Fuel 144 (2015) 244–258

Contents lists available at ScienceDirect

Fuel

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

Investigation of the influences of steam injection on the equilibrium combustion products and thermodynamic properties of bio fuels (biodiesels and alcohols)

Guven Gonca *

Yildiz Technical University, Naval Arch. and Marine Engineering Depart, Besiktas, Istanbul, Turkey

HIGHLIGHTS

- Combustion simulation is performed for bio fuels with a reliable model.
- Change of adiabatic flame temperatures and Cp of bio fuels are examined.
- Effects of steam injection on combustion products are investigated.
- Steam injection method diminishes NO emissions considerably.

ARTICLE INFO

Article history:
Received 23 April 2014
Received in revised form 25 November 2014
Accepted 11 December 2014
Available online 24 December 2014

Keywords:
Steam injection
Combustion products
Chemical equilibrium
Biodiesel
Alcohol
No emission

ABSTRACT

Even though biodiesel fuels are renewable and have less toxic emission profiles, the most prominent drawback of usage biodiesel in diesel engines is higher NOx compared to petroleum based diesel fuel. However, application of the steam injection technique into diesel engines increases engine performance and reduces NOx emissions. In the present study, the effects of bio fuel combustion with steam injection on the equilibrium combustion products and thermodynamic properties such as specific heat of the exhaust mixtures and adiabatic flame temperatures of bio fuels (biodiesels and alcohols) used commonly, such as canola oil methyl ester (COME), sunflower oil (SFO), cottonseed oil (CSO), soybean oil (SBO), corn oil (CO), rapeseed oil (RSO), ethanol (ETH) and methanol (METH), have been investigated by using a verified simulation code with experimental studies. The simulation code defines the mole fractions of exhaust species at chemical equilibrium depend on equilibrium-constant approach. The combustion products have been comparatively evaluated with respect to increasing steam rate. The results showed that while NO emissions and adiabatic flame temperatures remarkably diminish, specific heats increase with raising steam rate.

1. Introduction and literature survey

The resources of the fossil fuels are depleting and the environmental restrictions with regard to minimizing of pollutant emissions are increasing day by day. It is clear that new solutions must be found to meet the fuel demand and environmental requirements. Bio fuels (biodiesels and alcohols) could be proposed as a solution for the future. They are renewable and may be obtained from various plants. Also, bio fuels are expected as the essential short term alternative fuels in the European Commission's White Paper [1] and so many works on bio fuels have been carried out by engine researchers.

Altin et al. [2] investigated the performance and exhaust emissions of a single cylinder diesel engine fuelled with the vegetable oil fuels and their methyl esters (raw sunflower oil, raw cottonseed oil, raw soybean oil and their methyl esters, refined corn oil, distilled opium poppy oil and refined rapeseed oil). Canakci et al. [3,4] examined the emission and performance parameters of a diesel engine operating with biodiesels and standard diesel fuels by using Artificial Neural Networks (ANNs). The average errors were not greater than 5.5%. Agarwal [5] reviewed the characterization, production and current statuses of vegetable oil, biodiesel and alcohols and he examined the experimental researches and studies considering greenhouse gas emissions, efficiencies, fuel versatility, infrastructure, availability, economics, engine performance and emissions, effect on wear, lubricating oil. Sharma et al. [6] reviewed the latest developments of biodiesel by considering

* Tel.: +90 212 383 2980; fax: +90 212 383 2941.
E-mail address: ggonca@yildiz.edu.tr

http://dx.doi.org/10.1016/j.fuel.2014.12.032
0016-2361/

Nomenclature

C_v	constant volume specific heat($J\ g^{-1}\ K^{-1}$)	δ	atomic number of nitrogen for diesel fuel
C_p	constant pressure specific heat($J\ g^{-1}\ K^{-1}$)	ε	molar fuel–air ratio
m	mass (g)	ϕ	equivalence ratio
M	molecular weight		
NY	total mole number	*Subscripts*	
T	temperature (K)	0	before the combustion
$K_{\%}$	ratio of the steam mass to the fuel mass	a	air
		ad	adiabatic
Greek letters		af	air–fuel mixture
α	atomic number of carbon for diesel fuel	f	fuel
β	atomic number of hydrogen for diesel fuel	S	stoichiometric
γ	atomic number of oxygen for diesel fuel	ste	steam

biodegradability, emissions and performance parameters. Patil and Deng [7] carried out a research on producing biodiesel from the non-edible vegetable oils (Jatropha curcas and Pongamia glabra) and edible oils (corn and canola) using potassium hydroxide (KOH) as a catalyst. Fassinou et al. [8] applied the various correlations existing in the literature to some biodiesel samples in order to obtain fuels' higher heating value (HHV) with a high accuracy by comparison to the bomb calorimetric method. Balat [9] reviewed and investigated the production of biodiesel from various non-edible oil seed crops. Gumus et al. [10] examined the influences of injection pressure on the SFC and emissions of a DI diesel engine fuelled with biodiesel–diesel mixtures. Sanli et al. [11] developed a new empirical formula to predict higher heating values of waste frying oils based on regression analysis. They used 35 samples collected from different fast food, fish and hospital restaurants. They obtained more precise results by using this model when compared to other models existing in the literature, the average error was found as 0.37%.

Kannan et al. [12] examined the impact of ethanol addition to jatropha methyl ester (JME) in terms of viscosity reduction and they investigated combustion characteristics such as ignition delay, combustion duration and emissions released from a diesel engine fuelled with blends of ethanol, JME and conventional diesel fuel. Karabektas et al. [13] examined the influences of the mixtures including 15% of ethanol, methanol, biodiesel and vegetable oil (rapeseed oil) with conventional diesel fuel on the emission and performance characteristics of a diesel engine. Carbon monoxide emissions lowered with ethanol, methanol and vegetable oil. Hulwan and Joshi [14] conducted a research on feasibility of using ethanol in diesel–ethanol blends and utilization of ethanol as a co-solvent and improver of biodiesel properties. Saxena et al. [15] examined the utilization of wet ethanol in HCCI engines with exhaust heat recovery to obtain high input energy to ignite wet ethanol and to improve the energy balance of ethanol. Lei et al. [16] examined the effect of a novel emulsifier for ethanol–diesel mixtures on the performance and exhaust emissions of a diesel engine.

Cheng et al. [17] compared the influences of usage of biodiesel with emulsified and fumigated methanol on the performance parameters and emissions characteristics of a direct injection diesel engine. Sayin et al. [18] experimentally examined the influence of injection timing on the performance characteristics and exhaust emissions of a diesel engine operated with diesel–methanol mixtures. Sayin et al. [19] examined the effect of operating parameters, such as injection pressure and timing, on the performance and emission characteristics of a DI diesel engine fuelled with methanol–diesel blends. Zhang et al. [20] examined the influence of fumigation methanol on the combustion characteristics and particulate emissions of a 4-cylinder direct injection diesel engine under various fumigation level and engine loads.

Lin et al. [21] examined the influence of saturated monoglycerides, glycerin, and soap on cold soak filterability of biodiesel produced from canola. Lee et al. [22] experimentally investigated the synthesis of biodiesel from waste canola oil by using supercritical methanol. Also, they examined the influences of reaction conditions on the biodiesel yield. Sayin et al. [23] examined the injection timing on the emission characteristics of a diesel engine operating with canola oil methyl ester–diesel fuel mixtures. Saka and Kusdiana [24] examined the transesterification reaction of rapeseed oil in supercritical methanol without using any catalyst. Wang et al. [25] used a new solid base catalyst in the transesterification of rapeseed oil with methanol to obtain biodiesel.

Candeia et al. [26] examined the effect of soybean biodiesel content on basic properties of biodiesel–diesel mixtures. Bazooyar

Table 1
The properties of the fuels.

	Chemical formula	Density (g/cm^3 at 20 °C)	Lower heat value (MJ/kg)	Cetane number
DF [39]	$C_{14.4}H_{24.9}$	0.84	42.5	45
ETH [42]	C_2H_5OH	0.78	28.4	6
METH [42]	CH_3OH	0.79	20.27	4
COME [23]	$C_{18.08}H_{34.86}O_2$	0.885	38.73	60.4
SFO [2]	$C_{55}H_{105}O_6$	0.878	40.579	45
CSO [2]	$C_{54}H_{101}O_6$	0.874	40.58	45
SBO [2]	$C_{53}H_{101}O_6$	0.872	39.76	37
CO [2]	$C_{56}H_{103}O_6$	0.915	37.825	37.6
RSO [2]	$C_{57}H_{105}O_6$	0.914	37.62	37.6