity of exhaust smoke was quantified using the AVL415 smoke measurement meter. Additionally, we employed a gas analyzer to evaluate the concentrations of exhaust gases [4]. The smoke meter is used for smoke measurement. Fig 1 shows the engine setup.

Fig 1. Engine Test Facility

In ambient conditions, the experiment was conducted at 303.15 K, which is equivalent to room temperature. The injection time was set at 16 degrees TDC, and the intake manifold injection pressure was maintained at 60 MPa. The compression ratio was set at 18. The study examines the performance of six distinct fuel blends: B10WCO (10% soybean waste cooking oil biodiesel and 90% diesel), B20, B30, B40, B50, and pure diesel (B0). The engine specifications are illustrated in Table 1.

Table 1. Engine Specifications

Make	Kirloskar
Engine Cycle	4-stroke
Rated Speed	1500 rpm
Rated Power	3.5 kilowatts
Type of Dynamometer	Eddy current dynamometer
Bore Diameter	87.5 millimetres
Stroke Length	110 millimetres
Cooling System	Water cooled
Displacement	0.661 liters (661 cc)
Ignition System	Compression-Ignition
Compression Ratio	12-18

2.2 Analytical Hierarchy Process (AHP)

AHP is a Hierarchical method that is part of Multi-Criteria decision-making that helps with decision-making at several levels, each of which has a limited number of factors. It is a popular tool for making decisions because of its efficiency, ease of use, and analytical convenience. AHP allows for both subjective and objective assessments and provides an approach to improve consistency metrics. Usually, the results show up as weighted scores or prioritized rankings for each choice or variable [28]. There has been an evident rise in the usage and significance of MCDM, particularly AHP, in recent years. The Managerial Decision-Making Process in the Context of Sustainable Development is one of the most notable examples of AHP's competence [29]. Various researchers [29–35] used AHP techniques to find extensive applications across various domains, facilitating the ranking of solutions from optimal to suboptimal outcomes.

AHP consists of 7 steps:

Step 1: Constructing the Hierarchy structure:
Identify the decision goal and break it down into criteria and sub-criteria hierarchically.

Step 2: Construction of Matrix of Pairwise Comparison:
Compare the significance of the criteria and sub-criteria pairwise using a scale that expresses the relative significance or preference. Let *xij* denote the significance of criterion *i* compared to criterion *j*. The value *xij* is typically filled in based on the judgment of decision-makers. This process generates a square matrix called the pairwise comparison matrix.

$$\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ \vdots & & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mm} \end{bmatrix} \text{ Where } x_{ij} = \frac{1}{x_{ij}} \quad (1)$$

Comparative analyses are performed to assess the relative value of each criterion. The available values for pairwise comparisons are members of the set: {1,2,3,4,5,6,7,8,9 and, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9}. The pair-by-pair comparisons are organized in a matrix. Pairwise comparisons between criteria and alternatives were used to determine their relative significance or preference. A scale developed by Saaty is typically used for these comparisons. Table 2 provides the Significance Description's Degree.

Table 2. Degree of Significance Description of Saaty's scale [36]

Intensity	Definition	Explanation
1	Equal significance	Each of the two actions contributes equally to the goal.
2, 4, 6, 8	Intermediate value	When compromise is needed
3	Moderate significance of superior to the other	Moderate preference for one activity over another based on experience and judgment
5	Essentially strong over the other	Understanding and decision favor one action over the other.
7	Very strong significance	Activity is highly recommended, and there is tangible proof of its domination.
9	Extreme significance	The maximum level of preference is shown for one activity over another.

Step 3: Normalization of Pairwise Comparison Matrix:

Divide each of the items in a column by the total of the items within that column to normalize the pairwise comparison matrix.

$$w_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (2)$$

Where w_{ij}The normalized value and n is the total number of criteria.

Step 4: Calculating criteria weights:

Calculate the priority vector by averaging the columns of the normalized pairwise comparison matrix.

$$\text{Priority Vector} = \frac{1}{n}\sum_{j=1}^{n} w_{ij} \quad (3)$$

Where *n* is n is the total number of criteria.

Step 5: The Eigenvalue computation

$$\lambda = \Sigma \frac{\left(\frac{(\Pi \ a_{ij})^1}{n}\right)}{n} \quad (4)$$

Where n is the total number of criteria and a_{ij} Is the matrix of pairwise comparisons at row i and column j.

Step 6: Consistency Index:

Equation 4 is used to generate the consistency index (CI), which is a measure of the pairwise comparison matrix's relative consistency.

$$CI = \frac{\lambda - n}{n - 1} \quad (5)$$

Random index:
The reference value for the random index (RI) is determined by the matrix's size and is used to calculate the consistency ratio. It is pre-determined and depends on the order of the matrix. There are standard RI values for different matrix sizes and these are shown in Table 3.

Table 3. Random Consistency Index Table

No of Criteria	11	10	9	8	7	6	5	4	3	2	1
RI Value	1.5	1.4	1.4	1.4	1.3	1.2	1.1	0.9	0.5	0	0

Step 7: Consistency Ratio (CR):

The consistency ratio (CR) is calculated by dividing the consistency index (CI) by the random index (RI). It is used to determine if the pairwise comparisons are consistent enough to be reliable.

$$CR = \frac{CI}{RI} \tag{6}$$

If the value of consistency ratio (CR) falls lower than a certain level. (typically 0.1) the judgments are considered sufficiently consistent [36]. Otherwise, adjustments may need to be made to improve consistency. These mathematical calculations contribute to the reliability and consistency of the judgments made in pairwise comparisons, leading to more accurate decision-making in the AHP process.

2.3 TOPSIS Computation

Step 1: The Decision Matrix's Normalization:
Normalize the decision matrix X where xij represents the performance of alternative i on criterion j. Divide each element (xij) by the square root of the total squares of all the items in the same column to normalize it.

$$rij = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x^2{}_{ij}}} \tag{7}$$

Where n is the total number of criteria.

Step 2: Decision Matrix with Weighted Normalization:

Multiply each normalized value by the weight of the corresponding criterion

$$v_{ij} = w_{ij} \times r_{ij} \tag{8}$$

Where, w_{ij} is the weight of criterion j

Step 3: Ideal and Negatively Ideal Solutions:

Determine which of the two ideal solutions is negative (A^{+}) and which is ideal (A^{-}), (highest values for each criterion; lowest values for each criterion).

$$A^{+} = \left(\max\left(v_{ij}\right)\right)_{j=1}^{m} \tag{9}$$

$$A^{-} = \left(\min\left(v_{ij}\right)\right)_{j=1}^{m} \tag{10}$$

Step 4: Calculation of Euclidean distance:

Determine the Euclidean distance between the ideal solution and the negative ideal solution

$$D^{+}(i) = \sqrt{\sum_{j=1}^{m}\left(v_{ij} - A_j^{+}\right)^2} \tag{11}$$

$$D^{-}(i) = \sqrt{\sum_{j=1}^{m}\left(v_{ij} - A_j^{-}\right)^2} \tag{12}$$

Where the alternate distances to the ideal and negative-ideal solutions are, respectively $D^{+}(i)$ and $D^{-}(i)$.

Step 5: Relative Closeness to the Ideal Solution:
Calculate the relative closeness of each alternative to the ideal solution. This can be done by dividing the negative distance by the sum of the positive and negative distances.

$$C(i) = \frac{D^{-}(i)}{D^{+}(i) + D^{-}(i)} \tag{13}$$

3. Result and Discussions

Fig 2 depicts the emission characteristics of different biodiesel blends (B10WCO to B50WCO) in comparison to conventional diesel (B0 Diesel) under various engine loads. Higher biodiesel blends result in significantly lower CO and HC emissions, which is indicative of better combustion efficiency [37]. Better oxygen utilization is indicated by a decrease in O2 emissions and an increase in CO2 emissions with biodiesel content. The results indicate that an increase in blend percentage is associated with a rise in CO2 emissions due to the higher oxygen content in waste cooking biodiesel [38]. Higher biodiesel ratios result in higher NOx emissions because of higher combustion temperatures at higher loads, while smoke opacity significantly drops, with B50WCO exhibiting the lowest values across all loads. Oxygen emissions decrease as engine load increases, while carbon dioxide and nitrogen oxide emissions increase. This is a result of the increased fuel injection into the combustion chamber during periods of high load, which results in an uneven mixture of fuel and air and incomplete combustion [39].

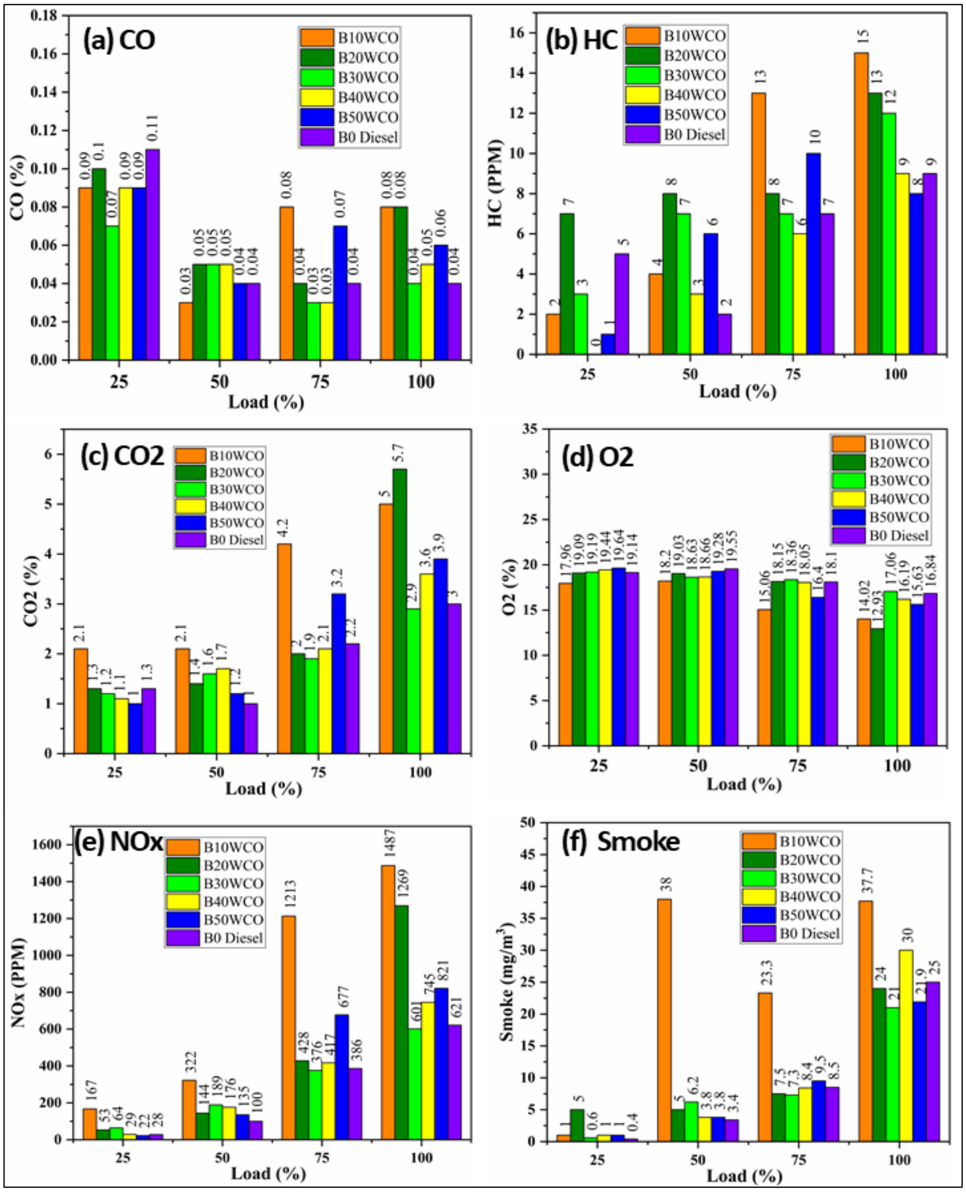

Fig 2. Emissions (a) CO (b) HC (c) CO2 (d) O2 (e) NOx (f) Smoke versus engine load for different biodiesel blends

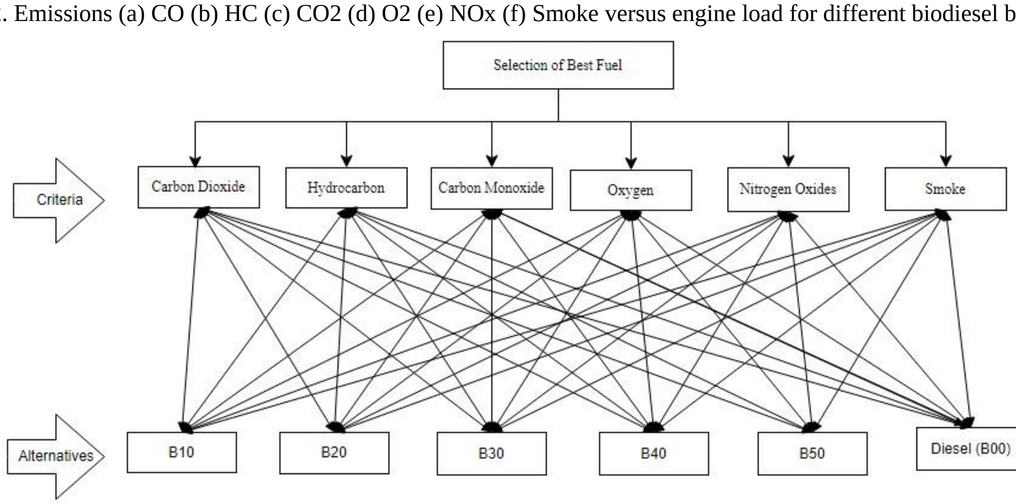

Fig 3. Decision Hierarchy Structure

A pairwise comparison matrix is developed to assess and contrast various biodiesel blends. Based on Equation 1, Table 4 illustrates the pairwise comparison matrix. Fig 3 illustrates the decision hierarchy structure, which evaluates the emission performance of biodiesel blends based on a variety of criteria, including carbon dioxide, hydrocarbons, carbon monoxide, oxygen, nitrogen oxides, and smoke. Diesel and biodiesel blends, including B10, B20, B30, B40, and B50, are viable alternatives. Per its intensity of significance, each criterion is assigned an intensity rating. Saaty's scale is delineated in Table 2.

Table 4. Pairwise Comparison matrix construction

Criteria	CO	HC	CO2	O2	NOx	Smoke
CO	1	3	0.33	0.33	0.2	0.2
HC	0.33	1	0.2	0.2	0.2	0.2
CO2	3	5	1	3	0.33	0.33
O2	3	5	0.33	1	0.33	0.33
NOx	5	5	3	3	1	3
Smoke	5	5	3	3	0.33	1

The weights of each criterion are determined using AHP techniques. Equation 2 is employed to perform the initial normalization of the pairwise comparison matrix, and equation 3 is employed to calculate the weights of each criterion. Table 5 provides the weights for each criterion. Equation 5 was employed to determine the Eigenvalue (λ). The priority vector is represented by the eigenvector associated with the largest eigenvalue, which indicates the relative significance of the criteria or alternatives. This eigenvalue represents the overall significance of the matrix's criteria. The next step is to calculate the consistency ratio (CR) to confirm that the pairwise comparisons of the decision-makers are consistent. The consistency ratio is used to evaluate the consistency of the judgments made in pairwise comparisons. A CR number near zero indicates acceptable consistency, while larger values suggest potential variations that should be addressed [40]. Equation 5 was implemented to compute the consistency ratio. The consistency ratio (CR) is defined as the ratio of the random index to the consistency index. Its objective is to evaluate the level of consistency that is necessary for pairwise comparisons to be regarded as reliable. The predetermined RI values are dependent on the number of criteria [41]. In Table 3, the standard RI values are provided.

Table 5. Calculated weights of criteria using AHP.

Sr. No	Criteria	Weight	Rank
1	CO	0.0632	5
2	HC	0.0381	6
3	CO2	0.1661	3
4	O2	0.1203	4
5	NOx	0.3625	1
6	Smoke	0.2499	2

Based on the calculated criteria weights and raking (Table 5), NOx was ranked first, followed by CO2 and smoke. In addition, the data is consistent, as the calculated CR value is 0.0871, which is significantly less than 0.1. The results are inconsistent and require modifications to ensure consistency if the value of CR is greater than or equal to 0.1.

TOPSIS was implemented to determine the optimal blend for various loads, as detailed in Section 2.3. The initial step is to normalize experimental emission data. Emission data that has been normalized is illustrated in Table 6. We employed Equation 7 to normalize the matrix. The data in Table 7 are weighted normalized values that were obtained by employing Equation 8. For the ideal positive and negative solutions, Equations 9 and 10 were employed, as illustrated in Table 8. The alternative distances to the ideal and negative-ideal solutions were calculated using Equations 11 and 12. The ideal closeness rating for each blend at various loads is presented in Table 9, which was obtained by calculating the relative closeness of each alternative to the ideal solution using Equation 13. Each blend's relative closeness ranking at each load is illustrated in Table 10. Fig 4 shows the ranking of biodiesel blends load-wise.

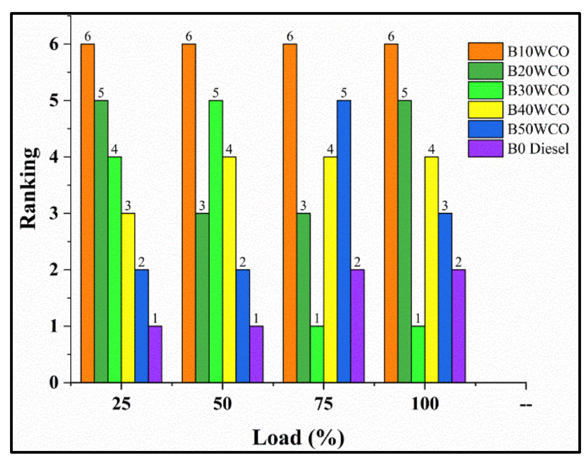

Fig 4. Ranking of Biodiesel Blends

The results of AHP-TOPSIS analysis when emissions are considered indicate that the preferred order of the best blend concerning others at 100 % load is B30WCO > B0 Diesel > B50WCO > B40WCO > B20WCO > B10WCO. For 75% Load, the preference is B30WCO > B0 Diesel > B20WCO > B40WCO > B50WCO > B10WCO. For other loads, the ranking is given in Table 9. B10WCO is at the lowest rank for all the loads considered emission results.

Table 6. Normalized matrix of experimental values.

Load (%)	Blends	CO (%)	HC (ppm)	CO2 (%)	O2 (%)	NOx (ppm)	Smoke (mg/m^3)
25	B10WCO	0.10227	0.059	0.178	0.104	0.372	0.085
	B20WCO	0.11364	0.206	0.11	0.111	0.118	0.424
	B30WCO	0.07955	0.088	0.102	0.112	0.143	0.051
	B40WCO	0.10227	0	0.093	0.113	0.065	0.085
	B50WCO	0.10227	0.029	0.085	0.114	0.049	0.085
	B0 Diesel	0.125	0.147	0.11	0.111	0.062	0.034
50	B10WCO	0.07895	0.077	0.174	0.106	0.246	0.568
	B20WCO	0.13158	0.154	0.116	0.111	0.11	0.075
	B30WCO	0.13158	0.135	0.132	0.108	0.144	0.093
	B40WCO	0.13158	0.058	0.14	0.109	0.134	0.057
	B50WCO	0.10526	0.115	0.099	0.112	0.103	0.057
	B0 Diesel	0.10526	0.038	0.083	0.114	0.076	0.051
75	B10WCO	0.21053	0.186	0.204	0.094	0.277	0.283
	B20WCO	0.10526	0.114	0.097	0.113	0.098	0.091
	B30WCO	0.07895	0.1	0.092	0.115	0.086	0.089
	B40WCO	0.07895	0.086	0.102	0.113	0.095	0.102
	B50WCO	0.18421	0.143	0.155	0.102	0.155	0.115
	B0 Diesel	0.10526	0.1	0.107	0.113	0.088	0.103
100	B10WCO	0.16667	0.163	0.155	0.097	0.205	0.168
	B20WCO	0.16667	0.141	0.177	0.09	0.175	0.107
	B30WCO	0.08333	0.13	0.09	0.118	0.083	0.093
	B40WCO	0.10417	0.098	0.112	0.112	0.103	0.134
	B50WCO	0.125	0.087	0.121	0.108	0.113	0.098
	B0 Diesel	0.08333	0.098	0.093	0.117	0.086	0.111

Table 7. Weighted Normalized matrix

Load (%)	Blends	CO (%)	HC (ppm)	CO2 (%)	O2 (%)	NOx (ppm)	Smoke (mg/m^3)
25	B10WCO	0.00646	0.00224	0.02957	0.01256	0.13481	0.02117
	B20WCO	0.00718	0.00784	0.01830	0.01335	0.04278	0.10587
	B30WCO	0.00503	0.00336	0.01690	0.01342	0.05166	0.01270
	B40WCO	0.00646	0.00000	0.01549	0.01359	0.02341	0.02117
	B50WCO	0.00646	0.00112	0.01408	0.01373	0.01776	0.02117
	B0 Diesel	0.00790	0.00560	0.01830	0.01338	0.02260	0.00847
50	B10WCO	0.00499	0.00293	0.02883	0.01274	0.08916	0.14192
	B20WCO	0.00832	0.00586	0.01922	0.01332	0.03987	0.01867
	B30WCO	0.00832	0.00512	0.02197	0.01304	0.05233	0.02316
	B40WCO	0.00832	0.00220	0.02334	0.01306	0.04873	0.01419
	B50WCO	0.00665	0.00439	0.01648	0.01350	0.03738	0.01419
	B0 Diesel	0.00665	0.00146	0.01373	0.01369	0.02769	0.01270
75	B10WCO	0.01331	0.00707	0.03387	0.01130	0.10036	0.07074
	B20WCO	0.00665	0.00435	0.01613	0.01362	0.03541	0.02277
	B30WCO	0.00499	0.00381	0.01532	0.01378	0.03111	0.02216
	B40WCO	0.00499	0.00326	0.01694	0.01354	0.03450	0.02550
	B50WCO	0.01164	0.00544	0.02581	0.01231	0.05601	0.02884
	B0 Diesel	0.00665	0.00381	0.01774	0.01358	0.03194	0.02581
100	B10WCO	0.01053	0.00621	0.02580	0.01169	0.07446	0.04194
	B20WCO	0.01053	0.00538	0.02941	0.01078	0.06355	0.02670
	B30WCO	0.00527	0.00496	0.01496	0.01422	0.03010	0.02336
	B40WCO	0.00658	0.00372	0.01858	0.01350	0.03731	0.03337
	B50WCO	0.00790	0.00331	0.02012	0.01303	0.04111	0.02436
	B0 Diesel	0.00527	0.00372	0.01548	0.01404	0.03110	0.02781

Table 8. Ideal Positive and Negative Solution

Load (%)	Blend	Si+	Si-
25	B10WCO	0.118782478	0.084901835
	B20WCO	0.100983985	0.092716616
	B30WCO	0.034458519	0.125627714
	B40WCO	0.014087331	0.140873284
	B50WCO	0.012888046	0.145470001
	B0 Diesel	0.009031182	0.149028667
50	B10WCO	0.143900737	0.004531089
	B20WCO	0.015652367	0.133084947
	B30WCO	0.028444401	0.124537302
	B40WCO	0.023434345	0.134137688
	B50WCO	0.010751917	0.138395855
	B0 Diesel	0.001913098	0.143969895
75	B10WCO	0.087077502	0.002434157
	B20WCO	0.005371438	0.08297773
	B30WCO	0.002535148	0.087055443
	B40WCO	0.005503981	0.082181071
	B50WCO	0.028717436	0.061597378
	B0 Diesel	0.00529872	0.083757456
100	B10WCO	0.049679012	0.004412072
	B20WCO	0.037025165	0.019078354
	B30WCO	0.00381961	0.05051386
	B40WCO	0.013212645	0.039921201
	B50WCO	0.012688465	0.039041375
	B0 Diesel	0.00564476	0.048044341

Table 9. Ideal Closeness Ranking

Blend	25 % Load	Rank	50% Load	Rank
B10WCO	0.416830506	**6**	0.0305264	**6**
B20WCO	0.478659411	**5**	0.894765029	**3**
B30WCO	0.784750264	**4**	0.814066646	**5**
B40WCO	0.909090896	**3**	0.851278528	**4**
B50WCO	0.918614519	**2**	0.927910981	**2**
B0 Diesel	0.942862264	**1**	0.986886079	**1**
Blend	**75 % Load**	**Rank**	**100 % Load**	**Rank**
B10WCO	0.027193738	**6**	0.081567455	**6**
B20WCO	0.939202171	**3**	0.340056285	**5**
B30WCO	0.971702966	**1**	0.9297006	**1**
B40WCO	0.937230108	**4**	0.751332797	**4**
B50WCO	0.682029616	**5**	0.754716715	**3**
B0 Diesel	0.94050138	**2**	0.894862091	**2**

Table 10 Relative Closeness Ranking

Load (%)	B10WCO	B20WCO	B30WCO	B40WCO	B50WCO	B0 Diesel
25	6	5	4	3	2	1
50	6	3	5	4	2	1
75	6	3	1	4	5	2
100	6	5	1	4	3	2

4. Conclusion

Reducing harmful engine emissions may be achieved by selecting a biodiesel blend that is both biodegradable and sustainable. Using the AHP-TOPSIS approach, this investigation has successfully identified the optimal biodiesel blend for an internal combustion engine based on emission parameters. Using the TOPSIS method, six potential fuel blends were ranked, and the AHP was employed to prioritize the weighting of the emission criterion. CO, HC, CO2, O2, NOx, and smoke were the criteria for evaluation in the engine exhaust emissions. The transesterification process reduces waste cooking oil's acid value, making it suitable for biodiesel production. Different biodiesel blends significantly influence engine emissions, with specific blends reducing pollutant levels. Higher biodiesel blends result in lower CO and HC emissions, improved oxygen utilization, and higher NOx emissions due to higher combustion temperatures. The B30WCO blend exhibits optimal performance at higher engine loads (75% and 100%) in the AHP-TOPSIS study comparison results, while the B0 Diesel blend is most effective at lower engine loads (25% and 50%). Among all the blends, the B10WCO blend has the lowest ranking under all loading conditions. The objective of the ranking approach is to provide a precise assessment of each decision-making technique that has been selected. For future research and testing, the amount of biodiesel blend should be adjusted in minor increments to improve the accuracy of blend selection. The field of alternative fuel research is expanding rapidly, driven by the necessity for enhanced engine efficiency, energy regulations, and environmental concerns.

Acknowledgment

The authors would like to express their gratitude to all those who have assisted them in completing this research.

Nomenclature

WCO	:	Waste cooking oil
AHP	:	Analytical Hierarchy process
TOPSIS	:	Technique for Order of Preference by Si milarity to Ideal Solution
CI	:	Compression ignition
CO	:	Carbon Monoxide
HC	:	Hydrocarbons
CO2	:	Carbon dioxide
O2	:	Oxygen
NOx	:	Nitrogen oxides
λ	:	Eigenvalue
CR	:	Consistency Ratio
RI	:	Random index

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT Author Statement

Tejaswita Kajale: Conceptualization, Writing-original draft
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Jitendra Hole: Data curation, Formal analysis, Supervision
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