A Review Of Laminar Burning Velocity Of Gases And Liquid Fuels.

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ABSTRACT:

The laminar burning velocity is a fundamental property of a fuel that affects many aspects of its combustion behaviour. Experimental values are required to validate kinetic simulations, and also to provide input for models of flashback, minimum ignition energy and turbulent combustion. The laminar burning velocity is one of the most essential parameters for analysis and performance predictions of various combustion engines. It is the velocity, relative to the unburned gas, with which a plane, one-dimensional flame front travels along the normal to its surface. The majority of turbulent combustion models require knowledge of laminar burning velocity of the fuel-air mixture as a function of the mixture strength. Also reliable experimental data are needed in order to test and calibrate thermo-kinetic combustion models which have been quite successful for combustion predictions of simple hydrocarbon fuels. There are different methods to determine the burning velocity such as Heat flux burner method, Flat flame burner method, Bunsen burner method, Slot burner technique, Counter flow diffusion flow, Soap bubble technique, and Tube propagating method.

KEYWORDS: *Burning velocity, Bunsen burner, Flame front, Flame speed.*

I. INTRODUCTION

The laminar burning velocity is one of the fundamental properties of a reacting premixed mixture and its reliable data are constantly needed for combustion applications. So far, several techniques for measuring the one-dimensional laminar burning velocity have been used, and for a wide range of temperature, pressure, and fuel rather accurate measurements have been obtained by employing flat or curved flames in stagnation flow, propagating spherical flames in combustion vessel or flat flames stabilized on burner. With all those measurement technique proper care could be taken to remove the effect of flame stretch either during experimentation or through further data processing.

1.1 Importance of laminar burning velocity

Laminar burning velocity is an important parameter of a combustible mixture as it contains fundamental information regarding reactivity, diffusivity, and exothermicity. Its accurate knowledge is essential for engine design, modeling of turbulent combustion, and validation of chemical kinetic mechanisms. In addition, the determination of burning velocity is very important for the calculations used in explosion protection and fuel tank venting. Burning velocity is defined as the linear velocity of the flame front normal to itself relative to unburned gas, or as the volume of unburned gas consumed per unit time divided by the area of the flame front in which that volume is consumed. Laminar burning velocity is highly useful for modeling turbulent burning velocity. Turbulent flow occurs when a fluid undergoes irregular fluctuations and mixing. Laminar flow is defined as the flow which travels smoothly in regular paths or layers.

1.2 Flame front propagation

For efficient combustion the rate of propagation of the flame front within the cylinder is quite critical. The two important factors which determine the rate of movement of the flame front across the combustion chamber are the reaction rate and the transposition rate. The reaction rate is the result of a purely chemical combination process in which the flame eats its way into the unburned charge. The transposition rate is due to the physical movement of the flame front relative to the cylinder wall and is also the result of the pressure differential between the burning gases and the unburnt gases in the combustion chamber.

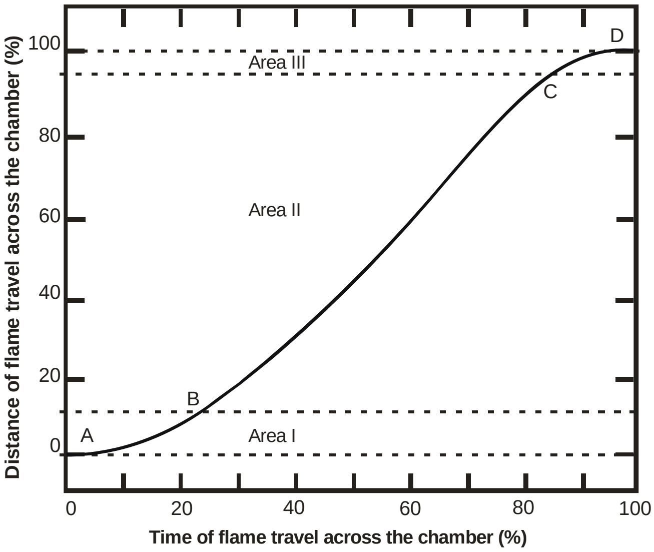


Figure 1: Details of flame travel

Figure shows the rate of flame propagation. In area 1, (A→B), the flame front progresses relatively slowly due to a low transposition rate and low turbulence. The transposition of the flame front is very little since there is a comparatively small mass of charge burned at the start. The low reaction rate plays a dominant role resulting in a slow advance of the flame. Also, since the spark plug is to be necessarily located in a quiescent layer of gas that is close to the cylinder wall, the lack of turbulence reduces the reaction rate and hence the fame speed. As the flame front leaves the quiescent zone and proceeds into more turbulence areas (area2) where it consumes a greater mass of mixture, it progresses more rapidly and at a constant rate (B→C) as shown in figure. The volume of unburned charge is very much less towards the end of flame travel and so the transposition rate again becomes negligible thereby reducing the flame speed. The reaction rate is also reduced again since the flame is entering a zone area (area 3) of relatively low turbulence (C→D) in figure.

1.3 Factor influencing the flame speed

The study of factors which affect the velocity of flame propagation is important since the flame velocity influences the rate of pressure rise in the cylinder and it is related to certain types of abnormal combustion that occur in spark-ignition engines. There are several factors which affect the flame speed, to a varying degree, the most important being the turbulence and the fuel-air ratio. Details of various factors that affect the flame speed are discussed below.

1.3.1 Turbulence

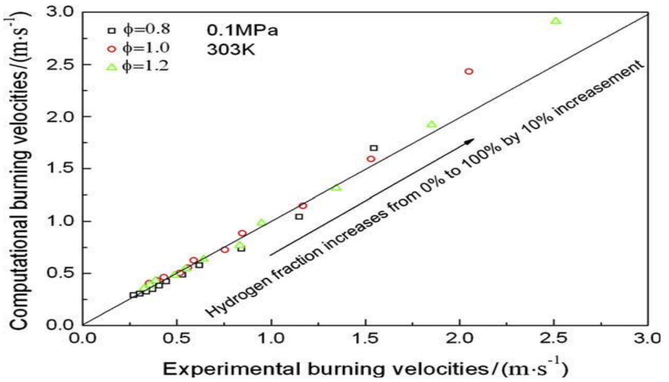
The flame speed is quite low in non-turbulent mixtures and increases with increasing turbulence. This is mainly due to the additional physical intermingling of the burning and unburned particles at the flame front which expedites reaction by increasing the rate of contact. The turbulence in the incoming mixture is generated during the admission of fuel- air mixture through comparatively narrow sections of the intake pipe, valve openings etc., in the suction stroke. Turbulence which is supposed to consist of many minute swirls appears to increase the rate of reaction and produce a higher flame speed than that made up of larger and fewer swirls. A suitable design of the combustion chamber which involves the geometry of cylinder head and piston crown increases the turbulence during the compression stroke.

1.3.2 Fuel-air ratio

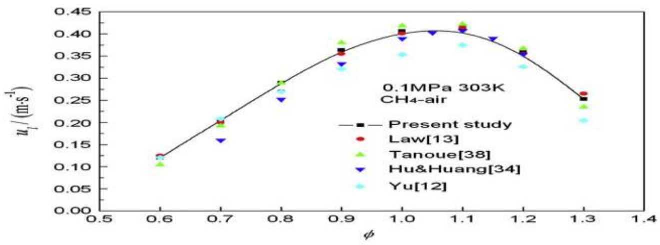
The fuel air ratio has a very significant influence on the flame speed. The highest flame velocities are obtained with somewhat richer mixture. When the mixture is made leaner or richer the flame speed decreases. Less thermal energy is released in the case of lean mixtures resulting in lower flame temperature. Very rich mixtures lead to incomplete combustion which results again in the release of less thermal energy. 1.3.3 Temperature and pressure Flame speed increases with an increase in intake temperature and pressure. Higher initial pressure and temperature may help to form a better homogeneous air-vapour mixture which helps in increasing the flame speed. This is possible because of an overall increase in the density of the charge.

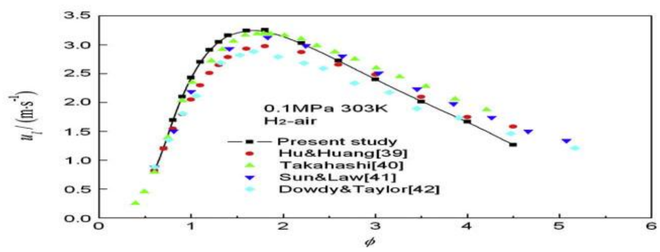
1.3.4 Compression ratio

A higher compression ratio increases the pressure and temperature of the working mixture which reduce the initial preparation phase of combustion and hence less ignition advance is needed. High pressures and temperatures of the compressed mixture also speed up the second phase of combustion. Increase compression ratio reduces the clearance volume and therefore increases the density of the cylinder gases during burning. This increases the peak pressure and temperature and total combustion duration is reduced. Thus engines having higher compression ratios have higher flame speeds. According to S.Y. Liao et al carried out the study on Determination of the laminar burning velocities for mixtures of ethanol and air at elevated temperatures. It has measured the laminar burning velocities for ethanol-air premixed flames at various temperature and equivalence ratio. The flames are analyzed to estimate flame size, consequently, the flame speeds are derived from the variations of the flame size against the time elapsed. It was studied the effects of the fuel/air equivalence ratio, initial temperature and pressure on the laminar flame propagation. It was conducted the premixed laminar combustion of ethanol-air mixture experimentally in a closed combustion bomb. And it was found the laminar burning velocity 58.3 cm/s at normal pressure of 0.1 MPa and temperature of 358 K.Xuan Zhang et al carried out the study on Measurements of laminar burning velocities and flame stability analysis for dissociated methanol–air–diluents mixtures at elevated temperatures and pressures. In this the laminar burning velocities and Markstein lengths for the dissociated methanol–air–diluent mixtures were measured at different equivalence ratios, initial temperatures and pressures. The influences of these parameters on the laminar burning velocity and Markstein length were analyzed. It was found that the peak laminar burning velocity occurs at equivalence ratio of 1.8. The Markstein length decreases with an increase in initial temperature and initial pressure. Measurements of laminar burning velocities and flame Stability analyses are conducted using the outwardly spherical laminar premixed flame for DM–air and DM–air–diluents mixtures. The laminar burning velocity and Markstein length at different equivalence ratios, initial temperatures, initial Pressures and N_2/CO_2 dilution ratios are obtained.Erjiang Hu et al carried out the numerical study on laminar burning velocity and NO formation of the premixed methane–hydrogen–air flames.



It was found that the unstretched laminar burning velocity is increased with the increase of equivalence ratio and it decreases as the mixtures become fuel-rich.





Peak value of unstretched laminar burning velocity of methane–air mixture is presented at the equivalence ratio of 1.1 and that of hydrogen–air mixture is presented at equivalence ratio of 1.8.Methane-dominated combustion is presented when hydrogen fraction is less than 40%, where laminar burning velocity is slightly increased with the increase of hydrogen addition. When hydrogen fraction is larger than 40%, laminar burning velocity is exponentially increased with the increase of hydrogen fraction. With the increase of hydrogen fraction, the overall activation energy of methane–hydrogen mixture is decreased, and the inner layer temperature and Zeldovich number are also decreased. All these factors contribute to the enhancement of combustion as hydrogen is added.

S. Jerzembeck et al carried out the research on Spherical flames of *n*-heptane, iso-octane, PRF 87 and gasoline/air mixtures. These are experimentally investigated to determine laminar burning velocities and Markstein lengths under engine-relevant conditions by using the constant volume bomb method. Data are obtained for an initial temperature of 373 K, equivalence ratios varying from ϕ = 0.7 to ϕ= 1.2, and initial pressures from 10 to 25 bar. To track the flame front in the vessel a dark field He–Ne laser Schlieren measurement technique and digital image processing were used. The laminar burning velocities are obtained through a linear extrapolation to zero stretch. The experimentally determined Markstein numbers are compared to theoretical predictions. A reduced chemical kinetic mechanism for *n*-heptane and iso-octane was derived from the Lawrence Livermore comprehensive mechanisms.S.P. Marshall et al are done research on the laminar burning velocity measurements of liquid fuels at elevated pressures and temperatures with combustion residuals. It was found that the laminar burning velocity is a fundamental property of a fuel that affects many aspects of its combustion behavior. Experimental values are required to validate kinetic simulations, and also to provide input for models of flashback, minimum ignition energy and turbulent combustion. A constant volume vessel (rated at 3.4 MPa) in conjunction with a multi-zone model was used to calculate burning velocity from pressure and schlieren data, allowing the user to select data uncorrupted by heat transfer or cellularity. n-Heptane, iso-octane, toluene, ethylbenzene and ethanol were tested over a wide range of initial pressures (50, 100, 200 and 400 kPa), temperatures (310, 380 and 450 K) and equivalence ratios (0.7–1.4), along with tests using combustion residuals at mole fractions of up to 0.3.

Shuang-Feng Wanga et al carried out the study on Laminar burning velocities and Markstein lengths of premixed methane/air flames near the lean flammability limit in microgravity. In this literature the researchers studied the effects of flame stretch on the laminar burning velocities of near-limit fuel-lean methane/air flames have been studied experimentally using a microgravity environment to minimize the complications of buoyancy. Outwardly propagating spherical flames were employed to assess the sensitivities of the laminar burning velocity to flame stretch, represented by Markstein lengths, and the fundamental laminar burning velocities of unstretched flames. Resulting data were reported for methane/air mixtures at ambient temperature and pressure, over the specific range of equivalence ratio that extended from 0.512 (the microgravity flammability limit found in the combustion chamber) to 0.601. Furthermore, the burning velocities predicted by three chemical reaction mechanisms. Additional results of the present investigation were derived for the overall activation energy and corresponding Zeldovich numbers, and the variation of the global flame Lewis numbers with equivalence ratio. The implications of these results were discussed.

II. DISCUSSION

Various literatures on evaluating the laminar burning velocity has been reviewed briefly and it is noticed that laminar burning velocities for hydrocarbon-air mixture are about 0.4 m/s and under turbulent flow conditions are unlikely to be much above 1.5 m/s. The Bunsen burner will accept flow velocities up to five times the burning velocity so that the maximum flow velocity which can be considered with this design of burner must be about 2 m/s. With rising oil prices and global warming being a dominant environmental issue, it seems that the use of alternative fuels in future is inevitable. These leading goals for both energy security and clean air project have resulted in heightened interests in the worldwide utilizations of alternative fuels in burners and engines. One of the most important parameters for any fuel is the laminar burning velocity. This property forms an important input parameter for models of turbulentCombustion and ignition limits. It is also important in engine simulations, which directly affects power output and efficiency. The experimental procedure used in this work follows closely that of Bradley et al, Metghalchi and Keck, Law et al, and Gülder, these groups also investigated spherical expanding flames at high pressures to determine laminar burning velocities of premixed mixtures in a preheated closed vessel with optical access. In these works, data measured over a similar range of stretch rates were extrapolated to zero stretch value following the approach. Lewis, streholow, Vagelopolous among others has found that the relationship between equivalence ratio and burning velocity is in the form of a bell curve approximately care necessary. The first step is entered on Ø=1. In order to calculate the equivalency ratio ϕ. For this experiment a series of calculations are necessary.

$$\phi = (fuel/air)_{actual} / (fuel/air)_{stoic}$$

A significant characteristic that affects burning velocity is the degree of turbulence in the flame. Ideally, the flame being measured should be laminar. A laminar flame has parallel flow lines, and therefore results in a uniform, steady flame. The Reynolds number (Re) is used to determine the state of the flow for a given apparatus. The equation for the Reynolds number is

$$R_e = \rho vd/\mu$$

Most importantly, for Re<2300 the flow is laminar, and for Re > 3200 it is typically turbulent. A laminar flame is precise and sharply defined which is necessary to accurately determine burning velocity. ρ is density of mixture, v is the average velocity, d is diameter of burner tube, μ is dynamic viscosity.

The flame speed is determined by,

$$S_b = dr_b / dt$$

Where, S_b is the flame speed with respect to the burned gas and r_b is the flame front displacement. Therefore, values of the Schlieren radius r_{sch} determined by image tracking of Schlieren cinematography are close to r_b. Flame images were analyzed with an image processing code specifically developed for the experimental configuration to track flame front radii over time. The burned propagating flame speed S_b was determined from first-order least squares fits through four radii adjacent to each point under consideration. Contrast levels were set to define consistently flame fronts at all times.

The unburned unstretched flame speed (S_u) was obtained from continuity,

$$S_b \rho_b = S_u \rho_u$$

The values ρ_b and ρ_u are the burned and unburned densities of the mixture and were computed with the one dimensional flame code Flame Master.

III. FUTURE SCOPE

The experimental setup for this project had several flaws that are significant sources for the margin of error in the data.Particular focus should be on a redesign of the apparatus Possible improvements should include a section of greater vertical distance prior to the slot itself to attempt to induce a flow that is more laminar, and generally less twists and turns in the tubing and adapters. For the Bunsen burner apparatus the most significant improvement would be to add a second tube to the apparatus. The tube would surround the existing burner tube, and it would provide a flow of an inert gas, such as nitrogen. This flow would stop the leakage that occurs in a horizontal direction under atmospheric conditions. This is ideal to provide an exact cone shaped flame, which will in turn provide a more accurate measurement for surface area and finally burning velocity. Burning velocity is depends on the size of the burner tube, a detailed analysis of the effect of tube diameter on burning velocity measurements is part of a future study related to this work.

IV. CONCLUSION

The laminar burning velocity is one of the fundamental properties of a reacting premixed mixture and its reliable data are constantly needed for combustion applications. So far, several techniques for measuring the laminar burning velocity have been used, and for a wide range of temperature, pressure, and fuel rather accurate measurements have been obtained by employing flat or curved flames in stagnation flow propagating spherical flames in combustion vessel or flat flames stabilized on burner. With all those measurement techniques proper care could be taken to remove the effect of flame stretch either during experimentation or through further data processing. Measurements were based on motion picture schlieren photographs of outwardly propagating spherical flames. A heated spherical combustion vessel has been used with systems for fuel injection, ignition, experiment control, data acquisition and high speed schlieren photography. This study focuses on the effects of initial temperature and fuel/air equivalence ratio on the laminar burning velocities of gases and liquids.

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