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Performance and emission characteristics of an agricultural diesel engine fueled with blends of Sal methyl esters and diesel

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ABSTRACT

The present work deals with an underutilized vegetable oil; Sal seed oil (*Shorea robusta*) as a feedstock for biodiesel production. The production potential of Sal seed oil is very promising (1.5 million tons in a year) in India. The pressure filtered Sal seed oil was transesterified into Sal Methyl Ester (SME). The kinematic viscosity (5.89 cSt), density (0.8764 g/cc) and calorific value (39.65 MJ/kg) of the SME were well within the ASTM/EN standard limits. Various test fuels were prepared for the engine trials by blending 10%, 20%, 30% and 40% of SME in diesel on volumetric basis and designated as SME10, SME20, SME30 and SME40 respectively. The BTE, in general, was found to be decreased with increased volume fraction of SME in the blends. At full load, BSEC for SME10, SME20, SME30 and SME40 were 13.6 MJ/kW h, 14.3 MJ/kW h, 14.7 MJ/kW h and 14.8 MJ/kW h respectively as compared to 13.9 MJ/kW h in case of diesel. At higher load conditions, CO, UHC and smoke emissions were found lower for all SME blends in comparison to neat diesel due to oxygenated nature of fuel. SME10, SME20, SME30 and SME40 showed 51 ppm, 44 ppm, 46 ppm and 48 ppm of UHC emissions respectively as compared to 60 ppm of diesel. The NOx emissions were found to be increased for SME based fuel in comparison to neat diesel operation. At peak load condition, SME10, SME20, SME30 and SME40 had NOx emissions of 612 ppm, 644 ppm, 689 ppm and 816 ppm as compared to 499 ppm for diesel. It may be concluded from the experimental investigations that Sal seed biodiesel is a potential alternative to diesel fuel for reducing dependence on crude petroleum derived fuels and also to reduce pollution significantly.

1. Introduction

Energy is one of the key drivers for socio-economic development and fossil fuels contribute about 80% of the world's energy needs [1]. However, uncertainties about long term supply of these fuels coupled with prize increase and environmental degradation due to indiscriminate burning of these fuels is of great concern as well. The global warming and environmental degradation mandates emission reduction strategies, either by improved engine technology or use of environmental friendly fuels [2–4]. Biodiesel has emerged as one of the most important sustainable fuels for reducing air pollution and providing new energy sources in rural communities in line with the Millennium Development Goals [5–7]. It is very promising owing to its renewability, thus guaranties energy security and environmental benefits.

India's crude oil requirement in 2011–12 was 210 million tones with indigenous production capacity of only 18%. India already has 17% of the World's population and just around 0.8% of the World's known oil and natural gas reserves. The energy demand is expected to increase due to its increasing population [8]. Diesel engines play a significant role in Indian economy [9]. Therefore, diesel consumption in India is nearly 4–5 times higher than that of gasoline [8]. However, such engines are also main contributors of harmful emissions and there is an urgent need to look for alternatives to petroleum derived diesel to reduce these harmful emissions [10].

Significant research work has been documented with regards to the production, characterization and engine applications of biodiesel derived from variety of vegetable oils. Koh and Ghazi [11] reviewed the different biodiesel production routes using *Jatropha curcas* oil, highlighting molar ratio of alcohol to oil, catalyst concentration, reaction temperature and reaction time as the main factors affecting the biodiesel yield. The performance of biodiesel in diesel engines has been extensively investigated. The engine power output was found to be equivalent to that of diesel fuel. Dhar et al. [12] reported maximum torque for 10% and 20% KOME

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Definitions/Abbreviations

D100	Neat diesel	ppm	parts per million
SME	Sal methyl ester (Sal seed biodiesel)	°C	degree celsius
SME10	blend of 10% SME and 90% diesel	K	Kelvin
SME20	blend of 20% SME and 80% diesel	cSt	centi-stoke
SME30	blend of 30% SME and 70% diesel	MJ/kg	mega joules per kilogram
SME40	blend of 40% SME and 60% diesel	KW h	kilo-watt-hour
°CA	degrees of crank angle rotations	RPM	rotations per minute
BMEP	brake mean effective pressure	cc	centimeter cube
CO	carbon monoxide	wt.%	percentage by weight
UHC	unburnt hydrocarbons	v/v	volume wise substitution
NOx	oxides of nitrogen	DAS	data acquisition system
BTE	brake thermal efficiency	BSFC	brake specific fuel consumption
BSEC	brake specific energy consumption	*w*/*w*	weight wise substitution

blends which were higher than mineral diesel. Higher Karanja biodiesel blends produced slightly lower torque. These findings are similar to results reported by Karnwal et al. [13].

Similarly, Raheman and Ghadge [14] found comparable performance of Mahua biodiesel and its blends with petroleum based diesel. Other findings include; emissions reduction, increase brake power and BSFC. The BSFC, for all biodiesel–diesel blends increases with increasing blending ratio and decreases with increasing engine speed [15]. Raheman and Ghadge [14] found that, CO, UHC and smoke emissions of Karanja biodiesel blends were lower than that of mineral diesel but NOx emissions were slightly higher. Shehata et al. [16] prepared biodiesel from Cotton seed, Palm and Flax oils, showing less brake power, high BSFC, lower CO and smoke with marginal increase in NOx emissions. Murlidharan et al. [17] indicated almost similar results. Mufijur et al. [18] have also reported reduction in UHC and CO emissions but higher NOx emission.

It is evident that most of the work has been focused on edible oils and a small quantum of work has been carried on non edible oils for biodiesel production and its subsequent utilization. It is also pertinent to note that amongst the non edible oils, Jatropha, Karanja, Mahua and some other feedstocks have been explored. However, Sal seed oil, which is a under utilized non-edible vegetable oil in India, is not adequately studied. The present work deals with the production of biodiesel from "Sal seed oil", its physico-chemical characterization and evaluation of engine performance and emission characteristics.

2. Materials and methods

Sal seed oil was purchased from a local vendor in New Delhi, India. All materials and reagents used were of analytical grade (AnalaR) except otherwise stated. Containers and other apparatus were initially washed with liquid detergent, rinsed with 20% (*v*/*v*) nitric acid and finally rinsed with distilled water.

2.1. Sal seed (Shorea robusta)

Shorea robusta is a large tree up to 50 m tall. It has clean bole, straight and cylindrical branches. The tree develops a long taproot. Its fruit at full size is about 1.3–1.5 cm long. Fig. 1 presents the various parts of the tree and its seeds [19].

2.2. Production and characterization of SME and blends

Biodiesel was produced using transesterification process in which, the triglycerides was reacted with an methanol in presence of KOH as catalyst [20]. The free fatty acid (FFA) content of the Sal seed oil was less than 2%, so a single stage transesterification process was used to produce Sal methyl ester. The transesterification was conducted using 0.5% (*w*/*w*) Potassium hydroxide as catalyst, 65 °C reaction temperature and 90 min reaction time with constant stirring at 450 rpm, followed by different stages as presented in Fig. 2. The same process parameters were used to produce large quantity of biodiesel in the 10 l capacity reactor [21]. The general scheme of the transesterification reaction is presented in Fig. 3, where *R* is a mixture of fatty acid chains.

Based upon the preliminary trials with higher percentage of SME conducted earlier, some undesirable operational challenges were noticed and the maximum blending percentage of 40% was selected for the present work. Four test fuel samples were prepared with 10%, 20%, 30% and 40% of SME with mineral diesel (*v*/*v*) and were designated as SME10, SME20, SME30 and SME40 respectively. The neat diesel was coded as D100. The physico-chemical properties were evaluated for all test fuels taking into considerations experimental uncertainties. The fatty acid profile was determined using Gas chromatographic technique described by Alhassan et al. [22].

2.3. Experimental engine setup

A single cylinder, four stroke, water cooled diesel engine was used for the present work. The engine develops 3.5 kW at rated speed of 1500 rpm. The injection pressure was 200 bar. Such engines are extensively utilized in agricultural sector of India for irrigation. The block diagram of experimental setup is presented in Fig. 4. The loading was provided by an eddy current dynamometer coupled with the engine shaft. In addition, a magnetic rpm sensor was attached at the end of the dynamometer for rpm measurement. Two separate tanks were used for diesel and biodiesel (SME) blends. Air flow rate was measured using a mass airflow sensor while fuel consumption rate was measured by 20 cc burette and stop watch with level sensors. The gaseous emissions were measured from an exhaust surge tank. UHC, CO, and NOx were measured with the help of an AVL Digas emission analyzer and smoke opacity was measured using an AVL 437 smoke meter. The uncertainties and measurements repeatability are presented in Table 1.

3. Results and discussion

The experimental results are reported and discussed in the present section. The results of the physico-chemical studies of Sal seed oil is presented as under.