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Performance and NO_x emissions of Mahua ester blends with pyrogallol antioxidant in a single cylinder diesel engine

Biodiesel has attracted research because of its environmental benefits and energy security. In this research, the suitability of using Mahua B20 biodiesel blend in a single cylinder diesel engine has been carried out. The performance characteristics such as brake specific fuel consumption, brake thermal efficiency and NO_x exhaust emissions of B20 Mahua biodiesel with pyrogallol antioxidant by changing its concentration from 0 ppm to 750 ppm is examined and compared to regular diesel. The engine performance results reveals that minor improvements in brake specific fuel consumption and brake thermal efficiency is observed with considerable reduction in NO_x emission at an optimum 750 ppm antioxidant concentration in comparison with B20 Mahua blend without antioxidant. Thus, Mahua B20 blend with antioxidant can be used to run diesel engine without any modification.

Keywords: Antioxidant, biodiesel, emissions, Mahua, NO_x, pyrogallol and performance

1.0 Introduction

The environmental issues such as global warming and threat of exhaust emissions from diesel engine have gained global attention in developing alternative non-petroleum fuel for diesel engines. Biofuels being a renewable energy resource, could be a possible solution to address the negative environment impact and rising fuel prices for automobiles. [Gautamet al. 2013 and Makameet al. 2008]

Vegetable oils are triglycerides with number of branched chains of different lengths. Many researchers have reported the usage of different edible and non-edible vegetable oils such as canola, soya bean, jatropha, karanja, corn, sesame and neem as a fuel in compression ignition engine which has yielded encouraging results. [Agarwal et al. 2007 and Hongmei et al. 2007]. Several studies have shown that using biodiesel in CI engines, the emission levels of carbon monoxide, hydrocarbons and smoke in engine exhausts has been significantly lowered but with increase in NO_x emission in comparison with conventional diesel fuel. [Demirbas, 2009 and Palash et al. 2013]. The other raw materials identified by researcher's to meet the rising energy requirement for IC engines are animal fats such as chicken fat, pork lard, yellow grease and fish oil. [Encinar et al. 2011; Lin and Li 2009; Taymaz and Coban 2013]. However, the milk dairy waste scum is also proved to be a suitable feed stock for biodiesel synthesis and a substitute fuel for diesel engines in recent years [Yatish et al. 2016 and Srikanth et al. 2017].

In this research, Mahua biodiesel blend is used to run diesel engine. Mahua is one among the forest based tree of Indian origin which is found across the country. The trees are capable of growing in semi fertile land and withstand dry climate. Mahua is a slow growing species which reaches a maximum height of 20m with an average height of 0.9 to 1.2m at the end of the fourth year. The kernel of the seed contains about 50% of oil. Approximately 34-37% of the total weight of the seeds is converted to oil when it is extracted using screw expeller [Kumar and Sharma 2011; Jena et al. 2010 and Puhan et al. 2005]. The different parts of the tree such as seeds, flower, bark and oil are used for medicines and other industrial applications.

The B20 blend of Mahua biodiesel is found to be a suitable alternative fuel for heavy duty diesel engines as reported in [Godiganur et al. 2009] without affecting the engine performance and considerable reduction in carbon monoxide (CO) and hydrocarbon emission (HC) with increase in NO_x emissions. The findings of [Gautam and Anoop 2013] reveals that Mahua B20 blend results in higher thermal efficiency in comparison with other blends and can be well adopted as an alternative fuel for agricultural diesel engines. Experimental research carried out by [Saravanan et al. 2010] reported that Mahua could be a substitute for diesel fuel as its performance is found similar to that of diesel with lower engine exhaust emissions.

The maximum reduction of 43.55% in engine NO_x exhaust emissions was obtained with 0.025% molar concentration of butylated hydroxyl toluene (BHT), butylated hydroxyanisole (BHA) and p-phenylenediamine additives in Jatropha

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biodiesel for the experimental studies carried out by [Varatharajan. and Cheralathan 2012].

The experimental studies carried out by [Balaji et al.2016] reveals that; the addition of propyl gallate (PG) antioxidant in Neem biodiesel marginally progresses the thermal efficiency with noteworthy declining levels of smoke and oxides of nitrogen exhaust emissions when operated on 4.4kW single cylinder compression ignition engine.

It was observed in the research studies carried out by [Dueso et al. 2018] using renewable antioxidant extracted from bio-oils when blended with methyl esters derived from sunflower operating a four-in-line CI engine that; smoke opacity and NO_x emissions were lowered by 4% and 3% respectively while engine performance was reduced by less than 1% in comparison with neat diesel.

The examinations were carried out by [Rizwanul Fattah et al. 2014] with the addition of butylated hydroxyanisole (BHA) and butyl-4-hydroxytoluene (BHT) antioxidant at 1,000 ppm concentration to B20 palm biodiesel to examine the engine performance and emission characteristics. It was also found that the addition of antioxidants increased the oxidation stability of palm biodiesel without having negative impact on fuel properties.

2.0 Materials and method

2.1 Transesterification of Mahua oil

The biodiesel isproduced from raw Mahua oil using base transesterification method by eliminating acid esterification as the value of free fatty acids (FFA) found to be very low. Initially the optimization of process parameters affecting the reaction was carried out and biodiesel was produced for the optimal values obtained as reported in the authors previously published paper [Balaji et al. 2018]. Base transesterification was carried out in a reaction vessel maintaining the reactants mixture of 30% methanol with 1% of base catalyst (potassium hydroxide) at 55°C positioned on a magnetic stirrer revolving at 400 rpm for a period of 1.5 hr as shown in Fig.1 After the completion of this reaction; the mixture is transferred to separating funnel, and allowing to settle over a period of time forming biodiesel (upper layer) and glycerol (bottom layer). Finally, the methyl esters recovered from the above stage is water washed with warm water and heated further to remove remains of excess catalyst and moisture content.

Fig.1: Transesterification experimental set up

2.2 Experimental Procedure

The test engine trials were conducted on a four stroke, single cylinder of Kirloskar model diesel engine, provided with water cooling arrangement with a rated power of 5.2-kW at constant speed. The technical details of the test engine is listed in Table 1. The arrangement of the test engine with auxiliaries is displayed in Fig.2. The pyrogallol (PY) antioxidant in different concentration of 0, 250, 500 and 750 ppm concentration by weight was included in B20 Mahua biodiesel. The test samples used during the experiment trials were diesel, B20 Mahua biodiesel blends. The readings of exhaust emissions such as oxides of Nitrogen (NO_x), CO, HC emission and fuel

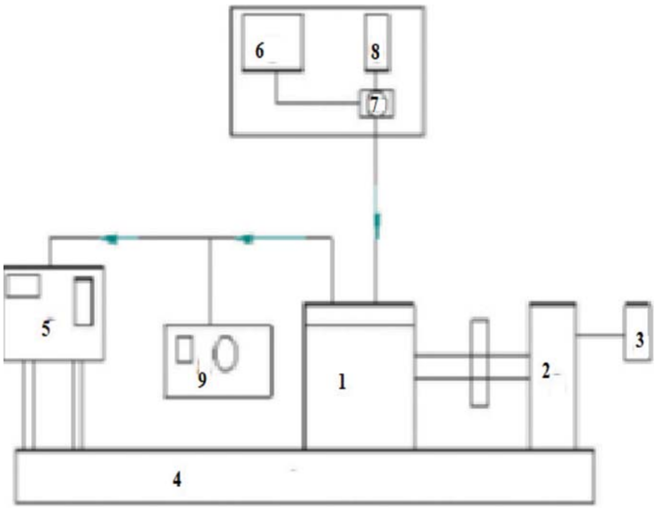

Fig.2: Engine experimental set up

(1) Test engine (2)Loading device (3)Loading controls (4)Test bed (5) Smoke meter (6) Fuel tank (7) Two way valve (8) Burette (9)Exhaust gas analyzer

Table 1: Description of test engine

Features	Description
Model	Kirloskar engine
No of cylinder	1
Cylinder diameter	87.5mm
Cylinder stroke	110mm
Compression ratio	17.5:1
Rated power	5.2 kW

consumption rate were obtained at steady-state conditions of engine for different loads at a constant speed of 1500 rpm. The AVL DIGAS-444 five-gas analyzer is used for measurements of exhaust emissions of the test engine.

3.0 Results and discussions

3.1 Brake specific fuel Consumption (BSFC)

The effect of BSFC at different loading conditions for the test fuel blends is shown in Fig.3. Due to higher calorific value of diesel fuel in comparison with biodiesel, its specific fuel consumption is lowest at all the loadings. It is also observed that the BSFC decreases with increase in loading for all the test fuel blends. Similar trends were also reported by other scholars [Godigannur et al. 2010 and Basavaraj et al. 2004]. The BSFC of B20 is lower than B100 while, the BSFC of B20 with PY antioxidant in different concentration is found to be marginally lower at higher loadings in comparison with B20 without antioxidant. For the test fuel B20 with 750 ppm PY, the BSFC is 3.3% and 3.84% lower than the B20 without antioxidant at 50% and 75% loading conditions. Such similar findings were also reported in [Swarup Kumar and Bhabani Prasanna 2013; Balaji et al. 2019].

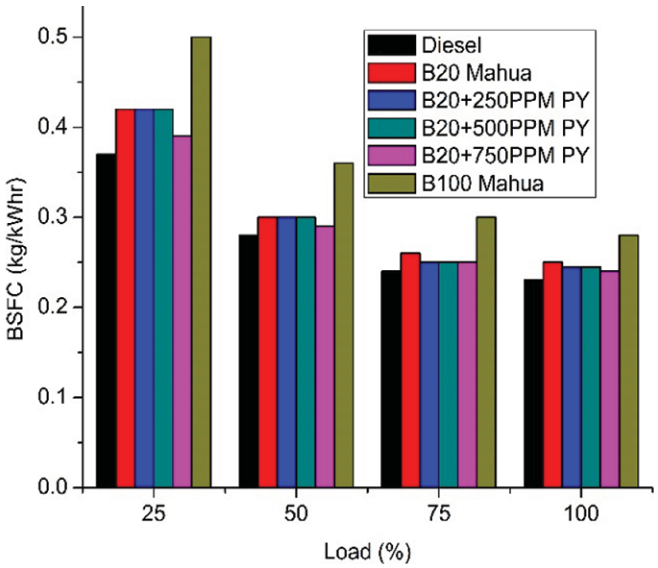

Fig.3: Variation of BSFC with test fuel blends

3.2 Brake thermal efficiency (BTE)

The effect of brake thermal efficiency at different loading conditions for the test fuel blends is shown in Fig.4. The BTE of diesel fuel is found to be highest due to lower specific fuel consumption and for B100 is lowest due to higher fuel consumption at all the loadings, while for B20 lies intermediate. With increase in load on the engine the BTE increases for all the test fuel samples. This trend was also observed in findings of [Godigannur et al. 2009, Balaji et al. 2017 and Tamil Selvan et al. 2017]. It is also observed that with increase in antioxidant concentration in test fuel sample, slightly the BTE is increased at higher loadings. For the test fuel B20 with 750 ppm PY, the BTE is 2.4% and 1.26% higher than the B20 without antioxidant at 50% and 75% loading conditions.

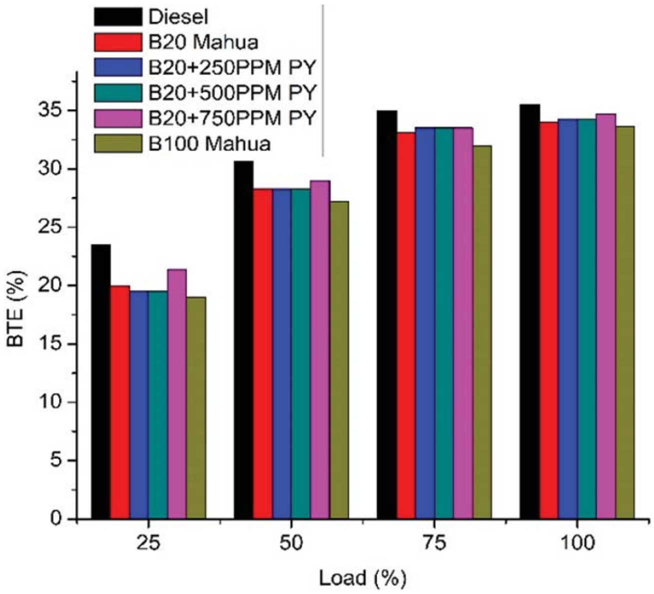

Fig.4: Variation of BTE with test fuel blends

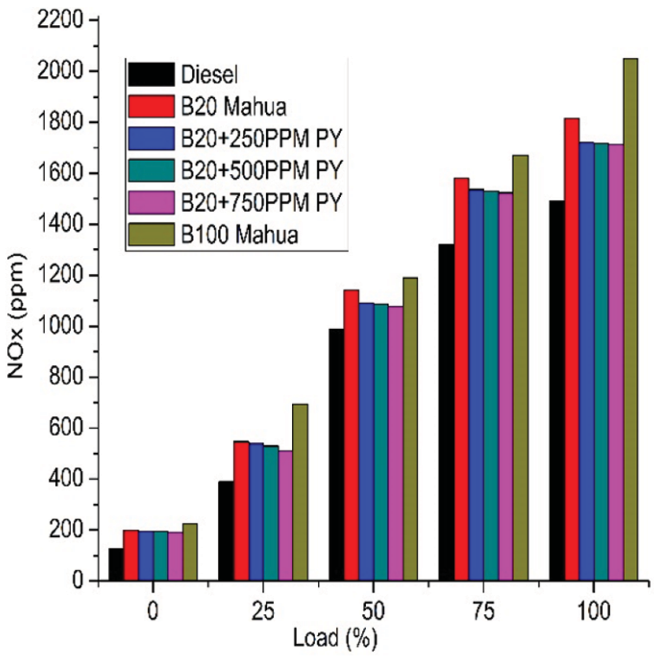

Fig.5: Variation of NO_x with test fuel blends

3.3 Nitrogen oxides emission (NO_x)

The effect of nitrogen oxides at different loading conditions for the test fuel blends is shown in Fig.5. It can be observed that NO_x emission increases linearly with loading for diesel and other test fuel samples. The emissions are highest for B100 due to existence of oxygen content in the structure while lowest for diesel at all the loading conditions [Clark et al. 1984 and Huseyin et al. 2010]. As the antioxidant concentration increases in B20, there is considerable reduction in NO_x emissions as it would hinders the affinity of fuel to combine with oxygen. For the test fuel B20 with 750 ppm PY, the NO_x emissionsare 5.6% and 3.6% lower than the B20 without antioxidant at 50% and 75% loading conditions. This similar results are also reported in [Balaji et al. 2019 and Syed Asif Avate et al. 2015].

4.0 Conclusions

Based on the performance tests and emissions tests conducted on a single cylinder diesel engine using PY antioxidant on B20 Mahua ester blends following conclusions can be driven.

- The addition of PY antioxidant to B20 Mahua blend influences the performance parameters and NO_x emissions of a CI engine.
- The addition of PY antioxidant to B20 lowers the SFC and average reductions of 4.57% is observed for 750 ppm of PY concentration.
- The addition of PY antioxidant to B20 improves the BTE and average increase of 3.11% is observed for 750 ppm of PY concentration.
- The inclusion of PY antioxidant to B20 lowers the NO_x emissions and average reductions of 5% is observed for 750 ppm of PY concentration.
- The B20 blend with 750 ppm of PY concentration is considered to be the best concentration to improve the engine performance and reduce NO_x emissions.

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