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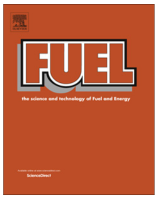

Effect of iso-octane/methane blend on laminar burning velocity and flame instability

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HIGHLIGHTS

- We did experiments for binary blends of methane/iso-octane and CNG/iso-octane.
- Addition of methane to iso-octane increases the stretched burning velocity.
- Blended fuel has higher laminar flame speed than base fuels in some regions.
- Hydrodynamic instability would be more for 70% methane than the other fuels.
- Methane has more Markstein length and number than the other blends in rich region.

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ABSTRACT

CNG–gasoline blended fuel has been considered as a potential choice of alternative fuel for spark ignition (SI) engines specially turbocharged one to utilize advantages of both fuels.

In this study methane (main component of CNG) is added in two volumetric fractions of 30% and 70% to iso-octane (representative fuel of gasoline). Spherical flames are experimentally investigated at initial temperature of 363 K and pressure of 1 bar in constant volume chamber. Classical schlieren technique used to characterize the combustion of blended and base fuels. Unstretched flame propagation speed and Markstein lengths are obtained via nonlinear methodology in different equivalence ratio. The laminar burning velocities, Markstein number and burning flux of blended fuel are then extracted and compared with base fuels. The results show that addition of methane to iso-octane increases the unstretched propagation speed in lean region but decrease the unstretched propagation speed in rich region. Blended fuels response to stretch is a linear combination of base fuels in lean region ($Ø > 1$); but methane has more Markstein length and Markstein number than the other fuels in rich region ($Ø > 1$). Laminar burning velocity and flame stability of 30% methane blended fuel is close to iso-octane. Laminar burning velocity of 70% methane blended fuel is higher than base fuel at $Ø = 0.9$. The tests also repeated for CNG/iso-octane blended fuel and similar trend obtained for laminar burning velocities.

1. Introduction

The use of alternative fuels in automotive engines has gained more attentions due to the increased conventional fuel prices and enforcement of stringent emission limits. The use of CNG in modern spark ignition turbocharged engine offers many advantages such as high knocking resistance, low CO_2 emissions and high specific power outputs. On the other hand, compared to gasoline, the volumetric efficiency is significantly decreased when CNG is port-injected due to its low energy density. It is also notable that the low ignitability and low flame speed of methane (the main component of natural gas) pose great challenges for its utilization in combustion engines [1]. Therefore, a combination of gasoline and CNG has been proposed as an alternative fuel in SI engines to utilize advantages of both fuels [2–6].

In order to understand the combustion properties of gasoline/methane mixture and to develop high-performance combustion engines utilizing gasoline and natural gas, fundamental investigation on the ignition, flame propagation, flame stability, and extinction of methane/iso-octane fuel is essential.

Laminar burning velocity is a physiochemical property that influences on the performance and emissions of the combustion process in many combustion devices.

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Nomenclature

A	area (m^2)
ADI	adiabatic model without radiative loss
OF	oxygen fuel ratio
α	stretch rate (1/s)
f	burning flux (kg/m^2 s)
Ø	equivalence ratio
L_b	Markstein length (mm)
m	volume fraction of methane
MF	2-methylfuran
DMF	2,5-dimethylfuran
n	number of mole
r	flame radius (mm)
R	relative reduction in unstretched laminar flame speed caused by radiation
ρ_u	density of unburned gases (kg/m^3)
ρ_b	density of burned gases (kg/m^3)
s_b	stretched flame propagation speed (mm/s)
S_b^0	unstretched flame propagation speed (mm/s)
S_u^0	laminar burning velocity (cm/s)
st	stoichiometric
t	time (s)
δ_T^0	unstretched laminar flame thickness (mm)
X	number of moles of oxygen per one mole of mixed fuel

Laminar burning velocity is also used in engine simulations to predict turbulent burning velocity which is related to burn duration [7], and directly affects the power output [8,9]. Laminar flame speed of fuel blends has been concerned in recent years. Chen et al. [10] performed theoretical analysis and presented a model for the laminar flame speed of binary fuel blends. Their model showed that the laminar flame speed of binary fuel blends depends on the square of the laminar flame speed of each individual fuel component. The performance of their model as well as models reported in the literature was assessed for methane/hydrogen mixtures. The effect of additives to the laminar flame speed of methane is investigated by many researchers. Most effort has been confined to the hydrogen addition to increase of methane (CNG) flame speed [11–15]. Some others, focused on other additives like acetone but remarkable variation on the flame speed has not been observed [16]. Chen et al. [17] investigated the laminar flame speed of methane–dimethyl ether fuel blends. They also measured the flame stability, Markstein length, and Lewis number. The laminar flame speed of binary fuel is increased but not as much as hydrogen addition.

Fuel additives to iso-octane have been considered as a potential choice of alternative fuel pathway for spark ignition (SI) engines. It is notable that iso-octane is used to represent gasoline in fundamental studies of gasoline blended fuels. Jerzembeck et al. [18] determined laminar burning velocities and Markstein lengths of gasoline and some other fuels under engine-relevant conditions by using the constant volume bomb method. Laminar flame speed of DMF (2,5-dimethylfuran) and its blend with iso-octane was investigated by Tian et al. [19,20]. Ma et al. [21] also investigated on the laminar burning characteristics of MF(2-methylfuran)–iso-octane blend. Hydrogen was also added to iso-octane to propose a model by Tahtouh et al. [22]. The influences of pressure, equivalence ratio and ethanol mole fraction on iso-octane/air flame velocity was investigated by Varea et al. [23].

In previous works, the laminar flame propagation characteristics of CNG and gasoline blended fuels have not been studied. In the present paper, the schlieren photography is used to investigate the laminar burning velocity, flame instability and burning flux. In this research, we are providing a survey on equivalence ratio to understand the flame properties of CNG-gasoline blended fuel. As gasoline is a mixture of many species and would be too complex for detailed chemical reaction mechanism analyses, therefore iso-octane is used in this study as a representative component of gasoline, similarly to previous works [24].

2. Experimental approach

2.1. Facility

The experimental setup is shown in Fig. 1 and consists of a constant-volume cylindrical chamber (CVC) with a diameter and length of 135 mm. Two sides of this chamber are fitted with quartz glass windows to provide optical transmission path. These glasses could withstand static pressure up to 100 bars. Four band heaters were used to heat the chamber up to 500 K. A PID controller with K-type thermocouple was used to measure and preserve the gas temperature constant inside the chamber. Two direct injectors were installed on the top of chamber with an adaptor to feed CNG/CH_4 and iso-octane separately into the chamber. To ensure the complete evaporation of liquid fuel inside the combustion chamber, fuel was injected into the heated and evacuated chamber. After injection, the feed line was pressurized with air to fill the combustion chamber. Rotation of inlet air in the chamber causes complete mixing of air and fuels. Initial pressure of combustion chamber was adjusted by two pressure transducers with a range of (0–1 bar) and (0–30 bar). The internal pressure of the vessel was continuously monitored via an AVL, GU12P piezo-resistive absolute pressure transducer 0–200 bars. The temporal evolution of expanding flame was recorded via Z-type high speed schlieren photography.

2.2. Mixtures preparation

All tests were performed at initial temperature of 363 K and initial pressure of 1 bar and were repeated at least 3 times at each point. The equivalence ratios (Ø) varied from 0.8 to 1.2.

Fuel–air Mixtures can be expressed as $mCH_4 + (1-m)C_8H_{18} + X(O_2 + 3.76N_2)$ where m is methane mole fraction in mixed fuel and X is the number of moles of oxygen per one mole of mixed fuel.

Total equivalence ratio is defined as $ø = \frac{(OF)_{st}}{x}$, therefore X can be derived as $X = \frac{12.5-10.5m}{ø}$. Partial pressure method utilized to fill the CVC with precise injection of each fuel separately at desired Ø. In this method partial pressure of each fuel is related to its mole fraction.

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

$$p_{fuel} = p_{iso\text{-}octane} + p_{Methane} \qquad (2)$$

where $p_{iso\text{-}octane}$ and $p_{Methane}$ are partial pressure of iso-octane and methane respectively.

Calibration of direct injectors for liquid and gaseous fuel was done for each Ø. Fig. 2 shows the calibration of injector for iso-octane–air mixture. The R-squared value is 0.9983 which indicates that the regression line approximates the real data points well. t is the injector opening time and ΔP is pressure increase inside the chamber after fuel injection.

The properties of fuels that used in the experiments are presented in Table 1.Iso-octane with purity of 99.5% and methane