EFFECTS OF ANTIOXIDANT ADDITIVES ON EXHAUST EMISSIONS REDUCTION IN COMPRESSION IGNITION ENGINE FUELED WITH METHYL ESTER OF ANNONA OIL

by

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In this present study, biodiesel is a cleaner burning alternative fuel to the Neat diesel fuel. However, several studies are pointed out that increase in NO_x *emission for biodiesel when compared with the Neat diesel fuel. The aim of the present study is to analyze the effect of antioxidant (p-phenylenediamine) on engine emissions of a Diesel engine fuelled with methyl ester of annona oil. The antioxidant is mixed in various concentrations (0.010 to 0.040% (w/w)) with methyl ester of annona oil. Result shows that antioxidant additive mixture (MEAO + P200) is effective in control of* NO_x *and HC emission of methyl ester of annona oil fuelled engine without doing any engine modification.*

Key words: *annona methyl ester, transterification, p-phenylenediamine, emissions, Diesel engine*

Introduction

The increase in utilizationof diesel fuel loads leads to fast depletion and force to go for alternate fuel. One of the alternate sourcesis from vegetables and plants, since they can be produced from the plants grown in rural areas [1]. The increase in usage of fossil fuel consumption leads the researchers to go for better alternate energy for engine operation. So the biodiesel gives reproducibility, non-toxicity, sulphur-free, and similar physical properties to Diesel engines [2]. The major disadvantage of biodiesel is their higher viscosity which leads to poor atomization, which in turn may lead to injector pump failure, ring sticking, and abnormal combustion [3]. Biodiesel from plants such as soyabean, peanut, sunflower, jatropha, mahua, neem, rape, coconut, karanja, cotton, mustard, linseed, and castor have been tried in many parts of the world as alternate fuel for compression ignition engine [4]. Biodiesel can be produced from non-edible oils obtained from plant species, karanja (*pongamia pinnata*), jatropha (*jatropha curcas*), mahua (*madhucaindica*), neem (*azadirachtaindica*), *etc*. [5, 6]. Use of biodiesel in conventional Diesel engines results in substantial reduction in emission of unburned HC, CO, and particulate [7] . The NO_x emission from biodiesel is higher compared to normal diesel fuel because of its higher thermal efficiency [8]. Neat vegetable oil has highest potential of reducing lifecycle greenhouse

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gas emissions as compared to biodiesel and diesel [9]. India's self-sufficiency in petroleum oil as consistently declined 60% in 1950 to 30% in 2010 and is expected to go down to 8% by 2020 [10, 11]. As India is deficient in edible oil and demand for edible oil exceeds supply, the Government decided to use non-edible oil from jatropha oil seeds as biodiesel feedstock [12-14].

Many researchers' proved that biodiesel and their blends of diesel fuel reduces HC, CO, and smoke density [15, 16] and increases NO_x emission relative the diesel fuel [17, 18]. The NO_x is a major cause of photochemical smog, ozone depletion and acid rain. The use of biodiesel leads to increase in NO_x emissions and threaten to the environment. The development of improved NO_x reduction technologies is therefore of critical importance to the global environment [19]. While using biodiesel the reduction of NO and HC emissions by using antioxidant is the simplest, easiest and cost effective as there is no engine modifications and the percentage of antioxidant with biodiesel is also very less [20-22]. Antioxidants are hopeful additives for improving oxidation stability and effective in controlling NO_x emission while using biodiesel [23, 24]. Some of studies reported that the use of antioxidants increases CO emission [25]. Thus, 20% biodiesel blends addedwith antioxidant can be used in Diesel engines without any modifications [26].

In the present study, methyl ester of annona oil is used as a test fuel and p-phenylenediamine used as antioxidant additive. The effects of antioxidant additive on NO_x and HC emission along with methyl ester of annona oil operated direct injection Diesel engine are studied.

Materials and methods

Test fuels

Annona squamosa is a member of the family of custard apple trees called annonaceae and a species of the genus annona known mostly for its edible fruits annona [27]. It is commonly found in India and cultivated in Thailand and originates from the West Indies and South America. *Annona squamosa* produces fruits that are usually called sugar apple or custard apple in English, sitafal in Marathi, sharifa in hindi, and sitaphalam in Tamil and Telugu in India and corossolier and cailleux, pommier cannelle in French [28, 29]. It is mainly grown in gardens for its fruits and ornamental value. It is considered as beneficial for cardiac disease, diabetes hyperthyroidism, and cancer. The root is considered as a drastic purgative.

Transesterification

Transesterification is the process of using an alcohol (*e. g.* methanol or ethanol) in the presence of catalyst such as sodium hydroxide (NaOH) or potassium hydroxide (KOH), which chemically breaks the molecule of the raw oil into methyl or ethyl esters with glycerol as a by-product, which reduces the high viscosity of oils. This method also reduces the molecular weight of the oil to 1/3 of its original value, reduces the viscosity and increase the volatility and cetane number to levels comparable to diesel fuel.

Experimental set-up

Experiments are carried out in a single-cylinder, water-cooled, naturally aspirated direct injection Diesel engine coupled with an eddy current dynamometer. An eddy current dynamometer coupled to the engine is used as a loading device. The fuel flow rate, speed, loads, exhausts gas temperature, and gas flow rate are measured through data acquisition system. The AVL 444 DI-gas Analyzer is used to measure the CO, HC, and NO_x emissions. The engine and data acquisition system is shown in fig. 1.

P-phenylenediamine is accurately weighted using a high precision electronic weighing balance and added to measured quantity of annona biodiesel. To make 0.010%-m of antioxidant mixture, 100 mg of antioxidant is added to 1 kg of biodiesel. A 3000 rpm speed mixer was used to prepare a homogeneous mixture of antioxidant additive and fuel. The emission at different antioxidant concentrations such as 0.010%-m (MEAO + P100), 0.020%-m (MEAO + P200), 0.030%-m (MEAO + P300), and 0.040%-m (MEAO + P400), with a constant engine speed of 1800 rpm are analyzed. The antioxidants addition effects on NO, HC, and CO emission are also studied in the present investigation.The properties of methyl ester of annona oil, with various antioxidant mixtures are compared with Neat diesel fuel as shown in tab. 1.

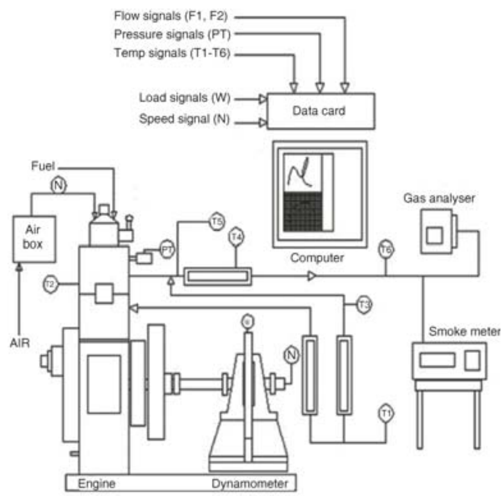

Figure 1. Engine and data acquisition system

Table 1. Comparison of important properties of test fuels

Property	Diesel	MEAO	MEAO + P100	MEAO + P200	MEAO + P300	MEAO + P400
Kinematic viscosity in cst at 400 °C	3.1	5.18	5.18	5.18	5.16	5.16
Calorific value [kJkg^{-1}]	43200	39575	39572	39499	39496	39493
Density at 150 °C [kgmm^{-3}]	830	880.2	878	876	874	872
Cetane number	46.4	52	52	52	52	52
Flash point [°C]	56	76	76	76	76	76
Fire point [°C]	64	92	92	92	92	92

Specifications of the apparatus

The experiment was conducted in the following instrument/equipment and the details are given in tabs. 2 and 3.

Diesel engine

Exhaust gas analyzer

An AVL gas analyzer is used to measure the exhaust gas composition. The brief specification of exhaust gas analyzer is given in tab. 3.

Testing procedure

Engine is started and warmed up at low idle, long enough to establish the recommended oil pressure, and was checked for any fuel and oil leaks. The engine is run on no-load condition and speed is adjusted to 1800 rpm by adjusting fuel injection pump. Engine is run to gain uniform speed; after which it was gradually loaded. Experiments are conducted at different load levels. The engine is run for ten minutes and data are collected during the last four minutes.

Table 2. Engine specification

Engine specification	
Manufacturer	Kirloskar oil engines limited
Model	SV1
Type of engine	Vertical, 4-stroke single cylinder
Rated output	8 hp (5.9 kW)
As per IS: 11170	
Speed	1800 rpm
Compression ratio	17.5:1
Bore and stroke	87.5 × 110 (mm)
Injection pressure	210 bar

Table 3. Gas analyzer specification

Exhaust gas analyzer specification	
Manufacturer	AVL private limited
Type	AVL 444 DI gas analyzer
Ranges	CO – 0 to 10% HC – 0 to 10000 ppm NO_x – 0 to 5000 ppm

The emission tests are carried out at different antioxidant mixture concentrations. The exhaust gas is sampled from exhaust pipe line and passed through an exhaust gas analyzer for measurement of CO, unburnt HC, NO_x present in the exhaust gases. The experimental uncertainties are shown in tab. 4.

Table 4. Experiment uncertainties

Parameters	Systematic errors (±)
Speed	±1rpm
Load	±0.1 N
Time	±0.1 second
Brake power	±0.15 kW
Temperature	±1 °C
Pressure	±1 bar
NO_x	±10 ppm
CO	±0.03%
CO_2	±0.03%
HC	±12 ppm
Smoke	±1 HSU

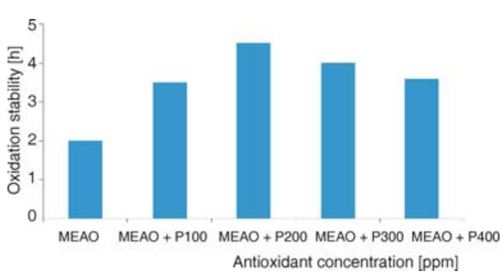

Figure 2. Oxidation stability *vs.* antioxidant concentration

Results and discussion

Oxidation of stability of test fuel

Figure 2 shows the variation of oxidation stability with antioxidant concentrations. The Rancimat method was used to determine the oxidation stability for MEAO, 0.010%-m (MEAO + P100), 0.020%-m (MEAO + P200), 0.030%-m (MEAO + P300), and 0.040%-m (MEAO + P400) in agreement with EN15751. According to the test results, the oxidation stability for MEAO, MEAO + P100, MEAO + + P200, MEAO + P300, and MEAO + P400 is 2 hours, 3.5, 4.5, 4, and 3.6 hours, respectively.

Oxides of nitrogen

Figure 3 shows that variation of NO_x emission with brake power (BP) for different antioxidant concentrations. It can be seen from figure that NO_x emission increases with increase of engine load. The NO_x emission up to of 0.020%-m of antioxidant mixture after that it increases. Further it is also seen that NO_x emission of 0.020%-m of antioxidant mixture is decreased by 40.16% when compared to Neat diesel fuel, respectively. Thisis due to the reduction in the formation of free radicals by antioxidants.

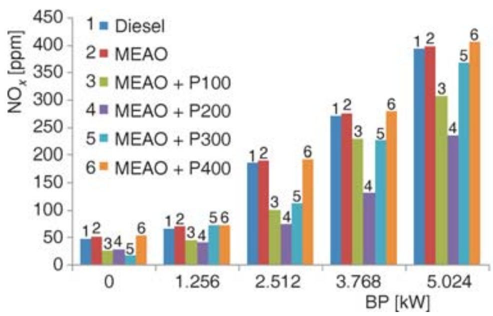

Figure 3. Brake power *vs.* NO$_x$

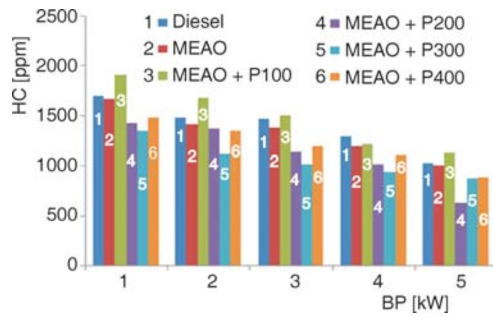

Figure 4. Brake power *vs.* unburned HC

Hydrocarbon emission (HC)

Figure 4 shows that variation of HC emission with BP for different antioxidant concentrations. It can be seenthat HC emissions decrease with increase of engine load. The HC emission decreases with the percentage of antioxidant additives along with the methyl ester of annona oil, up to of 0.020%-m of antioxidant mixture after that it increases. Further itis also seen that HC emission of 0.020%-m of antioxidant mixture is decreased by 37.97% when compared to that Neat diesel fuel at full load condition. This is due to fact that antioxidant p-phenylenedamine is a reducing agent and reduce functional groups present in the methyl ester of annona oil. The oxygen content of biodiesel may have provided some better conditions particularly in the fuel rich region, which enhanced the oxidation of HC emissions. This leads to reduction in HC emission.

Carbon monoxide emission

Figure 5 shows that variation of CO emission with BP for different antioxidant concentrations. The CO emission of 0.020%-m of antioxidant mixture is increased by 6.67% when compared to that of Neat diesel fuel at full load condition. This is due to incomplete combustion from the addition of antioxidant additives. The oxidation of CO is directly related to the OH radicals present in the reaction.

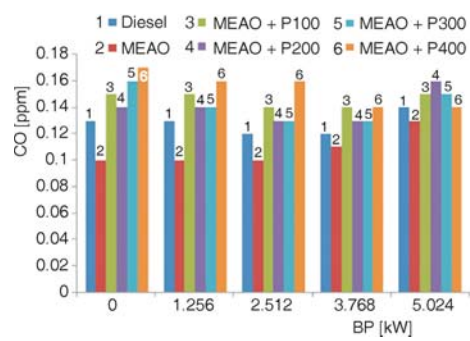

Figure 5. Brake power *vs.* CO

Brake thermal efficiency

Figure 6 shows that variation of BTE with BP for different antioxidant concentrations. It is seen that BTE is lower for methyl ester of annona oil at all loads when compared to that of diesel fuel due to its poor mixture formation and high viscosity. The BTE decreases with the percentage of antioxidant additives along with the methyl ester of annona oil at all loads due to incomplete combustion from the addition of antioxidant additives.

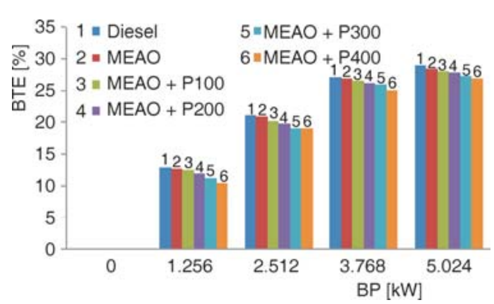

Figure 6. Brake power *vs.* BTE

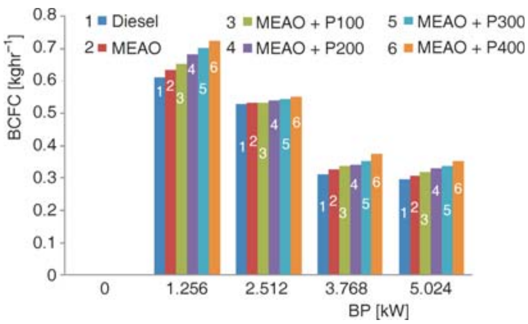

Figure 7. Brake power *vs.* BSFC

Brake specific fuel consumption

Figure 7 shows that variation of brake specific fuel consumption (BSFC) with BP for different antioxidant concentrations. It is observed that BSFC increases with diesel at full conditions. The addition of antioxidant mixture slightly increases the BSFC at all loads. This is due to incomplete combustion from the addition of antioxidant additives. Further it is also due to the little more fuel supplied to the engine to compensate the power loss due to incomplete combustion.

Conclusions

The effects of antioxidant addition on NO_x, HC, and CO emission and performance parameters such as BTE and BSFC with methyl ester of annona oil have been studied at different concentration of p-phenylenediamine. The following conclusion are drawn from the present investigation.

- The oxidation stability increases with the addition of antioxidant.
- It is observed that p-phenylenediamine is an effective antioxidant for controlling NO_x emissions.
- The NO_x emission is reduced by 40.16% and HC emission is reduced by 37.97% at full load for MEO + P200 when compared to that Neat diesel fuel.
- CO emission for all concentrations increases when compared to that of neat diesel fuel.
- The BTE and BSFC is almost same which is not affected by the addition of antioxidant concentration because the addition of antioxidant is very small.
- It is concluded that NO_x emission and HC emission can be reduced considerably by using antioxidant p-phenylenediamine along with the methyl ester of annona oil. It is simple and cost effective method without change in any engine modification.

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