Fuel 170 (2016) 235–244

Contents lists available at ScienceDirect

Fuel

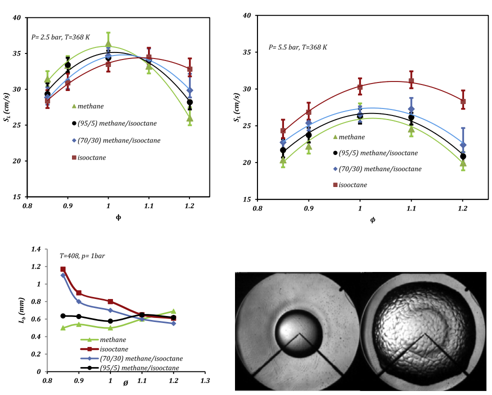
journal homepage: www.elsevier.com/locate/fuel

Effects of pressure and temperature on laminar burning velocity and flame instability of iso-octane/methane fuel blend

Mahdi Baloo [a,b], Bijan Mollaei Dariani [a,*], Mehdi Akhlaghi [a], Mostafa AghaMirsalim [a,b]

[a] *Mechanical Engineering Department, Amirkabir University of Technology, Iran*
[b] *IPCO Engine Research Centre, 1398813711 Tehran, Iran*

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 26 June 2015
Received in revised form 15 December 2015
Accepted 16 December 2015
Available online 28 December 2015

Keywords:
Laminar burning velocity
Markstein length
Blended fuel
Schlieren

ABSTRACT

In this work, spherically expanding flames are used to measure the unstretched flame propagation speed and Markstein length of an alternative fuel (iso-octane/methane fuel blend) at initial temperatures between 368 and 448 K, and pressures between 1 and 5.5 bar by using the Schlieren photography method.

Methane is added in two volumetric fractions of 70% and 95% to iso-octane in a constant volume chamber. Markstein lengths are obtained via nonlinear methodology over an extensive range of equivalence ratios between 0.85 and 1.2. From these new experimental data, a laminar burning velocity correlation based on unburned gas temperature, pressure, equivalence ratio and methane mass fraction was proposed.

It is seen that the unstretched flame propagation speed of blended fuel are located between the pure fuels but did not follow simple mole-fraction based weighted average of parent fuels and flame stability is enhanced by adding more methane to the fuel blend. Initial pressure rise has a suppression effect on flame propagation and pure methane receives the most influence from this effect. Initial temperature rise increase the propagating speed in all mixtures.

1. Introduction

In recent years, concern about exhaust emissions and greenhouse effect of conventional fuels has directed engine designers

* Corresponding author at: No. 424, Hafez Avenue, 15875-4413 Tehran, Iran. Tel.: +98 21 64543413; fax: +98 2166001164.
E-mail address: dariani@aut.ac.ir (B.M. Dariani).

http://dx.doi.org/10.1016/j.fuel.2015.12.039
0016-2361/

to take advantages of alternative fuels in automotive engines. Natural Gas (NG) can be used as an alternative energy resources with more environmental benefits. Cleaner combustion characteristics, high knocking resistance and relatively low cost are the advantages of Natural Gas in spark ignition (SI), but lack of fueling stations, bulky fuel tanks and lesser range of mileage compared to gasoline powered vehicles are its main disadvantages. Consequently, mixing of gasoline and Natural gas has been offered as an alternative fuel in spark ignition engines to utilize advantages of both fuels [1–5]. Most of the previous works focused on potential benefits of concomitant use of gasoline and natural gas on turbocharged direct and port fuel engines. Obiols et al. [3] observed significant reductions in fuel consumption and HC emissions. Momeni et al. [5] showed that fuel consumption, HC and CO emissions of concomitant injection are lower than gasoline mode and some problems of NG mode such as high cylinder pressure and heat loss via engine cooling system, are reduced by simultaneous injection of both fuels. Alongside these researches, basic investigation on flame characteristics of binary fuel blend of gasoline and natural gas is necessary.

Laminar burning velocity is one key parameter of a combustible mixture related to mixture composition, stoichiometry, temperature and pressure which affects combustion performance [6–9]. It is used to validate the chemical reaction mechanisms and reaching a better understanding of the turbulent combustion process. Many researches have been done on Laminar burning velocity of binary fuel blends due to the new interests in the utilization of fuel blends in internal combustion engines.

Chen et al. [10] introduced a theoretical model for the laminar flame speed of binary fuel blends. Their model pointed that the laminar burning velocity of binary fuel blends depends on the square of the laminar flame speed of each pure fuel.

As an alternative fuel, Broustail et al. [11] added Butanol and ethanol to iso-octane individually in three volume fractions and measured the laminar burning velocity and Markstein length of fuel blends in a closed combustion chamber at different initial pressures and an initial temperature of 423 K. They proposed a correlation for laminar burning velocity as a function of initial pressure, equivalence ratio and alcohol concentration.

Varea et al. [12] experimentally investigated the effects of pressure, equivalence ratio and ethanol mole fraction on iso-octane/air flame velocity and a general correlation was then suggested to express the effect of equivalence ratio, pressure and ethanol mole fraction in iso-octane at temperature of 373 K.

Although the laminar burning velocity of reference fuels such as methane (main component of NG), iso-octane (main component of gasoline) has been extensively studied at different pressures and temperatures, there is little information available about the flame characteristics of iso-octane-methane fuel blend.

The objectives of the present work are to examine the effects of initial temperature and pressure on the laminar burning velocity and Markstein length of iso-octane-methane fuel blend. This study presents laminar flame burning velocity data with 70% and 95% volumetric methane concentrations in iso-octane/methane fuel blend. The new experimental data has been compared to the pure fuels. All mixtures are tested in three temperatures of 368, 408 and 448 K and three pressures of 1 bar, 2.5 bar and 5.5 bar. Table 1 summarizes the test matrix and methane mole and mass fractions in blended mixtures.

2. Experimental setup and measurement technique

The details of the experimental setup are reported in Baloo et al. [13]. Briefly, the experimental setup consists of a cylindrical combustion vessel with a heating system, a mixture preparation system, a high-speed via Z-type high Schlieren photography system, an ignition system and a data acquisition system. The cylindrical chamber (Inner diameter: 135 mm; Volume: 1.9 l) has two quartz windows of 100 mm diameter. Four band heaters made it possible to heat the chamber up to 500 K. A PID controller with K-type thermocouple is used to maintain the gas temperature constant inside the chamber. A high speed digital camera was synchronized with the spark timing to record the image sequences at a sampling rate of 4000 fps. Two direct injectors were installed on the top of chamber to inject iso-octane and methane separately into the chamber (Fig. 1).

Methane with purity of 99.995% and iso-octane with purity of 99.5% were used as representative components for natural gas (NG) and gasoline respectively (Table 2).

Fuel–air mixtures can be considered as $x\mathrm{CH_4} + (1-x)\mathrm{C_8H_{18}} + Y(\mathrm{O_2} + 3.76\mathrm{N_2})$ where x is methane mole fraction in blended fuel and Y is the number of oxygen moles per mole of blended fuel.

Partial pressure method was applied to fill the combustion vessel with a gasoline direct injection nozzle, which was driven by an ECU-computer system injection.

$$p_{mix} = p_{air} + p_{fuel} = p_{fuel}\left(1 + \frac{p_{air}}{p_{fuel}}\right) = p_{fuel}\left(1 + \frac{n_{air}}{n_{fuel}}\right) = p_{fuel}(1 + 4.76Y) \quad (1)$$

$$p_{fuel} = p_{isooctane} + p_{methane} \quad (2)$$

where n_{air} and n_{fuel} are number of mole of air and fuel respectively.

Flame propagates outwardly after the ignition occurs at the center of chamber with two extended steel electrodes. A high speed photographic record provides a worthful history of the evolving flame shape and size. The Schlieren image were processed using an image processing MATLAB code to determine the laminar flame characteristics [14].

The effects of spark ignition interference and the wall confinement [15,16, 13] are minimized by selecting images with the flame radii of 6–25 mm.

Fig. 2 shows an example of flame propagation for a stoichiometric mixture of 70% methane/30% iso-octane (M70) at 1 bar and 448 K. The flame radii were measured in two vertical and horizontal directions and the average value was selected as temporal flame diameter.

The flame propagation speed (S_b) is measured according to the temporal derivative of the flame radius with respect to burned mixture, $S_b = dr/dt$.

In the case of free spherically propagating flames, curvature and strain of flame surface stretch the flame front. This stretch can significantly change the flame speed and hence, the burning

Table 1
Fuel type and test matrix.

Fuel	Methane mole fraction	Methane mass fraction	Pressure (bar)	Temperature (K)	Equivalence ratio (ϕ)
Methane	1	1	1, 2.5, 5.5	368, 408, 448	0.85–1.2
(70/30) methane/isooctane (M70)	0.7	0.24	1, 2.5, 5.5	368, 408, 448	0.85–1.2
(95/5) methane/isooctane (M90)	0.95	0.72	1, 2.5, 5.5	368, 408, 448	0.85–1.2
isooctane	0	1	1, 2.5, 5.5	368, 408, 448	0.85–1.2