Energy Conversion and Management 88 (2014) 277–283

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Experimental study on emissions and performance of an internal combustion engine fueled with gasoline and gasoline/n-butanol blends

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ARTICLE INFO

Article history:
Received 19 May 2014
Accepted 13 August 2014
Available online 7 September 2014

Keywords:
n-Butanol
Gasoline
Blends
Exhaust emissions
SI engine performance

ABSTRACT

In this paper, exhaust emissions and engine performance have been experimentally studied for neat gasoline and gasoline/n-butanol blends in a wide range of working speeds (2600–3400 r/min) without any tuning or modification on the gasoline engine systems. The experiment has the ability of evaluating performance and emission characteristics, such as break power, torque, in-cylinder pressure, volumetric efficiency, exhaust gas temperature and concentrations of CO_2, CO and UHC. Results of the engine test indicated that using n-butanol–gasoline blended fuels slightly decrease the output torque, power, volumetric efficiency, exhaust gas temperature and in-cylinder pressure of the engine as a result of the leaning effect caused by the n-butanol addition; CO, CO_2 and UHC emissions decrease dramatically for blended fuels compared to neat gasoline because of the improved combustion since n-butanol has extra oxygen, which allows partial reduction of the CO and UHC through formation of CO_2. It was also noted that the exhaust emissions depend on the engine speed rather than the n-butanol contents.

1. Introduction

In order to face the challenge of climbing petroleum demand and the effects of atmospheric carbon dioxide (CO_2) levels on global climate, there is a growing interest in the use of renewable fuels; one possible renewable fuel is to use biofuel [1–5]. It has been shown that biofuels are powerful option in reducing greenhouse gases by 80% or more below the 1990 levels in the transportation sector and also their lower lifecycle emissions of CO_2 [6]. Biofuels have in general the advantage of reducing most of the regulated emissions such as unburned hydrocarbons (UHC) and carbon monoxide (CO) from engines [7–14].

The first-generation of biofuels are produced from edible crops and vegetables and that may lead to food shortages [15]. In contrast, the second-generation biofuels can be produced from alternative lignocellulosic materials, such as wood, vegetable waste and nonedible plants, offering an even more favorable well-to-wheel CO_2 balance without negative impact on food supply [16–20].

n-Butanol is one of the second-generation biofuels. It can be produced in a similar process to the production of ethanol. Compared to gasoline, corn-based n-butanol as a transportation fuel could save about 39–56% fossil fuel while reducing greenhouse gas emissions by up to 48% on a lifecycle basis [21]. Besides, n-butanol has several advantages over other biofuels such as ethanol and methanol [22–27]. n-Butanol has a lower auto-ignition temperature than methanol and ethanol. Therefore, n-butanol can be ignited easier when it is burned in gasoline engines. Besides, n-butanol has a number of advantages over ethanol and methanol in the transport sector. It is as easily transported as gasoline through pipelines because it has physical properties similar to gasoline and, in turn, it has lower tendency to separate from the base fuel when contaminated with water. In addition, n-butanol can be blended with gasoline fuel without phase separation. This could make it more cost-effective with the existing gasoline infrastructure [28]. n-Butanol has also a higher octane number, this make it more suitable additive than ethanol and methanol for gasoline fuel. Besides, n-butanol is much less evaporative and it releases more energy per unit mass than ethanol and methanol. n-Butanol is less corrosive and its energy content is higher than ethanol and methanol [29]. The net energy stored in n-butanol is 6.53 MJ/L compared to 0.40 MJ/L stored in ethanol [30]. In addition, n-butanol's closer resemblance to gasoline in the air–fuel ratio enables the usage of a greater percentage of n-butanol in its blend with gasoline than ethanol and methanol without impacting on the fuel storage and fuel economy [31].

Investigation of n-butanol as a blended fuel with gasoline has been conducted by several research groups. The first recent study used n-butanol in SI engine was by Rice et al. [32] who applied 20% by volume blend of n-butanol in gasoline in a four-cylinder

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http://dx.doi.org/10.1016/j.enconman.2014.08.031
0196-8904/

spark-ignition engine. They measured emissions levels of CO and UHC and they found that blended fuel and gasoline had similar UHC emissions, while the n-butanol blended fuels exhibited lower CO emissions than pure gasoline. Alasfour [33] investigated the effect of using 30 vol.% n-butanol blended with gasoline in a single-cylinder SI engine. The engine efficiency showed a reduction by 7% compared to pure gasoline fuel. Dagaut and Togbe [34,35] studied the oxidation of n-butanol–gasoline mixtures (85 vol.% n-butanol and 15 vol.% gasoline) to develop a chemical kinetic mechanism for the n-butanol–gasoline blends. Dernotte et al. [36] examined the emissions characteristics of several n-butanol–gasoline blends (0, 20, 40, 60 and 80 vol.% of n-butanol in gasoline) using a port fuel-injection spark-ignition engine and found that B60 and B80 produced 18% and 47% more UHC emissions than neat gasoline, respectively. It was also found that B80 was the only n-butanol blended fuel, which it did not produce lower CO emissions than neat gasoline. Another research was conducted by Gautam and Martin [37,38] using n-butanol–gasoline blend of 90 vol.% gasoline and 10 vol.% n-butanol at 900 r/min and stoichiometric ratio. Results showed that emissions of the blended fuel were significantly lower than the neat gasoline (16–20% lower CO, 18–23% lower CO2 and 17–23% lower UHC). Wallner et al. [39] investigated the combustion, performance and emissions of pure gasoline and 10% n-butanol (B10) blend in a direct-injection four-cylinder SI engine. Results showed that brake specific fuel consumption (BSFC) increased by 3.4% for B10 compared with gasoline, while the CO and UHC emissions did not show a significant difference between gasoline and the fuel blend. The burning velocity of the B10 was higher than gasoline, while combustion stability and the brake thermal efficiency did not vary significantly between the both fuels. Yacoub et al. [40] examined blend of n-butanol and gasoline with carbon numbers C1 to C5. The results indicated that all n-butanol blends had lower CO and UHC emissions. Williams et al. [41] evaluated the maximum achievable thermal efficiency of SI engine using gasoline and n-butanol–gasoline blend. Results indicated that thermal efficiency, combustion and emissions were not adversely affected as a result of adding n-butanol to gasoline. Yang et al. [42] discussed the feasibility of fueling gasoline engines with n-butanol–gasoline blends, ranging from 10% to 35% n-butanol by volume. Test results showed that the engine power could be maintained when the n-butanol concentration was below 20%. The maximum engine power went down and BSFC went up slightly when the concentration of n-butanol approached 30%. The raw UHC and CO emissions were significantly reduced in all investigated cases. Gu et al. [43] tested five blended ratios (B0, B10, B30, B40 and B100) and results showed that the UHC and CO emissions of blends are lower than those of gasoline. Pure n-butanol (B100) increases the UHC and CO emissions compared to those of gasoline. They also showed that the addition of n-butanol decreased the particle number concentration emissions. Feng et al. [44] conducted an experimental study for pure gasoline and 35% volume butanol–gasoline blend. The results showed that engine torque, BSEC and CO and HC emissions were better than those of pure gasoline at both full load and partial load with 35% volume butanol addition. But CO_2 emission was worse than that of the original level of pure gasoline.

Although there are numbers of valuable publications concerning n-butanol–gasoline blended fuels in SI engines, as discussed early, there are limited information on combustion characteristics and emissions within a blended range less than 10 vol.% n-butanol. Besides, most of n-butanol/gasoline blends are tested in SI engines with fuel injector system; however, SI engines with carburetor system had not been tested in such fuel; using carburetor fuel system promotes homogeneous mixture formation and that may influence on engine performance and emissions. Accordingly, it is evident that more studies are needed to evaluate the impact of n-butanol in SI engines before any firm general conclusions can be drawn. The objective of this paper is to investigate engine performance and pollutant emissions of CO, CO_2 and UHC for various n-butanol–gasoline blends up to 10 vol.% n-butanol (3, 7 and 10 vol.% of n-butanol in gasoline) in a single cylinder SI engine with carbureted fuel system. The importance of investigating n-butanol blending ratio less than 10% is that small rates of n-butanol (up to 10 vol.%) can be mixed with gasoline without any needs for engine modifications, e.g., no extra costs to modify automobiles and their related industries; besides, n-butanol is still more expensive than gasoline. This study may be the first time that the influence of 3 and 7 vol.% n-butanol blends is studied in SI engines, according to the best of our knowledge. Besides, previous studies were inconclusive and puzzling on the impact of n-butanol in CO and UHC emissions, see e.g., [32,36–40,42,43,45,46]. In the current study, we aim to settle the trends of CO and UHC emissions.

2. Experimental apparatus and procedure

The engine used for the experiments was a single cylinder spark ignition engine with an over square layout. The engine geometrical specifications are 65.1 mm bore, 44.4 mm stroke, 0.147 L swept volume and 7 compression ratio. Further details on the engine specifications and parameters are reported in Table 1. The engine head has two valves and a centrally located spark plug. The fuel was fed into combustion chamber using carburetor system. No external devices were connected to control of the intake air pressure or temperature, which are in a range of 0.85–0.9 bar and 290–305 K in Taif city, respectively. A pressure transducer was flush installed in the region between intake and exhaust valves at the side of the spark plug. The transducer allowed to perform in-cylinder pressure measurements in real-time. The engine output power and torque are measured by the eddy-current dynamometer. The engine is equipped with a temperature sensor to measure the exhaust gas temperature. The volumetric efficiency is calculated online by a personal computer via software. To reduce the initial conditions effects on measurements, the engine was operated until the steady state conditions. After warmed-up condition, the measurements take a place. Each experiment was repeated three times and the measured values were averaged. Experiments were performed at variable engine speeds of 2600–3400 r/min (the speed range of the test engine). Tests were carried out initially using gasoline fuel to generate the reference line data. Then, n-butanol/gasoline blends (10, 7 and 3 vol.% of n-butanol in gasoline) were prepared and tested under same working conditions. The properties of the fuels used in this study are presented in Table 2. The engine test rig is capable of measuring different parameters for engine performance such as engine torque, power, volumetric efficiency, cylinder pressure and exhaust gas temperature. Such measured data are directed to digital displays on the control panel as well as to a personal computer (PC) data

Table 1
Engine specifications and parameters.

Engine type	Spark-ignition engine
Model	CT 150 (2011)
Bore (mm)	65.1
Stroke (mm)	44.4
Swept volume (L)	0.147
Compression ratio (–)	7
Power (kW)	1.5
Number of cylinders	1
Number of valves	2
Fuel type	Petrol–gasoline
Fuel aspiration	Naturally aspirated
Fuel delivery	Carburetor