Fuel 210 (2017) 133–144

Contents lists available at ScienceDirect

Fuel

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

Full Length Article

Experimental study on combustion and emission performance of a spark-ignition engine fueled with water containing acetone-gasoline blends

Yuanxu Li [a,b], Karthik Nithyanandan [b], Xiangyu Meng [b,c], Timothy H. Lee [b], Yuqiang Li [b,d], Chia-fon F. Lee [b,e,*], Zhi Ning [a]

[a] School of Mechanical, Electronic and Control Engineering, Beijing Jiaotong University, Beijing 100044, China
[b] Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, IL 61801, USA
[c] Dalian University of Technology, Dalian, Liaoning 116024, China
[d] School of Energy Science and Engineering, Central South University, Changsha, Hunan 410083, China
[e] School of Mechanical Engineering, Beijing Institute of Technology, Beijing 100081, China

HIGHLIGHTS

- Water containing acetone (WA)-gasoline blends with various water content were tested.
- Unregulated emissions of WA-gasoline blends were investigated using GC/MS and GC/FID.
- WA-gasoline blends could advance combustion phasing and enhance thermal efficiency.
- WA-gasoline blends could reduce the CO, NO_x and aromatic hydrocarbon emissions.

ARTICLE INFO

Article history:
Received 1 April 2017
Received in revised form 5 June 2017
Accepted 14 July 2017

Keywords:
Water containing acetone
Unregulated emissions
Gas chromatograph
SI engine
Performance

ABSTRACT

Acetone is widely recognized as a major organic solvent and also a basic ingredient for varnishes and paints. In comparison with ethanol, acetone has more attractive properties as a potential alternative fuel such as its higher energy density, heating value, and volatility. However, the water content in acetone production would lead to a high cost for dehydration, and may prohibit acetone from being widely used in internal combustion engines. This has prompted research on using water containing acetone as a potential alternative fuel. In this study, various acetone-gasoline blends such as A10 (10 vol% acetone and 90 vol% gasoline by volume), A20 (20 vol% acetone and 80 vol% gasoline by volume), A19.5W0.5 (19.5 vol% acetone and 0.5 vol% water and 80 vol% gasoline) and A19W1 (19 vol% acetone and 1 vol% water and 80 vol% gasoline) were used as fuels in a port-fuel injection (PFI) spark ignition (SI) engine. The performance of test fuels was compared with that of G100 (gasoline) under various equivalence ratios (Φ) from 0.83 to 1.25 and at engine loads of 3 and 5 bar BMEP. In addition, aromatic compound emissions such as benzene, toluene, ethylbenzene, xylene (BTEX) were also measured by gas chromatograph (GC) with mass spectrometer and flame ionization detector. The results showed that A19W1 generally had a more advanced combustion phasing, higher brake thermal efficiency, and lower carbon monoxide (CO), nitrogen oxide (NO_x) and BTEX than those of other test fuels. Therefore, water containing acetone-gasoline blends could be used as a good alternative fuel due to the improvement of engine performance and reduction of emissions.

1. Introduction

During the past few decades, an increased consumption of fossil fuels by the transportation industry has exacerbated the oil crisis and environment problems. Among various environment pollutants, automobile exhaust is one of major sources of atmospheric pollution. Typically, regulated emissions such as particulate matter (PM), nitrogen oxide (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO) and unregulated emissions such as polycyclic aromatic hydrocarbons (PAHs), aldehydes, acids are the main components in vehicle exhaust gas [1–6]. Therefore, more considerations have been taken into the utilization of alternative fuels in engines.

* Corresponding author at: Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, IL 61801, USA.
E-mail address: cflee@illinois.edu (Chia-fon F. Lee).

http://dx.doi.org/10.1016/j.fuel.2017.07.058
0016-2361/

Nomenclature

ABE	acetone-butanol-ethanol
ATDC	after top dead center
AFR	air-fuel ratio
AKI	anti-knock index
BMEP	brake mean effective pressure
BSFC	brake specific fuel consumption
BTE	brake thermal efficiency
BTEX	benzene toluene ethylbenzene xylene
CA	crank angle
CO	carbon monoxide
FDD	flame development duration
FID	flame ionization detector
GC	gas chromatograph
MBT	maximum brake torque
MFB	mass fraction burnt
MS	mass spectrometer
NO_x	nitrogen oxide
PAHs	polycyclic aromatic hydrocarbons
PFI	port-fuel injection
PM	particulate matter
RCD	rapid combustion duration
RPM	revolutions per minute
SI	spark ignition
SO_2	sulphur dioxide
UHC	unburned hydrocarbons
Φ	equivalence ratio

Among these alternative fuels, ethanol has attracted enormous interest due to its several properties: ethanol is reproducible, and has a higher flame speed [7–9]; ethanol also has a high octane number, which allows the use of high compression ratio and improves the thermal efficiencies [10,11]. Nevertheless, when using as an alternative fuel, ethanol still has several critical issues that should be further examined: ethanol has a much lower heating value (26.8 MJ/kg) than that of gasoline (42.7 MJ/kg), which shows an increase in fuel consumption, especially at higher blend ratios [12]; ethanol also has a higher latent heat of vaporization, which might cause cold start issues due to its poor evaporation [13–15]; some bio-ethanol productions are obtained from crops, which could lead to a crisis of food shortage [16].

Acetone is widely recognized as a major organic solvent and also a basic ingredient for varnishes and paints [17–19]. Although the exposure to high concentrations of acetone over long periods of time may cause minor uncomfortable in human livers [20] and high concentrations of acetone could be potentially corrosive to rubber [21], it has some more attractive properties as a potential oxygenated fuel. In comparison with ethanol, acetone has a higher octane number, energy density and heating value, and has a lower latent heat of vaporization [22]. Additionally, the sources of acetone production are not only from natural gas, coal or petroleum, but also from biological fermentation [23], in which the volume fraction of acetone in all fermented products is up to 64.43% [24]. Hence acetone could be considered a good alternative fuel applying to internal combustion engines.

Based on the considerations listed above, several studies have investigated the effect of acetone addition on combustion and emission performance. Elfasakhany [19] investigated the performance and emissions of a SI engine using acetone gasoline blends. Results indicated that AC3 (3 vol% acetone and 97 vol% gasoline) has improvements in cylinder pressure, brake power and torque compared with those of neat gasoline. Besides, the mechanism of acetone combustion in gasoline engine was proposed as well. Meng et al. [23] used G100 (gasoline), E30 (30 vol% ethanol and 70 vol% gasoline) and AE30 (22.5 vol% acetone, 7.5 vol% ethanol and 70 vol% gasoline blends) to conduct an experimental study in a PFI SI engine. They found that AE30 had lower UHC emissions and improved fuel consumption than those of G100 and E30. Hong et al. [25] carried out a shock tube investigation on the effect of acetone in *n*-heptane/oxygen mixtures on soot formation, and found that soot formation reduced effectively by acetone addition. Lin et al. [26] studied the impacts of 1–3 vol% dehydrated acetone into diesel blends on energy efficiency and emissions. They concluded that 3 vol% acetone-gasoline blended fuel improved combustion efficiency and resulted in lower brake specific fuel consumption (BSFC), NO_x emissions and PM compared with those of diesel. Wu et al. [27] conducted a constant volume chamber experiment researching on the effects of acetone on the combustion characteristic of acetone-butanol-ethanol (ABE)-diesel blends. They found that the ignition delay was much shorter when blends with higher fraction of acetone were used. Furthermore, blends with acetone addition showed a lower soot formation due to their better premixed combustion and shorter combustion duration. Li et al. [28,29] investigated the effect of ABE-gasoline blends on performance, combustion and emission of SI engine, results showed that ABE (3:6:1)30 had better engine performance compared with gasoline. Nithyanandan et al. [30,31] conducted investigations on the impact of acetone content in ABE-gasoline blends on the performance and emissions of a SI engine. They concluded that acetone addition could improve combustion quality significantly, and higher acetone content can reduce CO and unburned hydrocarbons (UHC) emissions.

Although there have been some studies focused on the investigation of using acetone as an alternative fuel or as an oxygenated additive, there is still a main issue, which is the acetone contains a small percentage of water during its production process, discourages the use of acetone due to the dehydration of acetone consumes more energy and increases the production costs. Recently, some investigations are focusing on water containing alcohol with gasoline blends and water containing acetone with diesel blends, which have reported that water containing in alcohol-gasoline or alcohol-diesel blends could improve the energy efficiency of engines and reduce the pollutant emissions, especially NO_x and UHC emissions [32–36].

As mentioned above, the study on SI engines fueled by water containing acetone and gasoline blends is rarely reported. In addition, there is hardly any investigation about the unregulated emissions in the exhaust of water containing acetone-gasoline blends. These unregulated emissions are harmful as they would increase the risk of cancer or other severe damages to immune, neurological and respiratory system in humans [37,38]. Among these unregulated emissions, benzene, toluene, ethylbenzene and xylenes (BTEX) are some of the most toxic compounds. Moreover, BTEX can get into the human body via skin and respiratory system [39]. Therefore, it is very important to measure the concentration levels of BTEX for both air pollution and human health aspects. In this study, the performance and combustion characteristics of a PFI SI engine fueled with G100 (pure gasoline), A10 (10% acetone and 90% gasoline by volume), A20, A19.5W0.5, A19W1 (19% acetone and 1% water and 80% gasoline by volume) were demon-