CI&CEQ
Chemical Industry & Chemical Engineering Quarterly

Available online at
Association of the Chemical Engineers of Serbia AChE
www.ache.org.rs/CICEQ

Chem. Ind. Chem. Eng. Q. 29 (1) 75–85 (2023) CI&CEQ

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PREPARATION AND PHYSICOCHEMICAL PROPERTIES OF NATURALLY GROWN GREEN *SPIROGYRA* ALGAE BIODIESEL

Article Highlights

- Cultivation of green algae for 120 days without any externally supplied chemicals or nutrients
- The maximum amount of dried algae powder to algae oil was achieved
- B10 to B100 diesel-biodiesel blends are prepared and characterized
- Mathematical equations are developed for analyzing the fuel properties
- B40 was proposed as an optimum blend ratio for further engine experiments

Abstract

In this study, biodiesel was produced from a naturally grown green algae (Spirogyra). The algae were cultivated in an open pond for 180 days without any fertilizers or nutrients. The dried algae powder to oil yield and significant fuel properties of viscosity, density, cetane number, calorific value, flash point, pour, and cloud points are investigated for B10 to B100 blends. The results of solvent oil extraction show that at a 1:2 (algae powder to solvent) ratio and 65 °C, algae oil yield was 22.66%. Furthermore, Box-Behnken assisted response surface optimization technique was implemented. From the 29 random experiments, 96.24% Spirogyra algae oil biodiesel (SAOBD) yield was achieved under the optimum conditions of 50 °C, 180 minutes, the molar ratio of 9:1, and catalyst concentration of 0.5 wt%. The fatty acid composition reveals that 73.95 wt% saturated FAC was observed in SAOBD. The significant fuel properties are measured by following ASTM-D6751 standards, and 40% SAOBD in diesel fuel could be an optimum blend ratio for engine experimentation. Finally, regression equations with high correlation coefficients (R^2) were developed to predict the various blend ratios for the fuel properties.

Keywords: algae biodiesel, algae cultivation, fuel properties.

SCIENTIFIC PAPER

UDC 662.6:582.263

Fossil fuel-derived petro-diesel is considered one of the primary fuels in the transportation, agricultural and industrial sectors. The high efficiency, availability, and low cost of petro-diesel during the earlier days of its discovery made them a popularly used fuel. However, with the rapid consumption, fossil fuel availability is on the verge of extinction. Furthermore, the exhaust emission from the petro-diesel fuelled engines contributes to the depletion of air quality and increases global environmental air pollution levels [1]. Therefore, the search for clean-burning and renewable fuels is gaining wide attention. To mitigate the challenge, research on different feedstock oils confirmed that biodiesel derived from naturally available oils could replace the existing petro-diesel fuel [2]. Moreover, biodiesel is popular for its non-toxicity, biodegradability, low carbon, and high oxygen profiles [2]. In general, second-generation oils like non-edible (jatropha, pongamia, mahua, neem, etc.) and low-cost feedstocks (waste cooking oils) are commonly used for the production of biodiesel [3]. However, these oils still face impediments like availability, cultivation in arable lands, high free fatty acid (FFA) content, low yield, etc. Therefore, research on third-generation

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Paper received: 15 February, 2022
Paper revised: 29 June, 2022
Paper accepted: 15 July, 2022

https://doi.org/10.2298/CICEQ220215015K

algae oils [4] is gaining wide popularity among the nations for biodiesel production.

Algae oils have various classifications based on their growth and climatic conditions. The major types are green algae, blue-green algae, red algae, brown algae, phytoplankton, seaweeds, and other algae strains [4]. They mainly rely on the influence of sunlight and Carbon-dioxide (CO_2) for their growth. Compared to first and second-generation oils, algae have the fastest growth rate, produce more oil, and survive in highly saline waters. Furthermore, algae require limited nutrients for their growth with high lipid content (40% to 80%) and high triglycerides than any other terrestrial plants [5]. Studies reveal that algae cultivation and oil extraction are cost-effective. More than 85% of the oil can be extracted if the correct type of algae species is selected [5]. However, the separation and extraction of cellular components of algae are considered one of the cost drivers during the conversion of algae to biodiesels [6].

The concept of algae oil to biodiesel is not a new invention in this 21st century, as the first scientific study on algae was started at the end of the 19th century. However, with the increase in population and pollution, the search for renewable and alternative fuels has become imperative. Therefore, researchers are inclining toward algae cultivation, harvesting, oil extraction, and refining using fresh and marine water. The algae cultivation in seawater [7] attracts researchers due to the maximum share of water on the earth's surface. Furthermore, they don't require any chemical fertilizers for their growth which can save money and energy. The microalgae biomass production in seawater has a great potential for mass production with full utilization of ocean resources, including temperature control, wave energy for mixing, and culture medium preparation [8]. On the other hand, algae cultivation in fresh water and wastewater [9,10] is also popular. Currently, with the advent of the latest technology from industry 4.0 [11], the maximum benefit of extracting the oil from microalgae and converting it to biodiesel is made more economical with the latest optimization and artificial intelligence (AI) tools [12–14].

From the above discussions, it is evident that there is a great scope for algae oil as a sustainable fuel. In the present study, an attempt is made to cultivate algae (*Spirogyra*) without using fertilizers or chemicals in an open tank from June 2021 to December 2021. The algae were collected at regular intervals of 15 days from August 2021 to December 2021, processed for oil extraction, and further transesterified to biodiesel. The physicochemical properties of prepared biodiesel (B10 to B100) are reported.

MATERIAL AND METHODS

Cultivation of *Spirogyra* algae

The cultivation of green algae (*Spirogyra*) is located at 83°24′53.96′′E (83.414994) longitude and 17°59′39.26′′N (17.99424) latitude from June 2021. The cultivation of green algae (*Spirogyra*) is carried out in an open tank of 7.9 m in length, 4.2 m in width, 2 m in external depth, and 1.6 m in internal depth. A maximum temperature of 32.9 °C and a minimum temperature of 19.6 °C were observed from June 2021 to December 2021 in the location. The average temperature was recorded as 26.8 °C, and the pH value varied from 5.76 to 7.32. Similarly, the average sun hours for this period are observed as 10.1. The temperature and natural sunlight play a significant role in algae cultivation, especially outdoor. As algae are ubiquitous photosynthetic organisms, sunlight is an essential source for autotrophic growth and photosynthetic activity. From the available literature [15], it is evident that 20 °C to 30 °C is considered an optimum temperature for the growth of a wide range of algae, and the light irradiation varies from 33 μmol $m^{-2}s^{-2}$ to 40 μmol $m^{-2}s^{-2}$ to achieve maximum growth rate. Therefore, proper care is taken in achieving the required temperature and light for algae cultivation. Initially, the tank is filled with fresh water, and green water from the nearby pond/river is mixed with the freshwater to initiate the algae growth process. As stated in the introduction, no chemicals or fertilizers were used to grow algae. However, the essential nutrients are supplied naturally from rainfall, sunlight, and carbon dioxide due to the cultivation in an open atmosphere. After the desired growth of algae is observed in the tank, the green algae (*Spirogyra*) is collected and processed for oil extraction. The processing involves cleaning algae with deionized water, separating wet algae layer by layer, and drying it under natural sunlight for 10 hours. The dried *Spirogyra* is powdered and stored in an airtight container for further process.

Extraction of *Spirogyra* algae oil

The oil can be extracted from algae using physical techniques, like ball milling, microwave heating, and ultrasonication, and chemical methods, like solvent extraction, lyophilization, and supercritical CO_2 methods. Each technique has its advantages and limitations [16]. In this study, the oil was extracted from *Spirogyra* algae by the solvent extraction method using a Soxhlet apparatus. The setup consists of a temperature control heater, condenser, Soxhlet extractor, and other necessary glass beakers. The optimum extraction conditions were applied to achieve maximum benefit in the extraction of *Spirogyra* algae

oil. A measured quantity of 300 grams of *Spirogyra* algae powder (SAP) is loaded in the Soxhlet extraction chamber with 600 ml of solvent *n*-hexane in the round bottom flask and heated to 65 °C and maintained throughout the process. The vapors of *n*-hexane flow up to the reflux condenser, where it is cooled by circulating cold water. The condensed *n*-hexane was combined with dry algae powder in the extraction chamber, and the mixture later flowed through the siphon arm into the round bottom flask. The process continued until the entire algae powder in the extraction chamber was consumed, and the mixture of algae oil and *n*-hexane was collected in the round bottom flask through the siphon tube. After 18 hours of extraction, the prepared SAO is separated from the solvent through steam distillation. The *Spirogyra* oil was stored in an airtight glass beaker for transesterification. The extracted algae oil efficiency can be estimated using the equation below Eq. (1).

$$\text{Algae oil efficiency}(wt\%) = \frac{\text{Mass of oil extracted } (grams)}{\text{The total mass of dried algae}} x100 \quad (1)$$

Transesterification process

The obtained algae oil, through the steam distillation process, is heated up to 110 °C to remove traces of water content in algae oil. Later, the basic fuel properties of *Spirogyra* algae are estimated. It is observed that the kinematic viscosity of the *Spirogyra* algae oil (SAO) is above 19 mm^2/s, density is 898.2 kg/m^3, and FFA is 1.69%. Therefore, the high viscous SAO is transesterified into low viscous *Spirogyra* algae oil biodiesel (SAOBD) by the transesterification process [17,18]. Homogeneous catalyst sodium hydroxide (NaOH) and methanol (CH_3OH) were used to initiate the transesterification reaction process. A temperature-controlled hot plate magnetic stirrer, glass beakers, and a thermometer were used for the transesterification process. Initially, the desired quantity of raw SAO is taken in the glass beaker and placed on a hot plate magnetic stirrer. The catalyst and methanol are later added to the contents. Until the oil reaches the rated temperature, the contents are stirred continuously. During this process, the oil's triglycerides were transformed into methyl esters (SAOBD) and glycerine. After separation from glycerine, the obtained SAOBD was washed with warm deionized water and heated to remove the water. Then, the SAOBD was blended with mineral diesel fuel at various proportions starting from 10% to 90%, with an increment of 10% by volume. For instance, B10 represents 900 ml of diesel fuel blended with 100 ml of SAOBD10. A high-speed stirrer was utilized for blending the fuels, and each blend was prepared by stirring continuously for 30 min.

Table 1. Process variables and their ranges

S. No	Parameters	Codes	Low Level	Medium Level	High Level
1	Catalyst (wt.%)	X_1	0.5	1	1.5
2	Temperature (°C)	X_2	45	50	55
3	Time (min)	X_3	60	120	180
4	Molar ratio	X_4	6:1	9:1	12:1

The same procedure is repeated with varying process variables like catalyst, alcohol, time, and temperature to identify the influential parameter in the transesterification process as per the matrix design (DOE) using Minitab-19 statistical software, as shown in Table 1. Box-Behnken (BB) designed response surface method (RSM) was used to optimize the process parameters to achieve maximum algae biodiesel yield. A total of 29 experiments were conducted randomly by varying the process parameters, as shown in Figure 1a, and the experimental biodiesel yield was calculated using Eq. (2). Different physicochemical properties of the SAOBD were determined. The blended fuel properties are compared with the popularly followed three international fuel standards of ASTM-D6751, EN-14214, and IS-15607, as shown in Table 2.

$$\text{Biodiesel yield}(\%) = \frac{\text{Weight of biodiesel produced}}{\text{Weight of oil used}} x100 \quad (2)$$

Yield and model fitting

Spirogyra algae oil yield estimation

The wet algae of 10 kg were collected every 15 days from the pond, and later, it was cleaned. After cleaning almost 40% of the weight was lost by unwanted materials like mud, snails, etc., attached to the *Spirogyra* algae. The cleaned *Spirogyra* algae were dried and ground into a fine powder for further lab-scale oil extraction. The same procedure was repeated, and the algae were collected at regular intervals for 120 days.

For the lab-scale algae oil extraction, 300 grams of the dried *Spirogyra* algae powder was used along with solvent (*n*-hexane) in a ratio of 1:2. The yield from each batch was 68 ml of *Spirogyra* algae oil. Hence, 8.4 kg of dry-cleaned algae powder yielded 1.9 liters of algae oil, further used for estimating physicochemical properties. After the steam distillation, the maximum quantity of *n*-hexane was recovered, which can be reused for subsequent experimental trials. As a result, the SAO yield calculated using Eq. (1) was 22.66%.

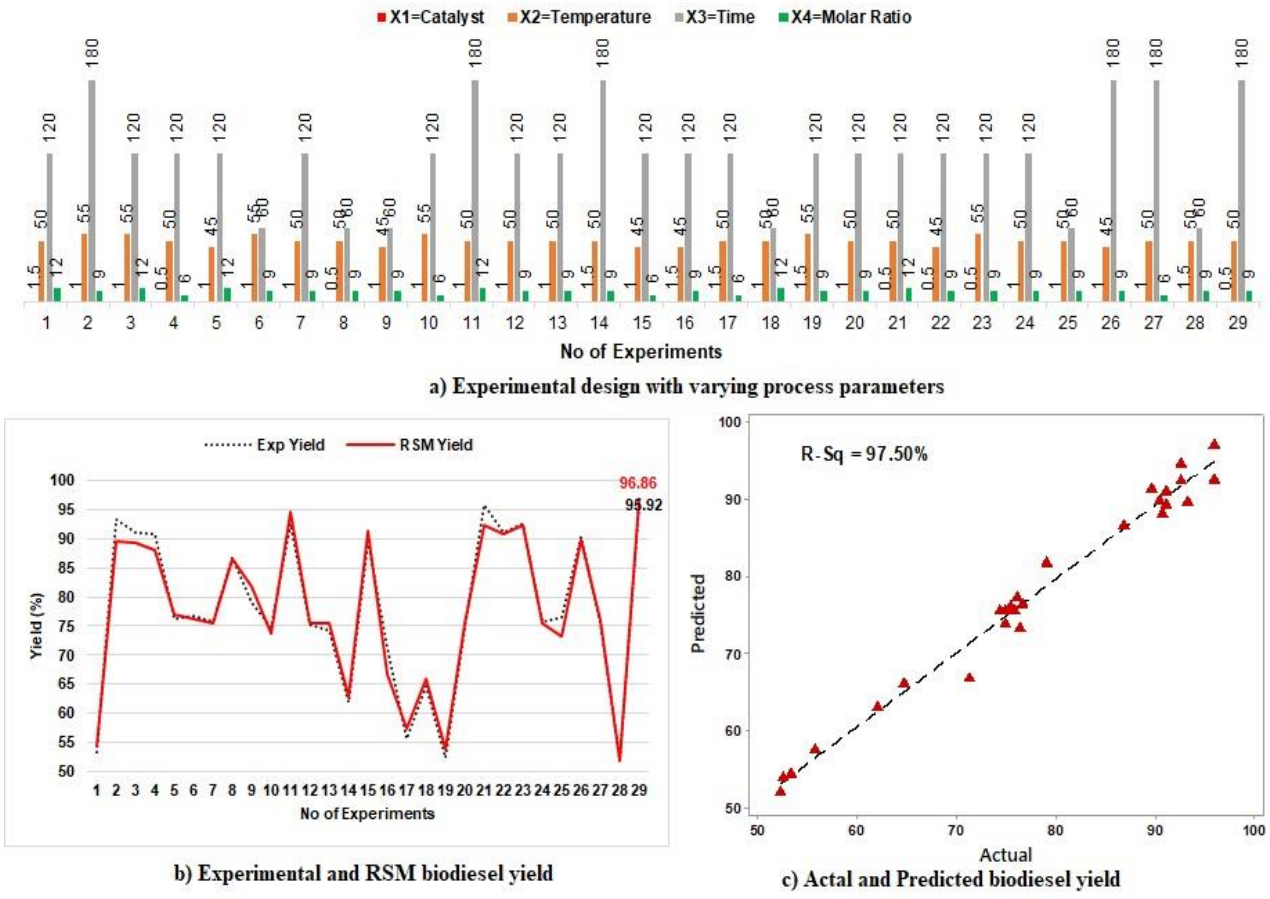

Figure 1. Number of experiments and their yield estimation results.

Table 2. International biodiesel fuel property standards and their range [19]

S. No	Properties	Units	IS-15607	EN-14214	ASTM-D6751
1	Kinematic viscosity at 40 °C	mm^2/sec	2.5–6	1.9–6.0	3.5–5.0
2	Density at 15 °C	kg/m^3	860–900	860–900	860–890
3	Flash point	°C	min 120	min 93	min 120
4	Calorific value	kJ/kg	-	-	-
5	Cetane number	-	min 51	min 47	min 51
6	Cloud point	°C	-	-	-3 – -12
7	Pour point	°C	-	-	-15 – -16

Biodiesel yield and model fitting

During the transesterification process, the significant process variables like alcohol, catalyst, time, and temperature were varied randomly to achieve a maximum biodiesel yield. As shown in Figure 1b, the maximum biodiesel yield (based on 29 experimental trials) of 95.92% was achieved with the alcohol-to-SAO molar ratio of 9:1 and the catalyst amount of 0.5 wt.% at 50 °C for 180 min. The statistically predicted maximum biodiesel yield of 96.86% was in close agreement with the experimental yield. Subsequently, confirmation tests, conducted under the optimum conditions in triplicate, resulted in an average yield of 96.24%.

Based on the 29 experimental data, a regression equation was developed to find the relation between the process variables (X_1, X_2, X_3, and X_4) and biodiesel yield (%). The quadratic model is presented by Eq. (3):

The model's accuracy was assessed through the coefficient of determination R^2 and the adjusted coefficient of determination Adj R^2, which were 97.50% and 95%, respectively. Therefore, more than 97% of the variance was attributed to the variables. The same is evident in Figure 1c, comparing the predicted and actual biodiesel yields.

$$\text{Yield}(\%) = 899 + 109.4(X_1) - 26.70(X_2) - 0.779(X_3) - 32.39(X_4) - 15.80(X_1 \cdot X_1) + 0.2347(X_2 \cdot X_2) + 0.000830(X_3 \cdot X_3) + 0.615(X_4 \cdot X_4) - 2.027(X_1 \cdot X_2) + 0.0046(X_1 \cdot X_3) - 1.26(X_1 \cdot X_4) + 0.00431(X_2 \cdot X_3) + 0.497(X_2 \cdot X_4) + 0.0498(X_3 \cdot X_4) \quad (3)$$

The influencing process parameter from the set of four variables that show a significant effect in achieving maximum biodiesel yield can be analyzed with the ANOVA analysis, shown in Table 3. The statistically significant process variables can be found with the *p*-test. The lowest *p*-value with the highest *F*-value denotes the most influencing parameter in achieving the biodiesel yield from SAO. The catalyst concentration (X_1) is identified as a significant process parameter, followed by the reaction time (X_3). Furthermore, there is only a 0.01% chance that a large *F*-value may occur due to noise, and the probability of the value greater than F and less than 0.050 represents the model terms are significant. Similarly, the values greater than 0.100 represent the model as insignificant. Finally, the model *F*-values is 38.99, which is significant, and the lack of fit is non-significant.

Analysis of fatty acid compositions

Fatty acid composition (FAC) in biodiesels is predominant for biodiesel fuel properties. Therefore, FAC was tested using the gas chromatography method [20]; the results are shown in Table 4. In the present investigation, palmitic acid was identified as a major component with 28.63 wt.%, followed by lauric acid (21.90 wt.%) and oleic acid (21.62 wt.%). As a result, the total saturated fatty acid content was 73.95 wt.%, with the maximum share of palmitic acid, and the total unsaturated fatty acid content was 24.12 wt.%. The available studies [20,21] showed that a highly unsaturated FAC in biodiesel promotes a rise in viscosity and a decrease in heating value. On the other hand, saturated FAC in biodiesel will help regulate NOx emissions during combustion [22,23]. Table 4 compares the present FAC profile with the literature [24].

Table 3. Analysis of variance (ANOVA)

Source	DF	Adj SS	Adj MS	F-value	P-value	
Model	14	5012.34	358.02	38.99	<0.0001	S[a]
Linear	4	3877.77	969.44	105.56	<0.0001	S
X_1	1	3538.05	3538.05	385.26	<0.0001	S
X_2	1	22.94	22.94	2.50	0.136	NS[b]
X_3	1	314.50	314.50	34.25	<0.0001	S
X_4	1	1.17	1.17	0.13	0.727	NS
Square	4	444.22	111.05	12.09	<0.0001	S
X1*X1	1	102.36	102.36	11.15	0.005	NS
X_2*X_2	1	225.78	225.78	24.59	<0.0001	S
X_3*X_3	1	54.10	54.10	5.89	0.029	NS
X_4*X_4	1	12.96	12.96	1.41	0.255	NS
2-Way interaction	6	550.80	91.80	10.00	<0.0001	S
X_1*X_2	1	102.72	102.72	11.19	0.005	NS
X_1*X_3	1	0.08	0.08	0.01	0.929	NS
X_1*X_4	1	14.40	14.40	1.57	0.231	NS
X_2*X_3	1	6.68	6.68	0.73	0.408	NS
X_2*X_4	1	221.86	221.86	24.16	<0.0001	S
X_3*X_4	1	205.06	205.06	22.33	<0.0001	S
Error	14	128.57	9.18			
Lack-of-fit	10	127.02	12.70	32.77	0.002	NS
Pure error	4	1.55	0.39			
Total	28	5140.91				

[a] S - Significant, [b] NS - Non-significant.

Table 4. Comparison of the present with available literature FAC profiles

S.No.	FAC	Structure C:D	SAOBD100 (wt.%)	Algae Biodiesel [24]
1	Caprylic Acid	C8:0	0.3	-
2	Capric Acid	C10:0	0.3	-
3	Lauric Acid	C12:0	21.90	-
4	Myristic Acid	C14:0	15.29	-
5	Palmitic Acid	C16:0	28.63	15.64
6	Stearic Acid	C18:0	4.86	2.10
7	Oleic Acid	C18:1	21.62	54.89
8	Linoleic Acid	C18:2	2.5	4.88
9	Arachidic Acid	C20:0	1.28	2.24
10	Behenic Acid	C22:0	1.39	0.33
	Other		1.93	

RESULTS AND DISCUSSION

Physicochemical properties of *Spirogyra* biodiesel

The fuel properties play a significant role during combustion, storage, and transportation. Therefore, studying the significant fuel properties gives an insight into the physical and chemical behavior during usage. Moreover, research on biodiesels is becoming imperative due to their improved fuel properties. Therefore,SAOBD was blended with mineral diesel fuel (B10 to B100), and the significant fuel properties were studied using the international standard ASTM-D6751.

Kinematic viscosity

The viscosity of liquid fuel plays a predominant role during fuel injection. Therefore, it is always recommended to use low viscous fuels, which help achieve better fuel atomization during combustion and eliminate the fuel injector clogging. In this study, the kinematic viscosity was measured by a redwood viscometer as per the ASTM-D445. The variations of the kinematic viscosity are plotted in Figure 2. Pure biodiesel (SAOBD100) has a maximum kinematic viscosity of 4.23 mm^2/sec, which is 51.61% higher than mineral diesel fuel (2.79 mm^2/sec) due to the presence of large size triglyceride molecules in the SAO. High viscous fuels are not recommended for diesel engine combustion, resulting in incomplete combustion, thereby increasing toxic exhaust emissions. However, due to high compression ratios in diesel engines, pure biodiesels are also tested by different research groups [25] and claim that the efficiency is improved.

Furthermore, as observed in jatropha biodiesel, the kinematic viscosity change narrows beyond 60 °C [26]. Figure 2 shows that kinematic viscosity decreases with the increase in diesel percentage in the blend (Table 2).

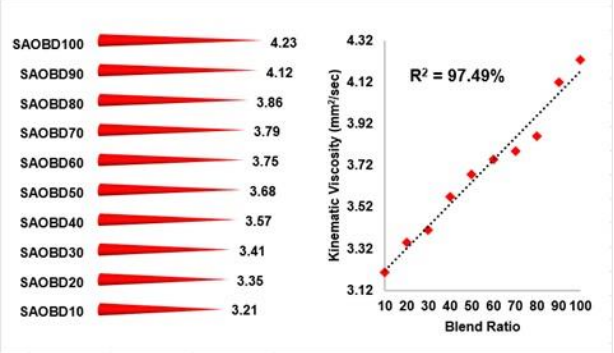

Figure 2. Variation of kinematic viscosity with the coefficient of determination.

Density

Density is measured with a relative density meter by following the ASTM-D1298 standards, and the variations are shown in Figure 3a. A high density characterizes the biodiesel (887 kg/m^3) due to its high molecular weight compared to mineral diesel fuel (830 kg/m^3). Like kinematic viscosity, the density of pure biodiesel is reduced by adding diesel fuel. The fuel density affects the fuel performance, the quality of atomization, and combustion quality as diesel engines utilize the fuel injection pump system to admit the fuel into the combustion chamber. Due to high density, the required quantity of fuel mass may not reach the combustion chamber, which alters the fuel/air ratio, low energy content, and low power output of the engine. The density of methyl or ethyl esters depends mainly on the molar mass, water content, and free fatty acids [21]. However, the density of the blends with the SAOBD content higher than 60% meets the required standards.

Cetane number

The quality of combustion in diesel engines depends on the cetane value of the fuel. Therefore,

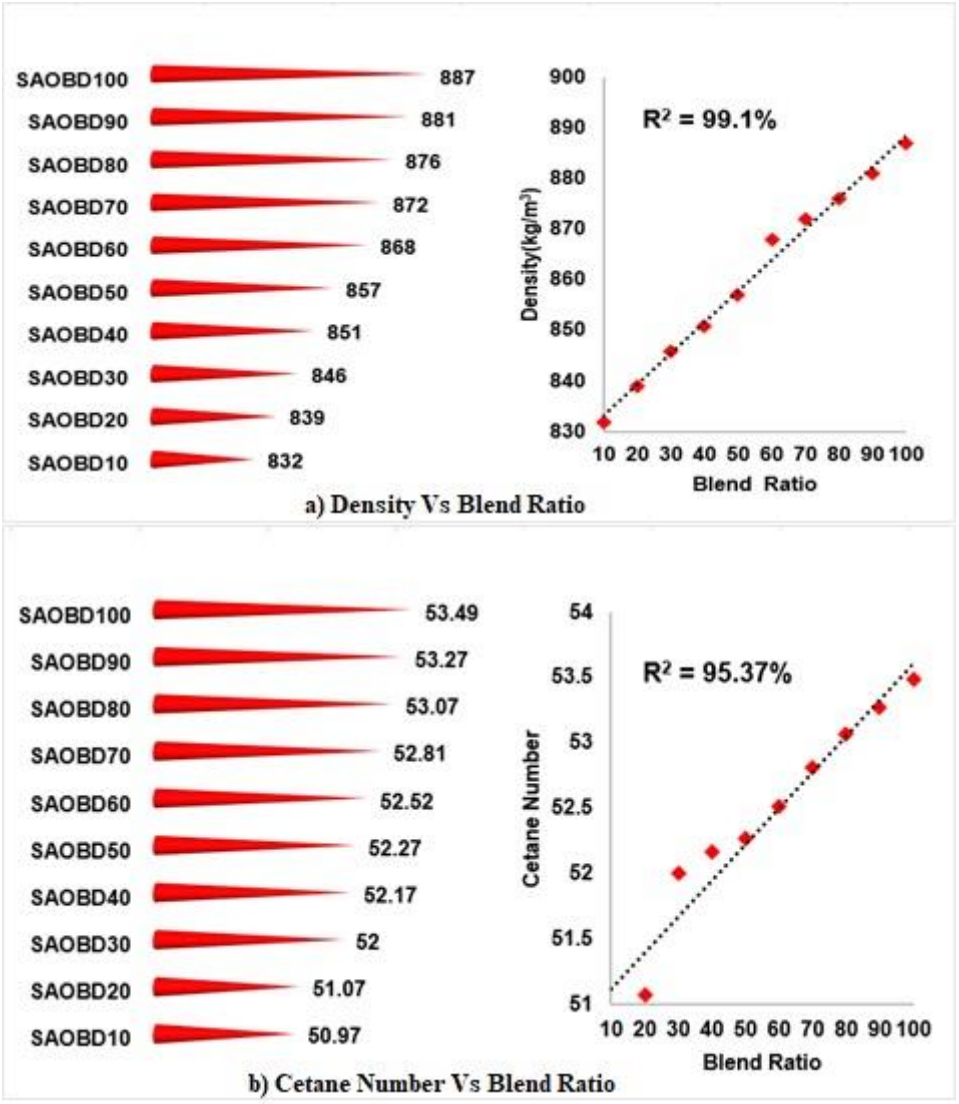

Figure 3. Variation of density and cetane number with the coefficient of determination.

a high cetane number of fuels are always recommended for a diesel engine as they reduce the delay period. Compared to diesel fuel, biodiesel possesses a relatively high cetane number due to the fatty acid compositions [20]. Figure 2b presents the cetane value for various blends. The cetane value increases with the increase in biodiesel percentage in the blends, as shown in Table 2. The international standards recommend the minimum cetane number of 47. In the present study, the values of cetene number for all the diesel-biodiesel blends are within the limits of the prescribed standards.

Calorific value

The calorific value or heating value is considered one of the significant fuel properties, as the engine's fuel consumption and power output mainly rely on it. The heating value reveals the information on the heat liberated by burning a unit mass of fuel. Biodiesels obtained from different feedstocks of plant and animal oils generally have a lower heating value than diesel fuel. It may vary due to the chemically bonded oxygen molecules in biodiesels. Furthermore, the heating value of biodiesel increases with the number of carbon atoms and decreases with the number of double bonds [19]. The heating values determined in the present study using a bomb calorimeter following ASTM-D240 standards are shown in Figure 4a. Unlike viscosity and density, the calorific value decreases with the increase in biodiesel percentage in the blends with diesel fuel.

Flash point

Transportation and storage of fuel are essential for fuel commercialization, and this smooth operation can be achieved with less volatility fuels like biodiesel. The biodiesels possess high flash points, which helps in safe transportation, storage, and distribution. Approximately the flashpoint of biodiesel is 150% more

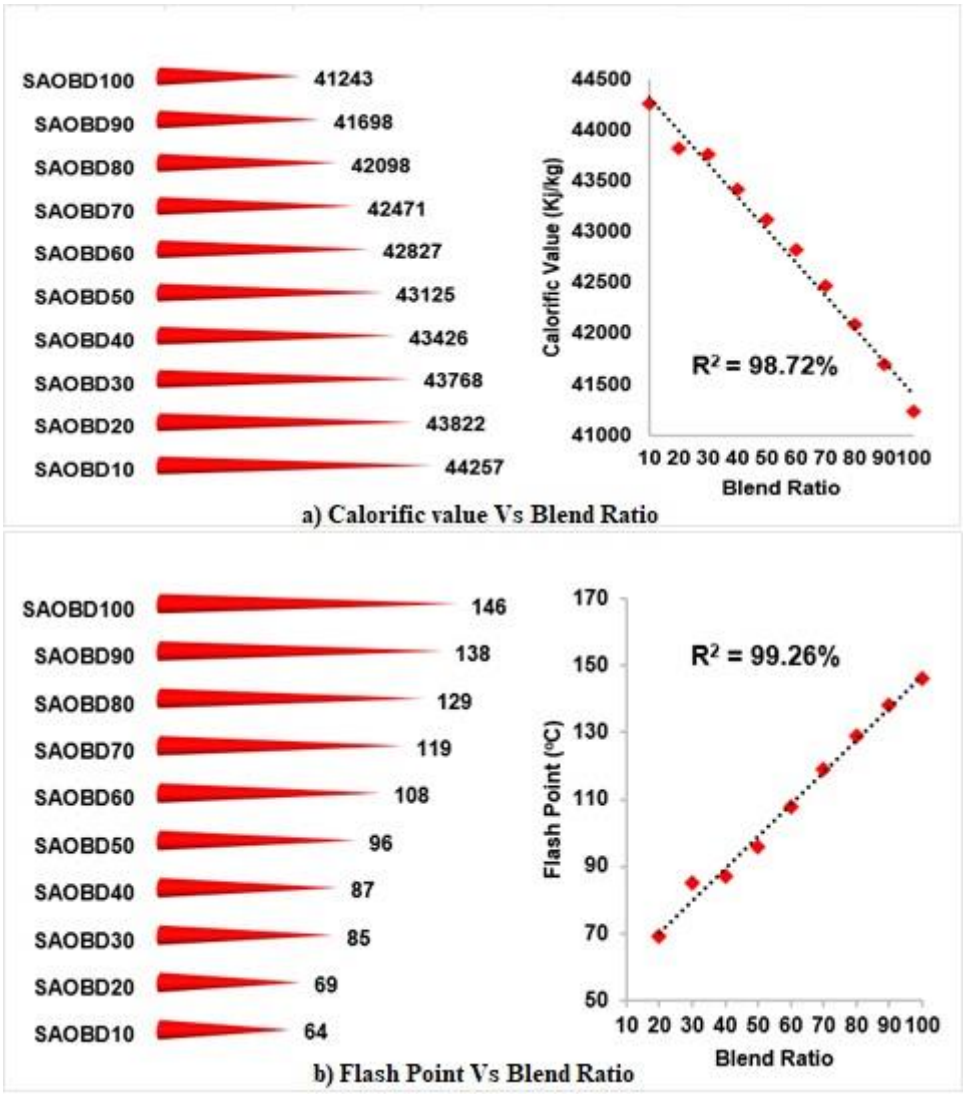

Figure 4. Variation of calorific value and flash point with the coefficient of determination.

than mineral diesel fuel, and these high flashpoints in biodiesels ensure less flammability hazards. The flashpoint for biodiesel-diesel blends was measured with a Pensky marten closed cup apparatus following the ASTM-D93 standards; the results are shown in Figure 4b.

Low-temperature fuel properties

The physicochemical properties of the fuel significantly affect the temperature change (high or low) as the fuel properties may alter, especially at low temperatures. This change is predominant for biodiesel due to saturated and unsaturated fatty acid compositions. Moreover, biodiesels are more likely to react to atmospheric conditions, especially at low temperatures. Therefore low-temperature fuel properties like pour and cloud points were measured following ASTM-D97 and ASTM-D2500 standards, respectively; the data for various blends are shown in Figures 5a and 5b. The cloud point reveals the information of the minimum temperature at which wax crystallizes or clouds will start when the fuel is cooled down. Similarly, the fuel starts taking gel shapes for the pour point and has no more flowability at minimum temperature. Both the properties of diesel-biodiesel blends appear to be within the limits of the established international fuel standards.

Optimum blend ratio and mathematical modeling

The blends of 10% and 20% biodiesel with diesel fuel, popularly known as B10 and B20, are currently being applied worldwide. These blends meet the essential requirements of various international standards and can be used without any modification to the engine design [23,25] as there is a great concern to fuel refinement policies to mitigate the challenges of energy and the environment. Therefore, researchers are focusing on blending more biodiesel percentage

into diesel fuel. This study shows the tested fuel properties, like kinematic viscosity, density, cetane number, calorific value, flash point, pour point, and cloud point, for all the blends (B10 to B100) as per the international standards of ASTM-D6751 are within limits. Based on these results, a 40% SAOBD blend with diesel fuel may be recommended for further engine performance analysis as it meets the other international fuel standards. For instance, the kinematic viscosity, cetane number, and calorific values of the B40 are optimum (Table 2). However, above a 40% blend ratio, the kinematic viscosity, which plays a vital role in combustion atomization, increases. Hence, the SAOBD40 blend was chosen as the optimum for further investigation. The fuel properties of SAOBD10 to SAOBD100 are in close agreement with the available literature [27]. Furthermore, regression equations with coefficient of determination R^2 (Table 5) were developed using Minitab19 statistical software to predict the significant fuel properties of B10 to B100. A similar investigation has been carried out with mahua and jatropha oil-based biodiesels, resulting in the mathematical equations for different diesel-biodiesel blends [27,28].

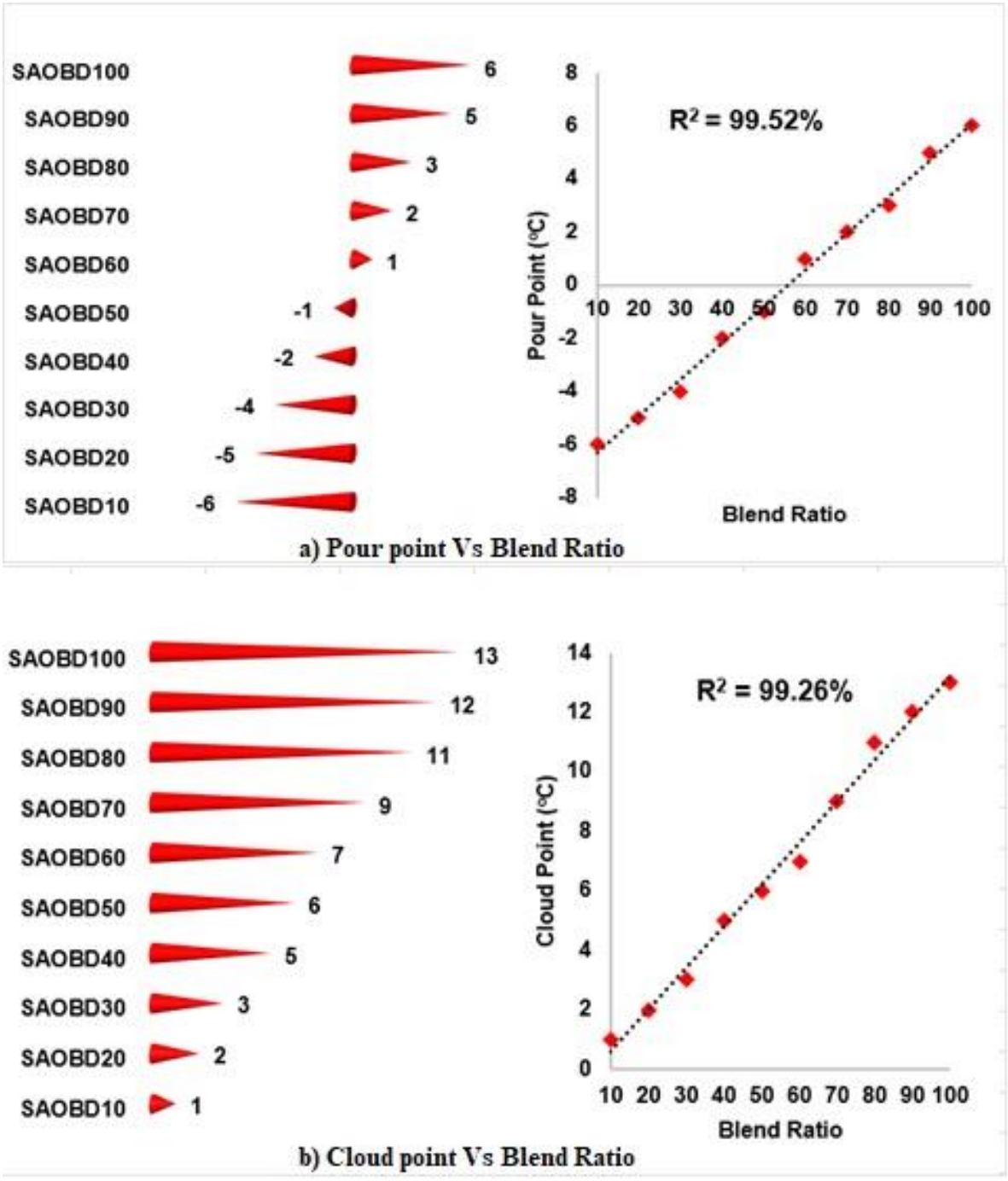

Figure 5. Variation of pour point and cloud point with the coefficient of determination.

Table 5. Mathematical equations for unknown blend ratios

S. No	Property	R^2, %	Adj R^2, %	Mathematical relationship
1	Kinematic viscosity (mm^2/s), 40 °C	97.49	97.17	3.1120+0.010636(X)
2	Density (kg/m3), 15 °C	99.1	99.0	827.1+0.6139(X)
3	Cetane number	95.37	94.79	50.844+0.02764(X)
4	Calorific value (kJ/kg)	98.72	98.56	44657.1-32.43(X)
5	Flash point (°C)	99.26	99.17	52.47+0.9388(X)
6	Pour point (°C)	99.52	99.46	-7.667+0.13578(X)
7	Cloud point (°C)	99.26	99.17	-0.800+0.14000(X)

CONCLUSION

Biodiesel production from algae oil is gaining great potential due to its high conversion rate (raw oil to biodiesel), and it can be grown in any water. In the present study, an attempt is made to cultivate and extract oil from *Spirogyra* algae, and based on the observations, the following conclusions are summarized.

The *Spirogyra* algae are grown naturally without externally supplied nutrients or chemical fertilizers. However, the average temperature of 26.25 °C and sun hours of 10.1 must be maintained for better algae cultivation. The maximum algae oil yield of 22.66% is achieved for a 1:2 ratio (algae powder to solvent), and 90% of the solvent is recovered and reutilized. The maximum algae oil biodiesel yield of 96.24% is achieved during the transesterification process, and catalyst concentration is identified as a significant process variable in ANOVA analysis.

The significant fuel properties for the blends (SAOBD10 to SAOBD100) are characterized as per ASTM-D6751 and observed within the limits of ASTM-D6751, EN-14214, and IS-15607. The optimum blend for engine experimentation may be proposed as SAOBD40 due to the optimum kinematic viscosity (3.57 mm^2/sec), cetane number (52.17), and calorific values (43426 kJ/kg). The regression equations developed for fuel properties achieve the highest coefficient of determination (R^2).

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NAUČNI RAD

DOBIJANJE I FIZIČKOHEMIJSKA SVOJSTVA BIODIZELA NA BAZI PRIRODNO GAJENE ZELENE ALGE (*SPIROGIRA*)

U ovoj studiji, biodizel je proizveden od prirodno uzgajanih zelenih algi (spirogira). Alge su uzgajane u otvorenom bazenu 180 dana bez ikakvih đubriva ili hranljivih materija. Istraživani su prinos ulja iz osušenih algi u prahu i značajna gorivna svojstva mešavine B10 do B100, kao što su viskoznost, gustina, cetanski broj, toplotna moć, tačka paljenja, tačka tečenja i tačka zamućenja. Rezultati ekstrakcije ulja rastvaračem pokazuju da je pri odnosu alga:rastvarač 1:2 na 65 °C prinos ulja algi iznosio 22,66%. Nadalje, primenjena je tehnika optimizacije površine odziva uz pomoć Boks-Benkenivim planom (29 eksperimenata). Prinos biodizela iz ulja alge od 96,24% je postignut pod optimalnim uslovima od 50 °C, 180 min, molskog odnosa 9:1 i koncentracije katalizatora od 0,5%. Sadržaj estrara zasićenih masnih kiselina u biodizelu je 73,95%. Značajna gorivna svojstva su određena prema standardima ASTM-D6751. Optimalna mešavina za eksperimentisanje sa motorom sadrži 40% biodizela. Takođe, razvijene su regresione jednačine sa visokim koeficijentima determinacije koje predviđaju gorivna svojstva za različite odnose namešavanja..

Ključne reči: algalni biodizel, gajenje algi, gorivna svojstva.