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Full Length Article

Effect of cetane enhancer on *Moringa oleifera* biodiesel in a thermal coated direct injection diesel engine

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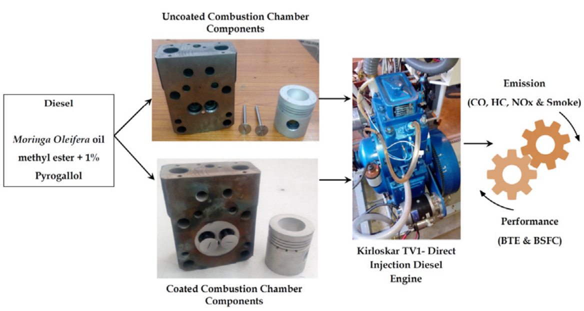
GRAPHICAL ABSTRACT



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ABSTRACT

In the present study, raw *Moringa oleifera* oil was converted into biodiesel using transesterification process. The physical and chemical properties were examined based on ASTM standards and compared with diesel. The chemical composition of biodiesel was examined with Fourier Transform Infrared Spectroscopy (FTIR) and Gas Chromatography and Mass Spectrometry (GC–MS). To improve the properties of the prepared biodiesel sample, an anti-oxidant namely 1% Pyrogallol was added. The engine combustion chamber components like piston head, cylinder head and intake and exhaust valves were thermally coated with Yttria Stabilized Zirconia (YSZ) to convert the conventional engine into low heat rejection engine. Kirloskar TV1 model direct injection water cooled diesel engine with eddy current dynamometer was used for experimental analysis. In coated engine, the improved brake thermal efficiency and reduced brake specific fuel consumption were observed with biodiesel and additive blend. Lower carbon monoxide (CO), hydrocarbon (HC), oxides of nitrogen (NOx) and smoke were observed with biodiesel and anti-oxidant blend than diesel fuel.

1. Introduction

The reserves of fossil fuels were shrinking with their cumulative demand every day. Unremitting usage of these resources leads to the emission of harmful greenhouse gases to the environment. Recently, engine exhaust emissions have increased drastically owing to the continuous development in the transportation sector. Thus, the exhaustion of conventional fuel, environmental changes and oscillation in the price of fuel has induced the researchers to explore eco-friendly alternative energy resources. Biodiesel is considered as the most prominent alternative to the conventional fuel since it is biodegradable, non-toxic, and renewable and less carbon content fuel.

Biodiesel was chiefly acquired from various sources like vegetable oils, animal fats, and waste cooking oil. Production of biodiesel initiated from edible and non-edible sources. Use of edible oils for the biodiesel production was not advisable due to impact of negative food

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cycle. Biodiesel was obtained from non-edible oils using transesterification process. Transesterification process was mainly carried out to improve the calorific value and reduce the kinematic viscosity of oil. Recently, many biodiesels were produced from non-edible oils namely, Kusum (*Schleichera Oleosa*) oil, Tobacco (*Nicotiana tabacum*) oil, *Argemone mexicana* oil, Amari (*Amoora Wallichii King*) oil, Lemongrass oil, Kutkura (*Meyna spinosa* Roxb. Ex.) oil, *Annona* oil and so on. Table 1 shows the effect of biodiesel and its blends on engine performance, combustion and emission characteristics.

Moringa oleifera is a persistent species that belongs to Moringaceae family. It was originated from the northeast Indian areas and extensively distributed in India, Egypt, the Philippines, Ceylon, Thailand, Malaysia, Burma, Pakistan and Singapore. Typically, *Moringa oleifera* grows in tropical climate since, it is drought tolerant and ability to grow in poor soil. *Moringa oleifera* contains 33–41% of oil content. Fatty acid profile of *Moringa oleifera* showed the presence of acids like oleic acid (> 70%) and behenic acid. *Moringa oleifera* is also termed as "behen oil" and "ben oil" owing to the presence of behenic acid (docosanoic acid). The aforesaid properties of *Moringa oleifera* permit the use of this oil for the biodiesel production.

On comparing with diesel, the usage of biodiesel in engine did not produce the rated power due to its lower calorific value [9,10]. Also, the presence of esters in the oils may affect the fuel line leads to chocking in fuel injector and decrease in fuel filter life. To attain the rated power with the biodiesel, many techniques were employed in diesel engine like thermal barrier coating, pre-heating, addition of an additive to fuel, varying the injection pressure and injection timing. Among the aforesaid techniques, thermal barrier coating and addition of an additive to biodiesel were considered as the vital techniques for the better performance and emission characteristics. Thermal barrier coating helps to retain the heat inside the combustion chamber due to low heat rejection to the cooling water. The coating of combustion chamber components helps to reduce the heat transfer. Many materials were available for thermal barrier coating and some of them were partially stabilized zirconia [11–13], Yttria partially stabilized zirconia [14], zirconium oxide [15], Combination of 88% ZrO_2, 4% MgO and 8% Al_2O_3 [16,17], Magnesium zirconate [18], Combination of Al_2O_3-TiO_2 [19], Waste fly ash [20], Al_2O_3 [21] and so on. The combustion chamber components like cylinder head, piston head and inlet and exhaust valves were thermally coated to obtain better performance and emission characteristics. Table 2 shows the effect of biodiesel and its blends on performance, combustion and emission characteristics of thermally coated diesel engine.

The addition of an anti-oxidant to the biodiesel was considered as the next prominent technique to improve the quality of fuel, without any major modifications in engine. In case of thermal barrier coating, higher NOx emission was produced with biodiesel samples. Synthetic based anti-oxidants were widely used with biodiesel to obtain increased oxygen content in fuel. The presence of oxygen in the fuel leads to complete combustion of the fuel. Butylated hydroxy anisole, Tert-butylhydroxyl quinone, Propyl-gallate and Butylated hydroxy toluene [23] were used as an anti-oxidants with various biodiesels and investigated in diesel engine. 2,6-di-tert-butyl-4-methylphenol (BHA) and 2(3)-tert-butyl-4-methoxy phenol (BHT) were employed as an anti-oxidant to investigate the fuel properties of diesel and palm diesel blends [24]. Three antioxidants namely N, N′-diphenyl-1, 4-phenylenediamine (DPPD), N-phenyl-1, 4-phenylenediamine (NPPD) and 2-ethylhexyl nitrate (EHN) were used with 20% of *Calophyllum inophyllum* biodiesel (CIB20) in a direct injection diesel engine. Aimed at engine exhaust emission, biodiesel with anti-oxidant showed lower NOx emission than pure biodiesel with an increase in CO and HC emissions [25]. The aforesaid results were affirmed with anti-oxidants like A- tocopherol acetate [26] and L-ascorbic acid [27] with neem oil methyl ester and annona methyl ester respectively. To promote the ignition property of biodiesel, certain anti-oxidants like iso-amyl nitrate and di-tertiary butyl peroxide can be mixed with biodiesel (pine oil) and investigated

Table 1
Effect of biodiesel and its blends on engine performance, combustion and emission characteristics.

Source of biodiesel	Engine used	Performance	Combustion	Emission	Ref.
Kusum biodiesel blends (B5, B10, B15 and B20)	Tata India (Telco model), 4 C, 4S, WC, CR 22:1, RP- 39 kW @ 5000 rpm	B10: BTE- ↑, BSFC- ↑ and BSEC- ↓	–	CO- ↓, HC- ↓, NOx- ↑	Yadav et al. [1]
Tobacco biodiesel blends (10%, 20%, 50% and 100%)	Super star, DI, WC, RP- 14.7 kW @ 1500 rpm,	BTE- ↓, BSFC- ↑	–	CO- ↓, HC- ↓, NOx- ↑ and Smoke- ↓	Parlak et al. [2]
Argemonemexicana biodiesel blend (20% and 40%)	Kirloskar (TV1), 1C, 4S, DI, WC, RP- 3.5 kW @ 1500 rpm	BTE- ↓, BSFC- ↑	–	CO- ↓, HC- ↓ and NOx- ↑	Parida and Rout [3]
Chicha biodiesel blends (20%, 40%, 60% and 80%)	Kirloskar (TAF1), 4S, 1C, DI, WC, RP- 4.4 kW @ 1500 rpm	BTE- ↓, BSFC- ↑	–	CO- ↓, CO_2- ↑, HC- ↓ and NOx- ↑	Tamilselvan and Nallusamy [4]
Lemon peel oil biodiesel blends (20%, 40%, 50% and 100%)	Kirloskar (TAF1), 4S, 1C, DI, WC, RP- 4.4 kW @ 1500 rpm	BTE- ↑, BSFC- ↓ and BSEC- ↓	ICP- ↑, HRR- ↑	CO- ↓, HC- ↓, NOx- ↑ and Smoke- ↓	Ashok et al. [5]
Lemongrass biodiesel and blends (10%, 20%, 30% and 40%)	Kirloskar (TV1), 1C, 4S, DI, WC, RP- 5.2 kW @ 1500 rpm	BTE- ↓, BSEC- ↑	ICP- ↓, HRR- ↓	CO- ↓, CO_2- ↑, HC- ↓, NOx- ↑ and Smoke- ↑	Dhinesh et al. [6]
Kutkura biodiesel blends (10% and 20%)	Kirloskar (TV1), 1C, 4S, DI, WC, RP- 3.5 kW @ 1500 rpm	BTE- ↑, BSFC- ↑	–	Smoke- ↓	Kakati and Gogoi [7]
Annona biodiesel and blends (20%, 40%, 60%, 80% and 100%)	Kirloskar (SV1), 1C, 4S, DI, WC, RP- 5.9 kW @ 1800 rpm, CR- 17.5:1	B20: BTE- ↑, BSFC- ↓	ICP- ↑, HRR- ↑	CO- ↓, HC- ↓, NOx- ↑ and Smoke- ↑	Senthil and Silambarasan [8]

C- Cylinder, DI- Direct Injection, 4S- Four stroke, WC- Water cooled, CR- Compression ratio, RP- Rated power, ICP- In-Cylinder Pressure, HRR- Heat Release Rate, ↑- Increase, ↓-decrease.