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# IMPROVEMENT OF PERFORMANCE OF VEGETABLE OIL FUELLED AGRICULTURAL DIESEL ENGINE

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## Abstract

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In recent years, there has been a considerable effort to develop and introduce alternative renewable fuels to replace conventional petroleum based fuels. This led to the choice of non edible Mahua Oil (MO) as one of the main alternative fuels to diesel oil in India. When MO was used as fuel in the diesel engine, it results in lower thermal efficiency and higher smoke emission due to its higher viscosity and lower volatility. Hence in the present work, Liquefied Petroleum Gas (LPG) was inducted along with the air and the LPG supply was varied from zero to the maximum value that the engine could tolerate. The engine tests were conducted on a single cylinder diesel engine, which is used in the agricultural machinery. The engine test with MO+LPG was compared with the LPG+MO biodiesel (MEMO) and Diesel+LPG. From the engine results it is observed that the MO+LPG dual fuel mode operation results in performance close to the MEMO+LPG. The MO+LPG operation results in higher brake thermal efficiency and lower smoke emission as compared to the MO operation. From the present work, it is concluded that the underutilized and non edible MO can be used as a renewable alternative fuel for the diesel engine, for the development of rural economy and for the energy security of India.

*Key words:* Alternative Fuel, Mahua Oil, Engine Performance, Sustainability
*Abbreviations:* MO – Mahua Oil; MEMO – Methyl Ester of Mahua Oil ; LPG – Liquefied Petroleum Gas; BTE – Brake Thermal Efficiency; CO – Carbon Monoxide; NOx – Oxides of Nitrogen; MMT - Million Metric Tones

## Introduction

During recent years high activities can be observed in the field of alternative fuels, due to rapid decrease in world petroleum reserves and environmental concerns originating from exhaust emissions. In the year 2004 – 2005, India imported 75 % of crude oil from other countries and the demand for diesel and gasoline increased drastically in the year 2008 - 2009. It has been estimated that the demand for diesel will be 66.90 Mt for the year 2011-2012. Hence, government of India has taken necessary steps to fulfill future diesel and gasoline demand and to meet the stringent emission norms. Non edible vegetable oils and alcohol are being considered to be supplementary fuels to the petroleum fuels in India. These biofuels are

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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 (Subramanian et al., 2005). In the transportation sector, a large number of investigations have been carried out internationally in the area of vegetable oils as fuel. Jamieson (1943) listed over 350 oil-bearing crops while Allen et al. (2000) analyzed atomization characteristics of fifteen biodiesel. Various researchers have shown that the use of vegetable oil and their derivatives is competitive compared to mineral diesel (Agarwal et al., 2008 and Peterson et al., 2007).

Many researchers (Kapilan et al., 2008, Raheman et al., 2006 and Sukumar et al., 2007) have tried to use biodiesel derived from MO as fuel for diesel engine. In most of the countries including India, biodiesel is expensive than the diesel and also biodiesel is not available commercially in the market. Most of the work reported in the literature involves only the laboratory studies. Hence in recent years, efforts have been made by several researchers (Deepak et al., 2006, Hebbal et al., 2006, Huzayyin et al., 2004 and Ramadhas et al., 2005 ), to use vegetable oils as alternate fuel for diesel. Also in rural and remote areas of developing countries, where electrical power is not available, vegetable oils play a vital role in decentralized power generation for irrigation and electrification purposes. In these remote areas, different types of vegetable oils are available locally but it may not be possible to chemically process them and hence these oils are not being properly utilized. Keeping these facts in mind, a set of experiments were conducted on a diesel engine which is used for agricultural, irrigation and electricity generation purposes, using non edible MO which available in India and in Asian countries.

Mahua is a medium to larger tree belongs to *Madhuca longifolia* of family Sapotaceae with wider and round canopy. The variety *Latifolia i*s common throughout the Indian sub-continent and South East Asian countries. Mahua is found in mixed deciduous forests, usually of somewhat dry type, often growing on rocky and sandy. Figure 1(a) shows the mahua tree. Mahua is a slow growing species, attains a mean height of 0.9 to 1.2 m at the end of the fourth year. Each mahua seed contains two kernels of size 2.5 X 1.75 cm. Figure 1(b) shows the mahua seeds. The kernel of seed contains about 50% oil. The oil yield in an oil expeller is nearly 34% - 37%. The fresh oil from properly stored seed is yellow in color. 200 Mahua trees can be planted in a hectare. The average seed yield from the matured tree is 60 kg and hence the yield is 12 000 kg / hectare. The life span of Mahua tress is 50 to 60 year.

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, LPG and CNG (Compressed Natural Gas) are suitable for Internal Combustion 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 (Santosh et al., 2006). In India, LPG is commercially available in rural areas and the cost of the LPG is 25 % lower than the diesel.

## Materials and Methods

The MO is underutilized and non edible oil and hence it was used as a substitute for diesel. The MO was filtered and refined before it was used as fuel. Since MO operation resulted in higher smoke, Liquefied Petroleum Gas (LPG) was inducted along with the air in order to improve the performance of the diesel engine. The biodiesel (MEMO) was derived from MO by transesterification using methanol and sodium hydroxide. The performance of the diesel engine with MO+LPG was compared with MEMO+LPG and Diesel+LPG.

The experimental setup used for the engine test is shown in Figure 2. During the engine test, the engine speed was maintained constant at 1500 rpm. Initially the experiments were conducted on the engine using MO as the fuel, for the baseline date. In dual fuel mode operation, the engine was started by hand cranking with MO as fuel and the engine was allowed to warm up. After that the LPG was introduced into the cylinder through the control valve, rotameter, flame arrester, mixing chamber and air intake manifold and its flowrate was maintained constant. The engine was stabilized before taking all the readings and the LPG flowrate was varied from zero to the maximum value that the engine could tolerate. Similar procedure was used for the other fuels (MEMO+LPG and MO+LPG).The details of the engine used for the present work is given in Table 1.

**Table 1**
**Engine details**

| | |
|---|---|
| Engine | 4 – S, Single cylinder, water cooled diesel engine |
| Make | Kirloskar |
| Rated Power | 3.7 kW @ 1500 rpm |
| Bore X Stroke | 87.5 X 110 mm |
| Compression Ratio | 16.5 :1 |
| Injection pressure | 200 bar |

## Results and Discussion

### *Properties of MO*

The properties of the fuels were determined in the Fuels Laboratory as per ASTM standards. Table 2 compares the properties of the MO, MEMO and diesel. From the table, it is observed that the flash point, fire point, density and kinematic viscosity of MO are higher than the diesel and MEMO. The higher flash point of the MO and MEMO makes it safe for transportation and storage. Since MO and MEMO has oxygen in its molecular structure, their calorific value is lower than the diesel. The corrosion characteristics study of biodiesel obtained from MO on engine parts like piston and piston liner, using long duration static immersion test method, indicates that the mahua biodiesel showed little or no corrosion as compared to diesel (Savita et al., 2007).

### *Cost analysis of MO*

The cost of MO is lower than the diesel because it's non edible and underutilized oil. Table 3 shows that cost of the MO per kg is lower than the diesel but the calorific value of MO is also lower than the diesel. Hence the cost of MO is almost 0.7 times the cost of the diesel. In rural and remote areas, farmers who are having Mahua in their lands can use its oil in the agricultural machinery like diesel pump set, tractor, diesel power generator, power tilter etc. It will reduce dependence of diesel or power supply in these areas.

**Table 2**
**Properties of MO and diesel**

| Property | MO | MEMO | Diesel |
|---|---|---|---|
| Flash point, °C | 212 | 129 | 56 |
| Pour point, °C | 14 | 5 | -20 |
| Calorific value, kJ/kg | 35614 | 36914 | 42960 |
| Kinematic viscosity at 40°C, cst | 27.63 | 4.85 | 2.68 |
| Density at 15°C, kg/m$^3$ | 915 | 883 | 846 |
| Cetane number | _ | 49 | 48 |

### *Properties of the LPG*

Hence in the present work, LPG was used as a gaseous fuel. Table 4 shows the composition of LPG. The LPG contains mainly butane and propane.

### *Engine Test*

When MO was used as sole fuel in the diesel engine, heavy smoke emission and fluctuations in speed

**Table 3**
**Cost analysis of MO**

| Description | Cost, US $ |
|---|---|
| Seed cost (Including collection cost) | 0.16 |
| 3.5 kg seed needed for 1 kg of oil extraction | 0.57 |
| Oil extraction for I kg of oil (Including labour cost) | 0.08 |
| Cost of refined oil per Kg | 0.65 |
| Revenue from sale of seed cake (for 1 kg ) | 0.08 |
| Cost of the refined oil after subtracting revenue | 0.57 |
| Cost of 1 kg diesel | 0.8 |

were observed at full load. But when the LPG was inducted, the smoke emissions were reduced gradually as the LPG flowrate increases. The dual fuel engine was running without knocking with MO for the LPG energy share of 50.09 % at full load. But knocking was observed beyond this level. This is due to the large amount of gaseous fuel admission at full load, which results in uncontrolled reaction near the liquid spray causing rough engine operation (Ganesan et al., 2002). The performance and emissions of the diesel engine with different LPG energy share were discussed below.

Brake Thermal Efficiency (BTE) is defined as the ratio of brake power to the heat supplied. Figure 3 shows the variation of BTE at different LPG energy share. From the figure, it is observed that the dual fuel mode operation results in higher efficiency as compared to the MO operation. This is due to the induction of LPG which results in better combustion of the fuel. At higher LPG energy share, the performances of the MO+LPG and MEMO+LPG are close to each other and less than the diesel.

The variation of smoke emission with the LPG energy share is shown in Figure 4. From the figure, it is observed that, as the LPG energy share increases, the smoke emission of MO+LPG decreases. This is due to the simpler structure with low carbon content of the LPG which results in reduction of smoke emission drastically. Hence gaseous fuel induction is one of the ways of reducing smoke emission of the vegetable oil fuelled CI engine. The MO results in higher smoke emission, due to the higher viscosity of the MO, which results in larger droplets and poor penetration of liquid fuel which adversely affect air entrainment and subsequent fuel and air mixing. This leads to the poor combustion of fuel and hence higher smoke emission. The MEMO+LPG operation results in lower smoke emission as compared to other fuels in dual fuel mode.

**Table 4**
**Composition of LPG**

| Composition, by % volume | |
|---|---|
| N-Butane, Iso Butane & Butyene | 70.4 |
| Propane & Propylene | 28.6 |
| Ethane & Ethylene | 0.5 |
| Pentane | 0.5 |
| Calorific value, MJ/kg | 47. 88 |
| Maximum flame temperature in air, °C | 2000 |
| Self Ignition Temperature, °C | 252 |

The variation of Carbon Monoxide (CO) emission with different LPG energy share is shown in Figure 5. From the figure, it is observed that as the LPG energy share increases, the CO emission gradually decreases and after certain LPG energy share it starts to increase. This is due to partial oxidation of the inducted LPG during the compression and also during the combustion. At higher LPG energy share, the CO emission of MO+LPG is close to Diesel+LPG and higher than the MEMO+LPG.

The variation of oxides of nitrogen (NOx) emission with the LPG energy share is shown in Fig.6. The NOx emission depends on the combustion temperature. If the combustion temperature of the fuel increases, then the NOx emission also increases. Even slow combustion of the fuel results in higher NOx emission. From the figure, it is observed that the MO operation results in lower NOx emission as compared to the dual fuel operation. This is due to the higher viscosity of the MO, which results in poor combustion and hence lowers combustion temperature. The NOx level increases with increasing LPG energy share due to faster combustion and higher temperatures reached in the cycle. The dual fuel mode operation results in lower NOx emission as compared to neat diesel and MEMO operation.

***Potential of MO and sustainable development***

The seed and oil potential of mahua tree in India is 0.5 million and 0.18 million metric tones respectively (Mohibbe et al., 2005). At present MO does not find any major applications and hence even the natural production of seeds itself remain underutilized. As a plantation tree, mahua is an important plant having vital socio-economic value. This species can be planted

**Table 5**
**Estimation of land availability (Sudha et al., 1999)**

| Land Type | Area, Mha | Potential for plantation, Mha | Farm land by 2010, Mha |
|---|---|---|---|
| Under stocked forests | 31 | 3 | |
| Protective hedge around Agricultural fields | 142 | 3 | |
| Agro forest | NA | 2 | 141835 |
| Fallow lands | 24 | 2.4 | |
| Land related programs of ministry of rural development | NA | 2 | |
| Public lands – railway tracks, roads, canals etc | NA | 1 | |
| Total | 197 | 13.4 | 141835 |

NA – Not Available
Mha - Million hectare

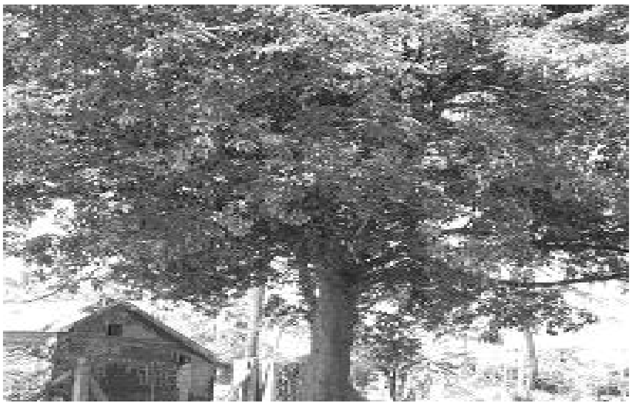

**Fig. 1. (a) Mahua Tree** **(b) Mahua Seeds**

**Fig. 2. Experimental setup**

on roadside, canal banks etc on commercial scale and in social forestry programs, particularly in tribal areas. Table 5 shows the use of wasteland availability planned by the Government of India, to grow jatropha species. From this table we can observe that only 6.8% of the available land (i.e. 13.4 Mha out of 197 Mha) has been planned for the cultivation of Jatropha. The area estimated to be under agriculture in India by 2010 is given as 141 835 Mha (Sudha et al., 1999 and Mohibbe et al., 2995). The huge amount of available land can be utilized for growing different species of trees, which produce oil-bearing seeds. The mahua, one such species, can be cultivated on these lands for

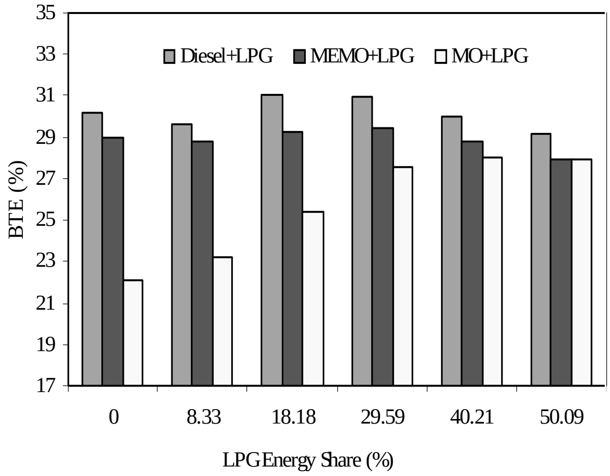


**Fig. 3. Variation of BTE with LPG energy share**

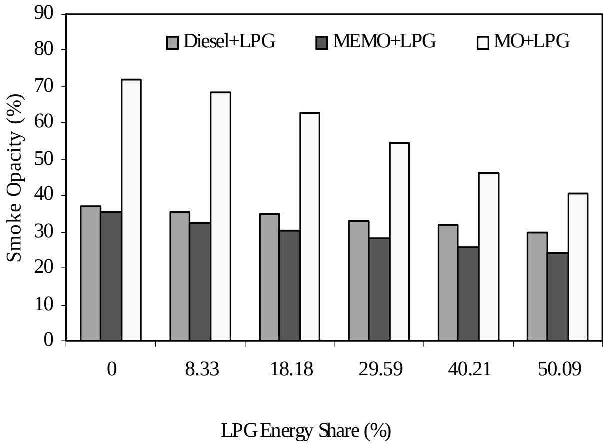


**Fig. 4. Variation of Smoke opacity with LPG energy share**

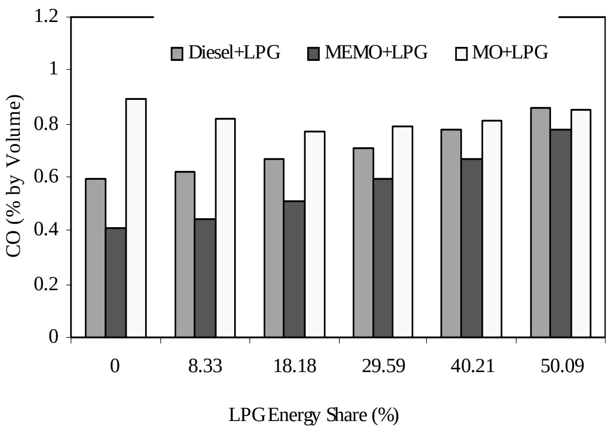


**Fig. 5. Variation of CO with LPG energy share**

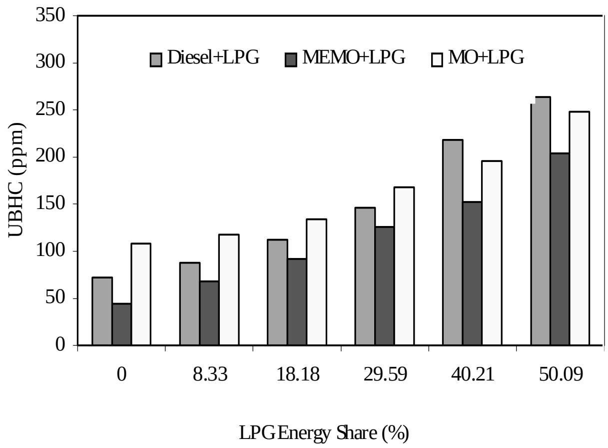


**Fig. 6. Variation of NOx with LPG energy share**

the sustainable development of rural economy. It has been estimated that the demand for diesel will be 66.90 Million Metric Ton (MMT) for the year 2011-2012. If 5 % MO is substituted for diesel, then the requirement of MO is 3.345 MMT.

The average seed yield from the matured tree is 60 kg and hence the yield is 12 000 kg / hectare. If 3.5 kg of mahua seeds are required to produce 1 kg of MO, then the MO yield is 3 429 kg / hectare. To meet the requirement of 3.345 MMT of MO, the plantation of mahua should be done on 9.76 Mha. This will generate 56 million jobs in plantation and maintenance work, in the year 2011-2012. This will generate the job opportunities in rural areas and improve the socio economic condition of the poor in those areas.

## Conclusion

Based on the present test, the following conclusions are drawn. The MO has higher flash point, viscosity, density and lower calorific value. The performance of the MO fuelled diesel engine was improved by the induction of LPG. The diesel engine works smoothly in the dual fuel operation with the brake thermal efficiency close to diesel. Also the dual fuel mode operation results in drastic reduction in smoke emission due to the simpler molecular structure of the LPG and lower NOx emission. Also the LPG+MO operation results in efficiency comparable to MEMO+LPG and Diesel+LPG operation. The cost of the MO is lower than the diesel. Hence the use of non edible MO as fuel in agricultural diesel engine will improve rural economy, sustainability and increase the environmental benefits. In an agricultural and developing country like India, the use of non edible vegetable oils in diesel engines offers many benefits, including sustainability, reduction of green house gas emissions, regional development and improvement in agriculture.

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