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Thermodynamic, environmental and economic effects of diesel and biodiesel fuels on exhaust emissions and nano-particles of a diesel engine

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ABSTRACT

In this study, diesel (JIS#2) and various biodiesel fuels (BDF20, BDF50, BDF100) are used to operate the diesel engine at 100 Nm, 200 Nm and full load; while the engine speed is 1800 rpm. The system is experimentally studied, and the energy, exergy, sustainability, thermoeconomic and exergoeconomic analyses are performed to the system. The Engine Exhaust Particle Sizer is used to measure the size distribution of engine exhaust particle emissions. Also, the data of the exhaust emissions, soot, particle numbers, fuel consumptions, etc. are measured. It is found that (i) most of the exhaust emissions (except NO_x) are directly proportional to the engine load, (ii) maximum CO_2 and NO_x emissions rates are generally determined for the BDF100 biodiesel fuel; while the minimum ones are calculated for the JIS#2 diesel fuel. On the other hand, the maximum CO and HC emissions rates are generally computed for the JIS#2 diesel fuel; while the minimum ones are found for the BDF100 biodiesel fuel, (iii) fuel consumptions from maximum to minimum are BDF100 > BDF50 > BDF20 > JIS#2 at all of the engine loads, (iv) particle concentration of the JIS#2 diesel fuel is higher than the biodiesel fuels, (v) soot concentrations of the JIS#2, BDF20 and BDF50 fuels are directly proportional to the engine load; while the BDF100 is inversely proportional, (vi) system has better energy and exergy efficiency when the engine is operated with the biodiesel fuels (vii) sustainability of the fuels are BDF100 > BDF50 > BDF20 > JIS#2, (viii) thermoeconomic and exergoeconomic parameters rates from maximum to minimum are JIS#2 > BDF20 > BDF50 > BDF100.

1. Introduction

Internal combustion diesel engines are important for automotive sector. They have lower exhaust emissions such as unburned hydrocarbon (HC) and carbon monoxide (CO), and better fuel economy than gasoline engines. Diesel engines are compression ignition engines and they have better compression ratio than spark ignition engines. Particle matter, smoke density and nitrogen oxides (NO_x) emissions of diesel engines are high. There are many studies on reducing exhaust emissions of diesel engines. Utilizations of diesel engines are increasing, so air pollution is increasing too. New alternative fuels for diesel engines have been globally investigated due to the high fuel prices, harmful exhaust emissions and instability in supply of diesel fuels. Fossil fuel

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Nomenclature

c_p	specific heat capacity (kJ/kg K)
$\dot{En}$	energy rate (kW)
ex	specific exergy (kJ/kg)
$\dot{Ex}$	exergy rate (kW)
h	specific enthalpy (kJ/kg)
H_u	lower heating value (kJ/kg)
K	capital cost ($)
$\dot{m}$	mass flow rate (kg/s)
n	speed of the engine in revolutions per minute (rpm)
P	pressure (Pa)
$\bar{R}$	universal gas constant (kJ/k mol K)
R_{en}	thermoeconomic parameter (kW/$)
R_{ex}	exergoeconomic parameter (kW/$)
s	specific entropy (kJ/kg K)
$\dot{S}$	entropy generation rate (kW/K)
SI	sustainability (–)
T	temperature (K)
T	torque (Nm)
$\dot{V}$	volumetric flow rate (m^3/s)
y	mol fraction (%)

Greek symbols

ε	chemical exergy factor (–)
ρ	density (kg/m^3)
μ	kinematic viscosity (m^2/s)
ψ	exergetic efficiency (%)
η	energy efficiency (%)
ω	angular velocity (rad/s)

Subscripts

0	reference (dead) state
air	air
ch	chemical
cw	cooling water
dest	*destruction*
env	*environment*
exh	exhaust
fuel	fuel
gen	generation
in	input
loss	loss
out	output
th	thermomechanical
W	work rate or power

utilization is unsustainable and it causes greenhouse gases. Searching for alternative fuels for diesel engines (e.g. renewable fuel) is an important matter for sustainability and environmental issues (Chandrasekaran et al., 2016; Venkanna and Venkataramana Reddy, 2012). In this regard, biodiesel fuels are better option for diesel engines. They are renewable and made easily from vegetable oils, animal fats, ethanol, etc. Biodiesel fuels have similar properties like diesel fuels, and their exhaust emissions are better than diesel fuels. There are some legal biodiesel productions arrangements for countries. Generally, biodiesel can be legally produced from vegetable oils, fried & cooking oils, etc. (Yilmaz et al., 2016; Pandey et al., 2016).

Even if biodiesel fuels are alternative options for diesel engines, the emissions are still not in desired levels to prevent global warming. Utilizations of the diesel engines in automobiles will not be decreased in the near future. Utilization of electrical engines in automobiles is the growing trend, because CO_2 emission arrangement of electrical engines are better than diesel engines. There will be 2.5 billion automobiles in 2050 and replacing internal combustion engine vehicles with battery electrical vehicles are not possible in the near future (Mori et al., 2015). Diesel engines will be still in use and using of biodiesel fuels with different percentages can be better options for less harmful emission and better fuel economy. Analyzing biodiesel fueled diesel engines with many aspects plays important role to investigate their sustainability.

Thermodynamic analysis is well-known analysis tool for determining characteristics of engines. First and second laws of thermodynamics are generally used for analyzing engines. First law of thermodynamics is about energy analysis. Energy analysis can give information about energy dispersals and losses of engines. Energy analysis alone is not enough to assess the best efficiencies of engines. Exergy analysis is used to understand and calculate the real efficiencies of engines by determining their losses and destructions. It bases on both first and second laws of thermodynamics. Exergy is also known as availability, potential or quality of energy. It is a useful tool for comparative analysis of engine parameters (Caliskan et al., 2010a, 2010b). Efficiency improvements and decreasing in system losses can be determined by exergetic assessment. Exergy can identify the environmental benefits and economics of energy technologies much better than energy (Dincer and Rosen, 2007). There are input and output streams as heat and work interactions with the environment. This transfer is happened with energy & exergy transfer in and out of the system; while some exergy is destructed due to irreversibility in the system. These losses and irreversibilities can be assessed by both thermoeconomic and exergoeconomic approaches (Caliskan and Hepbasli, 2011). Exergy is evaluated with a reference (dead) state. This reference state can be environment or restricted surroundings of the system (Caliskan et al., 2009).

Sustainable development is required for the efficient utilization of resources such as fuels. Exergy method is a useful tool for maximizing the benefits and using the resources efficiently. Sustainable quality assessment of energy for engines can be assessed with exergy analysis. In the sustainability analysis, Sustainability Index (*SI*), which is related to exergy efficiency and used to improve and contribute to the sustainable development, is used. (Caliskan et al., 2011).

The previously conducted studies are reviewed including exhaust emissions, fine particles, nano-particles, energy, exergy, sustainability, thermoeconomic, exergoeconomic aspects of diesel engine used for automotive sector. Tsujimura et al. (2007) studied on diesel truck engine fueled with gas to liquid fuel. The characteristics of the fuel are investigated and compared with Japanese exhaust