


Ahlem GHABI

25 years old
PhD student at the university of Orleans, France

 ahlem.ghabi@cnsr-orleans.fr

 +33675398291

- Energy Engineering - at the National School of Engineering Monastir, Tunisia.



- Master of Research in Energy, Fluid and Environment – University of Rouen, France.



- PhD on plasma assisted combustion – CNRS/University of Orleans, France.



Effects of pulsed gliding arc plasma on non-premixed CH₄/CO₂-Air flame stability



Authors:

Ahlem Ghabi, Thibault Darny, Stéphane Dozias, Eric Robert, Pablo Escot Bocanegra, Toufik Boushaki



Planning



Introduction



Experimental setup



Results



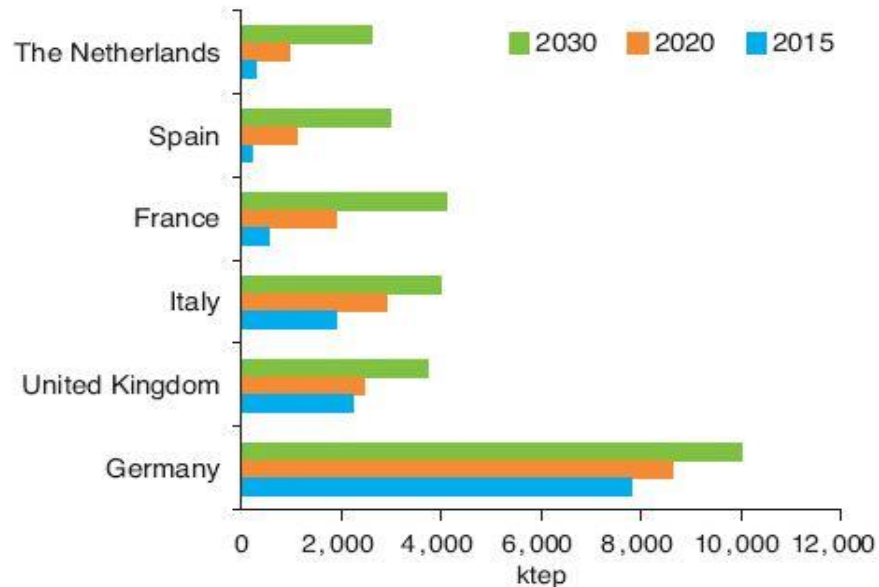
Conclusion and prospects

Context

Biogas: CH₄ (50-80%.vol); CO₂ (20-45%.vol) et N₂, O₂, H₂S et de NH₃ (<5%.vol).

Typical composition of dried raw biogas (from [Moletta 2015])

Unit Type	Agricultural	Wastewater treatment plant	Disclaimer (ISDND)	Industrial effluents	Household waste
CH ₄ (%)	50-60	60-70	35-65	60-80	64
CO ₂ (%)	40-50	30-40	15-50	20-40	35
Dinitrogen	?	0-0.2	5-40	0	1
Dioxygen (%)	0	0	0-5	0	0
H ₂ S (%)	0-0.001	0-0.4	0-0.003	0-2	?
Others (%)	0-0.01	0-0.01	0-0.01	0-0.01	0-0.01



Source: IFPEN

Biogas development potential in Europe by 2030



Variability of the biogas mixture leads to

- Combustion instabilities
- Modification of the lift-off heights
- Increase of the pollutant emissions

■ The aim of our study

Investigate the effect of a pulsed gliding arc plasma (PGA) for the active control of a swirling biogas flame.

Gas + electrical discharge

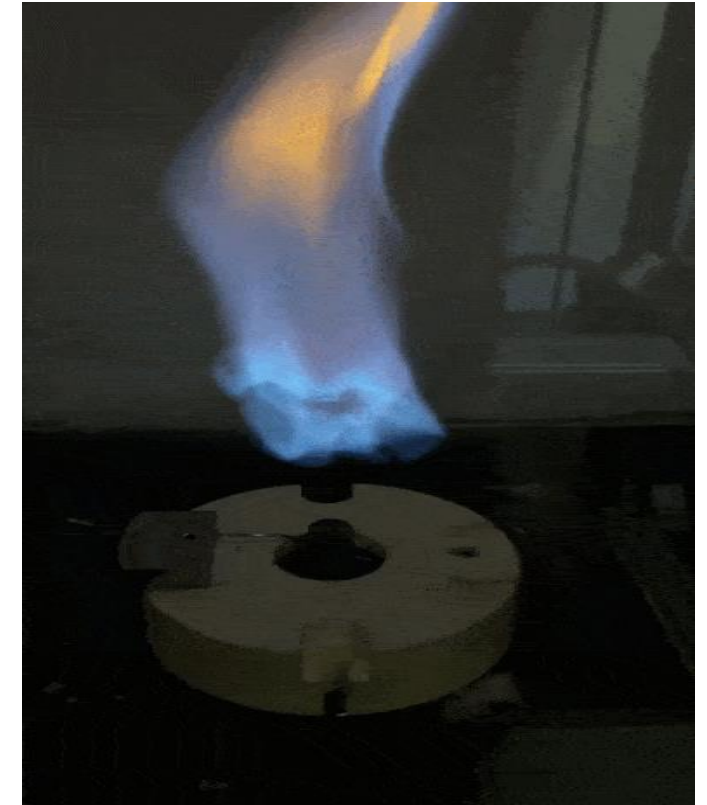


Plasma

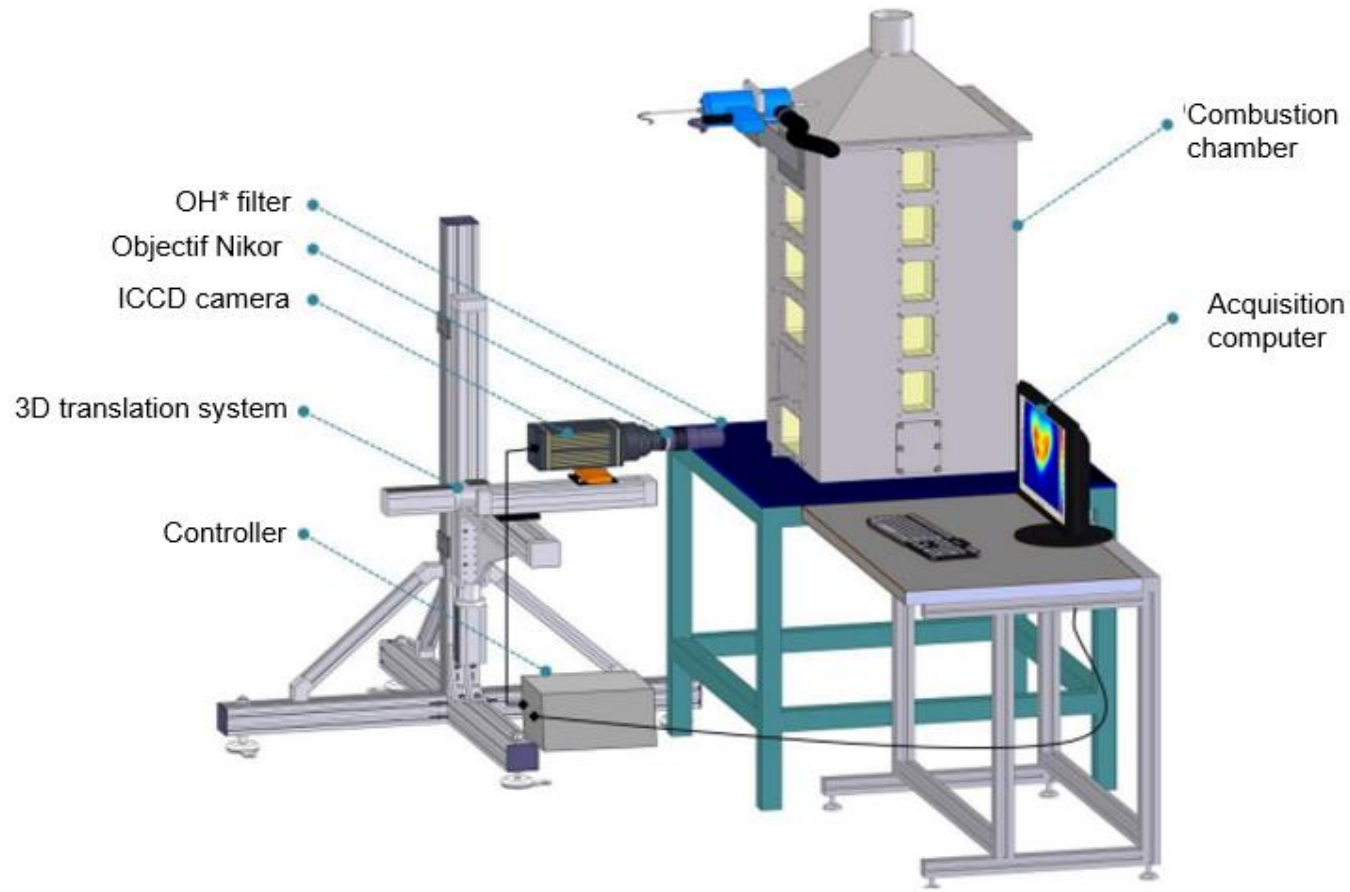


Reactive species
(radicals and excited molecules)/ **Heat**

- Increase lean burn flame stability.
- Reduce pollutant emissions.



Combustion chamber and measurement devices



Measurements and analysis of flue gases

- Concentrations of NO_x , CO , CO_2 , O_2 and SO_2 in flue gases are measured.
- HORIBA PG250 multi-gas analyzer

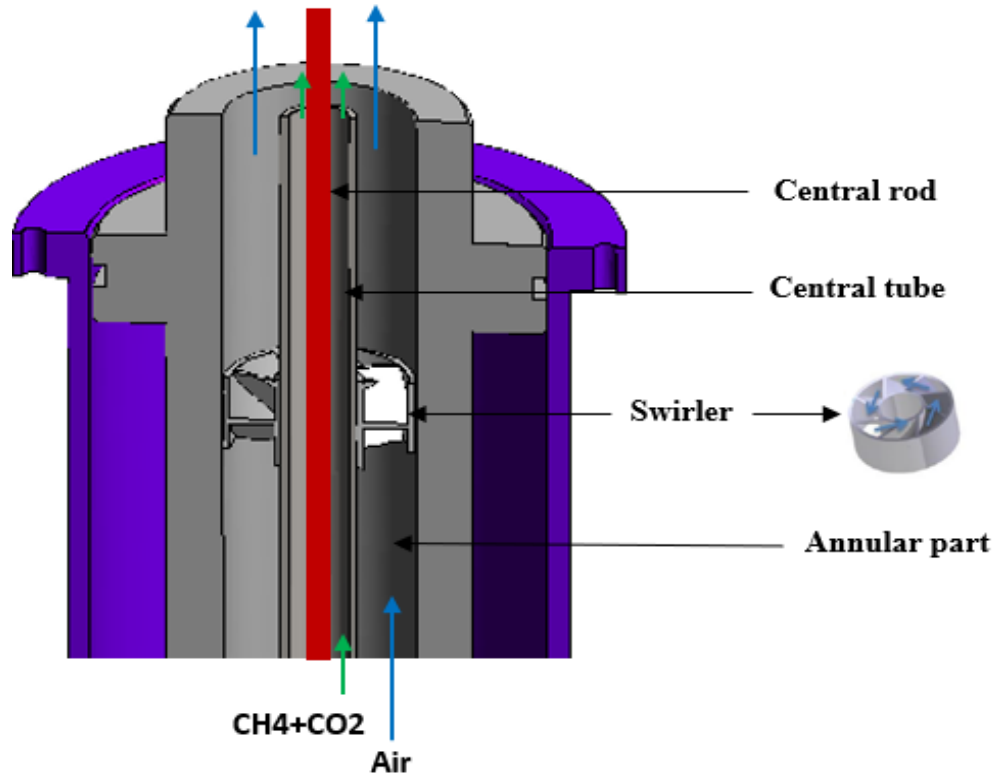
OH* chemiluminescence technique

- Apparatus : ICCD camera, a 105 mm UV lens, a $325\pm 55\text{nm}$ band-pass filter, an acquisition card with a computer.
- Visualization of flame front stability, lift-off heights and flame lengths.

Optical emission spectra

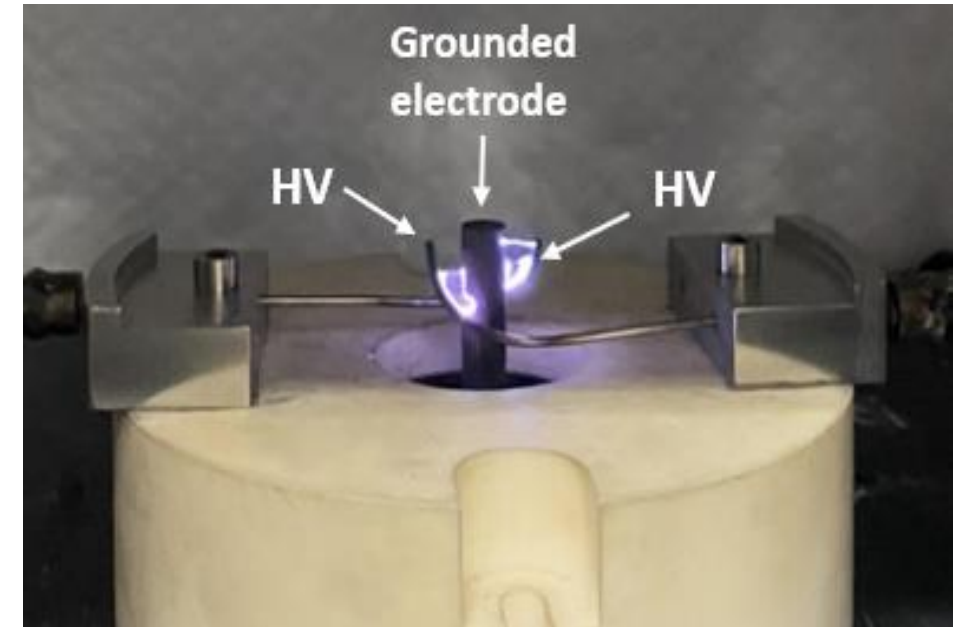
- Ocean FX-XR1, with a wavelength range of 200-1025 nm.

■ Burner schematic representation



- 2 concentric tubes with a swirler in the annular part and a central metal rod used as a cathode for the plasma.

■ Plasma configuration



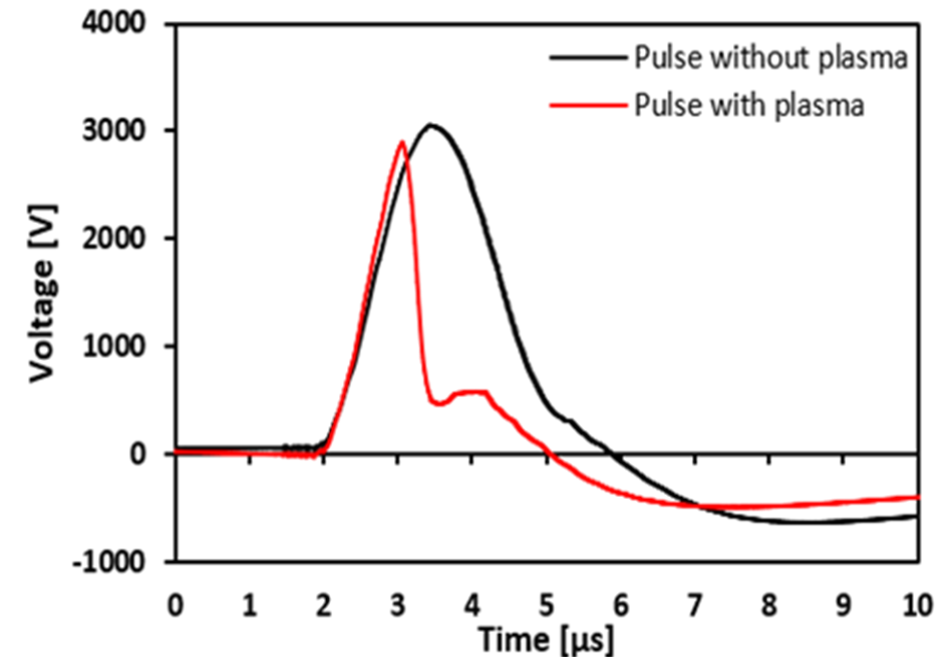
- The PGA plasma is generated between the grounded center rod of the burner (cathode), and two other high voltage (HV) electrodes symmetrically placed around the central rod.

■ Operating conditions

- Operating conditions: % of CO₂ in the fuel mixture, flow rates of CO₂, CH₄ and air, bulk velocity of the fuel (CO₂+CH₄) and air, swirl number and flame power.

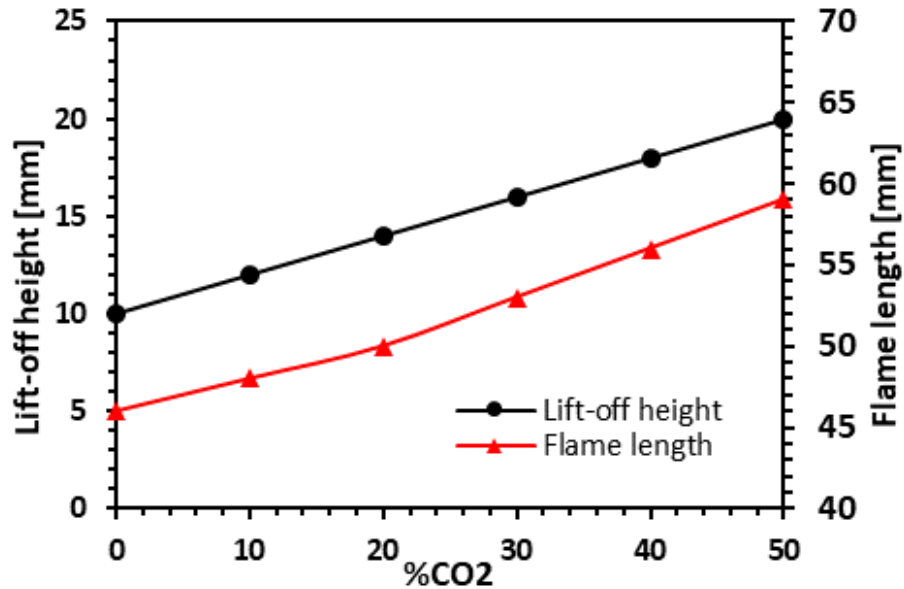
CO ₂ percentage in the fuel mixture	Air flow rate [NL/min]	CH ₄ flow rate [NL/min]	CO ₂ flow rate [NL/min]	V _{Fuel} [m/s]	V _{Air} [m/s]	Equivalence ratio ϕ	Swirl number	Flame power [kW]
0%	100	4	0	0.84	1.75	0.4	SN0.8	2.5
10%			0.5	0.94				
20%			1	1.05				
30%			1.7	1.21				
40%			2.4	1.41				
50%			4	1.70				

Temporal evolution of the HV pulse without (black line) and with (red line) plasma activation.



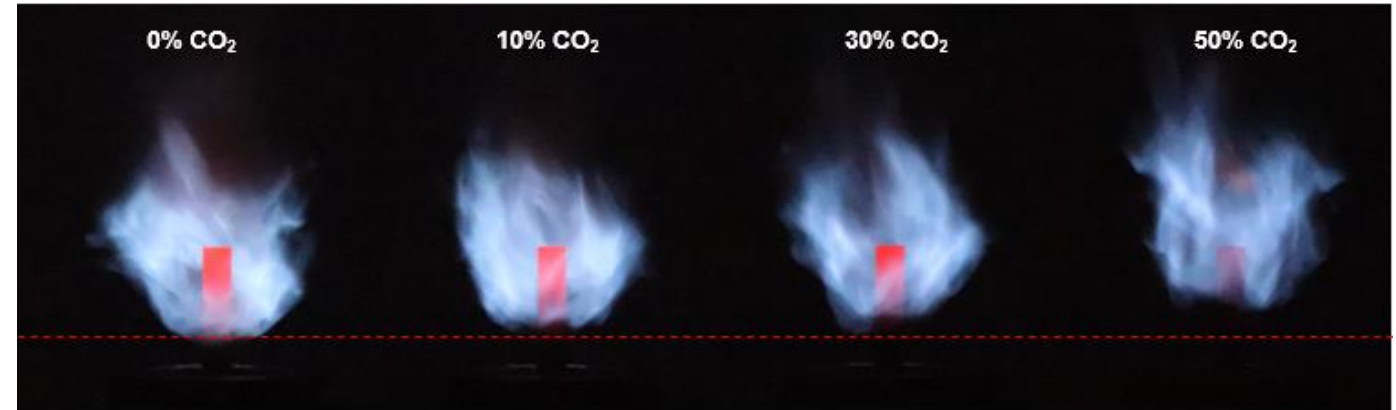
- The applied voltage is measured at between 3 and 3,5 ± 350 V.
- Pulse frequency fixed at 10kHz.

Effects of CO₂ addition to the fuel

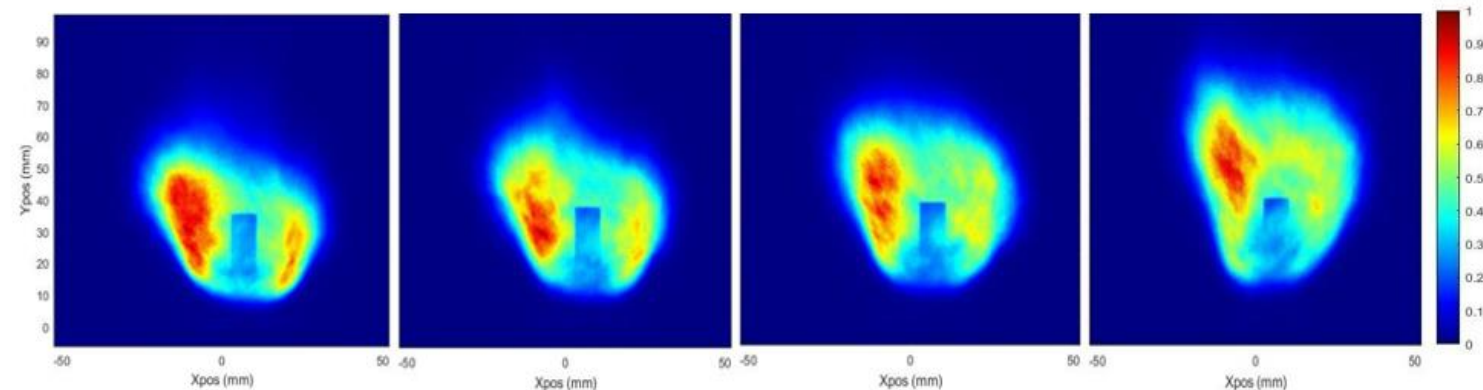


- $L_f \nearrow$ with the addition of CO₂ to the fuel due to the decrease of flame burning velocity and flame temperature which disadvantages the flame stabilization.

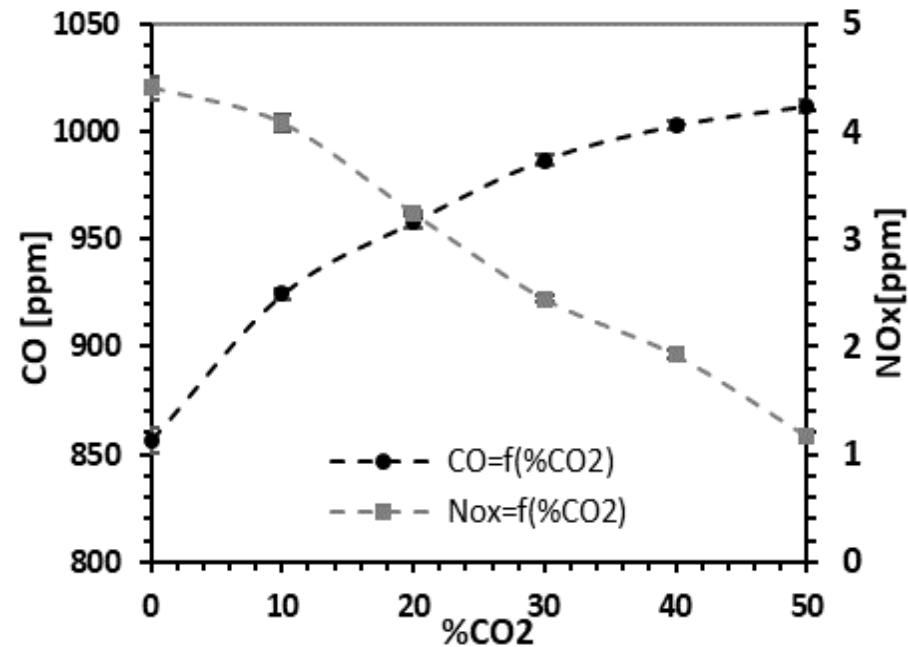
Direct photographs of flame, $\phi=0.4$, $Sn=0.8$



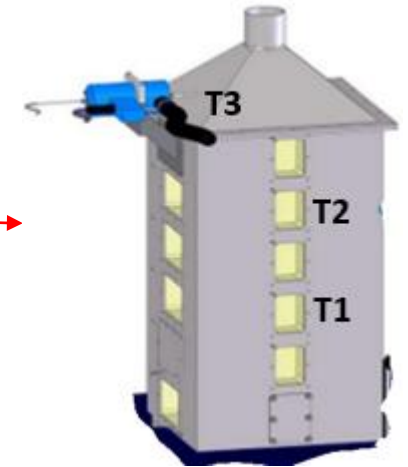
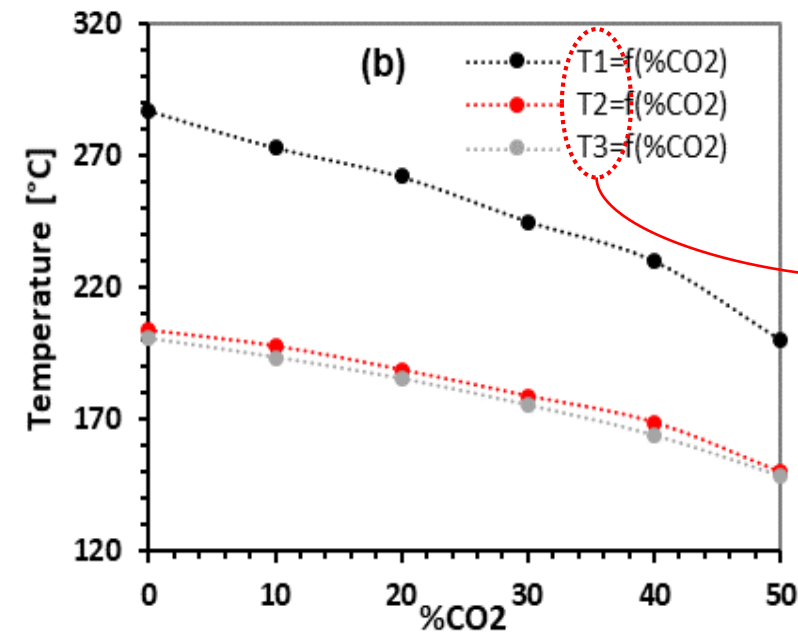
Average images of OH* chemiluminescence



NO_x and CO emissions = f (%CO₂)



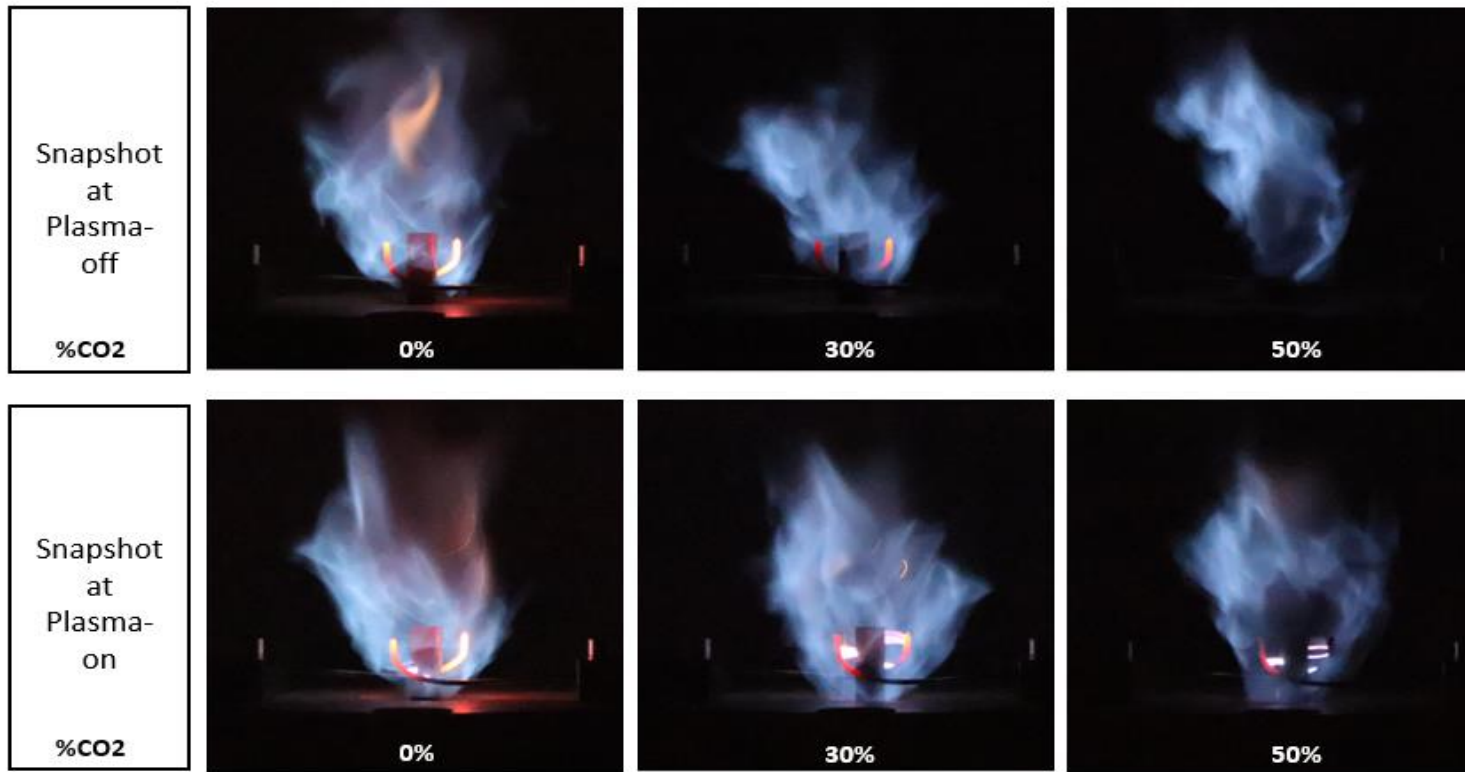
Flue gases temperature (at 3 different positions in the combustion chamber) = f (%CO₂)



- Increasing 50% of CO₂ in the fuel increases CO to 18% in flue gases → Due to thermal dissociation of CO₂ in the high-temperature regions of the flame.
- Low concentration of NO_x in both cases without and with addition of CO₂.
- Addition of 50% of CO₂ to the fuel decreases the temperature T1 by 22% → Due to thermal and radiative properties of CO₂.

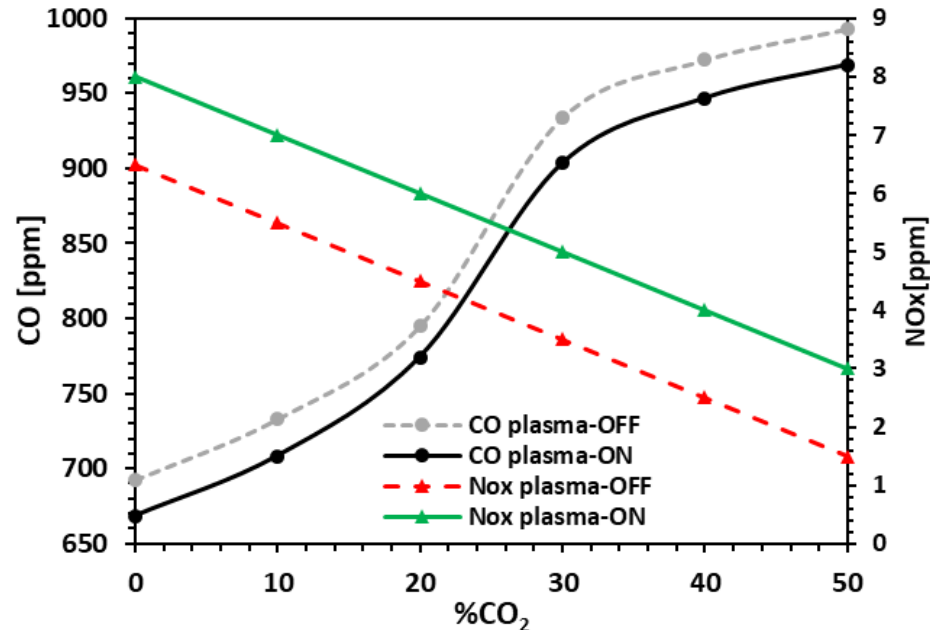
■ Combustion assisted by PGA plasma

Direct photographs (1/100s exposure time) of the flame in the case of plasma-OFF and plasma-ON (f=10kHz) with different percentage of CO₂ addition to the fuel (0%, 30% and 50%).



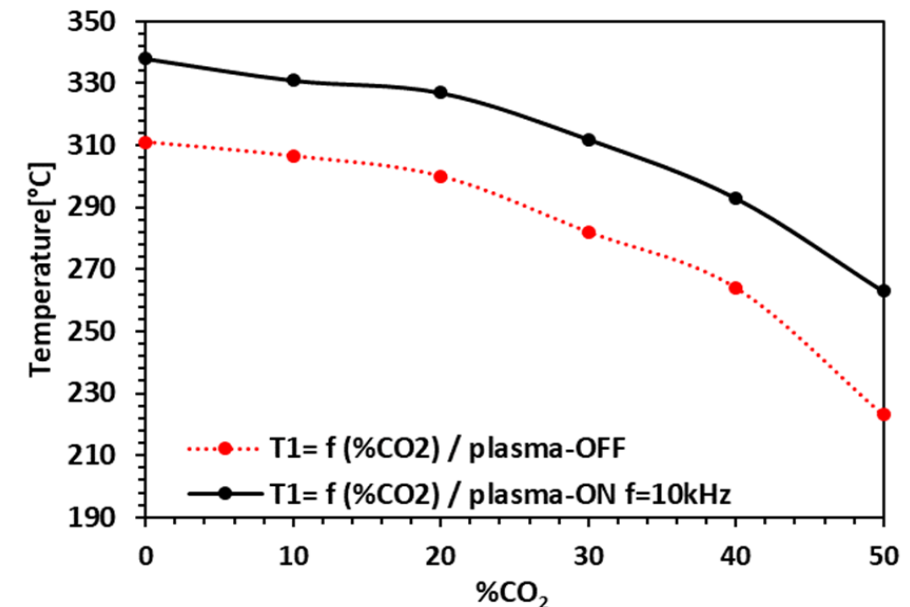
- With the presence of PGA plasma, the lift-off height decreases, by nearly a half time the initial one without plasma.

Effect of PGA plasma on NO_x and CO emissions at different CO₂ addition percentages



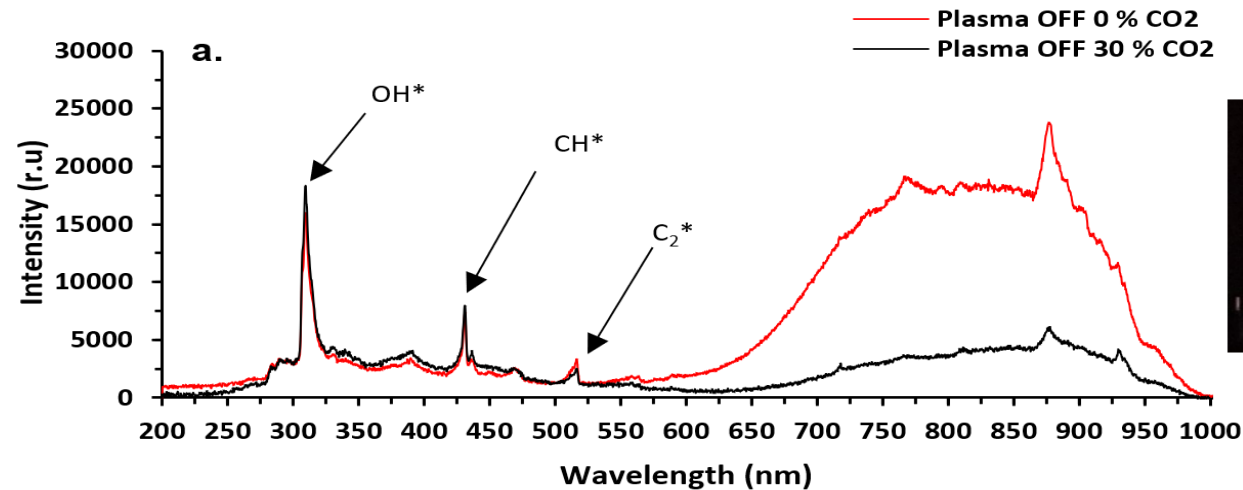
- Slight decrease of CO emissions with plasma → The enhance in conversion of CO to CO₂ with plasma.
- Low concentration of NO_x that remains almost same in both cases plasma-ON and Plasma-OFF.

Effects of PGA plasma on combustion gas temperature (T1) in the case plasma-OFF and plasma-ON



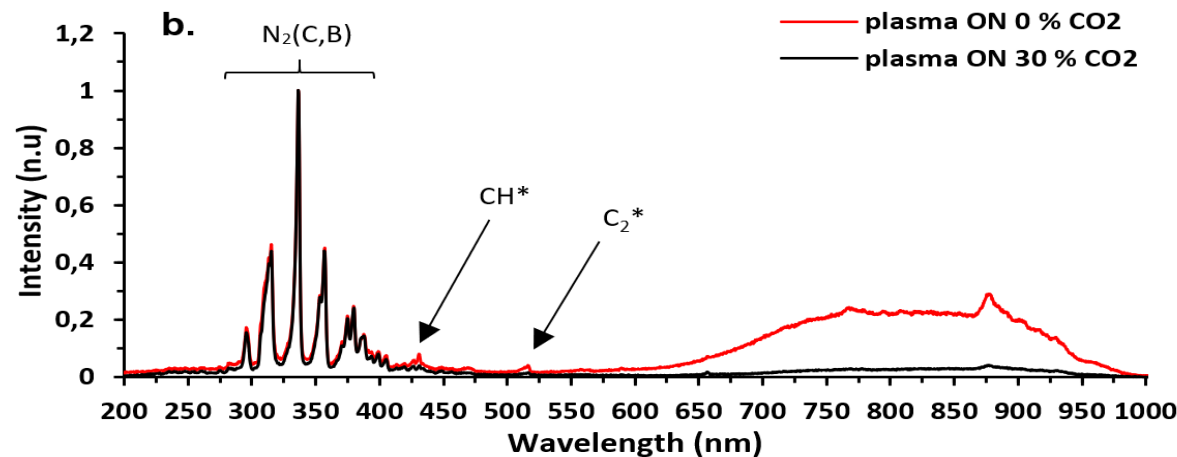
- Plasma activation (at f=10kHz) increases the temperature T1 by nearly 12%.

Emission spectra of (a.) CH₄-Air and CH₄/CO₂-Air flames and (b.) plasma-flames.



Plasma-OFF

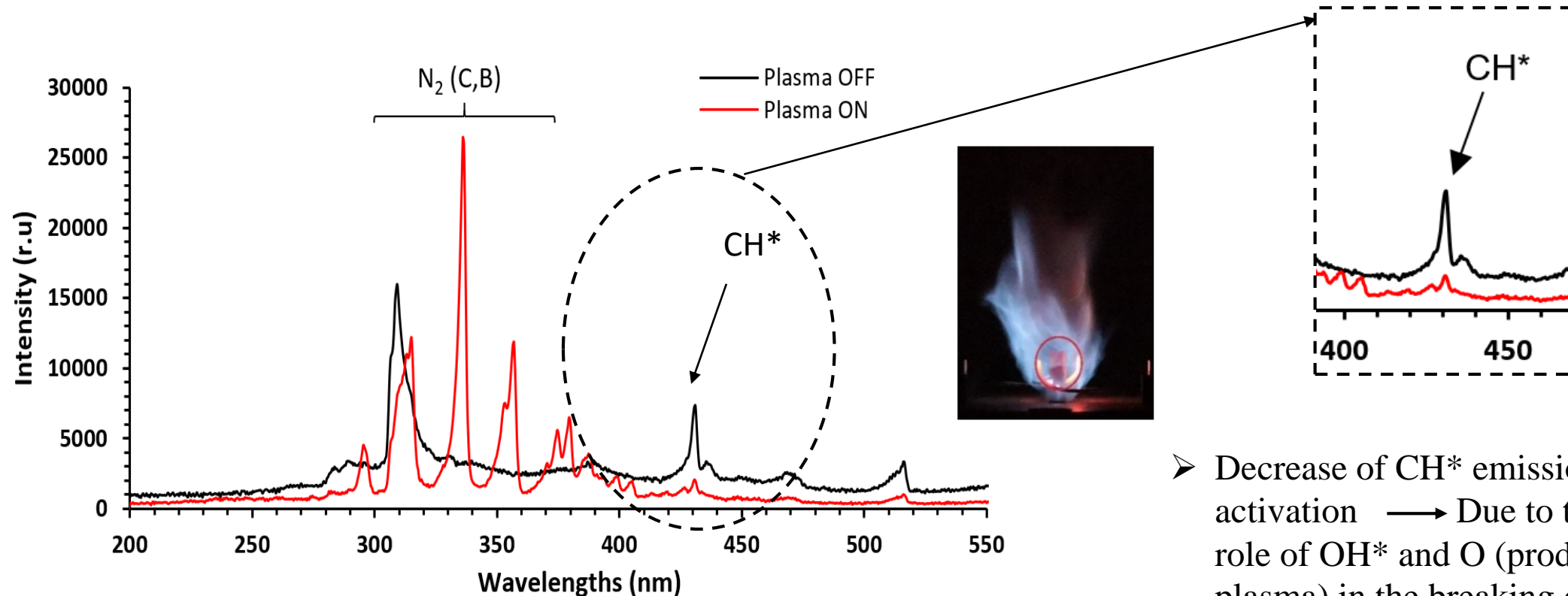
- More intense OH* (308,9 nm) and CH (431,3 nm) emissions with CO₂ addition.



Plasma-ON

- O (dissociation of O₂ with the excited N₂) is hid by the continuum of emission.
- the CO₂ addition leads to a decrease of the CH emission at 431.3 nm (by a factor 2.5).

Emission spectra of a CH₄-Air flame with and without plasma



- Decrease of CH* emission with plasma activation → Due to the important role of OH* and O (produced by plasma) in the breaking of C-H bond.

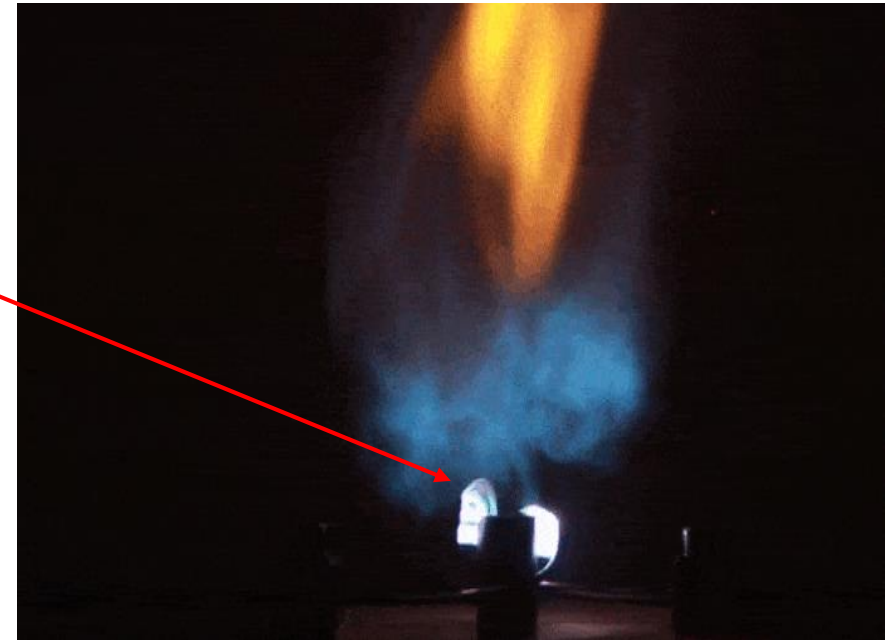
➡ **Combustion enhancement**

Conclusion

- The addition of CO₂ to the fuel leads to an increase of CO and a slight decrease of NO_x, with a reduction of combustion gases temperature.
- PGA plasma plays a role to stabilize the flame, the lift-off heights of the flames decrease with the presence of PGA plasma (due to the N₂* production).
- PGA plasma decreases CO (about 3%) production.
- NO_x concentration remains almost same in both cases with and without plasma.

Prospects

- Other cases of flame and plasma configurations will be investigated
- Interaction between flame and plasma
- Temperature measurements in the flame with and without plasma.
- Flow velocity with and without plasma (PIV; LDA)
- Plasma temperatures (rotational and vibrational)



Thank you for your attention!

Any questions?

Email Address: ahlem.ghabi@cnrs-orleans.fr

Appendix: pulsed gliding arc plasma

impulse power supply



Adjustable parameters: Frequency and voltage

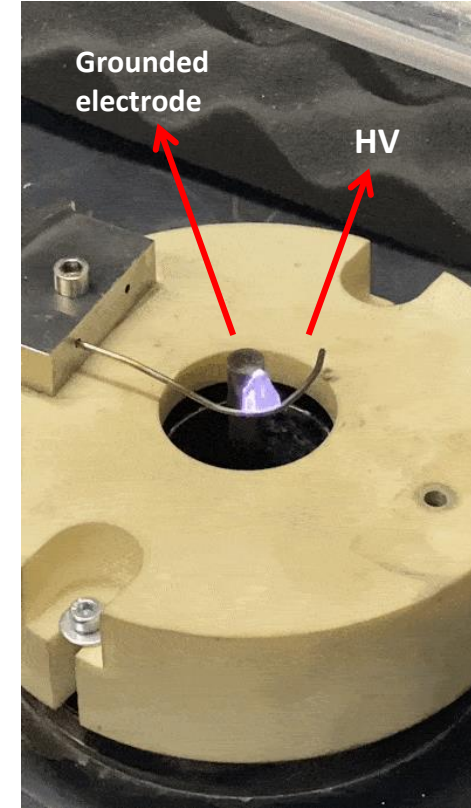
Characteristics:

Pulse duration: 2 μ s

Frequency: from 1 to 30 kHz.

Primary voltage: 0 to 350 VDC

Output voltage: 0 to 30kV



plasma is initiated in the area of minimal distance between the HV and the grounded electrode and then glided along the electrode.