Investigation of Combustion Characteristics of Flat Flame Burner

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Abstract

The objective of this work was to study the characteristics of one dimensional planar flame anchored at the exit of a flat flame burner. Laminar burning velocity, S_L was measured using heat flux method described in literature. Velocity field at the exit of the burner was measured using Particle Image Velocimetry (PIV) at hot and cold flow conditions. The OH intensity profiles was measured using Planar Laser Induced Fluroscense (PLIF). Existing flat flame burner comprised of burner plate with heating jacket, plenum chamber with cooling jacket. Burner plate having a radius of 30mm was custom fabricated and drilled with 1611 through holes having diameter of 0.5mm in staggered pattern with pitch distance of 0.7mm between the holes. Burner was capable of anchoring flames having burning velocity 15-75cm/s . Initially LBV was measured for methane-air mixtures maintained at 298K and 1bar. Plate temperature was measured using thermocouples placed on plate. Measured S_L was validated with literature and found to be in good agreement. PLIF method was used to measure the emissions from OH radicals exciting due to shining of 282.55nm with an energy of 5mJ/pulse. OH intensity data was calibrated using literature data. Flow was seeded with TiO_2 particles using nebuliser to measure velocity field using PIV. Dual pulsed Nd:YAG laser at 532nm with pulse energy of 15mJ/pulse was used. Post processing was done using DAVIS software. The obtained burned gas velocity matched with that of equilibrium value estimated using COSILAB. Three dimensional simulations of flat flame burner was performed in ANSYS FLUENT commercial software. One segment (30 degree) was chosen owing to the axisymmetricity of the planar flame. Domain has radius of 30mm and height 50mm. Reduced GRI reaction mechanism with 27 species and 192 reactions was used. Final simulated velocity profile showed good comparison with measured burned gas velocity data from PIV measurement.

Keywords: flat flame, species calibration, temperature, velocity fields, laminar premixed, perforated plate, S_L, ϕ

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1. Introduction

Flat flames have been proven to be valuable tool in laminar gas combustion. These standard flames have an advantage of eliminating problem of measurement along curved surface and flame zone is free from all contact surfaces [11]. They have been used for calibration and verification of various laser diagnostic techniques which explores variety of parameters such as temperature, flow field and species concentration [3, 6, 9]. For a flame to be used for calibration purpose the temperature should be spatially and temporally uniform throughout the measurement region. The burner must be able to stabilize flame over wide range of flowrates. Laminar flat flame burners either features flat porous plug plate (sintered disk) or flat plate with custom drill holes to stabilize the flame.

Porous plug burners have widely been used for producing flat flame when reference flame is required for laser diagnostics techniques. Several techniques like PIV require tracer particles to be seeded with combustible mixture. Porous plate in these burners tends to choke seeding particles thereby preventing it from such type of usage. However it is not possible with porous plug burners to reach an adiabatic state which is perfect situation.

The commercially available Mckenna burner is the widely used flat flame burner for calibration of laser diagnostic techniques. Flame for this burner stabilizes very close to the flame holder leading to heat conduction to the flame holder. Water cooling channel is provided to reduce temperature of burner head therefore heat losses will associated with it. This losses results to deviation of flame from adiabatic state and flame can no longer be one dimensional and homogenous [1]. The burner consist of sintered plate for the stabilization of flame. Such type of porous plate easily get contaminated by seeding particles which are carried by gas mixture.

OH is an intermediate species in the combustion zone and is formed in two important fast reaction following

$$H + O_2 \rightarrow OH + O \tag{1}$$

$$O + H_2 \rightarrow OH + H \tag{2}$$

The OH concentration remains high in the reaction zone, and then it decreases in post flame region. Therefore it acts as flame marker for flame front and post combustion zone. OH-PLIF measures qualitative information on OH radical distribution in the flame that can be observed along laser sheet. $A2\Sigma+ \leftarrow X^2\Pi$, $A2\Sigma+ \leftarrow X^2\Pi$ are the two most frequently used schemes for performing OH-LIF measurement. Much of the literature provides new methods of quantifying OH concentration few well known methods are presented below.

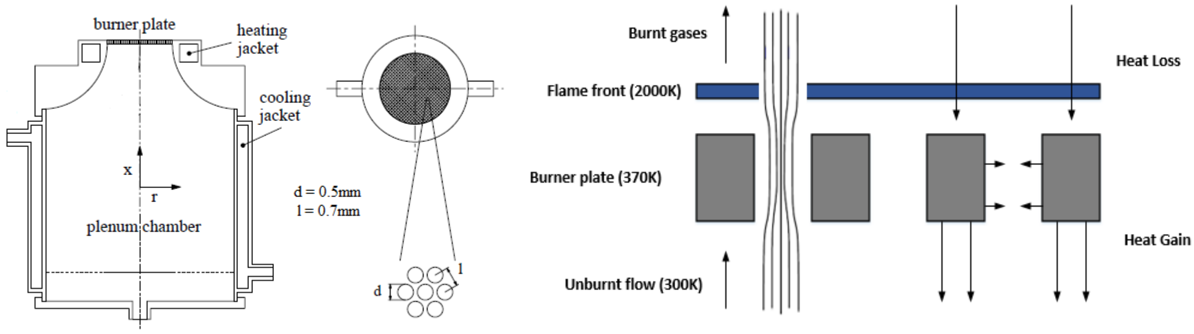
Arnold et al [3] established a two dimensional measuring technique for the quantification of absolute OH concentration fields. The method used combination of planar LIF measurements with 1-D absorption spectroscopy. Concentration of selected species at specific height was calculated using Bouguer-Beer's law. Bouguer–Beer's law calculates energy absorption of the flame at given condition. Energy absorption of flame was determined by measuring the difference of energy of laser before and after passing through flame using 1-D absorption spectroscopy. The calculated parameter was then applied to PLIF image to get absolute concentration for the entire OH field.

Another quantification method by Fredette was developed using thermocouple temperature measurement of flat flame at selected heights above the burner. Known parameters of flame along with temperature were entered into equilibrium computing program, STANJAN to get concentration of OH at the selected height of temperature measurement. Measurement was performed at several different locations. The average intensity obtained using OH-PLIF at these locations were equated with calculated concentration and calibration curve converting intensity to absolute concentration was obtained [8].

Boschaart and de Goey [2] developed another flat flame burner. The burner consisted of flat brass plate with perforation pattern which was capable of adiabatic stabilization of flat flames for wide range of mixture velocities. Adiabatic stabilization was achieved by making net heat loss from the flame to burner to zero. Heat flux method has been succesfully demonstrated for calculation of laminar burning velocity. Still no literature have been reported regarding calibration of laser diagnostic experiments using perforated plate burner to the best knowledge

The aim of this paper is to provide well characterised study of flat flame anchored on the heat flux burner.The present study have been divided into multiple major sections . Firstly OH-PLIF measurements were conducted to understand flame behaviour . Quantification of OH has been performed and and validation has been done for the same. Secondly PIV experiments were performed to measure velocity field downstream of the burner plate and to understand flow uniformity for both isothermal and reactive flow conditions. Lastly three dimensional simulations for flat flame burner was performed for better understanding of development of flow profile and to provide comparison with PIV measurements and temperature measurements.

2. Burner Design



(a) (b)

Figure 1: (a) Schematic of flat flame burner (b) Heat flux balance

The burner consist of plenum chamber, burner head, and burner plate. The flat flame is stabilised on brass plate of 2mm thickness and dia 30mm with custom drilled hexagonal perforation pattern consisting of 1611 holes of 0.5mm size and pitch of 0.7mm. The burner plate has been carefully designed to obtain flat, stretchless and adiabatic flame where temperature has one dimensional distribution. The inner surface of the burner was contoured to have streamlined flow. Two SS meshes were used at the inlet section of plenumm chamber to minimize the velocity fluctuations and straighten the premixed gas mixture inside the plenum chamber. The schematic diagram of the burner is shown in fig 1. The design of the present perforated plate burner have been adopted from de Goey and A van Marren [12, 11] used for calculating adiabatic burning velocities for several fuel/oxidizer mixture. The heat flux method by van Marren has been used for measuring adiabatic burning velocities where net heat loss from the flame to the burner was made zero by fine tuning the inlet velocity.[12]
Fig 1 gives general idea of the heat flux method using small part of burner plate. Left side shows streamlines of gas flow. The heat balance in the burner plate is shown in right side. The horizontal arrow represent the heat gain of the unburnt gas mixture. The vertical arrows represent heat loss from the flame to burner plate. The flame is effectively adiabatic when heat gain equal to heat loss resulting in zero heat flux and therefore constant temperature across the burner plate [11]

In present work a rig was assembled to implement heat flux method for adiabatic stabalization of flat flame on perforated plate burner. The rig consisted of temperature controlled burner head and plenum chamber. The burner head was fitted with water heating jacket(consisting of water circulaton bath – 10L – Equitron and 0.5HP water pump) which was maintained at 85_oC. Another cold water circulation jacket connected to cold water circulation bath was fitted to maintain plenum chamber at desired temperature of 20_oC. The air and methane flows were regulated using digital mass flow controllers (MFC) (ALICAT) seperately. Flow controller used for compressed dry air was 0-50 SLPM and for methane was 0-10 SLPM. Methane and air were allowed to mix in PU tube having length of 4mm. Residence time of gases inside this mixing tube was sufficient enough to attain premixed combustible mixture before plenum chamber. The following setup described results in very stablised one dimensional flame. The burner also allows seeding for tracer particles without any clogging. These features allows the burner for the calibration of all laser diagnostic techniques. Therefore burner was capable of anchoring flames having burning velocity from 15-75 cm/s.

3. Numerical Modelling

Numerical investigation was carried out to understand local flow field, species concerntration, and flame structure. The modelling of laminar premixed flame with reduced reaction mechanism was done using FLUENT.

3.1. *Governing Equation*

For reacting flow FLUENT solves conservation equations for mass, momentum, energy and species. The governing equations in cartesian coordinates are mentioned below

$$\nabla(\rho\vec{v}) = 0 \tag{3}$$

$$\nabla(\rho\vec{v}\,\vec{v}) = -\nabla p + \nabla\bar{\bar{\tau}} + \rho\vec{g} \tag{4}$$

$$\nabla.(\vec{v}(\rho E + p)) = \nabla.(k\nabla T - \sum_j h_j\vec{J}_j + \bar{\bar{\tau}}.\vec{v}) + S_h \tag{5}$$

$$\nabla.(\rho\vec{v}\,Y_i) = -\nabla.J_i + R_i \tag{6}$$

The heat conduction equation within the burner plate is solved to include the effect of the heat exchange between the gas mixture and perforated plate.

$$\rho_s C_s \frac{\partial T}{\partial t} = \nabla(k\nabla T) \tag{7}$$

where v is the velocity, Y_i is the mass fraction of each species i, ρ is the density of gas mixture,k_T is the thermal conductivity, J_i is the diffusion flux of species i, ν is the molecular viscosity.

A finite rate laminar species model with stiff chemistry solver was employed for solving volumetric reactions. Chemical kinetics mechanism used in the present study is reduced methane/air reaction mechanism having 27 species and 192 reactions. The chemical kinetic mechanism was imported in CHEMKIN format along with thermodynamic and transport properties. The SIMPLE algorithm was used for velocity - pressure coupling. Cold-flow simulations were performed first this was done by running the solutions till momentum equation gets converged to 10^{-6}. The mixture was then ignited by patching region above burner exit to temperature of 2000 K. The convergence limit was set to 10^{-6} for all equations.

3.2. *Computational Domain*

Computational domain is shown in fig 2. It consist of 30° segment of plate with radius of 15 mm. This segment has been selected based on axisymmetricity of plate. Physical domian is of 15 ×17 mm. The outer boundary is located far away from the inlet. The domain is modelled cylinderical in shape. The plate is 2mm thick with 12 grid points .Flame region 1mm is meshed with finer grid distribution of 11 grid points and grid is gradually increased in all direction above the flame. The grid has been made in commercial software GAMBIT with 766,046 cells.

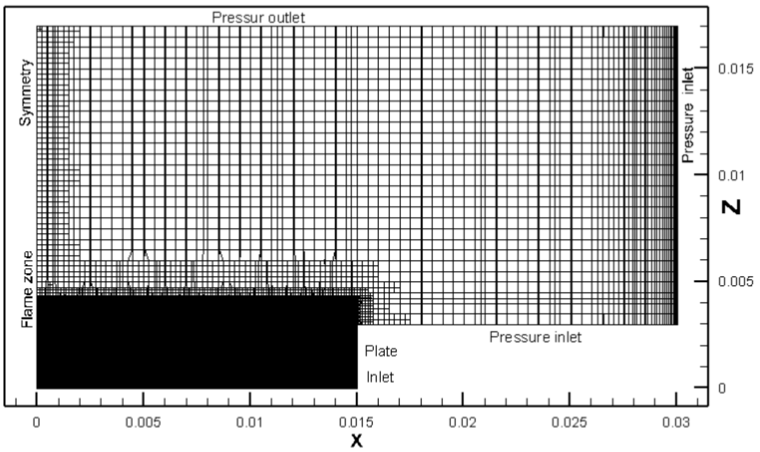


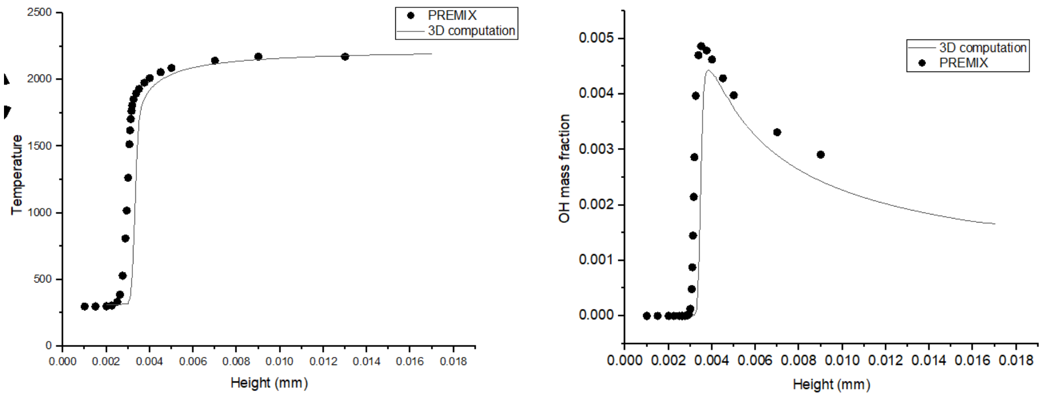
Figure 2: Computational grid used in present study

3.3. Boundary Conditions

- **Mixture inlet** - Uniform velocity profile (V_z =26cm/s / 39cm/s) - ϕ - 1 , $V_x = V_y = 0$, T = 300K
- **Burner rim** - Temperature constant - large heat transfer coefficient - T = 370K - V_x=V_y = V_z = $\frac{\partial Y_i}{\partial z}$ = 0
- **Vertical far field** - Open atmospheric flame - coflow induced by flame - pressure inlet - properties same as cold air - P = 1atm T = 300K
- **Horizontal far field** - Placed where all the variables become constant - P = 1atm - V = 0
- **Symmetry** - Centerline of burner - rotational symmetry - $\frac{\partial(\phi)}{\partial x}(0, z) = 0$ ϕ = T , Y_i , V_y , V_z

3.4. Validation of Numerical model

To validate the accuracy of FLUENT simulations the temperature and minor species profiles along z directions were computed and compared with 1D PREMIX code. The reaction mechanism file imported for both of these simulations were same. The temperature profiles with both 3D and 1D computations agrees well .The maximum burnt gas temperature through simulations is 2196 K. The temperature closely matches with adiabatic temperature (2200 K) calculated using PREMIX. The peak OH mass fraction from 3D computations is 10.1% less than the 1D computations.



(a) (b)

Figure 3: Comparison of 3D computations with PREMIX

4. Experimental Setup and Data Evaluation

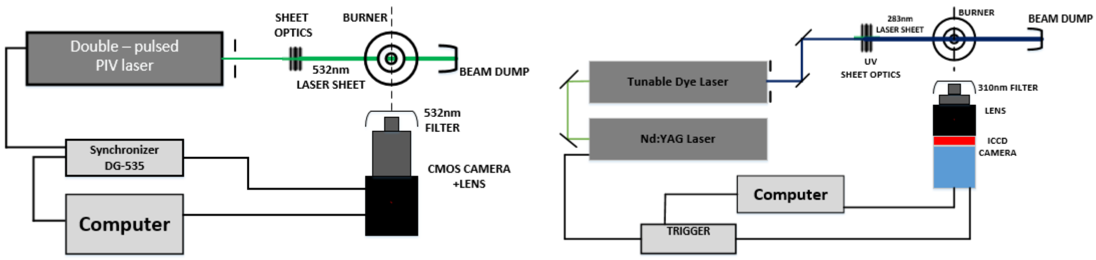
The heat flux method was implemented for the adiabatic stabalisation of flat flame over perforated plate. The burner plate was preheated to 358K using hot water. Five K- type thermocouple were attached into the blind holes at different radii and azimuthal direction to facilitate the plate temperature. The output voltage signal from K-type thermocouple was acquired in a Data Acquisation System (Agilent Make) at the sampling rate of 1000Hz. Uniform plate temperature was ensured and mixture was allowed to flow and a planar flame was anchored. Temperature profile was obtained for different unburned gas velocities. The measured radial temperature profile of the burner plate at a given flow velocity was fitted with a parabolic function:

$$T_p(r) = T_c(r) + Cr^2 \tag{8}$$

$$C = -\frac{q}{4kh} \tag{9}$$

For $\phi = 1$ gas velocity was varied from 33 cm/s to 39cm/s. C value was obtained from temperature profile and interpolation was done to obtain unburned gas velocity at zero heat flux. The study was further extended for different

ϕ and comparisons were made with the literature data and uncertainties are presented.



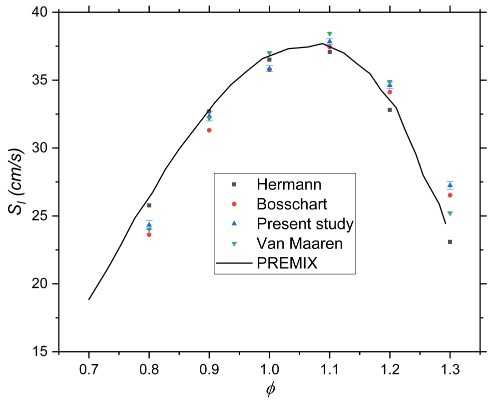
(a) (b)

Figure 4: (a) PIV setup (b) PLIF setup

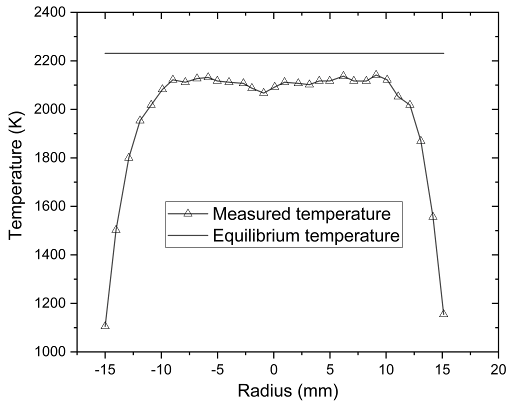
To measure velocity field downstream of burner PIV technique was employed. A schematic view of the experimental setup is shown in fig 4. A double pulsed Nd:YAG solid state laser (Evergreen Quantel 145 Laser) with wavelength of 532 nm was used to generate two laser pulses at energies of 17mJ and 12mJ respectively with time delay set to 250 μs (Reactive flow) and 1900 μs (Isothermal). DG-535 was used to synchronise the laser pulse with camera shutter timing. The laser sheet (1-2mm thickness) was formed using combination of cylinderical and spherical lens. Seeding particles were inserted in flow using nebuliser. Titanium dioxide (TiO_2) was the seeder used for the present study. Air was connected to nebuliser containing tracer particles. The scattered light of particles was detected with double shutter CCD camera (PCO Pixelfy-12 bit) with resolution of 460×700 pixels and lens of focal length 75 mm. A narrow band pass filter (532 nm) was used to collect mie scattered signal. PIV postprocessing was done using DAVIS 8.4 commercially available software. For calculation of vector fields the interrogation area was set to 64×64 with 75% overlap for the initial 3 passes and the final 2 passes was performed with 16 × 16 pixels with overlap of 50 %. This multipass method ensures better correlation and and improves Signal to noise ratio (SNR) and helps in more accurate and reliable computation of velocity vectors.

OH-PLIF (Planar laser induced fluorescence) was implemented to measure two dimensional distributions of OH radical. A schematic diagram of experimental setup of OH-PLIF is shown in fig 4. A tunable dye laser (Sirah Precision Scan) pumped by 532nm laser beam from Nd:YAG (Spectra Physics Quanta Ray PRO20-10) is used.The dye laser uses liquid dye Coumarin-153 and ethanol dye solution as a lasing medium. The wavelength of the output laser beam corresponds to peak of rotational line Q1(8)$A2\Sigma+ \leftarrow X^2\Pi$ (1-0) transition band of OH. The laser beam of wavelength 283 nm was converted to sheet using combination of lenses(f-25 cylinderical lens and two f+500 plano-convex lens) to height of 50 mm and width of less than 1 mm. The fluorescencne signal is captured using ICCD (Imager Pro 12 bit - 2048x2048 pixels) using UV lens(Nikon ,UV-Nikkor) with 105 mm focal length and aperture set to be f/4.5. A broad range OH filter (290-310 nm) was arranged beyond ICCD camera to capture OH fluorescence signal. A Programming timing unit (PTU) was employed to sync Nd:YAG laser and ICCD camera. The frequency of laser used was 10Hz with pulse width of 9s and this pulse was passed through energy moniter, this was used to moniter energy fluctuations and had pulse energy of 5mJ/pulse. To remove straylight from metal surface and eliminate reflections a background signal was imaged. To incorporate laser sheet variation in space, sheet profiles were imaged using acetone fluorescence.

5. Results and Discussion



(a)



(b)

Figure 5: (a) Variation of LBV of premixed methane air mixture with ϕ at 1 Bar and 300K (b) Temperature distribution at h=3mm

Validation experimens were conducted to ensure proper operation of burner system. Laminar burning velocity was measured for methane-air mixture at 300K and 1 bar for ϕ ranging from 0.8-1.3.Adiabatic burning velocities as function of equivalence ratio is plotted and shown in fig 8(a). The measured LBV values and calculations from CHEM1D software are presented in fig with available literature data. A reduced GRI 3.0 mechanism has been implemented for calculations for CHEM1D involving chemical species (27) and reactions (192). The present studied conditions shows good comparison with available literature data. For ϕ-1 LBV typically varies from 36+-1cm/s. For the present work burning velocity obtained is 35.8 cm/s which is in consistent with the available literature. Uncertainties involved in measurement of S_L will be mainly contributed by uncertainty in temperature measurement and flow velocity measurement using MFC.

After successful validation of heat flux burner using LBV measurements it was confirmed that the net heat losses and heat gain from flame to burner is equal i.e temperature across the burner plate is constant. Therefore the flame stabilised is adiabatic in nature. To confirm one dimensionality of flame temperature measurements were carried out using B-Type thermocouple (Pt /Pt -30% Rh Alloy) with bead of diameter 0.36 mm. The thermocouple was held in place by a clamp attached to a high precision Y-Z Axis Metric Stage for translation. Fig shows radial burnt gas temperature profile at h=3mm. It is quite evident that the profile is top hat with temperature uniformity between 12 mm to -12 mm. This region can be regarded as 1-D as spatial homogeneity is maintained throughout the region. The region outside the 1-D area i.e at the boundaries shows temperature gradients due to air entrainment from outer atmosphere. Measured temperature profile is corrected for radiation losses using method presented by Shaddix. It is seen that the measured temperature is 2130K which is close to equilibrium temperature 2231K for methane-air mixture of ϕ- 1. Therefore the flame is nearly adiabatic and homogenous.

*5.1. **OH-PLIF***

Temperature measurements exhibits no temperature gradients exists inside the reaction and post combustion flame zone. The present flame anchored can be regarded as well defined flat flame and can be used as reference for further laser diagnostics experiments.

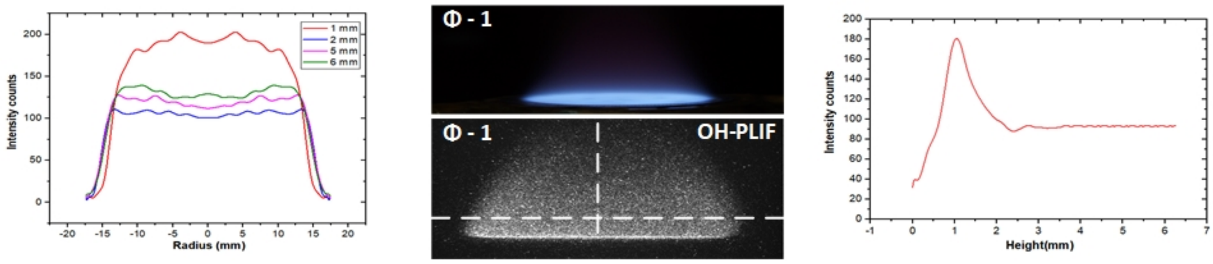
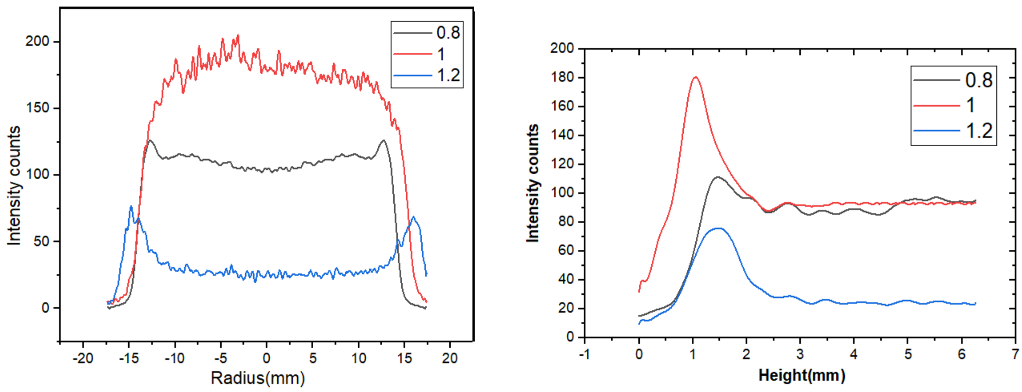


Figure 6: OH-PLIF Horizontal and Vertical distributions

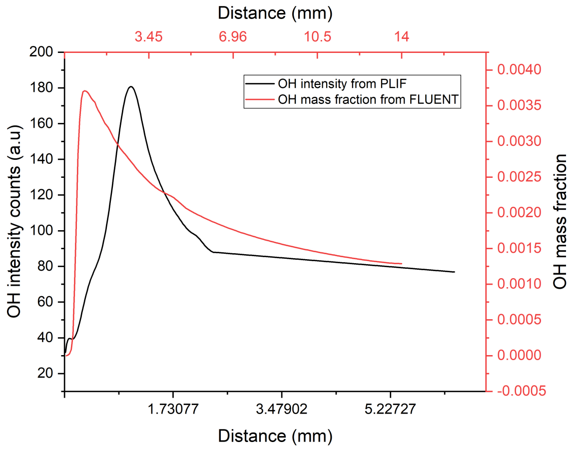
The OH-PLIF experiments were carried out using methane-air gas mixture at different ϕ ranging from 0.7-1.2 for velocities of $26cm/s$ and $35.7cm/s$ i.e S_L. Flame front can be seen as bright luminous region in direct photograpy image. Lower image shows typical PLIF image recorded by CCD camera. This image displays intensity values obtained from fluorescence at each pixel. Certain corrections are required to remove systematic errors which include environment interference, shot to shot laser power variations, uneven energy across laser sheet. A scaling was performed on image field to convert pixel units to length. Surrounding scattered light was subtracted from OH-PLIF signal image. The laser sheet variation in space was corrected using laser sheet profile obtained from acetone fluorescence. Attenuation correction was performed to make laser energy uniform radially. A moving average filter is implemented to reduce all surrounding noises. Qualitative OH distribution is presented in figure. It is implied that the distribution is top hat profile with OH distribution uniform 80 % of burner plate. At the edges the uniformity ceases to exist due to entrainment from surrounding air. The OH radical is an intermediate species in combustion that is formed in flame front. The concentration of OH is high in reaction zone and then decreases in post flame region as seen in figure. Therefore it acts as marker of both combustion zone and post combustion zone. Axial OH distribution is presented it is noted that the region where relative intensity of OH is highest roughly indicates the location of flame front.



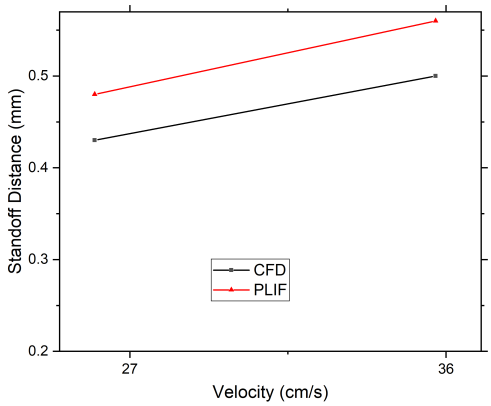
(a) (b)

Figure 7: (a)Radial profile of OH (b)Axial profile of OH

Figure indicates OH intensity variation with equivalence ratio. The OH intensity profile remains homogenous for lean and stoichiometric conditions. For rich flames the OH fluorescence intensity tends to be U-shaped and is no longer flat with two stable peaks at the boundary of flame. The intensity of peaks are double the intensity of middle region. In addition to this the OH radicals diminsh in middle region of flame from -10 mm to 10 mm. The maximum intensity for OH occurs for stoichiometric mixture for same inlet velocity. This change in intensity counts is due to change in fuel-air ratio which changes the OH radical concentration in flame.



(a)

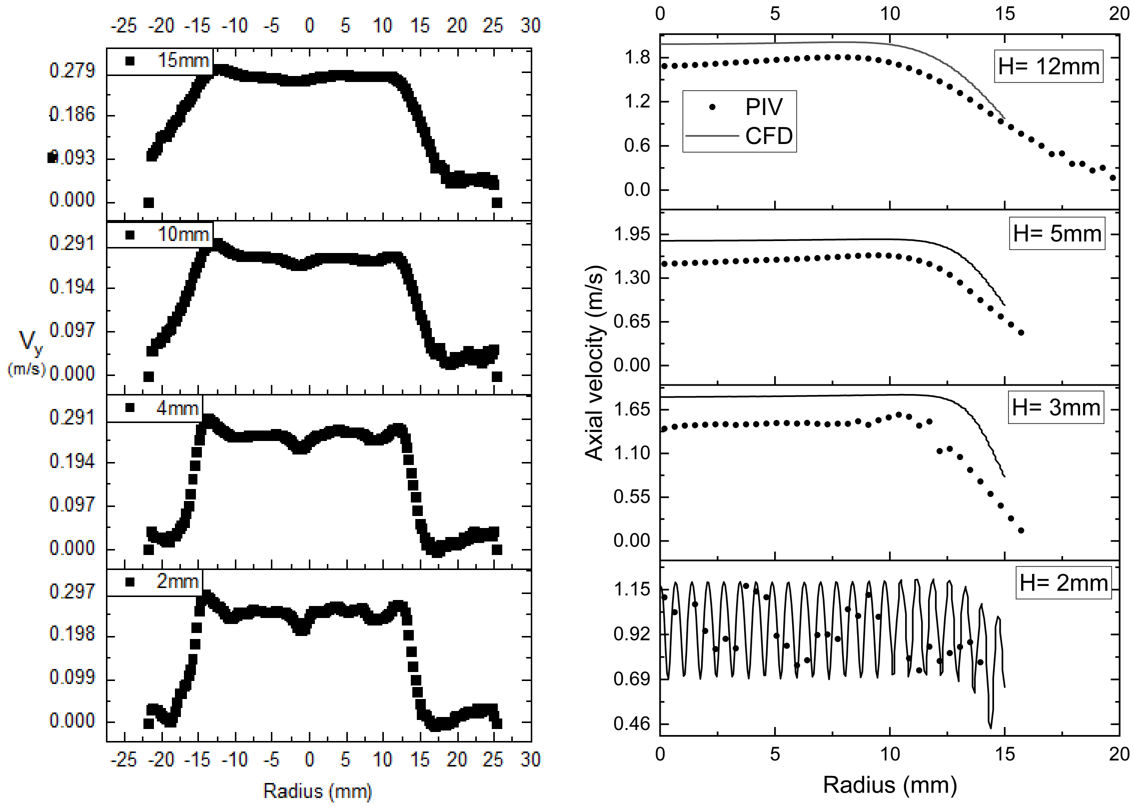


(b)

Figure 8: (a)Radial profile of OH (b)Axial profile of OH

For stationery flames, the flames will remain in one particular position such that local unburned gas velocity will be equal to flame propagation velocity. The distance between this flame front position and the burner surface is known as standoff distance. OH-PLIF also provides information on flame front position .From OH-PLIF images the bright region can be easily identified as the the flame front and its distance from burner surface will be the measured standoff distance. The parameter has been calculated for velocities of 26 cm/s and 35.7 cm/s at equivalence ratio of 1. It can be well noted that with decrease in inflow velocity flame is pushed more closer to burner. Figure shows comparison of experimentally measured standoff distance and CFD calculated distance . Calculation of flamefront position in CFD was done with the help of temperature profile. The inflection point in temperature profile was chosen to calculate the standoff distance. The selection of inflection point is selected based on point after which temperature increases drastically because of flame itself[ref] . Measured and simulated values shows a good comparison.
Uncertainty in the measurement of OH-PLIF are caused by following contributions. The uncertainty caused due to laser shot to shot power fluctuations is 8%. The measurement error due to MFC ranges from 2% - 4% with higher error for lean mixtures. The noises by ICCD which includes camera shot noises and noises in A/D conversion. This total accounts for 8%. Therefore total uncertainty associated with OH intesity counts is 7 %.

5.2. *PIV*

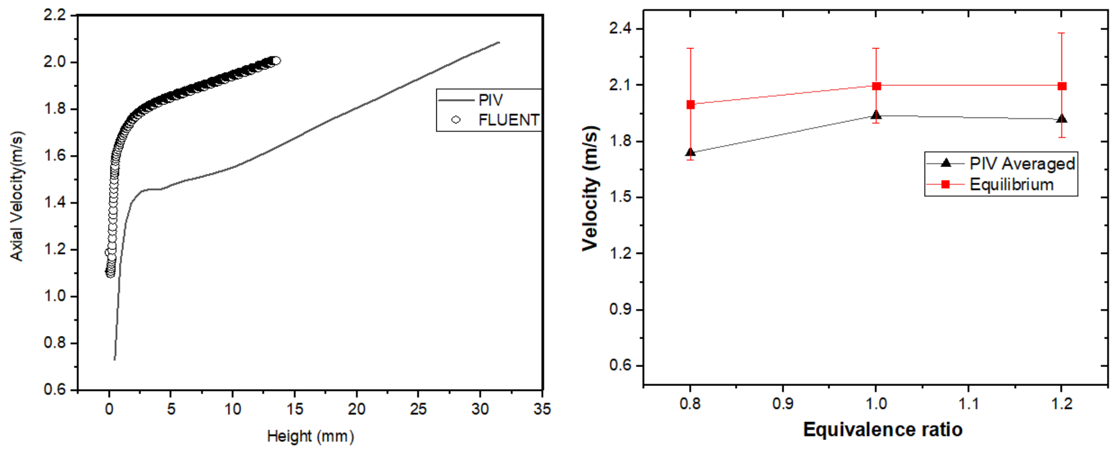


(a) (b)

Figure 9: (a)Velocity profiles (b)Streamlines

PIV measurements for isothermal conditions (without flame) was performed for velocity of 26 cm/s (Re = 685) at atmospheric conditions . Time delay of 1980 μs was set for coldflow experiments. Radial velocity profiles at different axial locations are presented in figure. Profiles less than 2 mm cannot be produced due to presence of strong laser reflection on the top of burner plate. It is noted that the velocity profiles are not exactly flat and have minor disturbances, velocities at the edges of burner are found to be 20% higher than the central region. The following observation is in agreement with measurements performed using LDV [4]. The velocity far away from the exit of burner is in good agreement with the inlet velocity. CFD simulation was performed to better understand formation of velocity profile

PIV measurements for methane-air mixture at reactive flow conditions was performed for velocity of 26 cm/s at eq.ratio. It can be seen from figure that velocity profile remain top hat with flow homogeneity between the region of -12.5 mm to 12.5 mm. Profiles are much more smoother and uniform in presence of flame when compared to cold flow measurements. No velocity peaks are noted at the edges of burner plate. A comparsion of axial velocity with experimentally measured and CFD simulations is presented. A velocity profiles very close to burner plate exhibit wavelets like pattern. These wavelets are independent flow jets (with parabolic velocity profile) issuing out of each hole. Each hole is neighboured by five other holes All of the jets from each of these holes converge completely across burner plate to form uniform velocity profile. Holes at the edges of burner plate are neighboured by less no of holes so the velocity is greater at the edges. In presence of flame rapid increase in velocity is noted due to expansion of gas, this increase in velocity creates an additional pressure drop which makes velocity more uniform over the burner plate that is not the case with cold flow (without flame) cases. It is seen in CFD simulations that flow uniformity exist between the region of -12.5 mm to 12.5 mm. This further supports the observations obtained in PIV measurements. Thus it may be concluded that 80% of the burning surface can be considered as 1D region for open atmospheric flames.



(a)

(b)

Figure 10: (a)Radial profile of OH (b)Axial profile of OH

CFD simulations predicts velocity profiles at all axial distances are top hat and uniform above the burner. The effect of bouyancy in the centreline velocity profile can be seen in Fig 10. Acceleration in post combustion zone marked by increase in velocity can be clearly seen. Velocity measured by PIV measurements tends to lag behind velocity calculated using CFD simulations. This can be explained using the effect of bouyancy on burnt gas region. The increase in velocity is the result of constant acceleration due to predominant difference in the mass density. Since PIV measurements solely depends on behaviour of tracer particles in the flow. Mass density of tracer particles will have an added effect in the bouyancy in presence of flame and hence the decrease in acceleration in piv reactive flow measurements.
Major contributions of uncertainty in PIV are from equipment (laser and MFC's) and processing algorithm. Calculated uncertainty for $\phi - 0.8, 1, 1.2$ are 0.3, 0.1, $0.17 m/s$ respectively.

6. Conclusion

In the present study properties such as S_L, OH Conc., velocity fields, temperature were studied. The flame stabilised by heat flux method is one dimensional adiabatic flame. Measurements of OH radicals in laminar premixed methane/air flat flames for ϕ ranging from 0.8 - 1.2 were successfully performed using PLIF. Quantative study was performed to get absolute OH concentration from calibration curve. PIV measurements were performed to get radial and axila profiles for coldflow and hotflow conditions. They were compared with the numerical simulated velocities fields. Uncertainties for the experiments are calculated and major factors that causes these are also presented.

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