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Performance Evaluation of Compression Ignition Direct Injection Diesel Engine on Dual Fuel Mode with Mango Oil Methyl Ester Biofuel

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ABSTRACT:

In this study, Mango seed Oil Methyl Esters (MOME) that is produced by base catalyzed transesterification method has been chosen as a bio-fuel. Experiments were conducted with fuels of known cetane number at various loads on a single cylinder, constant speed, air-cooled, four stroke, and direct injection vertical diesel engine with rated power of 4.4 kW. All experiments were conducted at injection pressures 200 bar. For the same engine, the performance, combustion and emission analysis was carried out for various blends(20% and 100%) of MOME, diesel with grain alcohol(ethanol 0.1pre-mixed ratio) on dual fuel mode. When the engine was operated with 20% of MOME and 0.1 pre-mixed ratio, the brake thermal efficiency was found to be very much closer to the BTE obtained with neat diesel due to more calorific value and more heat release rate during combustion. It is also observed that at this blend, Hydrocarbons (HC), Carbon monoxide (CO) and smoke density emissions were found to be less than that of diesel whereas NOx emissions were slightly more than that of diesel.

KEYWORDS:

Dual fuel engine; Grain alcohol; Mango seed Oil Methyl Esters; Compression Ignition Direct Injection engine

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1. Introduction

India is one of the major countries in the world which is importing petroleum products to meet its fuel requirements. Commercial fuel imports are mainly in the form of crude oil and natural gas. With improved awareness of environmental concerns caused by air pollution, it is important that fuel generation and usage is environmental friendly too. A number of researchers have used biodiesel derived from edible oils, non-edible oils, used cooking oils and animal fats as alternative fuels for diesel engines. Rao et al [1] have carried out transesterification process of used cooking oil using an alkaline catalyst. The combustion, performance and emission characteristics of used cooking oil methyl and its blends with diesel oil are analyzed in a Direct Injection (DI) Compression Ignition (CI) engine and compared with the baseline diesel fuel.

Balusamy et al [2] have investigated methyl ester of Thevetia Peruviana seed oil and blended with diesel fuel and tested in naturally aspirated single cylinder diesel engine at 1500 rpm. Brake thermal efficiency increases with increasing brake power (BP) for all fuels. At maximum load, BSFC of B20 (3.4%) and B100 (10.3%) are higher than that of diesel fuel due to higher density and viscosity of the fuel blends. Keskin et al [3] have showed that the cotton oil biodiesel fuel blends in a single cylinder DI diesel engine. Power output and toque of engine with blends of cotton soap stock biodiesel and diesel fuel decreased by 6.2% and 5.8% respectively. Lin et al [4] studied the effects of 8 kinds of Vegetable Oil Methyl Ester (VOME) in an unmodified DI diesel engine to investigate the effects of VOME on the DI diesel engine performance, exhaust emissions, and combustion characteristics. The use of VOME fuels in a diesel engine achieved the same engine power output as an engine run on diesel. Increase in BSFC relative to diesel was reported due to the lower calorific value of VOME fuels. The VOME fuels have higher cetane number and thus can provide better ignition quality. Higher viscosity and higher oxygen content of VOME fuels also yield better air-fuel mixing. Increased oxygen availability of VOME during combustion process improves the combustion. It was reported that the use of VOME fuels in a diesel engine reduced exhaust gas temperature, smoke and total hydrocarbon (HC) emissions with a marginal increase in nitrogen oxides (NOx) emissions.

Pandey et al. [8] investigated on biodiesel as an oxygenated fuel containing 10% to 15% oxygen by weight. Using biodiesel can help to reduce the world's dependence on fossil fuels and has significant environmental benefits. The reasons for these environmental benefits using biodiesel instead of the conventional diesel fuel reduces exhaust emissions such as the overall life circle of carbon dioxide (CO_2), particulate matter (PM), carbon monoxide (CO), sulfur oxides (SOx), volatile organic compounds (VOCs), and unburned HC significantly.

Conventional technologies for reciprocating IC engines are broadly divided into CI and spark-ignition (SI) engines. In CI engines, air is compressed at pressures and temperatures at which the injected liquid fuel fires easily and burns progressively after ignition. Whereas, SI engines (Otto engines) that runs according to the Beau de Rochas cycle, the carburetted mixture of air and vaporised fuel (high octane index) is compressed under its ignition point and then fired at a chosen instant by an independent means. In a dual-fuel engine, both types of above combustion coexist together, i.e. a carburetted mixture of air and gaseous fuel or any other secondary fuel is compressed like in a conventional diesel engine. The compressed mixture of air and secondary fuel does not auto-ignite due to its high auto-ignition temperature. Hence, it is fired by a small liquid fuel injection which ignites spontaneously at the end of compression phase. The advantage of this type of engine is that, it uses the difference in flammability of the two fuels used. Again, in case of lack of secondary fuel, this engine runs according to the diesel cycle by switching from dual-fuel mode. The disadvantage is the necessity to have liquid diesel fuel being available for the dual-fuel engine operation [5].

Banapurmath et al [6] conducted an experiment on a single cylinder, four-stroke, DI, water-cooled CI engine operated in single fuel mode using Honge, Neem and Rice Bran oils. In dual fuel mode combinations of producer gas and three oils were used at different injection timings and injection pressures. Dual fuel mode of operation resulted in poor performance at all the loads when compared with single fuel mode at all the injection timings tested. The brake thermal efficiency improved marginally when the injection timing was advanced. Decreased smoke, NOx emissions and increased CO emissions were observed in dual fuel mode for all the fuel combinations compared to single fuel operation.

Mango is a non-edible oil available in huge surplus quantities in India. Annual production of mango oil in India is estimated to be around 5,00,000 tons. Generally as a non-edible oil, it has been used in lamps for lighting purpose in rural areas. 80% yester yield is possible in transesterification of mango oil with alcohol. India has a shortage of edible oil, so bio diesel programmer is centered around non edible vegetable oils for feed stock diversification and utilization of currently available local resources, non-edible sources like neem, karanja, mahua, sal etc. should be scientifically investigated for efficient biodiesel production and engine utilization[7]. Henceforth, Mango Seed Oil Methyl Ester (MOME) has been chosen as a viable alternate fuel for diesel engine. The properties of fuels used are listed in Table 1.

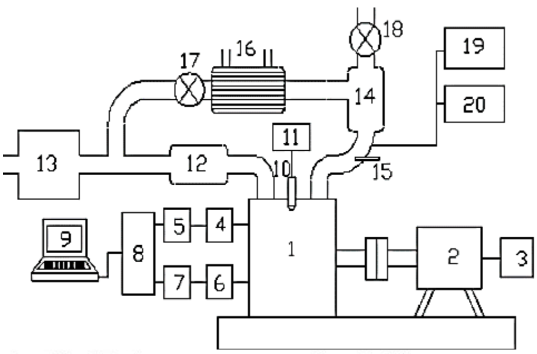
Table 1: Fuel properties

Fuel	Diesel	MOME	Ethanol
Specific gravity	0.8296	0.8951	0.789
Kinematic viscosity (cSt)	2.57	5.6	1.09
Flash point (deg C)	53	168	12.77
Fire point (deg C)	59	174	13.5
Pour point (deg C)	-8	0	-
Net Calorific value (MJ/kg)	44.68	40.874	26.95
Cetane number	51	52	7
Density(kg/m^3)	830	883	789

This paper presents an in-depth study of performance analysis and their impact on engine emissions and their characteristics, when using MOME and its blends. The use of MOME results in a decrease in UBHC (unburned HC), CO and particulate emissions and gives brake thermal efficiency comparable to diesel. But using MOME leads to increased NOx emissions when compared to diesel.

2. Experimental setup and procedure

The tests are conducted in a single cylinder, 4.4 kW, constant speed (1500 rpm), four-stroke, naturally aspirated, air-cooled diesel engine loaded with an electrical swinging field dynamometer. Fig. 1 shows the schematic diagram of the experimental set-up. AVL 615 Indimeter system is used to get the cylinder pressure vs. crank angle data using piezoelectric pressure transducer (AVL GH12D) and angle encoder (AVL 364). The pressure transducer works on piezoelectric principle for measurement of in-cylinder pressure. The AVL angle encoder set is suitable for both test bed and in vehicle operation and uses a sensor for measurements of angle within a resolution of 0.1°-1° crank angle. This angle encoder works on the optical function based on a slot marked optical disk and utilizes the reflection light principle. The master disc has one track with 720 pulses for the angle information which has trigger pulse information per revolution for synchronization purposes. The angle information is transmitted by light pulses from the encoder through an optical cable to an emitter-receiver-electronic. The ignition delay period, cylinder peak pressure, angle of occurrence of cylinder peak pressure and heat release rate can be obtained from pressure vs crank angle diagram.



1	Diesel Engine	11	Fuel flow measurement
2	Electrical Dynamometer	12	Mixing chamber
3	Dynamometer Controls	13	Air flow measurement
4	Pressure pickup	14	Settling chamber
5	Charge amplifier	15	Thermocouple
6	TDC position sensor	16	EGR Cooler
7	TDC amplifier circuit	17	EGR Valve
8	A/D Card	18	Back pressure control valve
9	Personal computer	19	Exhaust gas analyzer
10	Main Injector	20	AVL smoke meter

Fig. 1: Experimental setup

AVL 415 Variable Sampling Smoke meter is used to measure the smoke density in the exhaust. AVL 444 exhaust gas analyzer is used to measure HC, CO and NOx emissions. Exhaust gas temperature is measured using K type thermocouple. The engine is allowed to warm up till steady state conditions are reached. Engine speed, fuel consumption rate, exhaust emissions (HC, CO, and NOx), smoke Intensity, pressure vs crank angle diagram and exhaust gas temperature are measured at various BP outputs. At each BP output, the engine is operated for 15 min to attain steady-state conditions. The experiment is repeated with different blends of MOME. Standard injection timing of 23.4 μs before TDC is used for all tests. Measurement errors and uncertainties in the experiment are important to establish the accuracy of results. The pre-mixed fuel ratio is determined by taking the ratio of pre-mixed energy to total energy supplied to the cylinder. Table 2 gives the test engine specifications.

Table 2: Engine specifications

Parameter	Value
Make	Kirloskar
Model	TAF 1, DI air-cooled
Bore×Stroke (mm)	87.5×110
Compression ratio	17.5:1
Cubic capacity	661 cc
Rated power	4.4 kW
Rated speed	1500 rpm
Start of injection	23.4°bTDC
Connecting rod length	220 mm
Injection Pressure	200 bar

3. Results and discussions

In the current work experiments were conducted on a diesel engine with Ethanol as the inducted fuel and diesel/MOME oil as the injected fuel. All the tests were conducted at a constant rated speed of 1500 rpm in a single cylinder, four stroke, air cooled, DI diesel engine. Diesel flow rate, air flow rate, Ethanol flow rate, exhaust gas temperature, oxides of nitrogen, smoke, HC and CO levels were recorded to study the performance and emissions. Experiments were conducted in the following dual fuel modes to study the performance, combustion and emission characteristics of the engine: (i) Diesel (ii) Diesel and Ethanol. (iii) 20% MOME and Ethanol and (iv) 100% MOME and Ethanol. The variation of brake thermal efficiency against BP for the tested fuels is shown in Fig. 2. 100% MOME and Ethanol blend improves the efficiency marginally at rated power compared to Diesel and Ethanol blend operation but it is lesser than diesel operation.

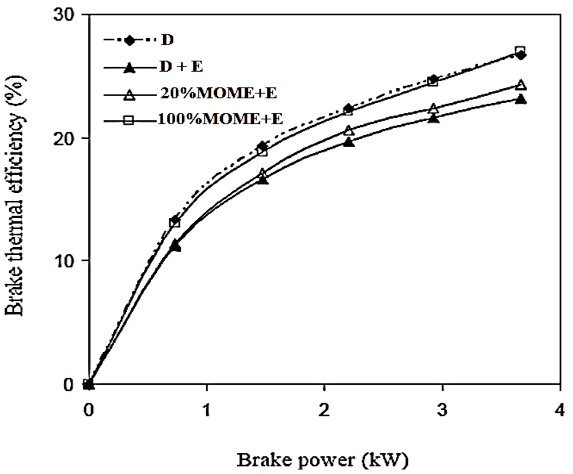


Fig. 2: Variation of brake thermal efficiency with BP

Fig. 3. shows the variation of exhaust gas temperature against BP. A marginal reduction in exhaust gas temperature is noticed throughout the engine operation in the dual fuel mode of operation. The early start of combustion and rapid combustion in pre-mixed combustion phase lower the heat release rate in diffusion combustion phase. Therefore the early finish time of heat release rate during the diffusion combustion phase is the reason for low exhaust gas temperature in dual fuel operation. The variation of NOx emission with BP is shown in Fig. 4. It increases for MOME operation in comparison to diesel operation. The early start of combustion and favorable condition for combustion promote better combustion and rise in the peak pressure during combustion, and it increases the NOx formation in MOME mode of operation.

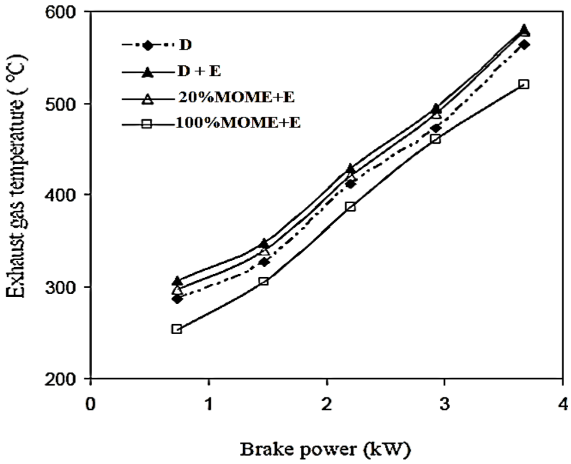


Fig. 3: Variation of exhaust gas temperature with BP

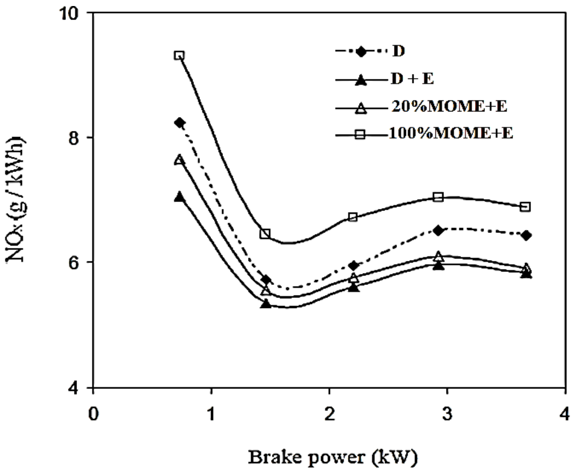


Fig. 4: Variation of NOx with BP

Fig. 5 shows the comparison of smoke emissions with BP. A marginal reduction in smoke emission throughout the engine operation can be noticed. The advancement and higher rate of pre-mixed combustion reduces the smoke emission in dual fuel mode of operation compared to diesel and ethanol blend operation but it is higher than diesel operation. Fig. 6 shows the variation of HC emission against BP. 100% MOME and ethanol shows the better combustion with less HC content with increase in BP. The variation of CO emissions against BP is shown in Fig. 7. The CO emission shows the similar results as HC emission.

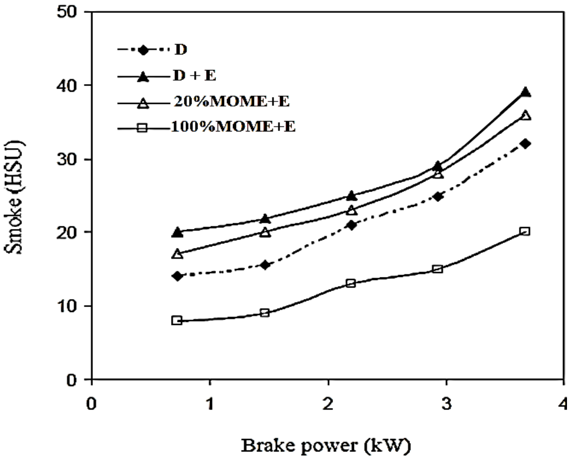


Fig. 5: Variation of smoke with BP

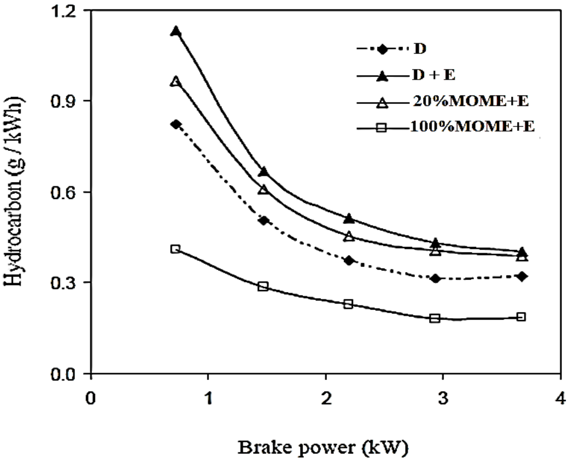


Fig. 6: Variation of HC with BP

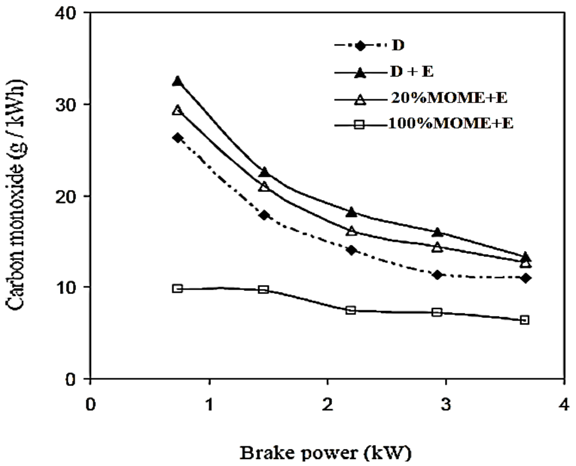


Fig. 7: Variation of CO with BP

4. Conclusions

The present work was performed to determine applicability of Mango Seed Oil Methyl Esters and their blends with ethanol in diesel engine on dual fuel mode. Performance and emission characteristics were displayed with ethanol 10% as pre-mixed fuel. MOME and its blends can be used without any major modification in diesel engines. The brake thermal efficiency of MOME and its blends is found to be lower at all BP outputs compared to diesel fuel.

As the percentage of MOME in the blend increases there is a decrease in brake thermal efficiency. CO, HC and particulate emissions for MOME and its blends are found to be lower at all BP outputs compared to diesel. As percentage of MOME in the blend increases there is a corresponding decrease in emissions. Considering the tradeoff between particulate and NOx emissions, 20% MOME blend provides an optimum solution with brake thermal efficiency comparable to diesel.

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