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Abstract: The present investigations aim to prepare the biodiesel using methyl esters of waste fish oil and waste coconut oil to determine the Physico-Thermal properties of combined biodiesel. The study investigated biodiesel blends (15%-90%) from MEWFO, MEWCO, and MEWFCO with diesel. Through meticulous analysis, significant physico-thermal properties (calorific value, density, and kinematic viscosity) were determined, revealing insights into their comparative performance. This analysis enriches our understanding of biodiesel characteristics and holds promising implications for optimizing biofuel formulations in the energy sector. Notably, these developed models demonstrate exceptional statistical significance, boasting a confidence interval of 95%. Moreover, the coefficient of determination for predicted Physico-thermal properties—calorific value, kinematic viscosity, and density—stands remarkably high at 98.38%, 99.58%, and 98.87%, respectively. Such robust predictive accuracy not only enhances our understanding of biodiesel characteristics but also holds profound implications for optimizing its utilization and production processes.

Keywords: Waste Fish Oil; Waste Coconut Oil; Regression Analysis; Biodiesel. ANOVA

1. Introduction

Biodiesel plays a crucial role in the current energy landscape as societies strive to reduce dependence on fossil fuels and mitigate environmental impacts associated with their use. The importance of biodiesel lies in its potential to provide a renewable and sustainable source of energy, thereby reducing greenhouse gas emissions and promoting energy security. Relying solely on traditional feedstocks like soybean or palm oil can lead to issues such as deforestation, land use change, and competition with food crops. By exploring alternative feedstocks like waste fish oil and coconut oil, we can diversify the sources of biodiesel production, reducing pressure on food crops and ecosystems. Waste fish oil and coconut oil are byproducts of existing industries (e.g., food processing, aquaculture) and often pose disposal challenges. Converting these waste streams into biodiesel not only provides a valuable energy resource but also helps in waste management and reduces environmental pollution. By diversifying feedstock sources, we can enhance energy security, reduce environmental impacts, and foster economic development, contributing to a more sustainable energy future. Energy is an important parameter when it comes to economical development, social development and human welfare. In recent times for modernization and industrialization were increased due to the energy requirements. Hence, many countries import crude oil from different resources; therefore due to the large requirements of crude oil also play a major role. The need for alternative source is required by which import of crude oil can be reduced[1)]. Fossil fuels were limited resources and hence more usage will lead to extinction of resources by continuous usage of fuels therefore alternative resources for diesel is started[2)]. To use of fossil fuel were also a major reason for emissions which leads to environmental pollutions to solve these issues an alternative fuel to solve the problem and global energy deficit[3)]. When compared to regular diesel, biodiesel has a greater flash point, is completely biodegradable, is nontoxic, and reduces air pollutants, hydrocarbons, and any other particle matter[4)].

The major potential of biodiesels are derived from plants, animals, waste cooking oil, vegetable oil, municipal wastes and so on[5,6,7,8)]. Recently biodiesel productions were from vegetable oil, industrial waste oil, and spent oil. Reused of biodiesel would not be a toxic in nature and can be degraded easily because of high flash point and less pollution. Therefore blending of biodiesel with diesel can be used for engines[9)]. The biodiesel was prepared using Moroccan waste fish oil as a raw material and to reduce the FFAs dual step esterification-transesterification were used. The extracted biodiesel was does not contain any trace of glycerol and it meet the standards[10)]. Experimentations were conducted for B20 (20% biodiesel) and B100 (100% biodiesel). The biodiesel properties were determined. The measured values for density was 0.838 (B20) and 0.900 (B100), kinematic viscosity was 5.17 (B20) and 5.30 (B100) and calorific values was 44.88 (B20) and 40.79 (B100)[11)]. Comparisons were made for fish oil (F20) and mahua oil (M20) with full load of 27.83% diesel with 25.56% of fish oil and 23.27% for mahua oil. The properties were compared for both the blends and the density for F20 was 0.838 gm/cm^3 and M20 was 0.837 gm/cm3, kinematic viscosity for F20 was 3.17 at 40°C and M20 was 3.20 at 40°C, calorific value for F20 was 44.88 MJ/Kg and M20 was 41.39 MJ/Kg were found[12)]. Amazon sailfin catfish was used to produce biodiesel and the physical and chemical properties were evaluated. This fish has a greatest threat in aquatic system, causing environmental problems in the regions and a serious economical problem. The methyl ester concentration was 47.03% m/m corresponded with methyl esters with saturated chains. Finally minerals were analyzed by using atomic absorption showed that quality of fuel was not compromised. Hence, to get a feasible biodiesel of Amazon sailfin catfish oil has a low cost raw material for alternative commercial use to reduce the ecological impact[13)]. For bio-energy generation fish oil wastes play a predominant role in Indian sub-continent. Due to abundant waste resource could serve an economical feedstock for the biodiesel preparation. Hence, discarded fish parts can be used to production of high quality biodiesel using methanol and sodium meth oxide as a homogenous catalyst under moderate operational conditions. The results revealed that around 98% of high pure biodiesel of fatty acid methyl ester can be extracted[14)]. It was discovered that just a small portion of the whole fish processing roughly 50% was used for fish waste. Depending on the type and variations, the oil content ranges from 40% to 65%. Thus, there was potential to use the fish waste and transform it into biodiesel, manure, or biogas for the creation of electricity [21)]. The fatty acid composition of a specific biodiesel can be used to compute its iodine value and saponification value[22)].

The excessive use of fossil fuels has caused significant harm to human health and the environment. To study this further, the researchers focused on determining the productivity of microalgae biomass and how temperature and time affect the production of biodiesel. When analyzing the biodiesel produced from Synchronous HS-9 microalgae, they found that it contained 3.16% monounsaturated fatty acids, 18.96% polyunsaturated fatty acids, and 77.87% saturated fatty acids[26)]. The main objective of the study was to determine how different concentrations of NPK medium affect the biomass weight of Leptolyngbya HS-16. The researchers used BBM as the control medium and NPK media with concentrations of 80 ppm, 160 ppm, and 240 ppm as the treatment mediums. The findings revealed that Leptolyngbya HS-16 thrived better in the NPK medium with a concentration of 80 ppm compared to the other concentrations. This was evident from the average biomass produced, reaching a peak of 3.008 mg/L, and the length of the Leptolyngbya HS-16. Furthermore, the 80 ppm NPK medium yielded a lipid content of 45%[27)]. Warmer temperatures and increased rainfall have impacted the glaciers in the Tien Shan Mountain system, resulting in more water flowing into the Ili River. However, water usage for agriculture did not have a noticeable effect. It is crucial to monitor changes in the flow rate as the entire ecosystem relies on the water level. Although the construction of the Kapchagay Reservoir has influenced the lake's water level and the volume of water in the river, the impact is currently overshadowed by the glaciers' sensitivity. The future outcome of the situation is unpredictable, but it is advised to closely observe and monitor it[28)]. The extracted biodiesel was mixed with commercially available diesel in different proportions for the study. The performance and emission analysis were conducted on a single cylinder four-stroke diesel engine. The analysis showed a decrease in brake specific energy consumption and a slight increase in brake thermal efficiency. The exhaust analysis revealed a significant reduction in engine emissions such as carbon dioxide, carbon monoxide, and hydrocarbons, leading to lower smoke opacity[29)]. Biofuel production is considered a significant solution for reducing human-caused CO_2 emissions, mitigating the greenhouse effect, and slowing down global warming. Thermochemical conversion is considered the most effective method for generating biofuels from biomass while minimizing the potential for global warming. Torrefied biomass is used to convert biomass material into a useful energy source while also enhancing its properties through torrefaction[30)]. The study examines the working principle of evaporative cooling and discusses various types such as direct evaporative cooling (DEC), indirect evaporative cooling (IEC), and combined evaporative cooling systems (IDEC). Evaporative cooling works by increasing the humidity level of the air, resulting in a cooler environment. The findings suggest that evaporative cooling holds promise for reducing energy consumption in hot and arid climates. It is also considered an economical and environmentally friendly cooling solution compared to conventional HVAC methods. Implementing evaporative cooling can lead to significant savings in fossil fuel usage (coal, petroleum, and natural gas) and a reduction in carbon emissions associated with buildings[31)]. To overcome these obstacles, coconut shells are subjected to pyrolysis, converting them into biochar to increase their calorific value and minimize smoke formation during combustion. Further, biochar briquetting is employed to enhance energy density and ensure uniform size. This study aimed to investigate the impact of different binders and their concentrations on the characteristics of biochar briquettes. Molasses, cow manure, and horse manure were used as binders. Among them, molasses proved to be the most suitable binder due to its adhesive properties and sufficient moisture content. The best characteristics of briquettes were observed when using a biochar-to-molasses ratio of 70:30. In drop tests conducted at heights of 1 meter and 1.8 meters, biochar briquettes with molasses as a binder demonstrated 99% size stability, indicating their durability and resistance to breakage[32)]. The study revealed that coconut shell biomass contains several significant components, and the temperature during the processes has a notable impact on both the characteristics of the resulting charcoal and the composition of the syngas. Lower temperatures resulted in a higher yield of charcoal (41.85%), while higher temperatures produced greater energy output (32 MJ/kg). At the maximum temperature, the gas composition was found to be favorable, with concentrations of 14.15% H2, 15.22% CO, 13.98% CO2, and 10.13% CH4. These findings highlight the potential of coconut shell biomass as a valuable energy resource[33)]. With the ever-evolving technology and growing energy demands, superconducting materials have become essential due to their extremely low electrical resistance. In this study, researchers focused on analyzing Niobium (Nb) thin films synthesized through magnetron sputtering under different sputtering conditions. The findings revealed that Niobium Nitride (NbN) demonstrates superconductive properties when operated at elevated temperatures. The optimal growth conditions were observed at an N2 partial pressure of approximately 15 Standard Cubic Centimeters per Minute (SCCM), with power densities ranging from 200 to 500W. At these conditions, the critical temperature for superconductivity was determined to be 14.5K[34)]. To provide valuable research data for both researchers and managers while contributing to the existing body of knowledge in this field. Through this review, various factors, functions, and the level of attention they received were identified, along with any existing gaps. The results revealed that selection and recruitment, as well as training and development, received the highest level of attention, with 87.5% and 75% respectively. On the other hand, disciplines management and socialization received the least attention, with only 6.25% and 3.12% respectively[35)]. To stabilize the rise in surface temperature to 1.5°C compared to pre-industrial levels, renewable energy requirements within the global energy supply must be met. To address the dual challenge of mitigating climate change and meeting escalating energy demands without exhausting fossil fuel reserves, the cultivation of bioenergy feedstocks holds promise as a viable alternative[36)].

Waste fish and coconut were gathered for the current research' biodiesel production as source materials. To create biodiesel, the extracted oil was treated with potassium hydroxide for transesterification and sodium hydroxide for saponification. The physical and thermal characteristics of the chosen volume percentage of waste fish oil and coconut oil were established. Finally, using statistical analysis, create prediction models for a few selected parameters, such as density, kinematic viscosity, and calorific value.

2. Experimental details

The detailed flow of experimentation and analysis of physico-thermal properties of prepared biodiesel is shown in Fig. 1. Waste fish oil and coconut oil were collect from restaurants, large food service and processing unit. The collected oil contains free fatty acids; therefore esterification process is carried out. This process is nothing but chemical reaction, it includes the reaction of alcohol with an acid chloride mechanism, and ester product contains the alkyl group with alkoxide combinations. Experimental investigations are conducted to produce methyl ester of waste fish oil and coconut oil is by using esterification process and is shown in Fig. 2 (a) – (b).

To process the esterification four steps were used such as heating, stirring, titration and separation process. Initially waste cooking oil and coconut oil mixture is taken in a round bottom flask and it is heated above 60°C and it allows to cooling, then 50ml of isopropyl alcohol and few drops of phenolphthalein indicator were added to the 5gm of oil in a 250ml conical flask. Based on the free fatty acid value and the sulphuric acid, 75ml of methanol is added to heat the mixture. Then the mixture is completely stirred for 1 hour and is shown in Fig. 1 (a). The mixed solution is titrated against 0.1N NaOH (0.1 Normality NaOH solution by mixing 2grms of NaOH crystals with 500 ml of water) in the burette. Then it starts to change the color from orange – yellow to dark link then note down the reading (Fig. 1 (b)). The collected mixture is poured into the separatory funnel and is shown in Fig. 1 (a). The collected oil is separated from the methanol which had a free fatty acid, repeated the procedure until the free fatty acid is reduced to 3. After that transesterification process is used to separate the glycerol from the oil to produce the biodiesel. Finally, to reduce the impurity in the biodiesel water wash is necessary to get a pure biodiesel.

Using ASTM standards, the prepared biodiesel's Physico-thermal characteristics, such as density, kinematic viscosity, and calorific value, were assessed [20]. The total number of samples (19 Nos), in these includes waste fish oil (WFO) blend with diesel (6 Nos), Waste coconut oil (WCO) blend with diesel (6 Nos), mixture of waste fish oil and waste coconut oil blend with diesel (6 Nos) and pure diesel (1 No.).

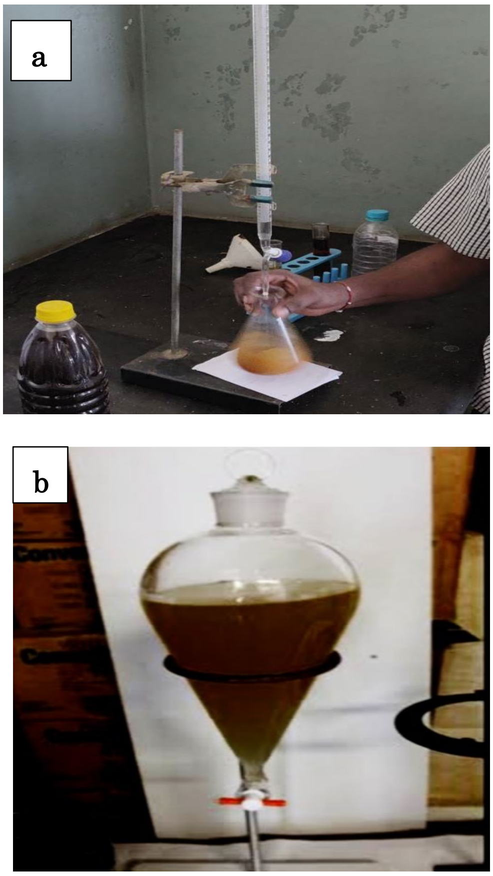

Fig. 1: Steps involved in esterification process: a) Titration Process b) Separation Process

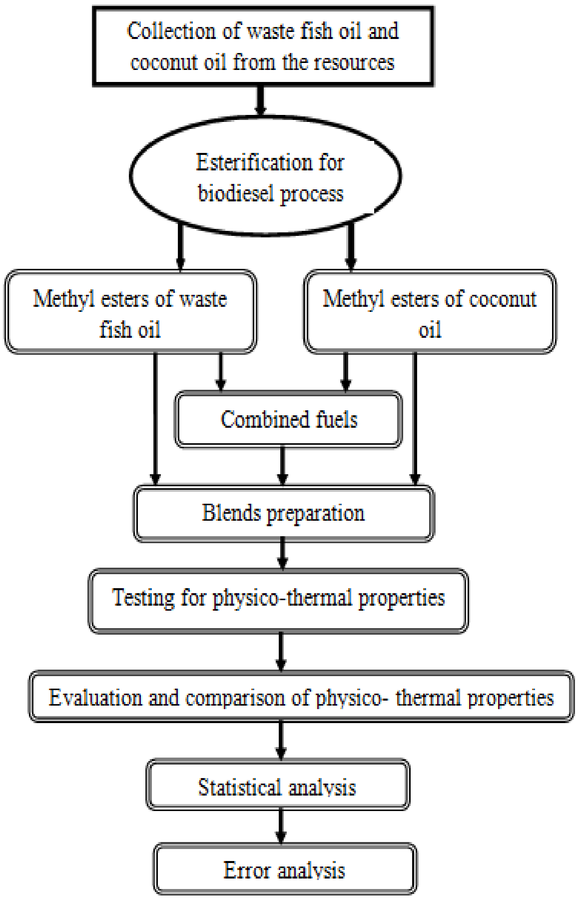

Fig. 2: Methodology flow chart

3. Results and Analysis

The prepared biodiesel blends such as B0 (100% diesel), B15 (15% of biodiesel with 85% of diesel), B30 (30% of biodiesel with 70% of diesel), B45 (45% of biodiesel with 55% of diesel), B60 (60% of biodiesel with 40% of diesel), B75 (75% of biodiesel with 25% of diesel) and B90 (90% of biodiesel with 10% of diesel) are tested for density (ASTM D-941), kinematic viscosity (ASTM D-445/17A) and calorific value (ASTM D-240). For MWFO 6 combinations are considered with diesel, for MWCO 6 combinations are considered, similarly combination of MWFC (MWFO and MWCO) 6 combinations are considered for experimentation. Whereas in case of combined biodiesel blends B15 (7.5% of MWFO and 7.5% of MWCO with 85% of diesel), B30 (15% of MWFO and 15% of MWCO with 70% of diesel), B45 (22.5% of MWFO and 22.5% of MWCO with 55% of diesel), B60 (30% of MWFO and 30% of MWCO with 40% of diesel), B75 (37.5% of MWFO and 37.5% of MWCO with 25% of diesel) and B90 (45% of MWFO and 45% of MWCO with 10% of diesel).

For all the combinations taken into consideration, graphs for density vs. blends, kinematic viscosity vs. blends, and calorific value vs. blends were generated based on the experimental studies. For all combinations, it was found that the blend percentage from 15% to 90% by volume increases as density and kinematic viscosity rise. The blended samples showed increased density and viscosity, mainly influenced by the higher density and viscosity of methyl ester of waste fish oil and waste coconut oil. Additionally, as the blend percentage increased from 15% to 90%, there was a noted decrease in calorific value. This drop in calorific value is attributed to the lower calorific values of the methyl esters used in the blends. These components may experience higher stress and wear due to the altered fuel properties, potentially leading to decreased reliability and increased maintenance requirements.

For blends ranging from 15% to 90%, it was discovered that the characteristics of MWFO, MWCO, and MWFC varied by 0.722% to 3.846% (MWFO), 0.121% to 3.169% (MWCO), and 0.602% - 3.395% (MWFCO) for calorific value, respectively. In case of kinematic viscosities of variance were found to be 8.368% - 39.790% (MWFO), 2.953% - 36.464% (MWCO) and 6.882% - 38.666% (MWFC) and in case of density the variance were found to be 2.247% - 8.741% (MWFO), 4.044 – 10.561% (MWCO), and 2.426% - 9.752% (MWFC) for prepared blended samples are shown in Fig. 3 to 5.

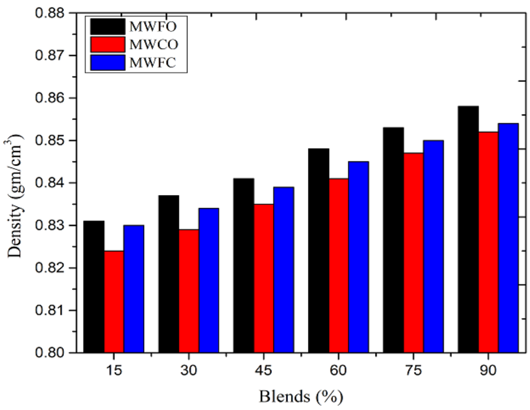

Fig. 3: Variation of density on blends (%) for MWFO, MWCO and MWFC

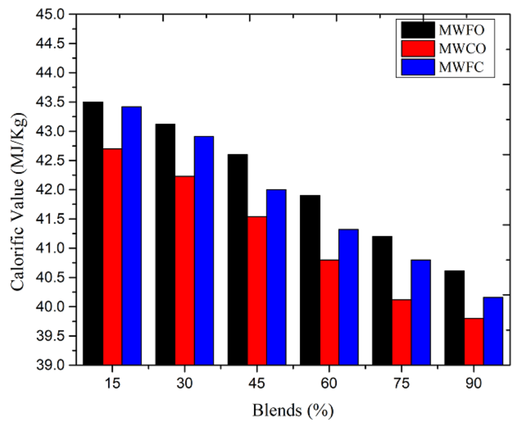

Fig. 4: Variation of calorific value on blends (%) for MWFO, MWCO and MWFC

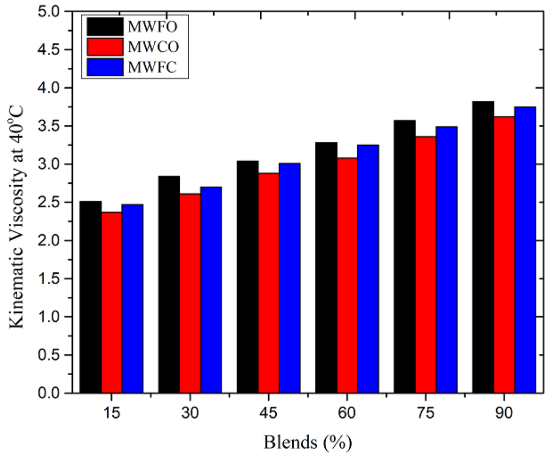

Fig. 5: Variation of kinematic viscosity on blends (%) for MWFO, MWCO and MWFC

4. Statistical Analysis of Physico-thermal properties of blended samples

To determine the effectiveness of various factors and assess the percentage contribution of input parameters such pure diesel, waste fish oil, waste coconut oil, and combination biodiesel (waste fish oil and coconut oil) on physico-thermal properties, ANOVA and regression analysis were used. Backward elimination approach was taken into consideration when performing the analysis to examine the response and continuous predictor with a 95% confidence interval (P 0.05) [15, 17, 18, 19].

The detailed parametric estimations were carried out of continuous predictors on response variable. Based on the F-test and T-test the performances of input variables were determined. ANOVA analysis [23,24,25] for density, kinematic viscosity and calorific values of estimated F-values of input variables are grater than F tabulated (1, 3, 5) and estimated T-values are grater than T-tabulated and is shown in table 1 – 6. Hence the experimental measured values are reasonably good comparing with the predicted values. Coefficients of determination for all the three properties are 98.38%, 99.58%, 98.87% and is represented in equations 1, 2, and 3 respectively

In Figs 6, 7, and 8, both the experimental data and the values predicted by the equations are displayed for density, kinematic viscosity, and calorific values, respectively. To assess the accuracy of the predicted equations, error plots were generated. These error plots illustrate the deviations between the predicted values and the actual experimental data. Notably, the error distribution appears random, with discrepancies occurring on both sides of the reference line (ranging from +1 to -1). This symmetrical distribution suggests that the errors are evenly distributed across the dataset, indicating a lack of systematic bias in the predictions. Consequently, the observed random error pattern suggests that the predicted equations provide a reliable approximation of the experimental data, thereby validating their effectiveness and accuracy.

Calorific Value

Table 1 ANOVA analysis for blended sample calorific value.

Source	F-Value	F-Tabulated	P-Value
Diesel	28.00	4.41	0.000
MEWFO	33.38		0.000
MEWFO * MEWFO	9.15		0.026
MEWCO * MEWCO	7.68		0.005

Table 2 Analytical study of the predictors for the calorific value of blended samples.

Source	T-Value	T-Tabulated	P-Value
Diesel	13.00	1.734	0.000
MEWFO	5.45		0.000
MEWFO* MEWFO	-2.48		0.026
MEWCO * MEWCO	3.29		0.005

Kinematic Viscosity

Table 3 ANOVA analysis for blended sample kinematic viscosity.

Source	F-Value	F-Tabulated	P-Value
Diesel	186.28	4.41	0.000
MEWFO	38.29		0.000
Diesel * Diesel	6.95		0.020
MEWFO* MEWFO	10.55		0.006

Table 4 Analytical study of the predictors for the kinematic viscosity of blended samples.

Source	T-Value	T-Tabulated	P-Value
Diesel	-13.95	1.734	0.000
MEWFO	6.19		0.000
Diesel * Diesel	2.64		0.020
MEWFO* MEWFO	-3.25		0.006

Density

Table 5 ANOVA analysis for blended sample density.

Source	F-Value	F-Tabulated	P-Value
Diesel	32.05	4.41	0.000
MEWFO	34.49		0.000
MEWFO * MEWFO	8.22		0.012
MEWCO * MEWCO	12.94		0.003

Table 6 Analytical study of the predictors for the density of blended samples.

Source	T-Value	T-Tabulated	P-Value
Diesel	-5.66	1.734	0.000
MEWFO	5.87		0.000
Diesel * Diesel	2.87		0.012
MEWFO * MEWFO	-3.60		0.003

5. Physico-Thermal Properties Prediction through Regression Analysis

Calorific Value (MJ/Kg) = 37.405 + 0.06665 Diesel + 0.04144 MEWFO+ 0.000157 MEWF*MEWFO + 0.000208 MEWCO* MEWCO. R^2=98.38% (1)

Kinematic Viscosity at 40°C = 3.7863 + 0.01871 Diesel + 0.0005920 MEWFO + 0.000035 Diesel* Diesel + 0.000040 MEWFO* MEWFO. R^2=99.58% (2)

Density (g/cm^3) = 0.84257 + 0.000191 Diesel + 0.000294 MEWFO + 0.000001 MEWFO* MEWFO + 0.000001 MEWCO* MEWCO. R^2=98.87% (3)

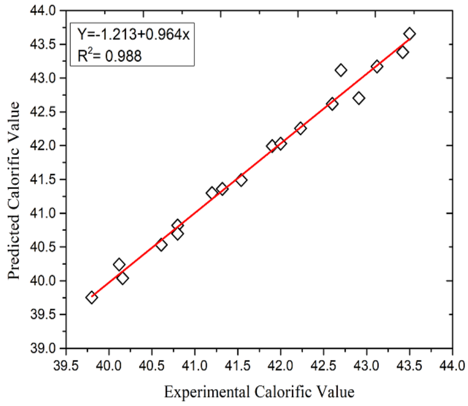

Fig. 6: Predicted vs actual results of calorific value

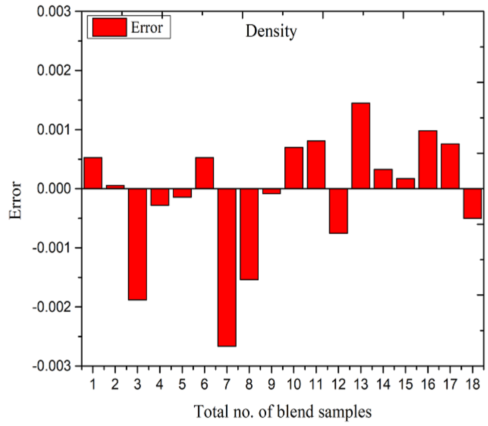

Fig. 9: Error analysis of different combinations for density

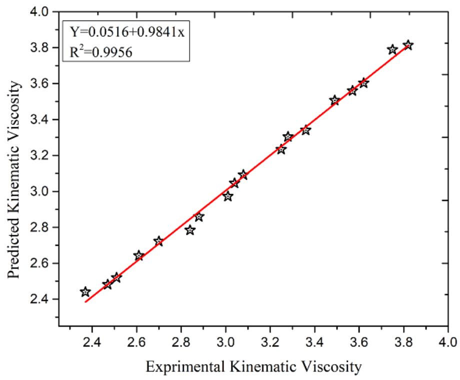

Fig. 7: Predicted vs actual results of kinematic viscosity

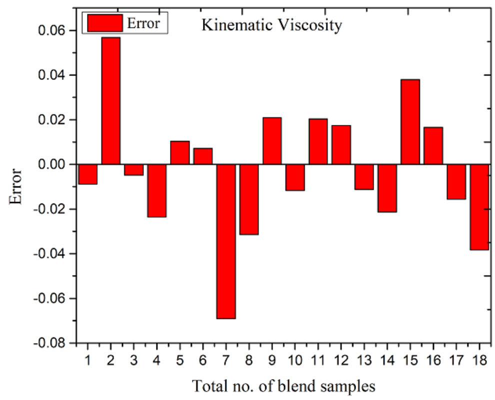

Fig. 10: Error analysis of different combinations for kinematic viscosity

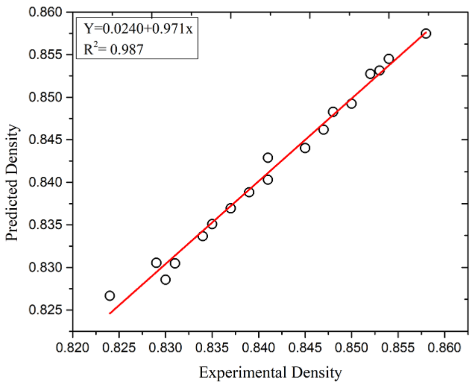

Fig. 8: Predicted Vs actual results of density

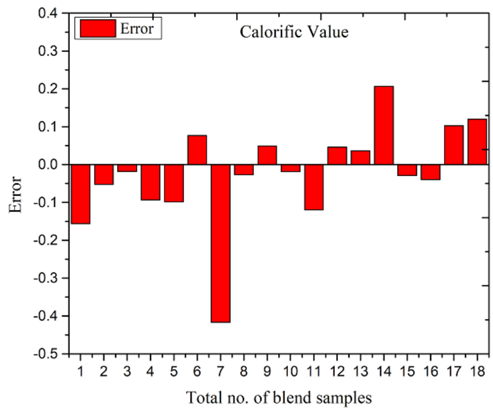

Fig. 11: Error analysis of different combinations for calorific value

5.1 Examination and Quantification of Variability and Error in Data Interpretation

Error analyses were plotted based on the total experimental and predicted values has shown Fig. 9, 10 and 11 for density, kinematic viscosity and calorific value respectively. It is clearly shows that for all the observations errors are less than 5% and the values are varying on either side of the reference value.

6. Conclusions

The present studies discuss the physico-thermal properties of blended samples of MEWFO, MEWCO and MEWFCO with diesel. The properties of blended samples were compared with the pure diesel to correlate the properties for the replacement of diesel and the results are discussed below.

1. The blend percentage increase from 15% to 90% it was observed that there is an increase in density and kinematic viscosity for all the combinations considered. Whereas, in case of calorific values blend

percentage increases with decrease in calorific value was observed.

2. The combined use of methyl ester of waste fish oil and methyl ester of coconut oil can improve the properties of density, calorific value and kinematic viscosity as compare with pure diesel.
3. Statistical analysis clearly explain the combined biodiesel blend for all the combinations, F-test shows that the calculated F-values are more than the F-tabulated hence null hypothesis is rejected.
4. Regression analysis show that the predicted equations were found to be statistically significant with a confidence interval of 95% and the coefficient of determination for all the three properties considered were 98.38%, 99.58% and 98.87% for calorific value, kinematic viscosity and density respectively.
5. By addressing these research areas, it will be possible to further understand the potential of blended fuels derived from Mahua oil, waste cooking oil, and waste frying oil as alternatives to conventional diesel, with implications for sustainability, energy security, and environmental protection.

Nomenclature

MWFO: Methyl esters of waste fish oil.

MWCO: Methyl esters of waste coconut oil.

MWFC: Combined methyl esters of waste fish oil and waste coconut oil.

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