Experimental Investigations on Premixed LPG-air Flame

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OBJECTIVE

The objective of the experiment is to:

1. Plot 2D temperature contour of the flame
2. Determine the radicals produced using Spectroscopic Analysis
3. Shadowgraph Image

INTRODUCTION AND THEORY

S-Type Thermocouples

A thermocouple consists of two wires of different materials joined at one end. There can be no electrical potential difference between the wires at the end point. When the end point comes in contact with a higher temperature due to difference wire material a potential difference is generated through which we can find the temperature. It is called Seedback Effect. Type S thermocouple consists of 90%Pt and 10%Rh–Pt by weight and are used up to 1600 °C.
To calibrate this thermocouple we use Nagman Temperature Calibrator. Desired temperature is set in the calibrator and thermocouple is inserted and we will note potential difference generated. We will do this process for multiple temperatures and plot a polynomial graph. Using this graph we can interpolate temperature for different potential difference.

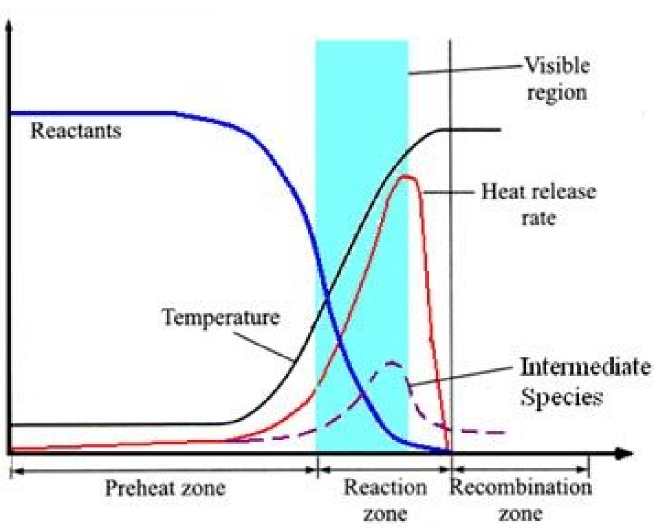
ROTAMETER

These are instruments to measure volume flow rate in a closed tube. A rotameter consists of a tapered tube made of glass with a small spherical smooth ball. When fluid is allowed to pass through ball changes its vertical position where its gravitational force equals the drag force produced by fluid flow. We can find new volume flow rate by scaling its new position. Buoyancy is also exerts force but neglected when fluid is air.
NOTE: The spherical ball must not float in the fluid, it has to have a higher density than the fluid, otherwise it will float to the top even if there is no flow (in stationary fluid).

PRE-MIXED AIR FLAME

A premixed flame is a flame formed under certain conditions during the combustion of a premixed charge of fuel and air. Since the fuel and air are available throughout a homogeneous stoichiometric premixed charge, the combustion process once initiated sustains itself by way of its own heat release.In a Bunsen flame, a steady flow rate is provided which matches the flame speed so as to stabilize the flame.

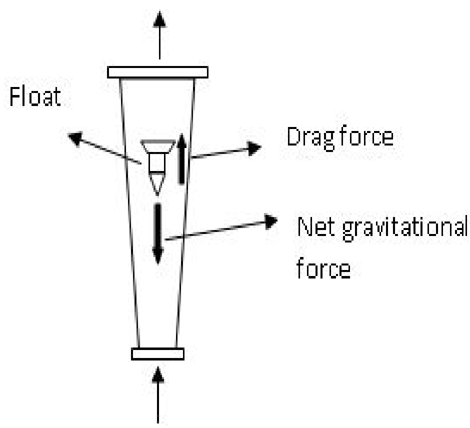
Blue cone (called Bunsen Cone) in the image is the reaction zone where all combustion happens. And the outer blue color is formed by chemiluminescence of excited radical such as C_2 and CH.

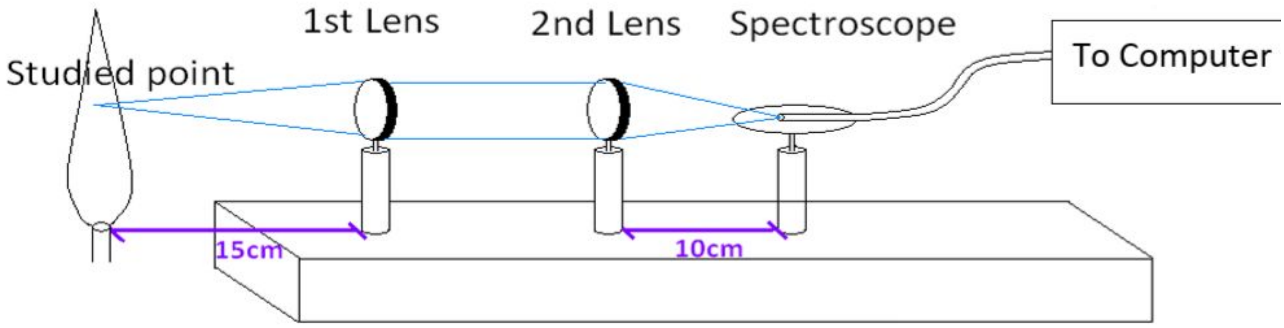


LPG and air are moves from upstream with the burning velocity S_U. Premixing of fuel and air occurs in the Bunsen tube and homogeneous premixed fuel/air mixture is discharged at tube exit which can be ignited. In steady state, flame forms Bunsen cone or flame becomes Laminar. LPG and air diffuse into the reaction zone and mixture gets heated up by heat conduction from the burnt gases. This results in LPG consumption, radical production, and oxidation when inner layer temperature is reached. There are increased temperature and gradients and maximum temperature reaches at cone surface. At this point, LPG is entirely depleted.
Velocity component normal to flame front is locally equal to the propagation velocity of the flame front which is called Burning Velocity.

EQUIPMENTS

S-Type Thermocouple, Nagman Temperature Calibrator, Rotameter, Constant Deviation Spectrometer (CDS), Two Convex Lenses (focal length 15cm and 10cm), Laser Generator, Screen and a camera.





PROCEDURE

1. For the first part, light the Bunsen Burner and set the volume flow rate of Air and LPG approximately to their stoichiometric ratio. Calibrate the temperature sensor and start taking temperature of points on a 2D plane. Plot a contour of the taken measurements.

2. For finding spectrum, set the lenses and the optical wire to take the rays coming from flame. Keep the lights in the room as minimum as possible. Turn on the fan of laser generator, switch on the key and turn on the laser. We have to adjust the integration in the computer time according to the environment. Take two sample spectrum, first with flame on and other with flame off. Take the difference of the two to get the final spectrum.

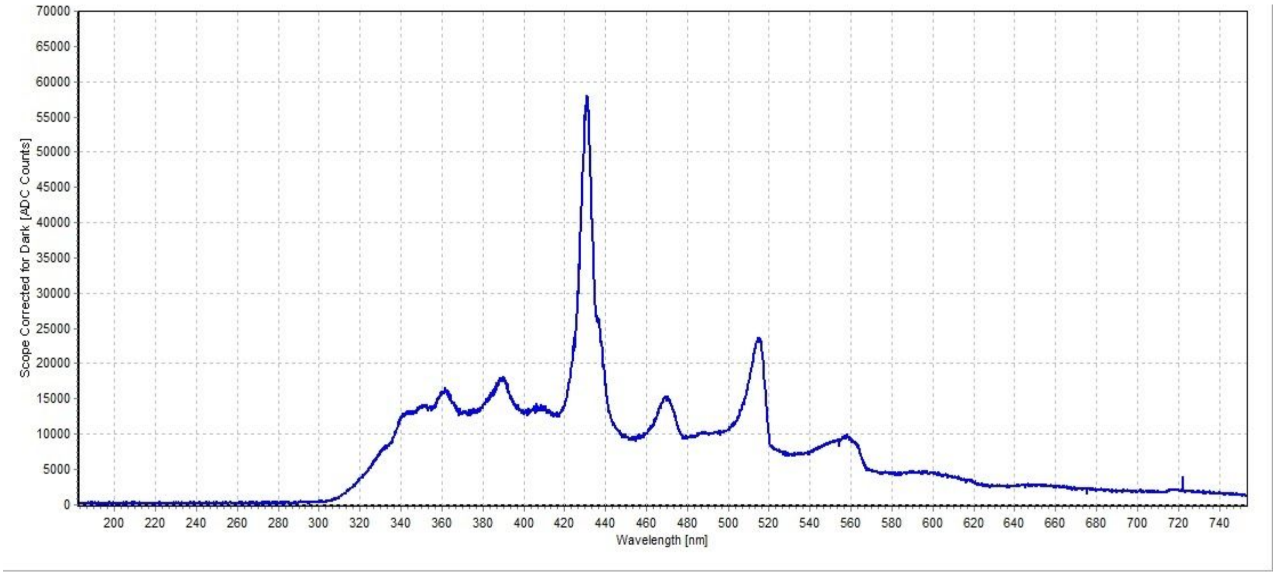
3. For shadowgraph image, again keep the lights as dim as possible. Turn the laser on like in the last step. Place a screen to image formed from the laser of the flame.

MEASUREMENTS

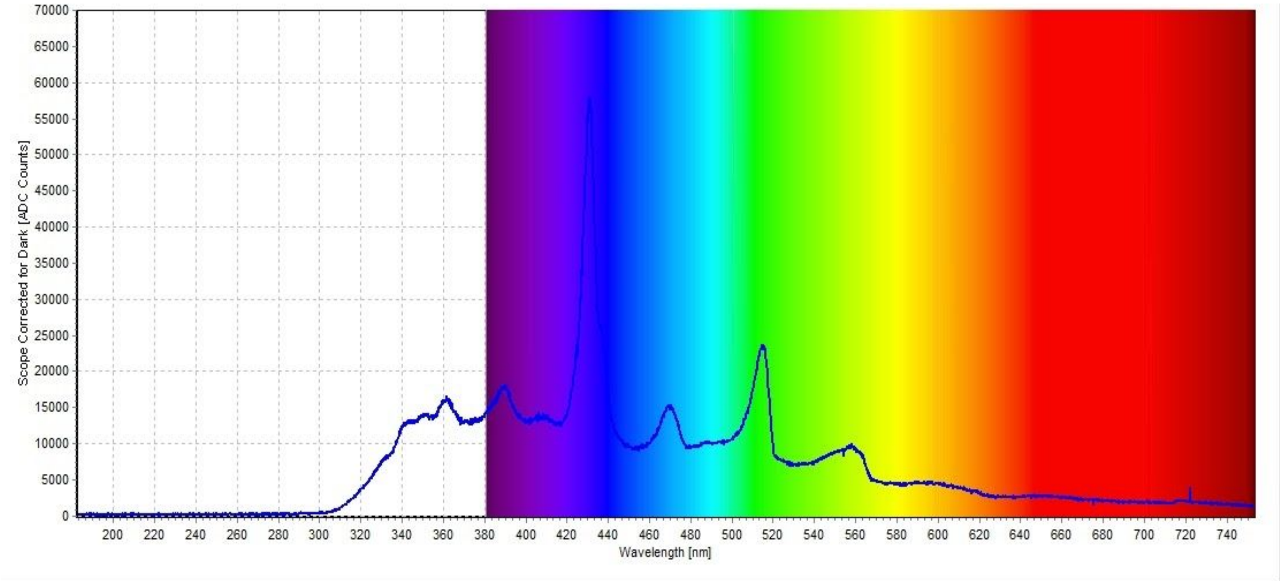
FLAME TEMPERATURE MEASUREMENTS

x/y (mm)	**-2.0**	**-1.6**	**-1.2**	**-0.8**	**-0.4**	**0.0**	**0.4**	**0.8**	**1.2**	**1.6**	**2.0**
0.7	27.3	28.7	115	795	1092	778	978	790	100	30	26.3
1.1	27.5	30	231	861	1097	815	1097	861	231	30	27.5
1.9	28.2	35	271	935	1117	1131	1117	935	271	35	28.2
2.7	29.6	56	331	761	1063	1088	1063	761	331	56	29.6
3.1	31	71	301	774	1016	1044	1016	774	301	71	32

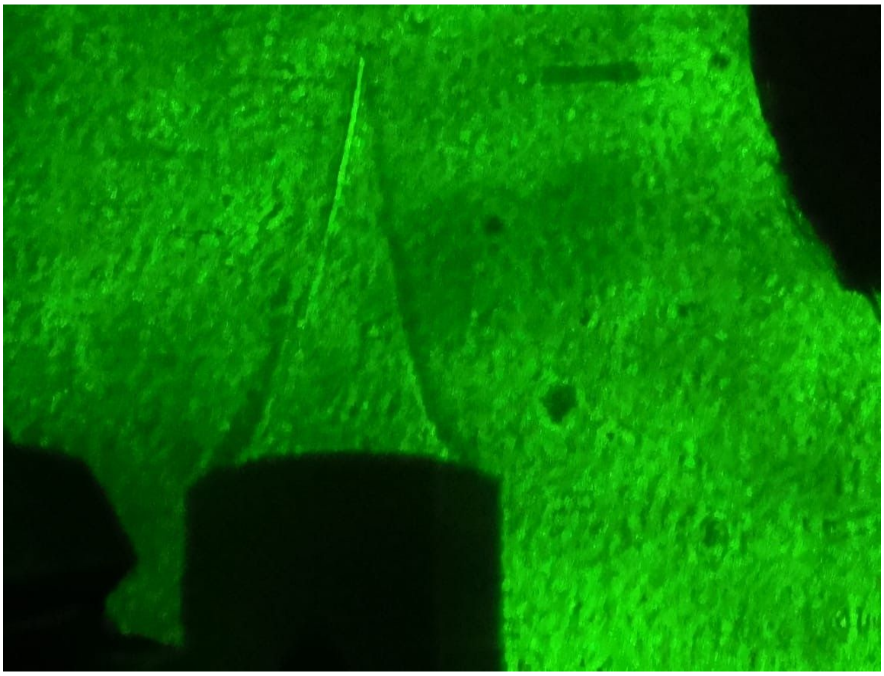
SPECTRUM FORMATION



Coloured Spectrum:



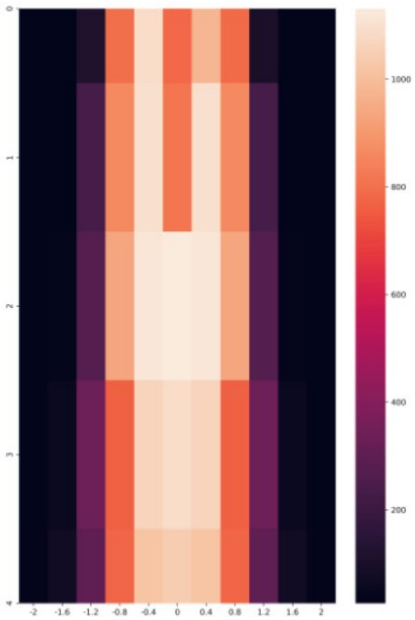
SHADOWGRAPH IMAGE



Length of Base of cone (l) = 10 mm
Height of cone (h) = 16.44 mm

RESULTS

FLAME TEMPERATURE CONTOUR



SPECTRUM

CH	420-440nm
C_2	460-475nm / 510-516nm
CN	359nm / 386nm
H_2O	Broadband around 600nm
CO_2	Broadband
OH	300-320nm

Using the above values we can determine that blue colour is formed due to CH radical and also check the intensities of other radicals like C_2, OH, etc.

EQUIVALENCE RATIO

Atmospheric Pressure (P_O) = 101325 Pa

Gauge Pressure (measured from manometer) of Air = 1 Kg/cm^2
Which gives, Total Pressure of Air (P_1) = (1 x 98066.5) + 101325 = 199391.5 Pa

Gauge Pressure of LPG = 1 Kg/cm^2
Which gives, Total Pressure of LPG (P_2) = (1 x 98066.5) + 101325 = 199391.5 Pa

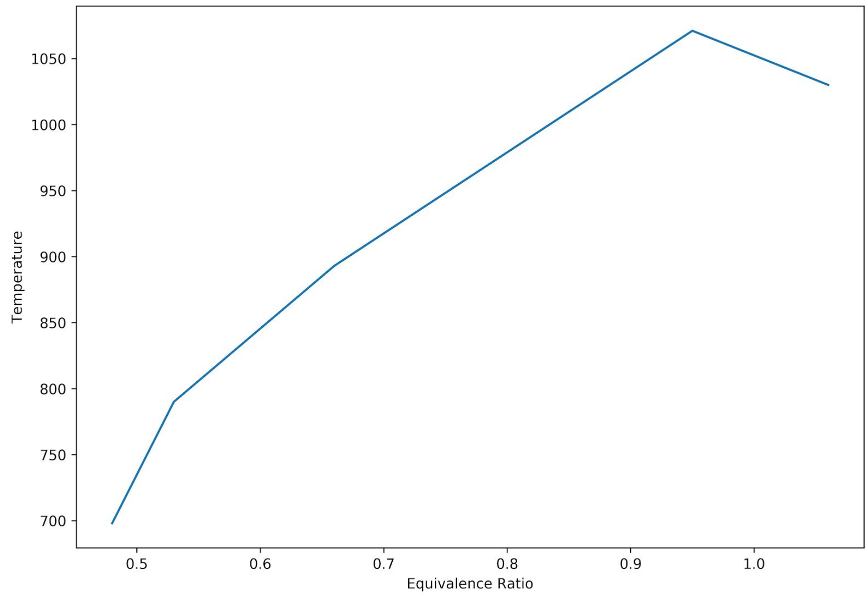
$\dot{Q}_{\text{indicated}}$ of Air = 6
$\dot{Q}_{\text{scale}}$ of Air ($\dot{Q}_1$)= $\dot{Q}_{\text{indicated}}$/60000 = 10^{-4} Kg/s
R_{air} = 287 $JKg^{-1} K^{-1}$ and T = 298 K
Scaled density of Air = P_O / (R_{air} x T) = 1.18473 Kg/m^3
Actual density of Air = P_1 / (R_{air} x T) = 2.33135 Kg/m^3

$\dot{Q}_{\text{indicated}}$ of LPG = 0.2
$\dot{Q}_{\text{scale}}$ of LPG ($\dot{Q}_2$) = $\dot{Q}_{\text{indicated}}$/60000 = 3.33 x 10^{-6} Kg/s
R_{LPG} = 157.7 $JKg^{-1} K^{-1}$ and T = 298 K
Scaled density of LPG = P_O / (R_{LPG} x T) = 2.15609 Kg/m^3
Actual density of LPG = P_2 / (R_{air} x T) = 4.24285 Kg/m^3

Mass of Air ($\dot{m}_1$) = $\dot{Q}_1\sqrt{\rho_{scale} * \rho_{actual}}$ = 1.66193 x 10^{-4} Kg/s
Mass of LPG ($\dot{m}_2$) = $\dot{Q}_2\sqrt{\rho_{scale} * \rho_{actual}}$ = 1.00819 x 10^{-5} Kg/s
Stoichiometric Ratio = 0.0643

Equivalence Ratio (Φ) = $\dfrac{\dot{m}_1/\dot{m}_2}{stoichiometric\ ratio}$ = 1.06

This is how to calculate <u>Equivalence Ratio</u>.



Plot of Equivalence Ratio vs Temperature: Temperature increases with the increase of LPG

SHADOWGRAPH

We have l = 10 mm and h = 16.44 mm
Therefore, area of cone (A_F)= 0.5 x l x h = 82.2 mm^2

Given diameter of the burner (d) = 10 mm
Area of burner opening (A_O) = $\pi d^2/4$ = 78.54 mm^2

To find v_O, we are going to use $A_O v_O = \dot{Q}_{scale}$.
To find S_U, we will use $A_O v_O = \dot{Q}_{scale} = A_F S_U$ to find **S_U = 1.2566 cm/s**

CONCLUSION

We learnt about laminar premixed air flame. We learnt how to perform spectroscopy, its uses and analyse its result. We also learnt how to calculate burner velocity with the use of shadowgraph image.

APPENDIX

Chemical composition of LPG gas (Approx.)

Propane	C_3H_8	44.7
Isobutane	C_4H_{10}	54.8
Ethane	C_2H_6	0.7
Avg. Mol Wt.		51.57

Heating Value for LPG is 46.1MJ/kg.

Stoichiometric fuel air ratio = 0.0643 Kg of LPG/Kg of air.

LIST OF SYMBOLS:

ϕ - Equivalence Ratio.

R - Universal Gas Constant.(J/kg.K)

$\dot{Q}_{actual}$ - Actual Flow rate. (m^3/s)

$\dot{Q}_{indicated}$ - Indicated Flow rate. (LPM)

ρ_{actual} - Density of metered fluid medium. (kg/m^3)

ρ_{scale} - Density of air medium in rotameter. (kg/m^3)

P_{guage} - Control line supply pressure.(psi)

P_{atm} - Local atmospheric pressure noted from barometer. (cm.Hg)

S_u - Burning Velocity

T - Local atmospheric temperature. (°C)

P_0 - Reference Pressure. (Pa)

PRECAUTIONS

1. Turn on the compressor, and then the LPG cylinder.
2. Ignite the burner first to avoid leaking of LPG and then set the flow rate.
3. Turn the fan on while using laser beam.
4. Don’t bend the optical wire.
5. Turn off the LPG cylinder first, and then the compressor.