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Mahua (*Madhuca indica*) seed oil: A source of renewable energy in India

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Mahua oil methyl, ethyl and butyl esters were prepared and studied in a four stroke, direct injection diesel engine for their performance and emissions. The engine test results showed high thermal efficiency in case of methyl ester compared to all other esters and diesel fuel. Different emissions such as carbon monoxide (CO), oxides of nitrogen (NO_x), hydrocarbons (HC) is low for alkyl esters compared to diesel. Among alkyl esters except NO_x all tail pipe emissions are lower in case of methyl ester compared to other esters. The ethyl ester shows lower NO_x emission compared to other esters. Based on this study, mahua oil methyl ester performs well compared to other esters on the basis of performance and emissions.

Keywords: Biodiesel, Diesel engine, Emissions, Mahua oil, Renewable energy

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Introduction

Worldwide energy consumption has increased 17 fold in the last century and, as a consequence, the carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NOx) emissions from the combustion of fossil fuels have damaged the atmosphere to a significant extent. CO_2 emissions have risen over the last two decades, reaching an atmospheric content of 360 ppm, estimating the world CO_2 emissions at about 26 billion metric ton per year, 80 percent of which comes from the combustion of fossil combustibles such as coal, petroleum and natural gas[1,2]. The vegetable oils are experimented in automobiles as a substitute to diesel either as raw oil or in the form of methyl or ethyl esters. The unrefined oils have rarely been used as combustible in the generation of thermal energy[3]. Biomass already provides the global energy demand (13%), largely used as domestic firewood for cooking and heating in developing countries. In developed countries there is a growing trend towards employing modern technologies and efficient bioenergy conversion using a range of biofuels, which are becoming cost-wise competitive with fossil fuels. This enables the developed countries to contribute towards meeting global reduction in carbon emission obligations[4].

Production of Non-edible Vegetable Oil in India

Depending on climate and soil conditions, different nations are looking into different vegetable oils for diesel fuels substitute; soybean oil in the USA, rapeseed and sunflower oils in Europe, palm oil in south East Asia and coconut oil in Philippines are being considered as substitutes for diesel fuels. Since edible oil demand is higher than its domestic production (Table 1), there is no possibility of diverting this oil for production of biodiesel in India. Being a tropical country, India is rich in forest resources having a wide range of trees, which yield a significant quantity of oilseeds. The production of non-edible oils in India is as follows: Mahua (*Madhuca indica*), 180000; Sal (*Shorea robusta*), 180000; Neem (*Azadirachta indica*), 100000; Karanja (*Pongamia pinnata*), 55000; Kusum (*Schleichera oleosa*), 25000; and Ratanjyot (*Jatropha curcus*), 15000 tons.

Mahua Oil

A large deciduous tree, found in Maharastra, West Bengal, Orissa, in South Indian forests and Sri Lanka. The orange brown pipe flesh berry (2.5-5.0 cm long) contains 1-4 shining seeds. Drying and decortification yield kernels (70% by wt). The yield of mahua seeds varies (5-200 kg/tree) depending upon size and age of

Table 1—Production and import of vegetable oil In India

Year	Production million ton	Import million ton	Total	Value Rs crore
1971	6.8	11.7	18.5	107
1981	10.5	16.2	26.7	3349
1991	33.0	20.7	53.7	6118
2001	32.0	57.9	89.9	30695
2002	32.0	73.5	105.0	96000

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the tree. The average yield of sun-dried mahua seeds is about 1.6 kg/tree. Mahua tree starts giving seeds after 10 years and it goes up to 60 years, when yield is 10 times more than the yield at the age of 10. Recovery of kernel is a village level activity and lack of proper facilities for drying and preservation affects quality. Kernel contains 20-50 percent oil depending on expelled by *ghani* or expeller. The expelled cake is solvent extracted to recover residual oil. The quality of expelled oils depends largely on storage conditions of the kernels, which are susceptible to fungus and insect attack. Fresh oil from properly stored seeds is yellow, while commercial oils are generally greenish yellow with disagreeable odor and taste. Free fatty acids of oil from fresh kernels are very less (1-2 %) compared to that from poorly stored kernels (30%). Mahua is perhaps the second most widely known tree in India after mango. Besides oil, flower and fruit give good economic returns. Almost all parts of Mahua tree are saleable. The cake after oil extraction is used as fertilizer and some times as cattle feed.

Transesterification

Transesterification is a process of producing a reaction in a triglyceride and alcohol in presence of a catalyst to produce glycerol and ester. Molecular weight of a typical ester molecule is roughly one third that of typical oil molecule and therefore has a lower viscosity. Alkalis (NaOH, KOH), acids (H_2SO_4, HCl) or enzymes (lipase) catalyze reaction. Alkali-catalyzed transesterification is faster than acid catalyzed transesterification and is most often used commercially[5].

Because the reaction is reversible, excess alcohol is used to shift the equilibrium to the product side. Alcohols are primary and secondary monohydric aliphatic alcohols (1-8 C atoms). In the transesterification process, methanol and ethanol are more common. Methanol is extensively used because of its low cost and its physiochemical advantages with triglycerides and alkalies are easily dissolved in it[6]. To complete transesterification, stoichiometrically 3:1 molar ratio of alcohol to triglycerides is needed. Studies have been carried out in different oils such as soybean, sunflower, rape, coconut, palm, used frying oil, Jatropha, rubber seed and cotton seed[7-16]. Mahua oil methyl and ethyl esters have been investigated as diesel substitutes[17,18]. This investigation aims to prepare methyl ester (MOME), ethyl ester (MOEE) and butyl ester (MOBE) of mahua oil, and study their performance and emissions in a direct injection diesel engine to determine exhaust emissions and engine performance in comparison with standard diesel fuel.

Experimental Details

Engine Test

The performance and emissions of MOME, MOEE and MOBE were studied in single cylinder, four stroke, constant speed, vertical, water cooled, direct injection (D.I), 5hp (3.68kw) Kirloskar diesel engine. The engine was coupled to a swinging field separating exciting type DC Generator and loaded by electrical resistance. Exhaust gas temperature was measured by an iron-constantan thermocouple. Carbon monoxide (CO), nitrous oxide (NOx) and hydrocarbon (HC) were measured by MRU Air fair emission monitoring systems "DELTA 1600-L and MRU OPTRANS 1600". Fuel consumption was measured by U-tube manometer.

The engine was started in neat diesel fuel and warmed up till cooling water temperature was stabilized. Then, fuel consumption, exhaust gas temperature and different exhaust emissions (CO, CO_2, HC, and NO_x) were measured. Similar procedure was repeated for MOME, MOEE and MOBE.

Results and Discussion

Total Fuel Consumption (TFC)

The total fuel consumption for MOME, MOEE, MOBE were comparatively higher than that of diesel fuel due to high specific gravity (Fig. 1). As the specific gravity of MOME is less compared to MOEE and MOBE, the total fuel consumption is also less.

Brake Thermal Efficiency (BTE)

Thermal efficiency purely depends on engine design, type of fuel used and area of application. Vegetable oil based fuel contains oxygen (10-12 %), which causes better combustion in case of esters compared to diesel. However, heat release does not only depend upon oxygen content but also heating value of the fuel. Here, vegetable oil based fuel have less heating value (10-12%) compared to diesel fuel. So the oxygen content and heating value of the fuel is purely responsible for thermal efficiency, which (Fig. 2) for methyl ester is high (28.31) than for diesel (26.36).

Exhaust Gas Temperature (EGT)

EGT indicates the burning efficiency (Fig. 3). In diesel engine, there are four stages in combustion process. If the afterburning stage is more or engine misfires or injection time is not proper then there is every possibility that EGT may be high. On the other hand, if the combustion process is perfect, then also

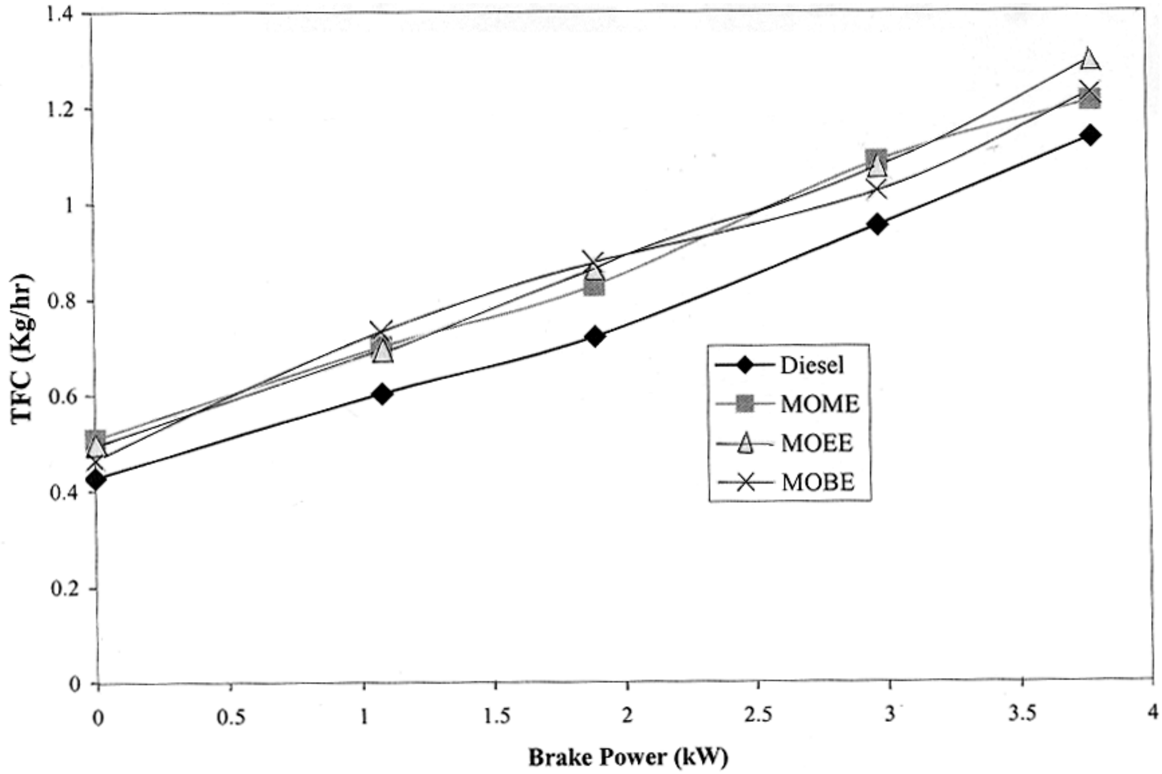

Fig. 1—Total fuel consumption of mahua oil alkyl esters and diesel with respect to brake power

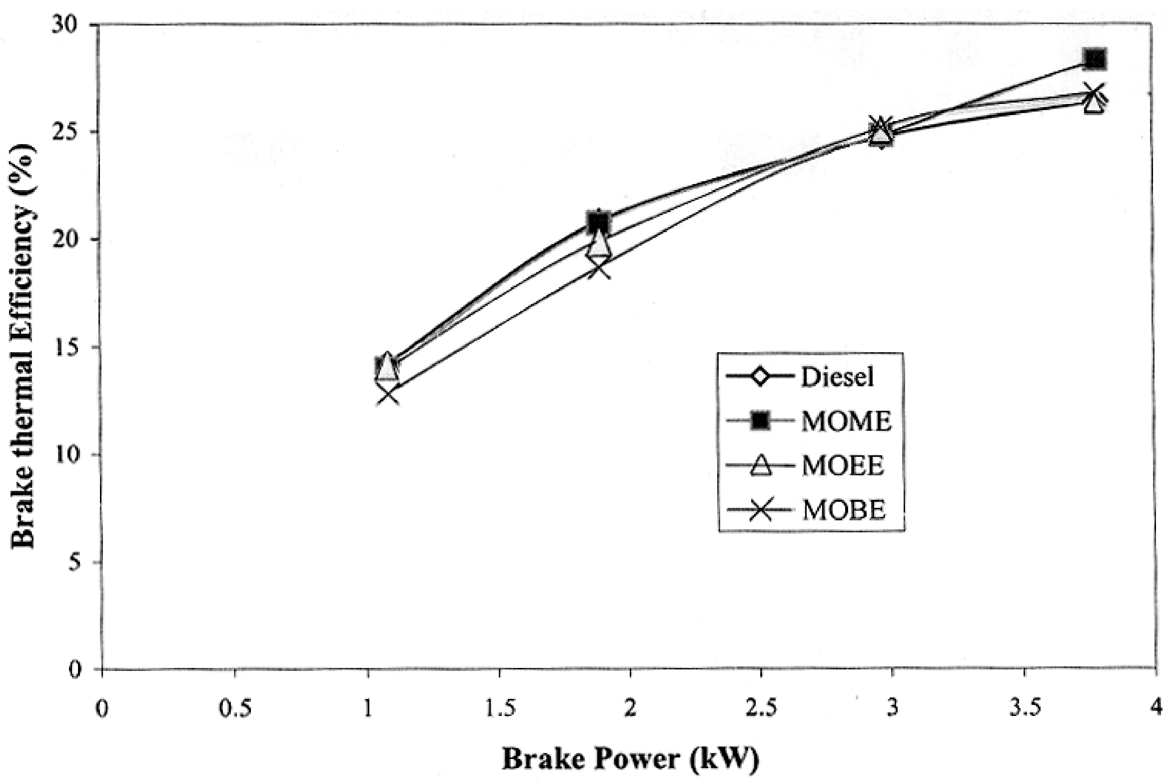

Fig. 2—Brake thermal efficiency of mahua oil alkyl esters and diesel with respect to brake power

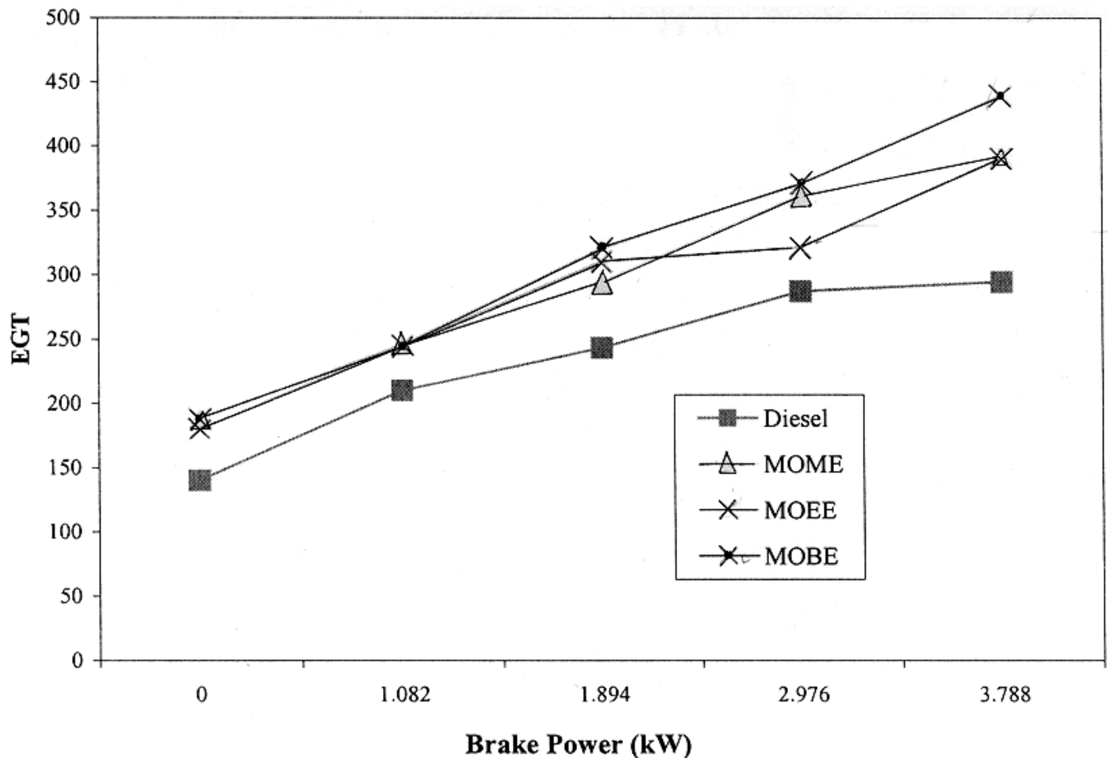

Fig. 3—Exhaust gas temperature of mahua oil alkyl esters and diesel with respect to brake power

EGT is likely to be high. It may be observed that thermal efficiency is more in case of methyl ester and this leads to a probable conclusion that the combustion process is better.

Carbon Monoxide Emission (CO)

Carbon emission depends upon combustion efficiency and carbon content of the fuel (Fig. 4), which during combustion undergoes a series of oxidation and reduction reactions. Carbon content of fuel is oxidized with O_2 available in the air to CO and then to CO_2. Carbon, which is not converted to CO_2, will come back as CO in the exhaust. For all esters, CO emission is lower than that of diesel (0.34 % v/v); methyl ester (0.07% v/v) gives better CO emission compared to other two esters.

Carbon Dioxide Emission (CO_2)

The CO_2 emission is more in case of ester based fuel due to the presence of oxygen (Fig. 5). For good combustion, all carbon must come as CO_2 in the exhaust but the situation is different. All carbon in the fuel cannot be converted to CO_2. But in case of biodiesel, additional O_2 present helps combustion compared to diesel. Hence, CO_2 emission in the exhaust is also more than that of diesel.

Hydrocarbon Emission (HC)

In conventional hydrocarbon fuels, HC burns inside the engine cylinder in presence of air. The amount of HC, which is not taking part in the combustion reaction, is likely to come out as unburned HC. But still for ester-based fuel, HC emission is less than diesel as follows: diesel, 89; MOME, 35; MOEE, 45; and MOBE, 50 ppm (Fig. 6).

Oxides of Nitrogen (NO_X)

NO_x are formed inside a diesel engine due to high flame temperature, peak pressure inside the cylinder, nitrogen content of the parent fuel and the residence time of the fuel inside the cylinder. In present test, none of the above parameter is known. As the cetane number of the ester-based fuel is high compared to diesel, the residence time or ignition delay may be less in case of ester-based fuel. Once again the oxygen content of the fuel enhances the ignition quality, thereby reduced delay period for esters. This may be the probable reason for low NO_X in case of esters (Fig. 7). On other hand, if the burning is efficient due to oxygen content and high cetane number than the flame temperature and peak pressure likely to be high. But none of this is clearly known. Hence it is very difficult to justify the reason for low NO_X in case of esters.

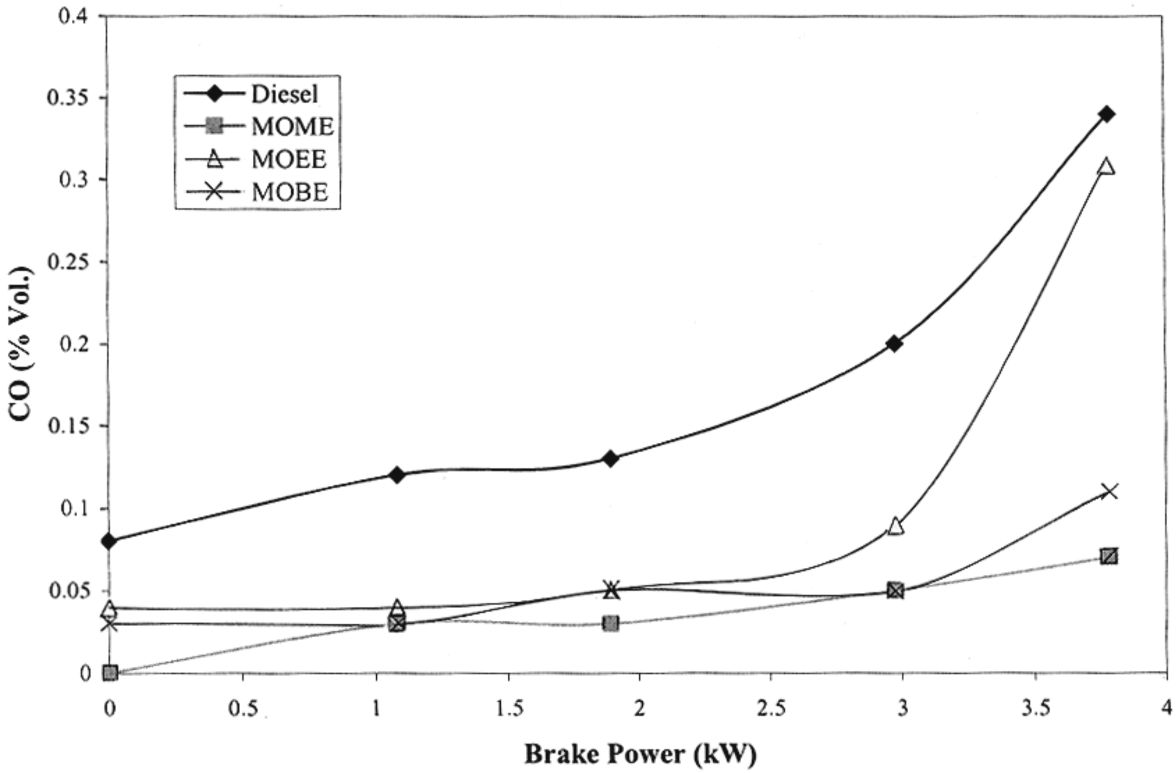

Fig. 4—Carbon monoxide emission of mahua oil alkyl esters and diesel with respect to brake power

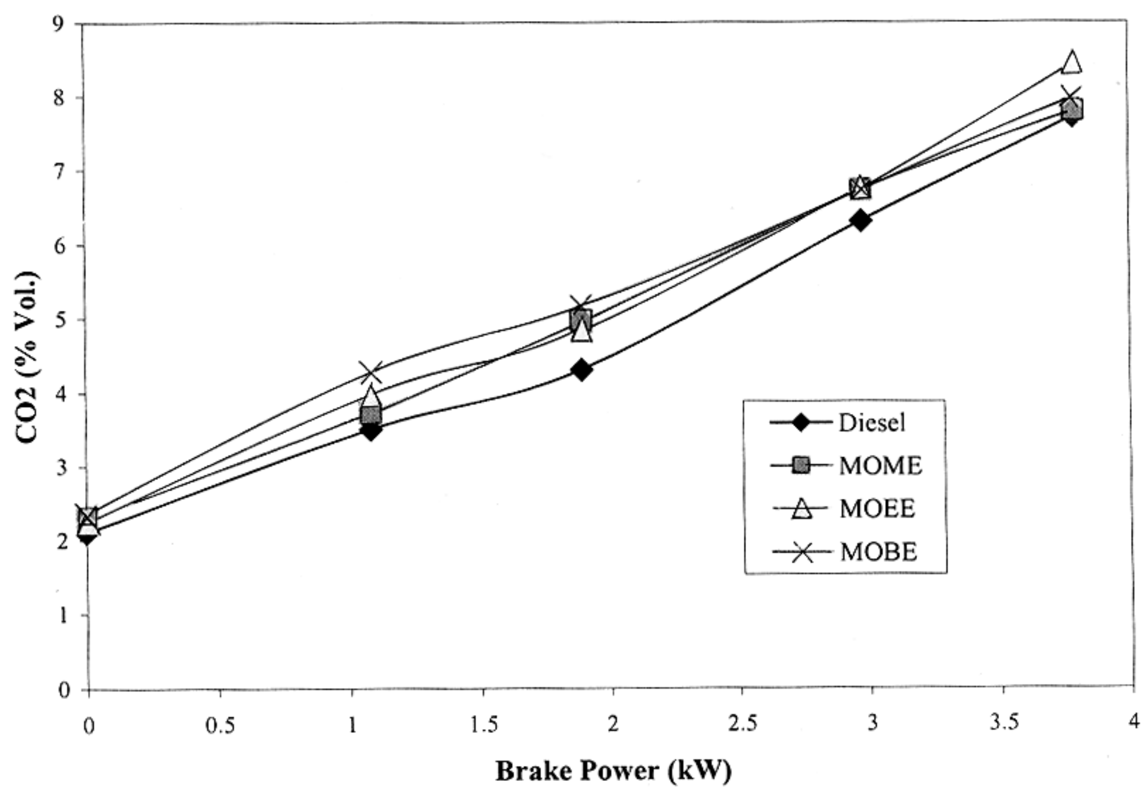

Fig. 5—Carbon dioxide emission of mahua oil alkyl esters and diesel with respect to brake power

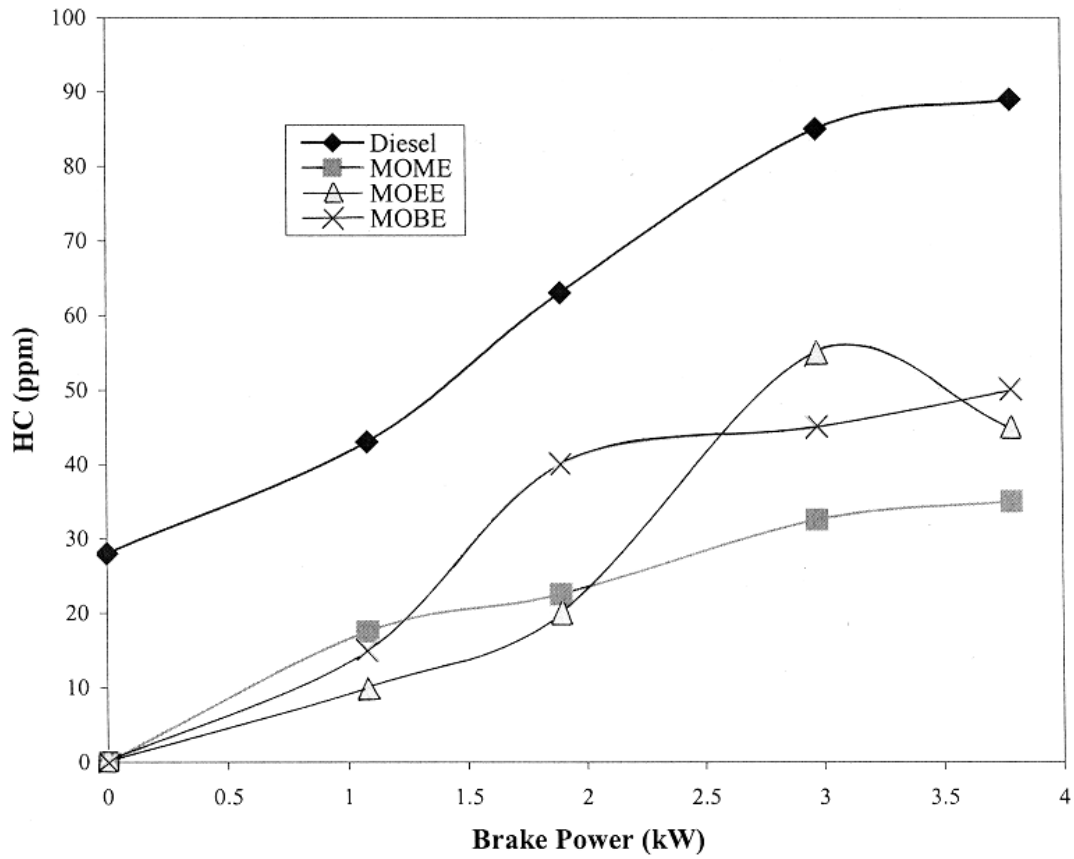

Fig. 6—Hydrocarbon emission of mahua oil alkyl esters and diesel with respect to brake power

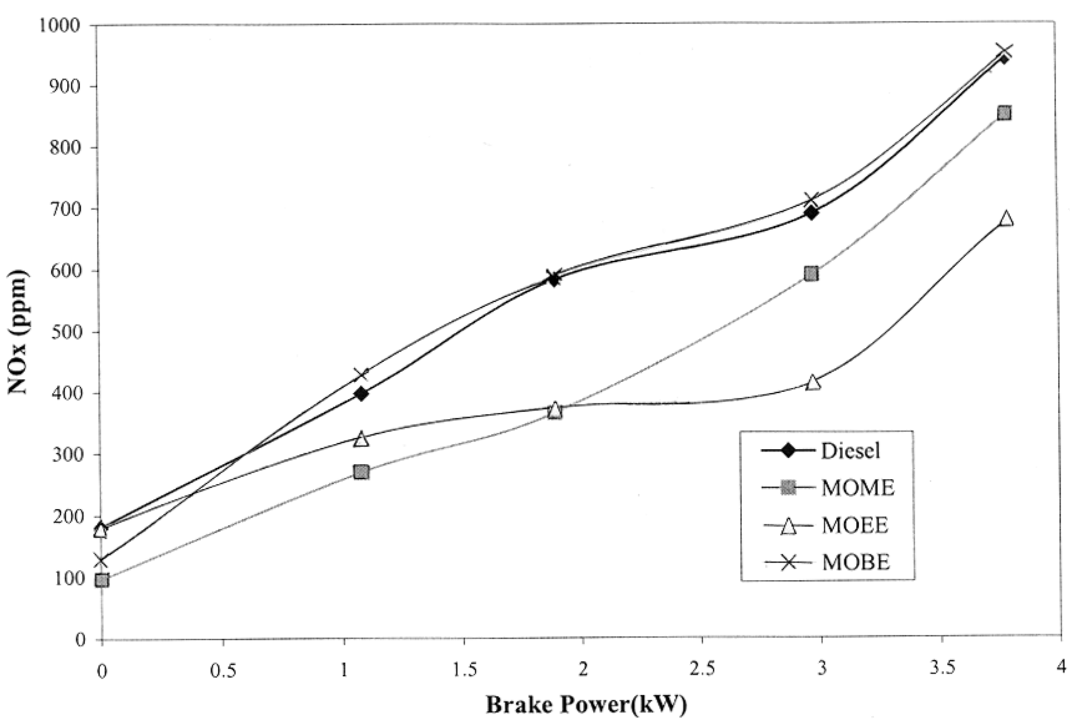

Fig. 7—Oxides of nitrogen emission of mahua oil alkyl esters and diesel with respect to brake power

Conclusions

A biomass–based renewable fuel was prepared by transesterification of mahua oil with methanol, ethanol and butanol and tested in a single-cylinder DI Diesel engine. CO and NO_x emissions from MOME, MOEE and MOBE were lower and CO_2 emission was slightly higher than those from the diesel fuel. Based on this study, even though, mahua oil esters can be regarded as a potential substitute for diesel fuel; MOME is the choice because of its low emissions compared to other two esters.

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