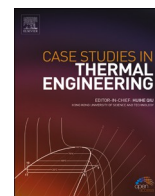




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## Diesel-fired boiler performance and emissions measurements using a combination of diesel and palm biodiesel

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## ABSTRACT

Biodiesel is widely accepted as a fuel that is similar to diesel with various advantages. Biodiesel's low-temperature flow qualities are one of its characteristics that limits its use. The goal of this study was to see how volumetric blends of palm biodiesel and diesel, and diesel as a fuel affected the performance and emissions characteristics of a diesel fired vertical coil type, water tube, and non IBR boiler. Various volumetric blends were prepared like PB25, PB50, PB75, PB100 and test in diesel fired boiler with variation in injection pressure. Performance of PB25, PB50, PB75, and PB100 fuels was observed 62.73%, 62.45%, 62.36%, and 62.32%, respectively, compare to pure diesel the value of all blends is either slightly higher or comparative. The maximum boiler efficiency with B100 fuel is 64.98%, which is lower than the pure diesel as fuel 65.30%. Because B100 has a higher kinematic viscosity, it has a larger droplet diameter which lead to poor spray formation and thus a lower boiler efficiency. At 11 bar fuel injection pressure, maximum EGT for diesel, PB25, PB50, PB75, and PB100 fuels is 300 °C, 295 °C, 308 °C, 328 °C, and 340 °C, respectively. Other blends, with the exception of B25, have higher EGT than diesel fuel. At a same fuel injection pressure of 11 bar, CO emissions from diesel, B25, B50, B75, and pure palm biodiesel fuels are 0.037%/Vol., 0.0336%/Vol., 0.0326%/Vol., 0.033%/Vol., and 0.036%/Vol., respectively. CO emissions for PB50 are the lowest of all the fuels tested, followed by B25, diesel, and B100. CO emissions from diesel, PB25, PB50, PB75, and PB100 fuels at maximum fuel pressure are 0.0605%/Vol., 0.0616%/Vol., 0.0605%/Vol., 0.060%/Vol., and 0.05%/Vol., respectively. When compared to diesel fuel, CO emissions from B100 fuel are 21% higher. The highest HC emissions are 18 ppm, 16 ppm, 14 ppm, 13 ppm, and 12 ppm for diesel, PB25, PB50, PB75, and PB100 fuel, respectively. When utilizing B100 fuel, HC emissions are reduced by around half compared to when using diesel fuel.

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## 1. Introduction

Modern industrial civilization have been powered by use of primary energy sources like conventional fuel such as coal, crude oil, and natural gas. In recent time the global ingesting of these resources was equally potential of 9 billion tonnes of crude oil. Due to intense economic expansion of the countries such as India and China, the demand of these resources increases drastically [15]. With the increasing rate of continuous supply of fuel, the country should make certain that it can maintain its current level of development. Recently, significant problems have arisen as a result of fossil fuel use, including a lack of supply, a sharp increase in economical value, non-renewability, pollution of the environment, and adverse effects on bio systems. This has prompted researchers to look for an alternative fuel that has a symbiotic relationship with sustainable development, conservation and management of energy, energy efficiency, and climate change [17]. Researcher found many other alternate energy sources in the point of this view such as LPG, CNG, ethanol, methanol, hydrogen, LNG, biodiesel and many other, India have huge potential for development of various biofuel among these alternative fuels [1]. Moreover, the sector like transportation and agriculture is major consumer of petroleum diesel, so it demand development of alternative fuel.

### 1.1. Biodiesel

Biodiesel is derived from various edible and non-edible vegetable source as well as from animal fats [18]. In India we have huge number of tree bone oil source are available such as Jatropha, palm, Karanj, Neem, and Mahua for production of biodiesel. Biodiesel produced from vegetable oil by transesterification process have same characteristics of petroleum, so that biodiesel can blends with petroleum diesel with any proportion to form alternative fuel or it is used in pure form [2]. Biodiesel can be used in compression ignition engine, diesel fired boiler or in other heating application with little modification or without any modification in combustion equipment. The same way as petroleum diesel fuel is, this product can be stored and used [3]. When used in conventional diesel engines, biodiesel reduced emission of HC, CO, and particulate matter. Biodiesel is green and clean fuel, containing in built oxygen and without containing Sulphur, allowing it to burn completely with less oxygen. Even when combined with petroleum diesel, the cetane number is increased [4].

### 1.2. Biodiesel production in India

Biodiesel's yearly potential is projected to be over 20 million tonnes per year In India, various crops cultivated on the wasteland which are not uses for any edible purpose may use for biodiesel production [5]. According the Survey done by GOI (Government of India) more than 175 million hectares of cultivated land are categorized as waste and degraded land [6]. Table 1 represent potential of India to produce oil from various non edible sees with production and % oil contains from various source. Various Agency of government of India like Forestry, Non-Conventional Energy, Rural Development, MNREL, Pollution control etc. are also involved in the same.

All of the participating agency in this programme source take the lead in development of alternative fuel. The GOI, plan through Planning Commission, and launched a countrywide effort to cultivate enormous tracts of waste lands by planting oil yielding trees, with the result that considerable amounts of biodiesel production will be available in the near future [7].

### 1.3. Palm biodiesel

Palm biodiesel is free of sulphates and is simple to work with existing equipment [18]. Palm biodiesel has higher flash point compare to diesel, for example. Hemp is a non-toxic material that is renewable and biodegradable. It also serves as a safety net for lowering palm oil prices by clearing out excess inventory in the industry [8]. Because of the increasing demand for edible oil in major consumer countries, the demand for this commodity is rapidly increasing, particularly in China, the European Union, Pakistan, India, and the United States, among other places [19]. The use of palm biodiesel contributes to the increase in demand and, as a result, to the increase in the price of palm oil to some extent. Contrary to conventional diesel fuel made from petroleum, palm biodiesel has a number of environmental advantages. According to several studies, the use of biodiesel reduces the emissions of sulphur dioxide, hydrocarbons, carbon monoxide and carbon dioxide, as well as particulate matter emissions [21]. Because it has a higher cetane number than petroleum diesel, biodiesel improves engine performance while also emitting less harmful emissions. Based on current practises in the Malaysian palm oil industry, it has been discovered that palm biodiesel, when compared to petroleum diesel, typically

**Table 1**  
Non Edible source along with yield found in India.

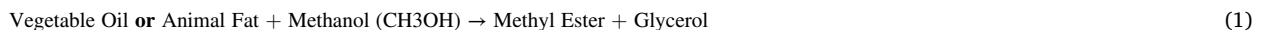
Non edible source	Oil Production in MT	Oil Percentage
Palm	500	30
Karanj	201	28–38
Kusum	80	34
Pilu	51	32
Jatropha	–	31–41
Jaoba	–	52
Bhikal	–	36

contributes to greenhouse gases emission savings of more than 70%. If biogas from palm oil mill effluents is captured and used for energy production [22]. If the biogas is released into the atmosphere, it will result in a reduction in greenhouse gas emissions of more than 50%. The production of biogas from palm oil mill effluents contributes significantly to global greenhouse gas emissions. The biogas is composed primarily of methane (60% to 70%), carbon dioxide (30% to 40%), and a trace amount of hydrogen sulphide [9]. In comparison to carbon dioxide, methane has a 23-fold greater global warming potential and thus contributes significantly to greenhouse gas emissions [23]. It increases the number of business and employment opportunities in Malaysia. It also allows for the extraction of phytonutrients such as carotenes (pro-vitamin A) and vitamin E from the plant's leaves. In this section, various property parameter of palm biodiesel and petroleum diesel are compared. Table 2 show that the physical and chemical property of biodiesel derived from palm in comparison with ordinary petroleum diesel which found in near about range so that palm biodiesel may use as alternative fuel to petroleum diesel in various heating application like Diesel Engine, Diesel Generator, Diesel fired Boiler, and in oil burner etc.

## 2. Literature review

Hill and colleagues measured and assimilated the plant's biological, chemical, and genetic characteristics as well as defining the various tree-borne oilseeds found in India, and they published their findings. If you compare non-edible oils to edible oils, you will find that they are much more cost effective [25]. Non-edible oils include corn, sunflower, coconut, and oil palm, and they are widely available all over the world, including India. It is possible to obtain large quantities of non-edible oils from a variety of species in India, including mustard seed and oil palm [29]. Sunflower and corn oil are also viable options for use in biodiesel production processes [10]. Table 3 shows India's potential for various tree born non-edible source along with oil yield per acre land. Furthermore from Table 3 it is found that India has huge potential to produce biodiesel from non-edible source on waste land.

Syed Khaleel Ahmed et al. explored three different ways to make bio-diesel from fats and oils. (1) Oil transesterification catalyzed by a base (2) Oil transesterification catalyzed by an acid (3) Oil conversion to fatty acids and ultimately to biodiesel the transesterification reaction is a stage in the process of turning oil or fat into fatty acid methyl or ethyl esters [11]. The general chemical process for making biodiesel with the use of transesterification is represented using equations (1) and (2)



The transesterification process for palm biodiesel production method was explained by a researcher using various catalyzed. Various catalyst like alkalis, acids, or enzymes use in this transesterification process as shown below Fig. 1.

Sodium hydroxide, potassium hydroxide, and potassium alkoxides like sodium methoxide, sodium ethoxide, sodium propoxide, and sodium butoxide are all examples of alkalis [30]. Acidic catalysts include sulphuric acid, sulfonic acids, and hydrochloric acid. Alkali media are commonly used in industry for transesterification because they have a higher yield and a shorter reaction time [12–14]. The low temperature and low pressure is responsible for the same, S. Mekhilef et al. [28] discovered that the properties of the transesterification process based on catalyst changed as a result of the catalyst treatment. In addition, this method has a high conversion rate of nearly 98%, as well as few side effects and a short reaction time, among other advantages. Due to the absence of an intermediate compound, this method is advantageous because the oil can be converted directly into biodiesel without the need for a catalyst. Fig. 2 depicts the chemical reaction that takes place during the procedure.

The various fatty acid chains of palmitic oil are represented using letters R', R'' and R''' in the above diagram. Based on the above transesterification process, the researcher also presents a palm oil biodiesel production technology. The catalyst was combined with alcohol in this method. A typical mixing machine is used to dissolve the catalyst in the alcohol. The oil made from palm is then added to the mixture in a closed reactor vessel. For recovery of alcohol and also to prevent environment whole process is carried out in closed system. To allow the reaction to take place, the mixture is held at a temperature more than the boiling point of alcohol, around 72 °C. Reaction time period varies from 3 to 6 h based on quality of oil, and additional alcohol is frequently employed to ensure that palm oil is completely converted to methyl esters [32]. After completion of chemical reaction we get two substance as product and that are glycerin and biodiesel. Biodiesel is our main production and glycerin is by product. Fig. 3 represent the whole process of biodiesel production based on catalyst transesterification process as mentioned above. Catalyst based transesterification process include various step like phase separation, methanol recovery, catalyst mixing.

**Table 2**  
Physico-chemical Properties of Biodiesel derived from palm and ordinary Diesel.

Characteristics/Property	Unit	Palm Biodiesel (palm methyl ester)	Petroleum Diesel
Source type	–	Renewable	Fossil
Calorific Value	MJ/kg	41.3	46.8
Gross Heat of Combustion	kJ/kg	40.135	45.8
Cetane Number	–	65	53
Flash point	°C	174	98
Pour Point	°C	16	15
Density at 40 °C	kg/L	0.855	0.823
Viscosity at 40 °C	cSt	4.5	4.0

**Table 3**  
India's potential for tree-born non-edible oil.

Tree born oil Source	Oil yield in acre of land
Corn	128
Sun flower	716
Oats	242
Soy bean	334
Peanut	798
Rice bran	625
Coconut	2023
palm	4473

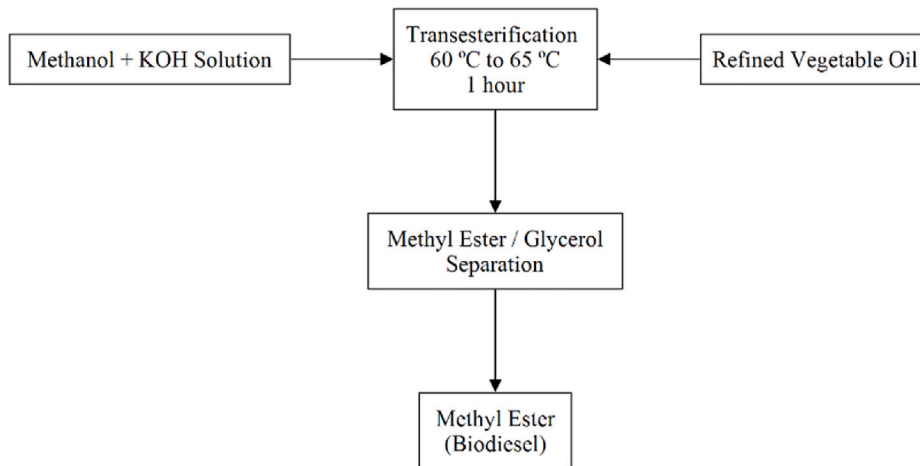


Fig. 1. Catalyst based transesterification process for biodiesel production.

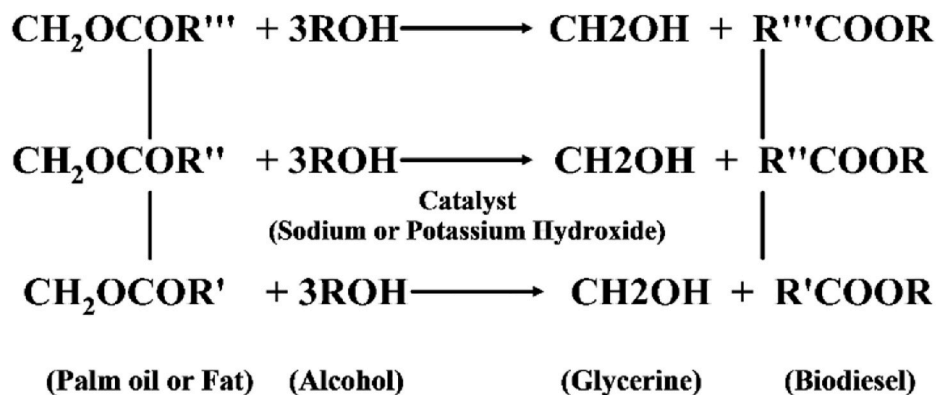


Fig. 2. Chemical formula of palm oil and palm biodiesel.

Dr. G.L rao et al. [26] looked at how qualities of biodiesel made from palm are improved by the transesterification process with use of catalyst, furthermore they compared the various fuel property of palm biodiesel with Indian standards and they found value of various property in given range for use. Various property before esterification are shown in Table 4. Whereas Table 5 demonstrates the differences in characteristics following esterification, with comparison to diesel using Indian standards also.

Palm oil methyl esters were also evaluated using standard procedures, which included the use of standard procedures. They discovered that the methyl esters' characteristics corresponded to those required by Indian biodiesel standards. Using a non-modified MWM 229 DI four-stroke diesel engine with fuel as preheated oil made from palm and diesel in their experiment, Silvio et al. [20] investigate the performance characteristics and emissions characteristics of the Diesel engine and fuel combination. According to the results of the test, the exhaust temperature increased with load when the engine was running on palm oil, and BSFC was over 10% more at low loads than at high loads. Also discovered was that the amount of CO emitted by both fuels increased as the amount of load increased. According to the results of the tests, the levels of carbon dioxide and excess oxygen emissions were near about same value

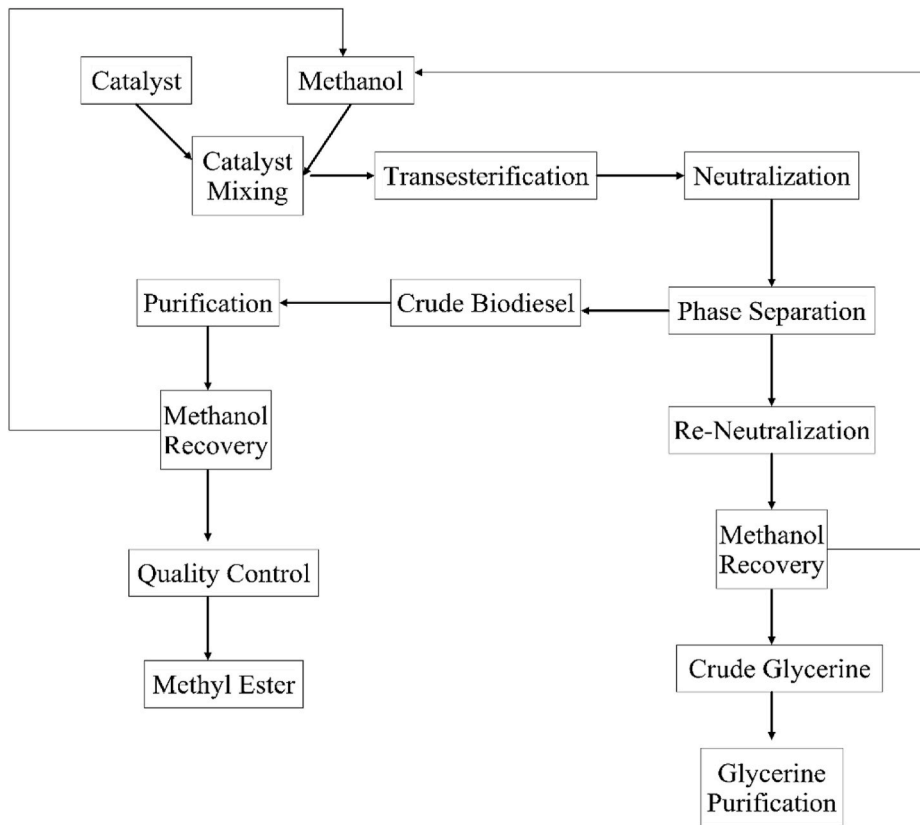


Fig. 3. Biodiesel production process.

**Table 4**  
Properties before esterification [5].

Property	Unit	Palm oil
Density	kg/m <sup>3</sup>	918
Kinematic Viscosity	cSt	39.7
Flash point	°C	266
Fire point	°C	295
Calorific Value (CV)	kJ/kg	36210

**Table 5**  
Properties after transesterification.

Property	Unit	Palm Biodiesel	Diesel	IS for Biodiesel
Density	kg/m <sup>3</sup>	880	850	860–900
Kinematic Viscosity	cSt	6.2	3.05	2.5–6
Flash point	°C	162	57	121
Fire point	°C	172	64	132
Calorific Value (CV)	kJ/kg	38050	42800	37273

regardless of whether the engine was powered by diesel or biodiesel. HC emissions were low (up to 75% of the load), but increased as the load increased; emissions of oxide of nitrogen increased as the load on engine increased in comparison to pure diesel fuel, oxide of nitrogen emissions of gases were lower when the engine was running on palm oil; and CO emissions were low (up to 75% of the load), but increased as the load increased. A CI engine with specification like DI single cylinder four stroke was operated with blend of ordinary diesel and palm biodiesel in experimental investigation done Amarnath et al. [27]. According to the results of the testing, the value of BSFC reduced as the torque, compression ratio, and injection pressure increase. It was the smallest when the torque is 20 Nm, the compression ratio is 18, and the injection pressure is 250 bar. No significant change in fuel consumption were observed. When comparing diesel and gasoline, the thermal efficiency of the brakes is 2.58% lower at full torque. Calorific value of palm biodiesel is less

compare to petroleum diesel, it has a lower thermal efficiency in the brake system than conventional diesel. When compared to diesel, the temperature of the exhaust gas produced by biodiesels is significantly lower. HC emissions are lower with biodiesel, whereas  $\text{NO}_x$  emissions are higher with the fuel. When the CR (compression ratio) and FIP (fuel injection pressure) are increased, Hydrocarbon emissions are reduced; however, when the torque is increased, there is no discernible difference in emissions. When running at 20 Nm, 18 CR, and 200 FIP, the Hydrocarbon emissions from diesel and palm biodiesel are 5 and 2 parts per million (ppm), respectively. The oxide of nitrogen values measured in parts per million (ppm) for palm biodiesel at a torque of 20Nm are 176 parts per million (ppm). Increased  $\text{NO}_x$  emissions are caused by increases in various operating parameter like CR (Compression Ratio), Engine Torque, and FIP (fuel injection pressure). S. S.Wirawan et al. [16] investigated the performance and emissions of CI engine in order to obtain comparative measurements of engine performance and exhaust gas behavior using blend of palm biodiesel. As the amount of biodiesel in the mixture was increased, the amount of CO, HC, and particle emissions decreased significantly. At 10% blend (B10), there was a significant reduction in particle emissions, whereas there was a significant reduction in hydrocarbon emissions starting at 20% blend (B20). In comparison to pure petro-diesel fuel, the results show that biodiesel blends produce lower  $\text{NO}_x$  emissions while also producing more torque and power. This could be due to the characteristics of the palm biodiesel that was tested, which has a higher cetane number and a lower viscosity value than the petro-diesel fuel sample, which could explain the difference. When comparing palm biodiesel to petroleum diesel, Jawad Nagi et al. [24] discovered that it has lower torque and thermal efficiency in diesel engines than petroleum diesel. This is due to palm biodiesel's lower heat value when compared to petroleum diesel, which results in less work being required to achieve a higher torque output than with petroleum diesel. The Brake thermal efficiency of palm biodiesel was also found to be lower than that of petroleum diesel, which was attributed to the slight lower calorific value of palm biodiesel. The exhaust gas emissions of a diesel engine were measured using palm biodiesel blends and petroleum diesel, respectively. Palm biodiesel blends produced lower  $\text{CO}_2$  emissions than petroleum diesel over entire engine load range, compared to petroleum diesel alone. When compared to petroleum diesel, palm biodiesel blends have demonstrated a tendency to reduce  $\text{CO}_2$  emissions. Given the oxygenated nature of palm oil and the lower carbon content of palm biodiesel blends, it is reasonable to expect a reduction in  $\text{CO}_2$  emissions in the near future. Unburned hydrocarbon emissions were reduced in all palm biodiesel blends, regardless of their composition (HC). Palm biodiesel blends, on the other hand, resulted in higher  $\text{NO}_x$  emissions, particularly when the engine is working harder. This is due to the increased oxygen content in palm biodiesel, which raises the combustion bulk temperature as more oxygen is consumed during the combustion process [31]. Because of these and other characteristics of palm biodiesel, as well as interactions with the fuel injection process and combustion chamber dynamics, the  $\text{NO}_x$  emissions are higher.

Short supply and high emissions of petroleum diesel necessitate the development of alternate fuels to meet India's energy needs. Biodiesel derived from non-edible oil is a good alternative fuel in India because of its large potential and comparable performance in diesel engines. When replacing current boiler combustion technology with new appropriate technology appears too complex and costly, combining biodiesel with diesel gives a halfway solution to severe concerns. However, pure biodiesel's performance in a boiler without any modifications is inferior to diesel and unsatisfactory. Furthermore, the amount of biodiesel in diesel can be increased by optimising the injection pressure, air fuel ratio, and preheating the fuel to solve the problem of biodiesel's higher viscosity and reduced volatility. Many researchers have measured the performance of palm oil and its esters on the CI engine. In addition, the performance of

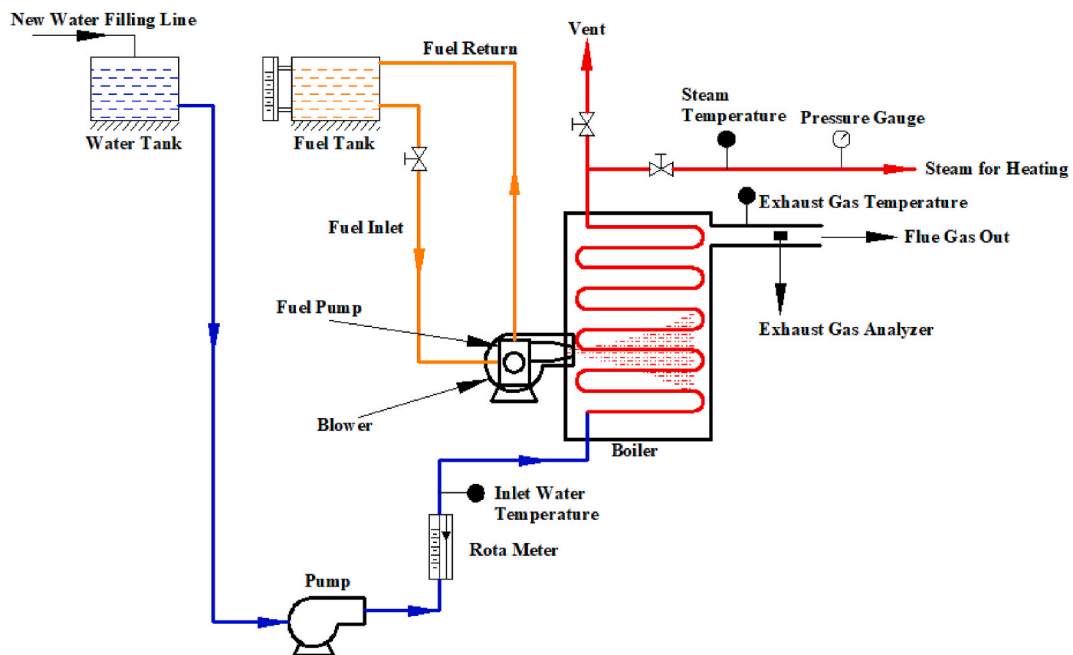


Fig. 4. Boiler experimental test setup.

a sun flower biodiesel blend in a diesel-fired boiler was measured by the researchers. According to the findings of the literature review, India has a large potential for palm oil production. Contrary to popular belief, there has been little research into the use of palm oil. Furthermore, instead of utilizing fuel mixes to test the performance of a CI engine, the performance of a diesel fire boiler can be measured. As a result, the focus of my research is on the impact of palm oil biodiesel mixing on the performance and emissions of diesel-fired boilers.

### 3. Experimental setup

The experimental design is depicted in Fig. 4. A vertical coil type, water tube boiler used to perform experimental investigation. Specifications of the boiler are listed in Table 6. In next part we discuss about various device used for measurement of experimental data like exhaust gas analyzer, electrical control device, and other details.

The exhaust gas analyzer illustrated in Fig. 5 is used to measure various contaminants. The exhaust gas analyzer Developed by Indus (type PEA 205) can monitor carbon monoxide, hydrocarbons, carbon dioxide, and oxygen levels. Value of Resolution and Range for each emission parameter is mentioned in Table 7.

Fig. 6 illustrates an electronic controller device. It displays all of the different parameters that are continuously associated with Experimental work that is performed with various sensors. In addition to measuring parameters such as steam temperature, fuel pressure, steam pressure, pressure cut-off (spring loaded safety valve), and blow down it also take precaution of various safety measures.

### 4. Experimental procedure

During the experiments, the steam pressure is maintained at 9 bar constant. For each fuel, observations are made at 9 bar pressures and 180 °C temperature for the duration of the experiment. Observations are made at a time when the temperature and pressure of the steam remain constant. At 9 bar, the performance and emission parameters are measured and analysed. Thermal efficiency is calculated for each test fuel, including diesel, based on the data collected through measurement.

- The amount of time it takes for 10 L of fuel to be consumed
- Exhaust Gas Temperature (in degrees Celsius)
- Mass flow Rate of Steam.
- The temperature of the steam
- Carbon Monoxide (CO)
- Hydrocarbon

The performance of the boiler with diesel is measured first, followed by the performance of the boiler with B25, B50, B75, and B100 measured with variations in fuel pressure. Data collected and calculated in this manner was used to compare with neat diesel. The following section describes a sample calculation for calculating thermal efficiency of boiler.

Mass flow rate of steam

Reading of Rota meter = 100 lph

Value of Heat input to Boiler

$m_f$  = Mass flow rate fuel = 19.458 kg/h

CV = Calorific value of fuel = 41932 kJ/kg

Heat input to boiler =  $m_f \times CV = 19.458 \times 41907 \text{ kJ/h} = 815.912 \times 10^3 \text{ kJ/h}$

Change in Enthalpy kJ/hr

$m_s = 100 \text{ kg/h}$

$\Delta h = (2574.84 - 104.67) \text{ kJ/kg} = 2470.17 \text{ kJ/kg}$

Heat carried out by steam = mass of steam  $\times$  change in Enthalpy

**Table 6**  
Boiler specification.

Make	Hi-Tech Boiler Pvt. Ltd
Type	Vertical, water tube coil type
Heating Capacity	19.6 L
Water flow rate	100 kg/h
Steam Pressure	10 Max
Steam Temperature	200 °C

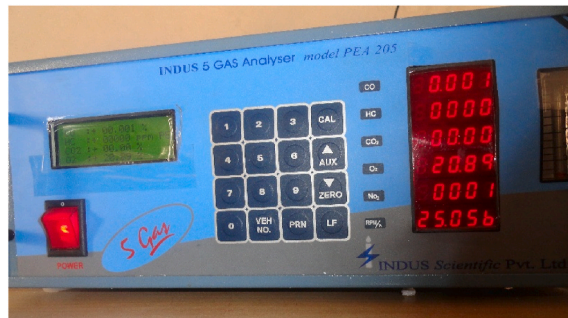


Fig. 5. Gas analyzer PEA 205.

**Table 7**  
Exhaust gas analyzer specification.

Gas	Range	Resolution
CO(%)	0–15	0.01
CO <sub>2</sub> (%)	0–20	0.01
HC (ppm)	0-3000 (Propane)	1
	0-15000(Hexane)	1
O <sub>2</sub> (%)	0–25	0.01

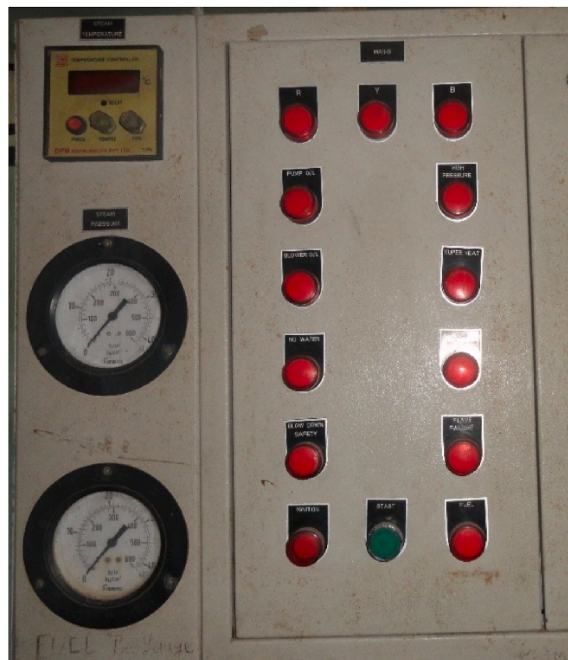


Fig. 6. Electronic controller device.

Heat carried out by steam =  $100 \times 2470.17 = 518.735 \times 10^3$  kJ/h

Boiler Efficiency

$$\eta = \frac{\text{Heat carried out by steam}}{\text{Heat supplied to boiler}}$$

$$\eta = \frac{518.735 \times 10^3}{815.912 \times 10^3} \times 100\% = 63.58\%$$



## 5. Results and discussion

The current investigation was carried out on an unmodified diesel-fired boiler that had been converted to operate in a dual mode configuration. The primary goal of the research was to find a way to fuel the diesel-fueled boiler with a blend of diesel and palm biodiesel. It is possible to measure the performance and emission characteristics of a diesel-fired boiler while varying the FIP (fuel injection pressure), and then compare the results with those of a pure diesel boiler.

The Outcome of Biodiesel Blending on the Performance of a Diesel-Fired Boiler Fuel injection pressure is varied in Figs. 7 and 8, allowing for comparisons of boiler efficiency and exhaust gas temperature when using diesel, palm biodiesel, and various blends of diesel and palm biodiesel as fuels.

Fig. 7 compares boiler efficiency with diesel and various palm biodiesel blends as fuel at varying fuel injection pressures. As shown in Fig. 7, as fuel injection pressure rises, boiler efficiency rises for all fuels, including diesel and palm biodiesel blends. The atomization characteristics of the spray improved as the fuel injection pressure increased (increase in inertial forces related to viscous forces) and proper vaporization of the fuel occurred in each fuel pressure, resulting in a tendency to complete more fuel combustion. As a result, boiler efficiency is on the rise. However, increasing fuel injection pressure further reduces boiler efficiency across all fuel blends. The reason for this is that the fuel air ratio is at its maximum, resulting in a reduction in available excess air. This will result in fuel combustion that is incomplete. Furthermore, losses due to dissociation are greater at high temperatures. The boiler's efficiency decreases as a result of the combined effect. At a fuel injection pressure of 14 bar, the maximum boiler efficiency obtained with diesel fuel is 65.88%. At a fuel injection pressure of 13 bar, the maximum boiler efficiency for B25 fuel is 66.04%. When compared to diesel, the maximum boiler efficiency of B25 fuel is approximately 2.4% higher. When using B25 as a fuel, maximum boiler efficiency is achieved at a fuel injection pressure of 14 bar, whereas it is achieved at a fuel injection pressure of 13 bar when using diesel. The oxygen content of palm biodiesel contributes to the higher boiler efficiency of B25 fuel, which aids in complete combustion. The above reason is strengthened even more by a reduction in CO percentage. With palm biodiesel as a fuel, there is also the benefit of a shorter combustion time. The maximum boiler efficiency achieved using B50 as fuel is 65.71% at a fuel injection pressure of 14 bar, which is 0.5% higher than diesel fuel. At all fuel injection pressures, boiler efficiency with B50 fuel is slightly higher than diesel but lower than B25 fuel. This could be due to palm biodiesel's higher kinematic viscosity. The kinematic viscosity of palm biodiesel increases as the percentage increases, resulting in larger droplet diameters during atomization. Because these large droplets take longer to burn completely, incomplete combustion occurs, lowering boiler efficiency. Lower petro-diesel density and viscosity improved spray atomization characteristics (increase in inertial forces related to viscous forces), and proper petro-diesel vaporization occurred at each fuel pressure in the chamber. When comparing the boiler efficiency of B75 and diesel at a fuel injection pressure of 13 bar, it is discovered that B75 has a higher boiler efficiency. The maximum boiler efficiency for B75 fuel is lower than diesel as load increases. In comparison to diesel, B75 has a maximum boiler efficiency of 65.62%, which is 1% lower than diesel. At the same fuel injection pressure, the boiler efficiency of B100 fuels is lower than diesel. Boiler efficiency peaks at 65.88%, 66.04%, 65.70%, 65.60%, and 65.50% for Diesel, B25, B50, B75, and B100, respectively. When compared to diesel, B100 has a 4.71% reduction in boiler efficiency. When there is a lower percentage of palm biodiesel in the blend, maximum boiler efficiency is achieved at a lower fuel injection pressure, such as 12 bar, whereas when there is a higher percentage of palm biodiesel in the blend, maximum boiler efficiency is achieved at a higher fuel injection pressure, such as 14 bar. This could be due to the palm biodiesel fuel's higher kinematic viscosity.

Fig. 8 depicts changes in exhaust gas temperature as a function of fuel injection pressure. For all fuels, EGT rises as the fuel injection pressure rises. In contrast to boiler efficiency trends, the highest EGT is achieved for all fuels at maximum fuel injection pressure. Using B100 fuel and a fuel injection pressure of 15 bar, the maximum EGT measured was 742.94 °C. With B25 fuel, the lowest EGT measured was 295.78 °C at 10 bar. In comparison to B100, EGT is reduced by about 18% with B25 fuel. At a fuel injection pressure of 15 bar,

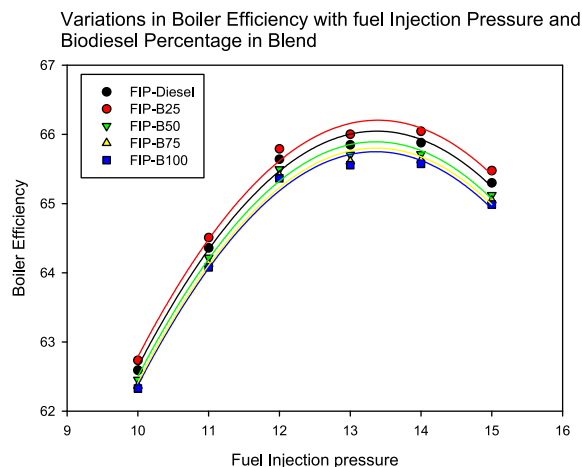


Fig. 7. Variations in boiler efficiency with fuel injection pressure and biodiesel percentage in blend.

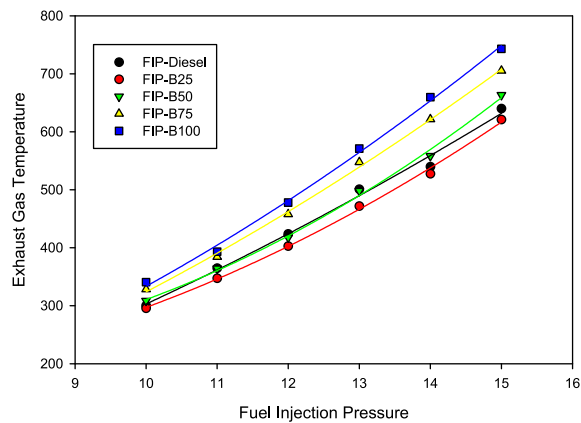


Fig. 8. Variations in Exhaust Temperature with fuel injection pressure and biodiesel percentage in blend.

maximum EGT measurements for diesel, B50, B75, and B100 fuels are 640 °C, 663.53 °C, 705.31 °C, and 742.94 °C, respectively. Other blends, with the exception of B25, have higher EGT than diesel fuel. The inbuilt oxygen content and shorter combustion duration are the primary reasons for the higher EGT value of palm biodiesel blended fuels. However, when compared to diesel fuel, B25 fuel has a lower EGT. Lowering EGT by using B25 fuel reduces harmful HC emissions as well. Because the oxygen content of palm biodiesel increases as the percentage of palm biodiesel in the blend increases, B50, B75, and B100 have higher exhaust gas temperatures than diesel. When compared to diesel, EGT rises by about 7%, 9%, and 16% for B50, B75, and B100, respectively. As heat losses due to exhaust gases increase with temperature, higher EGT can be a direct measure of lower boiler efficiency. Furthermore, a compact combustion chamber reduces heat loss to the boiler walls, resulting in higher EGT. The increase in EGT for Palm biodiesel blends is lower at fuel injection pressure than at final fuel injection pressure. The EGTs for B25 and B100 at initial fuel injection pressure are 295.79 °C and 340.62 °C, respectively. These results show a 7% increase in EGT. The increase in EGT is 18% at maximum Fuel injection pressure, as we saw earlier. As a result, the rate of increase of EGT is faster as the fuel injection pressure rises. Increased EGT has the additional disadvantage of lowering boiler efficiency. The reason for this is that at higher temperatures, dissociation losses occur. Furthermore, dissociation leads to increased CO emissions.

Carbon monoxide emissions are compared in Fig. 9 using diesel, B25, B50, B75, and B100 as fuels. Fig. 5 depicts CO emission variations as a function of fuel injection pressure and the percentage of palm biodiesel in the blend. For all fuels, the fuel injection pressure reduces CO emissions. CO emissions for all fuels increase after reaching a minimum value. For all fuels, this rise continues until the maximum fuel injection is reached. For all fuels, the variations in CO emission with fuel injection pressure are the same. Low furnace temperature could be the cause of high CO emissions at initial fuel pressure. The temperature of the furnace rises as the fuel injection pressure rises. CO emissions are reduced as a result, and their value reaches a minimum at 11 bar fuel injection pressure. Increased fuel injection pressure leads to increased CO emissions. The reason for this can be found here. Because biodiesels have a higher viscosity, they have poorer atomization and spray characteristics, which leads to incomplete combustion and higher CO emissions.

The increased inertial forces relative to constant viscous force, as well as the increased boiler temperature, improved the burning quality of biodiesels and petro diesel boilers, resulting in better vaporization of fuel and a reduction in the fuel local rich zone. As a result, the higher carbon content of petro diesel compared to biodiesels had a lower impact on CO emissions than viscosity. However, as the fuel pressure rises, a greater amount of fuel is injected. As a result, there is more air available, and the air-to-fuel ratio inside the boiler decreases. As a result, CO emissions will rise. CO emissions for diesel, B25, B50, B75, and B100 fuels are 0.056%/Vol., 0.053%/Vol., 0.047%/Vol., 0.042%/Vol., and 0.037%/Vol., respectively, at initial fuel pressure. Diesel fuel emits the most CO compared to all other fuels at this fuel pressure. At initial fuel pressure, CO emissions decrease as the percentage of palm biodiesel in the fuel increases. CO emissions are 15% lower when using B100 fuel than when using B100 fuel. The inbuilt oxygen content of palm biodiesel fuel is the main reason for this. At a fuel injection pressure of 11bar, CO emissions from diesel, B25, B50, B75, and B100 fuels are 0.037%/Vol., 0.033%/Vol., 0.032%/Vol., 0.033%/Vol., and 0.036%/Vol., respectively. B25 emits the least CO of all the fuels tested, followed by B50, B75, diesel, and B100. Nonetheless, with the exception of B100, all fuels produce similar CO emissions. Despite the fact that palm biodiesel contains oxygen, with increased fuel injection pressure, CO emissions from blends of diesel and palm biodiesel and pure palm biodiesel are now higher. The higher kinematic viscosity of palm biodiesel and blends is thought to be the main reason for this. Kinematic viscosity rises as the percentage of palm biodiesel in the blend rises. Atomization of blends and palm biodiesel results in larger droplet diameter at the same injection pressure. Larger droplet diameter necessitates more time for combustion, resulting in incomplete fuel combustion. As a result, the amount of CO emitted will increase. Furthermore, larger droplet diameters may impinge on the boiler wall, exacerbating the problem. Finally, the low volatility of palm biodiesel fuel results in higher CO emissions when using blends and palm biodiesel as a fuel versus diesel. CO emissions from diesel, B25, B50, B75, and B100 fuels are 0.060%/Vol., 0.061%/Vol., 0.060%/Vol., 0.065%/Vol., and 0.070%/Vol., respectively, at a maximum fuel injection pressure of 15 bar. When compared to diesel fuel, CO emissions from B100 fuel are 21% higher. The above results are strengthened by a reduction in boiler efficiency with B50, B75, and B100 in the same range of fuel injection pressure when compared to diesel fuel.

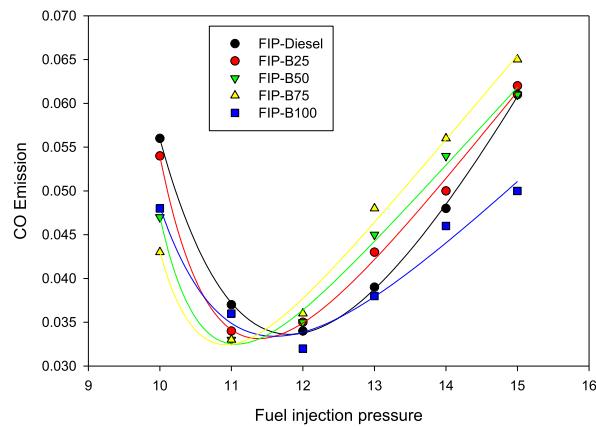


Fig. 9. Variations in CO Emission with fuel injection pressure and biodiesel percentage in blend.

HC emissions are shown in Fig. 10 as a function of fuel injection pressure and the percentage of palm biodiesel in the blend. For all fuels, HC emissions are highest at initial fuel injection pressure. Lower boiler temperature is the cause of higher HC emissions at low fuel injection pressure. For all fuels, increasing the fuel pressure lowers the HC emissions. The reason for this is that as the fuel injection pressure rises, the boiler temperature rises as well. For all fuels, HC emissions are lowest at a fuel injection pressure of 15 bar. HC emissions are highest at the beginning of the fuel injection process and decrease as the fuel injection pressure is increased. When palm biodiesel is blended with diesel, HC emissions are reduced at the fuel injection pressure. Increasing the percentage of palm biodiesel in the blend reduces HC emissions even more.

Among all fuels, B100 emits the least amount of HC. At 11 bar, the highest HC emissions for diesel, B25, B50, B75, and B100 fuel are 18 ppm, 16 ppm, 14 ppm, 13 ppm, and 12 ppm. Injection of fuel Pressure is the primary reason for palm biodiesel’s lower HC emission, which is due to its high oxygen content. As the percentage of palm biodiesel in the blend rises, the oxygen content rises as well, resulting in lower HC emissions when palm biodiesel is used as a fuel. All test fuels emit HC emissions of 9 ppm 9 ppm 8 ppm 8 ppm and 8 ppm and 8 ppm at 15 bar fuel injection pressure. Despite the fact that Fig. 10 shows the same HC emission value for different blends at maximum fuel pressure, the actual value may differ. In this case, a low-resolution exhaust gas analyzer may be unable to detect minor changes.

### 6. Conclusion

After conducting experiments with a vertical coil type Non IBR, water tube boiler that was fueled with a mixture of palm biodiesel and diesel, the following conclusions were reached. The results were compared to those obtained with diesel fuel.

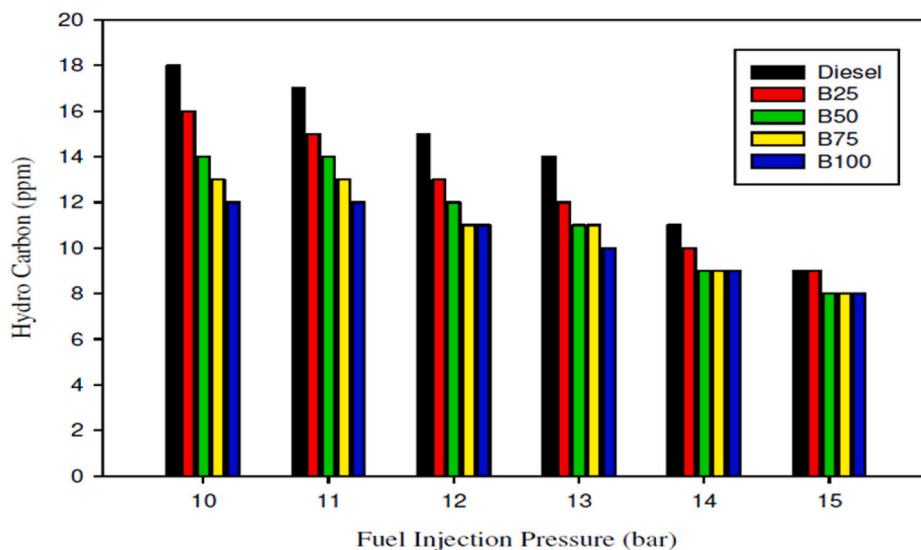


Fig. 10. Variations in HC Emission with fuel injection pressure and biodiesel percentage in blend.

- Palm biodiesel has properties similar to diesel. Palm biodiesel has an energy content that is 8.99% lower than diesel. Because of its lower calorific value, steam produced from pure palm biodiesel can be less than diesel. When compared to diesel, palm biodiesel has a 150% higher kinematic viscosity. Palm biodiesel requires a higher injection pressure than diesel to achieve smaller diameter droplets due to its higher kinematic viscosity.
- The boiler efficiency of B25, B50, B75, and B100 fuels is 62.73%, 62.45%, 62.36%, and 62.32%, respectively, which is higher than the diesel efficiency of 62.39%. B100 fuel has a maximum boiler efficiency of 64.98%, which is lower than diesel's 65.30%. Because B100 has a higher kinematic viscosity, it has a larger droplet diameter and thus a lower brake thermal efficiency.
- At 11 bar fuel pressure, maximum EGT for diesel, B25, B50, B75, and B100 fuels is 300 °C, 295 °C, 308 °C, 328 °C, and 340 °C, respectively. Other blends, with the exception of B20, have higher EGT than diesel fuel. At a fuel pressure of 11 bar.
- CO emissions from diesel, B25, B50, B75, and B100 fuels are 0.037%/Vol., 0.0336%/Vol., 0.0326%/Vol., 0.033%/Vol., and 0.036%/Vol., respectively. B50 emits the least CO of all the fuels tested, followed by B25, diesel, and B100. CO emissions from diesel, B25, B50, B75, and B100 fuels are 0.0605%/Vol. at maximum fuel pressure. 0.05%/Vol., 0.0616%/Vol., 0.0605%/Vol., 0.060%/Vol., and 0.0616%/Vol. When compared to diesel fuel, CO emissions from B100 fuel are 21% higher.
- The highest HC emissions for diesel, B25, B50, B75, and B100 fuel are 18 ppm, 16 ppm, 14 ppm, 13 ppm, and 12 ppm observed at lower fuel injection pressure. When using B100 fuel, HC emissions are reduced by about half compared to when using diesel fuel.

## 7. Future scope of work

The performance and emission characteristics of a diesel-fired boiler using a palm biodiesel blend were observed and result presented in this study, which showed good emission and performance results, but this study was limited due to time constraints. The following points could be considered as part of the same research's future work.

- Measurement and analysis of boiler performance and emission with variation in air-fuel ratios can be done in the same project
- The same study can be investigated with dual biodiesel blends.
- Development of a green biodiesel blend that optimizes the performance and emissions of a diesel-fired boiler.
- The blends prepared for this project's work were used in a short amount of time. As a result, the long-term stability of blends was not investigated. The long-term stability analysis of biodiesel blends also the point for future research consideration.

## Author statement

Krunal Khiraiya, Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - original draft, Writing.  
 Dr. P.V.Ramana: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - original draft, Writing.  
 Hitesh Panchal: Data curation, Writing - review & editing.  
 Kishor Kumar Sadasivuni: Formal analysis, Investigation, Writing - original draft, Writing – review & editing.  
 Mohammad Hossein Doranehgard - Data curation, Writing - review & editing.  
 Mohammad Khalid - Data curation, Writing - review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Table of Abbreviations

*IBR*: Indian Boiler Regulation  
*EGT*: Exhaust Gas Temperature  
*B25*: 25% blend of biodiesel with Petroleum Diesel  
*PB*: Palm Biodiesel  
*HC*: Hydro Carbon  
*CV*: Calorific Value  
*CO*: Carbon Monoxide  
*FIP*: Fuel Injection Pressure  
*CI*: Compression Ignition  
*CNG*: Compressed natural gas  
*LPG*: liquefied petroleum gas  
*PB 100*: Pure Palm Biodiesel  
*GOI*: Government of India  
*DI*: Direct Injection  
*BSFC*: Brake Specific Fuel Consumption  
*CR*: Compression Ratio  
*LPH*: Liter per Hour  
*K OH*: Potassium Hydroxide Nomenclature  
*m<sub>f</sub>*: Mass flow Rate of Fuel  
*cSt*: centistokes  
 $\Delta h$ : Change In Enthalpy  
 $\eta$ : Boiler Efficiency