Energy Conversion and Management 149 (2017) 228–243

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Effect of ethanol/water blends addition on diesel fuel combustion in RCM and DI diesel engine

Mohamed Nour [a,c,*], Hidenori Kosaka [b], Susumu Sato [b], Mahmoud Bady [d,e], Ali K. Abdel-Rahman [a,d], Kenta Uchida [b]

[a] Energy Resources Engineering Department, Egypt-Japan University of Science and Technology E-JUST, New Borg El Arab, Alexandria, Egypt
[b] Department of Mechanical and Aerospace Engineering, Tokyo Institute of Technology, Tokyo, Japan
[c] Department of Mechanical Engineering, Benha Faculty of Engineering, Benha University, Benha, Qalubia, Egypt
[d] Mechanical Engineering Department, Assiut University, Assiut 271516, Egypt
[e] Mechanical Engineering Department, Islamic University of Medina, Medina, Saudi Arabia

ARTICLE INFO

Article history:
Received 20 April 2017
Received in revised form 9 July 2017
Accepted 10 July 2017

Keywords:
Ethanol/water mixture
Combustion analysis
Two-color method
Emission characteristics
RCM
Diesel engines

ABSTRACT

The effect of ethanol/water blends addition on diesel fuel combustion and emissions is investigated experimentally in this study using optical diagnostics. Basic study is performed using rapid compression machine (RCM) under CI conditions. The tested ethanol energy fractions varied in the range of 10–40% of the total added fuel energy, while water volume ratios varied in the range of 10–40% of the injected ethanol. Ethanol and water were evaporated before entering the combustion chamber to eliminate their endothermic effect. Results reveal that addition of ethanol/water blends to diesel fuel results in longer ignition delay and promote the apparent heat release rate (AHRR) at the premixed combustion phase compared to absolute ethanol addition. Additionally, soot and NO_x emissions are reduced with ethanol/water addition compared to absolute ethanol addition and neat diesel combustion. The basic study is then extended to investigate the effect ethanol/water blends addition on diesel fuel combustion using single cylinder diesel engine. Waste heat in exhaust manifold is utilized to vaporize ethanol/water blends before combustion. Results reveal that ethanol/water blends injection leads to increase in peak cylinder pressure, indicated mean effective pressure (IMEP), and AHRR at premixed combustion phase. Additionally, the ignition delay increased with ethanol/water addition. NO_x emission is decreased up to 88% along with a reduction in soot by 50%. The lower ethanol to water volume ratios show better combustion efficiency, IMEP, NO_x and soot emissions compared to the higher ethanol to water volume ratios. The addition of water to ethanol leads to longer ignition delay and lower soot concentrations compared to absolute ethanol. Additionally, water addition reduces the flame temperature, which leads to NO_x reduction.

1. Introduction

Global concerns about depletion of conventional oil resources, deterioration of the environment, and security of fuel supply have motivated research and development of internal combustion engines. Diesel engines are widely used in transportation, electrical power generators, and pumps and considered as the primary source of NO_x and soot emissions. However, there is a tradeoff relationship between soot and NO_x formation in diesel engines and simultaneous reduction of both is difficult [1]. Advanced low-temperature combustion strategies offer prominent benefits of simultaneous reduction of both NO_x and soot emissions, with low specific fuel consumption [2].

The potential of using alternative fuels in diesel engines with advanced combustion strategies is imperative. The important criterion that should exist in alternative fuels used in CI engines is the high cetane number [3]. Despite the low cetane number of ethanol, it has been studied for decades in combination with diesel fuel because of its renewable resource base and oxygenated properties, which can significantly reduce the soot emissions [4,5]. The NO_x emissions also decreased due to ethanol's high latent heat of vaporization which reduces the flame temperature. The other

* Corresponding author at: Faculty of Engineering at Benha, Benha University, Egypt-Japan University of Science and Technology (E-JUST), Egypt.

E-mail addresses: mohamed.farag@ejust.edu.eg, mohamed.nour@bhit.bu.edu.eg (M. Nour).

URLs: http://www.beng.bu.edu.eg, http://www.ejust.edu.eg (M. Nour).

http://dx.doi.org/10.1016/j.enconman.2017.07.026
0196-8904/

Nomenclature

40E40W	40% ethanol energy fraction and 40% water volume ratio
ABDC	after bottom dead centre
AHRR	apparent heat release rate
ATDC	after top dead centre
BDC	bottom dead centre
BMEP	brake mean effective pressure
BSFC	brake specific fuel consumption
BTDC	before top dead centre
CA	crank angle [degree]
CA05	crank angle at which 5% heat is released
CI	compression ignition
CO	carbon monoxide
COV	coefficient of variance
D100	neat diesel fuel
DAQ	data acquisition system
DI	direct injection
EGR25	exhaust gas recirculation ratio of 25%
EVC	exhaust valve close
EVO	exhaust valve open
EVrC	exhaust valve re-close
EVrO	exhaust valve re-open
FPGA	field programmable gate array
fps	frames per second
HC	hydrocarbon
HCCI	homogenous charge compression ignition
IMEP	indicated mean effective pressure
IVC	intake valve close
IVO	intake valve open
KL	K: the absorption coefficient
KL	L: the geometric thickness of the flame along the optical axis
LHV	lower heating value [kJ/kg]
NO_x	Oxides of nitrogen [ppm]
OH	hydroxyl group
PAH	polycyclic aromatic hydrocarbon
PMT	photomultiplier
RCM	rapid compression machine
SOC	start of combustion
SOI	start of injection
TDC	top dead centre
VVA	variable valve actuating

English symbols

C_2	second radiation Planck's constant and equals to 1.43878×10^{-2} [m K]
p	cylinder pressure [MPa]
Q_{net}	apparent heat release rate [J/deg]
t	time
T	flame temperature [K]
T_a	apparent flame temperature [K]
V	cylinder volume [cm^3]

Greek symbols

θ	crank angle
σ_{imep}	standard deviation in IMEP
κ	specific heat ratio
λ	wavelength [μm]
α	constant and equals to 1.38

disadvantages of ethanol as an alternative to diesel fuel are the low heating value and unstable mixture with diesel fuel [6].

The autoignition properties and cetane number of diesel-ethanol fuel blends were examined by Kuszewski et al. [7] using constant volume combustion chamber at different fuel injection pressures of 80, 100, 120 and 140 MPa. The ethanol volume fraction varied from 0 to 14%. They reported that the increase in the ethanol fraction results in a longer ignition delay. However, the increase in the fuel injection pressure allows for shortening of that period. Additionally, for every 2% increase in ethanol volume ratio, the derived cetane number of the blend is reduced by an average of 1.7 units. Similar results of the autoignition properties of ethanol and diesel fuel blend were also obtained by Lapuerta et al. [8].

Ethanol has been used in diesel engines in several ways [9], such as blending with diesel fuel [10], fumigation [11], and ethanol-diesel dual fueling with ethanol injection in the intake port using separate injection systems [12,13]. The main advantage of blending ethanol and diesel fuel is that ethanol is directly injected into combustion chamber and exists in areas where it is more efficient to lower the emissions. However, ethanol and diesel fuel blends are stable only at ambient temperatures, and the two fuels separate at a temperature below 10 °C. The addition of an emulsifier or a co-solvent is a suggested way to avoid this separation [14]. On the other hand, ethanol-diesel dual fuelling with ethanol fumigation or ethanol injection in the intake manifold has the advantage of changing ethanol to diesel fuel ratio according to engine speed and load. However, both techniques suffer from the endothermic effect of ethanol because of its high latent heat of vaporization (780 kJ/kg) compared to that of diesel fuel (260 kJ/kg) [6]. To overcome this, exhaust manifold manifold injection of ethanol was investigated [15].

Quite recently, considerable attention has been paid to investigate the effect of ethanol/water mixture addition on diesel engine combustion and emissions. Martinez-Frias et al. [16] cited that the greatest fraction of the energy consumed in ethanol production is spent on water removal, distillation and dehydration. This energy represents 37% of the total energy that exists in ethanol and co-products. Therefore, by reducing the energy dedicated to water removal, the ethanol energy balance may considerably improve [16].

Li et al. [17] investigated the characteristics of evaporating, non-evaporating and burning spray of hydrous ethanol-diesel emulsified fuel. The hydrous ethanol contains 20% water by weight. The hydrous ethanol volume fraction varied from 10 to 30% in the emulsified fuel. They concluded that the maximum liquid penetration length in the evaporating spray increased drastically with the addition of hydrous ethanol. For burning spray, the luminosity of the flame decreased with the addition of hydrous ethanol, which indicates soot reduction in the flame. They explained that the soot reduction in the spray flame returns to better spray atomization and evaporation rate with the addition of hydrous ethanol to diesel fuel.

Gonca [18] studied the effect of steam injection on combustion, performance and emissions of a diesel engine fueled with ethanol and diesel fuel blends. Ethanol and steam were added by 15% and 20% volume ratios. The output torque and power of the diesel engine were reduced with maximum of 11% for ethanol-diesel fuel blends. However, with steam injection in the intake manifold, the maximum reduction in power was 7.6%. Gonca added that steam injection into the diesel engine positively affects the combustion efficiency and decreases NO_x formation. This is due to the fact that water droplets have excellent atomization, and vaporize rapidly