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Effect of Rice husk nanoparticles as additives on the Performance and Emission characteristics of Tannery fleshing waste oil Biodiesel on Compression Ignition Engine

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Abstract

The study is to reduce the exhaust emissions of compression-ignition (CI) engine fueled with tannery fleshing waste oil methyl-ester (TOME)-diesel blends by adding the organic fuel additive called Rice Husk (RH) nanoparticles. The synthesized TOME was mixed with diesel in two ratios such as 10% (TB10) and 20% (TB20) by volume basis. To this TB10 and TB20 fuels, 5 grams (0.5% by mass) of RH nano-additive was blended. The study revealed that the direct use of TB10 and TB20 fuels show higher brake specific fuel consumption (BSFC) and lower brake thermal efficiency (BTE) as compared to the neat diesel (ND). A reduced emission of Hydrocarbon (HC), Carbon monoxide (CO), smoke opacity and an increased emission of NOx is observed in TB10 and TB20 fuels as compared to Neat Diesel (ND). The BTE is found to be improved with TB10+0.5RH and TB20+0.5RH blends in comparison with TB10 and TB20 fuels at peak-load. For TB20+0.5RH at full loads, the smoke, HC and CO emission is decreased about 33.6%, 38.2% and 26.5%, respectively and NOx is increased up to 36.5% as compared to ND.

Keywords: Diesel engine; Tannery waste biodiesel; Rice husk nano additive; Alternate Fuels, Performance and Exhaust Emissions

1 INTRODUCTION

Transportation plays a vital role in our day-to-day life and it has become one of the basic requirements for human beings. In a developing country like India, the demand for transportation is increasing rapidly. A major portion of demands in transportation is conventionally met by the fossil fuels derived energy sources. Nangia reported that there is a tremendous increase observed in the usage of fossil fuels burnt in vehicles on a daily basis [1]. Kalghatgi estimated that the increasing vehicle population affects the atmosphere as it emits harmful pollutants [2]. The increasing trend of pollutions in the atmospheric air has become a huge challenge for the lives on the planet, which fundamentally affects the healthy life as reported by Andersen et al. [3]. Two set of studies by Al-Maamary, et al., and Gielen et al. revealed that the increasing demand for fossil fuels forces the countries to import petroleum products at a higher price from other countries [4,5]. This kind of dependency essentially affects the economy of the countries which import the petroleum and crude oil.

Considering such factors, one of the prominent solutions to overcome these problems is to produce and use biofuels such as biodiesel as an alternative fuel. Since biodiesel can be indigenously produced from cheap and abundantly available sources, there may not be the issues such as the exhaustion and shortage of resources. Further, Hosseinzadeh et al., Mahmudul et al., and Thapa, et al. have reported that biodiesel produces lower emission as compared to that of the conventional diesel fuel [6-8].

From the literature, it can be found that many researchers across the world investigated the biodiesel as an alternating fuel for internal combustion (IC) engine. An experimental investigation was done by Can et al., about canola oil-based biodiesel as a fuel in a diesel-engine with common rail direct injection (CRDI) technology [9]. The study found that there is a massive reduction in engine-out volatile compounds along with HC, CO, and smoke emissions. Further, it has also been observed that the B20 blend ratio can be highly effective after which the volatile organic compounds started to increase. Another experimental study by Balaji and Cheralathan was conducted with neem oil-based biodiesel and diesel blends and used in the conventional CI engine [10]. The authors reported that the biodiesel blends showed a lower engine-out emission with a slight improvement in the engine performance as well. The study also showed that a 10% blend of neem oil can be optimum for its blending with diesel fuel. The utilization of rice-bran oil biodiesel in a four-cylinder automotive diesel engine was studied by Dharmaraja et al. [11]. It was noted in the study that the brake power of the engine was notably reduced with biodiesel-blended fuel. Their study on emission front revealed that there is a decreased emission of particulate matter, HC and CO exhaust, but an increased emission of nitrogen oxides.

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Perumal and Ilankumaran conducted an experimental study on blending of pongamia methyl ester with the conventional diesel fuel [12]. From their result, it was observed that the use of biodiesel decreases the engine-out emissions such as HC, CO and particulate matter with marginal reduction in the combustion performance. Pradhan, et al. conducted a study on Mahua seed oil derived biodiesel in a diesel engine [13]. The pyrolysis process was employed in the production of Mahua oil and it was blended with mineral diesel oil at two different ratios such as 10% and 20%. The results of this study inferred that there was a marginal decrease in brake thermal efficiency (BTE) at low load operations, yet significant increase was found at full-load operations of the engine along with a mitigation in CO, HC and NOx emissions.

Though there are substitute fuels available for diesel-engines, there exist challenges in meeting the required performances and emission characteristics of the fuels. To overcome such challenges, the introduction of suitable additives to enhance the fuel properties has become essential in biodiesel research. Sharma et al. added the carbon nanotubes (CNT) and cerium oxide (CeO_2) as nano-additives into biodiesel blends and tested in a conventional diesel engine [14]. They found that the fuel with such additives improved the combustion characteristics and enhanced the performance of the engine. Hawi, et al. have analyzed the usage of used cooking-oil biodiesel mixed with normal diesel fuel with iron-doped CeO_2 nanoparticles as additive and tested in a conventional diesel engine [15]. The study demonstrated promising results in terms of reduced emissions for various blends of test fuel than that of the conventional diesel fuel, coupled with an increased brake specific fuel consumption (BSFC) values. Venu and Madhavan have conducted a detailed study on the engine performance with two different combinations of fuel blends such as diesel blended with biodiesel and blended with nanoparticles, where they used two different materials such as titanium oxides (TiO_2) and zirconium oxide (ZrO_2) [16]. The experimental result revealed that there is a substantial reduction observed in smoke, CO, NO, and HC emission, which is about 30%, 44%, 60% and 35% respectively with nanoparticles blended biodiesel. Further, it was observed that the brake thermal efficiency (BTE) was also found to be increased by 4%.

From the previous studies, it can be understood that without any modification in an existing engine, biodiesel could be used with the blending of nanoparticles as additives. However, the use of biodiesel in a diesel-engine will have an increasing effect on NOx emission, whereas the other emissions such as smoke, HC and CO can be reduced. The addition of nanoparticles with biodiesel blends has also been reported to show superior effects in achieving better combustion in diesel engines. In this direction, this present study investigates the effect of natural rice husk nanoparticles as an oxygenated additive for the biodiesel produced from tannery fleshing waste and tested for its exhaust emission characteristics in an unmodified diesel-engine.

2 MATERIALS AND METHODS

2.1 Biodiesel synthesis from tannery fleshing waste oil

There are three major steps followed to produce biodiesel and the process is called transesterification as reported by Moazeni, et al. [17]:

Step-1: Pre-treatment process- Triglycerides are extracted from free fatty acids of the oil.

Step-2: Transesterification Process- Conversion of Tryglycerides into ester (under Alkali Catalyst-Potassium Hydroxide).

Step-3: Final post-treatment process- Production of biodiesel from ester

Figure 1 shows the processes involved in biodiesel production from tannery fleshing waste oil. In general, during the pre-treatment process, a massive volume of free fatty acid from tannery fleshing waste oils are converted to triglycerides using ethyl alcohol and the acid catalyst (sulfuric acid). The temperature condition and duration for this reaction is 60±1 ºC and 140 minutes, respectively. The pre-processed product is then moved to a typical separating conduit to remove the impurities beside the excess ethanol at the top layer. Being the product of the pre-treatment process, it is then warmed at 35 ºC for the transesterification process in presence of alkali catalyst. The preheated product, in the form of a solution, is mixed with NaOH-dissolved ethanol solution using a mechanical stirrer to attain homogeneity. The reaction-solution is kept undisturbed for eight hours so that it naturally gets settled due to gravity. Finally, a pure form of tannery fleshing waste oil methyl ester (TOME/Biodiesel) was produced from the transesterification process.

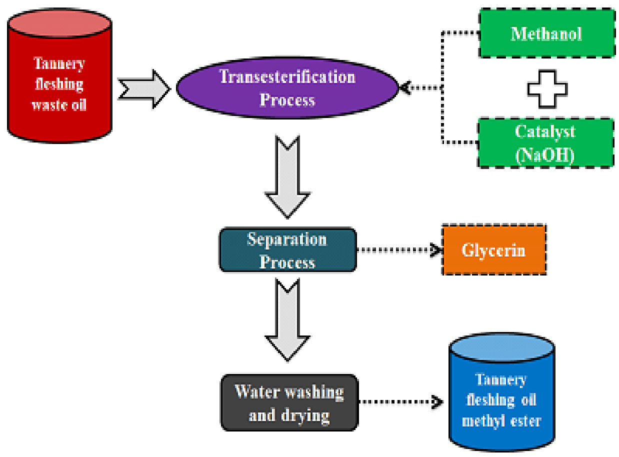

Fig. 1 Transesterification Process

2.2 Preparation of rice husk nano additives

In this process, the waste rice husk nanoparticle was synthesized as an additive for biodiesel. Being a suitable resource of rice husk, the local rice mills were approached to collect the same. Sufficient quantity of waste rice husk was collected from rice mills located in the villages near Vellore, Tamil Nadu, India. Initially, the grits and impurities were removed from the rice husk by washing it with distilled water in order to improve the quality of raw waste rice husk. After washing, it was dried for 24 hours in an open atmosphere. Then, the dried rice husk was grounded using a household domestic simple mixer. In order to achieve a controlled particle size, the mixture was strained through a mesh of 80-micrometre size. This pre-treated rice husk was processed through a ball milling process to reduce its size into nanoscale.

A planetary mono mill was used in this study to produce nanopowder and further nano-sized particle was achieved through mechanical miller machine. In order to achieve the rice husk of sizes less than 100 nanometers, the planetary ball milling process was employed. Then, the nano-sized rice husk was milled for 20 cycles in a miller. For every cycle, it was milled for 15 minutes with an idle time of 10 minutes. The miller's rotational speed was set constant at 300 rpm. Then, the grounded rice husk powder was dried at room temperature. Finally, the obtained final rice husk nanoparticle was used to blend with biodiesel. Figure 2 shows the processes involved in the production of rice husk nanoparticles from raw waste rice husk.

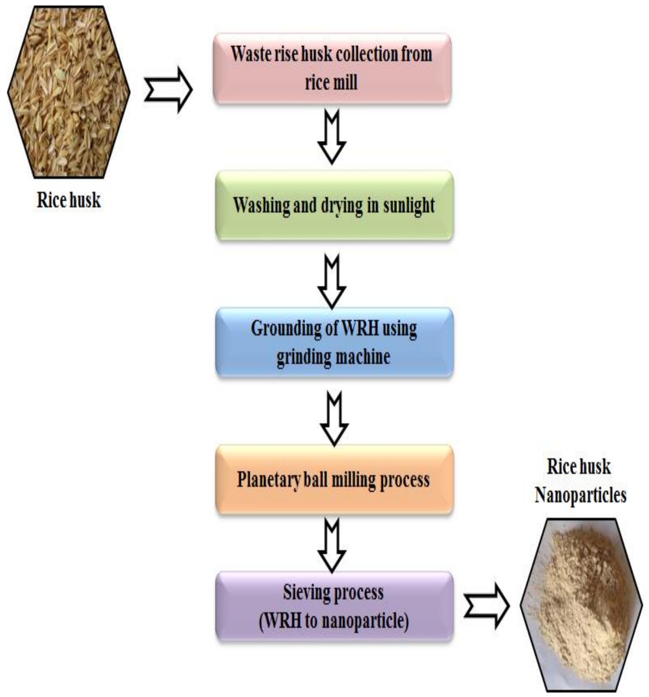

Fig. 2 Process involved in rice husk nano additive production

2.3 Test fuel preparation

In the current work, the prepared tannery waste-oil methyl ester was blended with diesel fuel at 10 and 20 vol.%, which are named as TB10 and TB20, respectively. To this, about 5 grams of rice husk nanoparticles (i.e. 0.5% by mass) was blended with TB10 and TB20 fuels as a nano additive. The nano additive blended biodiesels were named as TB10+0.5RH and TB20+0.5RH. These blends were found to be suitable biodiesel fuel with nano additives that can be used in CI engines and to conduct the experiments at desired conditions.

The properties of all the test fuels and blends were determined and calculated according to the American Standards for Testing Materials (ASTM) and are given in Table 1 Ong [18].

Table 1 Properties of Diesel and Tannery fleshing waste biodiesel with different blends.

Sl. No.	Property	Unit	Diesel	TOME	ASTM standard
1	**Kinematic viscosity at 40 °C**	(cSt)	4.5	6.2	ASTM D445
2	**Density**	(kg/m3)	830	874	ASTM D1298
3	**Calorific value**	(kJ/kg)	42,300	39,554	ASTM D240
4	**Cetane number**	-	45	53	ASTM D613
5	**Flash point**	(°C)	62	150	ASTM D93
6	**Fire point**	(°C)	68	159	ASTM D92

3 EXPERIMENTAL WORK

3.1 Test engine setup with instrumentation

The experiment was carried out in a Kirloskar make at a constant speed of 1500 rpm in a single-cylinder diesel engine. The photographic image of the entire engine testing equipment is shown in Fig. 3.

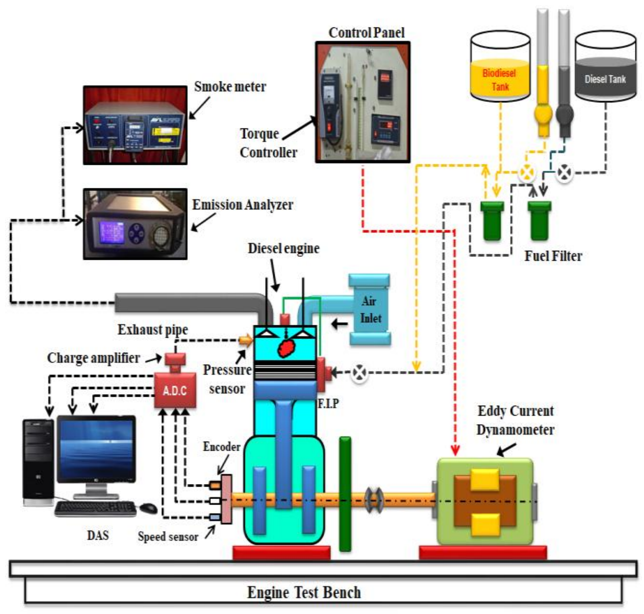

Fig. 3 Photographic image of the schematic arrangement of testing engine setup

Table 2 shows the complete operational specifications of the experimental engine used in this study. The test engine was coupled with eddy-current dynamometer through engine crankshaft to fluctuate the engine load during the experiment. The burette and stopwatch arrangement has been used for calculating the total fuel utilization by noting down the time-taken for the consumption of 10 CC of fuel by the engine. The exhaust emission gas temperature was estimated using a k-type thermo-couple mounted in the exhaust conduit arrangement. The exhaust emissions such as NOx, CO and HC were estimated using the AVL make 444 model Di-gas analyzer. The smoke emission was measured from the exhaust using AVL's 437C smoke opacity meter as reported by Ganapathy, et al. [19]. Table 3 shows the complete methodological specifications of the emission measurements used in the experiment.

Table 2 Specification of the test engine.

Sl. No.	Descriptions	Details
1	Make and Model	Kirloskar oil engines limited and AV-1 model
2	Engine-type	Single-cylinder, water-cooled, 4 stroke diesel engine
3	Bore and stroke	80 mm and 110 mm
4	Compression ratio	16.5:1
5	Injection timing	23^{o} before TDC (rated)
6	Injection pressure	200 bar
7	Speed	1500 rpm
8	Rated power	3.7 kW (5 BHP)
9	Engine capacity	554 CC
10	Loading device	Eddy current dynamometer

Table 3 Specification of exhaust emission measuring instruments.

Equipment name	Descriptions	Details
Exhaust gas analyzer	Make and model	AVL 444 di-gas analyzer
	Measures	HC, CO, NOx
	Range	HC: 0-2000 (ppm) ; CO: 0-10 (% volume) NOx: 0-5000 (ppm)
Smoke meter	Make and model	AVL 437C smoke meter
	Measures	Smoke opacity
	Range	0-100 (%)

4 RESULTS AND DISCUSSION

4.1 Performance study

The brake thermal-efficiency (BTE) is defined as the conversion efficiency of the given system to convert the heat energy (from fuel) into useful mechanical energy. Here, the system was an internal combustion (IC) engine indicating the combustion quality and the similar study done by Emiroğlu [20]. Figure 4 shows the changes in BTE as a function of brake power (BP) for neat diesel (ND), TB10, TB10+0.5RH, TB20 and TB20+0.5RH. It can be observed that the BTE was in linear relationship with BP for all the fuel blends. Further, from the BTE graph, it can be understood that at minor load condition, the BTE is almost remained same. However, at maximum loads (beyond 60%), the ND fuel produced the highest BTE among other blends. The two blends such as TB10+0.5RH and TB20+0.5RH produced high BTE values as compared to the other two blends of TB10 and TB20 without RH. In comparison with ND fuel, the thermal efficiency is found to be reduced by 2.8% for TB10+0.5RH. Simialrly, it is reduced by 4.4% for TB10 without RH additive. Accordingly, from the obtained results, it can be inferred that the blending of nanoparticles with biodiesel blends helps in enhancing the BTE of the engine. The increase in BTE upon the addition of nanoparticles additives could be attributed to the effect of the improved surface-to-volume ratio of nanoparticles in the fuel blends, which led to a superior combustion rate inside the cylinder. Such similar observations have also been reported by Devarajan, et al [21]. Also, the observed higher calorific value of nano-additive added biodiesel might be due to the improvement in the BTE for TB10 blended with RH nanoparticles as compared to the neat diesel.

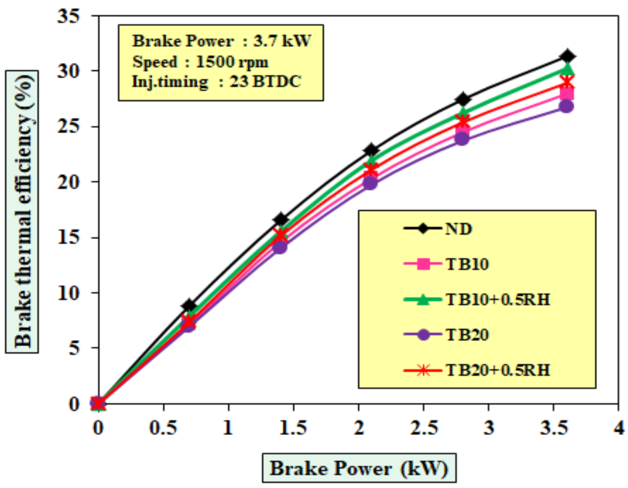

Fig. 4 Variation of brake thermal efficiency as a function of brake power

The brake specific fuel consumption (BSFC) is the measure of the quantity of fuel needed for the diesel-engine to run with given power for a unit time has been studied by Zhu, et al [22]. Accordingly, Figure 5 shows the variations in BSFC values as a function of BP for ND, TB10, TB10+0.5RH, TB20 and TB20+0.5RH. It can be observed from Fig. 5 that the BSFC is found to be increased to 5.2% for TB10 blend with RH nanoparticles as compared to the ND fuel. Since the biodiesel blends possess lower calorific value, a higher fuel quantity is necessary to generate the same power-output by ND fuel at all load conditions, which is also reported by Dhar and Agarwal [23]. The biodiesel blended with nanoparticles (TB10+0.5RH) exhibited the least fuel consumption than the same blend (TB10) without RH nanoparticles. It could be mainly due to the superior combustion process occurred due to the oxygenated RH nano additives, which is in good agreement with the report by Barrios et al. [24]. Notably, the increase in the biodiesel blend fraction enhanced the fuel consumption value about 7.6% for TB20+0.5RH. This might be attributed to the heating values of the blends.

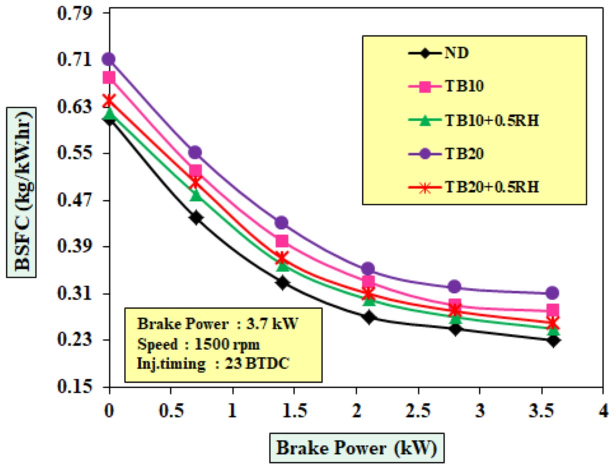

Fig. 5 Variation of brake specific fuel consumption as a function of brake power

4.2 Emission study

In general, the particulate matter is represented by smoke in diesel engines. During combustion, the smoke is formed by many tiny solids together with oil, ash, liquids of vapours and partially burnt fuel particles etc. Smoke comprises of carbon residue (soot) as their main content as reported by Chen, et al [25]. The variations in smoke emission as a function of BP for ND, TB10, TB10+0.5RH, TB20 and TB20+0.5RH is displayed in Fig. 6. In comparison with ND, all the biodiesel blends with and without RH nano-additives show lesser smoke emission. The considerable reduction of smoke value is mainly owing to the availability of intrinsic oxygen species in the biodiesel and helping the oxidation process during combustion as concluded by Uyumaz [26]. Further, the report by Örs, et al. revealed that the presence of nanoparticles in selective blends aids in dropping the smoke emission as the nano additives tend to enhance the combustion inside the cylinder by providing surplus oxygen molecules to the blends [27]. Accordingly, the smoke emission is reduced by 33.6% and 23.4% for TB20+0.5RH and TB10+0.5RH, respectively as compared to the diesel fuel operated at peak load points.

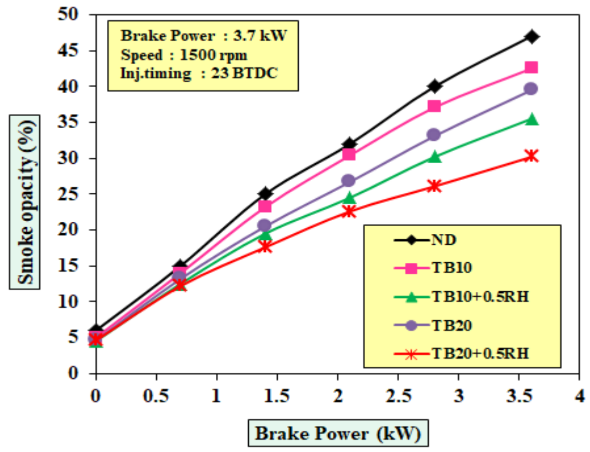

Fig. 6 Variation of smoke opacity as a function of brake power

Nitrogen oxides (NOx) are very dangerous to human health and it is classified as poisonous and reactive gaseous species. The NOx formation in an engine is primarily due to high temperature resulted from the maximum release of heat by burning of fuel at excess oxygen content inside the cylinder as reported by Ashok et al. [28]. Figure 7 shows the different oxides of nitrogen (NOx) emission along with BP for different biodiesel blends with and without RH nano additives such as TB10, TB10+0.5RH, TB20, TB20+0.5RH and diesel fuel. It was found that at medium load, the NOx emission was low in the case of 10% and 20% blends of biodiesel with nanoparticle as compared to ND fuel. At higher loads, the biodiesel blends (TB10 and TB20) and blends with nanoparticles emit higher NOx than the diesel fuel. When compared to diesel fuel operation, NOx emission is increased by 36% for TB20+0.5RH fuel blend. The improved combustion rate due to the higher heating value of nanoparticle blended biodiesel resulted in the formation of higher NOx emissions as observed by Bello et al. [29]. Nabi, et al. have reported that the surplus oxygens in biodiesel blends and higher combustion temperature inside the engine chamber led to higher NOx emission levels [30]. Here, the biodiesel and the blends with nanoparticles contain oxygens that enhance the peak cycle temperature inside the cylinder and resulted in higher NOx formation.

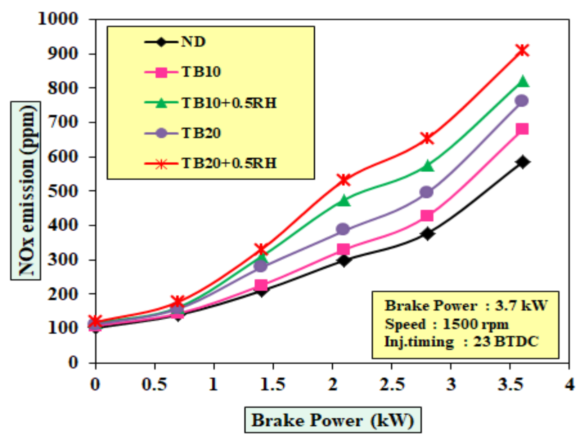

Fig. 7 Variation of NOx emission as a function of brake power

Figure 8 shows the variations in carbon monoxide (CO) as a function of BP for various biodiesel blends with and without RH nano additives such as TB10, TB10+0.5RH, TB20, TB20+0.5RH and diesel fuel. During the process of combustion inside the cylinder, CO is produced as an intermediate product owing to the deficiency of oxygen inside the engine cylinder, as reported by Fakinle, et al. [31]. From the graph (Fig. 8), it can be understood that at all the engine loads, the ND combustion emitted a higher CO as compared to the other biodiesel blends. The biodiesel blends TB10+0.5RH and TB20+0.5RH emitted around 15.2% and 26.5% lower CO emission, respectively as compared with ND at maximum load. The reduction in CO emission is mainly due to the better oxidation reaction taken place inside the cylinder during combustion with the presence of nanoparticles in the biodiesel blends as reported by Chen et al. [32]. Further, another decreasing trend is also observed in Fig. 8 with increasing biodiesel blend and the addition of RH nanoparticles. This infers that the CO is oxidized into CO_2 owing to the existence of more O_2 molecules in both biodiesel and biodiesel blends with RH nanoparticles as reported by Ooi, et al [33].

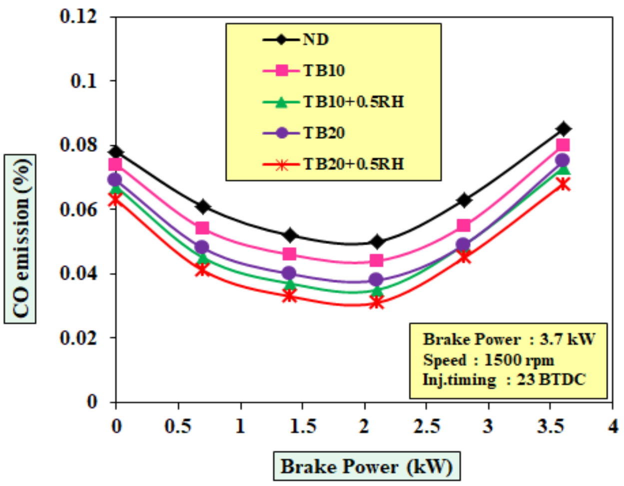

Fig. 8 Variation of CO emission as a function of brake power

The variations of hydrocarbon (HC) emission as a function of BP for ND, TB10, TB10+0.5RH, TB20 and TB20+0.5RH are shown in Fig. 9. At lower load points, it was found that the HC levels of biodiesel blends get reduced as compared when the diesel was used. The RH nanoparticles added in biodiesel blends resulted in lesser HC emission value. Further, the combustion process inside the combustion chamber is improved due to the addition of nanoparticles. The HC emissions were observed to be low at higher percentages of blends with nanoparticles. It can be noticed that the blends TB20+0.5RH and TB10+0.5RH resulted in lower HC emissions i.e. 38.2% and 24.4%, respectively as compared to the ND fuel. The excess oxygen molecules in the biodiesel fuels, owing to the existence of nano additives, helped in increasing the in-cylinder temperature and promoted the evaporation rate of the fuel. These actions enhanced the combustion process. Thus, the HC reduction was observed at all the operating conditions. At higher load-points, the air-fuel ratio plays an important role for different blends and neat-diesel on HC reduction. The oxygen content in biodiesel with nano additives ensured the complete combustion to the maximum extent and reduced the HC emissions in exhaust gases. A similar conclusion was also given by Vinukumar, et al [34].

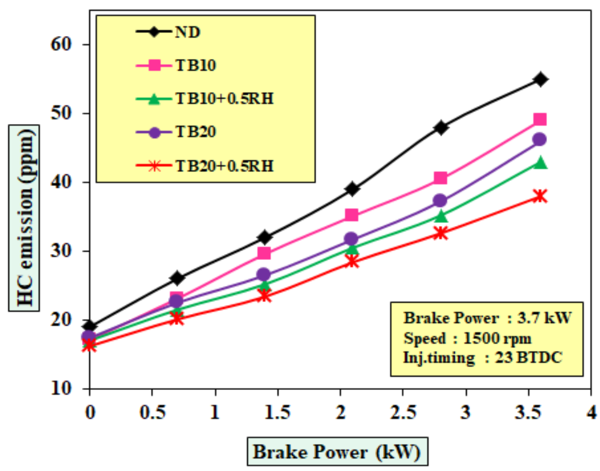

Fig. 9 Variation of HC emission as a function of brake power

5 COMBUSTION STUDY

5.1 Cylinder pressure Analysis

Figure 10 shows in-cylinder pressure variations with respect to crank-angle measured for diesel fuel and different blends of biodiesel, with and without nano-additives, at 1500 rpm engine speed that was operated at full-load conditions. In compression ignition engine, the in-cylinder pressure varies along the fraction of fuel burnt, particularly from the injection of fuel till the end of the combustion process. This mainly depends on the physical and chemical features of the fuel with air inside the cylinder, for instance, the capability of fuel to mix with air and to ignite early with excellent burning rate [35]. The premixed phase in combustion plays an important role in pressure rise-rate and increase in peak firing pressure. Figure 10 observes the highest peak pressure, i.e., 66.3 bar for TB10+0.5RH biodiesel blend with nanoparticles. The second highest peak pressure was measured at 54.7 bar for diesel fuel. This increased in-cylinder pressure is observed as the biodiesel blend with nanoparticles contains enriched oxygen content and while the latter enhanced the combustion phase in the premixed region [36]. However, the other biodiesel blends such as TB10 and TB20 exhibited peak pressure values that fall below the conventional diesel fuel. This might be due to relatively lesser-calorific values and oxygen contents.

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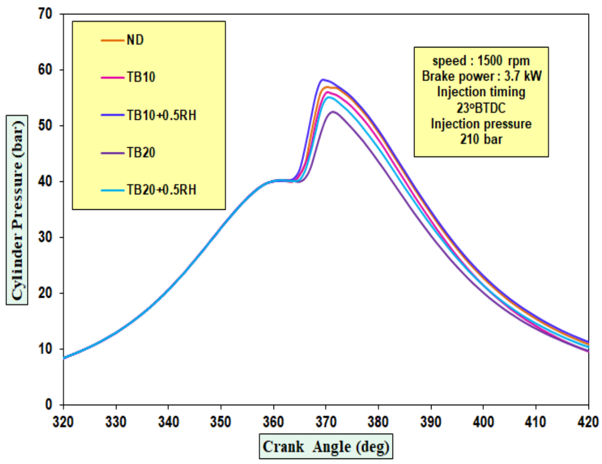

Fig. 10 Variation of cylinder pressure with crank Angle

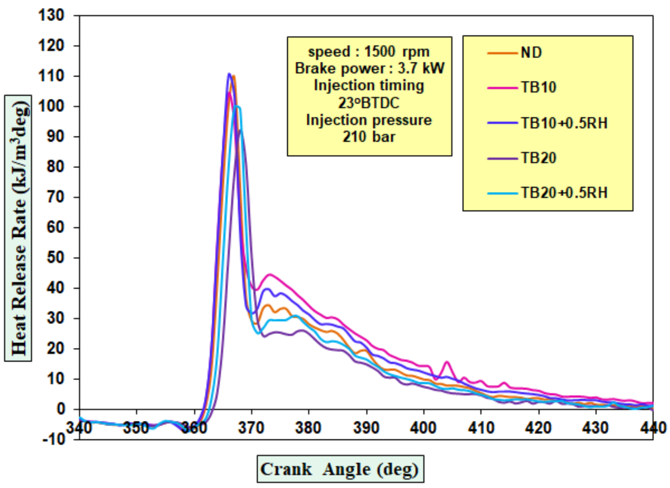

Fig. 11 Variation of HRR with crank angle

5.2 Heat release rate

The heat release rate is generally determined from in-cylinder pressure data with respect to crank-angle. Figure 11 shows the rate of heat-release with crank-angle for ND, biodiesel blends without nano additives (TB10 and TB20) and biodiesel blends with nano additives (TB10+0.5RH and TB20+0.5RH) at full-load conditions. It can be observed that the curve got shifted towards the right for biodiesel blends when compared with ND fuel. This denotes ignition delays in biodiesel blends than in ND fuel. This phenomenon occurred mainly due to poor volatility and high viscosity of biodiesel blends [37]. Ignition delay is the sum of physical delay and chemical delay in the combustion process. In physical delay, the vaporization plays a key role in any liquid fuel used. In the ignition delay period, particularly on the physical delay stage, the injected fuel evaporates by observing the heat from the combustion chamber. This makes the heat-release rate negative at the initial stage [38]. Once the actual combustion starts, the heat-release rate becomes positive. From the graph, it can be understood that the ignition delay was higher for biodiesel with nano additives. In high load condition, the heat release rate increased during the premixed period of combustion, owing to oxygen and biodiesel with nano additive [39]. For diesel, the peak heat release rate was found to be 113.2 kJ / m^3 deg CA; for biodiesel blends TB20+0.5RH nano additive, it was 102.6 kJ / m^3 deg CA and for biodiesel TB20 without nano additive, the value was 95.5 kJ / m^3 deg CA.

6 CONCLUSION

The exhaust emission and performance characteristics of the single-cylinder direct-injection CI engine were studied with the addition of RH nanoparticles in the blends of tannery fleshing waste oil biodiesel, diesel and their blends at two different proportions (TB10 and TB20). From the experimental inference observed from the study, the subsequent results are drawn as follows.

1. Owing to the decreased heating value and increased density of TB10 and TB20 blends, the performance of the engine got reduced as compared to the ND at all engine loads.
2. The addition of RH nanoparticles to the biodiesel blends enhanced the properties and improved the engine performances, i.e., 4.5% higher BSFC and 3.46% lesser BTE than that of the ND fuel at peak power output, while 5.6% and 7.6% for TB10+0.5RH blend and TB20+0.5RH fuels, respectively.
3. A significant mitigation in exhaust emission such as smoke, CO and HC (excluding NOx) was found for both TB10 and TB20 blends. Further, the reduction in such emissions was also recorded with the addition of RH nanoparticles. The maximum decrease in CO, HC and smoke was observed for TB20+0.5RH followed by TB10+0.5RH.
4. The TB20+0.5RH blend showed a reduced emission of HC and CO up to 18.14% and 24.45%, respectively. This reduction could be mainly due to the better oxidation of fuel molecules. As compared to the ND fuel, the smoke emission is reduced to 17.57%, 14.61% for TB20, 28.31% for TB10 and 22.54% with the addition of RH nanoparticles respectively at the peak load condition.
5. The NOx emission was increased by 6.56% and 8.71% for TB10 and TB20 respectively with the addition of RH nanoparticle at a peak power output.

Both TB10+0.5RH and TB20+0.5RH blends reduced the emissions from the engines. The performance values of these blends were close to ND fuel performance. The TB20+0.5RH blend showed maximum reduction in engine exhaust emissions except NOx, and in terms of engine emission reduction, this fuel blend appeared to be more suitable and promising. The overall work concludes that the addition of a small amount of nanoparticles as additive in biodiesel blends aids in decreasing the harmful emissions and could lead to the operation of the engine without any alteration.

7 ABBREVIATIONS

ASTM : American Society of Testing and Materials; TOME : Tannery fleshing waste Oil Methyl Ester; TB10 : 10 % Tannery fleshing waste Oil Methyl Ester + 90 % diesel fuel; TB20 : 20 % Tannery fleshing waste Oil Methyl Ester + 80 % diesel fuel; TB10+0.5RH : 10 % Tannery fleshing waste Oil Methyl Ester + 90 % diesel fuel+ 0.5 % rice husk nano additive; TB20+0.5RH : 20 % Tannery fleshing waste Oil Methyl Ester + 80 % diesel fuel+ 0.5 % rice husk nano additive; CO : Carbon monoxide; HC : Hydrocarbon emission; NOx : Oxides of nitrogen; BTE : Brake thermal efficiency; BSFC : Brake specific fuel consumption

8 DECLARATIONS

8.1 Authors' contribution

Jayagopal was responsible for Software, Data Generation, Formal Analysis, Writing-Original Draft, Writing-Review and Editing. Porpatham was responsible for Supervision, Conceptualization, Methodology, Writing- Review and Editing. Senthil Kumar was responsible for Supervision, Conceptualization. Each author had participated sufficiently in the work to take public responsibility for appropriate portions of the content. All authors read and approved the final manuscript.

8.2 Authors' contributions Conflict of Interests

The authors declare that they have no competing interests.

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