LAB 6 - Experimental Investigation on premixed LPG-Air Flame
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AE351
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- **OBJECTIVE:**

1) To determine 2-D temperature parallel to the flame front.
2) Spectroscopic analysis using Avast spectrometer.
3) Qualitative analysis using Shadow graphic techniques.

- **INTRODUCTION AND THEORY:**

- Fine gage *S-Type thermocouples* are made of Pt-10%Rh/Pt, are used when fast, accurate temperatures are required. The diameter of these wires is 0.125mm and the response time is 0.08secs. These fine wire diameters enable accurate temperature measurements, keeping the heat transfer at the point of contact to the flame and thermocouple minimum. In addition to that, the fine junction permits accurate pin-pointing of the measured values.

- To calibrate the S-Type thermocouple a *Nagman's Temperature calibrator*, is used this is of Model 1200HN is a semi-portable, multi-hole, dry block type, high-Temperature Calibrator which can generate temperature up to 1200K, consequently a voltage is generated by given temperature [Seebeck effect].

- *Rotameters* were used to measure the flow rates where the air and fuel are fed through the rotameters with a prescribed pressure and the discharge is being controlled by *a needle valve* at the exit. The air is supplied from a single-piston engine compressor.

A constant deviation Spectrometer (CDS) is used to measure radical emission intensities. These emissions with their ratios were then related to the equivalence ratio.
To find the relation between each radical intensity ratio and the equivalence ratio, *shadowgraph images* were procured from the flame over the burner with low-*intensity Diode-pumped-Solid-State LASER* which is operating with 220V AC at 50Hz, which can generate a beam of 100mw. The laser beam is passed through a double concave lens with a minimum focal length(2.5cm) so that light from the LASER beam spreads and shoots out on the screen, from which the photographs are been captured using a Digital Camera

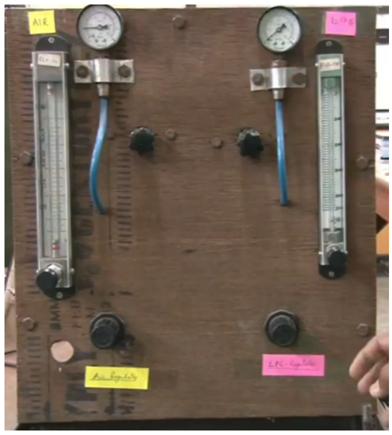
FORMULAE:	**LIST OF SYMBOLS:**
a) For Adiabatic Flame temperature: $q = mC_p \Delta T$ b) Rotameter Calculations: $\frac{Q_{actual}}{Q_{scale}} = \sqrt{\frac{\rho_{scale}}{\rho_{actual}}}$ $\dot{m}_{actual} = \rho_{actual}\dot{Q}_{actual} = \dot{Q}_{scale}\sqrt{\rho_{scale} * \rho_{actual}}$ $\rho_{scale} = \frac{P_{atm}}{RT}$ $\rho_{actual} = \frac{P_{gauge}+P_{atm}}{RT}$ c) Total Mass flow rate:	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/m3) P_{gauge} Control line supply pressure (psi) P_{atm} Local atmospheric pressure noted from barometer (in cm of Hg) T Local atmospheric temperature (°C)

$\dot{m} = \dot{Q}_{scale}\sqrt{\rho_{scale}\rho_{actual}}$ $\quad \dot{Q}_{scale} = \frac{\dot{Q}_{indicated}}{60,000} kg/s$	P_0	Reference Pressure (Pa)

- **EQUIPMENT AND OPERATING CONDITIONS:**

The experimental setup includes:

1. Air supply:
   Compressor (single piston) supplies the air, valve to control the airflow
2. Domestic cylinder: (for LPG)
3. Dialwood: from where the pressure of the flow of the LPG and Air
4. Rotameter attached in Dialwood, used to calculate the flow rate of the LPG and the air
5. 2D traverse: it can travel in both x and y direction
6. S type thermocouple mounted on a NI DAQ card.
7. Bunsen burner settling chamber. connected with LPG as well as the air

		
A 2D Traverse	**Single Piston Compressor**	**Dialwood (with attached Rotameters)**

- **PROCEDURE:**

1. Before starting the experiment, familiarize with various components of the test set as well as the instruments used for experimentation.
2. Familiarize with the basic principles of how the data is acquired using and reduced to the required values.
3. Note down the ambient temperature and pressure.
4. When the compressor and the LPG cylinder are turned on note down the gauge pressures from the control line.
5. To understand the nature of flame, the equivalence ratio was varied right from the Fuel rich premixed flame to stoichiometric AFR to Fuel lean Premixed Flame.
6. At a unique equivalence ratio (ϕ=0.95), input a grid format, and move the traverse 2-Diamentially along with the coordinates as given in the grid, measuring the temperature on those points.
7. Take shadowgraphic images using a digital camera at the equivalence ratio (ϕ=0.95)
8. At a point, 3cm above the Burner Rim, fix the thermocouple and vary the equivalence ratio.

9. At the same point, using a spectrometer get the intensity of radicals with the change in varying equivalence ratio.

T_0 (Ambient Temperature) = 290.85 K
P_0 (Ambient Pressure) = 101325 Pa
R (Universal Gas Constant) = 8.3145 J*mol^{-1}K^{-1})

Fuel(LPG)	AIR
Molecular Weight of LPG = 51.57 g*mol^{-1} **Specific Gas Constant = 161.227 J*Kg^{-1}k^{-1}** **$P_{indicated}$ = 1 Kg*cm^{-2}** **P_{gauge} = 98066.5 Pa** **$Q_{indicated\ Rotameter}$ = 0.1 LPM** **Q_{scale} =5*e^{-6} m^{3}s^{-1}** **ρ_{scale} = 2.16375 kg*m^{-3}** **ρ_{actual} = 4.25791 kg*m^{-3}** $\dot{m}_{actual} = 1.5 * 10^{-5} kg * s^{-1}$	**Molecular Weight of Air= 28.97 g*mol^{-1}** **Specific Gas Constant = 287.004 J*Kg^{-1}k^{-1}** **$P_{indicated}$ = 1 Kg*cm^{-2}** **P_{gauge} = 98066.5 Pa** **$Q_{indicated\ Rotameter}$ = 1.2 LPM** **Q_{scale} =2*e^{-4} m^{3}s^{-1}** **ρ_{scale} = 1.21551 kg*m^{-3}** **ρ_{actual} = 2.39193 kg*m^{-3}** $\dot{m}_{actual} = 3.4 * 10^{-4} kg * s^{-1}$

Temperature Readings for the Grid					
Y(in mm) → X(in mm) ↓	**0**	**4**	**12**	**20**	**28**
0	**678**	**1030**	**1140**	**1101**	**1062**
4	**755**	**1046**	**1070**	**1020**	**920**
8	**340**	**632**	**803**	**750**	**650**
12	**37**	**75**	**240**	**290**	**275**

Equivalence Ratio = 0.69211

Equivalence Ratio,ф VS Temperature,T @3cm	
ф	T
1.84	**893**
1.58	**1056**
1.38	**1140**
1.23	**1185**
1.107	**1080**
1.00671	**1080**

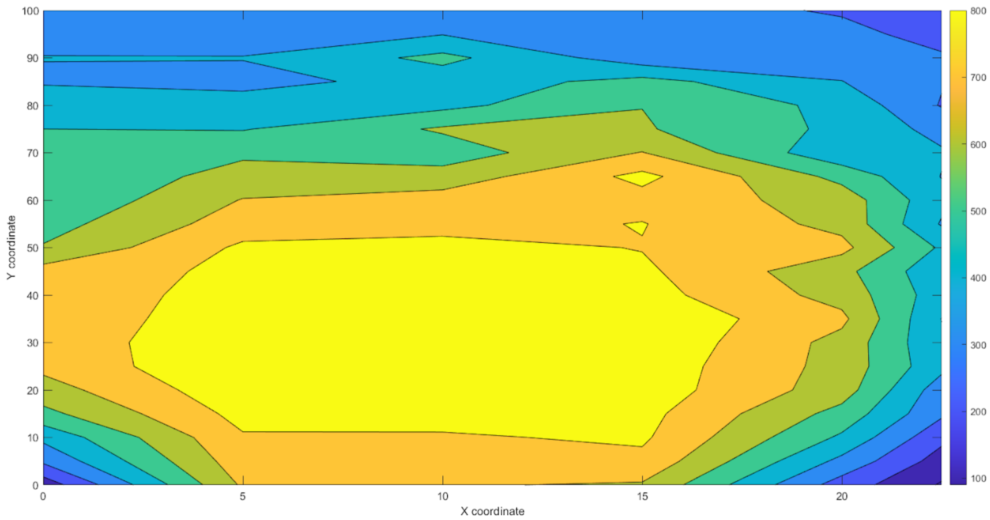
0.922	**1055**

- **RESULTS AND DISCUSSION :**

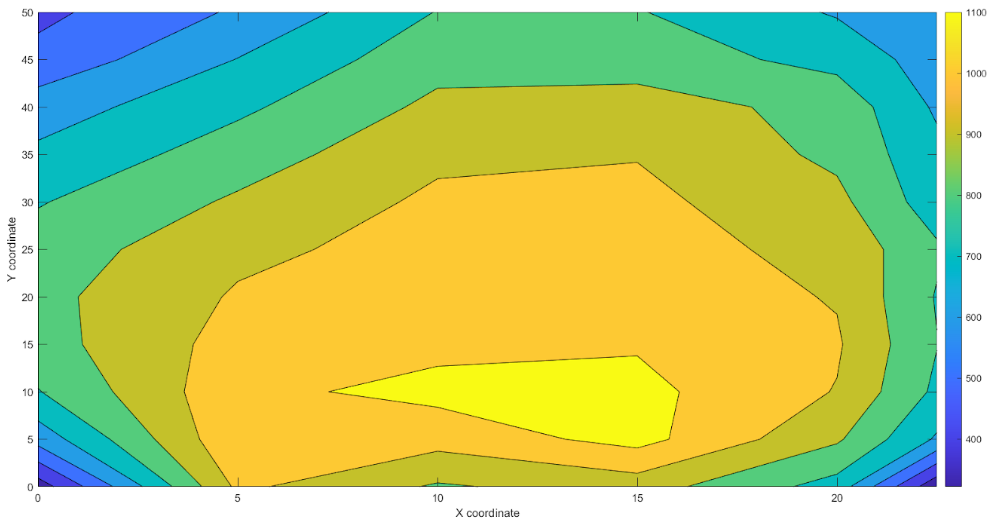
(a) Calculations and Plots

1) **A 2-D Temperature contour plot:**

Dataset used: airLPM3 [3.5 LPM Air and 0.2LPM fuel**]**



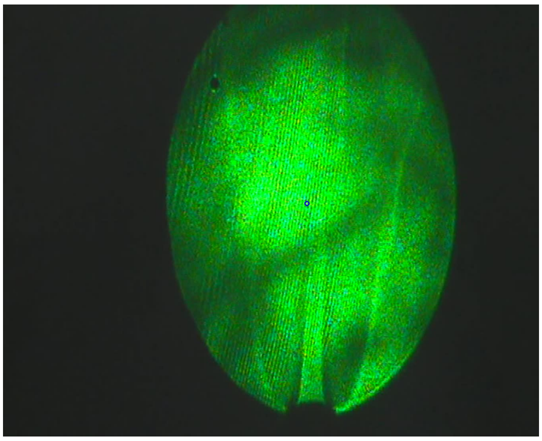
Dataset used: AirLPM5 [5.86 LPM Air and 0.2LPM fuel]



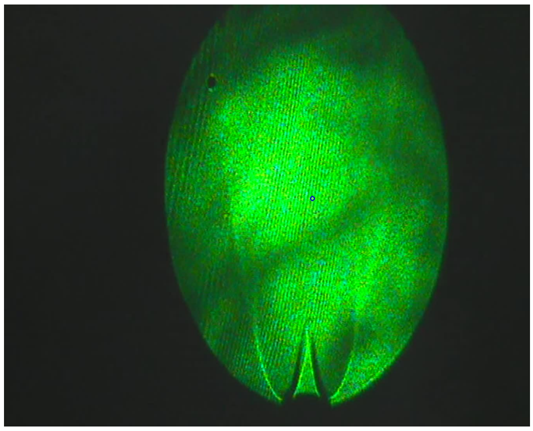
NOTE: Xcoordinate and Ycoordinate are in mm and Temperature is in DegreeC

2) **Shadow-graphic images**

Dataset used: 3LPM air	**Dataset used: 5.86LPM air**



Point of Maximum density: (764,497)



Point of Maximum density (790,496)

3) Plot Temperature vs. equivalence ratio (ф) at a position 3cm above the burner rim.

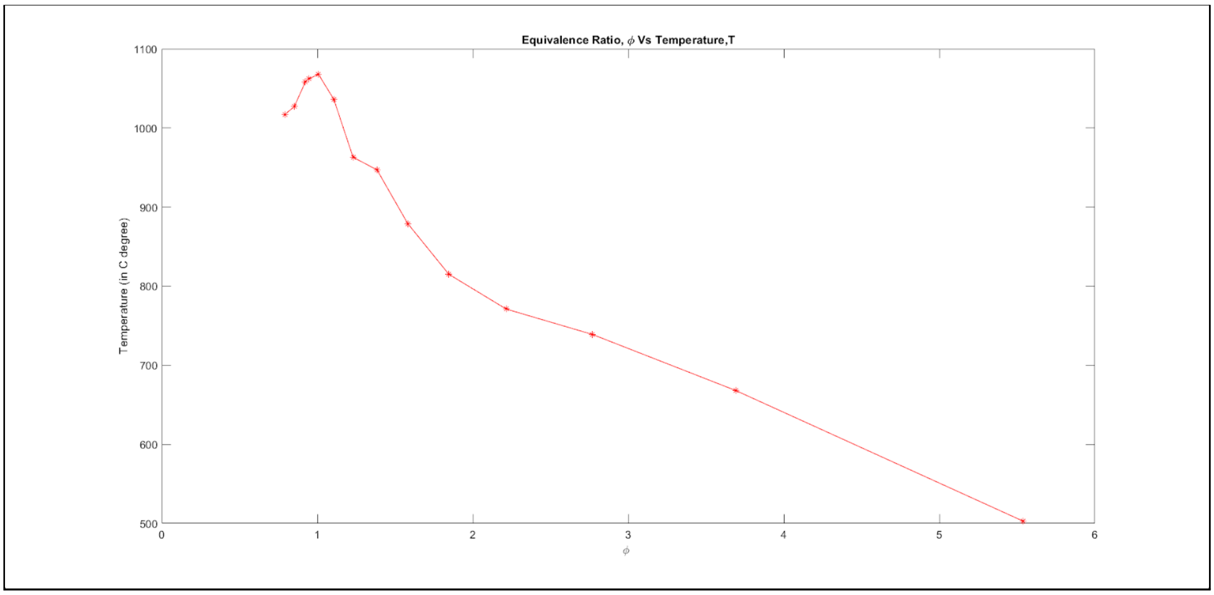
Stoichiometric fuel-air ratio = 0.0643 Kg of LPG/Kg of air.

$$\Phi = \frac{\left(\frac{\dot{m}_f}{\dot{m}_{air}}\right)}{0.0643} = \frac{1}{0.0643} * \frac{\dot{Q}_{f,indicated}}{\dot{Q}_{air,indicated}} * \frac{M_f}{M_{air}} * \sqrt{\frac{P_{f,gauge}+P_{atm}}{P_{air,gauge}+P_{atm}}} = \frac{1}{0.0643} * \frac{0.2\ LPM}{\dot{Q}_{air,indicated}} * \frac{51.57}{28.97} * \sqrt{\frac{0.1+1.01325}{0.1+1.01325}}$$

$$= \frac{5.5369}{\dot{Q}_{air,indicated}}$$

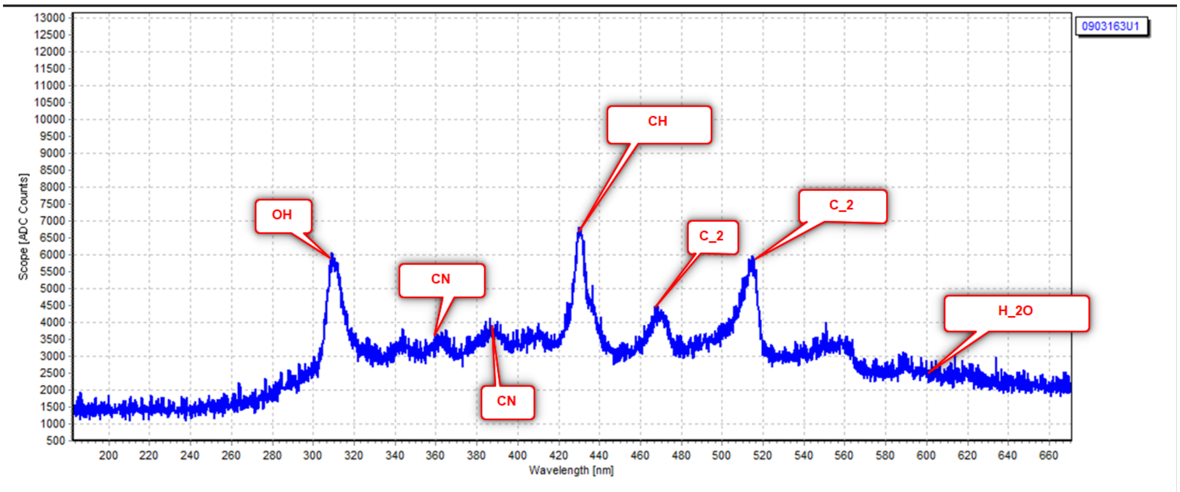
Q_air_indicated (LPM)	T(degrees)	$\Phi = \frac{5.5369}{\dot{Q}_{air,indicated}}$
1	503	5.5369
1.5	668	3.691
2	739	2.768
2.5	771	2.215
3	815	1.846

3.5	879	1.582
4	947	1.384
4.5	963	1.230
5	1036	1.107
5.5	1068	1.007
5.86	1062	0.945
6	1058	0.923
6.5	1027	0.852
7	1017	0.791

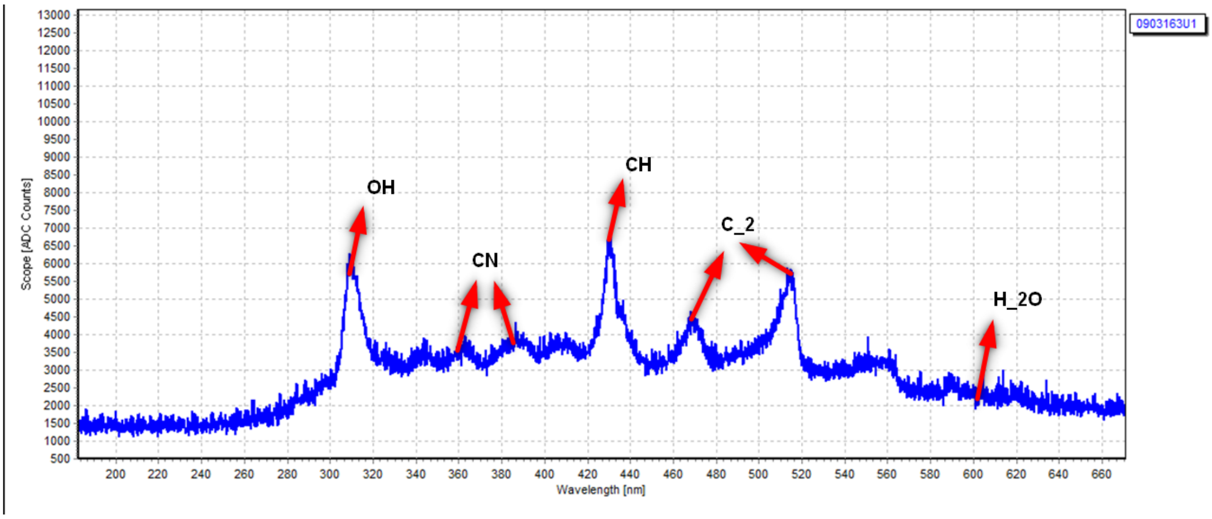


4) At the same position obtain various intensities by varying the equivalence ratio (ɸ), plot ratios of intensities like C2/CH, C2/H2O, H2O/CH, C2/OH, H2O/OH, and CH/OH with equivalence ratio(ɸ).

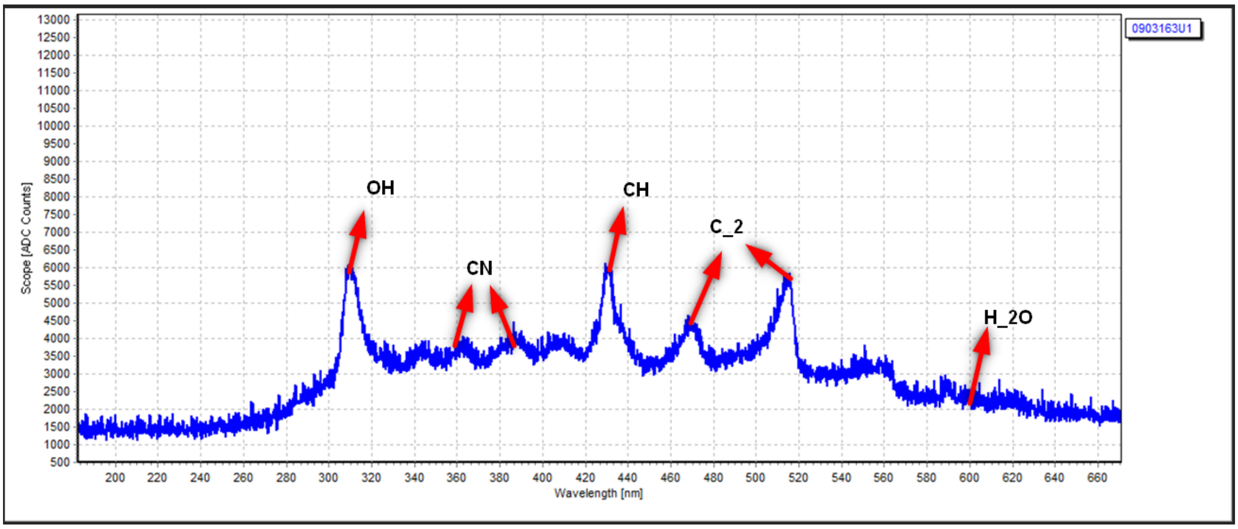
common radicals and products	Flame emission wavelength
CH	420-440nm
C_2	460-475nm / 510-516nm
CN	359nm / 386nm
H_2O	Broadband around 600nm
CO_2	Broadband
OH	300-320nm



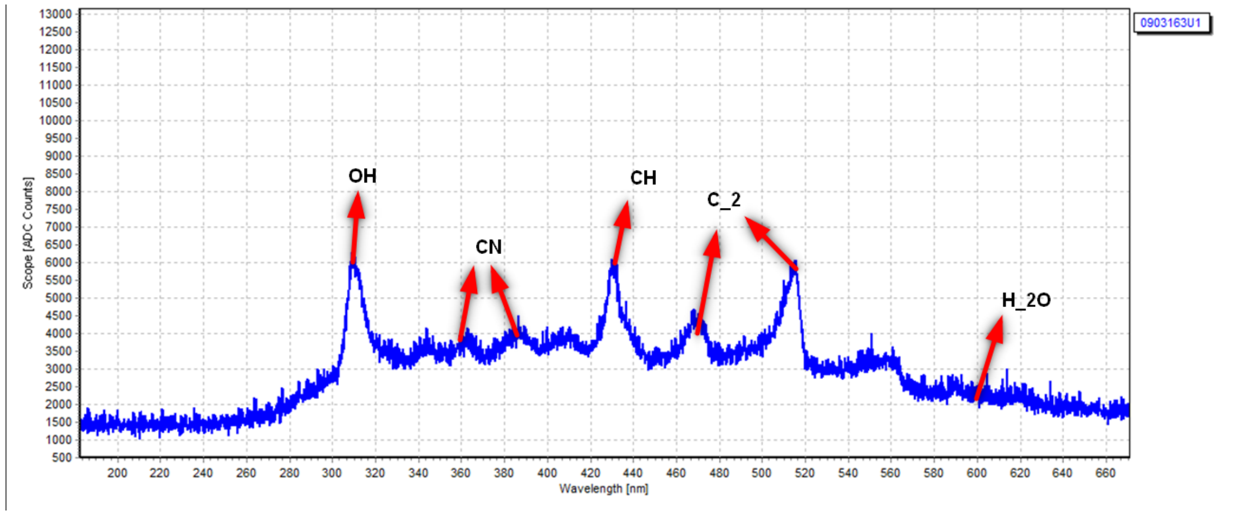
(Fig 1) 1.5LPM Air



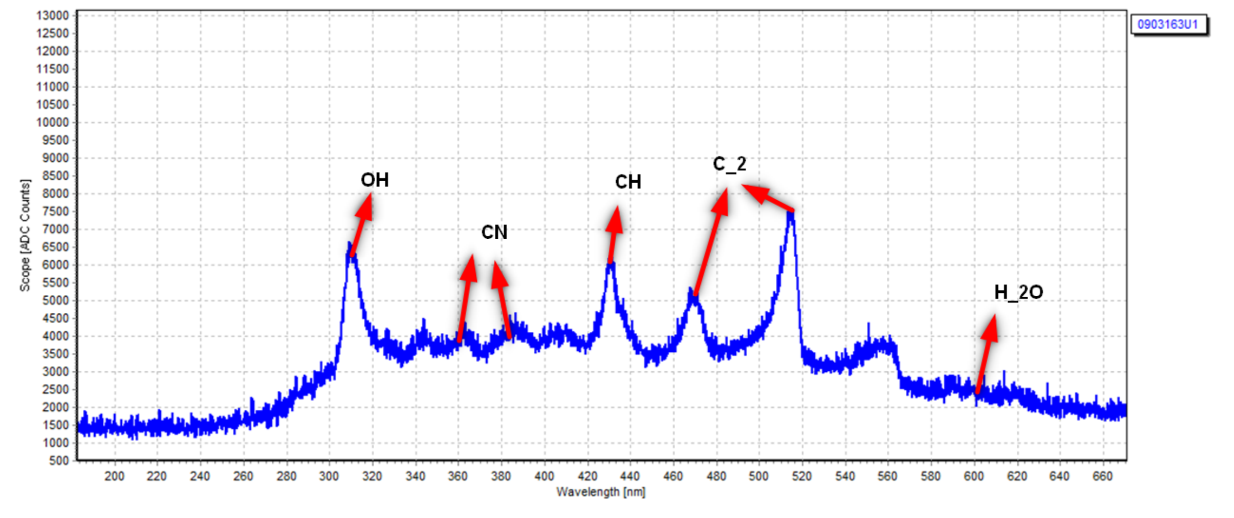
(Fig 2) 2LPM Air



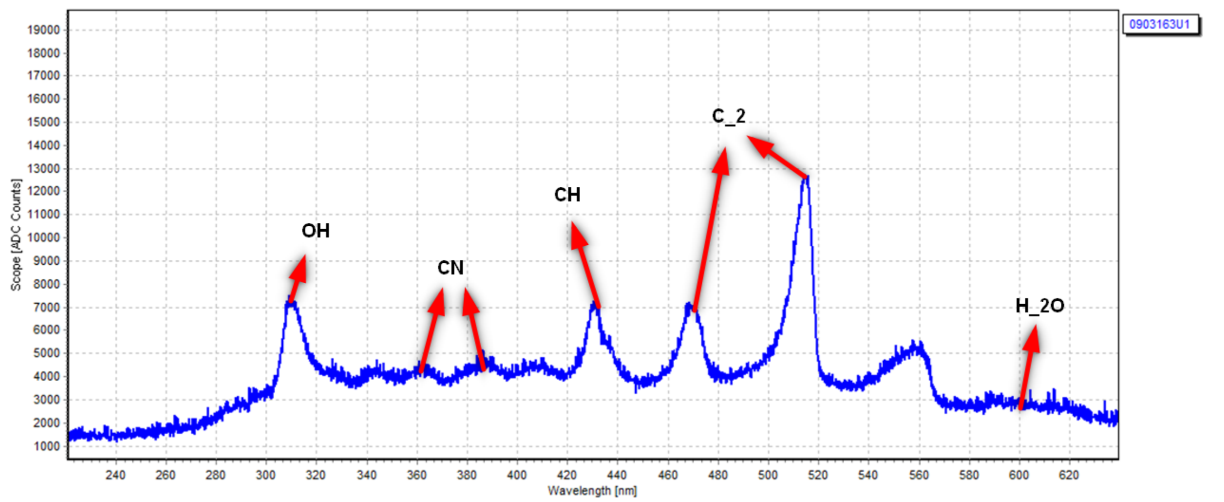
(Fig 2) 2.5LPM Air



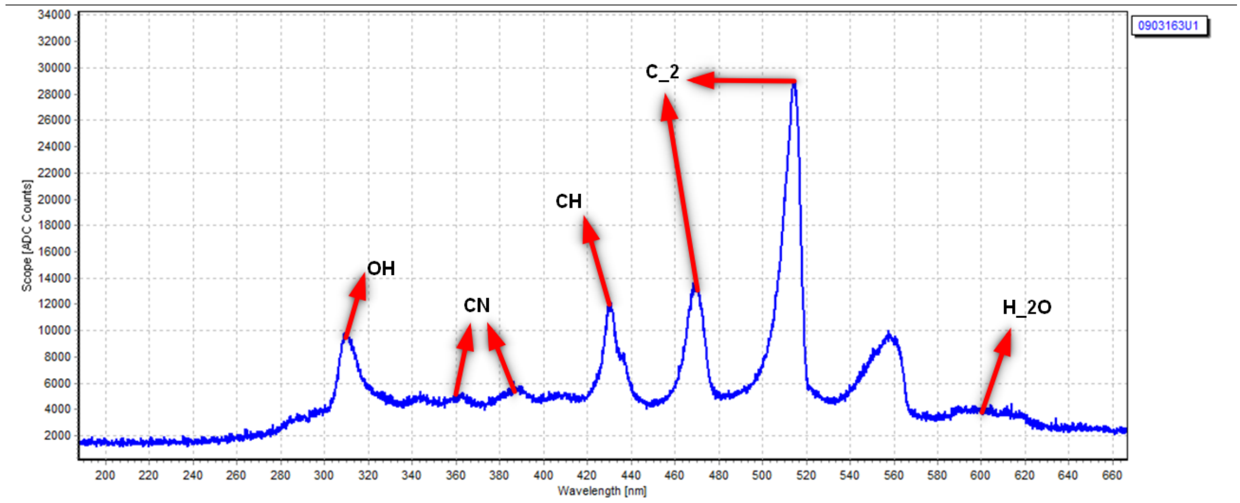
(Fig 4) 3LPM Air



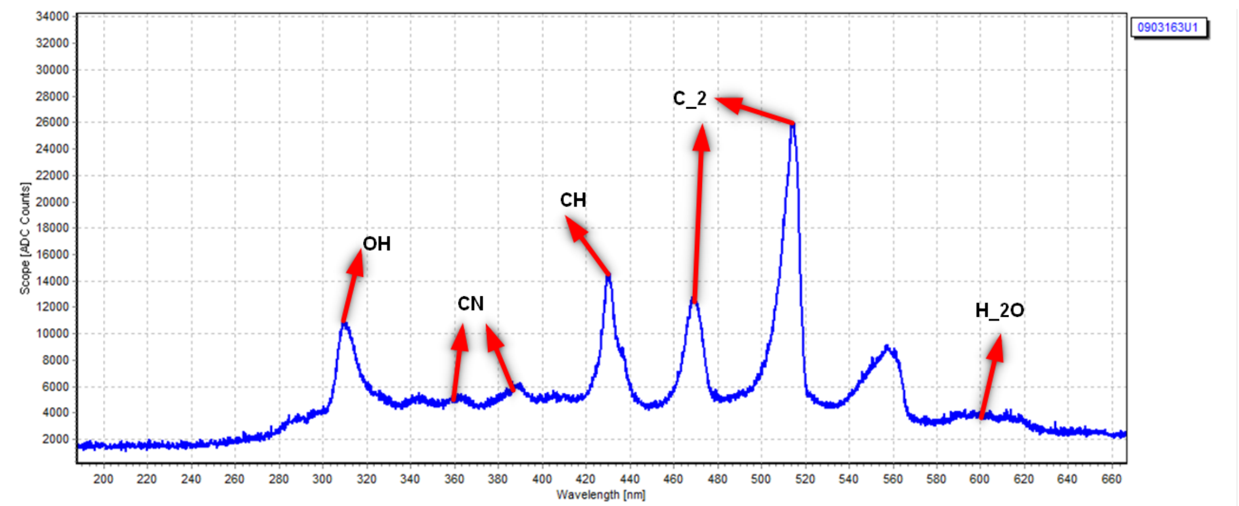
(Fig 5) 3.5LPM Air



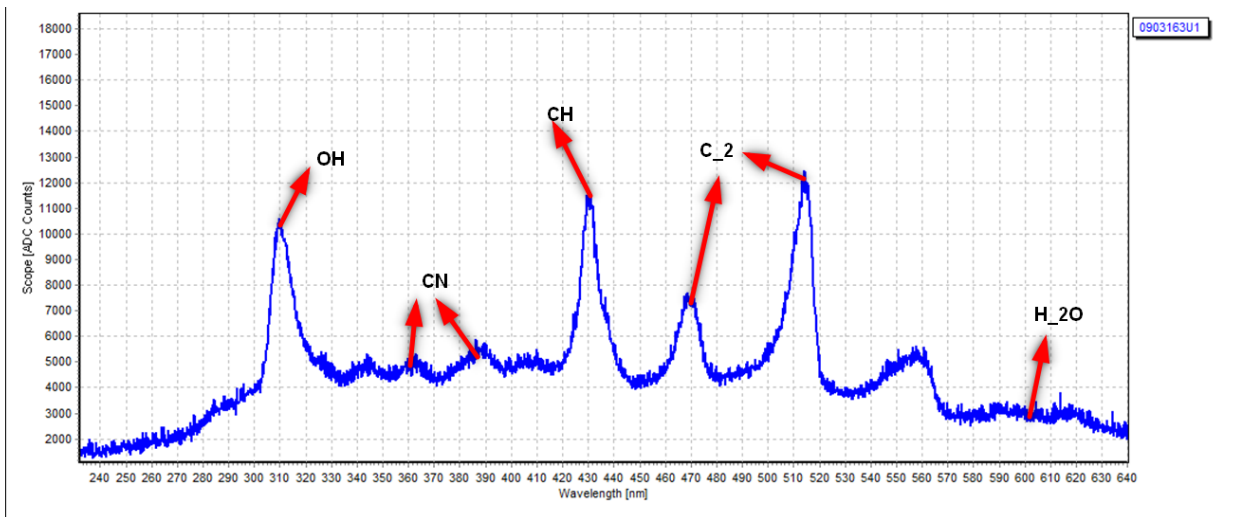
(Fig 6) 4LPM Air



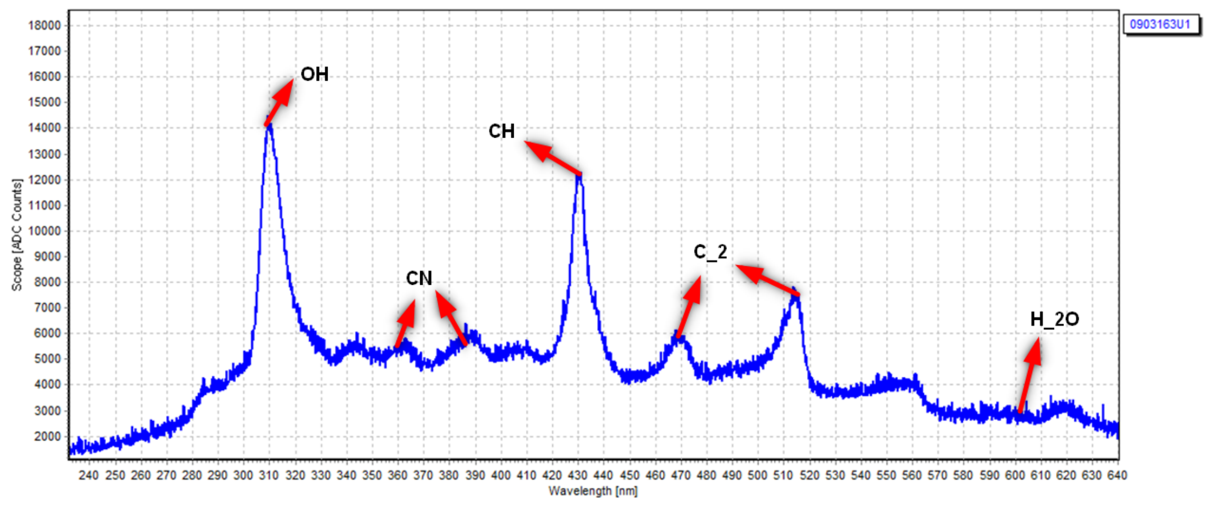
(Fig 6) 4.5LPM Air



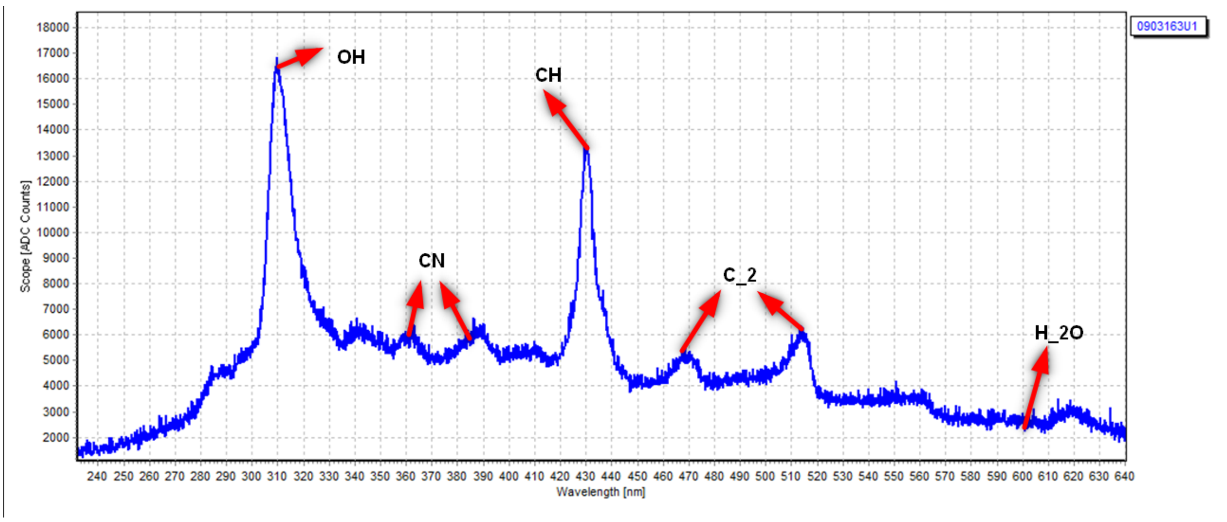
(Fig 7) 5LPM Air



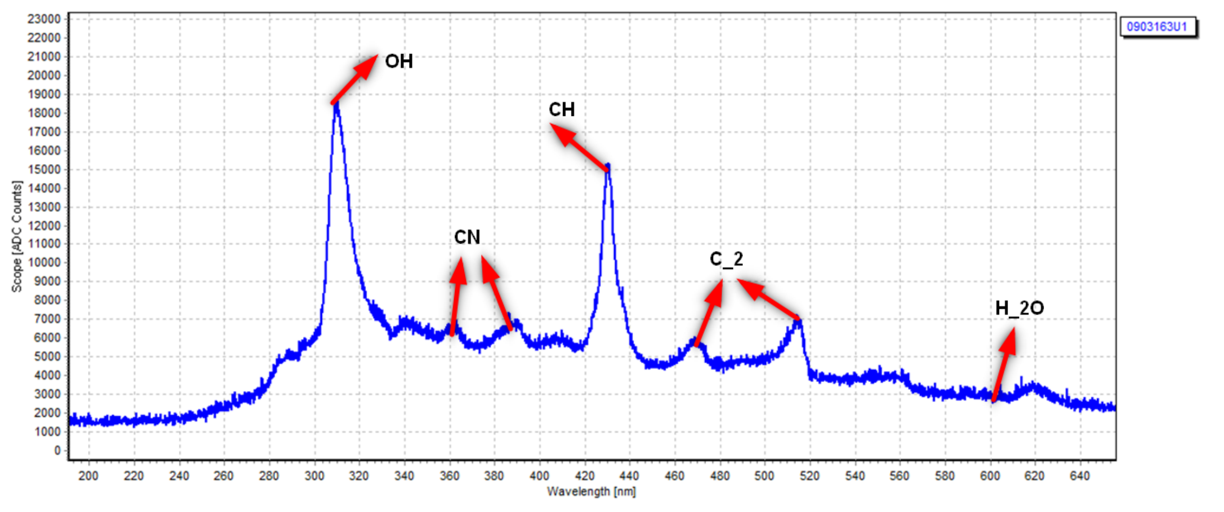
(Fig 8) 5.5LPM Air



(FIG 9) 6LPM air



(Fig 10) 6.5LPM Air



(Fig 11) 7LPM Air

For figure 1 (with $\phi = 3.69$)

C_2/CH = 6000/6900 = 0.88

C_2/H_2O = 6000/2500 = 2.4

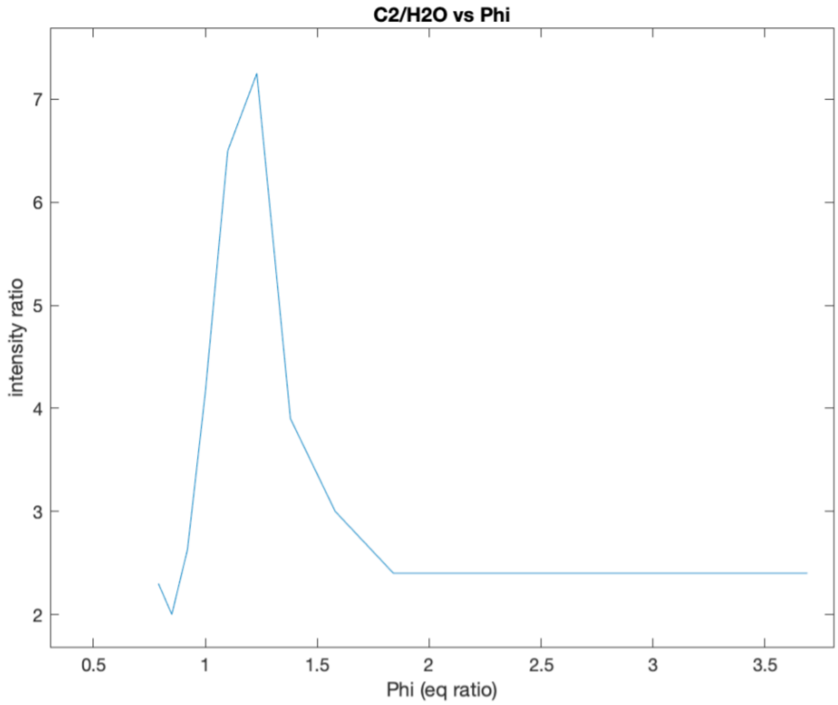
C_2/OH = 6000/6000 = 1

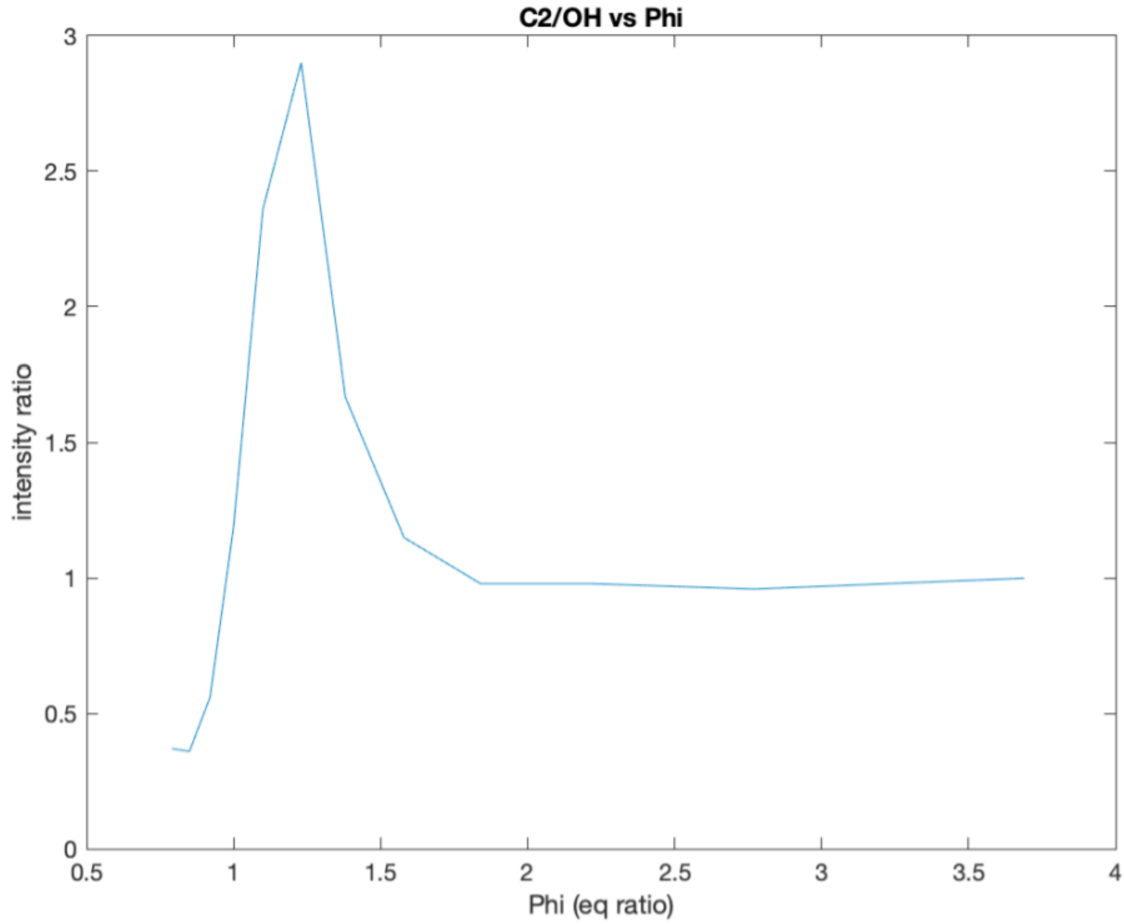
H_2O/OH = 2500/6000 = 0.41

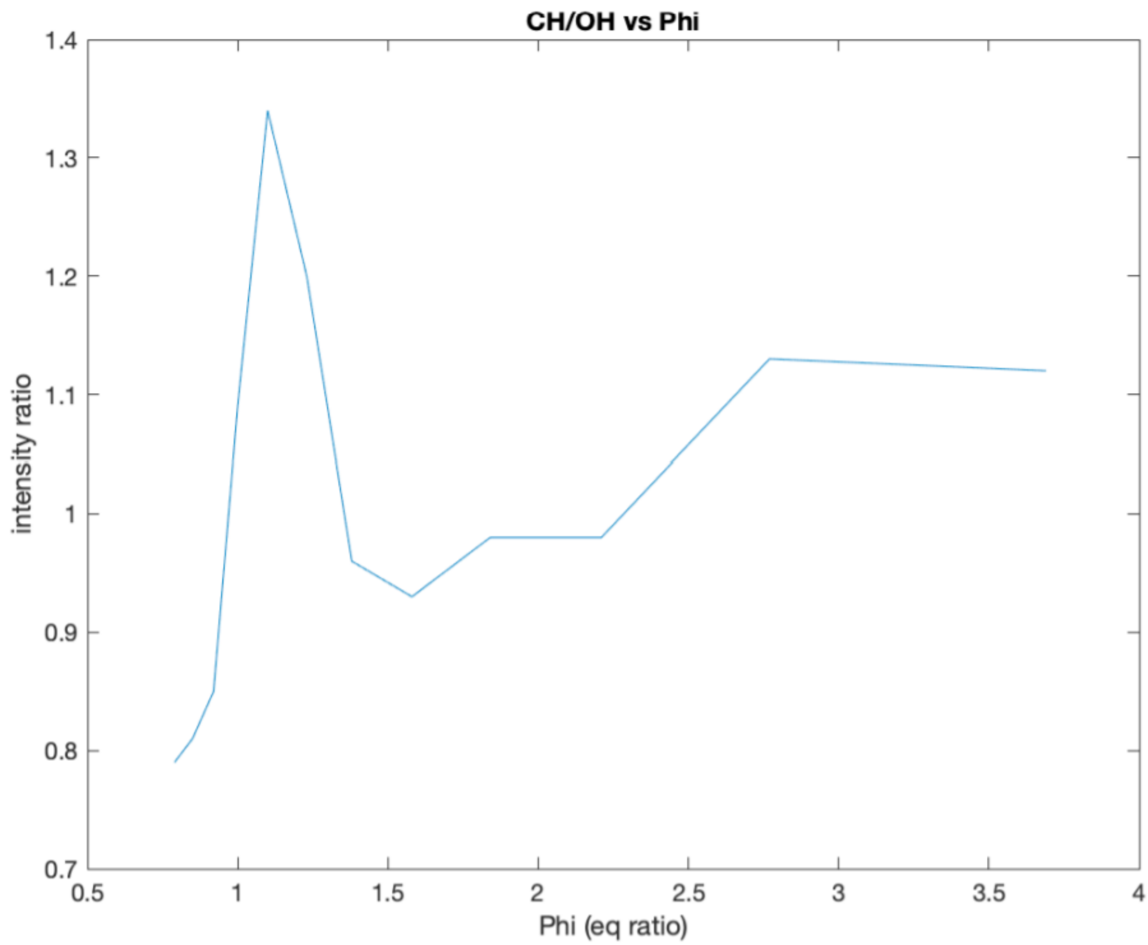
CH/OH = 6400/6000 = 1.12
H_2O/CH = 0.37

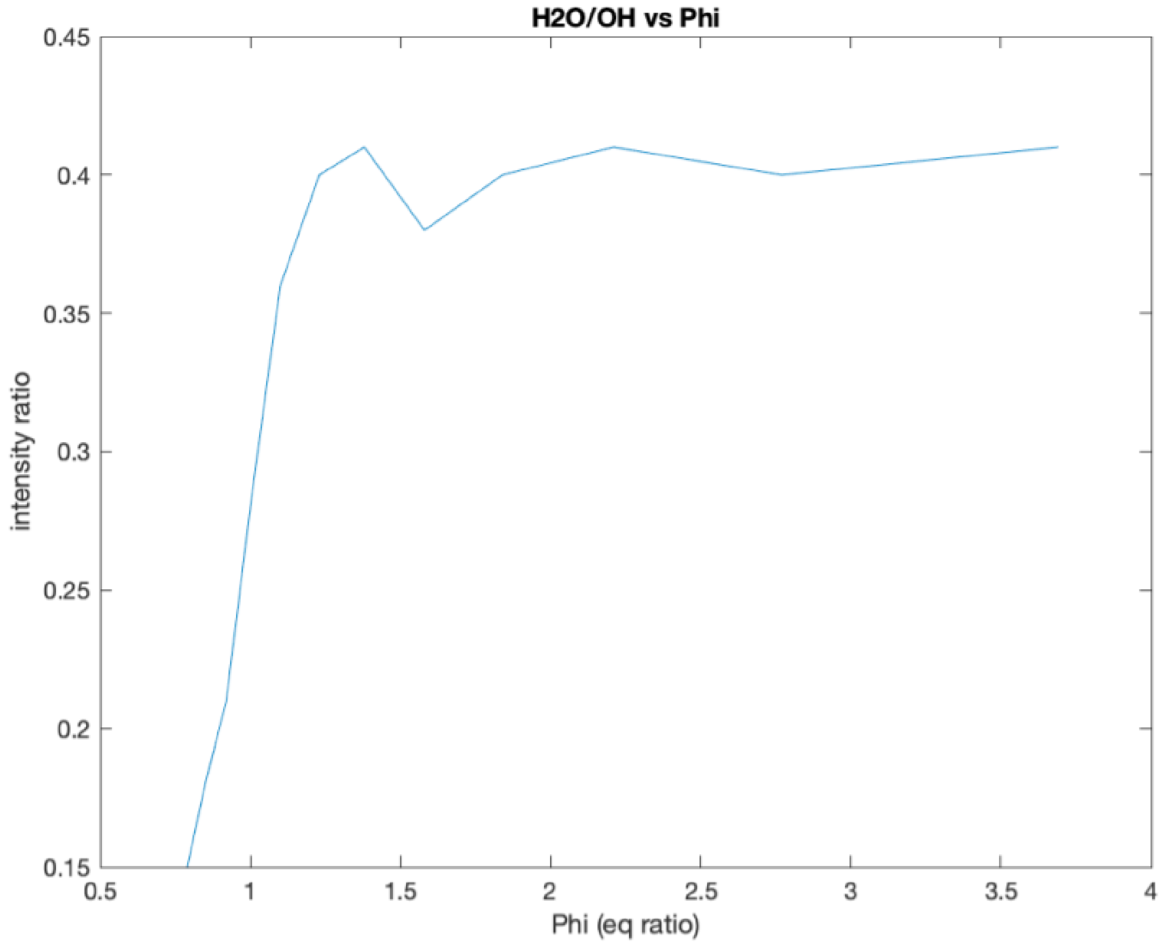
In a similar manner we can calculate for other figures as well.

ϕ (Equv Ratio)	C_2/CH	C_2/H_2O	H_2O/CH	C_2/OH	H_2O/OH	CH/OH
3.69	0.88	2.4	0.37	1	0.41	1.12
2.77	0.92	2.4	0.38	0.96	0.40	1.13
2.21	1	2.4	0.41	0.98	0.41	0.98
1.84	1	2.4	0.41	0.98	0.40	0.98
1.58	1.22	3	0.41	1.15	0.38	0.93
1.38	1.7	3.9	0.42	1.67	0.41	0.96
1.23	2.41	7.25	0.33	2.9	0.4	1.2
1.10	1.82	6.5	0.27	2.36	0.36	1.34
1	1.08	4.16	0.26	1.19	0.28	1.09
0.92	0.65	2.63	0.24	0.36	0.21	0.85
0.85	0.44	2	0.22	0.36	0.18	0.81
0.79	0.46	2.3	0.19	0.37	0.15	0.79

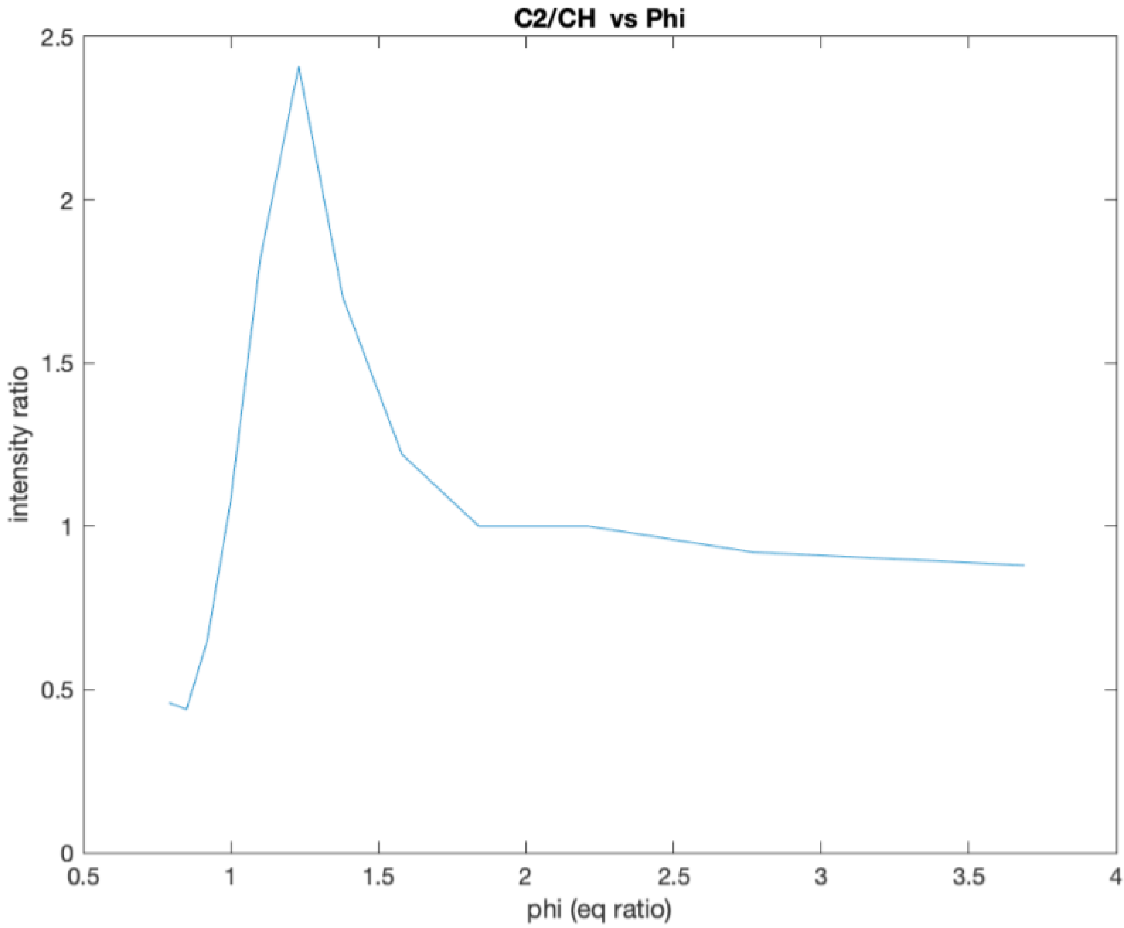



C2/OH vs Phi
intensity ratio
Phi (eq ratio)
0
0.5
1
1.5
2
2.5
3
0.5
1
1.5
2
2.5
3
3.5
4

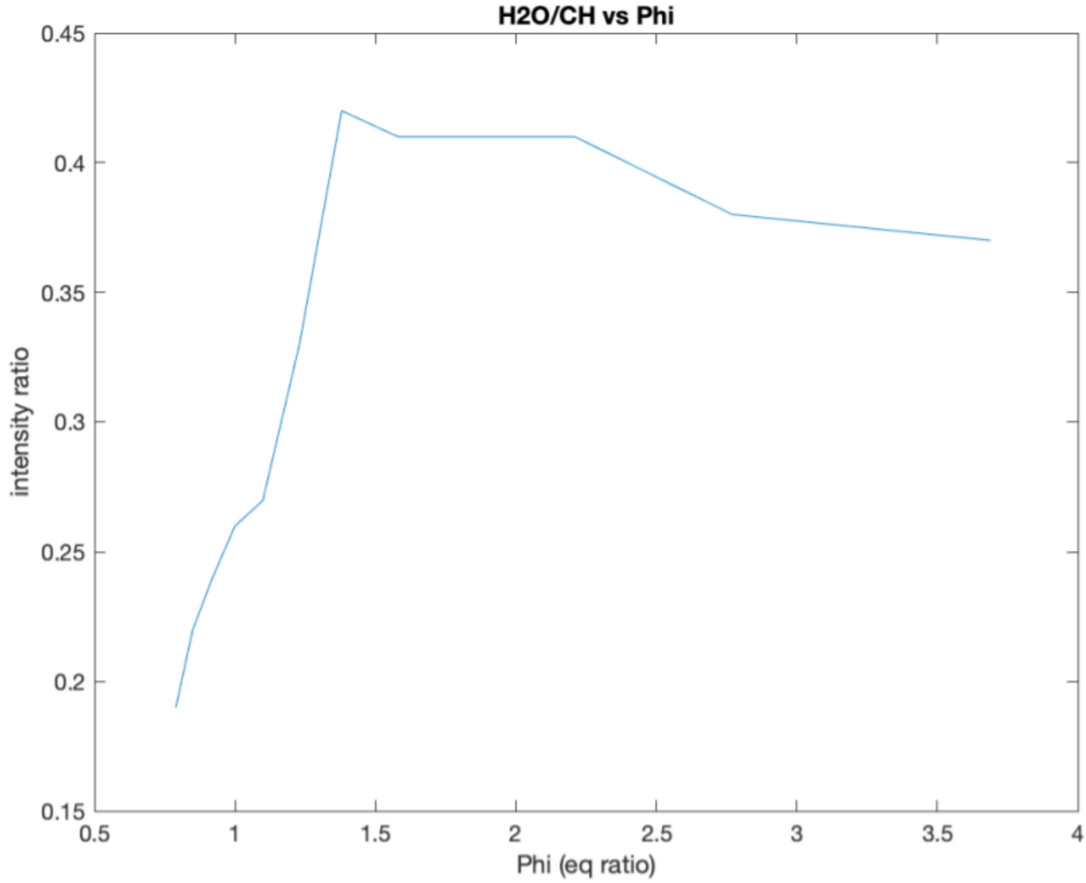

CH/OH vs Phi
intensity ratio
Phi (eq ratio)
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
0.5
1
1.5
2
2.5
3
3.5
4



H2O/OH vs Phi
intensity ratio
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.5
1
1.5
2
2.5
3
3.5
4
Phi (eq ratio)



C2/CH vs Phi
intensity ratio
2.5
2
1.5
1
0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
phi (eq ratio)



5) the adiabatic flame temperature at an equivalence ratio (0.95).

For ϕ = 0.95:

0.95 * [0.44 C_3H_8 + 0.54 C_4H_{10} + 0.007 C_2H_6] + 4.37* [O_2 + 3.76 N_2]
= 3.31 CO_2 + 4.25 H_2O + 16.43 N_2

$H_{Products} = \Sigma \dot{m}_i C_{p,i} (T_f - 298)$ T_f → Flame Temperature , i → product species

Molecular formula	Average Specific Heat Value
O2	52.24 KJ/Kg-Mol
N2	51.26 KJ/Kg-Mol
CO2	78.80 KJ/Kg-Mol
H2O	65.80 KJ/Kg-Mol

In an Adiabatic Combustion:

$H_{Reactants}$ + CV (Calorific Value of Fuel) = $H_{Products}$

$H_{reactants}$ are often negligible so, CV ≈ $H_{products}$

So CV = $\Sigma n_i C_{p,i} (T_f - 298)$ n_i → mole fraction ratio of the balanced equation, T_f → adiabatic flame temperature

$46.1*10^3 = (3.31 * 44.01 * 78.80 + 4.25 * 18 * 65.80 + 16.43 * 28 * 51.26)*(1/0.95 * 0.44 * 44.1 + 0.95 * 0.54 * 58.12 + 0.95 * 0.007 * 30.07)*(T_f - 298)$

T_f = 353.706K ans.

Sources of Error:

1. Turn on the compressor, and then the LPG cylinder. LPG cylinder knob should be completely turned on to avoid pressure losses in the feed line.
2. To avoid spilling gas (LPG), ignite the burner and then set the required flow rate in the rotameters.
3. While turning on the LASER, make sure that the fan is turned on, then turn on the key and switch on the LASER. Turn off the laser similarly.
4. While moving the traverse, don't touch the thermocouple, as it is the most delicate part of the experimental setup.
5. Turn off the LPG cylinder first, and then the compressor.

- **Conclusion :**
    1. *In the 2D temperature profile, the maximum temperature occurs approximately at centre*
    2. From the Temperature Vs Phi plot, we can conclude that *at the equivalence of 1 Maximum temperature is obtained*
    3. *From the Spectrometer Graph, we can decide how much incomplete combustion had taken place according to the equivalence ratio.*
    4.
- **Reference:**
    - Pictures from Google, Lectures and Lecture Notes of AE351 (Lab6)

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