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Numerical investigation of performance, combustion and emission characteristics of various biofuels

Upendra Rajak[a], Prerana Nashine[b], Thokchom Subhaschandra Singh[a], Tikendra Nath Verma[a,*]

[a] Department of Mechanical Engineering, National Institute of Technology Manipur, 795001, India
[b] Department of Mechanical Engineering, National Institute of Technology Rourkela, 769008, India

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ABSTRACT

Alternative fuels have been a major concern in today's era due to its promising characteristics in internal combustion engines. The computational analysis is a proven method by many researchers in determining combustion, performance and emission characteristics of an internal combustion engine, offering accurate results at par with experimental results. An attempt is being made by the author(s) in this paper for performing numerical study of nine (9) different alternative biofuels and pure diesel. Comparison has been carried out with the results of pure diesel in a single cylinder, naturally aspirated, water cooled, direct injection diesel engine with different engine load (20%, 40%, 60%, 80% and 100%), constant compression ratio (CR17.5), higher nozzle opening pressure (220 bar) and advance injection timing (23° CA before TDC). The study was performed after validating results of two experimental data using the proposed tool, which have shown that the numerical results were in good agreement with the experimental results. The numerical results of the different biofuels have depicted the possibility of using the fuels as alternative fuel for internal combustion engine.

1. Introduction

The increase in consumption is the reason for the increase in pollution and hence significant progress in the field of internal combustion engine research were made. Many researchers have used various biofuels as alternative and renewable source to determine the performance, emission and combustion characteristics of internal combustion engines. Pyrolysis is performed on waste plastics to obtain oil and the same is mixed with 5% and 10% with diethyl ether on single cylinder water cooled direct injection (DI) engine. The blended fuel (waste plastic and DEE) have improved the cetane rating of the fuel. It was seen that there were significant reduction in the smoke levels while using blended fuel as compared to pure waste plastic oil. The brake thermal efficiency (BTE) has increased and pollutants such as CO and NO_x were decreased. Addition of oxygenates have improved the process of combustion while reducing emissions. Another study have investigated an engine fed with eight (8) different renewable diesel fuels which includes pure diesel, jet fuel, traditionally derived biodiesel (FAME), deoxygenated canola derived fatty acids (DCFA), DFCA with varying H_2, continuous DCFA, deoxygenated lauric acid (DLA) and isomerize deoxygenated canola derived fatty acid alkanes. While diesel, jet fuel and FAME were used as benchmark fuels for the other new types of renewable fuels. The results have indicated lower mechanical efficiency but increased BTE of the renewable fuels. The combustion analysis indicated short ignition delays, low peak in cylinder pressures, reduced rate in increase in cylinder pressure and low heat release rate for the proposed renewable fuels. They have an added advantage of reduction in NO_x, soot and greenhouse gas emission [1,2]. Waste tire pyrolysis oil (WTPO) blended with diesel fuel is proposed to be used as fuel for investigating the performance and emission characteristics of a four stroke, four cylinder, naturally aspirated, DI diesel engine. The results shows that WTPO blended with diesel can be used as a potential fuel since it has similar characteristics like torque and power output as compared to diesel, without much modification in the engine [3,52]. Various additives were also added to improve the biodiesel blends to reduce fuel consumption and NO emission from diesel engines, such as 2-ethylhexyl nitrate (EHN), di-tertiary-butyl peroxide (DTBP) and pentanol. The additives have improved the combustion pressure (0.11–0.53 bar) and lower heat release rate (0.82–2.29 J/°CA) [4]. Some studies on diesel engine using higher alcohol/diesel fuel blend shows that without any modification, a diesel engine can run properly on 30% 1-butanol/70% diesel fuel or 25% 1-pentanol/75% diesel fuel [5]. Use of diesel-aegle marmelos oil-diethyl ether blends on various blends has been performed. 60:30:10 (diesel: aegle marmelos: diethyl ether) have increased the BTE by 4.3%, NO_x emission have been reduced by 3.9% at compression ratio (CR) 17.5 and full load conditions

* Corresponding author.
E-mail address: tikendra.me@nitmanipur.ac.in (T.N. Verma).

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Nomenclature

A_0, A_1, A_2	empirical factors
A/F	air/fuel
BMEP	brake mean effective pressure (bar)
BN	Bosch number
BSN	Bosch smoke number
BT	brake power (kW)
BTE	brake thermal efficiency (%)
b_m	depth of the spray forward front (m)
CA	crank angle (degrees)
CAE	crank angle encoder
CI	compression ignition
CN	cetane number of fuel
CPP	cylinder peak pressure (bar)
CR	compression ratio
CPT	cylinder peak temperature (K)
CSOBD	cotton seed oil biodiesel
DI	direct injection
ED	error deviation (%)
EGR	exhaust gas recirculation
EGT	exhaust gas temperature (K)
EEFO	ethyl ester fish oil
E_a	apparent activation energy for the auto ignition process (kJ/kmole)
FMEP	friction mean effective pressure (bar)
HSL	Hartridge Smoke Level
h_{wfr}	height of the NWF forward front
JME	jatropha methyl ester
K_T	evaporation constant
l	current distance between the injector's nozzle and the location of the EFM (m)
LCS	load cell sensor
LFR	liquid flow rate
LME	linseed methyl ester
L_c	cycle work done (kJ)
l_m	EFM's penetration distance (m)
MAOME	microalgae oil methyl esters
m	total mass (kg)
m_f	fuel mass per cycle (kg/h)
NOP	nozzle opening pressure (bar)
NWF	near wall flow
n	engine speed (rpm)
P	pressure (bar)
PD	pure diesel
PM	particular matter (g/kWh)
POU	percentage of uncertainty (%)
PSBD	palm stearin biodiesel
PTS	pressure transducer sensor
P_{max}	maximum cylinder pressure (bar)
P_b	brake power (kW)
q_c	cycle fuel mass (kg)
R	gas constant (J/(mol·k))
SE	standard error
SD	standard deviation
RME	rapeseed methyl ester
SFC	specific fuel consumption (g/kWh)
SME	soybean methyl ester
SOI	start of injection (degree)
SFC	specific fuel consumption (kg/kWh)
SFR	soot formation rate (1/deg)
SS	speed sensor
STP	spray tip penetration (mm)
V_p	mean piston velocity (m/s)
$\dot{S}_g$	net generation rate of the ith species (kg/s)
T	temperature (K)
TDC	top dead centre
TIS	temperature indicator sensor
T_b	temperature in a burnt gas zone (K)
TME	tallow methyl ester
V	volume of cylinder (cm^3)
V_1	current velocity of the EFM (m/s)
V_0	initial velocity of the EFM at the nozzle of the injector (m/s)
V_m	fuel spray evaluation process in a medium speed diesel engine (m/s)
V_k	swept volume (cm^3)
V_i & V_c	cylinder volumes at injection timing and top dead centre (cm^3)
x	fraction of fuel burnt
X_0	fraction of burnt fuel during ignition delay
Y_i	mass fraction
$[N_2]_e$	equilibrium concentrations of an molecular nitrogen
$[NO]_e$	equilibrium concentrations of an oxide of nitrogen
$[O]_e$	equilibrium concentrations of molecular oxygen
$[O_2]_e$	equilibrium concentrations of atomic oxygen
r_{H_2O}	volume fraction of water vapor in a combustion chamber
Y_i^{cyl}	stoichiometric coefficients on the reactant side
Y_i^j	stoichiometric coefficients on the product side
α, β, λ	constants
α_1	air-fuel equivalence ratio
τ	time (second)
τ_k	travel time for the EFM to reach a distance l from the injector's nozzle
ρ	density (kg/m^3)
ν	specific volume (m^3/kg)
ϕ	crank angle (degree)
ω	angular crank velocity (rpm)
ε	compression ratio
ξ_b	cylinder air charge usage efficiency
σ_{ud}, σ_u	fuel fractions evaporated during ignition delay period and up
Ω_i	molar rate of production (mol/s)
$\frac{dt}{dx}$	heat release rate (J/deg)
VCR	variable compression ratio
VE	volumetric efficiency (%)

[6]. A diesel ethanol blend D95E5 (95% diesel and 5% ethanol) have been found to have good potential for use as fuel for diesel engines. The results emphasized the potential of ethanol in reducing NO_x emission, smoke capacity and brake specific energy consumption (BSEC) [7].

Vegetable oil such as pongamia biodiesel was also evaluated as an alternative fuel in the transport, power and agricultural sector. Pongamia biodiesel have reduced CO emission by 8.2%, HC emission by 8.9%, BSFC increased by 4.2% and the thermal efficiency is reduced by 2.4% [8]. Duel fuel mode is used on a single cylinder diesel engine with fuel biodiesel/n-butanol, biodiesel/ethanol and biodiesel/2,5-dimethylfuran. Then results indicated that 20% blend ratio have overall advantages as compared to other blends and diesel. Fatty acid methyl ester (FAME) using Jatropha curcas oil (JCO) and methanol through homogenous catalyst NaOH and KOH is investigated. Thermo-gravimetric and differential thermal analysis (TGDTA) is performed on the blends. It was observed that JCO have the highest lowest activation energy (49.97 kJ/mol) and thus suitable for combustion. Cotton seed oil as a possible fuel on a diesel engine is analyzed and it was found that