COMPARISON OF PERFORMANCE OF BIODIESELS OF MAHUA OIL AND GINGILI OIL IN DUAL FUEL ENGINE

by

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In this work, an experimental work was carried out to compare the performance of biodiesels made from non edible mahua oil and edible gingili oil in dual fuel engine. A single cylinder diesel engine was modified to work in dual fuel mode and liquefied petroleum gas was used as primary fuel. Biodiesel was prepared by transesterification process and mahua oil methyl ester (MOME) and gingili oil methyl ester (GOME) were used as pilot fuels. The viscosity of MOME is slightly higher than GOME. The dual fuel engine runs smoothly with MOME and GOME. The test results show that the performance of the MOME is close to GOME, at the pilot fuel quantity of 0.45 kg/h and at the advanced injection timing of 30 deg bTDC. Also it is observed that the smoke, carbon monoxide and unburnt hydro carbon emissions of GOME lower than the MOME. But the GOME results in slightly higher NO_x *emissions. From the experimental results it is concluded that the biodiesel made from mahua oil can be used as a substitute for diesel in dual fuel engine.*

Key words: *alternative fuels, mahua oil methyl ester, gingili oil methyl ester, liquefied petroleum gas, dual fuel engine, performance*

Introduction

During recent years high activities can be observed in the field of alternative fuels, due to supply of petroleum fuels strongly depends on a small number of oil exporting countries. The demand for diesel and gasoline is increased drastically. It has been estimated that the demand for diesel will be 66.90 Mt for the year 2011-2012. In the year 2004-2005, India imported 75% of crude-oil from other countries to meet the energy requirements [1]. Hence, government of India has taken necessary steps to fulfill future diesel and gasoline demand and to meet the stringent emission norms. Biodiesel and alcohol are being considered to be supplementary fuels to the petroleum fuels in India. These biofuels are being looked to provide employment generation to rural people through plantation of vegetable oils and can be beneficial to sugarcane farmers through the ethanol program.

Mahua is the name for a medium to larger tree *Madhuca longifolia* of family *Sapotaceae* with wider and round canopy. The tree may attain a height of up to 20 meters. Mahua is a slow growing species, attains a mean height of 0.9-1.2 m at the end of the fourth year. The variety *Latifolia* is common throughout the Indian sub-continent. The drying and decertification yield 70% kernel on the weight of seed. The kernel of seed contains about 50% oil. The oil extracted from the seeds using screw expelled is nearly 34-37% of the total weight of the seeds [2]. Gingili oil is derived from a plant species called *Sesamum indicum*, which is an herbaceous annual belonging to the *Pedaliaceae* family that reaches about 1.8 m in height. It is also referred as benne, sesame, or teel oil. The large round seeds are extracted by shaking the dried plant upside down after making an incision in the seed pods. The seeds contain 60% oil, of which 15% is saturated and 45% polyunsaturated. It is used as a cooking oil, to manufacture of soaps, pharmaceuticals, and lubricants.

Shashikant *et al*. [3] developed a technique to produce biodiesel from mahua oil having high free fatty acids (19% FFA). The high FFA level of crude mahua oil has reduced to less than 1% in a 2-step pretreatment process of esterification using acid catalyzed (1% v/v H_2SO_4) reaction with methanol (0.30-0.35 v/v) at 60 °C temperature and one hour reaction time. This process gave an yield of 98% mahua biodiesel, which has comparable fuel properties with that of diesel and are within the limits prescribed by the American and European standards for biodiesel. Bhatt *et al*. [4] studied the suitability of mahua oil as alternative fuel for diesel engine. They mentioned that mahua could be easily substituted up to 20% in diesel without any significant difference in power output, brake specific fuel consumption, and brake thermal efficiency. The performance of engine with mahua oil blends improved with the increase in compression ratio from 16:1 to 20:1.

As far as low emission fuels are concerned, "gaseous fuels" appear to be capable of performing a prominent role. Various gaseous fuels such as biogas, producer gas, hydrogen, liquefied petroleum gas (LPG) and compressed natural gas (CNG) are suitable for internal combustion (IC) engines. But LPG and CNG are considered better alternatives because of their simpler structure with low carbon content, resulting in reduction of exhaust emissions drastically.

Sukumar *et al*. [5] investigated methyl and ethyl ester of mahua oil as fuel for a four--stroke direct injection naturally-aspirated diesel engine. Tests were conducted at a constant speed of 1500 rpm at varying brake mean effective pressures. Results showed that brake thermal efficiency of mahua oil methyl and ethyl ester were comparable to diesel. It was observed that the thermal efficiency at full load for diesel was 26.36%, whereas it was 28.3% for mahua oil methyl ester and 26.42% for mahua oil ethyl ester (MOEE). Papagiannakis *et al*. [6] modified a diesel engine to work in dual fuel mode and used diesel as pilot fuel and natural gas as primary fuel. From the experimental analysis, they reported that the dual fuel operation results in performance comparable with diesel operation at full load. They also observed that the soot emission and NO concentration lower than neat diesel operation. Under dual fuel operation, CO and HC emissions are generally higher compared to normal diesel operation. In dual fuel engine, the primary fuel (gaseous fuel) releases large amount of energy and secondary fuel or pilot fuel is required to start the combustion of the primary fuel.

Materials and methods

In India, LPG is easily available compared to other gaseous fuels. Hence, for the present work LPG was taken as gaseous fuel / primary fuel. Tab. 1 shows the composition and properties of LPG.

For the present work, mahua oil and gingili oil were selected as non-edible and edible oils, respectively, and their methyl esters were used as pilot fuel. Biodiesel *i.e.* methyl esters of oil was prepared by transesterification. Transesterification reaction was performed in a round bottom vessel of 1000 ml in volume. First, the vessel reactor was filled with 420 ml of oil (mahua oil / gingili oil). Then, measured amount of the methanolic potassium hydroxide, which was prepared by dissolving 4 g of potassium hydroxide in 170 ml of methanol, was added to the reactor. For refluxing purpose, a vertical water cooled condenser was placed on the top portion of the vessel and the reactor was immersed in a constant-temperature water bath. The temperature of the water bath was maintained at 70 °C and agitation was provided with a magnetic stirrer during the reaction. This reaction was carried out for two hours. After the transesterification, the condenser was removed and the products were heated, to remove excess methanol. After heating, the products were shifted to 1000 ml separator funnel, for phase separation. The top layer containing esters (biodiesel) were washed with warm water to wash out impurities like soap and other residues. Tab. 2. compares the properties of diesel, mahua oil methyl ester (MOME) and gingili oil methyl ester (GOME). From the comparison it is observed that the properties of biodiesel are close to diesel. But the viscosity of GOME is slightly lower than MOME.

Table 1. Properties of LPG

Property	Value
Composition [vol.%] – N-butane, iso butane, and butylene – Propane and propylene – Ethane and ethylene – Pentane	 70.4 28.6 0.5 0.5
Calorific value [MJ/kg]	47.88
Maximum flame temperature in air [°C]	2000
Self ignition temperature [°C]	525

Table 2. Fuel properties

Property	Diesel	MOME	GOME
Flash point [°C]	56	129	116
Fire point [°C]	63	141	130
Calorific value [MJ/kg]	42.96	36.14	37.84
Kinematic viscosity at 40 °C [Cst]	2.68	5.10	4.64
Density at 40 °C [kg/m^3]	828	863	859

Experimental setup

A single cylinder, four-stroke, water cooled, direct injection, computerized diesel engine test rig was modified to work in dual fuel mode. The schematic of the experimental setup is shown in fig. 1. An eddy current dynamometer was used for loading the engine. The engine speed was sensed and indicated by an inductive pick up sensor in conjunction with a digital rpm indicator, which is a part of eddy current dynamometer. The liquid fuel flow rate was measured on the volumetric basis using a burette and a stopwatch. Chromel alumel thermocouple in conjunction with a digital temperature indicator was used for measuring the exhaust gas temperature. The gas flow rate was measured using a rotameter with duralumin float. An AVL smoke meter

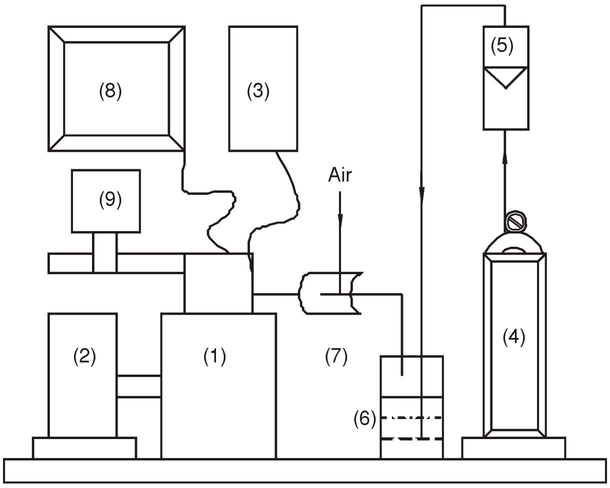

Figure 1. Experimental setup
(1) – Engine, (2) – Dynamometer, *(3) – Fuel tank, (4) – LPG cylinder, (5) – Rotameter, (6) – Flame arrestor, (7) – Fuel and air mixing chamber, (8) – Data acquisition system, (9) – Emission analyser*

was used to measure the smoke emission and DELTA 1600 L of MRU make exhaust gas analyzer was used for the measurement of emissions in exhaust gases. For the measurement of cylinder pressure, a pressure transducer was fitted on the engine cylinder head and a crank angle encoder was used for the measurement of crank angle. The pressure and crank angle signals were fed to a data acquisition card fitted with Pentium 4 personal computer.

The dual fuel engine was started by hand cranking with MOME as fuel and slowly LPG is introduced into the cylinder through the air intake manifold. For the pilot fuel quantity of 0.45 kg/h (25% of fuel consumed at full load), injection time of 30° bTDC and at steady-state condition, important observations such as gas flow rate, air flow rate, exhaust gas temperature, cylinder pressure, and exhaust emissions were recorded. Then the load is gradually increased up to full load. Similar procedure was followed for GOME.

Results and discussion

The dual fuel engine was running smoothly with MOME and GOME as similar to neat diesel operation in sole fuel mode. The performance and emissions of MOME and GOME are given below.

Brake thermal efficiency is defined as the ratio of brake power to the heat supplied. Figure 2. shows the variation of brake thermal efficiency with load. From the figure, it is observed that the thermal efficiency of MOME is lower than GOME at lower loads. This may be due to higher viscosity and lower volatility of the MOME, which results in poor fuel utilization and increased fuel consumption. This leads to poor brake thermal efficiency. But at higher loads, there is a slight variation in thermal efficiency of MOME and GOME. Due to higher load, the temperature of the compressed LPG and air mixture increases. Since there is a slight variation in viscosity of MOME and GOME, the higher temperature might have resulted in better evaporation and spray formation of smaller pilot quantity of viscous MOME. This might have resulted in combustion of MOME comparable to GOME. Hence the performance of MOME and GOME are comparable at higher loads.

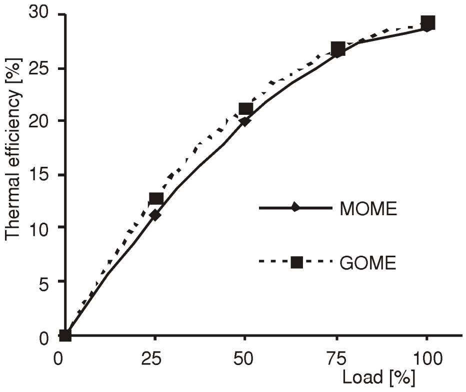

Figure 2. Thermal efficiency *vs.* load

The variation of carbon monoxide (CO) emission with load is shown in fig. 3. At low loads, there is a large variation in CO emission. Since the viscosity of MOME is higher than GOME, it results in larger droplets and poor penetration of pilot fuel. This leads to the poor combustion of pilot fuel and hence incomplete combustion of the primary fuel. But as the load increases, the difference in CO of MOME and GOME decreases due to higher temperature of compressed air/fuel mixture, which results in better combustion of the fuel at higher loads.

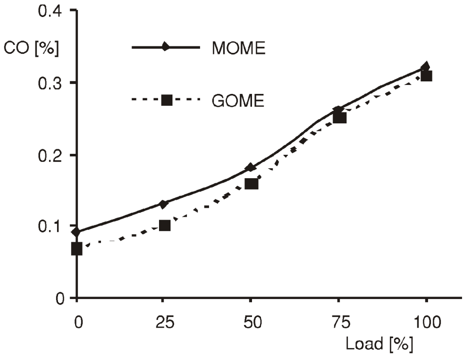

Figure 3. CO *vs.* load

Figure 4. shows the variation of unburned hydro carbon (UBHC) emission with load. At low

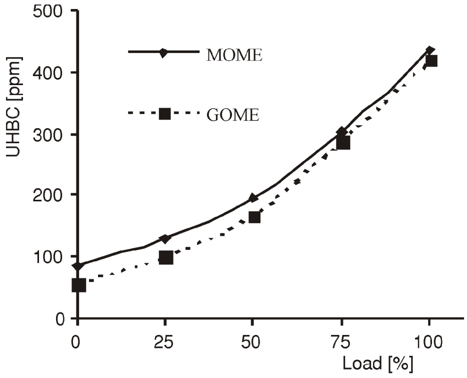

Figure 4. UBHC *vs.* load

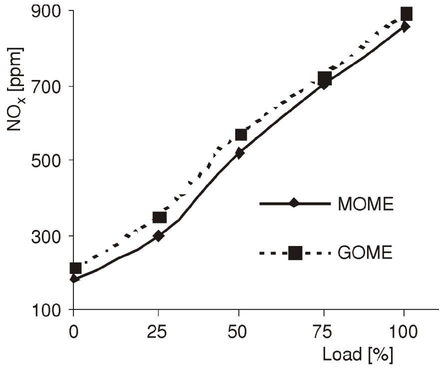

Figure 5. NO_x *vs.* load

loads, the variation in UBHC of MOME and GOME is high. But at higher loads, there is a slight variation in UBHC emission. This may be due to fuel homogeneity and better mixing of fuel and air mixture. The variation of NO_x emission with load is shown in fig. 5. The GOME results in higher NO_x emission. This may be due to the better combustion of GOME pilot fuel, which provides better ignition source for the combustion of LPG. This results in higher combustion temperature and hence higher NO_x emission. But the MOME operation results in lower NO_x emission. This may be due to the incomplete combustion of the fuel, which results in lower combustion temperature.

The variation of smoke emission with load is shown in fig. 6. The GOME results in lower smoke emission. This may be due to fatty acids composition of gingili oil and better combustion of GOME, which results in lower smoke emission. The fatty acids present in gingili oil are palmitic acid (9%), stearic acid (4%), oleic acid (41%) and linoleic acid (46%) and in mahua oil are oleic acid (37%), stearic acid (22.7%), palmitic acid (24.5%), linoleic acid (14.3%), and arachidic (1.5%). But the MOME results in slightly higher smoke emission due to its fatty acids composition and higher viscosity. In dual fuel engine, the first stage of combustion dependent on the ignition source provided by the pilot fuel and the second stage of combustion depends on the characteristics of the primary fuel. Figure 7 is the cylinder pressure *vs.* crank angle at full load. From the figure, it is observed that for MOME, the second stage of combustion becomes sluggish probably because the source of ignition for the LPG becomes weak. This might have resulted in lower pressure rise for the MOME as compared to GOME.

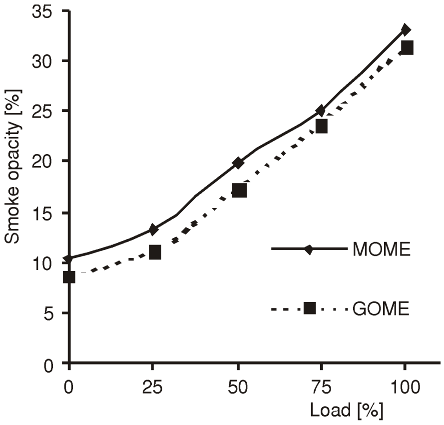

Figure 6. Smoke *vs.* load

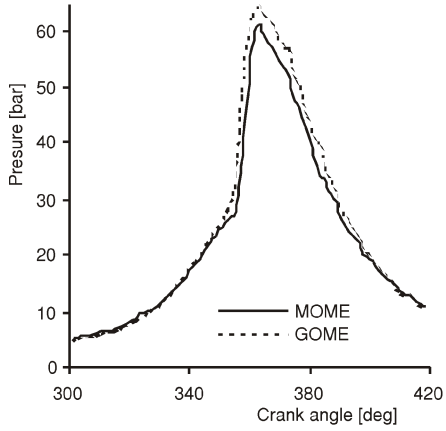

Figure 7. Pressure *vs.* crank angle

Conclusions

From the experimental results, the following conclusions are drawn. The dual fuel engine was running smoothly with the MOME and GOME. The viscosity of MOME is higher than the GOME. Due to higher viscosity, the MOME results in lower thermal efficiency and slightly higher exhaust emissions at lower loads. But at higher loads, there is not much variation in thermal efficiency and smoke, CO and UBHC emissions of the GOME and MOME. From the experimental results, it was observed that the performances with biodiesel produced from the non-edible mahua oil are close to the biodiesel produced from edible gingili oil. Hence instead of edible oil, non edible oil can be used to produce biodiesel.

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Nomenclature

bTDC – before top dead center
CNG – compresed natural gas
GOME – gingili oil methyl ester
LPG – liquefied petroleum gas
MOEE – mahua oil ethyl ester
MOME – mahua oil methyl ester
UBHC – unburned hydrocarbon

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