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e-ISSN: 2689-4934

ESTEEM Academic Journal Vol 21, September 2025, 81-91

ESTEEM
Academic Journal
(EAJ)

Experimental investigation on density, kinematic viscosity and calorific value of sunflower oil - pentanol binary biofuel blend

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ARTICLE INFO

Article history:
Received 23 January 2025
Revised 5 July 2025
Accepted 18 August 2025
Online first
Published 15 September 2025

Keywords:
Alternative biofuel
Binary blend
Mixture design
Pure vegetable oil

DOI:
10.24191/esteem.v21iSeptember.4680.g5013

ABSTRACT

The usage of fossil fuels as the main energy source has become a serious problem due to concerns over environmental pollution and the rising fuel prices worldwide. Straight Vegetable Oil (SVO), such as Pure Sunflower Oil (PSO), is a possible alternative biofuel to petroleum diesel fuel because of its physical qualities identical to fossil fuel. However, the higher viscosity and density of SVO limit its direct use in combustion engines, which will cause problems such as incomplete combustion and carbon deposits in the chamber due to the high viscosity and density. This work presents an experimental investigation to determine and soptimise the key properties of the Sunflower oil-Pentanol blend, which has the potential to be used to replace the existing fossil fuel. This study proposes a binary biofuel blend of Pure Sunflower Oil (PSO) with higher alcohol Pentanol (PEN). Design-Expert software is used to formulate, optimise, and predict the key properties of this binary biofuel blend. Based on mixture design analysis, a total of 8 blend ratios were obtained, which are 100PSO, 50PSO50PEN, 100PSO, 75PSO25PEN, 100PEN, 50PSO50PEN, 100PEN, and 25PSO75PEN. The developed model and experimental data for the density, kinematic viscosity, and calorific value models all yielded good results, with R^2 values of 0.9999, 1.0000, and 0.9949, respectively. All these responses meet the ASTM D6751 requirements for biodiesel and are suitable for use in a compression-ignition engine.

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https://doi.org/10.24191/esteem.v21iSeptember.4680.g5013

1. INTRODUCTION

The use of vegetable oil as a fuel for diesel engines goes back to when Rudolph Diesel initially used peanut oil in his engine at the Paris Exhibition in 1900 [1]. It is seen that the usage of vegetable oils as diesel fuel is as ancient as the diesel engine. More than 100 years ago, vegetable oils were utilised as a diesel fuel, but only in emergencies such as World War II [1]. Shortly, vegetable oils can replace a portion of petroleum distillates and petroleum-based petrochemicals as their properties are close to diesel. However, their direct usage in compression engines was limited due to their high viscosity and density, resulting in poor fuel atomisation, inefficient combustion, and carbon deposition on the injector, causing significant engine fouling [1-2]. Vegetable oil production has grown across the world in recent years. Depending on their environment, many countries generate various types of vegetable oil. There are around 350 oil-bearing crops recognised, but only soybean, palm, sunflower, safflower, cottonseed, rapeseed, and peanut oils are considered possible alternative fuels for diesel engines [3]. Rapeseed and sunflower oils are primarily produced in the European Union [3].

In contrast, soybean oil is primarily produced in the United States, palm oil is produced mainly in Southeast Asia, and coconut oil is produced mainly in the Philippines [3]. Vegetable oil can be classified into two types: edible and non-edible oils [4]. Oil crops with higher oil yields have the potential to lower production costs. At the moment, edible vegetable oils account for more than 95 % of the world's biodiesel production. Rapeseed oil (84%) is the most common edible oil source, followed by sunflower oil (13%), palm oil (1%), soybean oil, and others (2 %) [5].

Unfortunately, from previous studies, the efficiency of the engine powered by Straight Vegetable Oils (SVOs) is slightly lower than that of fossil fuels. This is due to the higher viscosity, density, low volatility, and heavier molecules in the fuels. This can be solved by bringing the SVO properties closer to those of diesel fuel [4]. Sunflower seed is an excellent source of biomass and biodiesel [5]. It is one of the bioenergy sources among all the edible oils that has piqued the interest of futurists and global policymakers. On a dry weight basis, the seeds have more than 50% oil content [6]. It is an alternative fuel for conventional petroleum-based diesel because it is a sustainable, domestic option with a low environmental impact [7].

Straight Vegetable Oils such as sunflower oil, palm oil, coconut oil, and rapeseed oil have gained much interest because of their benefits as renewable and locally generated energy supplies [8]. The oil is an attractive renewable alternative to replace fossil diesel. It is easy to produce at a low cost and has similar properties to fossil diesel. However, there are several drawbacks to using Straight Vegetable Oils (SVOs) as a fuel for internal combustion engines [9]. The use of SVOs directly will lead to the production of carbon deposits in the combustion chamber, poor fuel atomisation, coking of fuel injectors, ring carbonisation, and lubricating oil [10-12]. These issues happened due to the high viscosity, high density, heavier molecules, and low volatility of Straight Vegetable Oils (SVOs) compared to ordinary fossil fuels. Therefore, the method of blending Sunflower oil with higher alcohol was adopted to solve this issue. In this study, sunflower species are chosen to blend with pentanol to formulate a binary biofuel blend. This binary blend is expected to overcome the above issues while also providing suitable fuel properties for internal combustion engines.

https://doi.org/10.24191/esteem.v21iSeptember.4680.g5013

2. METHODOLOGY

2.1 Material purchase and storage

Pure Sunflower Oil (PSO) is the main material in this to formulate a binary biofuel blend. PSO test fuel was bought at a local supermarket for the binary biofuel formulation. PSO has been discovered to be one of the best raw vegetable oils available. This is due to its renewable nature, long-term viability, and energy content that is nearly identical to that of fossil fuels. The oil is light yellowish, clear, and has a sweetish taste but no odour. The Pure Sunflower Oil utilised in this study is purchased from the local market (Fig. 1).

Meanwhile, pentanol used in this study is purchased from Sigma Aldrich with 99% purity. Pentanol (PEN) has been discovered to be a good corrosion inhibitor that does not affect the engine's fuel lines [13]. PEN is classified as a long-chain alcohol with a high carbon chain. This alcohol is colourless and has a high solubility in stable blends with no phase separation.

Fig. 1. Pure Sunflower Oil

2.2 Blend formulation and preparation

In this study, the mixture design method was used to statistically analyse and statisticallyoptimise the density, viscosity, and calorific values of the PSO-PEN binary biofuel blend. The blends were prepared by blending sunflower oil and pentanol in various percentage ratios. By inputting the design parameters, the mixture design algorithm generated a total of eight experimental runs, consisting of five combinations of PSO-PEN blends and three replicate tests. Table 1 shows the list of blend ratios prepared according to the volumetric percentages (%) as proposed by the Design Expert Software. The PEN and PSO were measured accurately by using a set of measuring cylinders before they were blended. All blends were prepared without the presence of surfactant. Each PSO-PEN blend was properly mixed using the magnetic stirrer at 300rpm for 30 minutes to ensure homogeneity of the blend, as shown in Fig. 2.

2.3 Fuel properties characterisation

The physicochemical properties of PSO-PEN blends were established using American Society for Testing and Materials (ASTM) and in-house standards. Three different physicochemical properties were analysed, namely, density, viscosity, and calorific value. These three key properties are important in developing biofuel blends because density and viscosity can affect the fuel injection pump system, and

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calorific value is the energy emitted from the combustion of the biofuel in the combustion chamber, ensuring mixture compatibility in compression ignition engines. As a result, ensuring that this blend works efficiently is an important part of the methodological process. The densities (kg/m³) of the PSO-PEN blends are determined by measuring the blend volume using a 25 ml pycnometer (Gay-Lussac) following the DIN ISO 3507. The density was then calculated by dividing its mass by volume. The viscosities (mm²/s) of the PSO-PEN blends are determined using an ASTM D445 glass capillary viscometer (Cannon-Fenske). While the Calorific Values (CV) of the fuel samples are determined using a Bomb Calorimeter (IKA C200) according to ASTM D240.

Table 1. List of Prepared Blends

Fuel Blends (vol.% %)		Nomenclature
PSO	Pentanol	
100	0	100PSO
50	50	50PSO50PEN
100	0	100PSO
75	25	75PSO25PEN
0	100	100PEN
50	50	50PSO50PEN
0	100	100PEN
25	75	25PSO75PEN

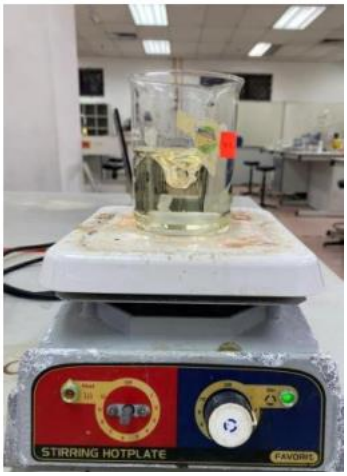

Fig. 2. Blend preparation using a magnetic stirrer

2.4 Data analysis - Analysis of Variance (ANOVA)

ANOVA is a statistical method that divides observed aggregate variability within a data set into two parts: systematic and random factors. Random data has no statistical impact on the data set, whereas systematic factors do. In a regression analysis, the ANOVA test is used to measure the impact of independent factors on the dependent variable. Design Expert 12 software is used to do the analysis. For given values of each factor, the equation in terms of actual factors may be used to create predictions about the response. For each factor, the levels should be indicated in the original units. This is because the coefficients are scaled to suit the units of each factor, and the intercept is not at the centre of the solution

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space. This equation should not be used to evaluate the relative influence of each factor. Optimisation studies for this blend are conducted using ANOVA to investigate the predicted maximum values of each measurement criterion.

3. RESULTS AND DISCUSSION

3.1 Blend phase separation test

The phase separation test is done to observe the separation of each blending mixture. There was a total of three blends in 100ml sample bottles, which were stored at room temperature as shown in Fig. 3. To determine the stability of the samples, they were kept for a required monitoring period. Table 2 shows the monitoring results of the past 30 days. All the PSO-PEN blends show no sign of separation, and the blend colour remains clear and homogeneous. This indicates that PSO-Pentanol blends are stable and suitable for engine application and long-term storage.

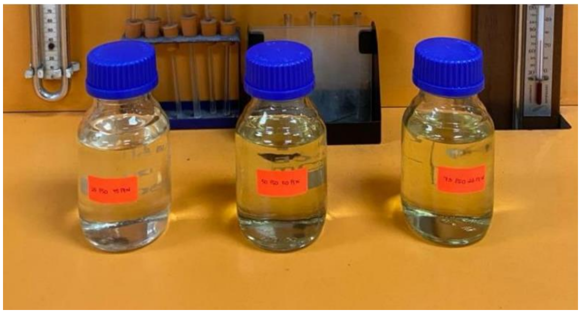

Fig. 3. PSO-Pentanol Blends shows a clear and homogeneous blend after being stored for a month.

Table 2. Phase separation test results

Monitoring Period	Monitoring Frequency	Result
1 hour	Every 5 minutes	No Phase Separation
24 hours	Every 30 minutes	No Phase Separation
7 days	Every 24 minutes	No Phase Separation
30 days (a month)	Every 72 minutes	No Phase Separation

3.2 Physicochemical properties of sunflower oil and pentanol blends

Table 3 shows the basic physicochemical properties of PSO and PEN. PSO's kinematic viscosity was greater than the ASTM standard, limiting its direct use as a diesel engine fuel. However, PSO contains a relatively high CV close to that of diesel fuel, making it a potential biofuel feedstock. A high CV is important to produce a good engine thermal efficiency and reduce fuel consumption. Thus, PSO has shown its potential as a biofuel feedstock. However, oil with high viscosity and density has a longer fuel spray penetration, which increases the probability of fuel impact, resulting in the creation of carbon deposits and an increase in gaseous pollutants [14]. Therefore, to reduce the density and viscosity of the PSO, a PSO-PEN blend was studied.

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Meanwhile, PEN properties were found within the ASTM range, which marks it as suitable for engine application. PEN has low viscosity and density properties, which are important to reduce the viscosity of PSO. Low viscosity fuel is important to produce a good fuel injection spray and fuel atomisation.

Table 3. Basic physicochemical properties of PSO-PEN blend

Fuel Properties	Sunflower Oil	Pentanol	Fossil Diesel	ASTM D6751
Kinematic viscosity at 40°C (mm^2/s)	33.72	2.89	3.5	1.9-6.0
Density at 15°C (kg/m^3)	920	815	843.1	880
Calorific Value (MJ/kg)	39.60	34.65	44.8	-

3.3 The effect of various blends on density

The density measurement was repeated four times for each number of runs to obtain an accurate average value for all blends. As shown in Table 4, the average result of the density measurement for all the blends has been recorded in the table. The data obtained from the experiment of the density measurement is then recorded into the Design Expert Software to be analysed. The density graph in Fig. 3 shows the relationship between the density of PSO-PEN. It was observed that the trend is linear, indicating that the density of the blend decreases proportionally with the increase in pentanol percentage. These results indicate that PEN is capable of being an agent to reduce the viscosity of PSO. In practice, density is a critical property of biofuels as it affects the combustion efficiency and fuel injection in engines. Overall, the graph has provided valuable insight for designing a biofuel blend with specific properties.

Table 4. PSO-PEN blends density results

No. of Run	PSO (%)	Pentanol (%)	Average density (kg/m^3)
1	100	0	951.84
2	100	0	951.46
3	50	50	898.73
4	50	50	897.67
5	75	25	925.21
6	25	75	871.22
7	0	100	843.23
8	0	100	843.10

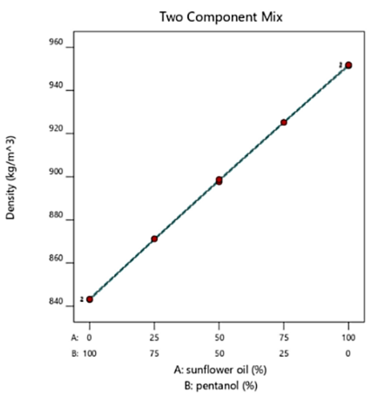

Fig. 3. The model graph of the correlation between blend ratios and density

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3.4 The effect of various blends on kinematic viscosity

The kinematic viscosity of all the blends has been tested using the ASTM D445 glass capillary viscometer (Cannon-Fenske). Different sizes of the tube that is used to determine the suitability of each blend according to the kinematic viscosity range required for each size of the tube. The kinematic viscosity measurement was repeated three times for each number of runs to obtain an accurate average value for each blend ratio. As shown in Table 5, the average result of the kinematic viscosity measurement at a temperature of 40 °C for all the blends has been recorded.

Table 5. PSO-PEN blends kinematic viscosity results

No. of Run	PSO (%)	Pentanol (%)	Average Kinematic Viscosity (mm²/s)
1	100	0	39.3822
2	100	0	39.5928
3	50	50	8.8369
4	50	50	8.8249
5	75	25	15.6567
6	25	75	5.3141
7	0	100	3.1442
8	0	100	3.2601

The data obtained from the experiment of the kinematic viscosity measurement is then recorded into the Design Expert Software to be analysed. The kinematic viscosity graph in Fig. 4 shows a graph obtained based on the Design Expert Software results. The graph shows that as the amount of PSO increases, the viscosity rises significantly. This is due to the PSO having the highest viscosity compared to PEN. This non-linear trend suggests that PSO-PEN blends interact chemically to create unique outcomes. Viscosity is an important fuel property as it impacts fuel flows and atomisation in the engine. A blend of PSO with PEN offers a lower viscosity; however, a higher ratio of PSO will result in a penalty of CV values. Therefore, finding the optimal blend ratio is important to meet both performance and practical needs.

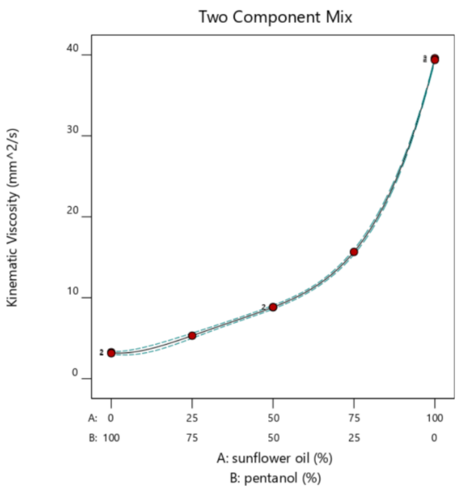

Fig. 4. The model graph of the correlation between blend ratios and kinematic viscosity

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3.5 The effect of various blends on calorific value

Calorific Values (CV) are an important factor to consider when choosing a fuel. CV is the amount of heat created when one gram of fuel is completely burned. This value represents the combustion efficiency by determining the chemical energy of the fuel. Calorific Values (CV) of all the blends have been tested using a Bomb Calorimeter (IKA C200) according to ASTM D240. The Bomb Calorimeter provided high-accuracy and repeatability data, and the accurate data obtained will benefit the study. The CV measurement was repeated three times for each number of runs to obtain an accurate average value for each blend ratio. As shown in Table 5, the average results of the CV measurement for all the blends have been recorded in the table.

The data obtained from the experiment of the CV measurement is then recorded into the Design Expert Software to be analysed. The CV graph in Fig. 5 shows the linear trend, with CV increasing as the percentage of PSO increases. PSO at 100% obtains the highest CV at around 39600 kJ/kg, while 100% PEN has the lowest CV at around 34700 kJ/kg. The increasing calorific value with higher sunflower oil content suggests that sunflower oil contributes significantly to the energy potential of the blend. However, while higher sunflower oil ratios enhance the calorific value, other factors such as viscosity and density characteristics must also be considered in optimising the blend. This graph provides insight into the energy performance of the PSO-PEN blend. An increase in CV is expected to improve the combustion efficiency of the engine [15].

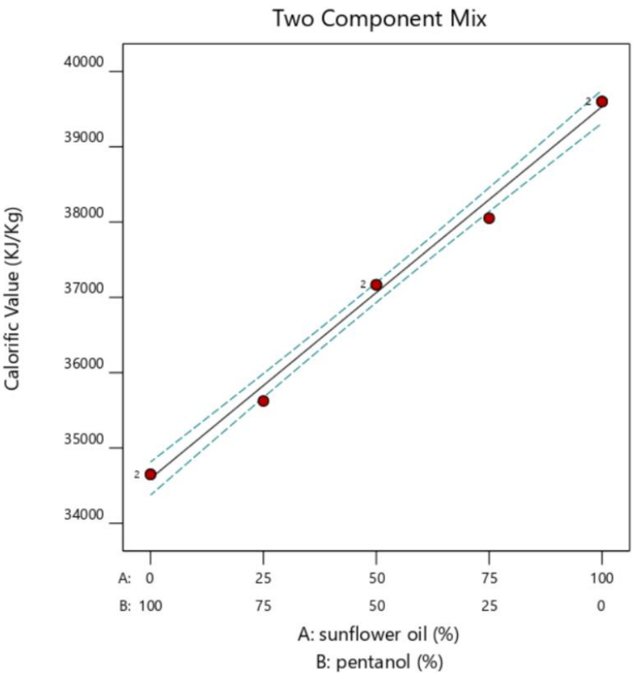

Fig. 5. The model graph of the correlation between blend ratios and Calorific Value

https://doi.org/10.24191/esteem.v21iSeptember.4680.g5013

Table 5. PSO-PEN blends calorific values results

No. of Run	PSO (%)	Pentanol (%)	Average Calorific Value (kJ/kg)
1	100	0	39690
2	100	0	39600
3	50	50	37152
4	50	50	37167
5	75	25	38051
6	25	75	35624
7	0	100	34710
8	0	100	34653

3.6 Analysis of variance (ANOVA)

The significance of each biofuel binary blend was analysed using Analysis of Variance (ANOVA). Table 6 shows the ANOVA results for the density, kinematic viscosity, and calorific value models. From the ANOVA results, the F-values for the density, kinematic viscosity, and calorific value mixture design models were 40675.61, 41918, and 1178.56, respectively. All models were significant, based on these results—furthermore, the Prob.> F values for these three models were less than 0.05, indicating that the models were significant.

Furthermore, both models' R^2 showed high values, indicating that the created models and experimental data were well-matched. The term "adequate precision" refers to the signal-to-noise ratio, which should be larger than 4. The precision ratios for the density, kinematic viscosity, and calorific value models in this experiment were 380.2951, 463.239, and 64.7337, respectively. All three approaches may be utilised to navigate the design space if there is enough signal.

Table 6. ANOVA Results for density, kinematic viscosity and calorific value

Source	Density	Kinematic Viscosity	Calorific Value
Model	Significant (Linear)	Significant (Quartic)	Significant (Linear)
F value	40675.61	41918	1178.56
Prob > F	< 0.0001	< 0.0001	< 0.0001
R^2	0.9998	1.0000	0.9949
Adjusted R^2	0.9998	1.0000	0.0041
Predicted R^2	0.9997	NA	0.9921
Adequate Precision	380.2951	462.239	64.7337

4. CONCLUSION

In conclusion, this study proposes and analyses a new biofuel blend based on Pure Sunflower Oil (PSO) blended with higher alcohol, Pentanol (PEN). The method used in this study is a blending method that requires a simple process and low cost. From this study, it was found that the binary mixture of PSO-PEN provides a biofuel with lower viscosity, density, and enhanced CV. Low viscosity and high CV properties are intended to improve fuel spray characteristics and atomisation, resulting in increased combustion efficiency. The ideal blend of PSO-PEN has been identified as a new potential source of renewable biofuel, according to these studies. However, although density, kinematic viscosity, and calorific value are the three most important fuel variables to consider when analysing internal combustion engine characteristics, there

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are more fuel characteristics that need to be considered as well. Consequently, the three major properties obtained from these experiments have been considered to meet the study's objectives.

5. ACKNOWLEDGEMENTS

The authors of this paper would like to express their sincere gratitude to Universiti Teknologi MARA (UiTM) for the Fundamental Research Grant Scheme (FRGS) from the Malaysian Higher Education Department (Grant No.600-RMC/FRGS 5/3 (087/2024)) for the financial support for this research.

6. CONFLICT OF INTEREST STATEMENT

We declare that there is no conflict of interest regarding the publication of this paper.

7. AUTHORS' CONTRIBUTIONS

Hazim Sharudin: Conceptualisation, data curation, formal analysis and writing original draft; **Sharzali Che Mat**: Conceptualisation, supervision, editing and validation; **Nur Irsalina Huda Nazri**: Conceptualisation, methodology, formal analysis; **Muhammad Arif Ab Hamid Pahmi**: Conceptualisation, writing review and format editing; **Azmi Husin**: Conceptualisation, formal analysis and validation; **Noor Iswadi Ismail**: Formal analysis and validation; **Mahamad Hisyam Mahamad Basri**: Writing review and format editing. **Rozaini othman**

8. REFERENCES

[1] Golikova, A., Shasherina, A., Anufrikov, Y., Misikov, G., Kuzmenko, P., Smirnov, A., Toikka, M., & Toikka, A., "Excess Enthalpies Analysis of Biofuel Components: Sunflower Oil–Alcohols Systems," *International Journal of Molecular Sciences*, vol. 25, no. 6, p. 3244, 2024. Available:https://doi.org/10.3390/ijms25063244

[2] S. Che Mat, M. Y. Idroas, M. F. Hamid, and Z. A. Zainal, "Performance and emissions of straight vegetable oils and its blends as a fuel in diesel engine: A review," *Renew. Sustain. Energy Rev.*, vol. 82, no. February, pp. 808–823, 2018. Available:https://doi.org/10.1016/j.rser.2017.09.080

[3] B. Sajjadi, A. A. A. Raman, and H. Arandiyan, "A comprehensive review on properties of edible and non-edible vegetable oil-based biodiesel: Composition, specifications and prediction models," *Renew. Sustain. Energy Rev.*, vol. 63, pp. 62–92, 2016. Available:https://doi.org/10.1016/j.rser.2016.05.035

[4] S. Che Mat, M. Y. Idroas, Y. H. Teoh, and M. F. Hamid, "Optimisation of viscosity and density of refined palm Oil-Melaleuca Cajuputi oil binary blends using mixture design method," *Renew. Energy,* vol. 133, pp. 393–400, 2019. Available:https://doi.org/10.1016/j.renene.2018.10.017

[5] Polat, F., Sarıdemir, S., Gad, M. S., El-Shafay, A. S., & Ağbulut, Ü., "Enhancing diesel engine performance, combustion, and emissions reductions under the effect of cerium oxide nanoparticles with hydrogen addition to biodiesel fuel," *International Journal of Hydrogen Energy*, vol. 83, pp. 884-896, 2024. Available:https://doi.org/10.1016/j.ijhydene.2024.08.031

[6] V. Ariharan and N. Parameswaran, "Studies on Sun Flower Oil for Its Potential Use As Biodiesel," *Asian J. Pharm. Clin. Res.,* vol. 9, no. 1, 2016. [Online]. Available: http://innovareacademics.in/journals/index.php/ajpcr/article/view/10023

https://doi.org/10.24191/esteem.v21iSeptember.4680.g5013

[7] Dhanarasu, M., RameshKumar, K. A., & Maadeswaran, P., "Effect of acetone as an oxygenated additive with used sunflower oil biodiesel on performance, combustion and emission in diesel engine," *Environmental Technology*, vol. 43, no. 24, pp. 3682-3692, 2022. Available:https://doi.org/10.1080/09593330.2021.1931471

[8] L. Aguado-Deblas et al., "Outlook for direct use of sunflower and castor oils as biofuels in compression ignition diesel engines, being part of diesel/ethyl acetate/straight vegetable oil triple blends," *Energies*, vol. 13, no. 18, 2020. Available:https://doi.org/10.3390/en13184836

[9] L. Aguado-Deblas et al., "Biofuels from Diethyl Carbonate and Vegetable Oils for Use in Triple Blends with Diesel Fuel: Effect on Performance and Smoke Emissions of a Diesel Engine," *Energies*, vol. 13, no. 24, p. 6584, 2020. Available:https://doi.org/10.3390/en13246584

[10] Uyar, M. M., Çıtlak, A., & Demirpolat, A. B., "Investigation of performance and emission values of new type of fuels obtained by adding MgO nanoparticles to biodiesel fuels produced from waste sunflower and cotton oil," *Industrial Crops and Products*, vol. 222, p. 119712, 2024. Available:https://doi.org/ 10.1016/j.indcrop.2024.119712

[11] Siyal, A. A., Mohamed, R. M. S. R., Musa, S., Rassem, H. H., & Khamidun, M. H., "A review of the performance of geopolymer catalysts for biodiesel production," *Biomass and Bioenergy*, vol. 190, p. 107373, 2024. Available:https://doi.org/10.1016/j.biombioe.2024.107373

[12] Vergel-Ortega, M., Valencia-Ochoa, G., & Duarte-Forero, J., "Experimental study of emissions in single-cylinder diesel engine operating with diesel-biodiesel blends of palm oil-sunflower oil and ethanol," *Case Studies in Thermal Engineering*, vol. 26, p. 101190, 2021. Available:https://doi.org/10.1016/j.csite.2021.101190

[13] Dhanarasu, M., RameshKumar, K. A., & Maadeswaran, P., "Effect of acetone as an oxygenated additive with used sunflower oil biodiesel on performance, combustion and emission in diesel engine," *Environmental Technology*, vol. 43, no. 24, pp. 3682-3692, 2022. Available:https://doi.org/10.1080/09593330.2021.1931471

[14] Adhikesavan, C., Ganesh, D., & Augustin, V. C., "Effect of quality of waste cooking oil on the properties of biodiesel, engine performance and emissions," *Cleaner Chemical Engineering*, vol. 4, p. 100070, 2022. Available:https://doi.org/10.1016/j.clce.2022.100070

[15] Muzammil, A., Riaz, F., Nadeem, H. U., Muzammil, S., Waris, K., Samra, H., & Siddique, M. H., "Sunflower oil" in *Green Sustainable Process for Chemical and Environmental Engineering and Science*, pp. 31-40, Elsevier, 2021. Available:https://doi.org/10.1016/B978-0-12-821886-0.00004-X