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Effect of fuel injection pressure and injection timing of Karanja biodiesel blends on fuel spray, engine performance, emissions and combustion characteristics

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ABSTRACT

In this investigation, effect of 10%, 20% and 50% Karanja biodiesel blends on injection rate, atomization, engine performance, emissions and combustion characteristics of common rail direct injection (CRDI) type fuel injection system were evaluated in a single cylinder research engine at 300, 500, 750 and 1000 bar fuel injection pressures at different start of injection timings and constant engine speed of 1500 rpm. The duration of fuel injection slightly decreased with increasing blend ratio of biodiesel (Karanja Oil Methyl Ester: KOME) and significantly decreased with increasing fuel injection pressure. The injection rate profile and Sauter mean diameter (D_{32}) of the fuel droplets are influenced by the injection pressure. Increasing fuel injection pressure generally improves the thermal efficiency of the test fuels. Sauter mean diameter (D_{32}) and arithmetic mean diameter (D_{10}) decreased with decreasing Karanja biodiesel content in the blend and significantly increased for higher blends due to relatively higher fuel density and viscosity. Maximum thermal efficiency was observed at the same injection timing for biodiesel blends and mineral diesel. Lower Karanja biodiesel blends (up to 20%) showed lower brake specific hydrocarbon (BSHC) and carbon monoxide (BSCO) emissions in comparison to mineral diesel. For lower Karanja biodiesel blends, combustion duration was shorter than mineral diesel however at higher fuel injection pressures, combustion duration of 50% blend was longer than mineral diesel. Up to 10% Karanja biodiesel blends in a CRDI engines improves brake thermal efficiency and reduces emissions, without any requirement of hardware changes or ECU recalibration.

1. Introduction

Diesel engines are extensively used and are dominating power sources for road transport sector due to their higher thermal efficiency, operational reliability, robustness, and lower hydrocarbon (HC) and carbon monoxide (CO) emissions. In the last two decades, biodiesel has emerged as a well-accepted alternative to mineral diesel because its utilization requires insignificant modifications in the engine hardware. With advanced fuel injection systems, fuel injection pressures have risen by an order of magnitude in comparison to older mechanical fuel injection systems. It is therefore very important to investigate the effect of fuel injection pressure on comparative performance, emissions and combustion characteristics of biodiesel and mineral diesel for effective utilization of biodiesel in modern CI engines. Boudy and Seers [1] estimated influence of fuel properties on the pressure-wave in the injector feed pipe and injector mass flow rate by modeling of a common-rail diesel injection system and reported that amount of injected fuel mass was mainly affected by the density of fuel. Yehliu et al. observed 12% higher brake specific fuel consumption (BSFC) for B100 (with 15% lower calorific value than diesel) in comparison to mineral diesel in a four-cylinder CRDI engine [2]. Suryawanshi and Deshpande [3] reported slightly higher brake thermal efficiency (BTE) for *Pongamia* biodiesel blends in comparison to mineral diesel. They also reported that retarding the injection timing by 4 crank angle degrees resulted in minor improvement in thermal efficiency at part loads however no change at full load. Grimaldi et al. obtained slightly higher engine efficiency, when the engine was fueled with biodiesel, particularly at high load in comparison to mineral diesel fueled engine [4]. Zhu et al. reported that oxygenated fuels including biodiesel, biodiesel–ethanol and

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biodiesel–methanol blends gave better BTE at all engine operating conditions vis-à-vis mineral diesel [5]. Gumus et al. observed that BTE of mineral diesel decreased as fuel injection pressure increased from 18 to 24 MPa but for biodiesel, BTE increased with increasing fuel injection pressure at full load [6]. Highest achieved BTE for diesel (at 18 MPa injection pressure) and biodiesel (at 24 MPa injection pressure) were 32.1% and 41.3% respectively [6]. Agarwal and Dhar [7] reported that higher fuel injection pressure leads to a longer spray tip penetration and larger spray area compared to lower fuel injection pressures after identical elapsed time beyond the start of injection (SOI) for Karanja biodiesel blends and diesel.

Baldassarri et al. reported 10% reduction in CO emissions by fueling a bus engine by B20 vis-à-vis mineral diesel [8]. Zhu et al. observed lower BSCO emissions for biodiesel fueled engine in comparison to diesel fueled engine [5]. Kousoulidou et al. observed that biodiesel does not have any effect on CO emission levels vis-à-vis mineral diesel in an engine equipped with common rail direct injection system [9]. Suh and Lee [10] reported reduction in CO emissions for biodiesel blends as well as mineral diesel with advanced injection timings. Wang et al. observed that 35% soybean biodiesel blend resulted in reduced HC emissions in comparison to mineral diesel [11]. Gumus et al. reported that NOx emissions generally decreased with increasing fuel injection pressure but the trend was not regular and significant [6].

Kuti et al. investigated the spray formation and combustion characteristics of Palm biodiesel and mineral diesel by using a CRDI system in a constant volume chamber [12]. They observed longer liquid length for biodiesel in comparison to mineral diesel due to higher boiling range of biodiesel [12]. Ignition delay (ID) was shorter for biodiesel due to its higher cetane number. ID reduced with increasing fuel injection pressure and decreasing nozzle diameter [12]. Suh and Lee [10] reported similar combustion pressure and rate of heat release for 5% soybean biodiesel blend and mineral diesel. Lee et al. investigated the effect of biodiesel blended fuels (Biodiesel derived from unpolished rice and soybean) on atomization and combustion characteristics of a common-rail single-cylinder engine. It was reported that higher surface tension and viscosity of biodiesel causes lower Weber number and decreases injection velocity of biodiesel-blended fuels respectively, and result in increased mean droplet size diameter with increasing biodiesel blend ratio. The spray tip penetration was observed to be longer for higher injection pressure. Higher cetane number of biodiesel causes shorter ignition delay, which was responsible for increased peak combustion pressure with increasing biodiesel blend ratio. With increasing biodiesel blend ratio, lower HC and CO were observed, whereas NOx emissions increased, possibly because of fuel oxygen in biodiesel coupled with shorter ignition delay of biodiesel. [13]. Experimental study by Can concluded that despite earlier start of injection, ignition delay decreased with addition of biodiesel at all engine loads, leading to relatively earlier SOC due to higher cetane number of biodiesel [14].

Depending upon the local availability, different feedstocks are being promoted worldwide for production of biodiesel. Biodiesel policy of India encourages utilization of non-edible vegetable oils for biodiesel production because India has shortage of edible oils [15]. Karanja also known as *pongamia pinnata*, is a tree borne oil seed, which naturally grows in south Asia [16–18]. Karanja is one of the important nitrogen fixing trees (NFTs) which produces seeds containing 30–40% oil (w/w). It is planted as an ornamental and shade tree but now-a-days, it has emerged as an important resource for oil, which can be used for production of biodiesel. The average seed yield of Karanja is about 4–9 tons/ha [19]. Based on review of several experimental studies, Ashraful et al. concluded that Karanja biodiesel is superior because of its cetane number, higher brake thermal efficiency, lower BSFC and lower emission characteristics in comparison to various other non-edible feedstock based biodiesels [20]. Its utilization for large scale biodiesel production will ensure stability of supply because it is well adapted to local climatic conditions. In this study, effect of Karanja biodiesel blends on engine performance, emissions and combustion characteristics have been experimentally investigated at different fuel injection pressures for exploring the prospects of Karanja biodiesel/blends utilization in modern transport engines equipped with common rail direct injection (CRDI) fuel injection system. In addition to detailed engine investigations, spray studies have also been carried out.

2. Experimental setup

2.1. Injection rate and spray droplet measuring system

In order to investigate the injection rate of Karanja biodiesel, an injection rate measuring system was used at various injection pressures as illustrated in Fig. 1. This system is based on the pressure variation in a measuring tube, which is filled with biodiesel. When the high-pressure biodiesel is injected into the tube, the fuel creates pressure wave is detected by a pressure sensor in the tube. During the fuel injection, the pressure in the tube was maintained constant at 20 bar. In the system, line pressure was continuously measured by using a pressure sensor. In this test, 1000 fuel injections were carried out for each condition and the measurements were averaged. The droplet sizes and velocity are measured by phase doppler particle analyzer (PDPA) system, which is shown in Fig. 1b.

Phase Doppler droplet analysis system comprises of a high-pressure fuel injection system, an Ar-Ion laser, a transmitter, a

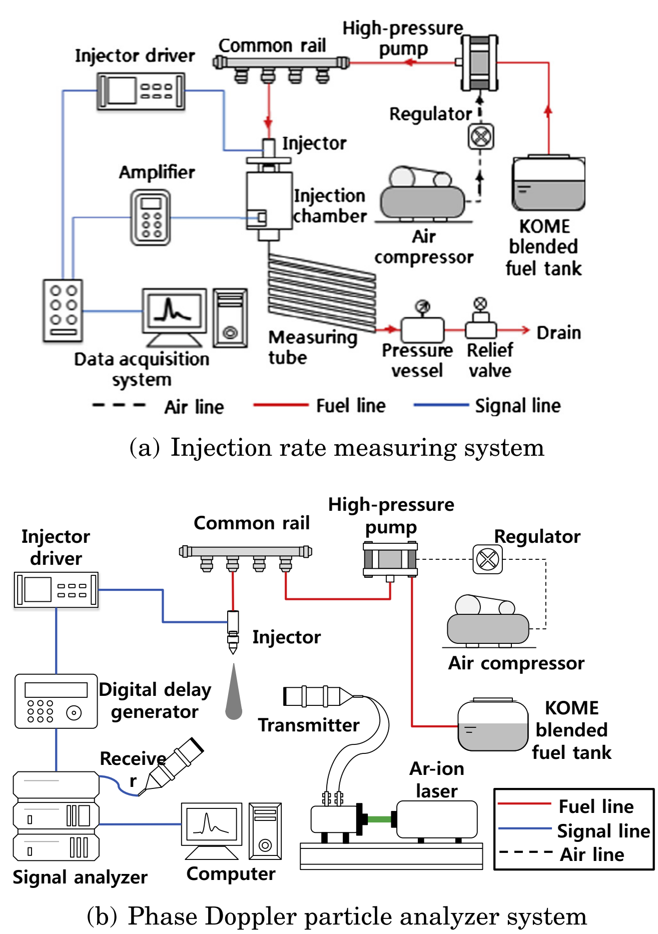

Fig. 1. Injection rate and phase Doppler particle analyzer system.