Journal of Current Research in Engineering and Science
JCRES
Bi-Annual Online Journal (ISSN : 2581 - 611X)

Volume 6- Issue 1, Paper 37,January 2023

Experimental study and measuring of fuel air mixutre burning velocity using stationary method

K. Gokulnath, C. Aravindh, M. Kishore ,N.Hariharan, A. Prakash
Department of Aeronautical Engineering
Paavai Engineering College
(Autonomous)
Namakkal, India

***ABSTRACT*- The purpose of this combustion research is measuring the laminar velocity of a gas-fuel mixture. This research gives us better understanding of ignition mixture mechanism, propagation of fuel, pressure, temperature of the fuel mixture etc. Accurate measurement and prediction of flame speed and laminar combustion rate are crucial to characterizing premixed combustion properties. The problem is lack of fuel, so it is necessary for the researchers to re-evaluate the combustion process and optimizing fuel consumption. So, it is necessary to identify the change of laminar burning rate and flame rate with thermodynamics conditions for understanding the impression of practical applications in all combustion systems such as working temperatures and pressures are significantly higher than ambient conditions. Stationary method where the Bunsen burner which is the classical device to generate a laminar premixed flame by measuring the cone angle α. The burn rates of liquefied petroleum gas (LPG) with oxygen-exhaust mixtures were calculated from cone angle recordings in an open ignition vessel using a Bunsen burner during the early phase of the explosion.**

The result of the research formulation provides better understanding of flame speed gives prior rate of change of velocity without affecting the vulnerability of engine.

Keywords—Cone angle,LPG-Air,Bunsen burner,laminar burning velocity.

I. INTRODUCTION

Liquefied petroleum gas (LPG) is widely used asclean alternative fuel in automotive engines, replacinggasoline and diesel, and as fuel for domestic use. Agreatamount of information about its combustion characteristics isavailable,requiredmainly for the analysis and prediction oftheefficienciesofvarious motorsand/orcombustors.Characteristic parameters of LPG-air explosions in closed spacesvessels of various geometries and dimensions (explosionpressures, pressure rise rates, burst times and severityfactors) were determined for various initial pressures andtemperatures and examined. other importantparameters associated with ignition of explosion by high andminimum distances of extinction of electrical sparks of low voltageignition energies and minimum ignition currents. A study of the propagation of explosions of liquid gas-air mixtures with different equivalence relations, initial temperatures etc. Pressures in a steady-state process gave values of burning speed. An experimental study of LPG-air combustion in a Bunsen burner reported combustion rates under conditions typical of a high-performance engine cylinder where initial pressures between 1.5 and 4 bar and initial temperatures between 330 and 380K. A complete set of burn rate data and their dependencies on initial temperature, pressure, and composition of LPG-air mixtures. Other interesting additives for LPG air, with a positive effect on engine efficiency, are based on the hydrogen. Hypothesis of a burning rate limit for flammability limit, this approach allowed the authors to evaluate the critical exhaust gas concentration for the complete inserting of the system.

II. LITERATURE SURVEY

A. Methodology

In this experiment of oxygen LPG. Combined with where static fires can occur *u*sed to measure combustion rates by placing a flame on the mouth of a burner, in *a* constant mixture of fuel and oxidant is fed at a constant rate. Many *d*ifferent types of burners have been used with different approaches to determine burning speed, with varying degrees of accuracy.

B. Blaze measurement of area

The simplest and oldest method of measuring the combustion rate of a cylinder burner, using the principle, was to divide the volumetric flow rate of the premixed fuel and oxidizer mixture by the approximate surface area of the flame. Although simple, the method has some significant problems, as described by Rallis and Garforth (1980). Perhaps the most important

Journal of Current Research in Engineering and Science
JCRES
Bi-Annual Online Journal (ISSN : 2581 - 611X)

point here is that using the flame front area, the burn rate obtained must be the average burn rate over the entire surface of the flame. Heat transfer to the edge of the burner will reduce the temperature of the flame from the temperature of the adiabatic flame, thereby reducing the combustion rate, while heating from all sides at the end may result in an increase in temperature. Heating or cooling different areas of the cone will also cause additional bending of the fire front. Considering a truncated cone described by Harris et al. (1949), the most important areas of error (the tip of the flame and the base of the flame at the mouth of the burner) can be eliminated, although there will be uncertainty about the rate of mass flow associated with the log. The difficulty in establishing the position of the flame front is also important from which to measure the front area of the fire.

III. MEASURING TECHNIQUES FOR LAMINAR BURNING VELOCITIES

Laminar combustion rates can be measured by making a premixed flammable mixture with a flow laminar to enter a fixed flame front with velocity equal to the combustion rate.

Burning rate is the rate at which fire spreads faster than non-combustible gas. This is different from the speed of fire. Laminar burning velocity is the speed at which a laminar burning wave propagates against a gas mixture that does not burn in front of it.

Methods for measuring laminar combustion rates fall into two main groups: Stationary flameand non-stationary flame methods. Commonly used techniques are reviewed here sinceexisting burn rate data has been obtained via a wide variety of these methods and so on kknowledge of the methods used is required.

A. Abbreviations and Acronyms

LDV – LASER DOPPLER VELOCIMETRY

CIS – CROWN IGNITION SYSTEM

LPG - LIQUIFIED PETROLEUM GAS

LPM – LITERS PER MINUTE

B. Units

- V_u – Flow velocity
- Q_{LPG} – Mass flow rate of LPG
- Q_{air} – Mass flow rate if air
- A_e – Area of the burner
- d – Diameter
- S_{Lu} – Burning velocity of flame
- α – Angle of flame in degree

C. *Stationary flame method*

Stationary flames can be used to measure combustion rates in aflame at the mouth of the burner containing a continuous mixture of fuel and oxidantfed at a constant rate. Different types of burners were used differently.Approaches burning rate determination with varying degrees of accuracy. These are summarized below.

This is one of the most common methods used for early burn ratemeasurements, largely due to the simplicity of the equipment involved Fire. The speed of Bunsen burners can be adjusted in several waysdescribed here. Burners can be cylindrical or slotted; cylinder burners.

They produce a cone-shaped flame, while slot burners produce a more prismatic flame.Singer (1953) provides an early comparison between cylinder and aperture and find burners. Those slot burners reduced the curvature of the flame front and were more suitable for it. Measurement using flame area method.

D. Bunsen burner

It is one of the most commonly used methods for early burn rate measurements, largely due to the simplicity of the equipment. The burn rate can be established from Bunsen burners from a variety of methods described here. Burners can be cylindrical or slot burners; Cylindrical burners produce a cone-shaped flame, while slot burners produce a more prismatic flame. From onwards 1953 provides a first comparison between cylindrical and split. burners and found that slotted burners reduced flame front bending and were more suitable for measurements utilizing the flame.

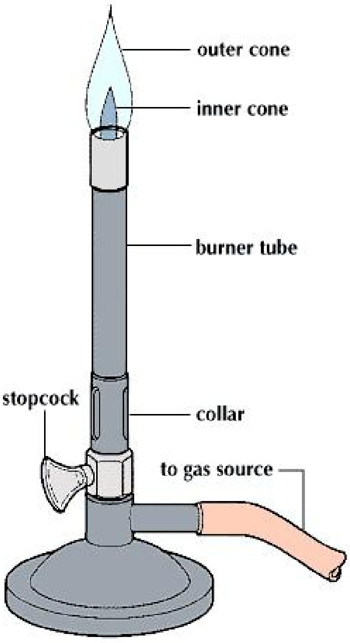

Fig. 1: Bunsen Burner

E. Flame area measurement of Bunsen Burner

The simplest and earliest method of measuring the burn rate of a cylindrical combustor was to divide the volumetric flow rate of the premixed fuel and oxidizer mixture by the estimated flame area where there are some important problems with the method as established by Rallis and Garforth. the main problem is to use the surface of the flame front, the burn rate achieved will necessarily be an average burn rate over the entire flame surface. It can be seen that the rate of combustion varies spatially, both due to curvature leading to stretching of the flame front and to temperature variations; Heat transfer to the edge of the burner reduces the flame temperature relative to the adiabatic flame temperature, causing the burning rate to decrease, while at the tip the temperature can increase due to heating on all sides of the cone. This heating or cooling of different areas of the cone also causes the flame front to curve further. By considering a truncated cone as the largest error areas (flame tip and flame foot at the burner mouth) can be eliminated, but then there is uncertainty in the associated mass flow to the trunk. The difficulty of establishing the position of the flame front from which the area of the flame front can be measured is also significant. Various methods are available; Daylight photography, shadow puppet and Schlieren photography, and each method produces a different flame front position. The area required to accurately determine the burning rate is the location of the points where the gas temperature rises just above the initial temperature. The burn rate was derived by considering the flow of unburned gas into the flame, this cone will always be within those that can be considered by the methods above.

F. Cone angle measurement

Cone angle measurement from the angle of the flame cone and the velocity of the incoming premixed fuel and oxidizer mixture, it is possible to estimate the burning rate, since the burning rate can be viewed as a vector perpendicular to the flame surface face-on once the flame has stabilized. However, with this method the problem of identifying the exact location of the flame front remains, which introduces errors in the measurements since α must be the angle of the cone created by the cold flame front.

$$S_{Lu} = V_u \sin \alpha$$

Where α is semi included angle of flame in degrees

It is also a further source of error that the angle of the flame varies along the flame front as a result of a again varying burn rate due to curvature and temperature variations, so that the measured burn rate depends on the selected area of the flame.

G. Flame thrust method

Flame propulsion method where the pressure difference is measured across 1D Founded, Louis and von Elbe (1961). The pressure difference can be measured usingpitot tube, as in the work of Edmondson y Heap (1969). The difficulty is here that the pressure difference is very small, so the measurements are greatly exposed error.

H. Non-stationary method

There are a variety of methods available to measure burning rates of propagating flames. The first and simplest involve measuring a flame propagating along a tube, but they have many problems associated with heat transfer to the tube walls, and led to Rallis and Garforth (1980) to regard such methods as 'inherently unsatisfactory'.

These methods do not appear to be in common use in current measurements of burning rate and so it will not be considered further. The most successful and versatile methods involve spherically expanding flames within a combustion vessel and can generally be divided into constant constant volume and pressure methods.

I. Constant pressure method of non-stationary method

Constant pressure combustion can be attained by a various method. One of the first methods of measuring the rate of combustion from flame propagation at constant pressure is the so-called "soap bubble method", in which the combustible mixture is trapped in a soap bubble at a pressure determined and lights up.

During the combustion process, the bubble (and therefore the volume occupied by the gases) expands, keeping the pressure constant. Flame velocities are determined by measuring the radius of the flame and have been found to be substantially constant under this constant pressure condition.

The advantages of a simple sphere geometry and a constant burned gas temperature led to easier modeling of flame propagation. Disadvantages include sensitivity to radius measurements, which introduce a source of error, and problems with contamination of the mixture by the soap bubble itself and diffusion through the film.

There are also limitations to the range of recording speeds that can be accommodated with this method. In a constant volume chamber, the initial stages of combustion occur without an overall increase in pressure, so measurements made (usually by Schlieren photography) during these initial stages can be viewed as constant pressure results. Some more complex constant pressure combustors have been used, in which the main combustion chamber is in a larger outer chamber which is interconnected to allow expanding gases to flow into the outer chamber to maintain a constant pressure during combustion. With the aim that these initial pressures are used to allow a higher pressure.

J. Constant volume method of non-stationary method

Constant volume combustion vessels are used to produce flames that spread spherically. Thus, constant-volume combustion chambers are often spherical, although some are cylindrical or even parallelepiped. Central ignition, usually spark-ignited through a pair of electrodes, but sometimes laser-ignited in a spherical flame that spreads outward through the mixture without burning. Two different methods are available: flame velocity measurements during the initial pre-combustion phase and pressure-time analysis during combustion.

There are several advantages to the use of such devices, the most important being that combustion is possible at high temperatures and pressures, as these vessels can normally withstand high absolute pressures. This overcomes a major problem in many burner processes. If an appropriate method is used to analyze the images of the flame front, the effect of stretching on burning rate can be accurately determined, since the conditions of flame stretching are inherently well defined for the case of a single flame. spherical that spreads outwards. Combustion rates for a wide range of temperature and pressure can be derived from pressure-time curve analysis.

IV. FACTORS AFFECTING BURNING VELOCITY

The rate of combustion will depend on the type of fuel and the ratio of air to fuel, depending on the composition of the compound under investigation. In the field of laminar burning rates, it is most common to refer to the mixture’s ratio φ, which is defined as the ratio between the air / fuel ratio and the stoichiometric air / fuel ratio. Therefore, the equivalence ratio will be greater than 1 in a fuel-rich mixture and less than 1 in a fuel-efficient mixture.

A. Fuel and air mixture composition

The burning rate is highly dependent on the composition of the underlying mixtureboth in terms of the type of fuel and the proportion of fuel and air. In the area oflaminar burning rates, it is more common to refer to the equivalence ratio φ of the mixture,defined as the ratio of the fuel/air ratio (FAR) to the stoichiometric fuel/air ratio (FARst).Therefore, a fuel-rich mixture has an equivalence ratio greater than 1 and a fuel-lean mixturemix less than 1.

B. Type of fuel affecting burning velocity

Combustion rates are strongly influenced by the adiabatic temperature of the flame, and therefore the enthalpy of combustion of a fuel has a large influence on the rate of combustion. This effect is evident between combustion rate and combustion enthalpy within fuel families. But the structure of the fuel is also important because it influences the reaction, particularly with aromatic compounds, the correlation between the rate of combustion and the adiabatic temperature of the flame is poor and the effects play an important role.

V. CONSTRUCTION OF BUNSEN BURNER

The configuration consists of agas burner unit with provisions for air intake and LPG intake. The burner is heightadjustable and thermally insulated on the inside. The burner assembly is mounted on a flanged table and vertical control panel which houses the two rota gauges, one for LPG and one for airflow measurement. Each rotameter has a control valve to regulate the flow.LPG is supplied from the small LPG bottle supplied with the unit. The air is supplied by the small compressor that comes with the device. The burner unit is surrounded by a glass chamber for better visibility and to avoid external interference. The angles protect the actuator used to externally measure the angle of the cone. The whole set is mounted on a study table with all

hose connections

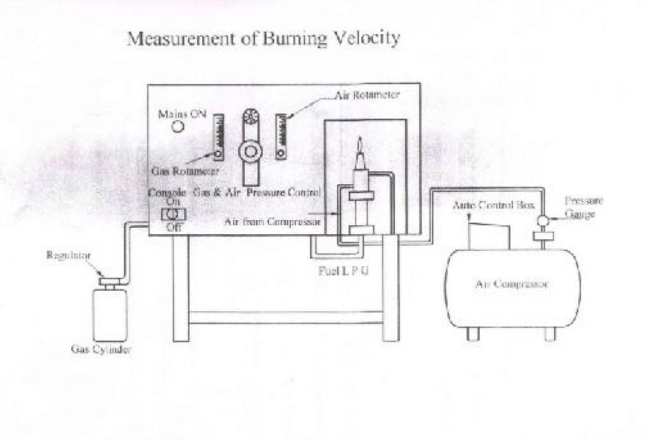

Fig.2: Experimental Bunsen Burner setup

A. Experimental theory of bunsen burner

The classic device for generating a laminar premixed flame is the Bunsen burner, in which gaseous fuel from the fuel feed enters the mixing chamber through an orifice, into which air is introduced from outside through adjustable openings. The cross-sectional area of the fuel port can be adjusted by moving the needle through an adjusting screw in the port. This allows the speed of the jet entering the mixing chamber to be varied, optimizing the maintenance of air and vacuum.

The mixing chamber must be long enough to create a premixed gas that exits the Bunsen tube to atmosphere. When the speed of the outflow is greater than that of the laminar tube towards the environment. If the outflow velocity is greater than the laminar burning velocity defined below, a Bunsen flame cone appears at the top of the tube. It represents a stationary premixed flame propagating normal to itself in the unburned mixture with burning rate SL. The kinematic equilibrium of this process is shown.

For a stationary oblique flame, the inlet velocity vector vu of the unburned mixture decomposes into a component $_{Vt,u\ that}$ is tangential to the flame and a component $V_{n,u}$ that is perpendicular to the flame front.

Due to thermal expansion within the flame, the normal velocity component increases, the mass flow rate through the flame must be the same in the unburned mixture and in the burned gas. Vector addition of the velocity components in the burned gas. It then leads to V_b pointing in a direction deviated from the flow direction of the unburned mixture.

Finally, since the flame front is stationary in this experiment, the burning rate s L u with respect to the unburned mixture must be equal to the flow rate of the unburned mixture perpendicular to the front. This allows the experimental determination of the burning rate by measuring the cone angle ∝ under the condition that the flow rate Vu through the tube outlet is uniform. If this isn't the case, the flame angle will undergo change with radial distance where the burning rate $S_{L\ U}$ is essentially constant.

B. Operating procedure of bunsen burner

First, make sure that all valves on the gas cylinder and on the rotameter compressor are closed. Then slightly open the regulating valve of the LPG cylinder. Prepare the ignition with a gas lighter or match. \

Then slowly open the LPG rotameter valve and turn on the gas. Then slowly open the air rotameter valve while observing the flame. Observe the flame through the glass and adjust the gas and air flow to maintain good blue and laminar flame condition.

A cone flame is created. Now measure the angle of the cone to the centre line of the cone (flame) with the meter gauge. (First set the angle guard to the 900 position and hold it in the same position, bring the guard arm to the tangent/inclined line of the outer flame and then lock it. Remove it and look at the angle and note.)

Repeat the same process, changing the gas and air flow. After completing the experiment, tightly close the LPG rotameter valve and the LPG cylinder regulating valve. Also close the airflow valve.

C. Procedure and Calculations

1. Effective area of a burner $A_e = \pi \frac{d^2}{4} m^4$ → 1

$$= \frac{3.14\times3.5^2}{4}$$

$$= 9.6162 \times 10^6 m^2$$

Where d = Diameter of burner: Ø 3.5 mm hole

2. $\left\{ \begin{array}{c}\text{Total mass}\\ \text{flow rate}\end{array} \right\} Q_{total} = Q_{air} + Q_{gas}\ m^3/s$

3. $\left\{ \begin{array}{c}\text{Mass flow}\\ \text{rate of air}\end{array} \right\} Q_{air} = \frac{Volume\ of\ air\ supplied\ in\ LPM}{60\times1000} m^3/s$

4. $\left\{ \begin{array}{c}\text{Mass flow}\\ \text{rate of lpg}\end{array} \right\} Q_{LPG} = \frac{Volume\ of\ gas\ supplied\ in\ LPM}{60\times1000} m^3/s$

5.Flow velocity, $V_u = \frac{Q_{total}}{A_e} m/_{s}$

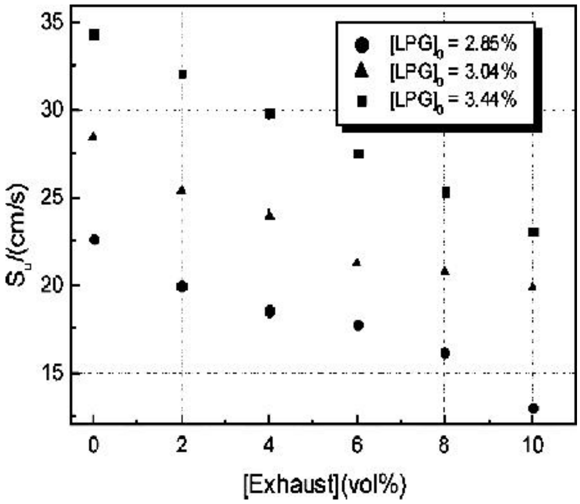

Fig. 3: Measured burning velocities of LPG‑airflames,atambientinitialpressureandtemperature.

Three sets of normal combustion rates determined for LPG air in the presence of its exhaust gases. The effect of exhaust gas introduction is greater compared to air because the exhaust gas contains significant amounts of water vapor and carbon dioxide in addition to nitrogen. Their individual influence on burning rate will be examined later using data from chemical models.

The impact of exhaust gas dilution on the normal combustion rate of LPG air can best be seen by looking at the relative combustion rates. As has already been observed for other characteristic flammability parameters of LPG-air-exhaust mixtures, dilution affects a lean fuel-air mixture more than a near stoichiometric one. pressure P0 away. The variation of normal burning rates versus pressure is given for all systems examined. Choosing the ambient pressure as reference, the baric coefficients of the LPG-air-exhaust mixtures for LPG-air mixtures were calculated.

The burning rates of liquefied gas with oxygen in the form of exhaust gas were determined from experimental pressure recordings from explosions in a Bunsen burner by cone angle measurements in the early stages of the process. Oxygen-mixed LPG burn rates agree well with literature data obtained by other measurement techniques. Due to the fact that the calculation of the combustion rate does not require values of the thermophysical properties of the fuel, the early-stage method seems to be suitable for complex systems consisting of a fuel consisting of air or mixed only with fuel and complex additives.

Combustion rates of LPG-air mixtures obtained from detailed combustion models have been overestimated. Normal burn rates are reduced by the progressive dilution of the LPG and air mixtures with their own exhaust gases at all initial pressures. The effectiveness of the exhaust gases in slowing the burn rate and inserting explosions also depends heavily on the ratio, which is determined by the initial equivalence ratio. Larger fluctuations in the propagation parameters are observed with this Bunsen burner method.

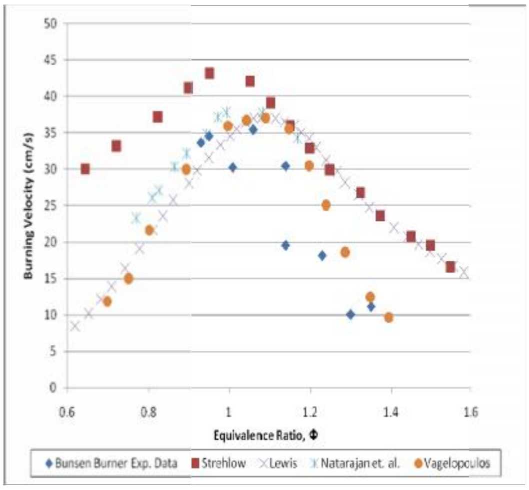

Fig. 4: Burning velocity and equivalence ratio

VI. RESULTS DISCUSSION

There are several physical factors that affect the results of the experiment. The main focus of this study is the calculation of the combustion rate in different equivalence relations Φ. To calculate the equivalence relation Φ, this experiment requires a series of calculations. the remaining units are in moles per hour. Also, the air is multiplied by 0.21, leaving only the number of moles per hour of oxygen. Next, the LPG value is divided by the oxygen value. This number is then divided by the stoichiometric ratio of fuel to oxygen 0.5 The next value is the equivalence ratio, Φ.

There are two methods for burning rate measurement using the slotted burner method experimental parameters that could contribute to a possible calculation error. The flow rate of the consumed gas u is measured with a suitable flow meter in cubic feet per hour. Rates are indicated by markings on the side of the flow meter in two cubic feet per hour increments. Alpha is measured with utilizing the flame. When measuring burn rate using the Bunsen burner method, there are three variables that could contribute to potential calculation errors.

The surface area of the conical flame is calculated by measuring the height and diameter of the base of the cone. Both lengths are measured with a metric ruler in one-millimeter increments. With this method, the volume flow is also measured with the flowmeters. The temperature of the unburned gases in a premixed flame canhave a considerable influence on the measurement of the combustion rate. All experiments in this studyare performed in an environment at room temperature. Since the tests are performed on the over the course of several days, the ambient temperature may fluctuate up to 2°C on any given day.

VII CONCLUSIONS AND FUTURE WORK

A. Conclusions

The main goal of this project is to measure laminar combustion rates with a variety of flame sizes. The speeds achieved with Bunsen burners are much higher than the data. This could be due to air being entrained from the sides of the flame, which cools to the flame's temperature and affects its burning rate. The group also had turbulence issues with this setup. Bunsen burner data is fairly accurate. The highest burn rates occurred when the equivalence ratio is approximately equal to 1, where the mixture of fuel and air is equal to stoichiometric conditions.

Thus, complete combustion takes place, which in turn maximizes the flame temperature. Flame temperature and burning speed are directly related, and therefore at Φ=1 the flame should have its highest possible burning speed**.**

B. Future work

The experimental setup for this project had several flaws that are major sources of error in the data. For the Bunsen burner device, the most significant improvement would be to add a second tube to the device. The tube would surround the existing combustor tube and provide a flow of an inert gas such as nitrogen. This flow would stop the leakage that occurs in the horizontal direction under atmospheric conditions.

This is ideal for providing a precisely conical flame which in turn allows for a more accurate measurement of surface area and ultimately burning rate. An additional benefit of the inert gas environment will be the flame stability it provides. This allows the data to cover a full range of equivalence ratios from lean to rich. Current engine designs experience flame blowout during lean mixtures, making sub stoichiometry burn rates nearly impossible to record.

REFERENCES

[1] O. Riccius, R. Smith, F. Guthe, P. Flohr, The GT24/26 combustion technology and high hydrocarbon fuels, in: Proceedings of ASME Turbo Expo 2005 Power for Land, Sea and Air, Reno, 2005.

[2] Iskender Gokalp, E. Lebas, Alternative fuels for industrial gas turbines, Applied Thermal Engineering, 24 (2004) 1655-1663

[3] J.P. Botha, D.B. Spalding, The laminar flflame speed of propane/air mixtures with heat extraction from the flflame, Proceedings of Royal Society of London A, 225 (1954) 71-96.

[4] A. van Maaren, D.S. Thung, L.P.H. de Goey, Measurment of Flame temperature and adiabatic burning velocity of Methane/Air mixtures, Combustion Science and Technology, 96 (1994) 327-344.

[5] L.P.H. de Goey, L.M.T. Somers, W.M.L. Bosch, R.M.M. Mallens, Modelling of small-scale structure of flat burner-stabilized flames, Combustion Science and Technology, 104 (1995) 387-400.

[6] A. van Maaren, L.P.H. de Goey, Laser doppler thermometry in flat flames, Combustion Science and Technology, 99 (1994) 105-118.

[7] K.J. Bosschaart, M. Versluis, R. Knikker, Th.H. van der Meer, K.R.A.M. Schreel, L.P.H. de Goey, A.A. van Steenhoven, the heat flflux method for producing burner stabilized abaibatic flflames: an evaluation with CARS thermometry, Combustion Science and Technology, 169 (2001) 69-87.

[8] K.J. Bosschaart, L.P.H. De Goey, Detailed analysis of the heat flflux method for measuring burning velocity, Combustion and Flame, 132 (2003) 170-180.

[9] K.J. Bosschaart, L.P.H. De Goey, the laminar burning velocity of flames propagating in mixtures of hydrocarbons and air measured with the heat flux method, Combustion and Flame, 136 (2004) 261-269.J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[10] Galmiche, B., F. Halter, F. Foucher and P. Dagaut (2011). "Effects of Dilution on Laminar Burning Velocity of Premixed Methane/Air Flames." Energy & Fuels **25**(3): 948-954.

[11] ANDERSON, J. W. and FEIN, R. S. Measurements of normal burning velocities and flame temperatures of Bunsen flames, J. Chem. Phys. 17, 1268-1273 (1949).

[12] Rallis C.J. and Garforth A.M., 1980, The determination of laminar burning velocity, Progress in Energy and Combustion Science, 6(4), pp. 303–329. doi: 10.1016/0360-1285(80)90008-8.

[13] Smith, D.B., Taylor, S.C. and Williams, A.: Problems with Defining and Measuring Burning Velocity. Paper presented at the Joint Meeting of the British and French Sections of the Combustion Institute, Rouen, France, April 18-21, 1989.

[14] Thompson L, Lopez J and Vasu S S 2017 Laser Ignition and Flame Speed Measurements in Oxy-Methane Mixtures Diluted With CO 2 (J Energy Resour Technol) vol 138 pp 1–9.

[15] Chen Z 2015 On The Accuracy Of Laminar Flame Speeds Measured from Outwardly Propagating Spherical Flames： Methane / Air at Normal Temperature and Pressure (Combust Flame) pp 2–13

[16] Wu X et al 2011 Laminar Burning Velocities Andflame Instabilities of 2,5-Dimethylfuran–Air Mixtures at Elevated Pressures (Combust Flame) vol 158 pp 539–546

[17] Varea E, Modica V, Renou B and Boukhalfa A M 2013 Pressure effects on laminar burning velocities and Markstein lengths for Isooctane – Ethanol – Air mixtures (Proc Combust Inst) vol 34 pp 735–744.

[18] Bradley D, Lawes M, Liu K and Woolley R 2007 Laminar Burning Velocities of Lean Hydrogen – Air Mixtures at Pressures up to 1 0 Mpa (Combust Flame) vol 149 pp 162–172

[19] Wu Y 2017 Experimental Investigation of Laminar Flame Speeds of Kerosene Fuel and Second Generation Biofuels in Elevated to Cite this Version (HAL Id：tel-01430861)

[20]] Xie Y, Wang J, Zhang M, Gong J, Jin W and Huang Z 2013 Experimental and Numerical Study on Laminar Flame Characteristics of Methane Oxy-fuel Mixtures Highly Diluted with CO 2 (Energy & Fuels)

[21] Xie Y, Wang J, Xu N, Yu S and Huang Z 2014 Comparative Study on the Effect of CO2 and H2O Dilution on Laminar Burning Characteristics of CO/H2/Air Mixtures (Int J Hydrogen Energy) vol 39 no 7 pp 3450–3458

[22] Wang Z H, Weng W B, He Y, Li Z S and Cen K F 2015 Effect of H 2 / CO Ratio and N 2 / CO 2 Dilution Rate on Laminar Burning Velocity of Syngas Investigated by Direct Measurement and Simulation (Fuel) vol 141 pp 285–292

[23] Hirasawa, T., C. J. Sung, A. Joshi, Z. Yang, H. Wang and C. K. Law (2002). "Determination of laminar flame speeds using digital particle image velocimetry - Binary Fuel blends of ethylene, n-Butane, and toluene." Proceedings of the Combustion Institute 29(1427-1434).

[24] Hu, E., Z. Huang, J. He, C. Jin and J. Zheng (2009). "Experimental and numerical study on laminar burning characteristics of premixed methane–hydrogen–air flames." International Journal of Hydrogen Energy 34(11): 4876-4888.

[25] Johnston, R. J. and J. T. Farrell (2005). "Laminar burning velocities and Markstein lengths of aromatics at elevated temperature and pressure." Proceedings of the Combustion Institute 30(1): 217-224

[26] Marshall, S. (2010). “Measuring Laminar Burning Velocities”. DPhil thesis, Department of Engineering Science, University of Oxford.

[27] Marshall, S., R. Stone, C. Heghes, T. Davies and R. Cracknell (2010). "High pressure laminar burning velocity measurements and modelling of methane and n-butane." Combustion Theory and Modelling 14(4): 519-540.

[28] Marshall, S. P., S. Taylor, C. R. Stone, T. J. Davies and R. F. Cracknell (2011). "Laminar Burning Velocity Measurements of Liquid Fuels at Elevated Pressures and Temperatures with Combustion Residuals." Combustion and Flame 158: 1920-1932

[29] Tahtouh, T., F. Halter and C. Mounaïm-Rousselle (2009). "Measurement of laminar burning speeds and Markstein lengths using a novel methodology." Combustion and Flame 156(9): 1735-1743.

[30] Takizawa, K., A. Takahashi, K. Tokuhashi, S. Kondo and A. Sekiya (2005). "Burning velocity measurement of fluorinated compounds by the spherical-vessel method." Combustion and Flame 141(3): 298-307.

[31] Vancoillie, J., J. Demuynck, J. Galle, S. Verhelst and J. A. van Oijen (2012). "A laminar burning velocity and flame thickness correlation for ethanol–air mixtures valid at spark-ignition engine conditions." Fuel.

[32] Varea, E., V. Modica, B. Renou and A. M. Boukhalfa (2013). "Pressure effects on laminar burning velocities and Markstein lengths for Isooctane–Ethanol–Air mixtures." Proceedings of the Combustion Institute 34(1): 735-744.

[33] Varea, E., V. Modica, A. Vandel and B. Renou (2012). "Measurement of laminar burning velocity and Markstein length relative to fresh gases using a new postprocessing procedure: Application to laminar spherical flames for methane, ethanol and isooctane/air mixtures." Combustion and Flame 159(2): 577-590.

[34] Verhelst, S., C. T'Joen, J. Vancoillie and J. Demuynck (2011). "A correlation for the laminar burning velocity for use in hydrogen spark ignition engine simulation." International Journal of Hydrogen Energy 36(1): 957- 974.

[35] Verhelst, S., R. Woolley, M. Lawes and R. Sierens (2005). "Laminar and unstable burning velocities and Markstein lengths of hydrogen–air mixtures at engine-like conditions." Proceedings of the Combustion Institute 30(1): 209-216.

[36] Wang, S.-F., H. Zhang, J. Jarosinski, A. Gorczakowski and J. Podfilipski (2010). "Laminar burning velocities and Markstein lengths of premixed methane/air flames near the lean flammability limit in microgravity." Combustion and Flame 157(4): 667-675.

[37] Zhang, Z., G. Li, L. Ouyang, Z. Pan, F. You and X. Gao (2011). "Experimental determination of laminar burning velocities and Markstein lengths for 75% hydrous-ethanol, hydrogen and air gaseous mixtures." International Journal of Hydrogen Energy 36(20): 13194-13206.

[38] Andrews G. E. and Bradley D., 1972, Determination of burning velocities: A critical review, Combustion and Flame, 18(1), pp. 133–153. doi: 10.1016/S0010-2180(72)80234-7.

[39] Basco A., Cammarota F., Di Benedetto A., Di Sarli V., Salzano E., Russo G., 2012, Experimental and Numerical Analysis of Laminar Burning Velocity of Binary and Ternary Hydrocarbon/H2 Mixtures, 26, pp. 381-386. doi: 10.3303/CET1226064.