Energy Conversion and Management 81 (2014) 534–546

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Numerical and experimental study of combustion, performance and emission characteristics of a heavy-duty DI diesel engine running on diesel, biodiesel and their blends

Luka Lešnik *, Jurij Iljaž, Aleš Hribernik, Breda Kegl

University of Maribor, Faculty of Mechanical Engineering, Smetanova 17, SI-2000 Maribor, Slovenia

ARTICLE INFO

Article history:
Received 23 December 2013
Accepted 17 February 2014
Available online 19 March 2014

Keywords:
Heavy-duty diesel engine
Biodiesel
Mixing controlled combustion model
Sub-model for parameter determination
Emissions

ABSTRACT

The presented paper introduces a performed study into the possibility of replacing mineral diesel fuel with pure biodiesel fuel or their blends with diesel fuel. The presented work was carried out experimentally and numerically on a heavy-duty bus diesel engine using mineral diesel fuel, neat biodiesel fuel made from rapeseed oil and their 25% (B25), 50% (B50) and 75% (B75) blends. The influence of biodiesel fuel and blends on engine combustion, performance and emission characteristics was studied experimentally on an engine test-bed and numerically using an AVL BOOST simulation program. A new empirical sub-model for determining a combustion model parameters was proposed within a BOOST program. All the model's parameters were determined regarding the properties of the tested fuel and engine speed. The obtained results show a reduction in engine power and torque when increasing the percentage of biodiesel fuel in the fuel blends due to lower calorific value of biodiesel fuel. Higher oxygen content in the biodiesel and blends contributed to a better oxidation process within the combustion chamber, which resulted in a reduction of carbon oxides (CO) and nitrogen oxides (NO_x) at three different engine speeds (1360, 1700 and 2000 min^{-1}) and full throttle position. Both the experimental and numerical results indicated that neat biodiesel or biodiesel-diesel blends can be used within a heavy-duty diesel engine with modified static fuel delivery angle (injection pump timing) of the mechanically-controlled injection system.

1. Introduction

Methyl esters of vegetable oils known as biodiesel are attracting increasing interest because of their low environmental impact and their potential as an alternative fuel. The consumption of biodiesel is increasing from year to year. It is stimulated by the raising of crude oil prices, the striving of individual countries to reduce their dependence on imported energy sources, and implementing the Kyoto protocol directives for the reduction of global emissions from greenhouse gasses [1]. World biodiesel production increased by more than 20 times in 2012 compared to 1990. At the same time ethanol production has increased more than 7-fold which makes biofuels fuels more accessible and attractive for commercial usage [2–4]. Many EU countries are already mixing biofuels with conventional fuels to meet European Union demand for biofuel usage in transportation.

Usage of biofuels mixtures with conventional fuels or usage of pure biofuels requires experimental and numerical testing of their influences on engine operating conditions and emission formation. Experimental testing is usually very costly and time-consuming and therefore numerical simulations are commonly used when performing parametric studies of biofuels' influences on engines' operating conditions, combustion process and emission formations. Detailed analyses of fuel spray-jet development within a combustion chamber and analyses of emission formation zones are usually made using complex 3D simulations [5]. Parametric studies of biofuels' influences on engine performance and emission formation are usually made using thermodynamic or phenomenological combustion models because they are significantly less time-consuming than 3D simulations and enable us to simulate the whole engine operation under several engine operating conditions, which make it possible to numerically perform engine emissions' test-cycles, etc. In phenomenological and thermodynamic combustion models the complex dynamics of air-flow, spray development and emission formation are replaced by model parameters. Model parameters hold some crucial information about spray

* Corresponding author.
E-mail address: llesnik@gmail.com (L. Lešnik).

http://dx.doi.org/10.1016/j.enconman.2014.02.039
0196-8904/

Nomenclature

Q	heat (J)
I	integral
α	angle (°CA)
τ	duration (°CA/ms)
C	constant/parameter
k	density of turbulent kinetic energy
E	energy (J)
λ	air excess ratio
CV	calorific value (MJ/kg)
CN	cetan number
X	oxygen content

Subscripts

c	cylinder
PMC	premixed combustion
IDCF	ignition delay calibration factor
UB	unburned zone
ref	reference
id	ignition delay
SOI	start of injection
fv	vaporized fuel
kin	kinetic
f,inj	fuel injected
diff	diffusion
stoich	stoichiometric
f	fuel
turb	turbulence
diss	dissipation
epx	experimentally obtained
ns	numerically obtained

Abbreviation

D2	diesel fuel
B100	pure biodiesel fuel
B25	mixture of 25% biodiesel fuel with D2
B50	mixture of 50% biodiesel fuel with D2
B75	mixture of 75% biodiesel fuel with D2
CO	carbon monoxide
CO_2	carbon dioxide
O_2	oxygen
NO_x	nitrogen oxides
HC	hydro carbon
MCC	mixing controlled combustion
NLPQL	non-linear programming by quadratic Lagrangian
CA	crank angle
BTDC	before top dead center
L–M	Levenberg–Marquardt
BSFC	break specific fuel consumption

development, combustion speed, and injection delay and therefore their accurate determination is necessary. Different engines and different fuels require different parameters values. The values for some parameters for commonly used combustion models and engines are already known but when a new type of fuel is introduced their determination needs to be based on user experience. Therefore, the results from experimental measurements are needed to confirm the results of numerical simulations and for properly selecting the values for combustion model parameters.

Combustion process in internal combustion engine highly depends on the start of injection process and its strategy. The injection timing influence on duration of fuel ignition delay phase which has further influence on premixed combustion phase, engine performance and emission formation process. Park et al. [6] studied the influence of different injection timing on engine performance and emission formation when running on diesel–ethanol and diesel–ethanol–biodiesel fuel mixtures. The effect of different injection strategies within a heavy-duty diesel engine on engine performance and emission formation were studied by Thumheer et al. [7]. Possibility to replace conventional fuels with biofuels with aim to reduce harmful emission formation has been studied in many papers. Studies can be made under full engine load (full throttle position) and different engines speeds or under different engine loads and different engine speeds. Roy et al. [8] tested how biodiesel fuels from pure and used canola oil influenced a direct injection diesel engine's performance and emission formation at high idling operations. Silitonga et al. [9] tested how properties of *Ceiba pentandra* biodiesel blends influence on performance and exhaust emissions of a diesel engine on different engine speeds at full engine load (full throttle position). The influence of rape seed oil biodiesel on engine combustion and emission formation at different engine loads and speeds was studied by Qi et al. [10], in work of Kegl and Hribernik [11–13] and in work done by Yamane et al. [14]. Holwan and Joshi [15] tested how different ethanol, diesel and biodiesel fuel mixtures' influence on engine performance and emission formation on several different engine loads. Some studies were also made using less known biofuels like fish oil fuel [16], KDV synthetic diesel fuel [17] and biogas [18] in compression ignition engines. Emission formation in diesel engines can also be reduced by adding additives in diesel or biodiesel fuels. Palash et al. [19] tested the impact of NO_x reducing antioxidant additive on performance and emissions of a multi-cylinder diesel engine fueled with Jatropha biodiesel blends.

It is generally known that the usage of biodiesel fuel reduces engine power and torque due to their lower calorific values. In engines with mechanically-controlled injection systems this leads to increased break-specific fuel consumption. Replacing mineral diesel fuel with biodiesel fuels can contribute to reduction of exhaust gas emissions, which highly depend on engine load and engine speed. Holwan and Joshi [15], Silitonga et al. [9] and Qi et al. [10] obtained reduction of NO_x emissions on full engine load when increasing the percentages diesel fuel while Labeckas and Slavinskas [17] obtained increase of specific NO_x emissions production when using synthetic diesel fuel. Yamane et al. [14] obtained decrease of produced NO_x emissions when running on different biodiesel fuels at full engine load. When increasing percentage of biofuel the reduction of CO emissions was obtained in [15,14,10]. Higher CO emissions were obtained when using *Ceiba pentandra* biodiesel blends on full engine load (full throttle position) [9], when using synthetic diesel fuel [17] and by usage of 70% mineral diesel fuel mixed with 30% rapeseed oil biodiesel fuel in commercial truck diesel engine [20].

Some of the investigations have been made using both experimental testing and numerical simulations. Experimental results are necessary for verifying those numerical results which depend on proper selection of combustion model parameters. Combustion model parameters need to be determined for all tested fuels on each engine's operating regime. This process is time-consuming and requires the results of experimental measurements for its validations. The dependency of numerical results from proper parameter selection needs to be minimized if only numerical simulations are to be used for performing parametric studies of biofuel's influence on engine performance and emission formation. The results of experimental measurements can also be used for