

Performance and Emission Characteristics of CI Engine Operated on Madhuca Indica biodiesel using Multi-Objective Optimization by Applying Taguchi Grey Relational Analysis

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ABSTRACT

This paper's analysis approach combines the orthogonal array design of experiments with grey relational analysis for optimization CI engine performance using blend of Madhuca Indica biodiesel as a fuel. Grey relational theory is adopted to determine the best input parameters that give lower emission and higher performance of CI engine. Five design parameters namely; compression ratio, injection pressure, injection nozzle geometry (no. of holes on nozzle of injector), additive (AA-93™) and fuel fraction were selected, and four levels for each factor. To reduce an experimental effort the experiments have been performed by employing Taguchi's L_{16} orthogonal array for various engine performance and emission related responses. Injection nozzle geometry was found to most influencing factors. The optimal combination so obtained was further confirmed through experimentation was suitable for optimizing the performance and emission parameters of diesel engine. The optimal combination of the input parameters in CI engine operated on Madhuca indica biodiesel blend is: Compression ratio (CR) 18, fuel injection pressure (FIP) 310 bar, injection nozzle geometry (ING) 3H, fuel fraction (FF) 15% and without additive (ADD).

Keywords: Madhuca Indica biodiesel, optimization, Taguchi method, Grey relational analysis

CITATION: Nigade, S., "Performance and Emission Characteristics of CI Engine Operated on Madhuca Indica biodiesel using Multi-Objective Optimization by Applying Taguchi Grey Relational Analysis," *SAE Int. J. Fuels Lubr.* 9(2):2016, doi:10.4271/2016-01-1278.

INTRODUCTION

Biodiesel production is a very modern and technological area for researchers as an alternative fuel for diesel engines because of the increase in the petroleum prices, its renewability and the environmental advantages [1,16]. Biodiesel can be produced from renewable sources such as vegetable oil, animal fat and used cooking oil [2-3]. The use of non-edible plant oils when compared with edible oils is very significant because of the tremendous demand for edible oils as food, and they are far too expensive to be used as fuel at present [2].

Nearly 1.60 million diesel engines are operating in India and finding wide applications in agricultural, transport and commercial sectors after the United States, China, and Japan in 2013, and it was also the fourth-largest net importer of crude oil and petroleum products [3, 6, 28]. The gap between India's oil demand and supply is widening, as demand reached nearly 3.9 million barrels per day (bbl/d) in 2013. U. S. Energy Information Administration projects India's demand will more than double to 8.2 million bbl/d by 2040 [6, 28]. The consumption of liquid petroleum products, especially diesel fuel, has grown up significantly due to growth of major economic sectors viz., transport, agriculture and industry. But, the excessive dependency on export grade fuel and limitations associated with fossil fuel become a

concern for desired [6,17]. To reduce the uncertainties associated with the petro-diesel, Government of India, like other nations of the world, have made plan to promote alternative sustainable fuels [6].

Energy strategy of a country aims at efficiency, security, and access to an environment friendly fuel which is an optimum mix of primary resources for energy generation [4,18]. According to Greenpeace report release on March 24, 2009 in New Delhi, renewable energy can successfully meet over 35% of power demand in India by 2030, and half of forecasted energy needs can be met just by efficient and judicious production, distribution and use of energy [6]. Green energy evolution will not only help save money but also alleviate the problem of climate change [11]. Biofuels are eco-friendly fuels and their utilisation would address global concerns about contamination of carbon emissions [5]. India has a ray of hope in providing energy security through development of biofuel. Indian approach towards the biofuels, in particular is somewhat different to the current international approaches which could lead to conflict with food security [3-4, 14]. It depends solely on non-food feedstock to be raised on degraded marginal or waste land that is not suited to agriculture, thus avoiding a possible conflict of security [25].

The country's energy demand is expected to grow at an annual rate of 6.8 per cent over the next couple of decades. Most of the energy requirements are currently satisfied by fossil fuels - coal, petroleum based products and natural gas [6-7]. Domestic production of crude oil can only fulfill 25-30 per cent of national consumption rest we are importing from other countries [21]. In these circumstances biofuels are going to play an important role in meeting India's growing energy needs. Biofuels offer an attractive alternative to fossil fuels, but a consistent scientific framework is needed to ensure policies that maximize positive & minimize the negative aspects of biofuels [22].

The crude oil import was raised drastically and nearby 2013 it's jumped to 347432 Crore and it might rise day-by-day according to consumption ratio [3, 4, 5, 6, 9]. Estimated demand for 2013-14 of petrol, diesel and LPG is 16335MT, 73500MT and 16712MT respectively. Almost 79% (78.75%) of Indian crude oil requirements have to be imported. The issue of oil import has come under focus in the context [3, 4, 5, 6, 23] of country spiraling current account deficit. As per the working group report this ministry for 12 five year plans the estimated demand of petroleum products during 2016-17 would be 186.2 MMT [1, 4-5]. India spends 92,000 Crore on diesel subsidy every year which is a great loss to exchange with the country being a signatory of green fuel treaty by next few years around a 20% diesel usage will be replaced by biodiesel [24]. The government of India has formulated an ambitious National Biodiesel Mission to meet 20 per cent of the country's diesel requirements by 2016-2017 [7].

Transesterification is the process by which the glycerides present in fats or oils react with an alcohol in the presence of a catalyst to form esters and glycerol [10]. The oils and fats are filtered and preprocessed to remove water and contaminants. If free fatty acids are present, they can be removed or transformed into biodiesel using special pretreatment technologies. The pre-treated oils and fats are then mixed with an alcohol (usually methanol) and a catalyst (usually sodium methoxide) [15]. The oil molecules (triglycerides) are broken apart and reformed into esters and glycerol, which are then separated from each other and purified [3-4]. The edible oils like soybean, sunflower, mustard, palm, cotton seeds, whose acid values are less than 3.0 are transesterified with methanol in the presence of sodium methoxide as catalyst [21]. Non-edible oil like, Mahua, karanja and jatropha oils having acid values more than 3.0 are undergoes esterification followed by transesterification [19]. The methyl esters produced by these methods are analyzed to ascertain their suitability as diesel fuels. The byproduct of this process is glycerol and it can be separated from biodiesel by separation under gravity and purified to get pure glycerin which can be used in cosmetic, pharmaceutical, soap industries resulting in final cost reduction of biodiesel production [8, 12].

The most common optimization technique used for engine analysis is response surface method, grey relational analysis, non-linear regression, genetic algorithm and Taguchi method. Taguchi technique has been popular for parameter optimization in design of experiments [13]. Application of Taguchi method for experimental planning has greatly reduced the experimental time and costs [8,12-13]. Grey relational analysis and entropy measurement are used to overcome the in multiple quality analysis [26, 27, 28]. In view of the above, the aim of the present investigation was to reduce the emission without

compromising the performance of CI engine. In order to get complete picture, several design & operating variables like fuel fraction, compression ratio, fuel injection pressure, nozzle geometry and fuel additive have been investigated for their combined effect on output variables like BSFC, CO & NO_x. Five major influencing input parameters with their four levels were selected for controlling them on the basis of three output variables. For optimizing multi-objective characteristics, Taguchi grey relational analysis (TGRA) technique has been used on their relative importance.

This work hoped a positive way towards energy security in future which will meet the qualities of Petroleum based Diesel Fuels produced from non-edible oils. Such alternative fuels will meet the same performance as that of Petroleum based Diesel Fuels with lowering the exhaust gas emission.

Assortment of Mahua as feedstock

- Mahua is tree born non edible oil seed which can be grown on waste marginal land and cultivated in warm regions.
- Mahua seed contains near about 40% oil. Potential capacity of mahua seed is 510000 tones in India.
- Ripen fruit can be used for human consumption and seed is used for oil extraction which can be used as fuel. It is also used for care of skin, manufacturing of soaps, detergents and vegetable butter.
- Seed cakes obtained after oil extraction used as very good fertilizers, biogas production and mushroom cultivation.
- Flowers used to produce alcoholic drink, bark is used for medicinal purpose
- Leaves are high nutritious can be fodder for cattle, goat and sheep's.

EXPERIMENTAL

Physical-Chemical Characterization of Madhuca Indica Biodiesel

The oil was extracted from Madhuca indica crush using soxhlet extractor with N-hexane as the solvent. The duration for each batch of extraction was fixed at 5h; while the volume of solvent per kilogram of seed was varied from 5 liter to 7 liter for maximization of oil yield. The extracted oil was then measured to calculate the content of oil in the kernel of madhuca indica. The physio-chemical properties and fatty acid composition of Madhuca indica oil (MIO) are shown in Table 1 and 2.

Table no. 1. Physiochemical properties of Madhuca indica oil

Sr. No	Physical character	Value
1	Refractive Index at 40°C	1.45-1.462
2	Iodine Value	64
3	Saponification value	189
4	Unsaponifiable matter	1.1%
5	Specific gravity	0.979
6	Colour	Dark Yellow



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The saponification value represents the number of milligrams of potassium hydroxide required to saponify 1gm of fat under the conditions specified. It is a measure of the average molecular weight (or chain length) of all the fatty acids present. The saponification value (SV) is measured in KOH mg/g (As per AOCS standard). The fatty acid composition of Madhuca indica oil is checked by using Gas Chromatography Mass Spectrum (GCMS) and is shown in Table 2. Oleic acid is the main constituents in the MIO.

Table no. 2. Fatty acid composition of the Madhuca indica oil

Fatty acid	Chemical Structure	Structure	Content mass (%)
Palmitic	$C_{16}H_{32}O_2$	16:0	17.6
Stearic	$C_{18}H_{36}O_2$	18:0	14.3
Oleic	$C_{18}H_{34}O_2$	18:1	46.2
Linoleic	$C_{18}H_{32}O_2$	18:2	17.5
Arachidic	$C_{20}H_{40}O_2$	20:0	1.7
Total Saturated Fatty Acid			33.3
Total unsaturated Fatty Acid			64.2

The fuel properties of the biodiesel (Madhuca indica biodiesel) and Diesel were determined using standard test procedures (are given in Table 3). The calorific value is a measure of energy content of the fuel and is a very important property of biodiesel, which determines its suitability as an alternative to mineral Diesel. The calorific value of Madhuca indica oil biodiesel (MIOB) and Madhuca indica oil is 37.2 and 35.8 MJ/kg, which is almost 83.1% and 79.9% of the diesel calorific value (44.8 MJ/kg), respectively. The lower calorific value of MIOB is because of the presence of oxygen in the molecular structure, which is confirmed by elemental analysis also. The flash point and fire point were tested with a closed cup Pensky Marten's apparatus. The flash point is the measure of the tendency of a substance to form flammable mixtures when exposed to air. This parameter is considered in the handling, storage and safety of fuels. The high value of flash point and fire point in the case of MIOB represents it is a safer fuel to handle.

Table no. 3. Comparison of Physico-chemical key properties of synthesized Madhuca indica biodiesel with different non-edible Methyl Esters (ASTM D 6751)

Property	Test Method	Diesel	*Jatropha Methyl Ester	MIOME
Density at 15°C (Kg/m ³)	ASTMD 1298	832	0.880	882
Kinematic viscosity @ 40°C (cSt)	ASTMD445	4.7	4.84	5.6
Calorific Value (MJ/kg)	ASTMD240	42.49	37.2	36,900
Flash Point(°C)	ASTM D93	53	103	129
Fire point(°C)	ASTM D93	58	132	174
Cloud Point (°C)]	ASTM D2500	-2	11	8
Pour Point(°C)	ASTM D2500	-5	6	4

*(Anjana Srivastava and Ram Prasad, 2000)

Engine Testing Method

The engine was provided with a hemispherical combustion chamber with overhead valves operated through push rods. Eddy current dynamometer has been used for measurement of output. The injector opening pressure and the static injection timing as specified by the manufacturer was 205 bar and 23°BTDC respectively.

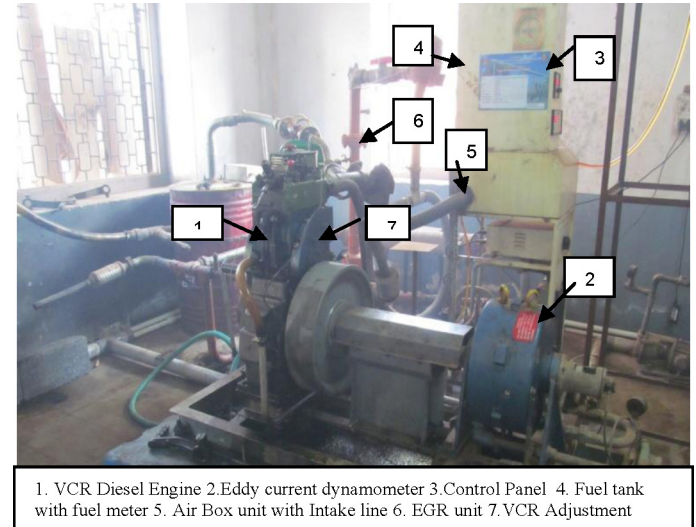


Figure 1. Experimental setup

The Cooling of the engine was accomplished by circulating water through the jackets on the engine block and cylinder head. A piezoelectric pressure transducer was mounted with the cylinder head surface to measure the cylinder pressure. Engine performance tests were performed on a single-cylinder, constant-speed (1500 rpm), four-stroke variable compression ratio (VCR) diesel engine fitted with an eddy current dynamometer as shown in Figure 1.

The specifications of the engine are given in Table 4.

Table no. 4. Experimental engine specifications

Engine Type	Single-cylinder, 4-stroke, constant speed (1500 rpm), variable compression ratio (VCR) CI engine
Make and Model	Kirloskar, TV1
Ignition System	Compression Ignition
Bore	87.5 mm
Stroke	110 mm
Displacement Volume	660 cc
Range of Compression Ratio	12:1 to 18:1
Arrangement of Valves	Overhead
Cooling Medium	Water Cooled
Rated Power	3.75 kW at 1500 rpm
Fuel Injection Timing	24° bTDC
Type of Combustion Chamber	Hemispherical Open