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Spray characteristics, engine performance and emissions analysis for Karanja biodiesel and its blends

Sanghoon Lee [a], Chang Sik Lee [b], Sungwook Park [b,*], Jai Gopal Gupta [c,1], Rakesh Kumar Maurya [c,2], Avinash Kumar Agarwal [c]

[a] Graduate School of Hanyang University, Seoul, 04763, Republic of Korea
[b] School of Mechanical Engineering, Hanyang University, Seoul, 04763, Republic of Korea
[c] Department of Mechanical Engineering, Indian Institute of Technology Kanpur, Kanpur, 208016, India

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ABSTRACT

The purpose of this paper is to investigate the effects of blending ratio of Karanja oil methyl ester (KOME) on spray characteristics and to analyze the engine performance and exhaust emissions of Karanja biodiesel blend vis-a-vis baseline diesel. Spray characteristics were analyzed using injection rate and spray visualization experiments for the following injection pressures: 50, 100 and 150 MPa. Engine performance, emission and combustion characteristics were also investigated at various engine operation conditions.

From a comparison of the spray evolution of Karanja biodiesel 40% (v/v) blend (KB40) vis-a-vis baseline diesel, the spray shape revealed a narrower and deeper penetrating spray development process for KB40. However, at an ambient pressure of 4 MPa, which is considered to be similar to the cylinder pressure of a test engine, KB40 exhibited a spray evolution behavior (spray penetration and shape) closely resembling that of diesel. In the engine experiment, lower max torque, brake thermal efficiency (BTE) and exhaust gas temperature, in addition to higher brake-specific fuel consumption (BSFC) were observed for biodiesel blend compared to diesel due to lower heating value of Karanja biodiesel.

1. Introduction

In the interest of increasing diversity of energy sources and to reduce the galloping petroleum consumption, the possibility of using alternative fuels for internal combustion engines are being explored worldwide. Amongst various alternative fuels, biodiesel has emerged as a promising substitute for the compressed ignition (CI) engines due its similar properties as that of petroleum diesel and its environmental benefits [1]. Biodiesel can be produced from edible or non-edible vegetable oils and is regarded as renewable, biodegradable and non-toxic fuel [1,2]. In addition, biodiesel contains oxygen, therefore it reduces harmful engine-out emissions and improves engine combustion performance [3,4]. For these reasons, biodiesel is considered as a promising fuel for Internal Combustion (IC) engines, and is widely used either as pure fuel or blended with mineral diesel in varying proportions, depending on availability.

Significant number of research studies have been carried out for successful usage of biodiesel in IC engine and these studies have reported on various aspects of spray characteristics, engine performance, emission characteristics and engine durability [5–15]. Fuel spray studies are very important because the fuel spray directly affects the mixing of fuel with air and resulting combustion. The spray characteristics therefore directly affect the engine performance, power output and emission. However the spray characteristics are directly controlled by the physical properties of fuel therefore it is important that biodiesel spray characteristics are thoroughly investigated and their relationship with the engine performance and emission is also established well before its large scale implementation. While performing spray visualization and phase Doppler particle anemometry (PDPA) experiments, Park et al. [5] reported that biodiesel has longer spray penetration due to its

* Corresponding author. School of Mechanical Engineering, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul, 04763, Republic of Korea.
E-mail address: parks@hanyang.ac.kr (S. Park).
[1] Current Affiliation: Department of Mechanical Engineering, Govt. Women Engineering College, Ajmer, 305002, India.
[2] Current Affiliation: School of Mechanical Materials and Energy Engineering, Indian Institute of Technology Ropar, Rupnagar, 140001, India.

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Abbreviations

BMEP	Brake mean effective pressure
$BSCO_2$	Brake specific carbon dioxide
BSCO	Brake specific carbon monoxide
BSFC	Brake specific fuel consumption
BSHC	Brake specific hydrocarbon
$BSNO_X$	Brake specific oxides of nitrogen
BTE	Brake thermal efficiency
CAD	Crank angle degrees
CO_2	Carbon dioxide
CO	Carbon monoxide
CD	Combustion duration
CRDI	Common rail direct injection
CI	Compressed ignition
CAP_{max}	Crank angle position for P_{max}
$CA_{ROPRmax}$	Crank angle position for $ROPR_{max}$
CA_{10}, CA_{50}, CA_{90}	Crank angle position corresponding to different heat release percentages (10%, 50% and 90%)
DOC	Diesel oxidation catalysts
EGR	Exhaust gas recirculation
EGT	Exhaust gas temperature
FIP	Fuel injection pressure
IC	Internal combustion
KB40, KB60, KB100	40%, 60% and 100% (v/v) Karanja biodiesel blend with diesel
KOME	Karanja oil methyl ester
P_{max}	Maximum in-cylinder pressure
$ROPR_{max}$	Maximum rate of pressure rise
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_X	Oxides of nitrogen
O_2	Oxygen
PDPA	Phase Doppler particle anemometry
PM	Particulate matter
SOC	Start of combustion
SOF	Soluble organic fraction
T_{ASOE}	Time after start of energizing
THC	Total hydrocarbone
ULSD	Ultra low sulfur diesel

higher surface tension and biodiesel spray is atomized to a lesser degree in comparison to mineral diesel. Analyzing the relationships among fuel properties and engine performance, Kegl [7] concluded that higher density, viscosity and lower vapor pressure of biodiesel under high fuel injection pressure systems lead to advanced injection timings, and it also leads to earlier increase in the in-cylinder gas pressure, temperature and heat release rate compared with mineral diesel. They also reported that higher oxygen content of biodiesel results in lower smoke and carbon monoxide emissions but slightly higher hydrocarbon emissions from the engine. Various meaningful results of emission characteristics of biodiesel fuelled engines are reported in several studies [8–14]. To investigate the emission characteristics of biodiesel, especially on particulate size-number distribution in the exhaust gas, Agarwal et al. [11,12] performed engine experiment using a single cylinder research engine equipped with a common rail direct injection (CRDI) system and carried out experiments with different start of injection timings and fuel injection pressures. They reported that increasing the fuel injection pressure resulted in reduction in number concentration of particulate at all engine loads. This is because increasing fuel injection pressures led to advanced injection timings with better atomized fuel spray, and more time available for preparation of combustible mixture. Regarding trend of higher NO_X emission from biodiesel fuelled engines compared to mineral diesel, Varatharajan and Cheralathan [8] summarized several factors based on different properties of biodiesel. They suggested that advanced fuel injection timing, increased adiabatic flame temperature, higher heat release rate, and stoichiometric burning of biodiesel are possibly responsible for higher NO_X emissions from biodiesel fuelled engines. In regard to engine durability and endurance test using biodiesel, Agarwal [9] experimentally evaluated deposit formation of biodiesel on cylinder head, piston top and injector tip by performing long-term endurance test. It was reported that the carbon deposits of biodiesel fuelled engines were substantially lower than that of diesel-fuelled engine. Comparing the weight of piston deposit scrapped, it was also found that deposits in the case of biodiesel-fuelled engine were 40% lower compared to diesel-fuelled engine. In addition, carbonization level of biodiesel injector after 512 h of operation was significantly less than that of diesel injector after 200 h of engine operation.

There are various biodiesels depending on its different origin and manufacturing processes, and it is also well known that depending on their physical and chemical properties such as carbon chain length, saturation, location and types of double bond, the characteristics of engine performance and emissions would be different [10,16]. Among various types of biodiesels, Karanja oil methyl ester (KOME) is considered as one of promising biodiesels due to its non-edible origin, similar properties to diesel, as well as its easy growth characteristics even in wastelands [17].

For these reasons, several attempts were made to use Karanja biodiesel as additive with mineral diesel [18–23]. Chauhan et al. [20] investigated the performance, emissions and combustion characteristics of Karanja biodiesel blends (5%, 10%, 20%, 30% and 100%) with mineral diesel in an unmodified diesel engine. They reported 3–5% lower brake thermal efficiency with Karanja biodiesel and its blends compared to mineral diesel. It was stated that higher cetane number of biodiesel leads to shorter ignition delay, which is responsible for lower fuel accumulation in the combustion chamber during premixed combustion phase, resulting in lower heat release rate and lower peak cylinder pressure. NO_X emissions were higher while CO, smoke density and HC were reported to be lower for biodiesel compared to mineral diesel. Dhar and Agarwal [21] investigated the effect of Karanja biodiesel and its blends on engine performance, emissions and combustion characteristics in a diesel engine of a medium size utility vehicle. Slightly lower torque and higher BSFC was observed with higher blends of biodiesel. Earlier start of combustion was reported for lower biodiesel blends, while it was slightly delayed for higher biodiesel blends. Brake specific carbon monoxide (BSCO), brake specific hydrocarbon (BSHC) and smoke emissions from Karanja biodiesel blends were lower than mineral diesel but brake specific oxides of nitrogen (BSNOx) emissions were slightly higher. Barik and Sivalingam [22] conducted experiments for KOME, dual fuel KOME and biogas obtained from anaerobic digestion of Karanja de-oiled cakes in a single cylinder, four-stroke, air-cooled, diesel engine and compared the results with baseline mineral diesel. It was reported that CO, HC emissions and smoke opacity were lowest for KOME because KOME