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Full Length Article

Analysis of properties and estimation of optimum blending ratio of blended mahua biodiesel

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ABSTRACT

The mahua (Madhuca indica) is a non edible oil tree abundantly found in India. The kernel of mahua fruit contains 35–40% of oil which can be a good source of biodiesel. In this paper biodiesel has been prepared from raw mahua oil by transesterification process and different properties of mahua biodiesel have been studied. It has been found that the physico-chemical properties are within the range of different specification standards like ASTM D-6751 of USA, EN-14214 of Europe and IS-15607 of India. It contains around 41.2% saturated and 58.8% unsaturated fatty acid. Though viscosity of raw mahua oil reduces after transesterification, still it is higher than mineral diesel. The cold flow properties like cloud point, pour point and cold filter plugging point (CFPP) are also higher than mineral diesel. In this study mahua biodiesel has been blended with mineral diesel in different volumetric percentage and properties of blended biodiesel have been evaluated against the relevant standards. The different regression equations have been derived to predict the properties at different blending ratio. The developed mathematical models show higher coefficient of regression value (R^2) between biodiesel properties and blending percentage. Blending ratio up to 0.3 i.e. 30% blending has been recommended as optimum blending ratio taking Cold Filter Plugging Point (CFPP) into account.

1. Introduction

The mineral diesel is the prime liquid fuel, being used in different sectors like transportation, power, agriculture etc. The transport sector plays an important role in the economic development of a country and alone consumes more than 70% of the total diesel consumption. Every year there is addition of number of transport vehicles to the existing fleet and proportionally diesel consumption is also increasing. Industrial and agricultural sectors also consume mineral diesel for generator set and water pumps. Diesel engines are being preferred for its high reliability, energy efficiency, durability and low operational cost by both manufacturers and users. But the source of mineral diesel is depleting whereas the demand is increasing day by day. This non-renewable fuel emits pollutants like Hydrocarbon (HC), Carbon Monoxide (CO), Oxides of Nitrogen (NOx), Particulate Matter (PM) and smoke while burning. The vehicular pollution is a major source of air pollution which is a prime cause of different respiratory diseases and global warming. The presence of sulphur in mineral diesel is the cause of acid rain. The harmful effect of pollution is not only limited to human beings, but it also affects the other species. These factors laid to use the biodiesel derived from biomass which is renewable in nature.

Biodiesel is a mixture of mono-alkyl ester of long chain fatty acids obtained from vegetable oil or animal fat through transesterification process [1]. It is a renewable fuel that contains 10–12% more oxygen and its properties are closer to diesel [2]. In transesterification process the lipid feed stock containing fatty acid methyl ester is converted to biodiesel. In this process when vegetable oil heated to a temperature of around (55–60 °C) is mixed with alcohol in presence of catalyst like sodium hydroxide (NaOH) or potassium hydroxide (KOH), the vegetable oil gets separated into two layers. The top layer having low density liquid is biodiesel and the thick bottom layer is called glycerol. Biodiesel is biodegradable and favourable to atmosphere [3]. Many researchers have studied the emission control of vehicles by using biodiesel and found that biodiesel reduces the exhaust emission pollutants like Carbon Monoxide (CO), Particulate Matter (PM) and Hydro Carbon (HC) to a greater extent. According to a study conducted by the united environment protection agency the use of 100%

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biodiesel can reduce the CO and PM to 48% and HC to 68% [4]. Other important characteristics of biodiesel are lower vapour pressure and higher flash point [5]. It also has higher cetane number [6]. Higher cetane number indicates shorter delay period and better combustion. Higher flash point shows that the biodiesel is safer when fire safety is concerned. But simultaneously it is having different demerits like poor oxidation stability, poor cold flow properties and higher Oxide of Nitrogen (NOx) emission [20,21]. At present the worldwide use of biodiesel is in the blended form. The blend of biodiesel and diesel is designated as 'Bn', where 'n' is a number varying from 0 to 100, B0 is mineral diesel and B100 is biodiesel. For example B35 represents 35% biodiesel in a biodiesel diesel blend.

Recently, biodiesel is mainly produced from edible sources like soybean in USA, rapeseed and sun flower in Europe, palm in Malaysia and coconut in Philippines [7]. But in a country like India where the demand of edible oil is higher as compared to other countries because of higher population, the biodiesel from edible oil sources is not viable. As per biodiesel policy of India, there is a target to blend 10% biodiesel with mineral diesel by 2017 and Bureau of Indian Standards (BIS) has established the standard IS-15607 for B100. India is rich in forest reserves and a source of non edible oil trees like Karanja, Mahua, Neem, Moringa, Croton, Karabi, Sea Mango, Kapoak, Kusum, Sal are available in abundance. Most of the seeds go waste in the forest. These forest origin plants do not require any care but simultaneously provide good source of income to tribal people by collecting seeds for oil production. The availability of some forest-origin non-edible oil seeds in India per annum are given by Karanja-55 Killoton, Mahua-180 Killoton, Neem-100 Killoton, Kusum-25 Killoton and Sal-180 Killoton [8,9]. Among these, mahua seed is one of the promising feedstock of biodiesel.

The mahua (Madhuca indica) is a medium-sized tree of Indian origin with a wide round canopy found in central and southern India, mostly in forest areas. It belongs to the family Sapotaceae. It can grow in arid environment and different soil conditions. It can grow up to 20 m in height. Both its flower and fruit are very sweet and delicious. The mahua flower is used for liquor production. It is rich in sugar and next to cane molasses. The mahua liquor is a source of income for the tribal people. Depending upon the maturity of the mahua tree, the yield ranges from 20 to 200 kg per annum. The kernel of mahua fruit contains 35–40% oil. The calorific value of mahua oil is 36 kJ/kg which is around 14% less than the calorific value of mineral diesel (42 kJ/kg). The direct use of raw mahua oil in diesel engine is not possible due to its unfavourable properties like higher kinematic viscosity, poor cold flow properties and poor spray characteristics. But it can be used after reduction of viscosity by different processes like pyrolysis, microemulsification, dilution, blending and transesterification.

The Prediction of various properties of biodiesel or blends of biodiesel and diesel is vital for the design of different systems of diesel engine. Characteristics like power output, combustion and emission are closely related to fuel properties. Different researchers have studied the physical and chemical properties of biodiesel and blend either experimentally or numerically. Saravanan et al. [10] tested mahua biodiesel in a single cylinder diesel engine and found that there is power loss of 13% with 20% increase in fuel consumption at full load. However there is reduction in CO, HC and NOx by 26%, 20% and 4% respectively. Puhan et al. [11] prepared Mahua Oil Methyl Ester (MOME)/biodiesel, studied its properties and also tested the performance in a single cylinder diesel engine and found that the mahua biodiesel produces lower power output and lower emission than mineral diesel. Raheman and Ghadge [12] studied the properties of mahua biodiesel and found that the kinematic viscosity of biodiesel obtained after transesterification is higher than that of diesel (3.98 against 2.98 mm^2/s for diesel), calorific value is lower than diesel (36.8 against 42.2 MJ/kg for diesel) and pour point is higher than diesel (6 °C against −8 °C for diesel). They tested both neat and blended biodiesel (20%, 40%, 60% and 80%) in a single cylinder diesel engine and recommended that the mahua biodiesel can be blended up to 20% without affecting the power significantly. Godigunur et al. [13] studied the engine performance of mahua biodiesel in a six cylinder diesel engine and recommended that mahua biodiesel can be blended up to 20% without affecting the engine performance and emission. Mofijur et al. [14] tested the blended jatropha biodiesel (B10 and B20) in a single cylinder diesel engine and recommended that both B10 and B20 biodiesel can be used in engine without any modifications. Chen et al. [15] studied the fuel properties and combustion characteristics of jatropha oil biodiesel blend and established a correlation between different fuel properties and recommended up to 40% blending with mineral diesel. Chen et al. [16] studied the fuel properties of soap nut oil biodiesel blend and established correlation between different fuel properties and recommended up to 5–20% biodiesel-diesel blend as the optimum blending ratio. Atabani et al. [17] studied the physico-chemical properties of different blended biodiesels like Croton megalocarpous, Calophyllum inophyllum, Moringa olefera, Palm and Coconut biodiesel and made a regression analysis and found that there is a strong relationship between the properties of diesel and biodiesel blends. Rao et al. [18] established a relationship between different properties like density, viscosity and calorific value among different biodiesels and found that there is a high value of regression among these properties. Dermibas et al. [19] calculated the higher heating value of various vegetable oil and their biodiesel from their viscosity, density and flash point by developing mathematical equations.

The above literature review reveals that mathematical equations can help to predict the fuel properties of blended biodiesel at different blending ratio and some researchers [15–17] recommended for the optimum blending ratio for a particular biodiesel. Raheman and Ghadge [12] and Godigunur et al. [13] recommended up to 20% blending for mahua biodiesel which is very low. No literature is available for prediction of properties of mahua biodiesel numerically. So an attempt has been made in this paper to develop a mathematical relationship between different properties and blending ratio and to find out whether more amount of blending can be done in case of mahua biodiesel or not.

In this paper the characterization of the different properties of raw mahua oil and biodiesel have been done and comparison has been made with different standards of biodiesel like ASTM-D6751, EN-14214 and IS-15607. Then the biodiesel has been blended with mineral diesel at different blending ratios and the properties of different blended fuel have been determined through standard procedure. The mathematical equation for each property has been derived by simple regression model which can help to predict the properties at any blending ratio. Based on the different standards of biodiesel and diesel blends an optimum blending ratio for blended mahua biodiesel has been suggested.

2. Material and method

Raw mahua oil was collected from local area and filtered. The same was kept to get settled. Biodiesel was prepared by transesterfication method. The oil was heated to a temperature of 60 °C and methanol (0.35 v/v) and catalyst sodium hydroxide (NaOH) (0.7% v/v) were added to it. Then the mixture was stirred vigorously and kept for 48 h. After transesterfication the total mixture was separated into two layers. The upper layer was methyl ester and lower layer was glycerol. The upper layer (methyl ester) was separated then warm water about 10% of the methyl ester was added to remove the catalyst present in the ester. The mixture was allowed to settle down for another 48 h. The physico-chemical