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Theoretical and experimental study on the performance of a diesel engine fueled with diesel–biodiesel blends

Guven Gonca [a, *], Erinc Dobrucali [b]

[a] Yildiz Technical University, Naval Arch. and Marine Eng. Depart, Besiktas, Istanbul, Turkey
[b] Turkish Naval Academy, Naval Arch. Depart, Tuzla, Istanbul, Turkey

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ABSTRACT

This study reports the effects of engine load and biodiesel percentage on the performance of a diesel engine fueled with diesel–biodiesel blends by experiments and a new theoretical model based on the finite-time thermodynamics (FTT). In recent years, biodiesel utilization in diesel engines has been popular due to depletion of petroleum-based diesel fuel. In this study, performance of a single cylinder, four-stroke, direct injection (DI) diesel engine fueled with diesel–biodiesel mixtures has been experimentally and theoretically investigated. The simulation results agree with the experimental data. After model validation, the effects of engine load and biodiesel percentage on engine performance have been parametrically investigated. The results showed that, effective power increases constantly, effective efficiency increases to a specified value and then starts to decrease with increasing engine load at constant biodiesel percentage and compression ratio. However, effective efficiency increases, effective power decreases to a certain value and then begins to increase with increasing biodiesel percentage at constant equivalence ratio and compression ratio.

1. Introduction

In recent years, renewable energy resources have been proposed as an alternative to petroleum-based fuels. Biodiesel, derived from vegetable oil or animal fat, is considered as an alternative renewable fuel for use in diesel engines, [1–8]. Biodiesels have both advantages and disadvantages, which can be listed as follow, respectively. The advantages of biodiesel as diesel fuel, apart from their renewability, are their minimal sulfur and aromatic content, higher flash point, higher lubricity, higher cetane number and higher biodegradability and non-toxicity. Also, biodiesel contains about 10–11% oxygen by weight. Conversely, disadvantages include their higher viscosity, higher pour point, lower calorific value and lower volatility. Moreover, their oxidation stability is lower, they are hygroscopic and as solvents, they may be cause corrosion of components, attacking some plastic materials used for seals, hoses, paints and coating. They show increased dilution and polymerization of engine sump oil, thus requiring more frequent oil changes [1–3,9–14]. Diesel engines are widely used as a power source for in-sea and on-land transportation vehicles. However, the emissions from diesel engines are considered one of the major sources of air pollution and seriously threaten the environment and the health of living beings. Some researchers have studied on environmental effects of the biodiesel fuels. Their studies have shown us that when biodiesel is used as a diesel engine fuel, sulfur levels, particulate matter (PM), (carbon monoxide) CO and unburned hydrocarbons in the exhaust gas are considerably less than those of conventional fuel [15–20].

Researches regarding fuel economy and exhaust emissions in internal combustion engines continue to increase as a challenge. There also have been significant improvements in finding an alternative renewable fuel. Many valuable researches have been conducted on the effect of biodiesel on performance and exhaust emission characteristics of diesel engines. Canakci [9] investigated the effects of using diesel–biodiesel blends on the performance, combustion characteristics and exhaust emissions of a compression ignition (CI) diesel engine. In his study, the specific fuel consumption (SFC) increased with the addition of biodiesel to conventional diesel fuel. Ozener et al. [21] carried out a study on combustion, performance and emission characteristics of a diesel engine operating with petroleum-based diesel and biodiesel blends obtained from soybean oil. It was shown that SFC could be decreased by using biodiesel blends in diesel engines. In Xue's investigation [22],

* Corresponding author.
E-mail address: ggonca@yildiz.edu.tr (G. Gonca).

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Nomenclature

A	heat transfer area (m^2)
CI	compression ignition
CO	carbon monoxide
C_v	constant volume specific heat (kJ/kg.K)
C_p	constant pressure specific heat (kJ/kg.K)
DC	Dual cycle
d	bore (m)
F	fuel–air ratio
FTT	finite-time thermodynamics
h_{tr}	heat transfer coefficient (W/m^2K)
H_u	lower heat value of the fuel (kJ/kg)
ICE	Internal combustion engines
l	loss
L	stroke length (m)
m	mass (kg)
$\dot{m}$	time-dependent mass rate (kg/s)
N	engine speed (rpm)
P	pressure (bar), power (kW)
PM	particulate matter
r	compression ratio
r_T	cycle temperature ratio
R	gas constant (kJ/kg.K)
SFC	specific fuel consumption
$\bar{S}_P$	mean piston speed (m/s)
$\dot{Q}$	rate of heat transfer (kW)
S	stroke (m)
T	temperature (K)
v	specific volume (m^3/kg)
V	volume (m^3)
Z	friction constant (kPa)

Greek letters

α	atomic number of carbon
β	pressure ratio, atomic number of hydrogen
δ	atomic number of nitrogen
ϕ	equivalence ratio
γ	atomic number of oxygen
λ	cycle pressure ratio
μ	friction coefficient (Ns/m)
ρ	density (kg/m^3)
η_C	Isentropic efficiency of compression
η_E	Isentropic efficiency of expansion
ψ	cut-off ratio

Subscripts

1	at the beginning of the compression process
a	air
c	combustion, clearance
cyl	cylinder
ef	effective
ex	exhaust
f	fuel
fr	friction
ht	heat transfer
i	initial condition
in	input
l	loss
max	maximum
me	mean
min	minimum
out	output
s	stroke, isentropic condition
st	stoichiometric
t	total
w	cylinder walls

biodiesels from waste edible oil have been reviewed to summarize the effects of biodiesel combustion on the combustion characteristics, engine performance and emissions. In a study conducted by Can [23], biodiesel fuels produced from two different kinds of waste cooking oils were blended with No. 2 diesel fuel and their effects on the engine performance and emissions were examined. As a result of his study, the ignition delay with the biodiesel addition was decreased for all loads with the earlier combustion timings. For the time being, the maximum heat release rate and the in-cylinder pressure rise rate were slightly diminished and the combustion duration was generally increased with added biodiesel. While there were no significant changes on CO emissions at the low-medium engine loads, some reductions were detected at the full load. CO_2 emissions were slightly increased for all loads. Ramadhas et al. [24] investigated the effects of engine load and biodiesel percentage on the SFC of a four-stroke DI, naturally aspirated single-cylinder diesel engine. According to their experimental evaluations, the lower biodiesel blends increased the brake thermal efficiency and diminished the fuel consumption and exhaust emissions were decreased with rise in biodiesel concentration. Consequently, their experimental results proved that usage of biodiesel, which was produced from unrefined rubber seed oil, in CI engines was an alternative to diesel. Tesfa et al. [25] performed experimental studies to investigate the influence of biodiesel properties on the combustion and performance characteristics of a CI engine. They found that the biodiesel types did not lead to any differences in specific fuel consumption and peak cylinder pressure. The specific fuel consumption for the engine running with neat biodiesel (No diesel fuel addition) was higher than the engine running with normal diesel by up to 15%. Muralidharan et al. [26] examined the combustion, emission and performance characteristics of a single cylinder; four stroke, variable compression ratio, diesel engine fueled with waste cooking oil methyl ester and its blends with conventional diesel. It was found that the performance of the B40 blend is worthy when compared with the conventional diesel at full (%100) load. Also, there was small rise in NO_X emission. However, They draw a conclusion that it was still comparable with that of standard diesel fuel and was in the suitable range, as well. Gonca [27,28,57] investigated the effects of steam injection on the performance and NO emission of a diesel engine fueled with ethanol [27], hydrogen [57] and examined the effects of steam injection on equilibrium combustion products and thermodynamic properties of bio fuels [28]. In the results, it was reported that the steam injection method decreases the NO formation of the diesel engine fueled with bio fuels and hydrogen.

Many investigations based on combustion simulations and thermodynamics have been carried out to optimize the performance of the diesel engines and its cycles which are classical diesel cycle, dual cycle and Miller cycle. Chen et al. [29] performed a thermo dynamical performance analysis of an air-standard dual cycle by taking into account the heat-transfer and friction-like loss terms. The results showed that the friction and heat transfer losses considerably abate the engine performance. Ozsoysal [30] determined the combustion efficiency of a dual cycle as a percentage of