International Journal on Emerging Technologies (Special Issue on NCRIET-2015) **6**(2): 298-305(2015)

ISSN No. (Print) : 0975-8364
ISSN No. (Online) : 2249-3255

Effect of injection pressure on performance and emission characteristics of single diesel engine with methyl-ester of Mahua oil as fuel

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(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: Import of petroleum products is a major drain on our foreign exchange sources and with growing demand in future years the situation is likely become even worse. Hence it has become imperative to find suitable fuels, which can be produced in our country. Non-edible vegetable oils such as Pongamia, Mahua Jatropha etc can either be fully or partially substitute for diesel oil. In this work, Mahua oil a non-edible type is used in this investigation for studying its suitability for use in diesel engine. This work deals with the results of investigations carried out in studying the fuel properties of methyl ester of Mahua oil blends with diesel fuel from 20 to 100% by volume and running in a single cylinder four-stroke diesel engine with this fuels at different injection pressure. Tests were performed on the uncoated engine; various properties of these fuels are evaluated and compared in relation to that of conventional diesel fuel. Engine tests have been carried out with the aim of obtaining comparative measures of specific fuel consumption, brake thermal efficiency, emissions such as CO, CO_2, NO_X, and un-burnt hydrocarbons.

Keywords: Methyl-ester, Mahua oil, Injection pressure, Bio-fuels etc.

I. INTRODUCTION

The world is presently confronted with the twin crises of fossil fuel depletion and environmental degradation. Indiscriminate extraction and lavish consumption of fossil fuels have led to reduction in underground-based carbon resources. The search for alternative fuels, which promise a harmonious correlation with sustainable development, energy conservation, efficiency and environmental preservation, has become highly pronounced in the present context. The fuels of bio-origin can provide a feasible solution to this worldwide petroleum crisis. Gasoline and diesel-driven automobiles are the major sources of greenhouse gases (GHG) emission as [1–3]. Scientists around the world have explored several alternative energy resources, which have the potential to quench the ever-increasing energy thirst of today's population. Various biofuels energy resources explored includes biomass, biogas as [4], primary alcohols, vegetable oils, animal fats, biodiesel, etc. These alternative energy resources are largely environment-friendly but they need to be evaluated on case-to-case basis for their advantages, disadvantages and specific applications. Some of these fuels can be used directly while others need to be formulated to bring the relevant properties closer to conventional fuels.

Due to the recent widespread use of petroleum fuels in various sectors, this study concentrates on assessing the viability of using alternative fuels in the existing internal combustion engines.

The present energy scenario has stimulated active research interest in non-petroleum, renewable, and non-polluting fuels. The world reserves of primary energy and raw materials are, obviously, limited. According to an estimate, the reserves will last for 218 years for coal, 41 years for oil, and 63 years for natural gas, under a business-as-usual scenario as [5, 6]. The enormous growth of world population, increased technical development, and standard of living in the industrial nations has led to this intricate situation in the field of energy supply and demand. The prices of crude oil keep rising and fluctuating on a daily basis. The crude- oil prices are at near record levels and are stabilizing at about US$120 per barrel now. The variations in the energy prices over last decade are shown in Fig. 1. This necessitates developing and commercializing fossil fuel alternatives from bio-origin. This may well be the main reason behind the growing awareness and interest for unconventional bio energy sources and fuels in various developing countries, which are striving hard to offset the oil monopoly.

A. Environmental and health implications of pollutants

Environmental concerns have increased significantly in the world over the past decade, particularly after the Earth Summit '92. Excessive use of fossil fuels has led to global environmental degradation effects such as greenhouse effect, acid rain, ozone depletion, climate change, etc. There is a growing realization worldwide that something constructive has to be done soon to reduce the GHG emissions. These are categorized as unregulated pollutants. Regulated pollutants include NO_x, CO, HC, particulate matter (PM) and unregulated pollutants include formaldehyde, benzene, toluene, xylene (BTX), aldehydes, SO_2, CO_2, methane etc. as [11–13]. These regulated as well as unregulated pollutants contribute to several harmful effects on human health, which are further categorized as short- and long-term health effects. The short-term health effects are caused by CO, nitrogen oxides, PM,(primarily regulated pollutants),while long-term health effects are caused mainly by poly-aromatic hydrocarbons (PAH's), BTX, formaldehyde, (primarily unregulated pollutants) etc. CO is fatal in large dosage, aggravates heart disorders, affects central nervous system, and impairs oxygen-carrying capacity of blood by forming carboxy-hemoglobin. Nitrogen oxides cause irritation in respiratory tract. HC's cause drowsiness, eye irritation, and coughing as [14–16].

These pollutants also contribute towards several regional and global environmental effects. Regional environmental effects such as summer smog are because of aldehydes, carbon monoxides, nitrogen oxides etc. Winter smog is because of particulate. Acidification is caused by nitrogen oxides, sulfuric oxides etc. Several global effects like ozone layer depletion, global warming etc, are caused by CO_2, CO, methane, non-methane hydrocarbons, nitrogen oxides etc. as [17, 18].

B. Biofuels For Transportation And Agricultural Sector

Transportation and agricultural sector is one of the major consumers of fossil fuels and biggest contributor to environmental pollution, which can be reduced by replacing mineral-based fuels by bio-origin renewable fuels. There are a variety of biofuels potentially available, but the main biofuels being considered globally are biodiesel and bio ethanol. Bio-ethanol can be produced from a number of crops including sugarcane, corn (maize), wheat and sugar beet. The last two are currently the main sources of ethanol in Europe as Ref [19]. Biodiesel is the fuel that can be produced from straight edible and non-edible, recycled waste vegetable oils, and animal fat as Ref [20–23]. Europe has committed to promotion of the use of biofuels or other renewable fuels as a substitute for gasoline or diesel in the transport sector. There are several factors that need to be taken care before recommending any alternative fuel to be used in existing technologies on a large scale.

II. LITERATURE REVIEW

A. Introduction

An extent to which a country is utilizing high grade petroleum products successfully to keep its heavy duty vehicles playing on the roads have became a yardstick to rate itself as a developed or a developing one. Diesel fuel is the single largest source to power vehicles both in transportation and agricultural sectors. With the increasing demand on the use of fossil fuels, a stronger threat to clean environment is being posed as the burning of fossil fuels is associated with emissions. These emissions are major causes of air pollution and hence of the environment. The most appealing alternative fuels are those, which can be used minimum modification of existing engines.

Liquid fuels from renewable resources are biodegradable and inexhaustible. In this regard vegetable oils having their physical and combustible characteristics close to diesel fuels may stand as immediate candidate substitute for diesel fuel. India which imports 70% of the oil it user is looking for alternative fuel to reduce its dependence on imports. Biodiesel is already in use in Italy, US, Malaysia and Japan just that its made from different natural sources in different places. In India biodiesel will be produced from oil-bearing trees like Honge, Mahua and Jatropha. Fortunately in India those plants are abundantly available.

In this chapter, characterization of vegetable oils and biodiesel, performance and emission studies carried out by earlier researchers with regards to the use of various types of vegetable oil as fuel in diesel engines are presented.

B. Objectives of Present Work

The following objectives were drawn up for this project work

1. To prepare the biodiesel from vegetable oils by trans-esterification. Since chemically modifying the structure of vegetable oils by esterification reduce the viscosity.
2. To study the comparison properties of Mahua methyl ester blends with diesel oil. For comparison, the same properties of the diesel oil were to be determined.

3. To run a typical diesel engine on a vegetable oil methyl esters in order to evaluate their performance in regard to BP, BTE, BSFC, EGT and emission such as NO_X, UBHC, CO, CO_2. For comparison, the same properties were to be determined for engine operation with conventional diesel oil also.
4. To blend vegetable oil methyl esters in different proportion with diesel oil and carryout the tests. This would serve the double objectives of reducing the viscosity of these esters and achieving partial substitute of diesel oil.
5. To run a diesel engine on a MME blends with diesel like B10, B20, B30 and B40 at different injection opening pressure (200,210 and 220 bar) since optimum IP gives the better performance.
6. To compare the performance and emission of Mahua methyl ester blends at optimum injection pressure. Thus optimum blend at optimum IP would gives the best performance.

C. Origin, Historical and Biological Aspects of Mahua Seeds

Mahua as Alternative Fuel. The world's rapidly dwindling petroleum supplies, their raising cost the growing danger of environment pollution from these fuels have led to an intensive search for an alternative fuels. The use of Mahua oil (*Madhuca indica*) as diesel substitute in compression ignition engine has now assumed greater importance because their large population and phenomenal growth rate. Mahua oil can easily be substitute for hydrocarbons that are getting scarce worldwide and save the country crores of rupees in foreign exchange. The vegetable oil has to be preheated for use since the viscosity of the oil is much higher than that of diesel at room temperature.

The Mahua trees are indigenous to India, grow even in draught prone area and are found abundantly over several parts of India. This is the renewable source and it is readily availability in India. In some countries, Mahua oil is considered as edible as it is using only for preparing ghee, but in our country it has been considered as non-edible oil. Mahua normally starts yielding in 6-7 years. It is possible to get a yield of 10-15 tons of Mahua seeds from one hectare. If Mahua is grown like coconut, it fetches the same income as coconut. The grower may get Rs.50, 000/- from one hectare. The total income from coconut will be less taking into account the expenditure incurred for water, manure and upkeep. This expense is almost nil in case of Mahua trees. In addition, it is free from the fear of theft and dieses. Growing Mahua would also help in protecting the environment. Using these vegetables oils as an alternative to diesel is beneficial to farmers as well since they can save on diesel and fertilizers cost.

It is therefore necessary to develop some means for improving the fuel economy of CI engine and also to investigate the suitability of Mahua oil for diesel engine operations. If the diesel engine could be fuelled on a cleaner fuel such as Mahua oil, it may be the most desirable engine of the future.

Applications. It is used mostly in manufacturing of soaps, particularly the laundry field. It is also used for edible and cooking purpose. Refined oil is used in manufacturing of lubricating greases. The oil is used for candles a batching as a raw material for production of fatty alcohol and stearaic acid. The tribal commonly consume the tori oil that contains 40-45% oil. The oil cake is also used as pesticide and manure. It contains 16% of protein. The oil cakes are profitably utilized as bio-fertilizers or cattle feed or sold to solvent extraction plants, where still more oil is extracted.

Medically the tree is very valuable. Flowers are prepared to relieve coughs, biliousness and heart-trouble while the fruit is given in cases of consumption and blood diseases. Mahua flowers show anti-bacterial activity Escherichia coli. The honey from flowers is edible and reported to be used for eyes. The bark is used in treating of rheumatism, ulcers, itching, bleeding and spongy gums, tonsillitis leprosy, heal wound and diabetes mellitus. The root base is applied for ulcers.

III. METHODOLOGY

This chapter describes briefly the methodology used for production of methyl-esters of Mahua seed oil through transesterification process. It studies characteristic fuel properties and experimental procedure adopted to evaluate performance of a single cylinder four stroke diesel engine on the blends. The experiments were conducted in the Internal Combustion Engine Laboratory, Department of Mechanical Engineering, REVA Institute of technology and management, Bangalore. The parameters studied and methodologies of analytical interpretations are discussed in this chapter.

The Mahua seed oil used in this present study was obtained by Nanjundeswara oil mill, Tumkur (Karnataka).The commercial diesel fuel was purchased from petrol pump which is nearer to REVA Institute of Technology and Management, Bangalore, (Karnataka). All chemicals (Methanol, KOH Catalyst) were procured during experimentation from Ganesh chemicals, Bangalore. All chemicals are brought locally and other reagents were analytical grade and large numbers of sample bottles were purchased from a shop to fill different biodiesel sample during experimentation.

The transesterification process setup and the required utensils are arranged in proper manner for production of biodiesel. The fuel properties have been determined by using equipments such as hydrometer, Redwood viscometer, closed cup flash and fire apparatus, cloud and pour point apparatus and bomb calorimeter. Properties of the biodiesel obtained after transesterification

Table 1: Properties of biodiesel.

Density(kg/m^3)	**880**
Specific gravity	**0.88**
Flash point(^{0}C)	**217**
Free fatty acids	**6.25%**
Acid number	**17.5**
Calorific value(KJ/kg)	**39988.12**

IV. EXPERIMENTAL SETUP

The experimental setup of the present work with various components is shown in the figure. 4.8

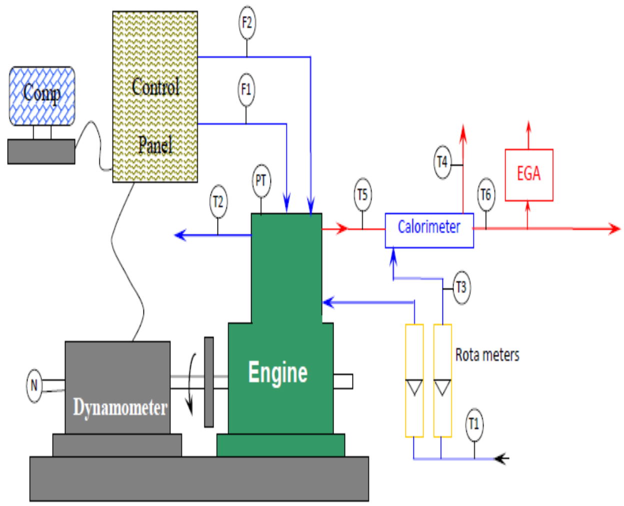

Figure 4.8. Schematic Diagram of Experimental setup of Diesel fuel Engine test rig.

Engine test procedure. A four stroke, single cylinder water cooled diesel engine is employed for the present study. The detail specifications of the engine used are given in table 1. 2 and experimental set up as shown in figure 4.8. QROTEK 401 Five gas analyzer was used to measure the concentration of gaseous emissions such as Oxides of nitrogen, unburned hydrocarbon, carbon monoxide, carbon dioxide and oxygen level. The performance and emission tests are carried out on the C.I. engine using various blends of diesel-biodiesel-ethanol blends as fuels. The tests are conducted at the constant speed of 1500rpm at various torque.

In this experiment, engine parameters related to thermal performance of engine such as brake thermal efficiency, brake specific fuel consumption, brake specific energy consumption, exhaust gas temperature are measured. In addition to that, the engine emission parameters such as Oxides of nitrogen, unburned hydrocarbon, carbon monoxide, carbon dioxide and oxygen level.

Engine. The photograph of diesel engine with pressure thermocouple for sensing exhaust gas temperature is shown in figure 4.8. It is of single cylinder, four strokes, water cooled compression ignition engine with a bore of 80mm and stroke 110mm. Fuel is supplied to the fuel pump by gravity feed, through the fuel tank and paper element filter. The engine can be started by hand cranking using decomposition lever.

Fig. 4.9. Compression ignition engine set up used for experimental purpose.

Engine and dynamometer specification

Table 2. Engine and dynamometer specification.

SL	PARAMETERS	SPECIFICATION
1	Type	TV 1(kirloskar made)
2	Nozzle opening pressure	200 to 225 bar
3	Governor type	Mechanical centrifugal type
4	Number of cylinders	Single stroke
5	Number of strokes	Four stroke
6	Fuel	Diesel
7	Compression ratio	16.5:1
8	Cylinder diameter(bore)	80mm
9	Stroke length	110mm

Electrical dynamometer

10	Type	Foot mounted, continuous rating
11	Alternator rating	3KVA
12	Speed	2800-3000RPM
13	Voltage	220 V AC

Experimentation Methodology

First the experimentation is performed with diesel (for getting the base line data of the engine) and then 100 % Mahua seed oil biodiesel and its diesel-ethanol and biodiesel blends of different percent volumes (B20, B40, B60 and B80). The performance of the engine is evaluated in terms of brake thermal efficiency, brake specific energy consumption, exhaust gas temperature, and emission of the engine is analyzed (HC, CO, CO_2, O_2 and NO_X).

Experimentation Procedure

1. Check for all electrical connections and proper earthing for the equipments.
2. Ensure water in the main water supply tank.
3. Ensure selected fuel about 2 litre in quantity in the fuel supply tank and fuel knob on regular position.
4. Maintain the water flow rate throughout the experiment.
5. Start electric-supply to the computer through the stabilizer and open the engine software.
6. Start electric power supply to the 5-gas analyzer.
7. Start the engine by rotating the handle and operating the decompression lever. Let the engine run on the minimum load and exhaust gas analyzer to get warmed up simultaneously.
8. Open the handle of the exhaust connection for inserting the gas sample probe of the 5-gas analyzer. Insert the probe. Choose NOx mode of the instrument from the display. After the reading is stabilized get the print out by choosing the print option. Note the fuel name and torque value on the print out for future reference.
9. Change the torque gradually by rotating the loading knob and observing in the monitor for torque value. Allow the engine to run for 10 minutes for stabilization at new torque. After stabilization again turn the fuel knob to metering position. After one minute after the fuel logging is over, feed the cooling water and calorimeter flow rates and turn back the fuel knob to regular position. Take the reading of 5-gas analyzer as mentioned above. Also fuel flow rate for 10cc of fuel is also noted down.

10. Repeat the procedure for different torque values.
11. Reduce the torque to minimum position (no load condition) gradually ensuring that the RPM's are not shooting beyond 1500 RPM and allow the engine to stabilize.
12. Save the files with appropriate names.
13. Put off the engine.
14. Allow the water pumps to be on for 15 minutes so that engine gets cooled down and then put off the water flowing valves.

IV. RESULTS AND DISCUSSION

Worldwide, biodiesel is largely produced by methyl transesterification of edible and non edible oils. The concept of methyl transesterification is gaining attention as ethanol is derived from renewable biomass sources. The studies were, therefore, conducted on methyl esters transesterification process for raw mahua seed oil, characteristic fuel properties of diesel and their blends with diesel and ethanol. The fuel consumption test and rating test of a constant speed CI engine was also conducted to evaluate the performance of the engine on diesel and methyl esters of mahua oil with diesel-ethanol blends.

The performance and emission observations are given in table 5.1.1 to 5.1.10 for different blends and at different Injection pressures (190, 200 and 210 bars) performed on CI engine.

Table : Performance and Emission characteristics for Diesel fuel at injection pressure of 200 bar

Water flow: 30cc/sec Engine Condition:
Type of fuel used: Diesel Injection pressure: 200 bar
Engine Speed: 1500 RPM Injection Timing: 27^0BTDC

PERFORMANCE CHARACTERISTICS.

S	T Nm	EGT (^{0}C)	Time (sec)	B.P (KW)	BTE (%)	TFC (kg/sec)
1	0	328	84.03	-	-	9.758
2	5	382	63.65	0.7853	14.198	12.88
3	10	444	47.77	1.5707	21.312	17.16
4	15	477	37.08	2.3561	24.816	22.114
5	20	557	29.45	3.1415	26.283	27.83

EMISSION CHARACTERISTICS

Torque N-m	Unburnt HC(ppm)	CO (%)	CO_2 (%)	O_2 (%)	NO_X (ppm)
0	59	0.08	2.20	17.48	103
5	69	0.07	3.40	15.78	219
10	75	0.06	4.80	13.82	534
15	80	0.06	6.30	11.67	990
20	84	0.07	7.40	10.23	1311

Table: Performance and Emission characteristics for 20% MME fuel at injection pressure of 200 bar

Water flow: 30cc/sec Engine Condition:
Type of fuel used: 20% MME Injection pressure: 200 bar
Engine Speed: 1500 RPM Injection Timing: 27^0BTDC

PERFORMANCE CHARACTERISTICS

SL	T (N-	EGT (^{0}C)	Time (sec)	B.P (KW)	BTE (%)	TFC (kg/sec
1	0	286	99.95	-	-	8.324
2	5	371	67.75	0.7853	15.1018	12.28
3	10	424	48.92	1.5707	21.8104	17.007
4	15	476	37.27	2.35619	24.926	22.32
5	20	619	29.985	3.1415	26.7377	27.74

EMISSION CHARACTERISTICS

Torque N-m	Unburnt HC	CO (%)	CO_2 (%)	O_2 (%)	NO_X (ppm)
0	58	0.06	2.00	17.74	122
5	67	0.07	3.30	15.91	220
10	75	0.05	4.70	13.94	570
15	74	0.05	6.40	11.61	1028
20	67	0.07	7.80	9.84	1400

Table : Performance and Emission characteristics for 40% MME fuel at injection pressure of 200 bar

Water flow: 30cc/sec
Type of fuel used: 40% MME
Engine Speed: 1500 RPM

Engine Condition:
Injection pressure: 200 bar
Injection Timing: 27^0BTDC

V. CONCLUSION

The overall studies based on the production, fuel characterization, engine performance and exhaust emission of Mahua seed oil methyl ester and Diesel-Mahua seed oil biodiesel blends were carried out
The following conclusions for Mahua seed oil methyl esters and its blends can be drawn:

-The production of Mahua seed oil methyl esters is a two stage transesterification process since it is having 6.3% of FFA and its FFA % is quite more to produce it from single stage transesterification process.
-The recovery of Mahua seed oil methyl ester of lowest kinematic viscosity (5.0 Cst) with 98 % recovery is possible at the following standardized parametric conditions.

First stage (Acid catalyzed)	Second stage (Base catalyzed)
Methanol concentration: 30%	Methanol concentration: 15%
Reaction temperature: 55-60^0C	Reaction temperature: 55-60^0C
Catalyst concentration : 0.2%	Catalyst concentration (KOH): 1.2%
Reaction time: 2 hours	Reaction time: 2 hours
Settling time: 2 hours	Settling time: 2 hours

-The diesel engine performed satisfactorily on biodiesel blends, so MME blends can be used as an alternative fuel in existing diesel engine without any hardware modification in the system.
-With increase in concentration of biodiesel in blended fuels, the increase of EGT was very less.
-The injection pressure 200 bar was found to be the optimum IP and better results were obtained for biodiesel blends at 200 bar IP.
-Lower EGT was obtained at higher injection pressure.
-The emission such as CO and UBHC were lower for biodiesel and increase of NOx emission in the case of biodiesel.
-The CO_2 emission is slightly higher for biodiesel blended fuels.
-The 20% biodiesel blend vegetable oil was found to be optimum concentration for biodiesel blends, which improved the thermal efficiency of the engine and reduced the BSFC compared to diesel fuel.
-The emission such as NO_x, CO and UBHC were reduced in B20 fuel vegetable oil and only CO_2 is higher when compared to diesel fuel.
-The 20% biodiesel blend represented a good compromise between increased CO_2 and reduction of NOx and CO.

Based on the exhaustive engine tests, it could be concluded that the blend B20 of MME with diesel fuel could replace the diesel for running the existing diesel engine without any hardware modification and the blend B20 was found to be the best blend in regard to performance and emission characteristics compared to all blends. Also it could be concluded that the biodiesel reduces the environmental impacts of transesterification, reduce the dependence on crude oil imports and offer business possibilities to agricultural enterprises for periods of excess agricultural production. Finally it could be concluded that the biodiesel was found to be a potential alternative fuel to diesel fuel. Since it's physical properties are close to those of diesel fuel and hence a renewable source of energy and it can be right solution for India.

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