Applied Energy 202 (2017) 459–470

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Comparison of biodiesel fuel behavior in a heavy duty turbocharged and a light duty naturally aspirated engine

Shashank Mishra, K. Anand *, S. Santhosh, Pramod S. Mehta

Indian Institute of Technology Madras, Chennai 600036, India

HIGHLIGHTS

- Several contradicting trends obtained with biodiesel in two different engines.
- Ignition delay are lower and higher respectively in heavy duty and light duty engine.
- Smoke emissions are lower and higher respectively in heavy duty and light duty engine.
- Biodiesel with higher saturated methyl esters produces lower nitric oxide emissions.
- Biodiesel with higher unsaturated esters results in poor performance, higher emissions.

ARTICLE INFO

Article history:
Received 2 March 2017
Received in revised form 10 May 2017
Accepted 26 May 2017

Keywords:
Turbo charged
Naturally aspirated
Ignition delay
Biodiesel
Composition

ABSTRACT

Biodiesel is an eco-friendly, renewable biofuel derived primarily from vegetable oils and is a potential carbon neutral alternative to fossil diesel for compression ignition (CI) engine applications. The biodiesels produced from different feedstocks vary significantly in their fatty acid methyl ester composition and physico-chemical properties and thereby, engine performance and emissions. In the present work, experimental investigations are done with four candidate biodiesel fuels, viz. sunflower, rice-bran, palm and coconut in two different engine configurations, viz. light duty naturally aspirated (NA) and heavy duty turbocharged (TC) to establish the effects of biodiesel composition variations as well as engine type variations on the engine characteristics. To establish biodiesel composition effects on engine characteristics, two new parameters, viz. straight chain saturation factor (SCSF) and modified degree of unsaturation (DU_m) are developed in this work, which can be estimated directly from the measured biodiesel composition. The obtained results show some contradicting trends with biodiesel compared to diesel in the two engines. The ignition delay is lower for biodiesel by 0.9 degree in the turbocharged engine, while, it is higher by 1 degree in the naturally aspirated engine. The dynamic start of injection timings are advanced for biodiesel in both the engines but the advance is relatively higher in the turbocharged engine. The heat release rates with biodiesel are premixed and diffusion phase dominant in the naturally aspirated and turbocharged engines respectively. The peak cylinder pressures and nitric oxide emissions are generally higher for biodiesel in both the engines. The smoke emissions with biodiesel are higher and lower respectively in the naturally aspirated and turbocharged engines. Further, investigations on biodiesel composition effects on the engine characteristics revealed a strong correlation between DU_m, SCSF and engine parameters. An increase in DU_m of biodiesel is found to deteriorate combustion quality, resulting in poor engine performance and higher emissions. However, biodiesel having higher SCSF exhibit better engine performance along with lower nitric oxide and smoke emissions. Thus, an estimate of DU_m and SCSF of candidate biodiesel fuels provides a first approximation of the extent of variations in engine parameters compared to diesel and thereby, helps in making a careful choice of biodiesel feedstock for automotive engine applications. Further, based on the results obtained with four different biodiesels in two different engine configurations, the present study reveals that the contradicting engine trends with biodiesel compared to diesel are more influenced by engine type variations rather than by biodiesel composition variations.

---

* Corresponding author.
E-mail address: anand_k@iitm.ac.in (K. Anand).

http://dx.doi.org/10.1016/j.apenergy.2017.05.162
0306-2619/

1. Introduction

The global interest in renewable, cleaner and carbon neutral transport fuels has increased significantly in the recent past for environmental and economic sustainability. Biodiesel derived primarily from vegetable oils by transesterification process has emerged as the most favorable renewable alternative to diesel fuel [1–5]. Biodiesel is non-toxic, bio-degradable, has no sulphur and aromatics, and has lower engine exhaust emission characteristics (except nitric oxide) [6–9]. More than 300 oil bearing crops have been identified so far as suitable candidates to produce biodiesel fuel depending upon economic feasibility and availability [10]. However, biodiesel is not economically feasible currently due to higher feedstock cost, and thus there is a tremendous impetus for research and technological development to curtail its cost [11]. The biodiesel composition includes saturated and unsaturated methyl esters of non-branched type with a dominance of methyl palmitate (C17:0), methyl stearate (C19:0), methyl oleate (C19:1), methyl linoleate (C19:2) and methyl linolenate (C19:3) [12]. The variations in concentrations of saturated and unsaturated methyl esters of biodiesels owing to differences in the feedstocks used for production are found to influence their physico-chemical properties and thereby, engine characteristics [13,14]. The two major types of CI engines which are being used commercially today in the agricultural and transport sectors are of naturally aspirated and turbocharged variants respectively. The exhaust heat energy in a naturally aspirated engine is unutilized as the exhaust is being emitted into the atmosphere. A turbocharged engine utilizes the exhaust waste heat and converts it into useful work through a turbine-compressor assembly, which in turn increases the engine volumetric efficiency and power output [15,16].

Many of the existing studies reported an advanced start of dynamic injection timings with biodiesels compared to diesel due to their higher bulks modulus and density [17]. The biodiesels with higher proportion of unsaturated methyl esters are found to have higher bulk modulus [18]. The ignition delay of biodiesels are in general shorter than diesel [17,19–27] because of advanced injection timings [19], higher cetane number [17,20,22,26,27], rapid pre-flame thermal cracking [23], presence of alcohol moiety [24] and rapid gasification [25]. However, some studies [21] reported longer ignition delay and combustion duration with biodiesels owing to their inferior spray characteristics resulting in poor fuel-air mixing. The biodiesels are found to exhibit poor spray characteristics in terms of larger sauter mean diameter, longer spray penetration and smaller spray cone angle [28]. A comparison of ignition delay among different biodiesels shows that it increases with an increase in unsaturated methyl ester constituents [20]. This is primarily due to the addition of radicals from the unsaturated esters which in turn reduces isomerization of peroxide radicals that lead to low temperature branching [29]. The peak in-cylinder pressure and heat release rates are found to increase with an increase in unsaturated methyl esters in biodiesel [17,20,25,26,29] owing to an early start of injection timings [26], longer ignition delay [20,29] and higher density [17,27]. The engine brake specific fuel consumption (bsfc) is higher with biodiesels compared to diesel because of their lower energy content [18,23,27,30,31]. The biodiesels with higher unsaturated methyl esters are found to increase bsfc owing to higher density. However, there are no uniform consensus reached with regard to engine brake thermal efficiencies when using different biodiesels [32]. However, slight decrease in brake thermal efficiency with biodiesels due to their lower energy content and higher bsfc is widely accepted trend in existing literatures [33]. An increase in nitric oxides (NOx) emissions with biodiesels is reported [17,23,26,31,34,35] owing to an advanced start of injection timings [23], presence of fuel bound oxygen [26,31,33], higher density [17] and higher thermal [34] and prompt [29] NO_x formation. However, lower NOx emissions are also reported with biodiesels in some literatures [32]. The smoke emissions in general are reported to be lower with biodiesel owing to fuel bound oxygen content [17,34]. Biodiesel has a higher cetane number compared to diesel and contains 10–11% oxygen by weight which reduces carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM) emissions in the exhaust gas [36].

There are various contradicting trends reported in the existing literatures [21,32] with regard to utilization of biodiesels in CI engines which could be due to variations in fuel type, engine type or operating conditions. However, the reasons behind those contradicting trends with biodiesels are explained solely based on investigations with either fuel type variations or engine type variations. There are no investigations comparing the effects of both biodiesel fuel type and engine type variations on the engine characteristics. The present work intends to full-fill this gap based on investigations in two different engine environments using four candidate biodiesel fuels to make a relative assessment of biodiesel compositional variations vis-a-vis engine type variations on engine characteristics to bring out the more dominant effect. Although biodiesel fuels are subjected to significant variations in their composition, there are no investigations so far correlating biodiesel composition with engine characteristics. An effort in this direction would help to make a careful choice of biodiesel feedstock for engine applications that results in minimal variations in engine characteristics compared to diesel and thereby, reduces or eliminates engine re-calibration with biodiesel. In the present work, two new biodiesel composition centric parameters, viz. straight chain saturation factor (SCSF) and modified degree of unsaturation (DU_m) are developed and their relationship with various engine parameters are established.

2. Materials and methods

2.1. Experimental test set-up

Experiments are performed in a light duty naturally aspirated (NA) engine and a heavy duty turbocharged (TC) engine whose important specifications are provided in Table 1.

Table 1
Specifications of test engines.

Parameter	Engine A	Engine B
Engine Type	Stationary constant speed 4-stroke engine	Automotive variable speed 4-stroke engine
Application	Agricultural pump sets	Diesel Truck
Aspiration system	Naturally aspirated	Turbocharged with intercooler
No. of Cylinders	1	4
Compression Ratio	17:1	17.5:1
Rated Speed (rpm)	1500	3200
Rated Power (kW)	3.5 @ 1500 rpm	70 @ 3200 rpm
Rated Torque (N m)	23.5 @ 1500 rpm	285 @ 1400 rpm
Displacement (cc)	481	3298
Cooling	Natural water circulation	Forced water circulation
Nozzle Opening pressure (bar)	210	230
Injector (no. of. holes × diameter)	3 × 0.600	5 × 0.209
Fuel delivery System	Jerk type in-line pump	Rotary distributor type pump
Static Injection Timing (°CA bTDC)	23	17