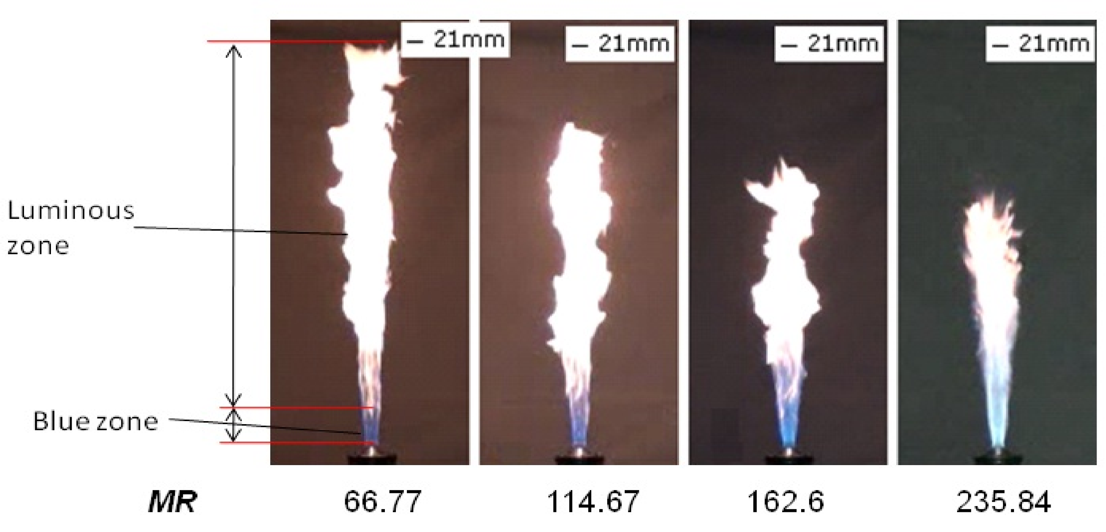
Image Processing

- The flame videos obtained are converted to frames using video to still image convertor software.
- The frames are analyzed using image processing software called **ImageJ**. The still images of the flame are processed by various techniques such as **Enhance contrast** and **Edge detection** for exact identification of flame tip from the nozzle rim.
- The number of pixels of the flame image in the vertical direction along the centerline from the burner rim to the point where the flame is visible is counted and is scaled with the known dimension, say, burner rim diameter to obtain the exact flame height.

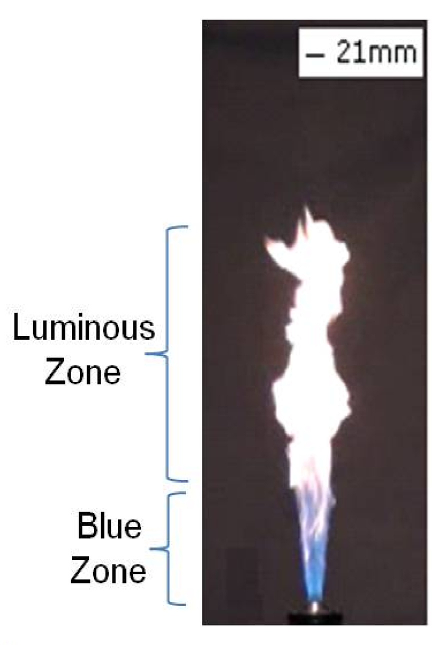
Variation of flame height with *MFR* for LPG-air IDF



Flame height decreases with an increase in the Momentum Ratio (*MR*).

Visible Flame Appearance with *MR* for LPG-air IDF

- Momentum ratio (*MR*) is defined as the ratio of momentum between air jet and the momentum of fuel jet.



$$MR = \frac{\rho_A A_A V_A^2}{\rho_F A_F V_F^2} = \frac{\rho_A A_A V_A}{\rho_F A_F V_F} \times \frac{V_A}{V_F}$$

ρ: density
A: port area
V: fuel
A: Area

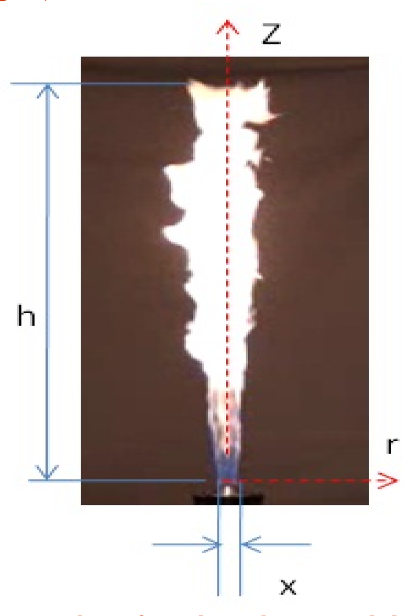
- The flame can be divided in two zones namely

1. blue zone
2. luminous zone (see figure)

- The blue emission is due to the radiation from excited CH* radicals in the premixed region at the flame base [1].
- The luminous zone is yellow due to the radiation from soot (carbon) particles.

Calculation of Visible Flame Height

Sample calculation for obtaining the visible flame height of turbulent LPG – air IDF for MR = 68.77 from single snapshot (see figure).



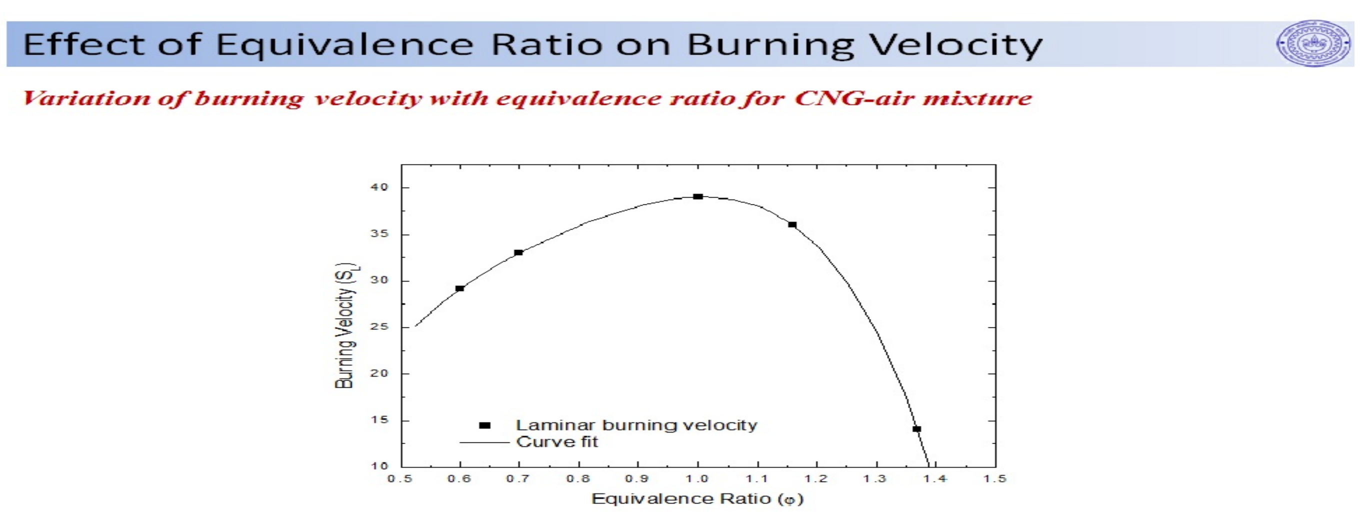
- The number of pixels in the vertical direction (along the centerline) from the burner rim to the point where the flame is visible (h) = 180 pixels
- Number of pixels of the burner diameter in the snapshot (x) = 7 pixels
- Actual dimension of the burner diameter (d_f) = 21 mm
- Scaling of the actual flame height (H_f) becomes

$$H_f : h = d_f : x$$

- Therefore, actual visible flame height can be obtained from the above expression as

$$H_f = \frac{h \times d_f}{x} = \frac{180 \times 21}{7} = 540\,mm = 54\,cm$$

Temporal Variation of Visible Flame



- Variation in visible flame height with time for MR = 66.77 is shown (see above figure).
- Undulations of the flame tip is observed from the time resolved images.
- The flame tip fluctuations occur due to buoyancy induced vortices shedding around it.
- As a result of local quenching, detached flame can be observed sometimes at the flame tip.

Error Analysis of Visible Flame Height

- Mean flame height (H_{fm}) is obtained from the average of the actual visible flame height of N flame images taken for analysis.

$$H_{fm} = \frac{\sum_{i=1}^{N} H_{fi}}{N}$$

- The deviation from the mean flame height is obtained using the following formula

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} (H_f - H_{fm})^2}{N}}$$

s: standard deviation of the flame height obtained from flame snapshots
H_{fi}: flame height of the ith image
i: index varying from 1 to N
H_{fm}: mean flame height
N: total number of flame images (26 in the present experiment)
Flame height is reported as

$$H_{fm} = \frac{\sum_{i=1}^{N} H_{fi}}{N}$$

Sample Calculation for Visible Flame Height

h	$H_f = \frac{h \times d_f}{x}$ (in mm)	$(H_f - H_{fm})^2$
180	540	2851.56
208	624	936.36
205	615	466.56
195	585	70.56
201	603	92.16
	$H_{fm} = 593.4\ mm$	$\sum_{i=1}^{N} (H_f - H_{fm})^2 = 4417.2\ mm^2$

- Sample calculation for obtaining the visible flame height of turbulent LPG–air IDF for *MR* = 68.775 from 5 flame snapshots is shown.
- A total of 26 snapshots were processed for finding the visible flame height at a particular *MR* in the present study.