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Experimental investigation on a DI diesel engine fuelled with Madhuca Indica ester and diesel blend

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ABSTRACT

Biodiesel is a fatty acid alkyl ester, which is renewable, biodegradable and non-toxic fuel which can be derived from any vegetable oil by transesterification. One of the popularly used biodiesel in India is Mahua oil (Madhuca Indica). In the present investigation Mahua oil was transesterified using methanol in the presence of alkali catalyst and was used to study the performance and emission characteristics. The biodiesel was tested on a single cylinder, four stroke compression ignition engine. Engine performance tests showed that power loss was around 13% combined with 20% increase in fuel consumption with Mahua oil methyl ester at full load. Emissions such as carbon monoxide, hydrocarbon were lesser for Mahua ester compared to diesel by 26% and 20% respectively. Oxides of nitrogen were lesser by 4% for the ester compared to diesel.

1. Introduction

Depending on climate and soil conditions, different nations are looking for different vegetable oils as a diesel fuel substitute; soybean oil in the USA, rapeseed and sunflower oils in Europe, palm oil in South East Asia and coconut oil in Philippines are being considered as substitutes for diesel fuel. As the edible oil demand is higher than its domestic production, it is not possible to use edible oils for vehicular applications. Being a tropical country, India is rich in forest resources having a wide range of trees, which yield a significant quantity of oilseeds [1]. The production of non-edible oils in India is as follows: Mahua-180; Sal-100; Karanja-55; Kusum-25; and Ratanjyot-15 kt y^{-1}. Mahua (Madhuca Indica) oil is a non-edible oil available in plenty in India. The two major species of genus Madhuca found in India are Madhuca Indica (latifolia) and Madhuca longifolia (longifolia). Madhuca latifolia is a medium sized to large deciduous tree, distributed in South India, and evergreen forests. The tree is planted in most parts of India, propagating either by itself or its own seeds [2,3]. M. Latijolia is a deciduous white tree M. Congijolia is evergreen or semi ever green tree. The storage condition determines the quality of expelled oil, as the kernels are susceptible to both fungus and insect attack during the storage. The Free Fatty Acid (FFA) of oil from fresh kernels is 1–2 percent. Poorly stored kernels yield oil of 30% FFA or even higher. Mahua seed contains 35% oil and 16% protein. The kernel contains about 50% oil and using expeller 34–37% of oil can be recovered [4]. The quality of expelled oils depends largely on the storage condition of the kernels. Fresh oil from properly stored seeds was yellow in colour, while commercial oils are generally greenish-yellow [5–7].

With used cooking oils as raw material, by adopting continuous transesterification process a high quality glycerol

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from biodiesel by-product (glycerol) was obtained. It has been mentioned that there are four primary ways to make biodiesel, direct use and blending, micro emulsions, thermal cracking (pyrolysis) and transesterification. The most commonly used method is transesterification of vegetable oils and animal fats. The transesterification reaction is affected by molar ratio of glycerides to alcohol, catalysts, reaction temperature, reaction time and free fatty acids and water content of oils or fats [1]. The effect of methyl ester of rapeseed oil as a fuel in an indirect injection diesel engine was studied [8]. It was observed that the efficiency improved by 10%, CO emission increased by 6% with a marginal increase in smoke and 45% reduction in hydrocarbon emission. Experiments were conducted on a 5.9 L diesel engine with esterified soybean oil for durability trial upto 160,000 km [9]. It has been reported that the engine output was increased by 3%. HC, CO, smoke and particulate matter showed lesser values whereas NOx emission was higher for biodiesel operation. It has been concluded that the fuel injection timing has to be optimized for reduced emissions and higher power for biodiesel operation. The effect of soybean oil ester on the performance and emissions on a 4 cylinder DI turbocharged diesel engine for 200 h of operation was performed [10]. It was observed that the engine performance and specific fuel consumption with soybean oil esters did not differ to a greater extent with that of diesel. It was also observed that the deposits on the pistons and top ring grooves were higher for methyl & butyl ester. It has been concluded that all the emissions of esters were similar to diesel except NOx. Carbon–carbon double bond introduces a kink into, and thereby distorts the linearity of, run carbon–carbon single bonds. This kinked configuration fosters intra- or inter-molecular interactions in the fuel that reduces compressibility, leading to earlier injection [11]. Aspects related to the feasibility of the production of biodiesel from waste-recycled oils is an attempt to help reduce the cost of biodiesel. From the results it was observed that, the best yield was obtained using a methanol-to-oil molar ratio of 6:1, potassium hydroxide as catalyst (1%) and 65 °C temperature for 1 h. The yield obtained from waste vegetable oil was 96% under optimum conditions, comparable to that obtained from neat vegetable oil [12].

2. Madhuca Indica

The calorific value of Mahua oil (Madhuca Indica) is lower by 14–15% compared to Diesel. However, its use in direct injection compression ignition engine is restricted by unfavorable physical property such as kinematic viscosity, poor atomization etc. [2]. The kinematic viscosity of Mahua oil is about 12 times higher than that of diesel. Therefore the use of Mahua oil results in poor fuel atomization, incomplete combustion, carbon deposition on the injector and valve seats sticking, resulting in serious engine fouling [13]. This necessitates a reduction in viscosity of Mahua oil for use as fuel in direct injection compression ignition engines [3]. The Mahua oil is converted into Mahua Oil Methyl Ester (MOME) by two stage processes, namely acid esterification followed by alkaline transesterification [14]. The properties of Mahua oil are given in Table 1 [26].

Table 1 – Properties of MOME.

Property	MOME
Chemical formula	$(C_{18}H_{34}COOH)_3\ C_3H_5$
Molecular weight, kg kmol^{-1}	926
Stoichiometric AFR on mass basis	12.53
Stoichiometric AFR on molar basis	402.22
Specific gravity	0.865
Flash point, °C	130
Fire point, °C	138
Acid value, (KOH value g kg^{-1})	0.47

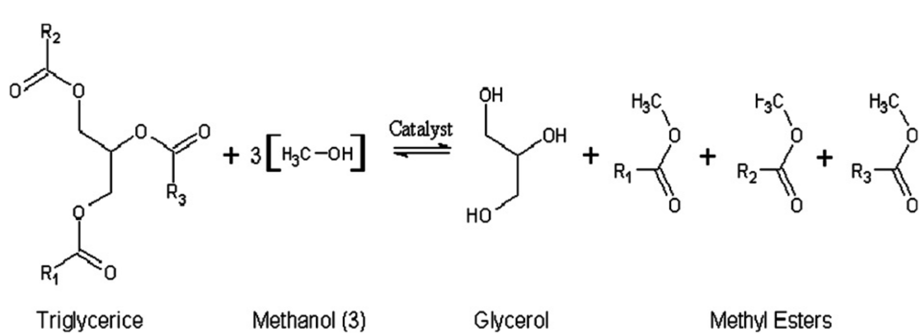
2.1. *Acid esterification*

Acid esterification is the chemical reaction between FFA and methanol in the presence of acid catalyst for the conversion of FFA into mono alkyl methyl ester [15–17]. The FFA present in Mahua oil is 16%. Since FFA reacts with alkaline catalyst and produces soap, if Mahua oil is directly used in the alkaline transesterification process, it is necessary to avoid soap formation which greatly affects the transesterification efficiency [5]. The acid esterification reaction is represented by equation (1).

$$RCOOH + CH_3OH \rightarrow RCOOCH_3 + H_2O \quad (1)$$

2.2. *Alkaline transesterfication*

Alkaline transesterification is the chemical reaction between triglyceride (triester) and methanol in the presence of alkaline catalyst to produce monoester [18]. The long and branched chain of triglyceride molecules are transformed into monoesters and glycerin [19]. The transesterification reaction is represented by the following reaction



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