

Emission and Performance Study of Diesel Engine Fuelled with Preheated Biodiesel from Exhaust Waste Energy

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Abstract

The need for alternative fuel instead of conventional fossil fuels (diesel or gasoline) has recently increased for several reasons, including the expected shortage of petroleum fossil fuels and the production of pollution by transportation. Consequently, researchers are interested in finding new alternative fuels. At present, the number of studies on biodiesel as a compression ignition engine fuel has increased. Current studies are mainly concerned with studying the use of exhaust gas temperature to preheat biodiesel fuel before it enters the combustion chamber. A heat exchanger is designed to increase the temperature of the biodiesel fuel prior to the combustion process. The performance characteristics of diesel engines and the emission of pollutants resulting from this modification were investigated under different operating conditions, including different engine loads and speeds. The results showed clear improvements in engine performance, including improved output power, specific fuel consumption and pollutant emissions. The engine power and specific fuel consumption improvements as a result of preheating reached up to 1.3 % and 8.27 %, respectively. Pollutant emission also decreased obviously, with carbon monoxide and hydrocarbon emission decreases of 12.95 % and 12.85 %, respectively. However, the emission of nitrogen oxides increased by 4.39 %.

Keywords: biodiesel production, engine emissions, performance, preheating

NOMENCLATURE

BSFC	Brake specific fuel consumption
B0	Pure diesel fuel
B10	Biodiesel 10 %
B100	Pure biodiesel
B15	Biodiesel 15 %
B20	Biodiesel 20 %
B50	Biodiesel 50 %
BTE	Brake thermal efficiency
CI	Compression ignition
CO	Carbon monoxide
CO ₂	Carbon dioxide
cSt	Centistoke units
EGT	Exhaust gas temperature
HC	Hydrocarbon
IC	Internal combustion
KOH	Potassium hydroxide
NO _x	Nitrogen oxides

INTRODUCTION

Various means of transportation have become very important in light of technological and economic progress worldwide. Population growth is steadily increasing with economic activity, which has resulted in increasing transportation needs. With increasing transportation density (especially for various types of diesel vehicles), the amount of pollutants emitted into the atmosphere will increase [1–3]. The pollutants emitted from engine vehicles can cause severe harm to the surrounding environment and humans [4–6]. Industrial and developed countries have legislated laws and regulations to restrict pollution levels from road vehicles. These laws and regulations have placed great pressure on automobile

manufacturers to find new ways to reduce emissions from road vehicles [7]. Researchers have also commissioned studies to improve the performance of these engines to reduce pollutant emissions. Several of these studies have focused on the use of alternative fuels to reduce pollutant emissions [8–11].

Biodiesel fuel is an alternative fuel that can reduce the amount of pollution caused by diesel engines [12–15]. Recently, automotive researchers have taken an interest in the production of different types of biodiesel from edible and non-edible oil [16–19]. Many methods, including esterification, are used for biodiesel production. Biodiesel is used directly as a fuel for diesel engines or is blended with diesel fuel at different rates to improve engine performance and reduce pollutant emissions [20–23]. Previous studies have focused on the effects of many types of biodiesel fuel on the performance of diesel engines to determine the best conditions for biodiesel use. In addition, many investigations have been conducted to study the effects of different biodiesel blends on engine pollution and performance under different operating conditions [24]. Several of these studies regarding the influences of biodiesel on compression ignition (CI) engine performance and emissions are summarized below.

Bari et al. [25] studied the effect of crude soybean oil, a 50% (by volume) mixture of crude soybean oil and petrol diesel on CI engine performance characteristics and emissions at different engine speeds. The experimental results were compared with sunflower oil and a 50% blend of sunflower oil with diesel fuel. The study indicated that it was necessary to preheat the oil up to 70–90°C to enhance the engine performance and combustion quality. Hazar et al. [26] aimed to study the influences of fuel preheating to 100°C

on the CI engine performance and emission characteristics fueled with raw rapeseed oil/diesel blends. The experiments were carried out for two blends (20 and 50% in volume) in a single cylinder diesel engine. The results indicated that significant improving of engine performance and decreasing of pollutants emission were obtained with preheated (at 100°C) blend 50 and 20%. Pugazhvadivu et al. [27] examined the influence of using mahua oil on the external performance of a single cylinder diesel engine. The output performance and pollutant emissions of the engine were studied to compare the use of diesel fuel and mahua oil. Practical experiments were conducted on the engine using mahua oil at a temperature of 130 °C to determine the effects of preheating on the engine performance parameters and the pollution emitted from the engine. The results of this investigation showed that the emissions of CO and hydrocarbon (HC) from the engine significantly decreased while the emission of NO_x increased when the mahua oil was preheated. Du et al. [28] used a new method called the electric field strength method to reduce the viscosity of biodiesel fuel. These authors found that the biodiesel viscosity decreased by up to 25.5%, which improved the engine performance and emissions. Tesfa et al. [29] studied the influences of temperature and the biodiesel fraction on the physical properties, such as density and viscosity, of rapeseed, corn oil and waste oil biodiesels-diesel fuel blends and reported new correlations between the density and viscosity of different blends of biodiesel with diesel fuel. Karabektas et al. [30] studied the Performance parameters and exhaust emissions of a diesel engine fuelled with diesel fuel and cottonseed oil methyl ester. Biodiesel was preheated to four different temperatures 30, 60, 90 and 120°C. The experimental investigation focused on external characteristics of diesel engine and pollutants emission. The results indicated that preheating biodiesel

up to 90°C leads to enhancement on the engine performance and emissions but causes higher NO_x emissions. Murillo et al. [31] studied the performance of diesel engines fuelled with the biodiesel-diesel blends B10, B30 and B50 under different operating conditions including different engine speeds and loads. The results of this investigation indicated that the engine output power decreased as the ratio of biodiesel to diesel in the blend increased. In addition, the engine fuel consumption was affected by the operating conditions. Furthermore, the influences of waste cooking oil and low sulphur diesel on diesel engine performance and emissions under different loads were investigated. Kumar et al. [32] evaluated the performance characteristics and pollutant emissions of diesel engines using various rates of cottonseed blended with biodiesel and fuel additives. The experimental result indicated that adding an additive enhanced the output performance of the diesel engine and decreased the NO_x, CO and HC emissions. Experimental tests were conducted to study the influences of preheating biodiesel, and the results indicated that engine performance was enhanced and pollutant emissions were decreased. This investigation concluded that engine performance and emissions clearly improved when the fuel inlet temperature was 60°C.

Previous literature indicates that the use of biodiesel as an alternative fuel is of great interest. Biodiesel can be used in diesel engines to improve engine performance characteristics and emissions. A literature review of the influences of biodiesel fuel on engine performance indicates that few studies have focused on the effects of biodiesel inlet fuel temperature on engine performance and emissions.

Therefore, in this study, the influence of the inlet temperature of biodiesel fuel before it enters the combustion chamber is

investigated. Practical experiments are performed on diesel engines at different engine speeds and at different loads to evaluate engine performance and pollutant emissions. The instrumentation systems and measurement equipment were prepared and connected with a diesel engine to measure various performance parameters (output brake power, specific fuel consumption, brake thermal efficiency, exhaust emission). Thermocouples were connected to a digital thermometer and installed in the engine to determine the exhaust and engine temperatures. To control the temperature of the biodiesel fuel at the inlet of the engine, a heat exchanger was designed so that the exhaust heat could be used to preheat the biodiesel before it entered the combustion chamber. The temperature of the biodiesel was controlled by placing a valve in the exhaust path to adjust the amount of exhaust that circulated around the fuel to exchange the heat energy. The temperature of the biodiesel fuel ranged from 30 to 70°C (30-40-50-60-70°C). At each entry, the biodiesel temperature was considered when evaluating the engine performance and pollutant emissions at different engine speeds and loads. These experimental tests are listed in prepared tables, and the experimental results were processed to study the effects of the inlet temperature of biodiesel fuel on engine performance. The experimental results show clear differences in engine performance regarding output power, specific fuel consumption and pollutant emissions due to differences in the biodiesel inlet temperature. The engine power and fuel consumption were enhanced by 1.3% and 8.27%, respectively, as a result of preheating. The CO and HC emissions decreased by 12.95% and 12.85%, respectively, and the NO_x emissions increased by 4.39% at an engine load of 75%. From these results, it can be concluded that preheating biodiesel fuel has a significant influence on engine

performance characteristics and emissions.

MATERIALS AND METHODS

This section reviews the method of biodiesel production and describes the experimental setup. The method used for biodiesel production from sunflower oil in the laboratory is presented in detail, and the physical and chemical properties of the biodiesel fuel are presented. The description of the experimental setup describes the experimented diesel engine and the instrumentation systems used in

the laboratory to measure all engine performance and emission variables under different operating conditions.

Biodiesel Production

The chemical and physical properties of biodiesel fuel depend on the original oil source, such as virgin edible, non-edible or used cooking oils. The production of biodiesel fuel from sunflower oil was executed in the laboratory according to the esterification method [33–35].

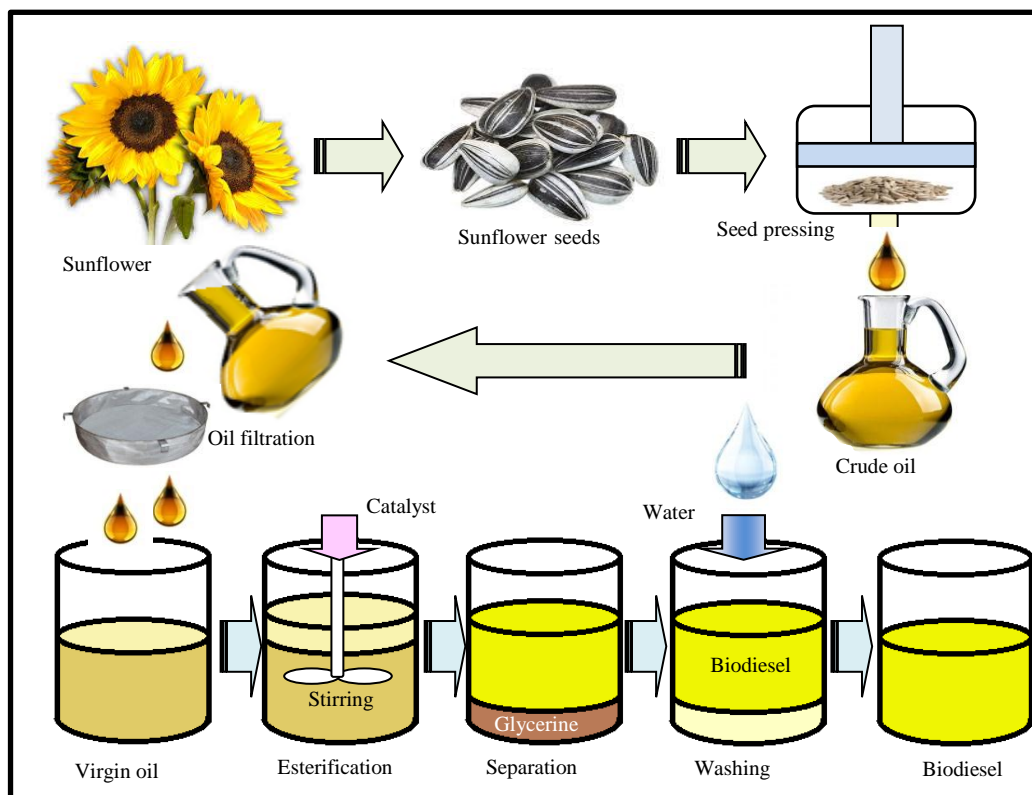


Figure 1: Schematic diagram of biodiesel production procedures.

The raw materials used in the reaction are sunflower oil, methanol and catalyst KOH (potassium hydroxide). Chemical reactions must be done in an atmosphere free of moisture. Fig. 1 shows a schematic diagram of biodiesel production procedures. The following steps describe the biodiesel production method used in the laboratory [36–39]:

- First, mix 200 ml of methanol with 7 g of KOH in a flask.
- Heat the mixture to 50°C and stir it well to guarantee that the methanol and KOH solution is thoroughly mixed.
- Prepare 1l of pure sunflower oil and heat the oil to 60°C.
- Mix the catalyst and methanol with the oil in a bowl. Next, place the bowl in a water bath at 55°C and stir it well for at least one hour.
- Then, place the final solution in a tightly closed glass container for the

separation and allow it to stand for 24 hours.

- After 24 hours, the upper layer is biodiesel fuel and the lower layer is glycerol that must be separated from the biodiesel.
- Next, wash the biodiesel with cold and hot water several times to remove the glycerol.
- Determine the chemical and physical properties of the biodiesel fuel, such as the fuel density and viscosity.
- Repeat the experiment several times to obtain an amount of biodiesel that is sufficient for laboratory experiments.

The conversion of sun flower oil into biodiesel was done in accordance with the steps described above. In order to ensure to carry-out all experimental work on the engine, a sufficient amount of biodiesel fuel has been produced. Table 1 illustrates the significant properties of biodiesel fuel and conventional diesel.

Table 1: Biodiesel and conventional diesel properties.

Property	Biodiesel	Diesel
Density g/cm ³	0.885	0.842
Kinematic Viscosity cSt @ 40 °C	4.6	3.34
Cetane number	47	55
Flash point °C	92	70
Calorific value, MJ/kg	43.1	45.4

Experimental Setup

A heat exchanger is designed to take advantage of the waste energy that the diesel engine rejects to the surrounding through the exhaust system. Hot gases from the tail pipe are used to preheat the fuel in the heat exchanger box, using a heat exchanger attached to a branch of the exhaust pipe. A heat exchanger was designed to utilize the rejected exhaust enthalpy to preheat the biodiesel fuel in range 30°C up to 70°C before it entered the diesel engine combustion chamber. It is a fuel tank in which a pipe branching from the main exhaust pipe is passed through in a spiral, as shown in Fig. 2. The biodiesel temperature is controlled by a valve installed on the exhaust pipe to control the exhaust flow rate. The preheated biodiesel fuel is drained to another tank placed on a sensitive scale to determine the mass of fuel consumed with time. The fuel tank delivers fuel to the fuel pump and engine after the temperature of the fuel is adjusted. To complete the practical experiments, multiple devices were used to measure engine performance and properties (pollutant emissions, fuel consumption, electric power, engine speed, air flow rate, exhaust and engine temperatures).

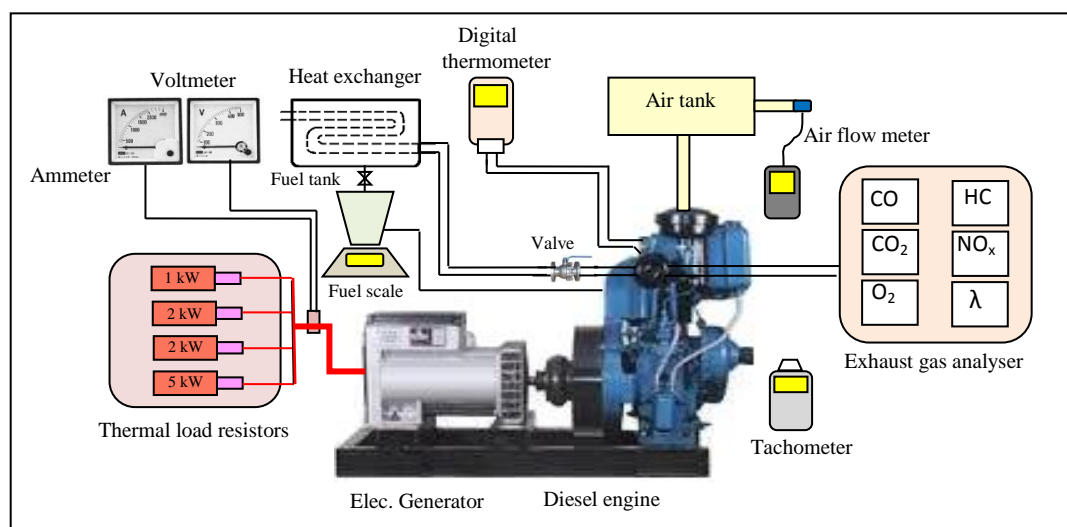


Figure 2: Schematic diagram of the diesel engine and instrumentation system.

A 10.4 kW off-road diesel engine equipped with an electric generator was used to accomplish the experimental work. The electric generator equipped with a CI engine converts the mechanical power produced from the engine into electrical power. To consume the produced electric power, controllable thermal resistors are connected to increase the thermal load gradually. In order to ensure the accuracy of the thermal load measurement to determine the output torque of the CI engine during the practical experiments. The current and voltage are measured on the cable connected to the thermal resistors by clamp instrument. This technique enables to determine the value of electrical energy consumed by thermal resistors accurately. Electric power consumption is calculated by multiplication the voltage, the current and power factor. From previous calculations, engine power can be calculated after considering the efficiency of the electric generator at all different operating conditions. Practical experiments are performed when the inlet temperature of the biodiesel is changed at different loads and engine speeds. Table 2 indicates the technical specification of the diesel engine used to conduct the experimental work.

Table 2: Technical specification of the CI engine.

Engine Parameter	Value
Engine model	P.C.U.
Engine type	Diesel
Displacement, cm ³	1190
Number of cylinder	1
Compression ratio	15
Bore/Stroke, mm	114/116
Cooling type	Air
Max power kW@rpm	10.4@1500

Table 3 provides the different accuracies and uncertainties of the measured properties. Table 4 shows the test conditions of the experimental work.

Table 3: Accuracies and uncertainties of the measured properties.

Property	Accuracy	Uncertainty
Load	± 0.2 N	± 0.2 %
Power	-	± 0.2 %
Fuel consumption	±2.0 g/h	± 1.5 %
Air flow rate	±1.0 cm ³ /h	± 0.2 %
BTE	-	± 2.5 %
Engine speed	±15 rpm	± 0.5 %
Temperatures	± 1 °C	± 0.1 %
Carbon monoxide	± 0.15 g/kWh	± 0.2 %
HC and NOx	± 0.10 g/kWh	± 0.2 %
Carbon dioxide	± 0.50 g/kWh	± 1.0 %

Table 4: Experimental conditions.

Parameter	Value
Engine speed, rpm	1500
Ambient temperature, °C	30
Relative humidity, %	50 to 55
Air density, kg/m ³	1.18
Lubricating oil temperature, °C	77 to 84

RESULTS AND DISCUSSION

This section deals in detail with experimental results to illustrate the effect of fuel preheating on engine performance and emission. The discussion of the results is divided into two main parts. The first part interests in the results of the engine performance such as output power, SFC and brake thermal efficiency at different loads and constant speed. The second part explains the engine emission of pollutants such as carbon monoxide, carbon monoxide, hydrocarbons and nitrogen oxides.

ENGINE PERFORMANCE RESULTS

Practical tests were performed on a small diesel engine to study the effects of inlet fuel temperature on engine performance. The inlet fuel temperature was only changed for biodiesel fuel; the inlet temperature of the diesel remained at the ambient temperature of 30°C. Biodiesel viscosity can be considered as the main reason why the effects of biodiesel preheating should be studied. Therefore, experiments were conducted to assess the

performance of the engine at different biodiesel inlet temperatures (30, 40, 50, 60 and 70°C). The results are presented for engine performance and pollutant emissions at different loads of up to 75% of the full load. Fig. 3 show the relationship between diesel engine powers at different loads while the biodiesel inlet temperature was changed. From Fig. 3, it can be shown that the engine power during the use of traditional diesel was higher than that of biodiesel at 30°C. This difference occurred for several reasons, among which the most important reason is that the heating value of the biodiesel is lower than that of ordinary diesel, which decreases the power of the engine when biodiesel is used.

Fig. 3 shows that the higher biodiesel fuel temperatures at the inlet into the engine correspond with smaller differences in the engine output power between the different types of fuel. This phenomenon indicates that a high biodiesel temperature at the inlet increases the degree of fuel evaporation inside the combustion chamber and thus improves the combustion behaviour of the fuel, which reduces the difference in the output power for both fuels. Increasing the biodiesel temperature at the inlet improves fuel atomization during the injection process, which increases the uniformity within the combustion chamber, improves the engine power, and reduces the difference between the biodiesel and diesel.

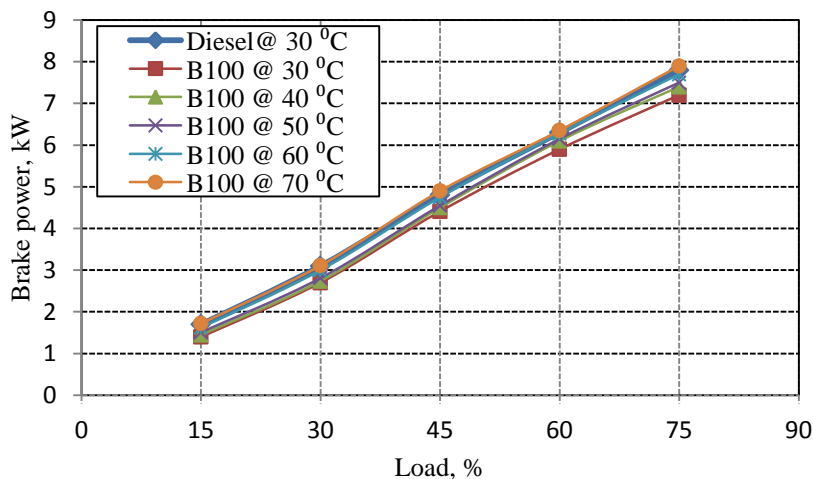


Figure 3: Output engine power at different loads.

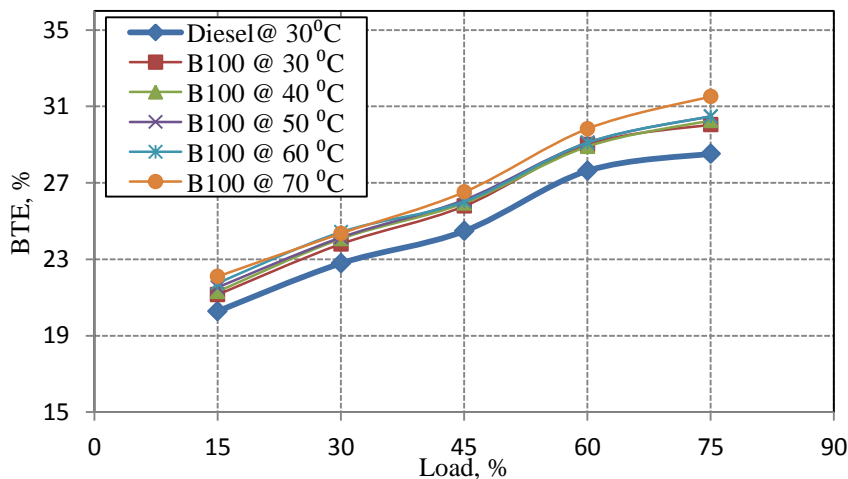


Figure 4: Brake thermal efficiency of the engine at different loads.

Fig. 4 shows the brake thermal efficiency (BTE) of the diesel engine at 1500 rpm and at different loads. A comparison of the BTE of diesel fuel at the ambient temperature of 30°C and the biodiesel fuel at different inlet temperatures is illustrated in Fig. 4. It can be observed from Fig. 4 that the BTE is clearly improved by increasing the temperature of the biodiesel at the inlet. This improved BTE can be explained by the greater temperature of the biodiesel at the inlet of the combustion chamber because the temperature alters the biodiesel density and viscosity. The higher temperature leads to better evaporation of the biodiesel fuel and thus enhances the mixing of the evaporated fuel with the air and improves the efficiency of combustion (resulting in more complete fuel combustion) [40–43]. Improved combustion within the combustion chamber means that less fuel is consumed and that the output power is higher. Since BTE is directly proportional to engine power and vice versa for fuel consumption, any change in these parameters will affect the BTE. From Fig. 4, the difference in BTE of two fuels is relatively low at low and partial loads. As the engine load increases, the percentage difference of the BTE increases and reaches up to 3% (the inlet temperature of the biodiesel fuel at 70°C and the inlet temperature of the diesel fuel at ambient temperature).

Fig. 5 shows the brake specific consumption (BSFC) of biodiesel and diesel fuel at different loads that were used to study the effects of preheating engine fuel on consumption. First, preheating biodiesel fuel could enhance the physical properties of the biodiesel, such as the density and viscosity of the fuel [44]. Also, preheating the fuel can improve the combustion efficiency by reducing the ignition delay period and prolonging the

propagation of the flame front. The BSFCs for the two fuels decreased with increasing engine load for the different biodiesel fuel inlet temperatures.

Fig. 5 shows that the biodiesel BSFC is higher than the diesel BSFC at the low inlet temperatures. This difference results from the heating value of the fuel. It is known that the heating value of diesel fuel is higher than that of biodiesel fuel; thus, the BSFC of the biofuel increases relative to the BSFC of diesel under the same operating conditions. As the temperature of the biodiesel fuel increases before the injection process, the BSFC somewhat decreases, and when the preheating temperature increases to 70°C, the BSFC significantly decreases. This result can be explained by the decreased density and viscosity of the biodiesel with increasing temperature, which helps to atomize the fuel particulates and enhance their mixing with air, leading to complete combustion and decreasing the BSFC.

Fig. 6 shows the exhaust gas temperatures (EGTs) for both diesel and biodiesel fuel at different fuel inlet temperatures during variant loads. The results show that the exhaust temperature increases when the engine load increases because the engine consumes more fuel and thus produces higher energy at high loads. Therefore, the exhaust temperature increases under these conditions. Fig. 6 also shows that the exhaust temperature increases as the temperature of the biodiesel before it enters the engine increases. This result can be explained by the improved combustion within the engine; therefore, the exhaust temperature increases as the temperature of the biodiesel fuel at the inlet increases. The maximum exhaust temperature occurs when the biodiesel temperature at the inlet temperature reaches 70°C.

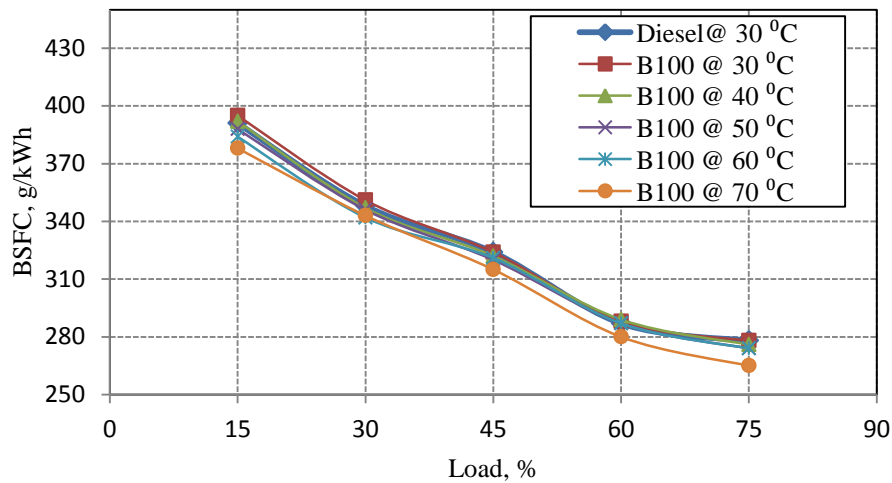


Figure 5: Brake specific fuel consumption of the engine at different loads.

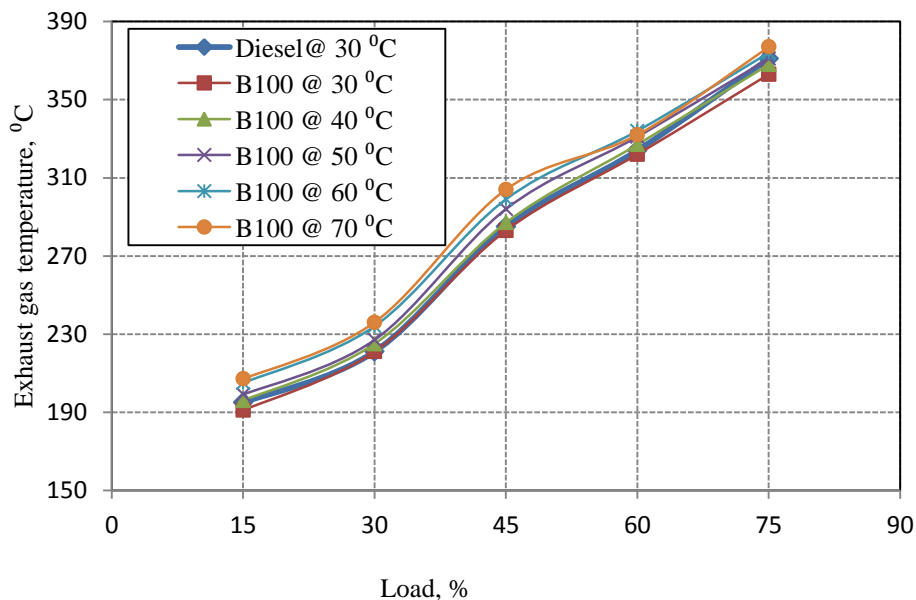


Figure 6: Exhaust gas temperature of the engine at different load.

Fig. 7 shows a comparison of the changes in engine performance characteristics such as P_B , BSFC, BTE and EGT when different biodiesel inlet temperatures are used at an engine load of 75% for biodiesel fuel and diesel (as a baseline).

From Fig. 7, the output power of the engine fuelled by biodiesel is clearly lower than that of the engine fuelled by diesel for the different inlet temperatures. The power of the engine

fuelled with conventional diesel was 7.8% higher than the power of the engine fuelled with biodiesel at the ambient inlet temperature. Also, the higher biodiesel inlet temperatures corresponded with smaller differences in the output power produced from the engine. This smaller difference was observed because the fuels were able to mix better with air and combust within the engine when the inlet temperature was high, which increased the engine power.

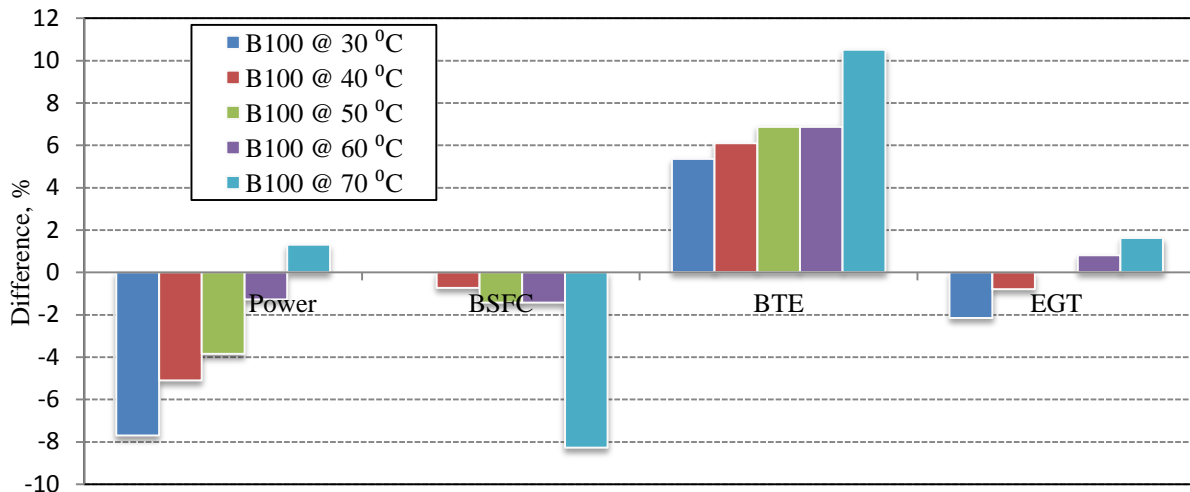


Figure 7: Differences in engine performance characteristics (P_B , BSFC, BTE and EGT, in %) for the different inlet biodiesel and conventional diesel inlet temperatures (baseline: diesel fuel) at an engine load of 75 %.

Fig. 7 also shows the difference between the BSFC of the engine for biodiesel and diesel when different inlet temperatures were used. This figure indicates that the BSFC is lower in the case of biodiesel than in the case of diesel. The difference of the BSFC increases as the biodiesel inlet temperatures increase due to the improvement of combustion within the engine cylinders, which thereby reduces the BSFC. It is also evident from Fig. 7 that the difference of the BSFC is greater than 8% for the biodiesel fuel when the inlet temperature is 70°C because the physical properties of the biodiesel, such as the density and viscosity, are improved; thus, the combustion is almost complete [32–33]. Because the BTE depends on the BSFC of the engine, the BSFC behaviour of the biodiesel fuel at different inlet temperatures directly affects the BTE of the engine. Noticeably, the BSFC of the biodiesel is lower in all cases, and the rate of decline increases as the biodiesel temperature at the inlet into the engine increases to 70°C. Since BTE is inversely proportional to BSFC and the calorific value of the fuel, each element has an effect on efficiency. It is obvious that the

BTE of the biodiesel engine is higher than the BTE of the diesel engine because the BSFC decreases when the biodiesel fuel is preheated.

A comparison of the EGTs of biodiesel and diesel fuels indicates that the EGT increases when the engine operates with preheated biodiesel fuel, especially when the inlet temperature is high. This effect can be observed when the inlet temperature of the biodiesel is high, which causes good combustion and thus increases the temperature of the exhaust gases.

Engine Emission Results

Carbon dioxide (CO_2) emissions are considered to be an indicator of the combustion status and BSFC of an engine. There is a direct relationship between the BSFC and CO_2 emissions of an engine [45]. It is clear from the figures presented within this manuscript that CO_2 emissions increase when the BSFC increases, and vice versa. In Fig. 8, it can be observed that CO_2 emissions were lower when biodiesel was used as the engine fuel, especially when the inlet temperature of the biodiesel was increased.

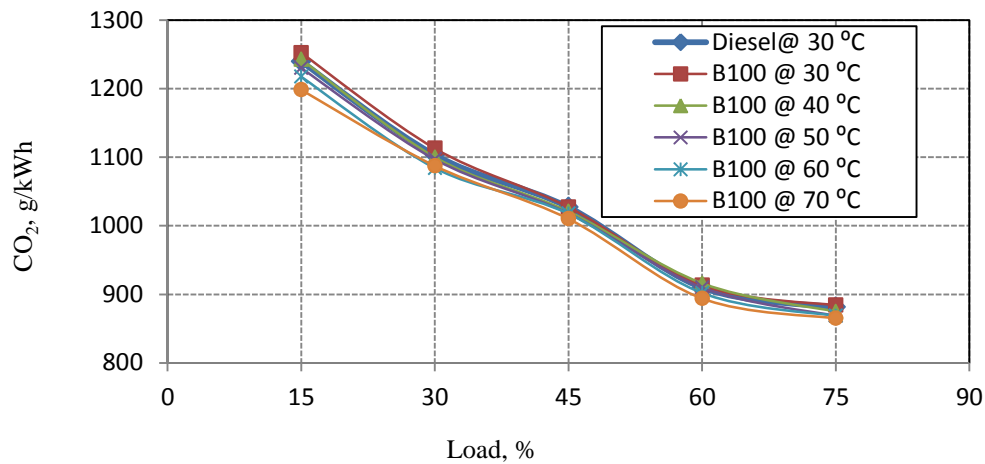


Figure 8: CO₂ emission of engine at different loads.

Fig. 9 illustrates the effects of engine loading on carbon monoxide (CO) emissions from diesel and biodiesel fuel combustion when different fuel inlet temperatures are used. The CO emissions decreased with increasing engine load due to the presence of eddy current flow inside the combustion chamber, which led to good mixing, improved combustion, and reduced CO emissions. This effect occurred because the oxygen content of the sunflower biodiesel enhanced the ignition properties and split the heavier particulates of the fatty acid present in the

biodiesel into smaller particulates that could then be converted into volatile gases and lead to earlier ignition [46].

Fig. 9 shows that less CO was emitted when using biodiesel than when using diesel due to the content of oxygen in the biodiesel fuel, which helped to increase the combustion efficiency and reduce CO emissions. Fig. 9 also show that the higher biodiesel inlet temperatures resulted in lower CO emissions due to the improvement of combustion inside the engine cylinders [47].

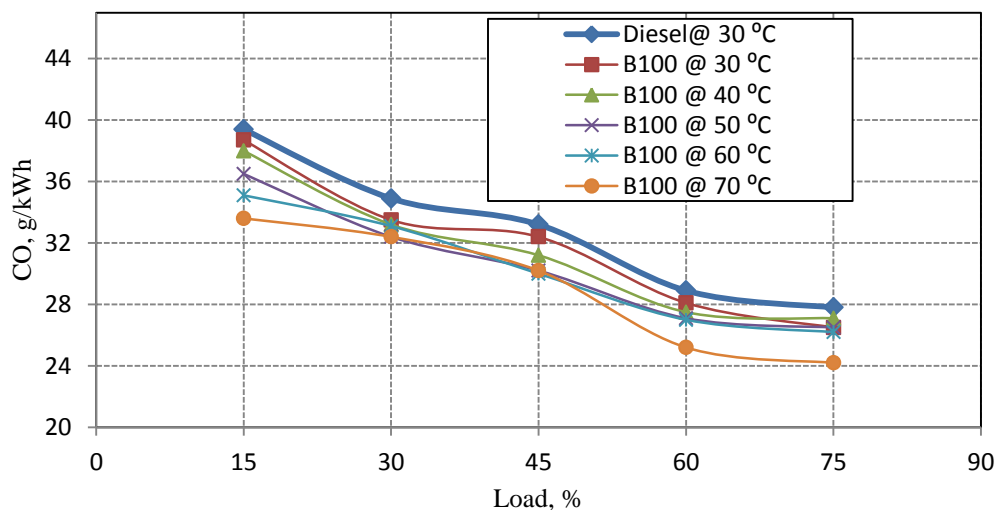


Figure 9: CO emissions from the engine at different loads.

The incomplete components of diesel and biofuel combustion are HC and CO

pollutants. These components are directly affected by the mixing and combustion

gradients inside the engine combustion chamber. Therefore, when using biodiesel, ignition is delayed, allowing for further fuel evaporation that reduces the emissions of HC. The inlet temperature of biodiesel

has a great impact on the atomization and evaporation of fuel inside the combustion chamber, which improves combustion and generally reduces HC emissions, as shown in Fig. 10.

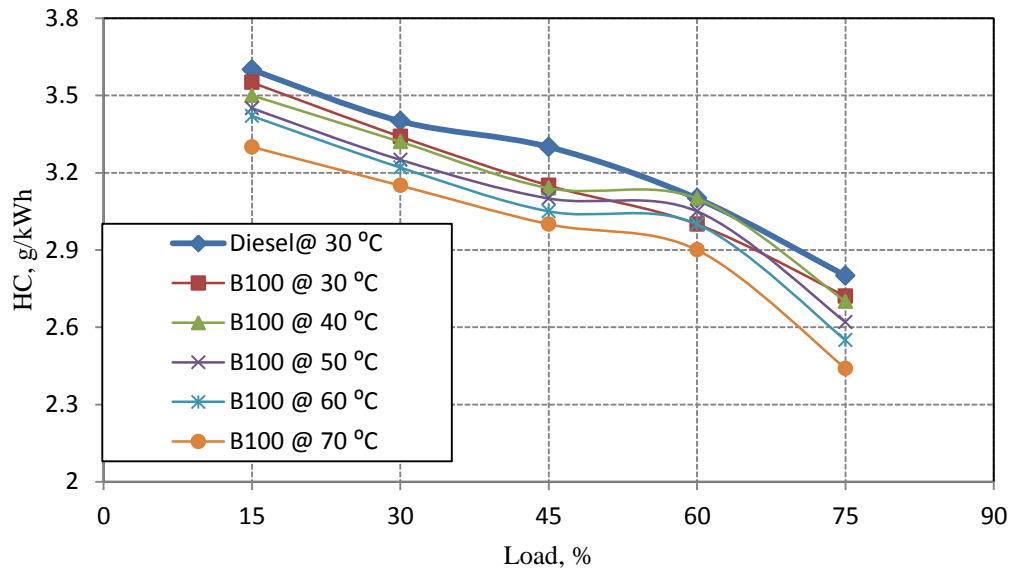


Figure 10: HC emissions from the engine at different loads.

Two significant parameters affect the emission of NOx. The first parameter is the temperature of the combustion gases within the combustion chamber, and the second parameter is the exposure time for high heat. Both of these factors lead to the generation of NOx [38]. Biodiesels have greater oxygen contents than other fuels, which improves their combustion behaviour and hence increases the peak

combustion gas temperature and results in an increase in NOx emissions [48]. NOx emissions are emitted from exhaust gas systems at higher concentrations due to the rapid auto-ignition produced by the high temperature of combustion gases. Therefore, by increasing the inlet temperature of the biodiesel, the exiting NOx concentration will increase at different engine loads, as shown in Fig. 11.

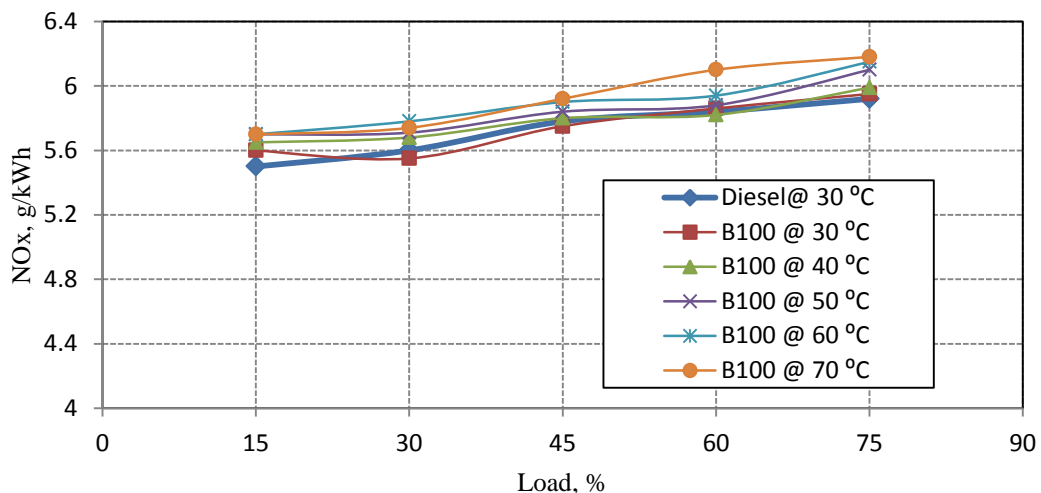


Figure 11: NO_x emissions from the engine at different loads.

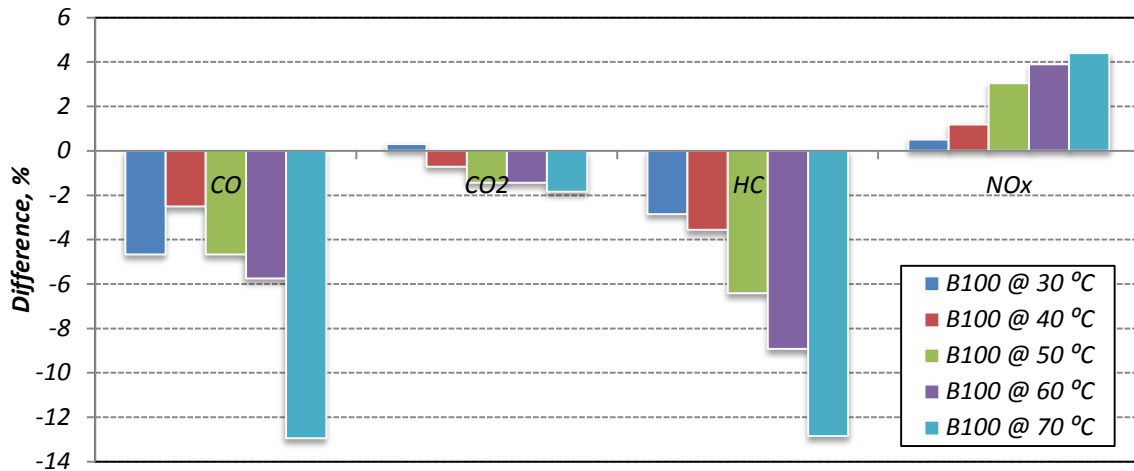


Figure 12: Difference percentages of the engine emission pollutants (CO_2 , CO , HC and NO_x) at different biodiesel and conventional diesel inlet temperatures (baseline: diesel fuel) at an engine load of 75 %.

Fig. 12 shows a comparison of all the pollutants emitted from the engine, such as CO_2 , CO , HC and NO_x at an engine load of 75 % and for different biodiesel inlet temperatures. It is clear from the figure that the difference percentages of CO and HC emissions are very low in the case of biodiesel with the difference percentages reaching up to 12 % for a high inlet temperature. A slight difference in CO_2 emissions was observed for the benefit of the biodiesel that reached up to 2 %. Fig. 12 clearly shows that the NO_x emissions in the case of biodiesel use are higher than those in the other case (conventional diesel) at all of the biodiesel preheating levels. Generally, Fig. 12 shows that the NO_x emissions from the biodiesel fuel are higher than those from diesel.

CONCLUSION

An experimental study was carried out on a diesel engine fuelled with sunflower oil biodiesel to evaluate the engine's performance characteristics and pollutant emissions. The conclusions drawn from the experimental results of biodiesel and conventional diesel fuel studies are summarized below.

- A heat exchanger was designed to

utilize with exhaust enthalpy energy to preheat the biodiesel fuel before entering the combustion chamber of the engine. The biodiesel was heated by a heat exchanger to achieve temperatures of 30° C to 70° C. The inlet temperature of the biodiesel was controlled to ensure that the fuel temperature remained constant during the experiments.

- The engine was studied at an engine speed of 1500 rpm and under changeable loads. The performance characteristics of the engine, such as the engine output power, BTE and BSFC, were determined. The emissions of different pollutants such as CO , CO_2 , HC and NO_x were measured for different operating conditions.
- The engine power as lower when preheated biodiesel with inlet temperatures of 30, 40, 50 and 60° C were used. The engine power improved by 1.3% at 70° C and for a load of 75%. The BTE was greater when the engine was powered by biodiesel rather than diesel, especially when the biodiesel temperature at the inlet was high, which resulted in an

improvement of 10.51%.

- The BSFC was significantly reduced when the engine was fuelled by 70° C preheated biodiesel rather than by diesel fuel, with a decrease of 8.27 %. CO₂ emissions were also reduced when biodiesel was used for all inlet temperatures, and the maximum reduction in CO₂ emissions occurred at an inlet temperature of 70°C and a load of 75 %.
- The emissions of CO and HC from the CI engine demonstrate the significant effect of using preheated biodiesel fuel. The rates of CO and HC emissions were reduced by 12.95% and 12.85%, respectively, for different inlet temperatures when biodiesel was used.
- One obvious drawback of using biodiesel in combustion engines is the resulting NO_x emissions. When using biodiesel, the engine emits larger amounts of NO_x when using biodiesel at all inlet temperatures and the difference reaches up to 4.39% at 70°C and load 75%.

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