DEPARTMENT OF AEROSPACE ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

EXPERIMENTS IN AEROSPACE ENGINEERING – II (AE 351A)

EXPERIMENTAL INVESTIGATIONS ON PREMIXED LPG-AIR FLAME

LIST OF SYMBOLS:

ϕ - Equivalence Ratio

R_u - Universal Gas Constant (kJ/kmol.K)

$\dot{Q}$ - Indicated flow rate on the rotameter (LPM)

ρ - Density of the metered gas (kg/m^3)

$\dot{m}$ - Mass flow rate of the gas (kg/s)

$M_{w\text{-}gas}$ - Molecular weight of the metered gas (kg/kmol)

P_0 - Atmospheric pressure (Pa)

T_0 - Ambient temperature (K)

S_u - Burning velocity (cm/s)

OBJECTIVE:

1) To determine the 2-D temperature contour across the flame.

2) To study the effect of equivalence ratio on flame temperature.

3) To calculate the burning velocity using Gouy's method.

DESCRIPTION OF EXPERIMENT:

Fine gage S-Type thermocouples are made of Pt-10%Rh/Pt, which are used when fast and accurate temperature measurements are required. The diameter of these wires is 0.125 mm, and the response time is 0.08 secs. These fine wire diameters enable accurate temperature measurements, keeping the heat losses to minimum. In addition to that, the small junction bead permits accurate pin-pointing of the measured location.

To calibrate this S-Type thermocouple, a Nagman's temperature calibrator is used. Model 1200HN is a semi-portable, multi-hole, dry block type, high-temperature calibrator which can generate temperatures up to 1200 K. Consequently, a voltage is generated because of the temperature difference (Seebeck effect).

Temperature at various uniformly distributed points is measured with S-type thermocouple in a simple premixed flame. Rotameters are used to measure the air and fuel flow rates. A needle valve in the flow line is used to control the discharge. Air is supplied from a single-piston reciprocating compressor.

Burning velocity is calculated using Gouy's Method for which the flame area is obtained using digital photographs.

PRECAUTIONS:

1) Turn on the air compressor and then the LPG cylinder. LPG cylinder knob should be completely turned ON to avoid pressure losses.

2) To avoid spilling of the fuel (LPG), ignite the burner and then set the required flow rate in the rotameters.

3) While moving the traverse, do not touch the thermocouple, as it the most delicate part of the experimental setup.

4) Turn off the LPG cylinder first, and then the air compressor.

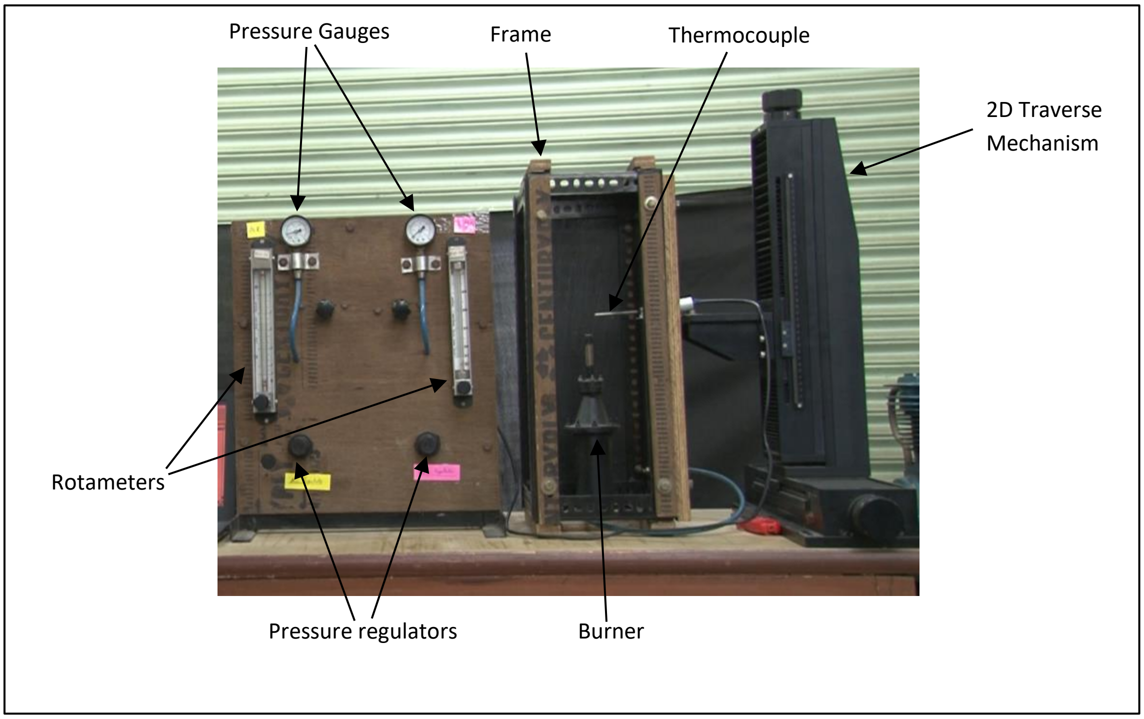


Fig.1 Experimental set-up

PROCEDURE:

1. Before starting the experiment, familiarize yourself with various components of the test set-up and the instruments used for experimentation.

2. Familiarize with basic principles of data acquisition and processing.

3. Note down the ambient temperature and pressure.

4. When the air compressor and the LPG-cylinder are turned ON, note down the gauge pressures from the control line.

5. To understand the nature of the flame, equivalence ratio was varied from fuel rich to stoichiometric to fuel lean conditions.

6. At a particular equivalence ratio (say $\phi = 0.95$), use a grid format and move the traverse 2-dimensionally along with the coordinates given in the grid and measure the temperature at those points.

7. Take flame images using a digital camera at the chosen equivalence ratio ($\phi = 0.95$).

8. At a point 3 cm above the burner rim along the axis, fix the thermocouple and vary the equivalence ratio.

9. After taking all the readings, tightly close all the valves and the ports.

FORMULAE:

a) **Rotameter Calculations.**

$\dot{Q} =$ Rotameter reading (LPM)

$$\rho = \frac{P_0}{R_{gas} \times T_0} \quad (\mathrm{kg/m^3})$$

$R_{gas} = R_u/M_{w\text{-}gas}$ (kJ/kg.k)

Mass flow rate of gas:

$$\dot{m} = \frac{\dot{Q}}{60{,}000} \times \rho \quad (\mathrm{kg/s})$$

b) **Burning Velocity Calculations:**

Measure the surface area of the flame front

1. From the flame photograph, get a processed black & white image from Matlab (see Fig. 3a).

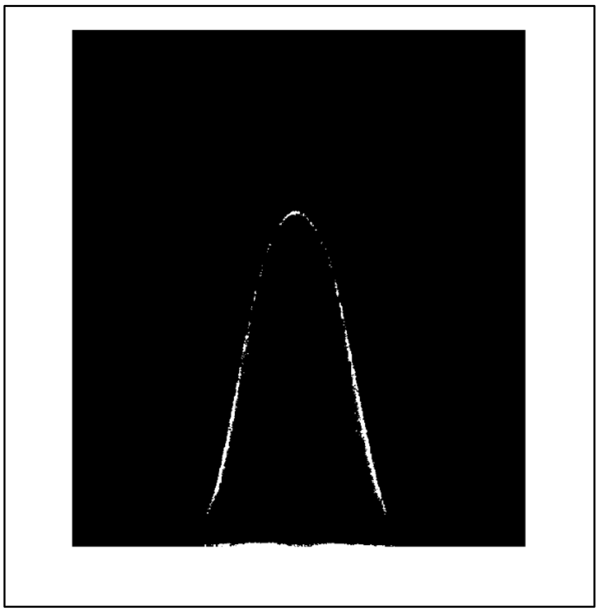
2. Connect the flame tip to the other end of the flame such that it forms a right-angled triangle as shown in the Fig. 3b.

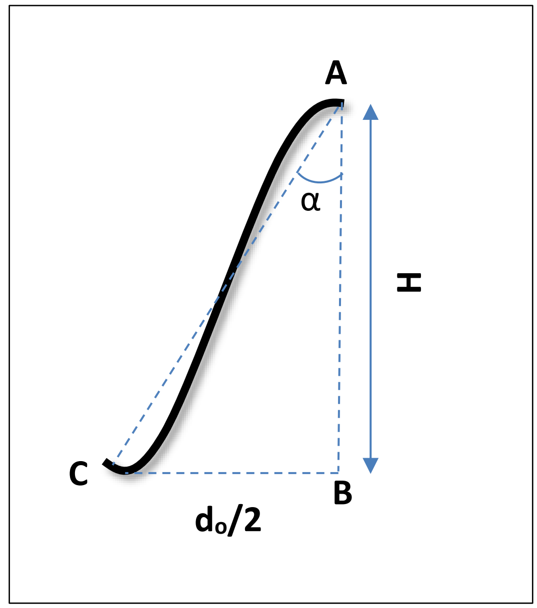
3. Calculate tan(α) using the pixel count for AB and BC.

$$\tan(\alpha) = \frac{\text{Pixel count of BC}}{\text{Pixel count of AB}}$$

4. Use the value of α, to calculate the flame height H (for d_o = 10 mm).

5. Calculate the surface area of the conical surface AC : $A_f = \pi r\left(r + \sqrt{H^2 + r^2}\right)$ ($r = d_o/2$)





(a) **(b)**

Fig. 2 Method to calculate flame area.

Area of the burner opening = $A_o = \pi r^2$ ($r = d_o/2$)

The total volume flow rate of gas (air + LPG) = $A_o \times V_o$

The average flow velocity in the burner opening = V_o

Total area of the flame front, A_f, moves with velocity S_u w.r.t the unburned mixture, thus:

$$\mathbf{A_o \times V_o = A_f \times S_u}$$

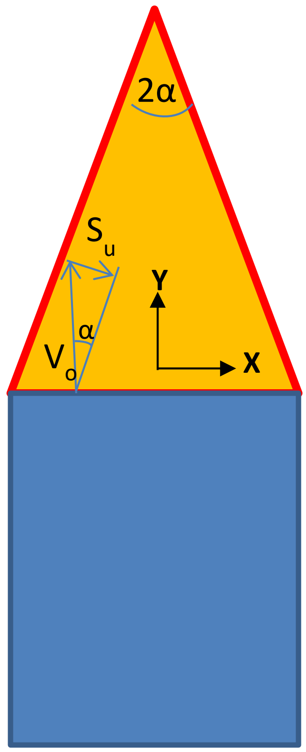


Fig. 3 Schematic of the flame front. S_u = burning velocity, 2α = cone angle.

RESULTS AND DISCUSSIONS:

1) Plot a 2-D temperature contour plot in a longitudinal plane, with x and y-axis as per the generated grid (Hint: use TEC-PLOT 360, Triangulate).

2) Plot temperature vs. equivalence ratio (ϕ) at a position 3 cm above the burner rim along the axis. (x = 0, y = 3 cm)

3) Calculate the flame area and the burning velocity using Gouy's method for the chosen equivalence ratio (ϕ = 0.95).

APPENDIX:

Universal gas constant (R_u) : 8.3145 (kJ/kmol.K)

Molecular weight of Air ($M_{w\text{-}air}$): 28.97 (kg/kmol)

Molecular weight of Lpg ($M_{w\text{-}lpg}$) : 51.57 (kg/kmol)

Mixture composition (vol. %) of LPG (approx.)

Propane	C_3H_8	44.7
Isobutane	C_4H_{10}	54.8
Ethane	C_2H_6	0.7

Avg. mol wt.	51.57 kg/kmol

Stoichiometric fuel-air ratio = 0.0643 kg of LPG/kg of air.

References

1) R Gupta, V Garg, Dr. A Kushari. "Spectroscopic Analysis of a Premixed LPG-air Flame", IITK, Kanpur 208 016, 2004.
2) "FLAMES Their structure, Radiations, and Temperature", Gaydon, A.G., Wolfhard H.G., Chapman & Hall LTD.
3) Combustion, Flames & Explosions of Gases, Bernard Lewis, Guenther von Elbe, Ph.D
4) Dinesh Kumar. S.J., "Experimental Investigations of LPG-Air Pre-mixed Flames", M.E Thesis, Birla Institute of Technology, Ranchi.