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Abstract:
The present work evaluates the performance, emissions, and flame characteristics of diesel fuel blended with 10%, 20%, and 30% organic palm oil-derived biodiesel using a burner test rig. Results revealed a significant lessening in CO and SO2 emissions with B30 but a slight increment in NOx emission. A downward trend in temperature profile with biodiesel proportion and upward trend with equivalence ratios were witnessed. For flame characteristic investigation, a time-based image-capturing method was applied using a high-speed camera to capture a photo of each burning droplet, and the burning time was recorded for collecting burning data. Results demonstrated that B30 is less sooty and has a more pronounced blue flame color than the other models. The burn duration of the B30 droplet drastically dropped by 1.15%, while its burn rate constantly increased by 1.44% in comparison to those droplets. Overall, B30 demonstrates potential to improve gaseous emissions and combustion performance.
Keywords: Biodiesel; emission; flame; droplet; combustion; temperature;

1. INTRODUCTION

Fuel demand is continuously increasing due to urbanization and transportation growth. Huang et. al. [1] have highlighted the environmental and health risks posed by diesel engines. Despite their high energy density, they emit significant amounts of particulate matter, SO_2, and NO_x. Burning fossil fuel from transportation industries such as motorcars, trucks, buses trains, and ships is the primary cause of the greenhouse effect on our earth. As reported by Elsayed and Hiroshi [2], in the year 2020, there are 27% of global warming related to greenhouse emissions produced by transportation industries. Based on this situation, the research [3] shows that the greenhouse effect can be reduced by replacing renewable energy usage in transportation industries. Biodiesel is one of the sustainable alternative energy resources that is not only able to fulfill high energy demand but is also capable of improving combustion performance and diminishing detrimental emissions (CO, UHC, SO2, etc.) simultaneously. Due to the intrinsic oxygen presence in biodiesel and superior cetane number to conventional diesel that promotes absolute combustion [4]. Biodiesel is a green renewable energy fuel that can be derived from organic materials such as palm oil, sunflower oil, soybean oil, canola oil, etc., and presents a viable alternative to conventional diesel due to its very close physicochemical properties [5]. However, biodiesel has a slight lower heating value than conventional diesel, which completely depends upon the feedstock used to extract biodiesel. The lower heating value of fuel affects the engine performance slightly negatively [6]. On the other hand, biodiesel stimulates complete combustion to eliminate the toxic combustion exhaust to some extent. This shows that biodiesel has different characteristics and leads to different performances during combustion. Towards combustion, a droplet of fuel has its own characteristic to get better combustion performances.

Study by Elkelawy et. al. [7] found that the biodiesel blends fuel with 50% with conventional diesel has enhances combustion rate with increased peak temperature by 5% inside the furnace. By adding 15% and 25% of bioethanol on the blends fuel also increased the flame temperature up to 9% and 4% respectively. It is due to high latent heat of combustion and low cetane number of ethanol. Meanwhile, the exhaust temperature of B40 biodiesel blend fuel increased slowly from equivalence ratio range of 0.8 to 1.3 compared to B20 and diesel fuels. It shows that temperature increased with increasing blends percentages [8]. Flame temperature is the one of the important factors that influenced flame characteristics, gas emissions and heat flow. In contrast, the study on comparison between biodiesel and diesel fuels in large scale furnace by Pereira et.al. [9]shows that the flame temperature of biodiesel has lower that diesel correspondence with reduction of NO formation. Pourhoseini et.al. [10] also reported that the axial flame temperature of B20 biodiesel blend is lower than diesel fuel due to calorific value decreased. It leads to incomplete combustion and produced high CO emissions. Other study showed that the B60 of both dill and cresson biodiesel blends fuel have higher flame temperature up to 770°C and 758°C attained at a distance 25cm and 20cm from burner surface. Then, this flame temperature had declined slowly as it move away from burner surface [11]. Authors claimed that occurrence is related to several factors such as calorific value changes, cetane number, density and ignition characteristics. On the other hand, B20 of palm oil biodiesel blend fuel performance on oil burner was investigated with a 60-degree of cone nozzle [12]. Result of B20 palm oil biodiesel blend fuel on oil burner combustion showed that when the injection pressure increased, the flame from the burner cone grew in width and shrank in length, which made a larger flame reaction zone that modification in combustion dynamics led to decrease the droplet size and enhances the mixing rate. It also raises the axial flame temperature but reduces the CO emission and soot particles. Flame shapes were studied by Darwish et.al. [13] using butanol blends fuel from B0 to B50 using burner. It shows that the flame length decreases with increasing p_g and decreasing ϕ at limited ϕ of 0.76 significantly. The flame length also decreases with higher blend percentage, indicates shorter flame length for B50. It was presented that the NO emission reduced but increased the CO emission with higher butanol concentration.

Another characteristic of combustion is the burn rate of fuel droplets which is important to see how fast the diffusion-controlled combustion between fuel vapor and air occurs. Rosyadi et. al. [14] mentioned that a study on a single droplet is important to reveal the fundamentals of combustion characteristics. Flame color is the visible color appear during combustion. It changes depending on many parameters including temperature, the fuel chemical makeup, and the presence of certain elements or compounds. When various chemical components or compounds inside the flame are heated and then excited, different light wavelengths are released, which is the primary cause of the variation in flame color [15]. The cause of the variation in flame color between diesel and biodiesel blends fuel are on their different chemical makeup. Research on the flame color of diesel and biodiesel blends fuel have shown that biodiesel flames generally exhibit lower luminosity and soothing tendency compared to diesel [16-17]. Biodiesel from different sources such as plants, animal fat, algae, etc., contain different amounts of intrinsic oxygen molecules, which may affect flame characteristics differently for instance different flame color may occur as compared to conventional diesel fuel. When comparing the combustion of diesel and biodiesel, utilizing flame color as a parameter can offer qualitative insights into the fuel consumption efficiency and combustion process [18]. It provides a straightforward visual cue to assess how the two fuels combustion behaviors differ from one another. Even though it may not be the most accurate or quantitative metric, analyzing flame color can be used as a first qualitative evaluation to spot differences in the way diesel and biodiesel blends fuel burn.

The term "burn rate" describes the rapid rate at which a substance, usually fuel, burns or undergoes combustion. It gauges how quickly fuel is used as well as how quickly the flame spreads throughout the fuel. The variation in burn rates between diesel and biodiesel can be attributed to several factors, including chemical composition. The major factors affecting the burning rate in diesel engines are identified as injection rate, engine speed, and combustion chamber design [19]. Besides, different fuels like diesel and biodiesel are made up of distinct molecular structures which also influence the burning rate [20]. Ghorbani et. al. [21] reported superior burning rate of biodiesel fuel in comparison to diesel fuel caused by intrinsic oxygen in biodiesel chemical structure. In addition, they also noted lower emissions of CO, SO_2, and CO_2 with biodiesel blends with respect to diesel fuel. The combustion efficiency variation depends upon the energy level of biodiesel blend. Chukwuezie et. al. [22] stated that ignition quality of fuel is correlated with the cetane number. Since biodiesel shows superior cetane number to diesel fuel therefore ignition quality of biodiesel is superior which directly creates impact on burn rate and combustion efficiency. However, the increase in cetane number can also lead to higher NOx emissions [23]. In the study of Das et al. [24], it is mentioned that the bulk burning rate of diesel was higher than that of biodiesel, indicating that the two had differing burning rates. Physicochemical properties like viscosity, density, and heating value may have attribution to this variation . These characteristics have an impact on fuel combustion, interaction with air, and energy release. Each droplet's duration will alter as a result of these characteristics interacting with the droplets during combustion. The practicality of biodiesel as an alternative fuel to diesel may be determined by looking at burn rates. Furthermore, investigating burn rates helps ascertain how employing biodiesel can affect pollutants, engine performance, and combustion efficiency.

The amount of time a fuel burns once it is ignited is referred to as its burn duration. It gauges how long combustion continues after fuel is ignited until the flame goes out or the fuel stops burning. The burning duration of a fuel droplet is a crucial element in the combustion process, primarily governed by its ignition delay and burning rate [25]. The behavior and efficiency of biodiesel and diesel fuels combustion may be understood by examining the variations in burn times between the two fuels. A metric for comparing the combustion efficiency of various fuels is the measurement of burn time. It provides important details on the duration of combustion, the kinetics of combustion, and the persistence of the combustion process of various fuels. Droplet burn duration can be influenced by many factors such as ambient oxygen mole fraction and the presence of inert-gas suppressants [26]. Diesel and biodiesel fuels come from various sources, so their molecular structures are differ [20,27]. The dynamics of combustion and the length of burning can be affected by these variations. Besides, with a greater cetane number and oxygen concentration than diesel, biodiesel frequently exhibits distinct ignition characteristics [28]. The fuel's ignition and sustained combustion rates can be affected by these variations, which in turn might affect the burn duration. Droplet burning was investigated by sampling droplet burning images from earlier research. According to the study, when compared to the period of combustion of diesel droplets, the burning time of a combination of diesel and palm biodiesel was much shorter by 17.7% [5]. This demonstrates that the two fuels utilized differ significantly from each other. This distinction may yield a more favorable outcome than the amount of oxygen in the mixture of biodiesel can influence how long this combustion takes. Therefore, the objectives of this research are to investigate the effect on the combustion performances and gaseous emission at different air mass flow rates and blend percentages of palm oil biodiesel fuel. In addition, to evaluate the droplet combustion characteristics of palm oil biodiesel blends and diesel fuels through a time-based image-capturing method including the burn rate combustion and burn duration of palm oil biodiesel at different blends of fuel percentages.

2. MATERIALS AND METHOD

2.1 Material

This study presented the palm-oil biodiesel blends with conventional diesel fuel in different percentages, 10%, 20% and 30%. They are labelled as B10 (10% palm oil biodiesel + 90% diesel), B20 (20% palm oil biodiesel + 80% diesel) and B30 (30% palm oil biodiesel + 70% diesel). Both palm-oil biodiesel and diesel fuels were bought from local supplier Excelvite Sdn. Bhd. Thus, both fuels are blended in required proportions through magnetic stirrer to make fuel blend homogeneous. The biodiesel fuel properties are listed in given Table 1 below.

Table 1: Properties of palm oil biodiesel fuel

Parameter	Test Method	Diesel	Palm oil biodiesel
Density at 15℃ (kg/m^3)	EN ISO 12185	833.1	874.5
Boiling Point (℃)	-	-	>260.0
Cetane Number	ASTM D6890	49	>75.1
Viscosity at 40℃ (mm^2/s)	EN ISO 3104	3.56	4.45
Sulphur Content (mg/kg)	ASTM D5453	-	<1.0
Flash Point (℃)	EN ISO 3679	77.5	172.0

2.2 Method

After the successful blending of fuels, the blends are tested on their combustion performances and characteristics using the burner test rig. Fig. 1 shows the burner test rig and the location of the thermocouples to measure the flame temperature profile. Combustion chamber of burner test rig is a hollow cylinder shape which is open at the end of chamber. At the other side of chamber is connected with Baltur light oil burner including fuel tank and fuel pipeline. There have 8 holes at the top of combustion chamber to allocate the thermocouples. Flame temperature profiles inside the chamber are measured using type-K thermocouples connected to the Hioki LR8431-20 data logger. The flame region will be generated by the combustion of fuel and data gathered considered as flame temperature profiles. Three thermocouples are mounted on the top of the chamber labelled as T1, T2, and T3. The study of flame temperature profiles and gas emissions are also measured at three different air –fuel ratio of 0.0053, 0.0097 and 0.0189 based the air flow rate indicator of Baltur burner. Biodiesel blends and diesel fuels are supply from the fuel tank throughout the pipeline. Meanwhile, Dräger MSI EM200 flue gas analyzer is placed at the end of the chamber to measure their gaseous emissions from each combustion test. The specifications of emission gas analyzer are listed in Table 2.

Figure 2 illustrates the schematic diagram of droplet combustion experimental setup and dimensions (mm) of designed droplet combustion setup that is used in present study. This study was set up at an atmospheric pressure, 1 atm. The droplet combustion test rig apparatus has several crucial components. An opaque substance that is incapable of reflecting or refracting light makes up the insulated area. This ensures the camera-captured image

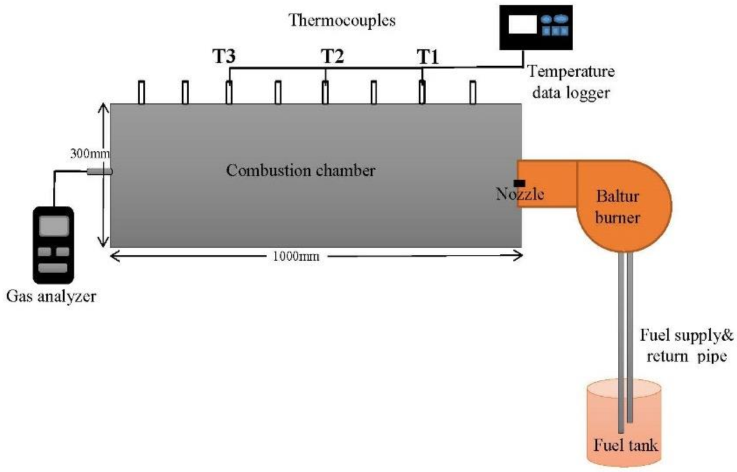

Fig. 1. Test burner rig

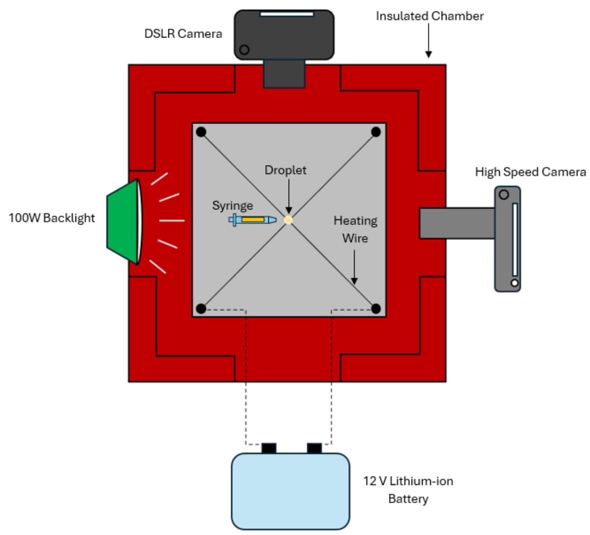

Fig. 2. Schematic diagram of the droplet combustion experiment set up and its designed dimensions.

does not grow blurry or harm it. There is 300 mm burning space in width, 300 mm depth, and 300 mm height. A nichrome wire that transmits an electric current using the 12V Lithium-Ion battery to burn the diesel or biodiesel blends fuel droplet is positioned at the center of the test rig. The droplet will be provided using syringe to fall horizontally on top of the center of nichrome wire region. Four post supports, one at each corner of the square base plate, were used to create a cross-nichrome wire with a 90° angle separation, and it is linked to the battery. A high-speed camera and halogen backlight are positioned between the droplets. This position is to guarantee that a shadow picture is produced. Meanwhile a laptop is attached to a high-speed camera to take pictures at up to 500 frames per second. The resolution is adjusted around 352 x 640 pixels, which is sufficient to fill the droplet's whole border. Conversely, the evolution of the flame is captured at a resolution of 3968 x 2976 using a DSLR camera as shown in Figure 2. The nichrome wire serves as a heater and function to burn the fuel droplet. The nichrome wires were positioned in the center of the test rig area, forming an ‘X' shape with their crosswise installation. The wire is operated in 150 mm long and 0.35 mm thick. These wires are linked to a 12V lithium-ion car battery to generate heat.

The halogen backlight turn on and the high-speed camera's resolution set to approximately 480 fps, 224 x 160 pixels, for capturing images at 480 frames per second. A DSLR camera is used to capture the development of the flame at a resolution of 3968 × 2976. Nichrome wires tied to the base test rig connected to the lithium-ion car battery through the jumper. The wires allow to be heated in 0.8 seconds until it reaches temperature of 400°C to provide uniform heating around droplet. The volume of diesel used to fill the syringe is 1 mL. Then, the syringe will be pushed, and a droplet of diesel will fall on top of the crosswire and burn. While burning, DSLR cameras and high-speed cameras starts capturing images of the burning process.

Table 2. Specifications of gas emission analyzer

Parameter	Principle	Range	Resolution	Accuracy
O_2	EI. chem. sensor	0-25 vol%	0.1 vol.%	0.3 vol%
CO	EI. chem. sensor, H_2-compensated	0-8000 ppm	1 ppm	0-4000 ppm: ±20 ppm or 5% of measured value
NO	EI. chem. sensor	0-4000 ppm	1 ppm	±5 ppm or 5% of measured value
NOx	EI. chem. sensor	0-200 ppm	1 ppm	±5 ppm or 5% of measured value
SO_2	EI. chem. sensor	0-4000 ppm	1 ppm	±10 ppm or 5% of measured value

3. RESULTS AND DISCUSSION

The variation in flame temperature profiles are noticed for different air-fuel ratio and biodiesel blends including diesel fuel. Figure 3 shows flame temperature profiles at air-fuel ratio of 0.0053. The results show that the diesel fuel produced the highest temperature profile compared to all biodiesel blended fuels. Diesel fuel used as reference base data to compare with all palm oil biodiesel blended fuels. For the air-fuel ratio of 0.0053, diesel fuel produced up to 992°C temperature, meanwhile B10, B20 and B30 produced temperatures of 902°C, 825°C and 788°C, respectively. Flame temperature profiles increased for biodiesel blends and diesel fuel when increase the air-fuel ratio to 0.0097 and 0.0189, as apparently depicted in Figure 4 and Figure 5. This might be caused by enough availability of oxygen that stimulates complete combustion. At all air-fuel ratios, lower temperature profiles were noticed for biodiesel blends in comparison to diesel fuel. In addition, increasing the biodiesel concentration in blend contributes to the generation of lower temperature profile. This might be attributed to lower calorific value and superior cetane value of biodiesel with respect to diesel fuel [29]. Ganjehkaviri, et.al. [30]found the decrement in temperature profile with higher proportion of biodiesel in blend whereas they noticed upward trend in temperature profiles with air-fuel ratio. Their findings are in good agreement with our results. Furthermore, highest temperature profiles for all tested fuels were witnessed at thermocouple T2 located at the center of combustion chamber of burner rig. This is because major energy portion of fuel release at the center during the burning process. Whereas, the last thermocouple located towards the end of chamber had the lowest temperature. It is because at this position, energy released by the combustion are slowly disappeared into the air.

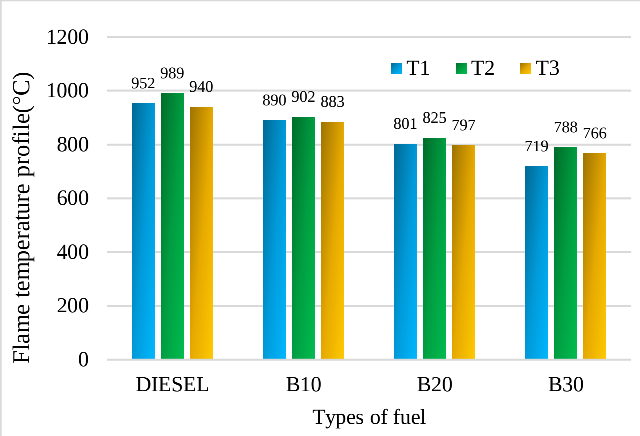

Fig. 3 Flame temperature profiles of biodiesel blends and diesel fuel at air-fuel ratio of 0.053

By supplying more oxygen to fuel leading to combust the fuel absolutely and provide ideal results for most of combustion operations. It aids in maximizing energy release while minimizing pollution emissions. Gaseous emissions of CO, SO_2 and NOx were collected concurrent with temperature profiles data taken accordingly. Fig. 6 shows that higher biodiesel blends fuel combustion have resulted in the minimum CO emissions in different air-fuel ratios. CO emissions consistently decreased at all equivalence ratios as the biodiesel blend fuel increased. Because biodiesel contains more oxygen than diesel fuel, it burns more efficiently and minimizes incomplete combustion occurred. It is also caused by lower carbon content in the blends and higher cetane value, which was responsible for this attained result [29]. Biodiesel blended fuel tends to decrease CO emissions at any blend percentage.

Figure 7 depicts the variation in NOx emission against air-fuel ratio. Meanwhile, according to data NOx emissions across various air-fuel ratios and blends of biodiesel exhibit a distinct trend. NOx emissions rise with the amount of biodiesel in the fuel blend for air-fuel ratios. The higher oxygen content of biodiesel causes higher combustion temperatures resulting in more NOx formation. As found by Norwazan et.al. [31], NOx emissions were increased by increasing the biodiesel blends either palm oil, or Jatropha or coconut oil based. Ahmad [29] reported the higher NOx production at lean region which is mostly because of thermal effect caused by high temperature region generates at mid-length of combustion chamber. Whereas in rich region, augmentation in NOx can be attributed to high proportion of oxygen present in supplementary biodiesel that stimulate NOx production by an oxidation process of fuel bound nitrogen. Moreover, NOx generation is also sensitive to stoichiometric conditions. In different study that used a Lombardini 2-cylinder, four- stroke direct injection diesel engine with a compression ratio of 22.8 was observed that palm oil biodiesel blends are emitting less NOx as compared to diesel. As increased as palm oil biodiesel blends resulted lower NOx emissions which can be explained by the oxygenation nature of biodiesel that leads to lower combustion temperature [32]. The variation in the results might be due to the different experimental setups used, different biodiesel content and type, burner or engine type and operating systems [30].

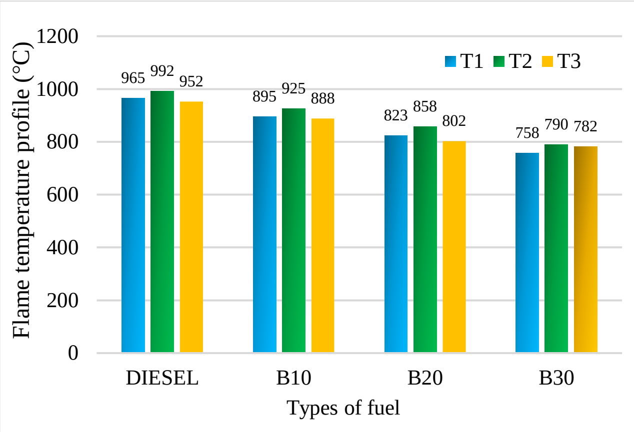

Fig. 4 Flame temperature profiles of biodiesel blends and diesel fuel ratio of 0.097

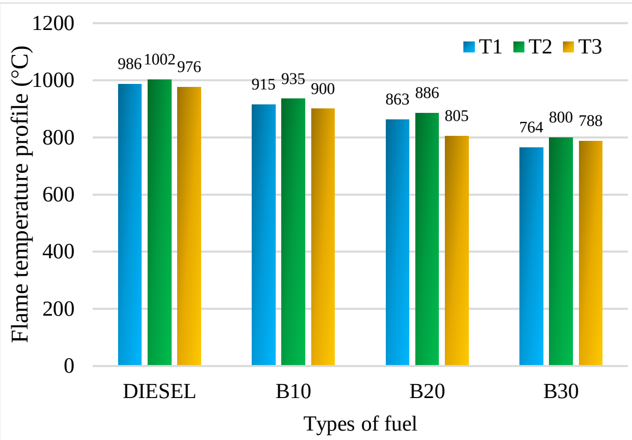

Fig. 5 Flame temperature profiles of biodiesel blends and diesel fuel ratio of 0.019

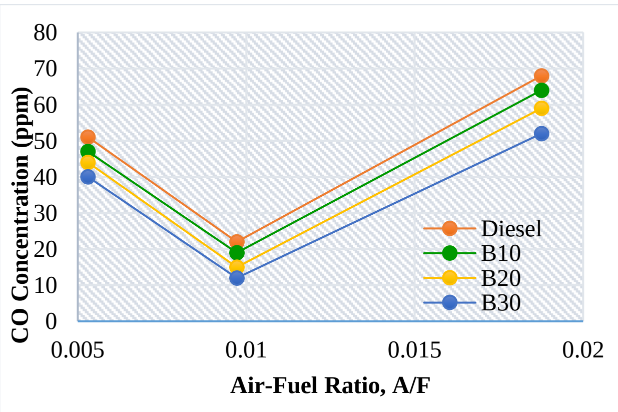

Fig. 6 CO emissions biodiesel blends fuel

Figure 8 demonstrates the variation in SO_2 emission against air-fuel ratios for tested fuels. It is clear from the figure that increasing the concentration of palm biodiesel in blend decreases the SO_2 emission at all equivalence ratios. This event might be caused by the absence of sulfur in biodiesel, therefore formation of SO_2 emission decline as the amount of biodiesel increases. As mentioned by Norwazan et. al. [31], diesel fuel emits higher SO_2 emissions than biodiesel blend fuels due to lower sulfur content in biodiesel fuels and their lower pollution output properties. It is also shown that SO_2 emissions emitted from the biodiesel fuel are raised due to the sulfur content that is affected by the esterification process using H_2SO_4.

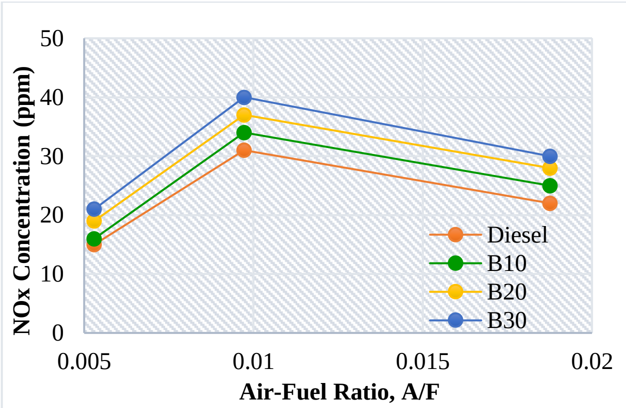

Fig. 7 NOx emissions of biodiesel blends fuel

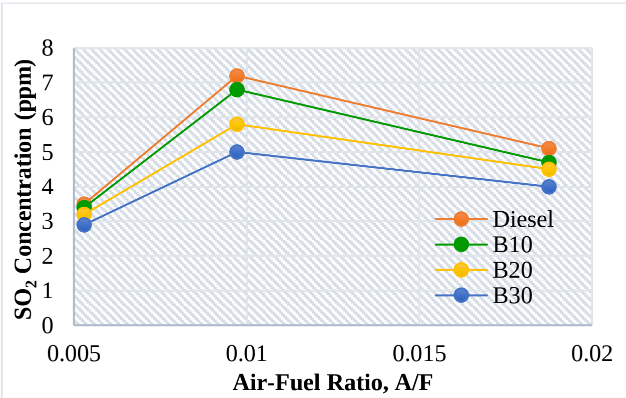

Fig. 8 SO_2 emissions of biodiesel blends fuel

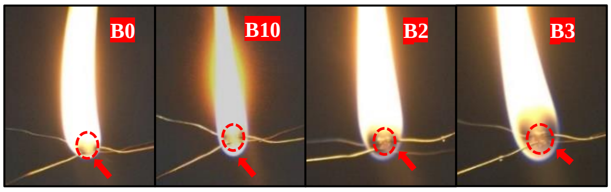

Fig. 9 Center of the flame formation around the droplet

An essential component of combustion research is the color of the flame, which reveals information about a substance's temperature, chemical makeup, and rate of combustion. It is mostly dictated by the temperature and materials burning particularly. Since the energy is released at certain wavelengths and particles are excited differently, various elements and compounds produce distinct colors. Diesel fuel contains carbon particles called soot, which become luminous during burning and give the fuel its characteristic yellowish-orange flame color with a bright core. High temperatures are applied to these tiny particles, making them light brilliantly and produce the distinctive yellowish-orange flame. The bright core typically indicates the hottest area of the flame, which is typically white or light yellow. Diesel also contains various chemicals including hydrocarbons, which add to the overall color of the flame. The hue changes to a colder shade of yellowish orange as the temperature drops. As shown in Figure 9, diesel fuel has a distinctive yellowish-orange flame with a bright center (red circle) due to the presence of carbon particles in the fuel. Both diesel and B10 blend fuel exhibit this bright center, a sign of elevated temperatures. Diesel flames have a sooty nature also can lead to an increase in particle emissions, which pose a serious risk to the environment and human health. The central area of the color is less and clearer for B20 and B30, respectively. The flame turns bluish, and transparent as the fuel's biodiesel concentration rises (see the red arrow). This demonstrates that as the quantity of biodiesel content rises, soot production decreases. Higher oxygen levels during combustion result in more complete combustion and less soot generation, as this blue color shows. In addition, when the biodiesel concentration rises, the flame around the droplet gets more bluish. It is showing that B30 has a greater blue concentration than diesel fuel (B0). This blue backdrop occurs because it indicates that burnt droplets contain oxygen. This burning's outcome demonstrates that B30 has more oxygen in it among all tested fuels [33]. The rate of full combustion will rise with a high oxygen level. The lack of aromatic hydrocarbons and the presence of oxygenated functional groups in biodiesel droplets provide a bluish flame that is sufficient to neutralize gas molecules and reduce sooty flame [34].

Images from a high-speed camera were thresholding to determine the droplet diameter values before and during combustion. Then, the droplet's diameters are obtained using a MATLAB image processing approach. The result obtain for the diameter is 3.56 mm. Diesel fuel's burn rate constant is found using the D-Square Law equation for burn rate [35]. For every droplet, five data points were collected in total, and the average for each period of burn duration was determined. This measurement was done to minimize the error and obtain more reliable results. According to the Fig. 10, the B30 droplet appeared to have the highest burn rate at 4.96 mm^2/s, while B0 and B10 had the lowest burn rates at 4.87 mm^2/s. This discrepancy most likely results from B30 having a greater oxygen content than that of B0 and B10 fuels. This high oxygen level gives a high chance of full combustion and also shortens the time to complete combustion process. Diesel has a mostly hydrocarbon content, which causes it to burn more slowly than other fuels. It also has a lower palm oil biodiesel proportion in B10 than other B20 and B30, which almost eliminates the difference between B0 and B10. The graph also demonstrates an downward trend as palm oil biodiesel blend content rises. Therefore, it was concluded that higher biodiesel concentrations in diesel blends result in faster burning and more efficient combustion [36]. Better combustion results usually occur due to enhanced evaporation and mixing rate.

Burning duration is determined as the period between the start of ignition and the end of combustion of a fuel droplet. It is affected by variables such as oxygen availability, droplet size, fuel mix, and ambient temperature. Depending on the environment and droplet size, the natural burn time of diesel fuel can vary from milliseconds to seconds. To record the time-based development of the burning droplet, the duration of droplet burning was examined in this study utilizing a high-speed camera and a stopwatch. The diesel fuel combustion process takes around 2.6 seconds to finish, the same amount of time as the B10. Nonetheless, the B30 blend exhibits a little decrease in combustion duration, requiring 2.57 seconds to finish the procedure. The greater burn rate of B30 might be the reason for this 0.03 second drop when compared to B0 and B10. The duration needed for the fuel to burn decreases as the burning rate rises. This suggests that the B30 blend has a higher combustion efficiency, complete burning process in less time. Improved combustion efficiency is a desired quality for lowering emissions and improving engine performance, and it is suggested by the higher burn rate. Fig. 11 makes it clear that diesel burns slowest through the combustion process, whereas B30 records the quickest burn time. B30 burns for a shorter time, which reduces heat loss in the engine region during combustion and improves the efficiency of the energy conversion process. Because of its efficiency, there is less incomplete combustion, which leads to less soot buildup and less particle emissions. The lower soot builds up enhanced combustion properties of the B30 blend may result in cleaner engine running and perhaps cheaper maintenance costs [37]. In contrast, study by Hashimoto et.al. [38] obtained that the droplet lifetime for palm-oil biodiesel is longer than that for diesel fuel and n-hexadecane at the same ambient temperature due to very low evaporation rate. Overall, using B30 blend reduces hazardous emissions linked to incomplete combustion, improving combustion efficiency while also contributing to environmental sustainability.

4. CONCLUSION

This study will help to conclude that the palm oil biodiesel blends will be able to produce the same amount of energy as fossil fuel or leads to an increase or decrease in temperature inside chamber where affect the energy produced by adding amounts of 10%, 20% or 30% of the palm oil biodiesel in diesel fuel. Using a burner test rig, this project examines their combustion performances and gaseous emissions that is resulted in diesel fuel has higher flame temperature profile due to calorific values diesel content increased. Based on the data obtained, a higher airflow produces a higher flame temperature profile because there is more oxygen available for the fuel to react with, producing more energy. The first objective of this research has been achieved and concluded that the emissions of B30 emits more environmentally friendly compared to diesel fuel by lowering CO and SO_2 emissions. Meanwhile, due to the high oxygen content in biodiesel fuel, NOx emissions increased mainly due to fuel characteristics. Moreover, the information suggests that B30's shorter combustion time reduces incomplete combustion, which in turn reduces particle emissions and soot generation. Additionally, B30 creates a stronger bluish hue at the outer layer of flame and implies cleaner combustion, as evidenced by the droplet flame figure. Thus, the results of shorter burn duration and faster burn rates proved to improve combustion features and boost engine performance. B30 blend fuel has environmental advantages such as lower greenhouse gas emissions and particulate matter, and aligns with international sustainability intentions, indicating that it is a strong contender to substitute conventional diesel.

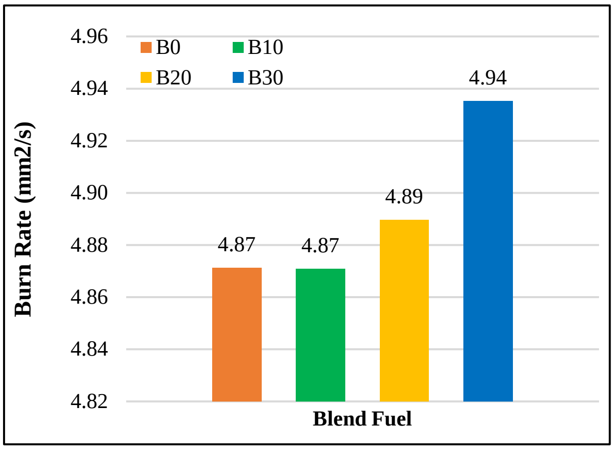

Fig. 10 Burn rate vs blends fuel

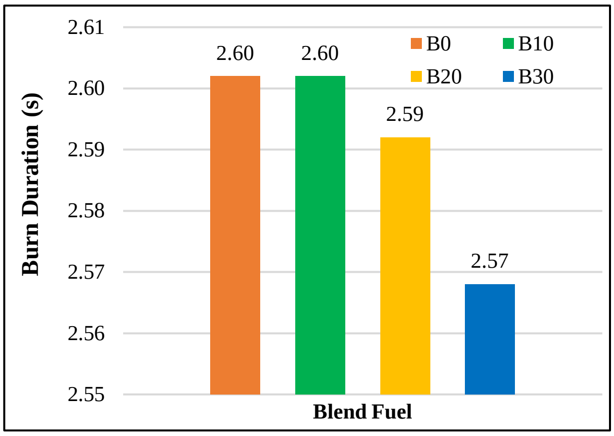

Fig. 11 Burn duration vs blends fuel

This study limited to burner test rig and droplet combustion testing which is not applicable for all type of combustion for example burning at high pressure in internal combustion engine. Besides, long-term effects of biodiesel blends on deposit formation on the burner wall are not addressed.

The higher blending testing is recommended for both flame temperature profile and droplet combustion testing using thick-wire as a heater to combust the fuel droplet. In addition, future research should focus on extensive emission analysis including hydrocarbon emission, smoke, particular matter, etc. and comprehensive engine testing to evaluate power output under diverse conditions. Detailed flame study is recommended to provide deeper insights into combustion kinetics. Economic analysis and conducting a life cycle analysis will assess the economic feasibility and environmental impact.

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