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A Study on the Effects of Preheating Thevetia Peruviana Biodiesel on the Performance of CI Engine

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Research Article

Abstract

Biodiesel is becoming increasingly popular as a substitute fuel for compression ignition (CI) engines because of its comparable characteristics to those of diesel and its little environmental impact. The development of diesel engines that run on biodiesel and reduce emissions of pollutants, while also improving thermal efficiency, are key concerns in engine design. The most crucial prerequisites for achieving these are precise and quick air-fuel mixing. However, biodiesel's viscosity is considered a drawback for its application as a substitute fuel for IC engines. Heating can greatly lower the viscosity, which can eliminate the problems caused by excessive viscosity during injection. Hence in this effort, preheated Thevetia Peruviana biodiesel (Methyl Ester) is utilized. The present research aims to examine how preheating biodiesel affects the operation of a direct injection (DI) diesel engine. Engine tests were done on a stationary, single-cylinder, constant speed, naturally aspirated, water-cooled CI engine with a preheated 20% blend of Thevetia Peruviana biodiesel (PH-TPME20 with a conventional jerk type injection system. Engine performance of preheated TPME20 was compared with the unheated 20% blend of TPME and diesel. Preheating reduced the viscosity of the oil, which resulted in a noticeable improvement in engine performance. A considerable drop in emission levels from the engine exhaust gas was noted. The preheating improved combustion characteristics i.e. it lowered the delay period and resulted in quicker release of heat because of improved fuel-air mixing, fuel vaporization, and atomization.

Keywords: Biodiesel; Combustion; Diesel Engine; Emissions; Performance; Preheating.

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1. Introduction

Researchers from all across the world are investigating internal combustion engines with replacement fuels due to the depletion of crude oil supplies, environmental pollution owing to the usage of petroleum-based fuels, and ever-rising petroleum-based fuel prices [1]. Previously, there have been attempts to use pure vegetable oils as a substitute for traditional diesel fuel [2, 3]. However, raw vegetable oils are not meant for direct use in diesel engines due to their increased viscosity [4, 5]. Thus, the transesterification has been normally adopted to convert vegetable oils into biodiesel [6-10]. For diesel engines, biodiesel is a good alternative fuel. They are less harmful to the environment, renewable, affordable, and have a better cetane number, less sulphur and more oxygen and have higher lubricity [11, 12]. Conversely, their drawbacks include decreased volatility and calorific value, as well as higher viscosity and pour point.

Several studies employing methyl esters of sunflower oil [13], palm oil [14, 15], mahua oil [16], pongamia oil [17, 18], soybean oil [19-21], jatropha oil [22, 23], and Tomato Seed oil [24] have been conducted on the performance and combustion of CI engines. These investigations show that the usage of raw biodiesel or its blends in diesel engines lowered hydrocarbons, carbon monoxide, and smoke by about 3-45% [25-27]. Conversely, many have noted a rise in NOx emissions, 'Brake-Specific Fuel Consumption' (BSFC) and a decrease in thermal efficiency, power output, and mean effective pressure [28-31]. The primary reason for biodiesel-fueled diesel engine's poor performance is mainly caused by its high viscosity, less calorific value, and low volatility [32, 33]. Even after transesterification biodiesel's viscosity was found higher by about 70-90% in contrast to the standard diesel. This property of biodiesel influences the atomization, vaporization, and mixing with air, which in turn influences the emissions, performance, and combustion of biodiesel [34]. The viscosity can be significantly reduced by heating, thus the issues due to high viscosity during the injection can be obviated [35]. Anis and Budiandono [36] studied the impact of preheating biodiesel blends on spray characteristics and injection pump performance and reported that injection pump performance was significantly impacted by biodiesel's high viscosity. Besides, they have also specified that as the blend's biodiesel content increased, so did the necessary preheating temperatures. Bhatt and Shrivastava [37] have reported that biodiesel can be atomized and vaporized more easily with preheating. Mekonen and Sahoo [38] observed a 17.4% reduction in BSFC, a 23% increase in BTE, a drop in CO, and UBHC emissions and an upsurge in oxides of nitrogen emissions after using a heat exchanger to preheat the biodiesel. A study that used heated garlic methyl ester found that emissions of CO, smoke, and HC decreased.[39]. By employing preheated pongamia oil, Nadaf et al. [40] focused their efforts on enhancing engine performance and concluded that the engine performed better in terms of BTE and BSFC. According to certain research, preheating the biodiesel or increasing the injection pressure in biodiesel-operated diesel engines increased the performance on account of enhanced atomization, improved vaporization and air-fuel mixing, which leads to better combustion [41, 42].

It is evident from the literature that there aren't many research publications available on Thevetia Peruviana biodiesel as an alternative fuel. There are no published works on the preheating of Thevetia Peruviana biodiesel in the literature. Hence here an effort has been taken to assess the influences of preheating of Thevetia Peruviana biodiesel on CI engine performance, combustion, and emission characteristics. Results were evaluated and related to standard diesel and unheated Thevetia Peruviana biodiesel operations.

2. Experimental Resources and Testing Procedure

2.1. TPME Production, Test Fuel and Its Characteristics

In this research, Thevetia Peruviana Methyl Ester (TPME) was utilized. TPME was prepared using the transesterification process. A catalyst called sodium hydroxide was employed in the trans-esterification procedure. Methoxide was first prepared for the transesterification process. To make methoxide, 160 millilitres of methyl alcohol was assorted with 5 grams of sodium hydroxide per litre of Thevetia Peruviana oil. After heating the oil to 60°C, prepared methoxide was added to the oil. The temperature of the reaction was maintained at this level employing a constant temperature bath and a stirrer spinning at 200 rpm to mix the reactants. Subsequently, the mixture was transferred into a separating funnel. The end products, biodiesel and glycerol, were permitted to settle in the separating funnel overnight to isolate the biodiesel. After the separation of biodiesel, the contaminants were removed from the biodiesel through four or five rounds of distilled water washing. The fuels' characteristics were then measured. Table 1 compares the fuel characteristics of diesel, TPME, and TPME20.

To ascertain how heating affects Thevetia Peruviana biodiesel's variation in viscosity, the oil was warmed up above room temperature in steps of 5°C and the viscosity was noted. Table 2 displays and compares the viscosities of diesel and TPME at various temperatures. Table 2 makes it clear that TPME viscosity at 50°C is nearly identical to diesel, negating the need for engine changes. However, as the heating value of TPME is lower by 7% compared to standard diesel, TPME blended with diesel. As a result, diesel and 20% of TPME by volume were combined to create a test fuel that was used for the investigation.

Table 1. Test fuel properties

Properties	DIESEL	TPME	TPME20	IS:15607 specifications	Test methods IS1448 / ASTM
Density (kg/m^3)	850	860	852	860-890	P16
Kinematic Viscosity (cSt)	3.4	5.96	4.32	2.5-6.0	P 25 / D 445
Heating Value (MJ/kg)	44.12	41.08	43.26		D5865
Flash Pt (°C)	76	158	86	120	P 21 / D93
Cloud Pt (°C)	6.5	10.8	7.1	-	D2500
Pour Pt (°C)	3.1	4.4	3.4	-	D2500
Cetane No	49	57.6	51	51	P9 / D613
Sulphur, mg/kg	29	0.003	18	≤ 50	P 83/D 5453

Table 2. Variation of viscosity of TPME and diesel with temperature

Viscosity in cSt	Temperature in °C					
	25	**30**	**35**	**40**	**45**	**50**
Viscosity of Diesel	3.42	3.1	2.85	2.59	2. 38	2.17
Viscosity of TPME	5.96	5.48	5.16	4.72	4.38	4.16

2.2. Experimental Setup and Procedure

Figure 1 represents the investigation arrangement that was employed. For experimentation, a 4-stroke, single-cylinder DI-CI engine was used. An eddy current dynamometer for measuring braking power and a system for acquiring data comprising a computer, combustion analyzer, piezo-electric pressure transducer, crank angle encoder, and thermocouple were used. A piezoelectric pressure transducer and a crank angle encoder were used to measure the pressure within the cylinder. The signal from them was detected and elevated to a higher level of electrical signal using a signal conditioning charge amplifier. To analyse these data, a SeS combustion analyser was employed. A five-gas analyzer was employed to measure CO and HC and to measure NOx and smoke a SIGNAL analyzer and a smoke meter were utilized respectively. The essential technical specifications of the engine used in this study are listed in Table 3.

Table 3. Descriptions of the test engine

Brand	Kirloskar
Category	single-cylinder diesel engine, 4stroke,
Cubic capacity	661 cc
Bore & Stroke	87.5 mm & 110 mm
Compression ratio	17.5:1
Rated power	5.2 kW
Ignition system	Compression ignition
Injection pressure	200 bar
Dynamometer	Benz systems ECB-70 eddy current dynamometer
Cylinder pressure sensor	Kistler Piezoelectric 6613CQ09
Exhaust Gas Analyser	AVL Gas Analyser (DIGAS 444)
NOx Analyser	SIGNAL Heated Vacuum NOx Analyser 4000VM
Smoke Meter	AVL 437 C Smoke Meter

The measuring range and resolution of emission measuring instruments used are given in Table 4. The engine was tested with diesel, a 20% blend of Thevetia Peruviana Methyl Ester (TPME20), and pre-heated TPME20 (PH-TPME20) to investigate performance, combustion, and emission characteristics. To achieve better atomization by reducing the viscosity, TPME20 was heated by a heat exchanger. The heat exchanger was maintained at a temperature of 50°C. In every test, the test engine was warmed up till the engine temperature reached a stable condition. The engine was set to run at 1500 rpm speed by adjusting the fuel injection pump. The manufacturer's recommended injection operating conditions were followed during the engine tests. Throughout the test, the temperature and flow rate of the cooling water were maintained unchanged.

Table 4. Emission measuring instruments range and resolution

Parameters	Range	Resolution
HC	0–20,000 ppm	1 ppm
CO	0–15%	0.01%
NO_X	0–5,000 ppm	1 ppm
Smoke	0–100%	1%

2.3. Analysis of Uncertainty

Various instruments and apparatus were employed in the experimental research to measure various parameters. These devices and tools are produced by various manufacturers utilizing various technology. The performance and precision of the measurements can change based on the experimental environment and operational parameters. Therefore, fixed or random errors are the cause of the uncertainty. Analytical techniques were used to evaluate the uncertainty in the measured parameters. The Holman root-mean-square approach is used to calculate the overall uncertainty. Table 5 presents the calculated uncertainty for the observed quantities.

Table 5. Experiment uncertainties

Parameters	Percentage Errors (%)
Speed	±2
Load	± 0.2
Time	± 0.1
Temperature	± 2
Pressure	± 2
Brake power	± 0.05
BTE	± 0.1
BSFC	± 0.2
NO_X	± 1
CO	± 0.02
HC	± 1.1
Smoke opacity	± 1

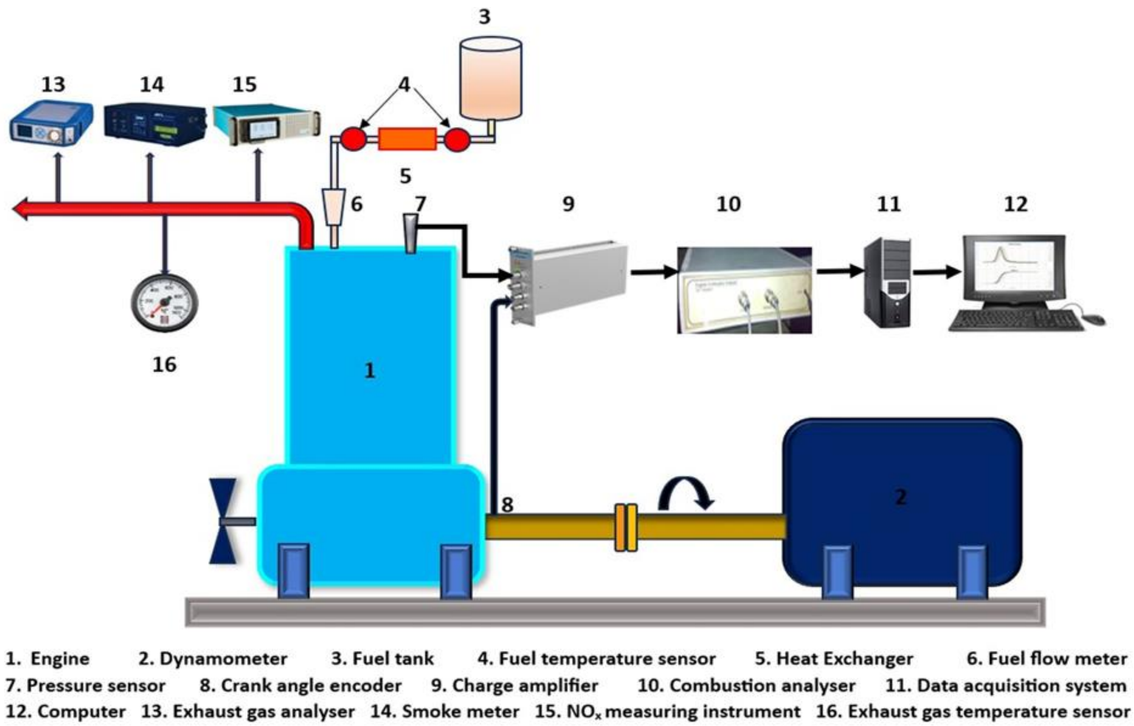

Fig. 1. Schematic illustration of experimental arrangement

3. Results and discussion

3.1. Combustion Characteristics

One significant factor in describing the knocking phenomenon of C.I. engines is the fuel's delay period. The ignition delay (ID) variations for diesel, TPME20 and preheated TPME20 are displayed in Figure 2. Preheated TPME20 had a noticeably shorter delay period than both unheated TPME20 and diesel. The ID of TPME20 lies in between PH-TPME20 and diesel. This suggests that TPME20 has a higher cetane number than diesel. For all fuels, the ignition delay had become shorter at higher loads. This can be explained by the decrease in exhaust gas dilution, especially at greater loads and higher temperatures during PH-TPME20 operation.

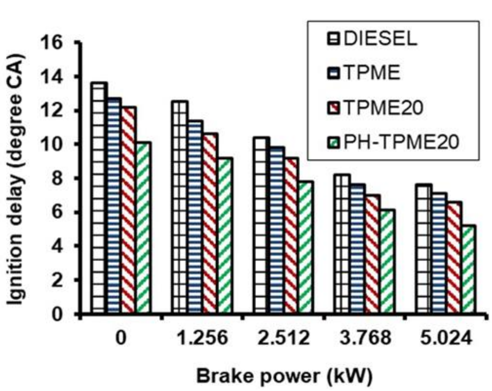

Fig. 2. Ignition delay vs brake power (BP)

A crucial element of this investigation is the in-cylinder pressure fluctuation. The differences in the engine's in-cylinder pressure when running on diesel, TPME20, and warmed TPME20 at maximum load are shown in Figure 3. The pressure fluctuations for the three tested fuels follow the same pattern at all loads of testing. Nonetheless, consistent with the findings of earlier research [43], the pressure data values of TPME20 were inferior in contrast to diesel and PH-TPME20. Higher fuel viscosity and a lower TPME heating value were the causes of this. The PH-TPME20 had a marginally lower in-cylinder pressure trend than the diesel, but significantly higher than the TPME20. This is explained by PH-TPME20's enhanced combustion, which is brought about by greater fuel vaporization, air-fuel mixing, and atomization.

In an effort to learn more about the engine's combustion process, heat release calculations are performed. Figure 4 compares the rate of heat release of diesel, TPME20 and preheated TPME20 at full engine loads. Figure 4 illustrates that the diesel had a marginally higher heat release than the PH-TPME20. Among the fuels, TPME20 had a lower heat release.

Inadequate atomization of TPME20 due to its increased surface tension and viscosity, might be the reason for this. Moreover, the heat release of the biodiesel blend during the diffusion combustion phase is marginally superior to diesel. This can be reasoned to TPME20's shorter delay period than diesel. PH-TPME20's heat release trend is almost similar to diesel. Better combustion, improved atomization, better fuel vaporization and air-fuel mixing can be reasoned to this. A comparable trend was reported by other researchers [41].

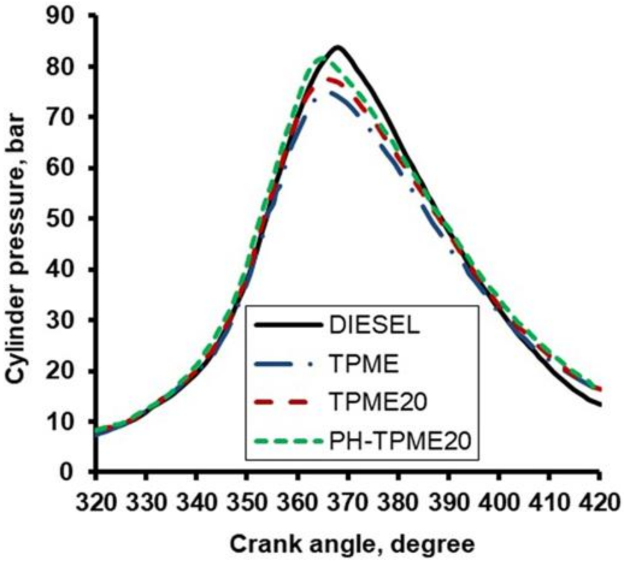

Fig. 3. In-cylinder pressure vs BP at full load

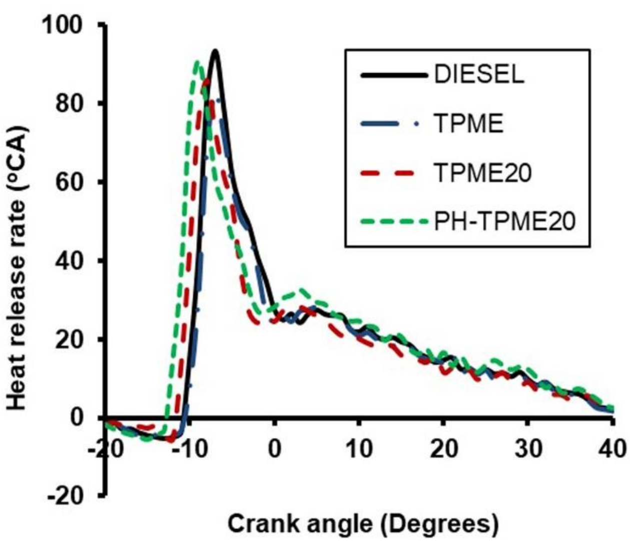

Fig. 4. Rate of heat release vs BP at full load

3.2. Performance Characteristics

The term "brake specific fuel consumption" refers to the proportion of fuel used to the engine power. This serves as a means of comparing the engine's efficiency. Figure 5 displays the engine's Brake Specific Fuel Consumption (BSFC) deviations for the diesel, TPME20 and preheated TPME20 at various engine loads. When operating at full load PH-TPME20's BSFC (0.259 kg/Kw-hr) was lower than the TPME20 (0.282 kg/Kw-hr). Similar variations were observed at all operating loads too. A reduction in BSFC signifies an engine's enhanced overall performance. Superior fuel atomization and vaporization that promote better combustion are accountable for these characteristics [36]. These outcomes align with the study findings of other investigators [43].

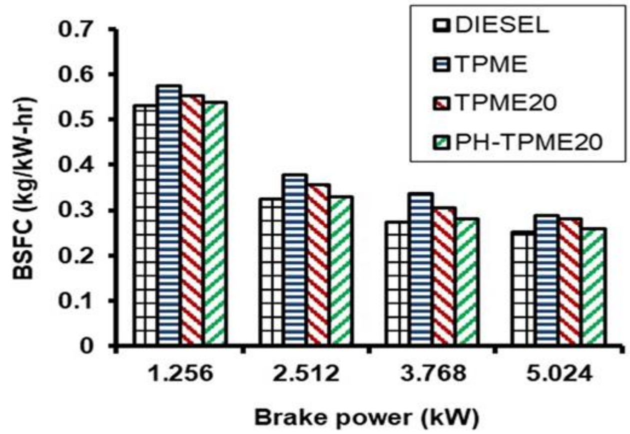

Fig. 5. BSFC vs brake power

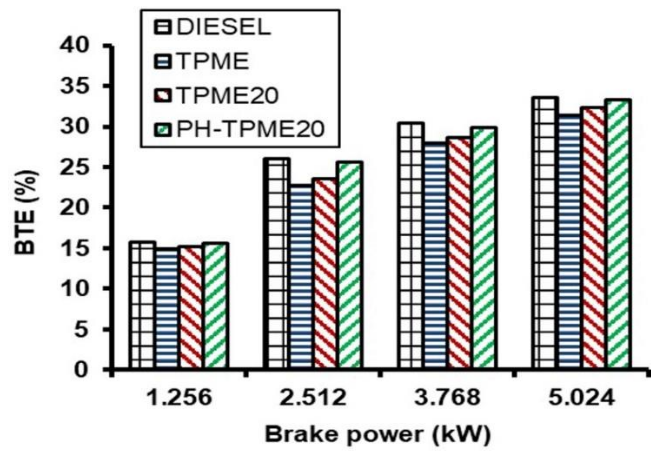

Fig. 6. BTE vs brake power

Brake thermal efficiency (BTE) is a metric used to quantify how well heat energy is converted into work in internal combustion engines. Figure 6 illustrates the variations in BTE to BP for diesel, TPME20, and preheated TPME20. It shows that, the BTE rises as brake power increases for all fuels. In contrast to diesel (33.58%), TPME20 had a lower BTE (32.32%). However, when using PH-TPME20, the BTE was greater than TPME20 at all loads. Better atomization leads to improved mixture formation and thereby enhances combustion and BTE [34]. These results are in line with previous researchers' findings [43].

3.3. Emission Characteristics

Unburnt hydrocarbons (UBHC) are produced when fuel burns partially and the flames close to combustion chamber walls are quenched. Figure 7 compares the emissions of UBHC for diesel, TPME20 and preheated TPME20 at all engine load conditions. In relation to diesel operation, UBHC emissions were lower for TPME20 and preheated TPME20 operations. Additionally, in contrast to the TPME20 operation, the engine operating with preheated TPME20 produced lower levels of UBHC emissions. This can be explained by improved fuel vaporization, air-fuel mixing, improved atomization, and oxygen substance in TPME.

When testing with PH-TPME20, there was a 26% reduction in HC emissions related to the engine working with diesel at full-loaded condition.

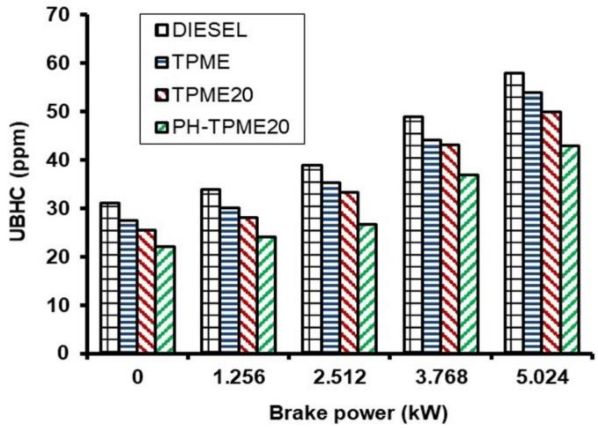

Fig. 7. UBHC vs brake power

The main causes of the formation of CO are low oxygen levels and incomplete fuel combustion. CO emissions with respect to the brake power developed for diesel, TPME20 and preheated TPME20 are displayed in Figure 8. CO emissions from TPME20 and preheated TPME20 operations were lower at all loads when compared to diesel emissions. Compared to the TPME20 operation, the preheated TPME20 operation emitted very low levels of CO emissions. This is explained by better atomization, improved fuel vaporization, air-fuel mixing, and complete combustion for preheated TPME20. CO emissions were 46.7% lower when tested with the PH-TPME20 than when operating with diesel at the maximum load. Jaichandar and Annamalai [31, 34] found comparable decrease in CO levels brought about by the oxygen present in biodiesel and improved vaporization and air-fuel mixing.

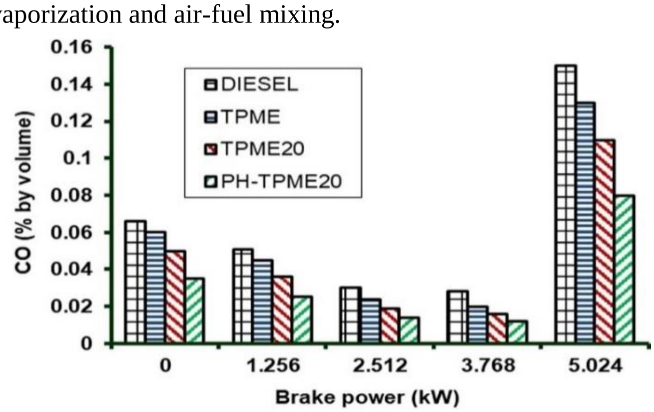

Fig. 8. CO vs brake power

Oxygen and nitrogen combine in a chain reaction to form oxides of nitrogen at very high temperatures during combustion. Figure 9 illustrates the changes in nitrogen oxide emissions for TPME20, preheated TPME20, and diesel at various loads. The PH-TPME20 engine produced more NOx emissions than the diesel or TPME20 engine. Increased oxygen availability in TPME and higher in-cylinder temperatures brought on by complete combustion of the air-fuel mixture owing to improved mixture formation might be the source of the spike in NOx emissions. For PH-TPME20, an additional factor is that a greater portion of the combustion was completed before the top dead centre. Kannan and Gounder [43] observed similar reduction in smoke levels due to availability of oxygen in biodiesel and better atomization and air-fuel mixing due to preheating.

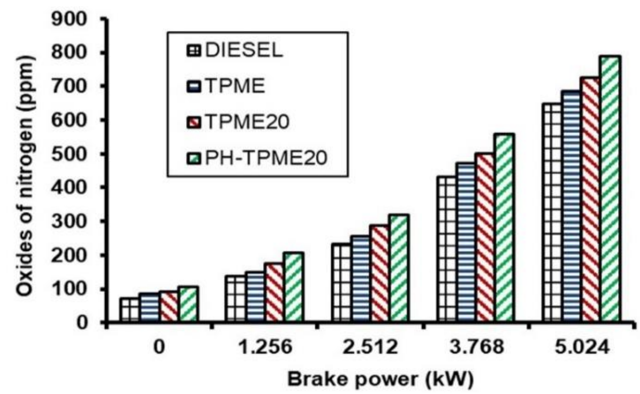

Fig. 9. NO_x vs brake power

At high temperatures, the rich zone, or the centre core of the fuel droplets, is where smoke forms most frequently in diesel engines. Figure 10 compares the smoke levels for diesel, TPME20 and preheated TPME20 at various loads. Compared to diesel, the smoke productions were dramatically decreased for both TPME20 and preheated TPME20 at all loads. The oxygen substance in the biodiesel blend was responsible for the decrease in smoke emissions. In contrast to TPME20, the preheated TPME20 operation produced fewer smoke emissions. This was brought about by greater air-fuel mixing and oxygen availability in the TPME, which led to more thorough combustion. Smoke emissions were 27% lower than diesel during full load operation when tested with the PH-TPME20. Other researchers noticed a similar tendency [31].

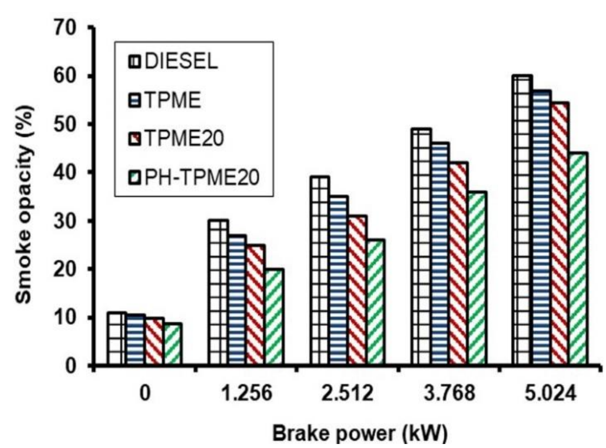

Fig. 10. Smoke vs brake power

4. Conclusions

A preheated TPME20 fuel was used to power a 5.2 kW CI engine. The impact of preheating the biodiesel on the engine's operating characteristics was investigated and compared with the typical diesel. The preheated TPME20's performance, combustion, and emissions significantly improved. Preheating enhances atomization, fuel vaporization, air-fuel mixing and combustion, which in turn enhances the engine's ability to run on biodiesel. The following sums up the findings of the present study:

Preheating the biodiesel,

- Raises BTE.
- Lowers the BSFC.
- Reduces smoke, HC, and CO emissions.
- Increases NOx emissions levels.
- Increases the in-cylinder pressure and heat release.

Conflict of Interest Statement

The author declares that there is no conflict of interest in the study.

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