Measurements of Laminar Flame Speeds of Alternative Gaseous Fuel Mixtures

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I. Introduction

Pollution has been a concerning issue for most developed countries. As the world's population increases, the demand on transportation means, which include civil aviation and automobiles, increases. Consequently, the emissions produced by the transportation means contribute to a large percentage of the pollution in large cities. As a result, governments have placed strict policies on the amount of the emissions produced by the combustion engines. Therefore, in order for a certain fuel to be used for running the engine, it does not only have to have great combustion characteristics, but also it must have low emissions produced.

The term "alternative fuel" refers to any fuel that can be used in the current combustion engines without altering the design of the engine. With the effect of air pollution and due to lack and increasing in the cost of petroleum products, it becomes an important to explore an alternative fuel that could substitute petroleum- based fuel in all combustion engines. There are various new energy sources (alternative fuels), which could be classified as mixture gaseous alternative fuel such as biogas, syngas, mixture of propane (C_3H_8), hydrogen (H_2) and carbon monoxide (CO) and mixture of methane (CH4), hydrogen (H2) and liquefied petroleum gas (LPG). The gaseous alternative fuel attracts the attention of the most of researcher all over the world due to its rich reserve volume and fairly abundant worldwide. However, there are a number of challenges, which we need to consider using the gaseous alternative as a fuel for the engine, such as the low heat release rate, the poor lean-burn capability and the instable combustion. On the other hand, there is a method which can enhance these problems. This method is to add a component which has a faster burning velocity into the fuel mixture [1].

The flame speed is defined as the speed which the unburned gas mixture move relative to and normal to the flame front. The flame propagation velocity is one of the important parameters affecting the efficiency of the combustion. Both laminar and turbulent flame speeds play a great role in examining the feasibility of using a fuel for combustion engines. It is very significant to recognize the effect of composition changes on their quantitative combustion characteristics. One of these essential characteristic in the combustion process is laminar flame speed. There are many flame vital properties which connected to flame speed such as flashback and blow off, flame stability, flame stabilization and quenching distance [2-9]. Understanding laminar flame speed is important to control and improve many factors of combustion process such as controlling ignition time, reducing emission and increasing fuel efficiency. Laminar flame speeds have been measured for some alternative fuel mixtures such as biogas, which consists of methane (CH4) and carbon dioxide (CO2). Using biogas as fuel has many disadvantages or challenges such as low heat release rate, poor lean-burn capability and the instable combustion. On the other hand, these problems can be improved by adding hydrogen which has high burning velocity [1] .Syngas fuels, consists mainly of hydrogen (H2) and carbon monoxide (CO), and may also contain methane (CH4), nitrogen (N2), carbon dioxide (CO2), water vapor (H2O) and other hydrocarbons, has also been tested [10].. It seems that the syngas fuels will be one of most promising energy sources in the near future, due to the high energy conversion ratio and lower emissions [11].

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A little research has been done to measure the characteristics of methane with LPG fuel mixture which is one of the best alternatives. The main aim of this work is to test new gaseous fuel mixtures which are promising in reducing the emissions of the combustion. These fuel mixtures combine LPG (liquefied petroleum gas) and methane with other gases and fuels such as hydrogen, oxygen, carbon dioxide and nitrogen. These gaseous fuel mixtures will be studied to observe how the fuel composition affects the combustion characteristics of the fuel and, in particular, the laminar flame speed.

II. Experimental Methods

The test rig consists of a 430 cm long tube that can withstand high temperatures with a 1-in diameter. In addition, it has smooth walls to avoid any turbulence affecting the flame speed. The inlet of the tube is attached to a mixing chamber to supply the fuel-air mixture with low velocity to ensure laminar flow with Reynolds number *Re* = 1000. The fuel will be supplied to the mixing chamber from a pressurized cylinder. A piezoelectric gas igniter will be used to generate a spark that has to be attached to the inlet of the tube to initiate the flame as shown in Fig. 1. The test rig will be connected to different instruments, controllers and monitoring systems. Two type K thermocouples with response time is about 50 ms are used to detect the temperature rise. The signal will be detected by using a Instek GDS-3152 Digital Storage Oscilloscope with 150 MHz sampling rate. In addition, the flame propagation speed is mentored simultaneously using high-sensitivity high-resolution Canon digital camera with videography resolution 1920 x 1080 pixel and 30 fps shutter speed. The leading edge of the flame front will be observed as the flame front is expected to evolve after ignition into a hemispherical shape.

The planned measurements to be taken are mixtures of gaseous fuels, which are Liquefied petroleum gas (LPG), methane, and hydrogen, that will be tested at different flow velocities within the laminar regime to measure the flame propagation speed. In addition, many mixture strength values, equivalence ratios from 0.1 to 3, will be considered for each fuel under investigation. The laminar flame speed will be also measured with different percentages of carbon dioxide and nitrogen, with the air-fuel mixtures. The accuracy of the measurement will be verified by measuring the laminar flame speed of some standard fuels like methane (CH_4) and compare the results with those in the literature. The experiment will be repeated many times for the same flow condition until a good repeatability is obtained.

After the flame is ignited and starts propagating along the tube, it passes by two thermocouples placed at two predefined positions. Thus, the increase in temperature due to flame front is detected by the thermocouples showing a voltage rise on the oscilloscope as two peaks, as shown in Fig.2. Then, the oscilloscope is stopped to pause the signals generated. After that, the waveform is saved and the noise of the signal is reduced by a certain filter. Thus, the time between the two peaks can be obtained with more accuracy. Knowing the distance between the two thermocouples and the time taken by the flame, its velocity can be calculated simply as the distance divided by the time. In order to verify that the results obtained using the oscilloscope is accurate, a digital video camera was used where a movie of the flame movement is taken and then the clip was analyzed. The procedure performed is that two LED lights were used at the same positions of the thermocouples then the lighting in the lab was switched off then the video was recorded. By using video editor software called “IrfanView” the frames can be extracted and the time taken can be calculated, Fig. 3, and similar to what was done in the previous method, the absolute laminar flame speed can be calculated. Again, at every equivalence ratio, ten trials were done and the average was calculated.

III. Preliminary Results

Figure 4 shows that the laminar flame speed, S_L, measured by the oscilloscope are in a good agreement with those of Ref. [11]. Regarding the data obtained from the camera, there is a noticeable shift from the reference curve, and this shift is about 8 cm/sec. One possible reason is that the camera may not exactly normal to the tube due to space limitation. Thus, the flame might seem just passing by the starting point but actually, it has already passed. However, having the entire curve shifted up is a good indication that the error is systematic and can be eliminated by adjusting the angle of the camera. Thus, for this setup using the thermocouples has proved to be much better than using the digital camera. Although, it is believed that if the digital camera is placed normal to the tube much accurate results can be obtained.

As shown in Figure 5, limited results are shown for LPG-methane air flames with 20% LPG- 80% CH_4. It appears that the increase in the speed than that of the methane-air mixture is increasing as the mixture becomes richer from $\emptyset < 1.1$ to $\emptyset = 1.1$. For instance, at $\emptyset = 0.7$ the LPG-air mixture is faster than that of the methane-air mixture by 3 cm/sec while at $\emptyset = 1.1$ it is about 10 cm/sec. On the other hand, the increase in the speed than that of the methane-air mixture is decreasing as the mixture becomes richer from $\emptyset = 1.1$ to $\emptyset > 1.1$. The overall of the laminar flame speed of LPG-air mixture is faster than that of methane-air mixture. Thus, the addition of LPG to methane-air mixture is expected to increase the laminar flame speed of the mixture. Regarding the results obtained from the oscilloscope for both methane-air mixture and LPG-air-methane mixture the influence of changing the composition to be 20% LPG- 80% CH_4 with air can be noticed as the speed has increased a lot. Where at the lean region ($\emptyset = 0.8$) the speed of new fuel composition appears to be more than that of methane-air mixture by 18 cm/sec which is considered as a huge increase about 60%. As these are just preliminary results, extensive measurements of S_L are being taken for different fuel mixture compositions. These results will be presented in the final submission of the paper

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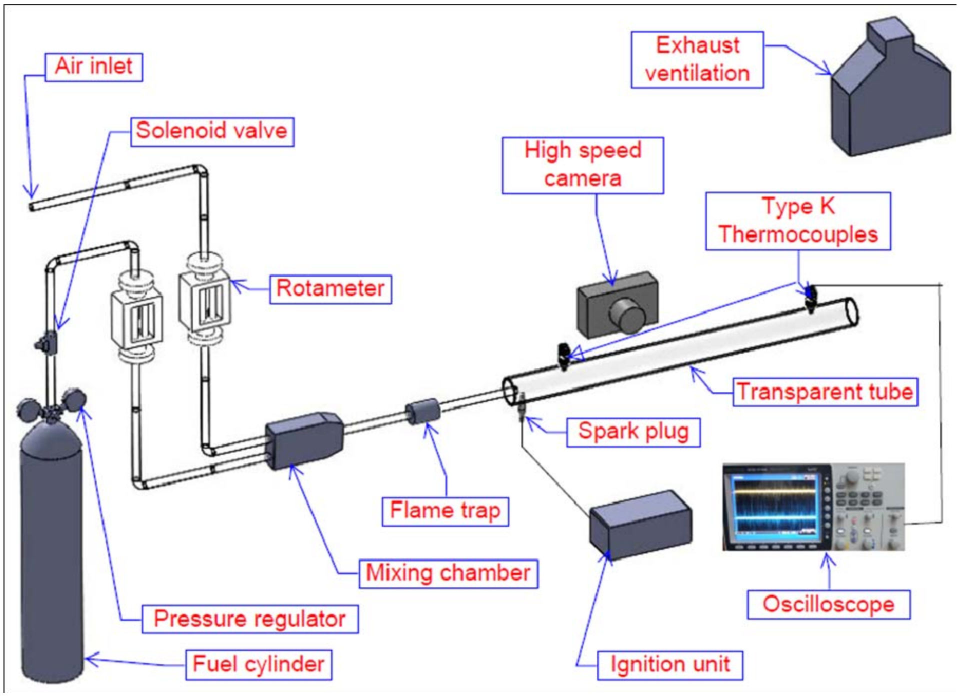

Figure 1. Schematic diagram of the test rig.

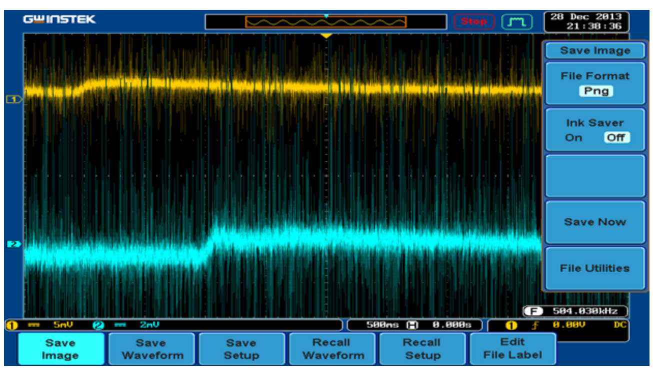

Figure 2. Typical thermocouple signals detected by the oscilloscope.

238 µs 5.9 ms 11.9 ms 17.8 ms 23.8 ms 35.7 ms

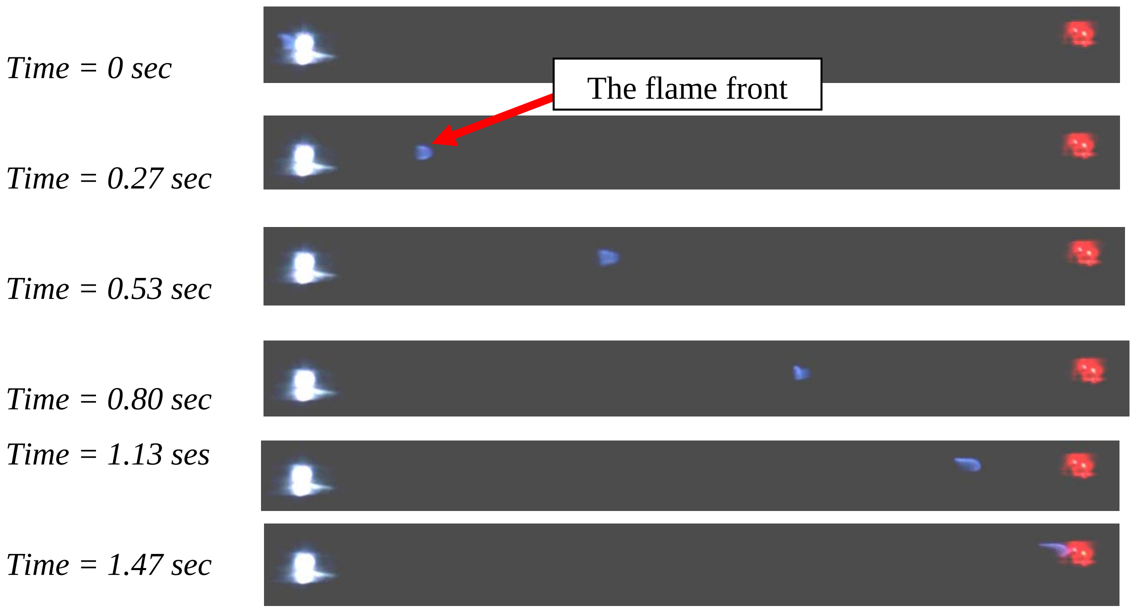

Figure 3. Snapshots of flame following ignition at *Re = 1000*.

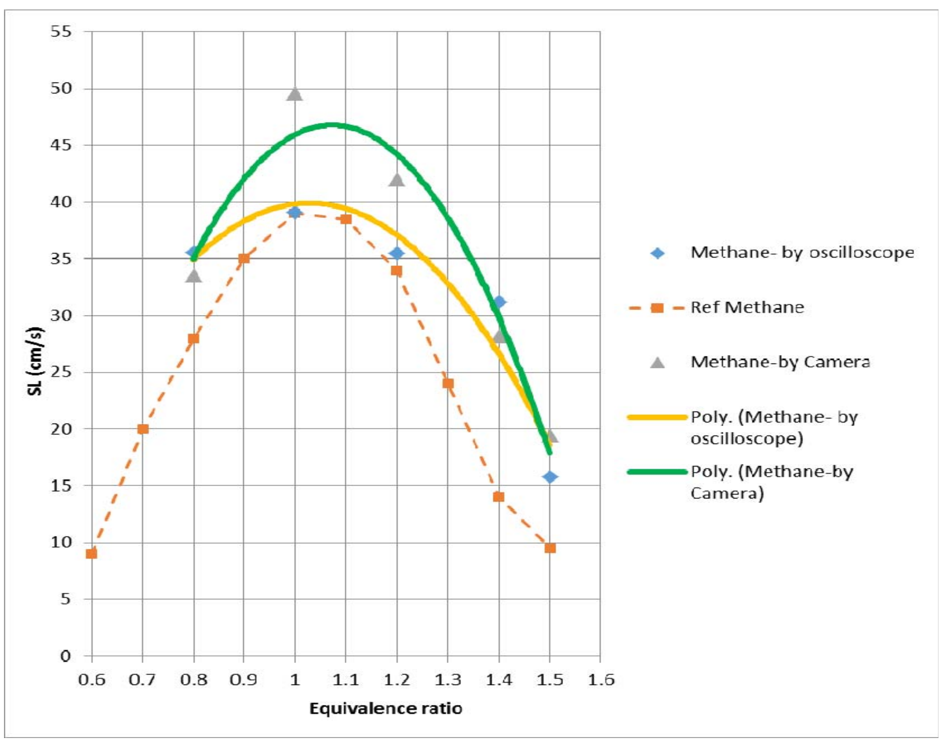

Figure 4. S_L of methane-air flames at different equivalence ratios in comparison with Ref. [11].

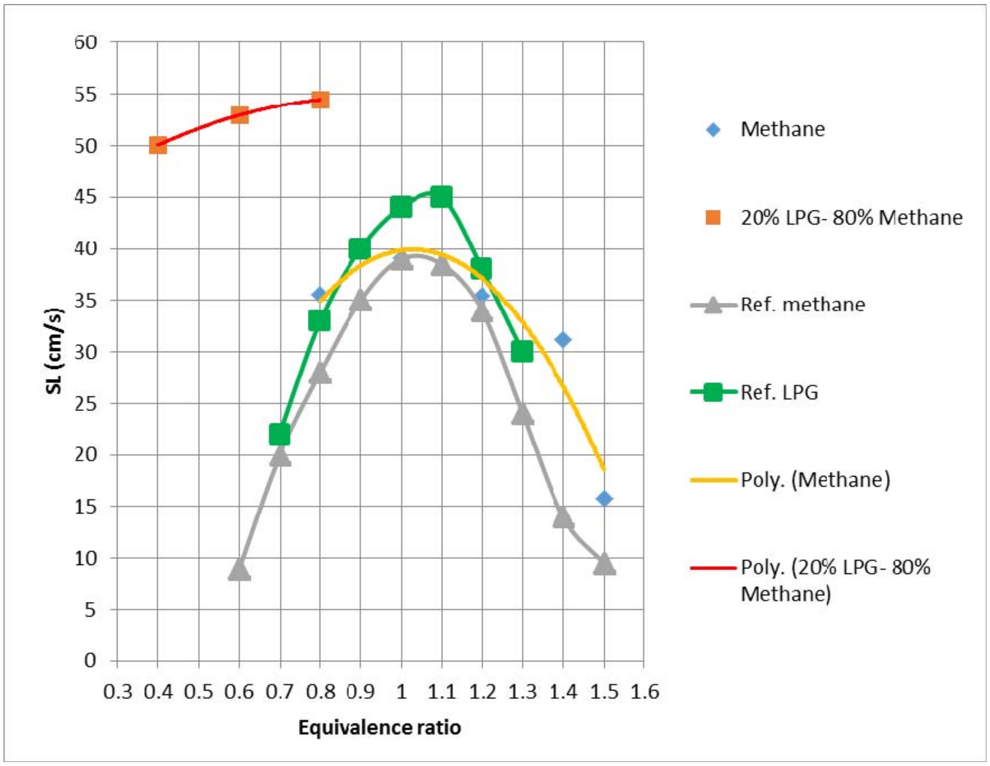

Figure 5. S_L of methane- LPG air flames in comparison with the results from Refs [12,13]