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Comparative study of performance and emissions characteristics of a diesel engine fueled with jatropha and karanja biodiesel

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This study presents extraction of oil by mechanical expeller and solvent extraction technique from jatropha and karanja seeds. Physico-chemical properties of extracted oil, jatropha oil methyl ester (JOME) and karanja oil methyl ester (KOME) were tested for their suitability in diesel engine. Mechanical extraction efficiency with expeller developed by IIT Delhi was found to be better (jatropha, 87%; karanja, 86%) as compared to traditional expeller (67-69%). Induction periods (oxidation stability) at 110°C were found to be: JOME, 1.76; and KOME, 2.24 h. Calorific value of JOME (38.65 MJ/kg) and KOME (40.75 MJ/kg) was comparatively lower to base diesel (44.50 MJ/kg). Comparative performance (brake thermal efficiency, brake specific fuel consumption) and emission (CO, THC, NO_x and smoke opacity) characteristics were tested in 4.4 kW, single cylinder, compression ignition engine with constant speed (1500 rpm).

Keywords*:* Biodiesel, Esterification, Oxidation stability, Transesterification

Introduction

Biodiesel as an alternate diesel fuel has attracted considerable attention around the world due to its renewable, biodegradable, eco-friendly and non-toxic nature[1,2]. Different tree borne non-edible oil seeds (jatropha, karanja, mahua, simaruba, castor and neem) have been identified as a potential source for biodiesel production in India. Crude oil consumption has continued to rise @ 4.8% per annum since 2005[3]. A National Mission on Biodiesel identified *Jatropha curcas* as the most suitable tree-borne oilseeds[4]. Indian approach to biofuels is based solely on non-food feedstocks to be raised on degraded or wastelands, thus avoiding a possible conflict of fuel *vs* food security[5]. One of the major technical issues facing biodiesel is its susceptibility to oxidation upon exposure to oxygen in ambient air[6]. Stability of karanja oil methyl ester (KOME) has been improved by adding different antioxidants[7-9] [tert-butylated hydroxy toluene (BHT), tert-butylated hydroxyanisole (BHA), pyrogallol (PY), propyl galate (PrG) and tert-butyl hydroxyl quinone (TBHQ)]. Oxidation stability describes degradation tendency of biodiesel and is of great importance in the context of possible problems with engine parts. During degradation, main oxidation products (peroxides and hydroperoxides) form shorter-chain compounds such as low molecular weight acids, aldehydes, ketones and alcohols[10-11].

This study presents oil extraction from jatropha and karanja seeds by solvent extraction and mechanical expression designed and fabricated by IIT Delhi[12], preparation of biodiesel [jatropha oil methyl ester (JOME) and KOME] and physico-chemical analysis of oil as well as methyl ester, besides comparative performance and emission study of biodiesel blends (B15) of JOME and KOME and diesel in single cylinder compression ignition (CI) engine.

Experimental Section

Oil Extraction and Characterisation

Jatropha and karanja seeds were collected from IIT campus, New Delhi, India. Seeds were cleaned manually to remove all foreign materials, sun dried and then dried in hot air oven till free from moisture. Seeds were decorticated manually to obtain kernel. For oil content determination[13], grounded samples were extracted by soxhlet apparatus using petroleum ether (b.p. 60-80°C).

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Table 1— Oil yield and extraction efficiency of jatropha and karanja seeds

Process	Jatropha oil		Karanja oil	
	Yield, %	Efficiency, %	Yield, %	Efficiency, %
Solvent extraction	34	100	32	100
Mechanical expeller (traditional)	23	66.67	22	68.75
Mechanical expeller (developed by IIT Delhi)	30	86.95	27-28	85.94

Both types of seeds (50 g each) were grounded separately for 1 min, and sieved (sieve, 2 mm). Extract was concentrated in rotavapour; residual oil was cooled and weighed.

Fatty acid Composition of Seed Oils

Fatty acid composition was determined by gas chromatographic (GC) analysis of fatty acid methyl esters (FAMEs)[14]. GC analysis was carried out against standard FAMEs (sigma make) on a Varian CP-3800 Gas Chromatograph equipped with a flame ionization detector (FID) and a 30 m × 0.25 mm WCOT column coated with 0.25 mm film thickness of polyethylene glycol (PEG) supplied by J &W (Carbowax column). Helium was used as carrier gas (flow rate, 1.0 ml/ min) at a column pressure of 22 KPa. Each sample (0.2 µl) was injected into injection port of GC using a split ratio of 50:1. Compound separation was achieved following a linear temperature program of 160°C (1 min), 160-240°C (4°C/ min), and 240°C (23 min); total run time was 45 min. Composition (%) was calculated using peak normalization method assuming equal detector response. Peaks were identified by co-eluation of standard FAME samples procured from Sigma-Aldrich and analyzed in the same GC conditions.

Transesterification of Oil

FAME of both types of oils was prepared by acid and alkali catalyzed reaction due to high acid value of oil[15]. Acid catalyzed pretreatment was conducted at 55°C with methanol (CH_3OH)/oil at a molar ratio of 6:1 and an acid (conc. H_2SO_4) of 0.5% w/w of oil. Reaction was continued till acid value was lowered and remained constant. Acid catalyst was removed before alkali-catalyzed transesterification. Reaction for preparation of FAME of both types of oils was carried out with CH_3OH/oil at a molar ratio of 6:1 and catalyst (solid KOH pellets; conc. 1% w/w of oil) at 65°C and stirring rate of 600 ppm[15]. Reaction mixture was separated in a separating funnel and upper FAME layer was washed with hot distilled water (70-80°C) until resulting water from washing remains neutral. Moisture was removed from biodiesel by drying at 90-100°C under vacuum and passing FAME layer over anhydrous sodium sulphate.

Fuel Characterization and Stability of Biodiesel

Fuel properties (density, viscosity, flash point, cloud point, pour point, water content etc.) of biodiesel were determined as per Bureau of Indian standards test method (IS-1448). Biodiesel ages more quickly than fossil diesel fuel due to chemical structure of fatty acid alkyl esters. Saturated fatty acid alkyl ester increases stability whereas unsaturated fatty acid alkyl esters reduce stability. Oxidation stability of both JOME and KOME was measured with a Rancimat 743 (Metrohm, Switzerland) instrument. Oxidation period was measured at air flow 10 l/h with the heating block set at 110°C. Experiments were conducted in duplicate and mean value of induction period was measured.

Performance and Exhaust Emissions in Engine

Comparative engine performance and emissions characteristics of JOME B15 and KOME B15 were tested in a Kirloskar make single cylinder, 4-stroke, water-cooled diesel engine (rated power output 4.5 kW at 1500 rpm). Different exhaust emissions from engine were studied keeping varying engine load (0, 25, 50, 75, and 100%) conditions. Each reading was replicated thrice to get reasonable values. Engine exhaust emissions were measured by “AVL 437 Smoke Meter” & “AVL Di-gas Analyser.

Results and Discussion

Oil Yield and Physicochemical Properties

Mechanical extraction efficiency with expeller developed by IIT Delhi was found to be better (Table 1) as compared to traditional expeller. Important physico-chemical properties of jatropha and karnja oils,

Table 2—Fuel properties of diesel–biodiesel blends of methyl ester of jatropha and karanja oil

Fuel blend	Calorific value (ASTM D420) MJ/kg	Density[15°C] (ASTM D4052) g/cm^3	Viscosity[40°C] (ASTM D445) cSt	Flash point (ASTM D93) °C	Cloud point (ASTM D2500) °C	Pour point (ASTM D97) °C
Diesel	44.50	0.83	2.85	77	-4	-9
JB 100	38.65	.88	5.18	151	5	1
KB 100	40.75	.87	4.93	147	6	2
JB15	43.62	0.84	3.36	90	-1.3	-2.7
KB15	43.94	0.84	3.38	89	-1.4	-2.4

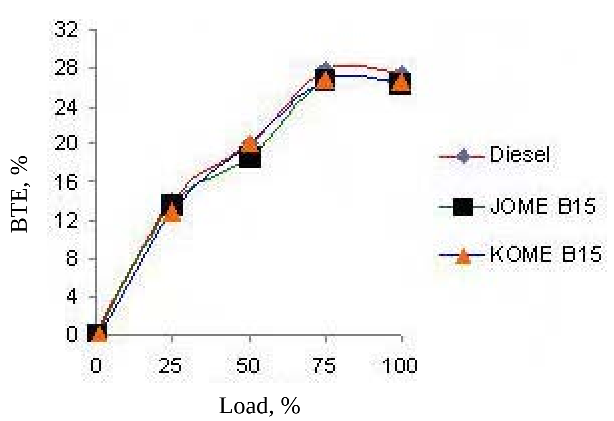

Fig. 1—Brake thermal efficiency for diesel and biodiesel blends

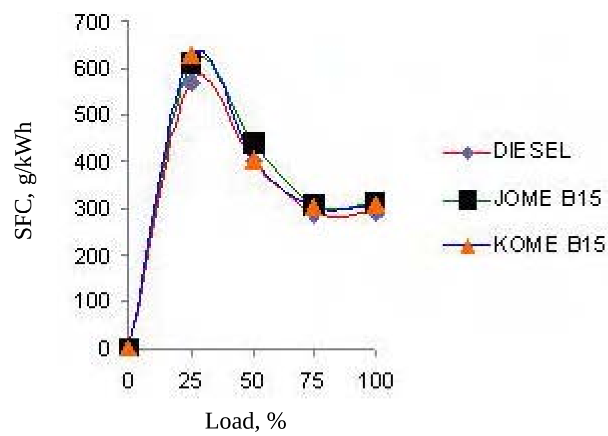

Fig. 2—Brake specific fuel consumption for diesel and biodiesel blends

respectively, were determined as follows: density, 0.92, 0.91 g/cc; viscosity[40°C], 34.8, 31.5 cSt; acid value, 9.86, 11.28 mgKOH/g; iodine value, 98.0, 86.6%; saponification value, 189.7, 188.3 mg KOH/g; and unsaponifiable matter, 1.60, 2.4% (w/w).

Fatty Acid Composition of Oils

Fatty acid compositions of jatropha oil and karanja oil, respectively, were found as follows: palmitic, 14.1; 11.6; stearic, 4.3, 7.5; oleic, 34.3, 51.5; linoleic, 29.0, 16.0; linolenic, 0.3, 2.6; and others, 18, 10.8%.Thus saturated fatty acids (palmitic and stearic) contributes 18.4% in jatropha oil and 19.1% in karanja oil. Saturated fatty acids increase ignition quality (cetane number), stability and cloud point of fuels. Unsaturated fatty acids (oleic, linoleic and linolenic) were: JOME, 63.6; and KOME, 70.1%. Due to higher percentage of unsaturated fatty acids in KOME compared to JOME, induction period for KOME was found 2.24 h, while for JOME it was 1.76 h at constant temperature of 110°C. Fuel properties of test blends (Table 2) were tested before engine study.

Engine Study

Performance

Comparative performance studies of JOME B15 and KOME B15 with base diesel were carried out in single cylinder CI engine. Variation in brake thermal efficiency (BTE, Fig. 1) and brake specific fuel consumption (BSFC, Fig. 2) were plotted to ascertain suitability of test blends for engine application. Performance characteristics were conducted at varying load (0-100% in five consecutive steps) on engine. As load increases, BTE of JOME B15 and KOME B15 blends increases as expected in the base diesel. Test blends of both JOME B15 and KOME B15 show marginally lower BTE compared to base diesel. However at 50% load, thermal efficiency of karanja biodiesel blends were observed almost same as base diesel. KOME B15 gives better thermal efficiency compared to JOME B15 at all loads. Calorific value (38.65 MJ/kg) of JOME is lower compared to KOME (40.75 MJ/kg). This effect leads to decrease of marginal BTE of all blends of JOME. Test blends of JOME and KOME exhibits marginally higher BSFC compared to

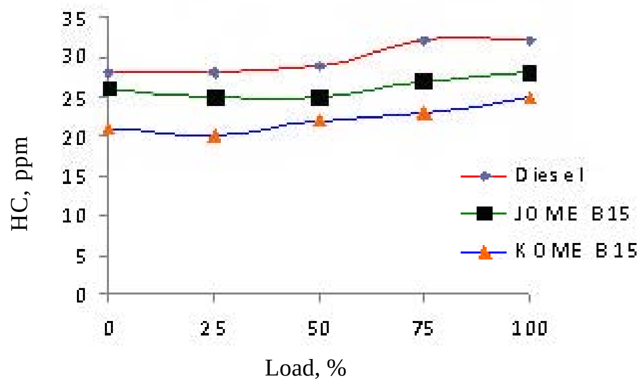

Fig. 3—Hydrocarbon for diesel and biodiesel blends

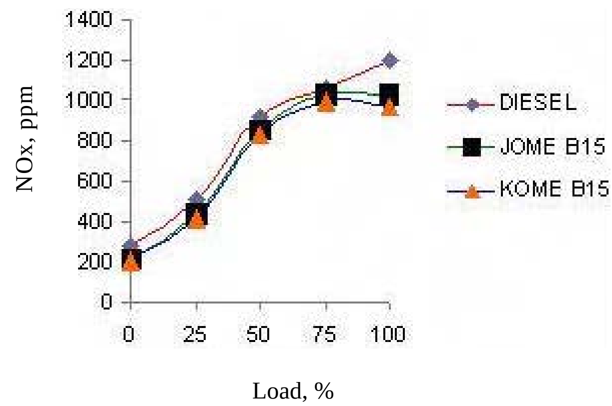

Fig. 4—Oxides of nitrogen (NOx) for diesel and biodiesel blends

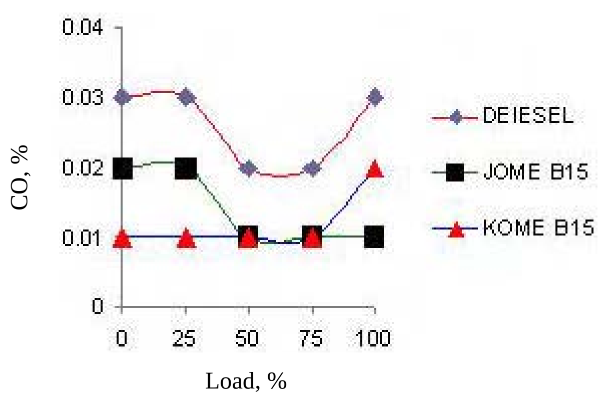

Fig. 5—Carbon monoxide (CO) for diesel and biodiesel blends

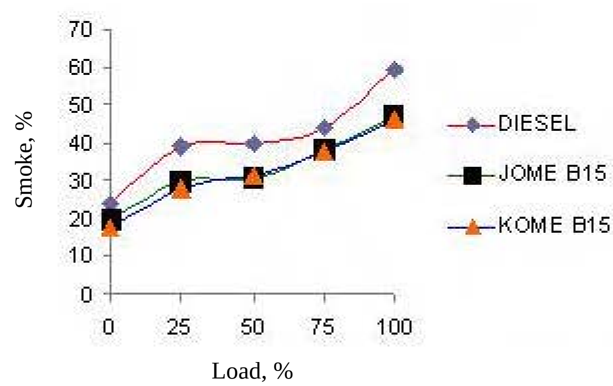

Fig. 6—Smoke for diesel and biodiesel blends

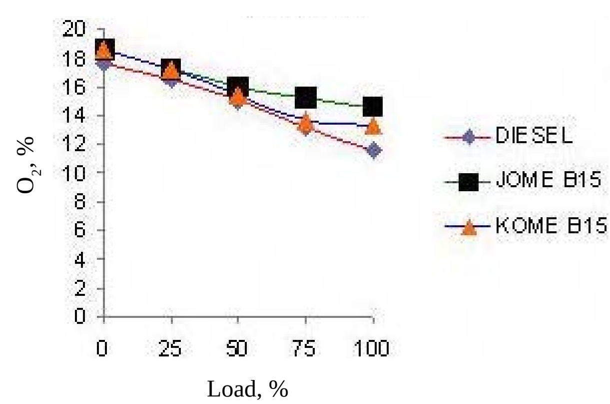

Fig. 7—Oxygen in exhaust for diesel and biodiesel blends

base diesel, attributed to low heating value and thereby more quantity of fuel is required for same quantity of power output. The same power output is due to lower calorific value of diesel-biodiesel blend fuel. However, trend of variation is same as base diesel.

Exhaust Emissions

In diesel engine, major pollutants [smoke, unburnt hydrocarbons (HC) and oxides of nitrogen (NOx)] are predominant. Different exhaust emissions [unburnt HC and NOx, and carbon monoxide (CO)] from engine were measured for biodiesel-diesel blends with base diesel. HC emissions for both the test blends were lower compared to base diesel (Fig. 3). However, in case of KOME B15, HC emissions were less than JOME B 15, possibly due to complete combustion of fuel leads to higher thermal efficiency of KOME B15 in comparison to JOME B15 at all loads. Up to 50% loads, emissions of NOx was lower (Fig. 4); in all cases, this can be attributed that combustion efficiency of biodiesel is higher than that of diesel, as also reported[16], resulting in lower combustion chamber temperatures and lower NOx formation. However, at higher loads, there was marginal increase of NOx for both types of test blends. At partial and higher loads, CO emissions show (Fig. 5) no rising trend and remain stable upto higher loads. Smoke for both the test blends were reduced significantly at all loads (Fig. 6). Presence of oxygen atoms in the straight vegetable based alky ester helps to combust fuel completely and reduces smoke substantially. Oxygen content in exhaust emissions was higher for both types of test blends (Fig. 7).

Conclusions

Efficiency of IIT Delhi developed expeller was found to be > 85% of total oil content. Major fatty acid found in two types of oils was oleic acid (C18:1) [jatropha (34%) and karanja (52%)] followed by linoleic acid (C18:2) [jatropha (29%) and karanja (16%)]. Straight vegetable based fuel oxidized in short periods. Induction time for KOME was found to be higher (2.24 h at 110in:°C) than JOME (1.76 h at 110°C). Both test blends (JOME B15 and KOME B15) showed performance close to diesel. Therefore, these blends can be used in IC engine. However, KOME B15 showed better performance at all loads (zero to full loads). Marginal lower BTE can be attributed to lower calorific value of test blends. Lower HC and smoke opacity emissions of biodiesel blends are added values from environmental point of view.

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