Journal of Applied Fluid Mechanics, Vol. 17, No. 9, pp. 1929-1937, 2024.
Available online at www.jafmonline.net, ISSN 1735-3572, EISSN 1735-3645.
https://doi.org/10.47176/jafm.17.9.2399

Study of the Flame Characteristics of Biodiesel Blend Fuel in a Semi-industrial Boiler

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ABSTRACT

The experimental investigation aimed to determine how the use of biodiesel derived from dill and cresson oil affected the performance of semi-industrial burners. Furthermore, an investigation will be conducted to assess the combustion properties of different blends of biodiesel, specifically B10, B20, B40, and B60. The study looks at biodiesel's chemical makeup, physical properties, and how it works in the system that moves it to the burner and the burner simulator's burning process. Biodiesel exhibits comparable qualities to conventional diesel oil, enabling the possibility of blending it to achieve the desired ratio. The results suggest that increasing the percentage of biodiesel leads to a reduction in flame distance and a rise in flame temperature. Furthermore, the complete combustion of the fuel is responsible for the brilliant and transparent flame. Additionally, using dill and Cresson fuels that come from biodiesel raises the average flame temperature by about 17% and 16.1%, respectively, compared to regular diesel fuel.

Article History

Received October 25, 2023
Revised February 27, 2024
Accepted March 19, 2024
Available online July 2, 2024

Keywords:

Industrial boiler
Renewable energy
Biodiesel
Emission
Flame

1. INTRODUCTION

The boiler has one of the highest fuel consumption rates among industrial machinery. Several considerations must be considered when assessing the fuel selection for a furnace. The elements above include fuel pricing, availability, steam demand, and supply guarantees. The utilization of oil-fired furnaces is relatively uncommon in the industrial and commercial sectors when compared to alternative fuel sources such as biomass, coal, and natural gas. However, the quantity of diesel fuel utilized for the boiler operation continues to be substantial. Concerns regarding the scarcity of energy and the volatility of oil prices necessitate additional reductions in petroleum oil consumption. Due to its sustainability and regenerative nature, biofuel derived from biomass is presently the most auspicious substitute for fossil fuels. Biofuel encompasses all biomass-derived liquid and gaseous fuels, including biodiesel, methanol, and biogas (Launhardt & Thoma, 2000). Biodiesel, which is derived from organic oils and lipids and has properties similar to diesel fuel, is one of the intriguing liquid alternative fuels for diesel engines and industrial burners (Veski, 2002). It was stated that to maintain maximum boiler efficiency, the optimal air-to-boiler ratio must be established (Elkelawy et al., 2021) Biodiesel production is anticipated to surpass 41.4 billion liters by 2025, as reported by the Food and Agriculture Organization of the United Nations (FAO) and the Organization for Economic Cooperation and Development (OECD) (Ghorbani et al., 2011; Tabatabaei & Aghbashlo 2018). A comparison is made between the combustion of B5, B10, B20, B50, B80, and B100 and that of petroleum diesel in an experimental boiler. Diesel has a marginally higher energy efficiency at greater concentrations than biodiesel, which is more efficient at lower concentrations. The implementation of biodiesel in furnaces has demonstrated favorable outcomes in terms of emissions reduction (Amirnordin et al., 2013). UTHM Biodiesel Pilot Plant study found biodiesel mixtures with 5%, 10%, and 15% diesel reduced hazardous emissions by 87%, suggesting palm oil biodiesel can reduce emissions. (Komariah et al., 2013) Expanding the use of biodiesel in all industries is a successful strategy. The target for industrial and commercial sectors is 5% in 2013, 10% in 2016, 20% in 2020, and 25% in 2025. However, the application is not as effective due to engine compatibility and cost concerns (Rachman & Komariah, 2014).

Nomenclature

Ø	equivalence ratio	D	dill of Biodiesel
B	biodiesel blend	H	unburned hydrocarbon fuel
Co	carbon monoxide	C	cresson of Biodiesel
Co2	carbon dioxide	F	fenugreek of Biodiesel

However, research has demonstrated that biodiesel exhibits inferior boiler performance compared to diesel oil (Heravi et al., 2015). The study examined the impact of vegetable oils in biodiesel-gasoil combinations on boiler emissions. Results showed sunflower and corn biodiesel mixes produced higher NOx, SO2, and temperatures. Factors like physicochemical properties, flame temperature, experimental settings, and operational systems influence NOx generation outcomes (Bhele, 2016). Laboratory testing found Jatropha biodiesel reduces CO, CO2, UbH, and PM emissions while increasing NOx emissions, making it a popular alternative to conventional fuels in power plants (Al-Esawi, et al. 2019). Comparing fuel mixtures containing 75% diesel and 25% biodiesel, the research reveals that increased rotating flow reduces carbon monoxide, unburned hydrocarbons, and particulate emissions. The article of investigation by Abdul Rahim et al. (2016). The CO2 emissions from the combustion of biodiesel and diesel fuel mixtures are highlighted. The excess CO2 emissions are due to the oxygen present in biodiesel fuels. Oxygen reacts with unburned carbon atoms during discharge, which increases CO2 production.

The observed rise in CO2 emissions signifies enhanced combustion efficiency and reduced CO levels (Abdul Malik et al., 2017). Researchers studied biodiesel fuel blends' efficiency and emissions in conventional diesel fuel nozzles and open-ended combustion chambers. Results showed lower temperature combustion, fewer pollutants, and decreased combustion wall temperature and emission concentration with an increased biodiesel fuel percentage (Norwazan et al., 2018). Researchers studied jatropha oil biodiesel blends with diesel, revealing decreased HC, CO2, and CO emissions. However, high oxygen content increased NOx emissions. B25 decreased emissions of CO2, SO2, and UHC by 42%, 33%, and 50%, respectively. According to research, the amalgamation of biodiesel and conventional diesel enhanced fuel properties. Biodiesel, composed of lipids and organic oils, exhibits considerable potential as a liquid substitute fuel for diesel engines and industrial furnaces (Elkelawy et al., 2022). The research findings indicate that using biofuel blends resulted in a significant reduction in emissions compared to using diesel oil. This reduction was particularly apparent regarding carbon monoxide, hydrocarbons (HC), and smoke opacity. These fuels are suitable for use in industrial furnaces without requiring any modifications. (Allawi, & Saleh, 2024). This review examines biodiesel-diesel mixes' performance, emission characteristics, and qualities in burner and CI engines worldwide. Biodiesel is becoming a potential alternative. Energy source due to its potential to reduce food chain burden and food scarcity. Balancing biodiesel usage with conventional diesel can produce a positive greenhouse effect. Upon reviewing existing research on this topic, no papers were found that investigated the utilization of dill oil and cresson oil as biofuels in incinerators. This adds a new aspect to the study of biodiesel blends. The primary objective of this study is to provide a new academic addition to the field by exploring the unexplored utilization of dill and cresson oil in incinerators. Moreover, this study aims to enhance our comprehension of the ecological and functional impacts of biodiesel mixtures.

2. BIODIESEL PRODUCTION

The streamlined flowcharts in Figs 1 and 2 illustrate the biodiesel manufacturing process utilized in the present research inquiry.

Fig 1. Biodiesel preparation steps

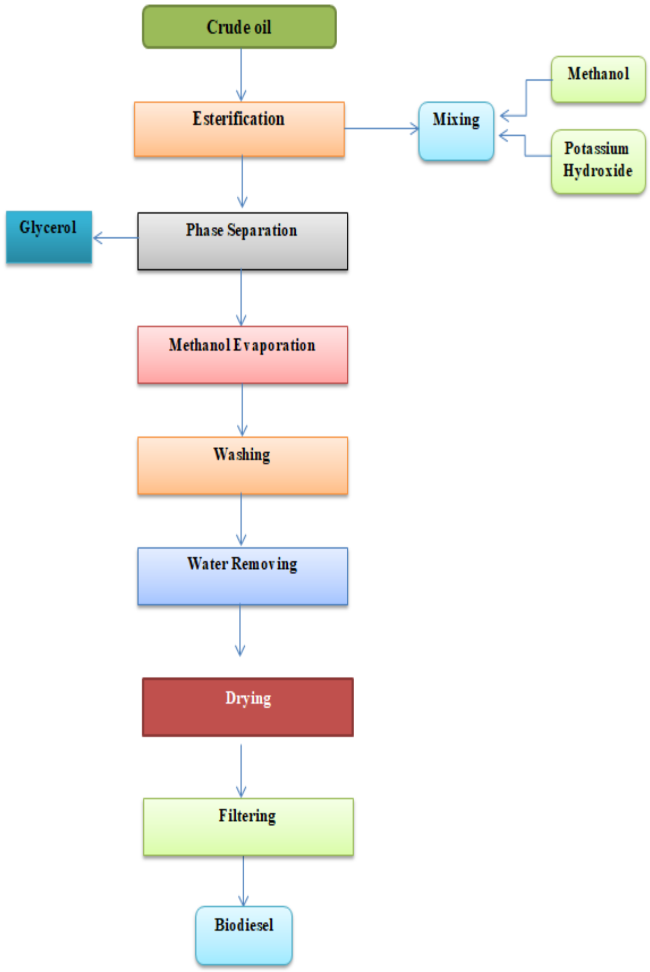

Fig. 2 Biodiesel manufacturing flowchart

Table 1. Physical characteristics of biodiesel and fossil fuels

Property	unit	diesel	BD10	BD20	BD40	BD60	BC10	BC20	BC40	BC60
Density @ 15ºC	kg/m^3	831	833.5	837	844	851	835.9	841.8	853.6	865.4
Kinematic viscosity @ 38.8 ºC	mm^2/s	2.51	2.62	2.84	3.21	3.5	2.81	3.05	3.54	3.98
Flash point temperature	ºC	62	69	78	87	101	77	89	101.5	118
Fire point temperature	ºC	73	88	99	112	125	95	111.5	123.5	136
Calorific value	MJ/kg	46.515	46.1	45.73	45.13	44.53	45.8	45.1	43.6	42.2
Cetane number	-	46.3	48.8	51.42	54.9	56.74	47.9	50.9	54.2	55.9

2.1. Physical Attributes

The biodiesel blend underwent comprehensive chemical and physical property analyses at various esteemed laboratories, including the fuel properties lab within the Petroleum Engineering Department at Kerbela University, the Fuel and Energy Techniques Department at Middle Technical University, and the Ministry of Petroleum and the Center of Research. The conclusive findings of these tests are detailed in Table 1. Notably, the transesterification process yielded an average of 96.1% biodiesel derived from Dill and Cresson sources.

3. EXPERIMENTAL SETUP

Under atmospheric conditions (P = 1 bar and T = 298 K), experiments were carried out in the combustion laboratory

Fig. 3 Equipment burner rig

Table 2. The Components of fuel used

Test fuel	Diesel volume	Biodiesel volume	Methanol volume
D 100	100 %	NIL	NIL
D90B10	90%	10%	NIL
D80B20	80%	20%	NIL
D60B40	60%	40%	NIL
D40B60	40%	60%	NIL
D80B10M10	80%	10%	10%
D80B15M5	80%	15%	5%

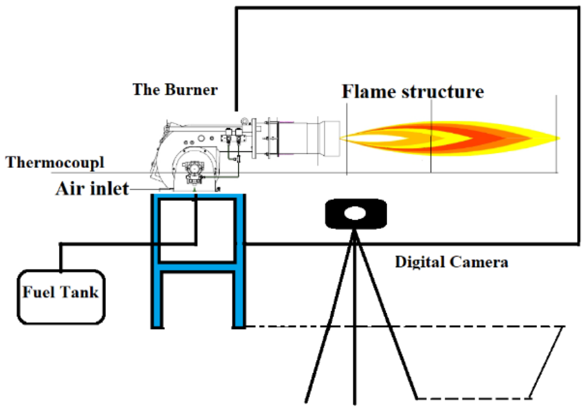

Fig. 4 Schematic diagram for burner rig

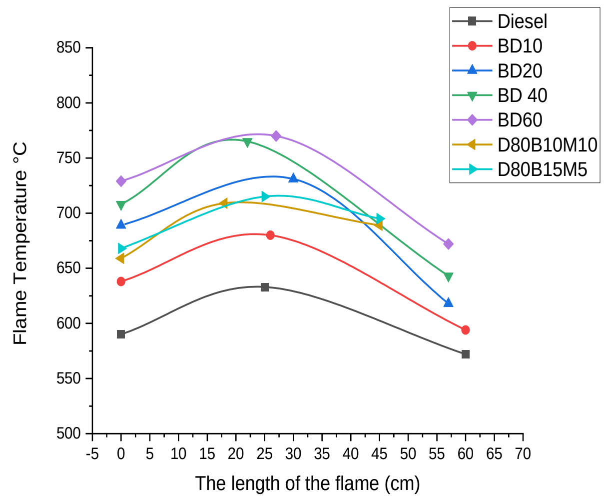

Fig. 5 Impact of using different dill biodiesel blend percentages on flame temperature

of the Mechanical Engineering Department, College of Engineering, Mustansiriyah University, Iraq. The experimental setup comprises a burner unit (Figs 3 and 4). The burner is the main element of the equipment's combustion system. Its main functions include fuel preparation, air-fuel mixture, and combustion control. The burner supplies the necessary amount of fuel and air and creates rapid mixing and flame production conditions. The air-fuel mixture's speed directly affects the flame's stability, shape, and emission. In general, the burner plays a crucial role in combustion.

Since it directly affects operating characteristics such as the efficiency of the combustion process, emission levels, and transient response, the burner is next to the combustion chamber inside a red plastic protector. The burner nozzle (a place where the flame is produced) is located inside the combustion chamber.

4. RESULTS AND DISCUSSION

A laboratory experiment was undertaken to generate samples of biodiesel fuel using diesel and vegetable oil. The experiment was to investigate the flame characteristics parameters associated with these samples. Table 2 displays the volume ratios of the various fuel types used in the research.

4.1. Impact of Varying Biodiesel Blend Ratios on Flame Temperature

The influence of temperature on several flame characteristics, such as pollutant emission and heat movement, is significant to the burner's performance. A K-type thermocouple measured the temperature along the flame to better understand and compare the flame dynamics under various experimental conditions. Figures 5 and 6 depict the variations in flame temperature within the flame penetration length and reaction zone for a fuel mixture. The data depicted in Figures 5 and 6 consistently demonstrate a decline in gas temperature with an increase in the distance separating the burner from the endpoint of the flame. Based on the observed results, it is apparent that the highest recorded flame temperature, around 770°C, at used biodiesel-type dill B60 is attained at a distance of 25 cm and 758°C used biodiesel-type cresson B60 at a distance of 20 cm. The outer portions of the flame exhibited a notable reduction in temperatures compared to the middle and nearby regions of the flame.

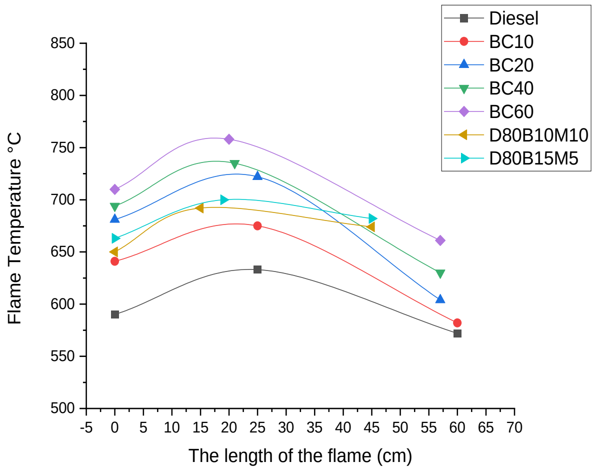

Fig. 6 Impact of using different cresson biodiesel blend percentages on flame temperature

Furthermore, the equivalence ratios have an impact on the flame temperature. Specifically, the flame temperature decreases at low equivalence ratios, whereas at larger equivalence ratios, it increases. These explanations also agree with the researchers (Hamdan et al., 2013; Elkelawy et al., 2023; Allawi & Saleh, 2024). The oxygen level in an oxygenated hydrocarbon fuel is crucial in determining its open-air flame temperature properties (Gongping et al., 2011).

As the mixture's biodiesel concentration increased, the flame's temperature likewise escalated. The observed rise in performance can be ascribed to the presence of oxygenate content in biodiesel and the elevated cetane number and decreased unburned hydrocarbons. Moreover, it has been noted that incorporating multifunctional methanol additives such as D80B10M10 and D80B15M5 has a notable impact on diesel and biodiesel fuels. This impact results in a noteworthy flame temperature increase compared to pure diesel and a biodiesel blend of 10%. These results also agree with the researchers (Elkelawy et al., 2022).

Due to its greater thermal value than biodiesel, methanol contributes to the increased flame temperature. Its function as a solvent and the presence of an oxygen atom facilitates complete combustion and increase combustion efficacy. However, it can be observed from Figures 5 and 6 that the flame experiences a cooling effect due to the elevated latent heat of vaporization. The flame temperature values of mixtures such as D80B10M10 and D80B15M5 are expected to fall lower than those of biodiesel. In addition, the reduced luminosity of methanol results in a reduced flame temperature.

4.2. Flame Temperature Distribution

The comparison of flame structure between diesel fuel and different biodiesel fuel ratios (B10, B20, B40, and B60) is depicted in Figs 7 and 8. Significantly, an increase in the percentage of biodiesel in the mixture results in a noticeable reduction in both the length of the flame and its visual attributes. This occurrence is frequently associated with variables, including ignition characteristics, calorific value changes, cetane number, and fuel density. Increased cetane numbers in the fuel contribute to reduced ignition delay, promoting a more thorough combustion process within the burner. As a result, the flame distance is diminished as the accelerated process causes each biofuel component to combust within a reduced period. Furthermore, including intrinsic oxygen facilitates the attainment of full combustion, resulting in a discernible alteration in flame color compared to conventional diesel fuel and a diminished accumulation of carbon within the flames.

In addition to the observations above, the flame temperature experiences a decline as it moves away from the burner. The peak temperatures of fuel mixtures are attained at varying distances from the burner, reflecting the diverse mixing ratios. Biodiesel was combined with methanol in proportions of 5% and 10%, alongside biodiesel proportions of 10% and 15%, with the remaining 80% comprising diesel fuel. This resulted in complete mixing ratios denoted by the formulas D80B15M5 and D80B10M10. These percentages encompass biodiesel fuel derived from dill and cresson. Notably, the flame length in this case is shorter than other fuel types, and the flame shape exhibits variability owing to the distinct specifications of the fuel types integrated into this mixture.

This can be attributed to methanol's relatively low cetane number and heating value compared to diesel and biodiesel. Furthermore, the elevated latent heat of vaporization exhibited by methanol plays a role in reducing gas temperature These results are consistent with (Amiri & Shirneshan, 2020).

4.3. Analysis of Uncertainty

Photographs of the flame were captured three times, and visual flame length measurements were recorded three times to verify accuracy, as depicted in Tables 2 and 3. The mean and standard deviation were determined following the given methodology.

Mean Value: Chen et al. (2012) and Beckwith & Marangoni (1985).

$$\overline{X} = (1/n)\sum_{i=1}^{n} xi \quad = 1,2,3,\ldots n$$

Standard deviation:

$$\sigma = \left[\left(\frac{1}{n-1}\right)^{1} \sum_{n-1}^{1} (x - x^{-})^{\wedge}2\right]^{\wedge}1/2$$

Uncertainty error:

$$\% = \frac{\sigma}{x}.100$$

Expanded Uncertainty:

$$Ud = [\frac{1}{n(n-1)}\sum_{i=1}^{n}(xi - \overline{x})^{\wedge}2]^{\wedge}1/2$$

Fuels	**Flame structure**	**The length of the flame**
Diesel		60 cm
BD 10		60 cm
BD 20		58 cm
BD 40		58 cm
BD 60		55 cm
D80B15M5		45 cm
D80B10M10		47 cm

Fig. 7 Flame structure of dill biodiesel blends

Fuels	**Flame structure**	**The length of the flame**
Diesel		60 cm
BC 10		56 cm
BC 20		53 cm
BC 40		50 cm
BC 60		48 cm
D80B15M5		46 cm
D80B10M10		45 cm

Fig. 8 Flame structure of Cresson biodiesel blends

Table 3 Analysis of uncertainty errors in the measured central flame length of diesel blended fuel. Dill type

Fuel blends	Flame 1 mm	Flame 2 mm	Flame 3 mm	Mean, X	Standard deviation, δ	Error, %	Expanded Uncertainty (U(d)), mm
Diesel	240	250	260	250	1	0.4	±0.4
BD 10	250	260	270	260	1	0.384	±0.408
BD 20	280	300	320	300	2	0.66	±0.577
BD 40	200	220	240	220	2	0.909	±0.57
BD 60	260	270	280	270	1	0.370	±0.408
D80B15M5	160	180	200	180	2	1.1	±0.54
D80B10M10	230	250	270	250	2	0.8	±0.56

Table 4 Analysis of uncertainty errors in the measured central flame length of diesel blended fuel. Cresson type

Fuel blends	Flame 1 mm	Flame 2 mm	Flame 3 mm	Mean, X	Standard deviation, δ	Error, %	Expanded Uncertainty (U(d)), mm
Diesel	240	250	260	250	1	0.4	±0.4
BD 10	240	250	260	250	1	0.4	±0.4
BD 20	230	250	270	250	1	0.42	±0.41
BD 40	205	210	215	210	1.8	0.85	±0.566
BD 60	160	180	200	180	2	1.1	±0.54
D80B15M5	140	150	160	150	1.56	1.04	±0.56
D80B10M10	185	190	195	190	0.5	0.3	±0.41

5. CONCLUSION

1- Biodiesel frequently has a higher oxygen content within its molecular composition than conventional diesel fuel. Including oxygen can augment combustion, resulting in a more effective and abbreviated flame.

2- The combustion of biodiesel frequently results in reduced emissions of unburned hydrocarbons and carbon particles in comparison to diesel fuel. The diminished presence of un combusted carbon can result in an elevated flame temperature.

3- Using dill-type biodiesel fuel at a 60% blend significantly increases the average flame temperature compared to cresson biodiesel and conventional diesel fuel.

4-When dill and cresson biodiesel are mixed with methanol in a ratio of D80B15M5 to D80B10M10, the flame length, and temperature are shorter than with other types of biodiesel and regular diesel.

5- Biodiesel can blend with diesel in a range of ratios, ranging from 10 to 60 percent.

CONFLICT OF INTEREST

The authors assert that the publication of this manuscript is free from any conflicts of interest.

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