Indian Institute Of Technology Kanpur

AE 351A

Experiments in Aerospace Engineering 2020-21

Semester II

Experiment No. 9

EXPERIMENTAL INVESTIGATIONS ON PREMIXED LPG-AIR FLAME

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1. Objective

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

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

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

2. Formulae

a. Rotameter Calculations

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

$$\rho = \frac{P_o}{R_{gas} T_o} \quad (kg/m^3)$$

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

mass flow rate of gas

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

b. Burning Velocity Calculation

Measure the surface area of the flame front

i. From the flame photograph, get a processed black & white image from Matlab

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

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

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

iv. Use the value of α, to calculate the flame height H (for d_0 = 10 mm).

v. Calculate the surface area of the conical surface AC :

$$A_f = \pi r(r + \sqrt{H^2 + r^2}) \ ; \ (r = {d_0}/{2})$$

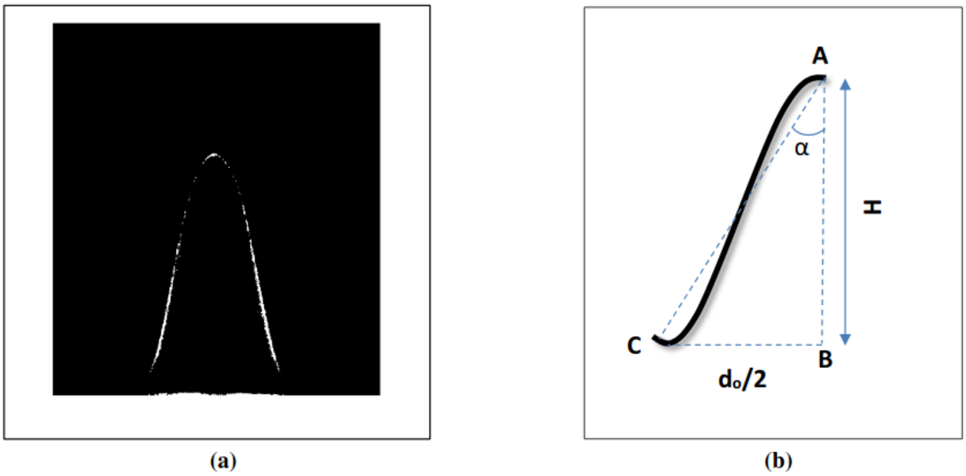

Figure 1 Method to calculate flame area

Area of the burner opening= Ao=πr^2 (r = do/2)

The total volume flow rate of gas(air + LPG)= Ao×Vo

The average flow velocity in the burner opening= Vo

Total area of the flame front, Af,moveswith velocity Suw.r.t the unburned mixture,thus:

Ao×Vo = Af×Su

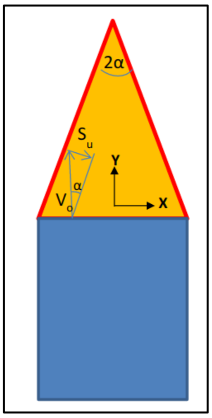

Figure 2 Schematic of the flame front. Su = burning velocity, 2α = cone angle.

3. Equipment’s

I. S-type Thermocouples

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.Temperature at various uniformly distributed points is measured with S-type thermocouple in a simple premixed flame.

II. Nagman's temperature calibrator

To calibrate S-Type thermocouple, a Nagman's temperature calibrator is used. Model 1200H 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).

III. Rotameters

Rotameters are used to measure the air and fuel flow rates.

IV. Needle Valve

A needle valve in the flow line is used to control the discharge.

V. single-piston reciprocating compressor

Air is supplied from a single-piston reciprocating compressor.

VI. lpg gas cylinder

VII. Digital Camera

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

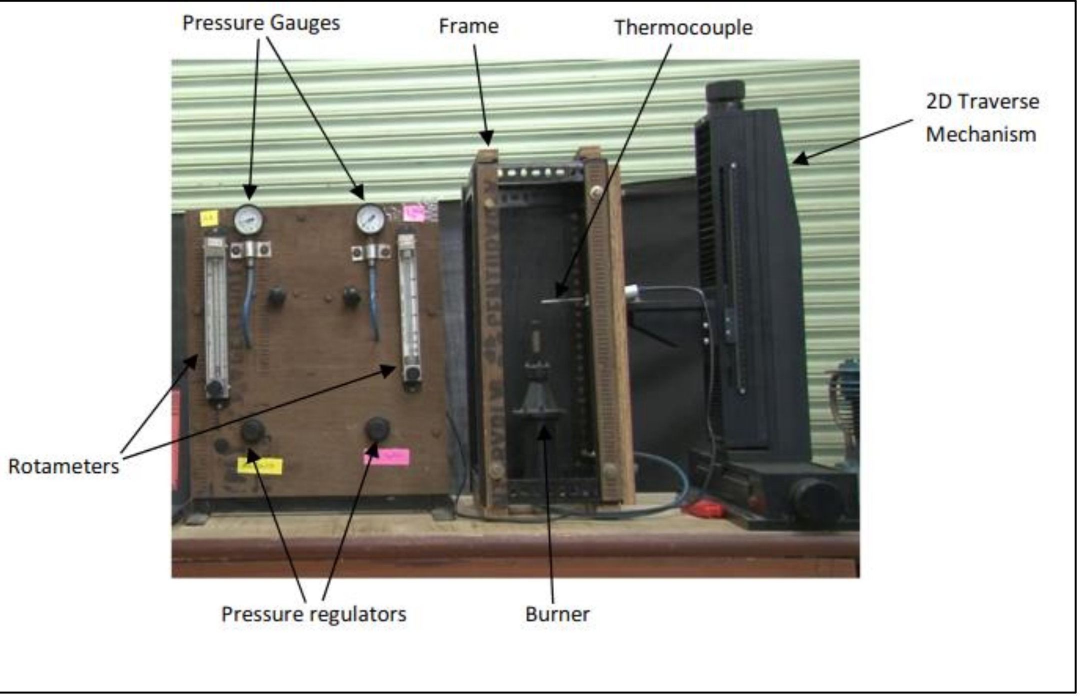

Figure 3 Exeperimental setup

4. Procedure and measurements

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

b) Familiarize with basic principles of data acquisition and processing.

c) Note down the ambient temperature and pressure.

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

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

f) At a particular equivalence ratio (say ϕ = 1.00671), 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.

g) Take flame images using a digital camera at the chosen equivalence ratio (ϕ = 1.00671).

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

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

5. Calculation

see appendix
$$\begin{cases} R_{air} = \frac{R_u}{M_{w-air}} = \frac{8.3145}{28.97} = 0.287\ kJ/kg.K \\ R_{lpg} = \frac{R_u}{M_{w-lpg}} = \frac{8.3145}{51.57} = 0.16123\ kJ/kg.K \end{cases}$$

Gouy's method

$$\tan\alpha = \frac{Pixel\ count\ of\ BC}{Pixel\ count\ of\ AB} = \frac{(306-167)}{(695-249)} = \frac{139}{449} = 0.31166$$

Flame Height : $\mathrm{H} = \frac{\mathrm{do}/2}{\tan\alpha} = \frac{5\mathrm{mm}}{0.31166} = 16.0432\mathrm{mm}$ (do = 10mm)

Surface Area of the canonical surface AC :

$$A_f = \pi r(r + \sqrt{H^2 + r^2}) \ ; \ (r = {d_0}/_2)$$

$$\boldsymbol{A_f = 342.501mm^2}$$

Area of the burner opening

Ao=πr^2 (r = do/2)

Ao = 78.54mm^2

Volume flow rate of gas = Volume flow rate of (air + lpg)

$$\dot{Q}_{gas} = \quad 0.000092 + 0.0000033 = 0.0000953 \ {}^{m^3}\!/_{s} \ \text{(table4)}$$

The average flow velocity in the burner opening

$$\mathrm{V_o} = \frac{\dot{Q}_{gas}}{A_o} = \frac{0.0000953}{78.54} \frac{{}^{m^3}\!/_{s}}{mm^2} = 1.2134 \, {}^{m}\!/_{s}$$

Total area of the flame front, Af,moveswith velocity Suw.r.t the unburned mixture,thus:

$$A_f S_u = A_o V_o$$

$$\boldsymbol{S_u = \frac{A_o V_o}{A_f} = \frac{78.54mm^2 \times 1.2134 \, {}^{m}\!/_{s}}{342.501mm^2} = 0.2824 \, {}^{m}\!/_{s}}$$

6. Results

a) 2-D Temprature contour

lab9.m

```
clc
clear
%%
load xyT.mat
lpgflamerawdata2
x = lpgflamerawdata2(:,1);
y = lpgflamerawdata2(:,2);
T = lpgflamerawdata2(:,3);
%Create regular grid across data space
[X,Y] = meshgrid(linspace(min(x),max(x)), linspace(min(y),max(y)));

%create contour plot
contourf(X,Y,griddata(x,y,T,X,Y));
xlabel('x (mm)');
ylabel('y (mm)');
colorbar
colormap('jet');
xlim([0,24]);
ylim([0,28]);
```

lpgflamerawdata2 =

0	0	37
0	4	75
0	12	240
0	20	290
0	28	275
4	0	340
4	4	632
4	12	803
4	20	750
4	28	650
8	0	755
8	4	1046
8	12	1070
8	20	1020
8	28	920
12	0	678
12	4	1030
12	12	1140
12	20	1101
12	28	1062
16	0	755
16	4	1046
16	12	1070
16	20	1020
16	28	920
20	0	340
20	4	632

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Figure 4 matlab code for contour of temprature

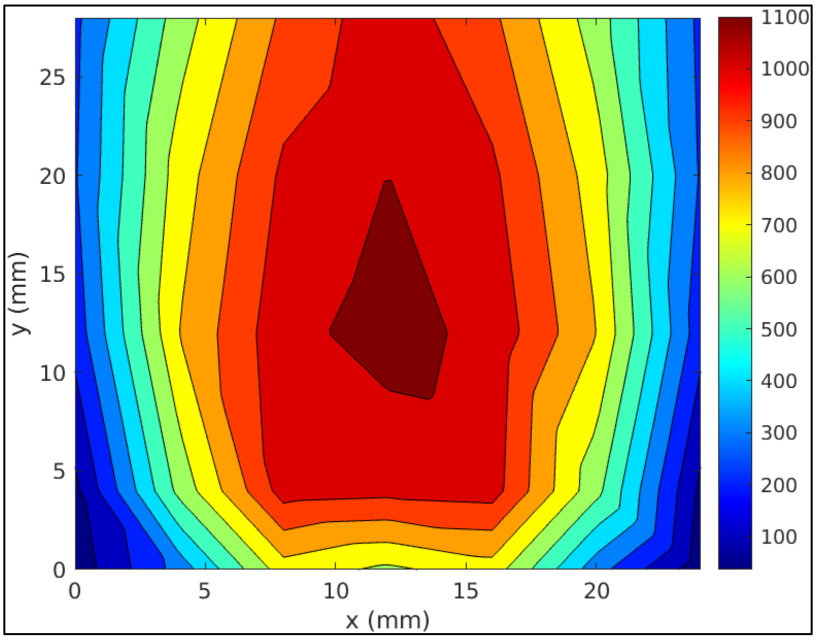

Figure 5 2-D Temprature Contour

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

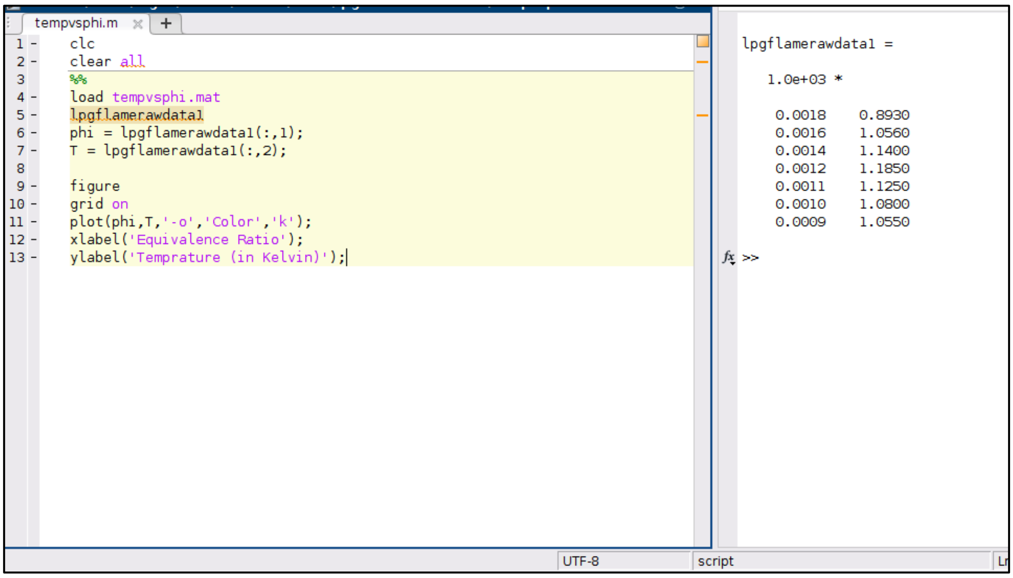

Figure 6 matlab code for graph between temprature and equivalance ratio

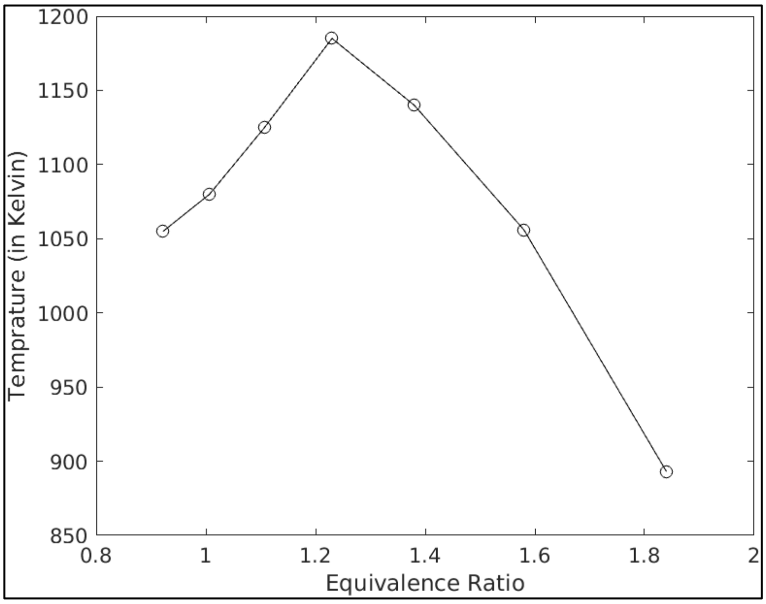

Figure 7 graph of Temp. vs Equivalence ratio

c) **Calculate the flame area and the burning velocity using Gouy's method for the chosen equivalence ratio (ϕ = 1.00671).**

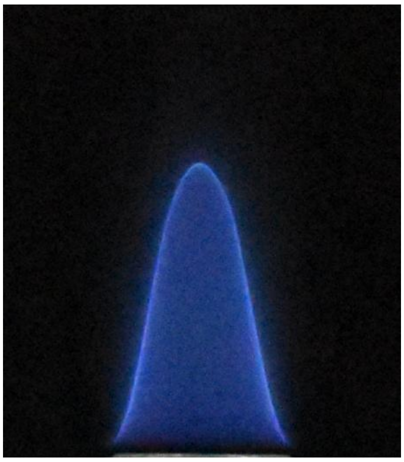

Figure 8 flame digital photo

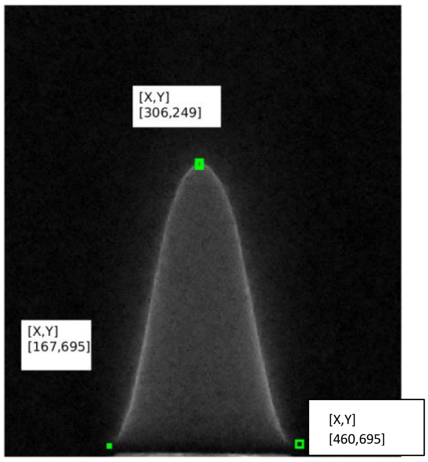

Figure 9 flame greyscale image

7. Source of Error

Error in measurement is due to

a) Calibration error

b) Disturbance in air during exeperiment

c) Equipment's malfunctioning

8. Precautions

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

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

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

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

9. Appendix

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

Molecular weight of Air (M w-air): 28.97 (kg/kmol)

Molecular weight of Lpg (M w-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.		51.57kg/kmol

Table 1

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

2-D grid readings (Ø = 1.00671)

		y				
		0	**4**	**12**	**20**	**28**
x	**0**	37	75	240	290	275
	4	340	632	803	750	650
	8	755	1046	1070	1020	920
	12	678	1030	1140	1101	1062
	16	755	1046	1070	1020	920
	20	340	632	803	750	650
	24	37	75	240	290	275

Table 2

Equivalence Ratio vs Temperature			
y = 3cm (Above the rim of the burner)			

Mass flow rate lpg (kg/s)	**Mass flow rate air (kg/s)**	**φ**	**T (K)**
0.00001	0.000085	1.84	893
0.00001	0.000099	1.58	1056
0.00001	0.00011	1.38	1140
0.00001	0.00013	1.23	1185
0.00001	0.00014	1.107	1125
0.00001	0.00016	1.00671	1080
0.00001	0.00017	0.922	1055

Table 3

Burning Velocity calculation data (φ = 1.00671)		
Volume Flow Rate of LPG : Q1 =	0.0000033	m^3/s
Volume Flow Rate of Air : Q2 =	0.000092	m^3/s

Table 4 volume flow rate