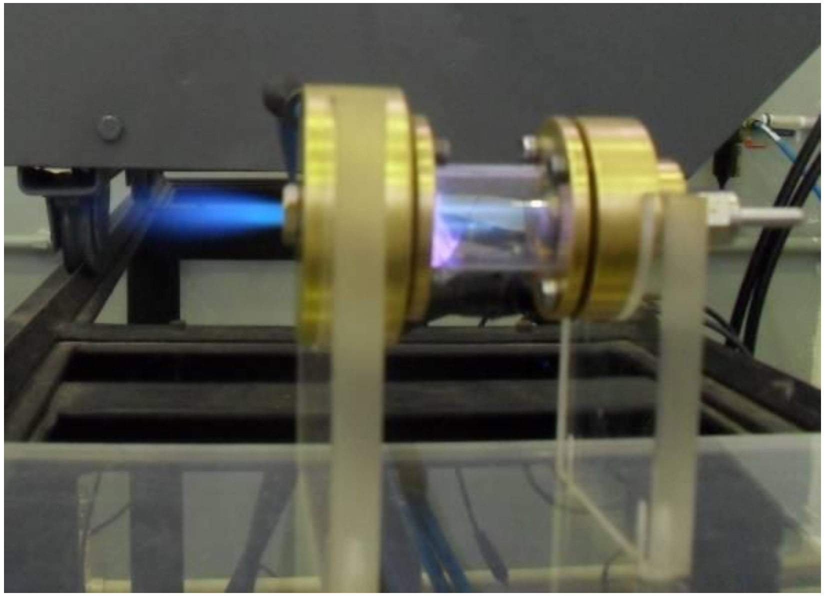
Plasma assisted combustion of natural gas using gliding arc discharge

J. C. Sagás, R. A. Varella, C. A. Martins,
H.S. Maciel, P. T. Lacava

Plasma assisted combustion

Thermal effects

- *Increased reactivity*



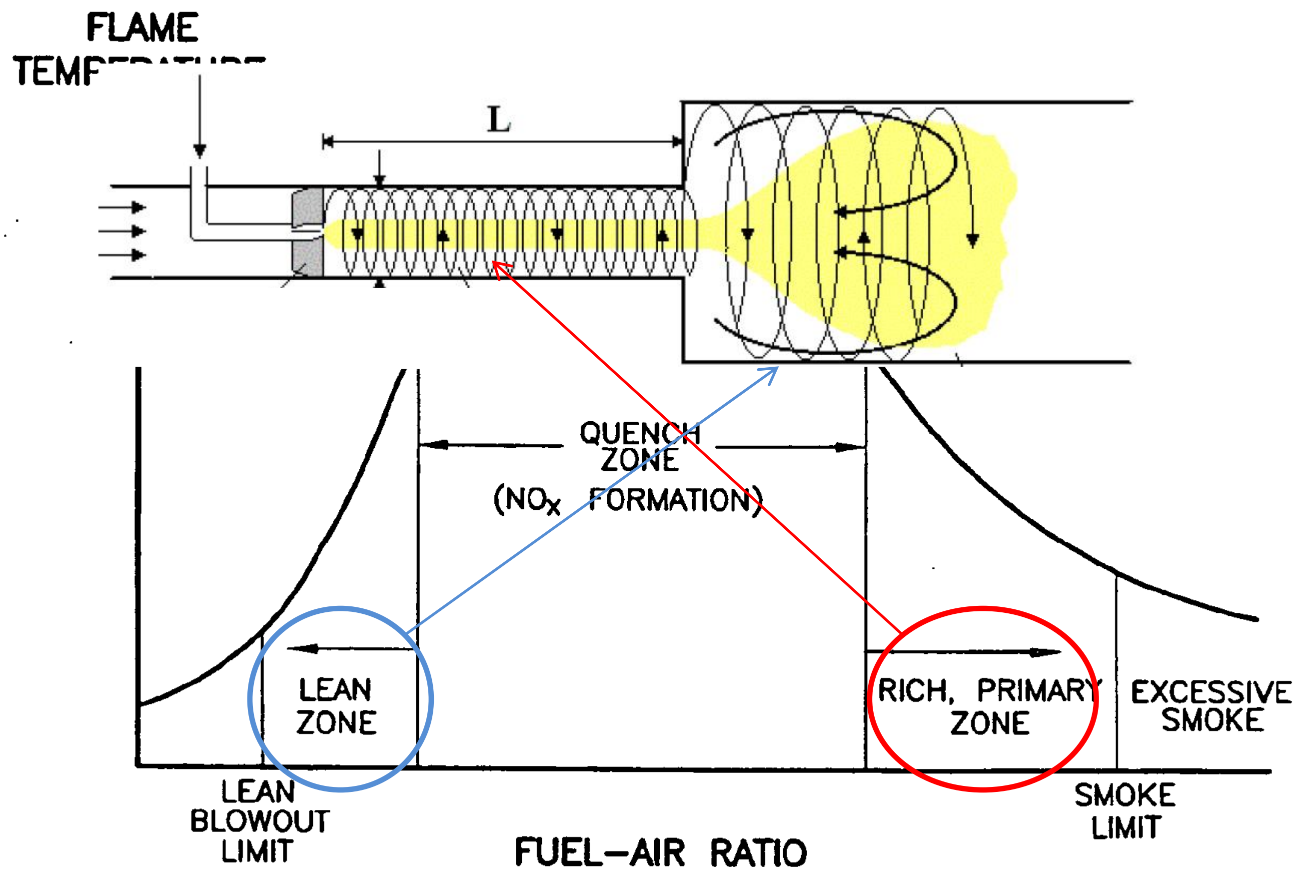
Transport properties

- *Ionic wind*

Kinetic effects

- *Radical pool generation*

Motivation



FLAME
L
QUENCH ZONE
(NOx FORMATION)
LEAN ZONE
RICH, PRIMARY ZONE
EXCESSIVE SMOKE
LEAN BLOWOUT LIMIT
FUEL–AIR RATIO
SMOKE LIMIT

Plasma in fuel-rich conditions

Increase of flammability limits

- *Soot?*

H_2 production

- *Syngas generation*

Injection of radicals in lean zone

- *Stability*

Objectives

- To analyze the effects of plasma assisted combustion in flammability limits, flame structure and hydrogen production

- To compare the pollutant emissions in conventional and plasma assisted combustion

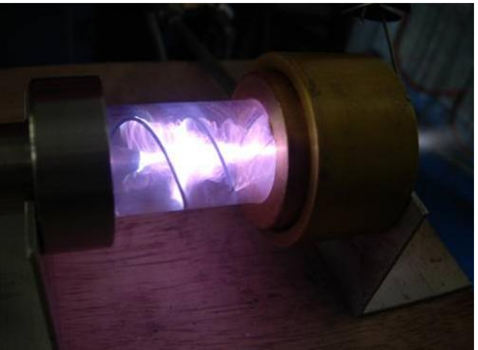
- *Plasma & Processes Laboratory*
- *Combustion, Propulsion and Energy Laboratory*

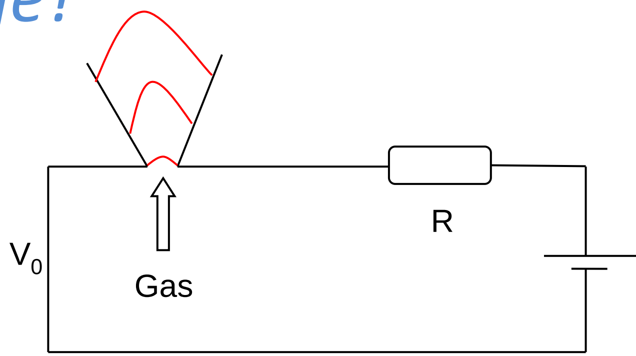
- *Laboratory of Plasmas, Films and Surfaces*

Gliding arc discharges

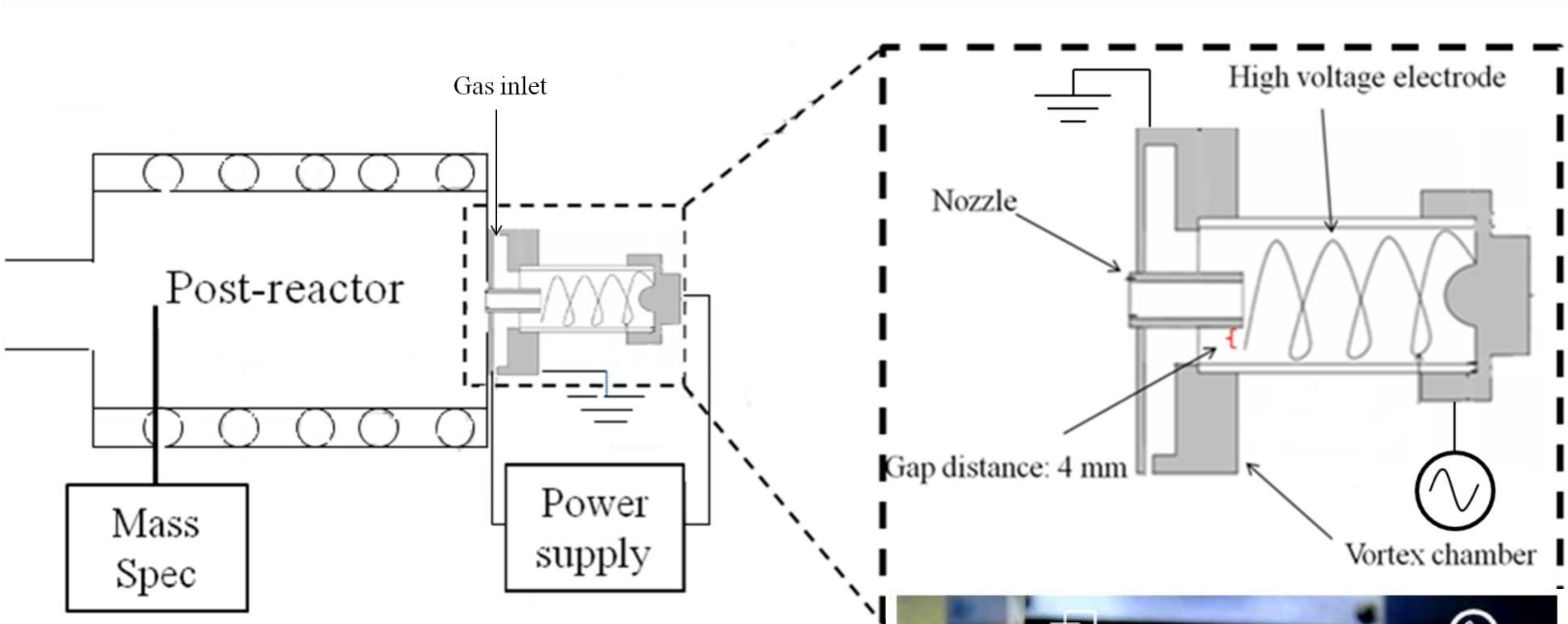
Non-steady state discharge

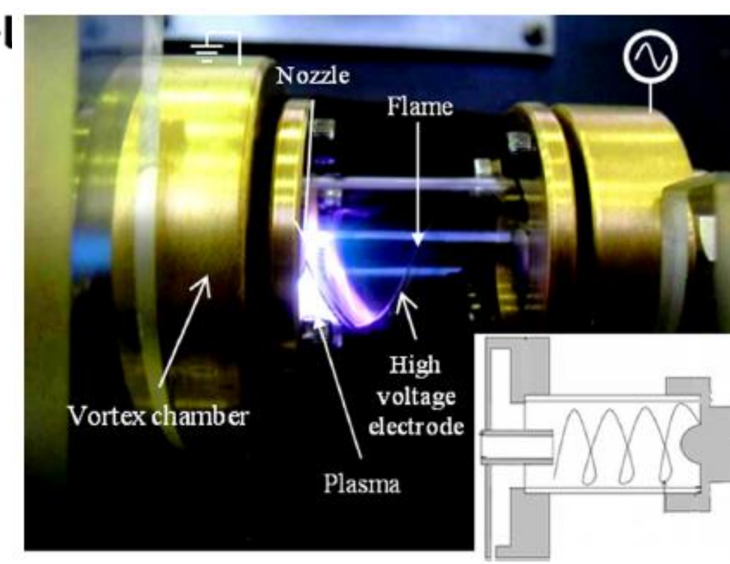
- *Divergent electrodes*
- *Breakdown occurs in the smallest gap*
- *The plasma column is pushed by the gas flow*
- *The discharge is extinguished and the discharge is restarted*
- *Thermal, non-thermal or transitional*
- *Arc or contracted glow discharge?*





Experimental setup – Part I



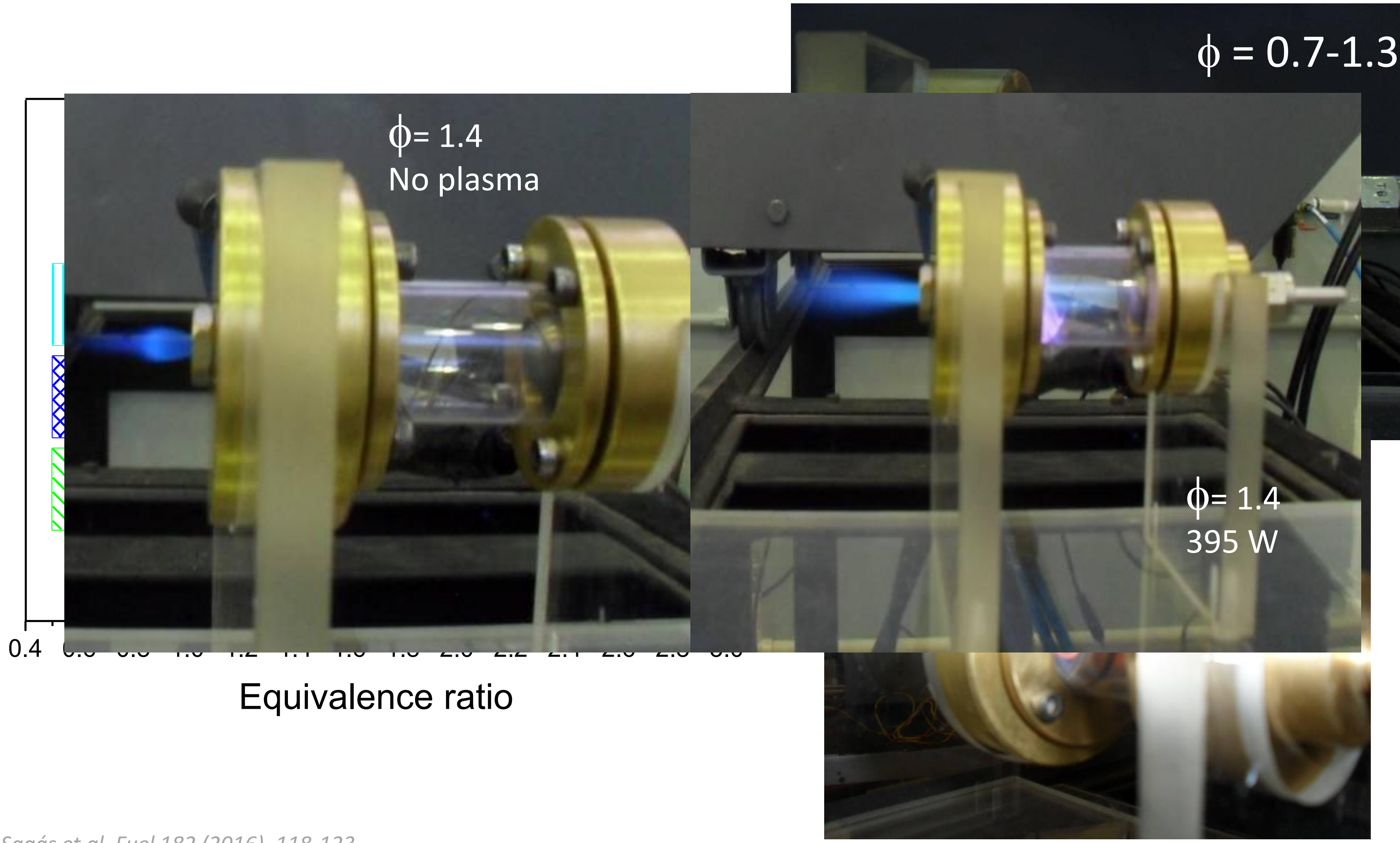


- AC power supply (60 Hz)
- Air flow rate: 0.80 g/s

$$\phi = \frac{\left(\dfrac{\dot{m}_{fuel}}{\dot{m}_{ox}}\right)}{\left(\dfrac{\dot{m}_{fuel}}{\dot{m}_{ox}}\right)_{st}}$$

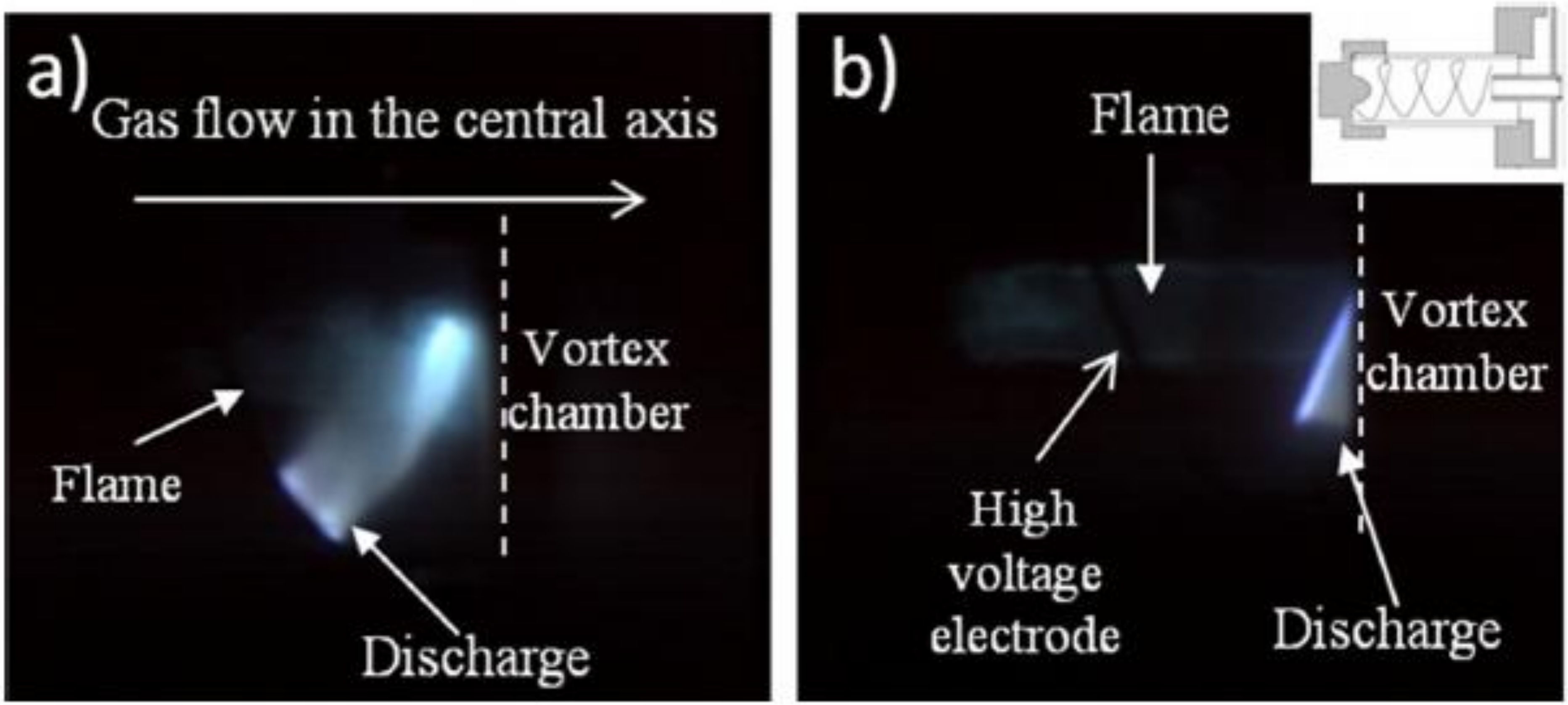
Sagás et al. Fuel 182 (2016), 118-123

Flammable range



Sagás et al. Fuel 182 (2016), 118-123

Flame structure

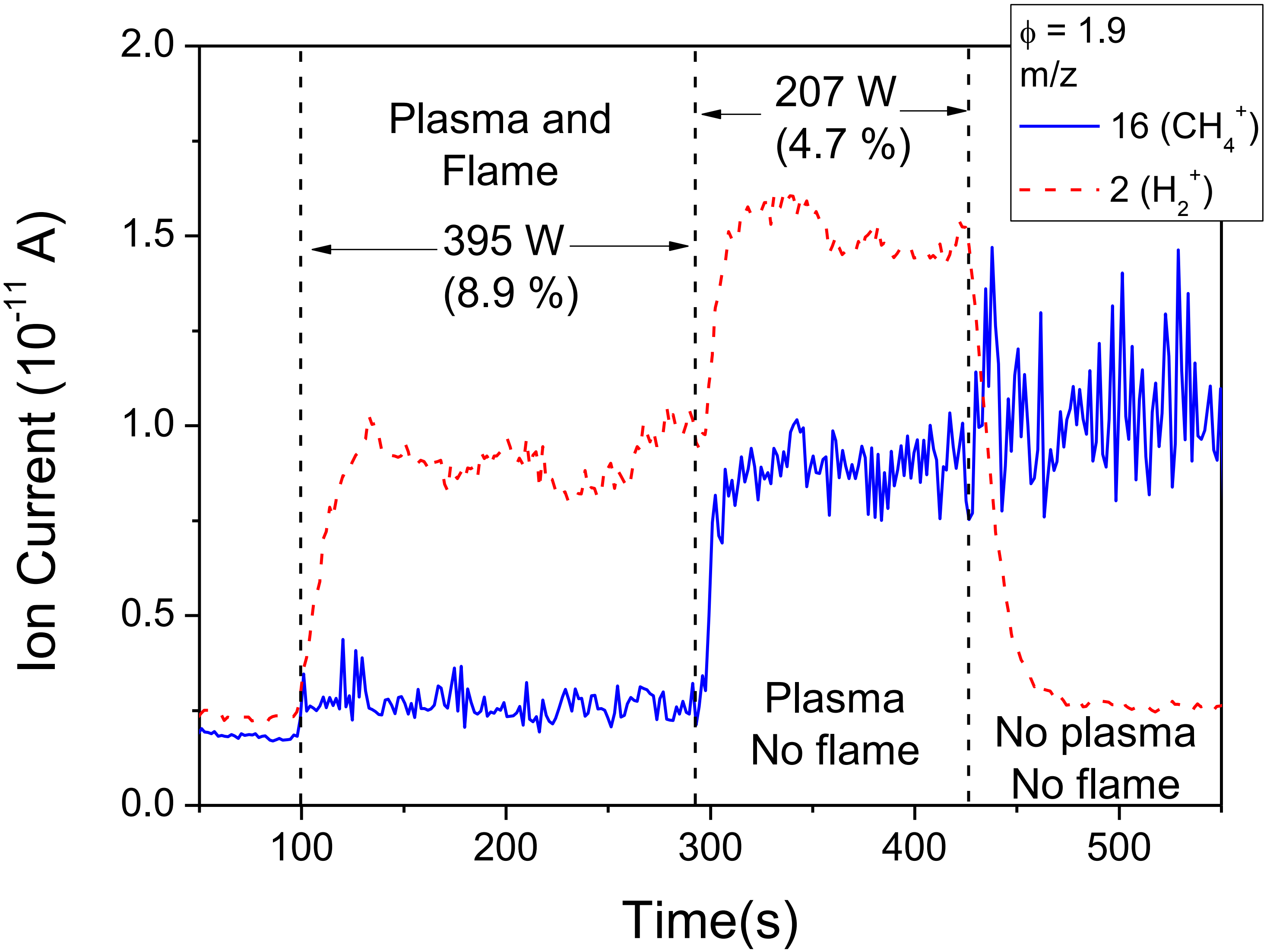


Sagás et al. Fuel 182 (2016), 118-123

High speed camera

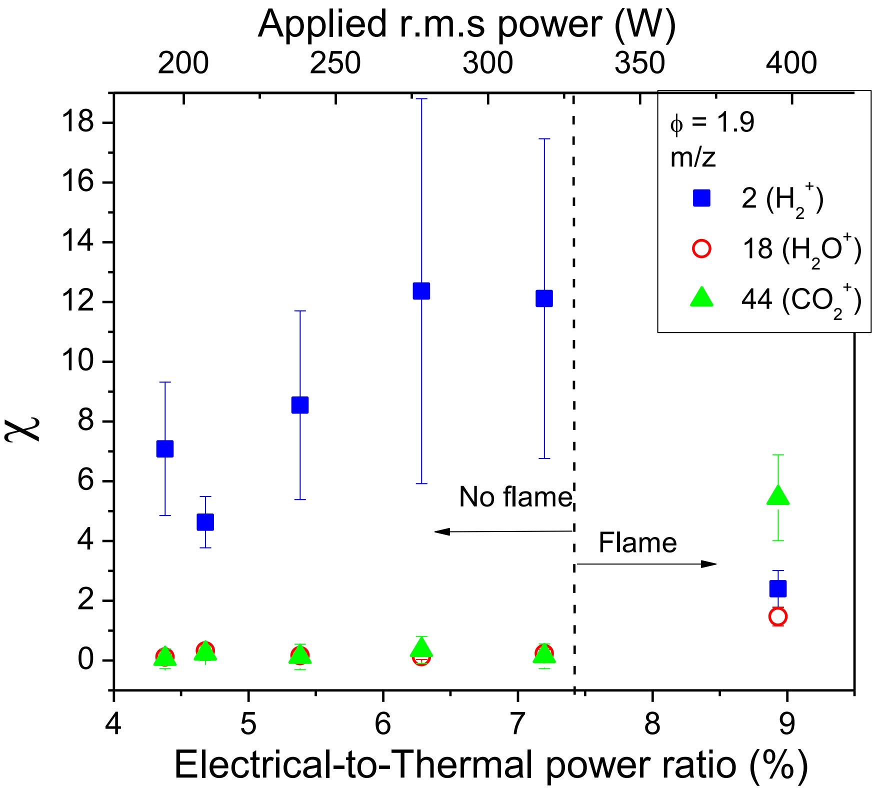
1000 *frames/s* – ϕ = 1.4 – 236 W

Mass spectrometry

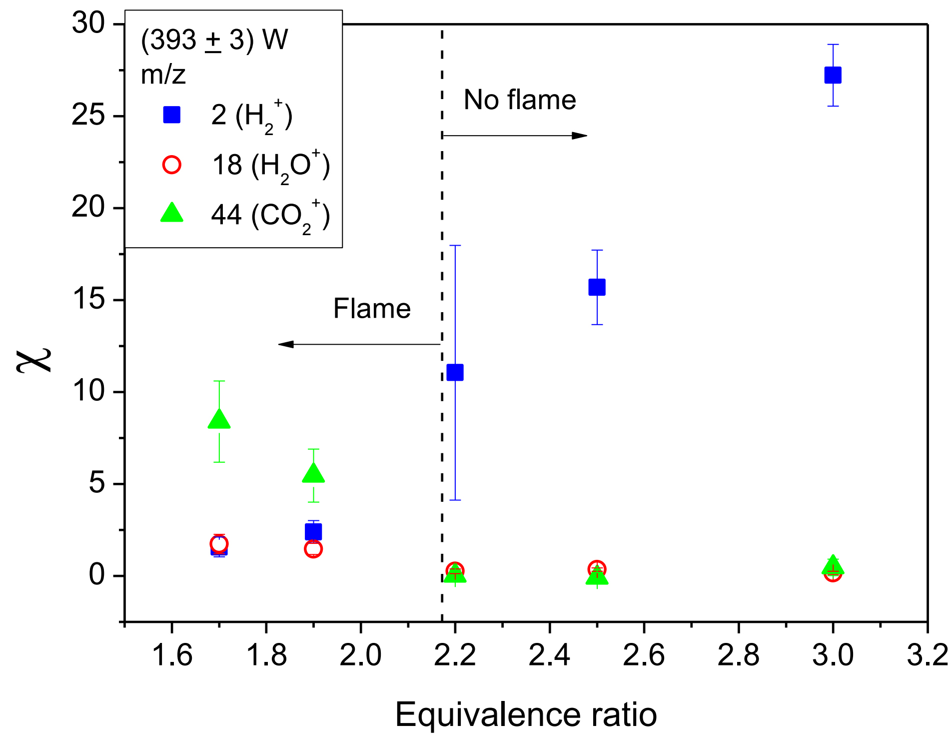


Sagás et al. Fuel 182 (2016), 118-123

Mass spectrometry

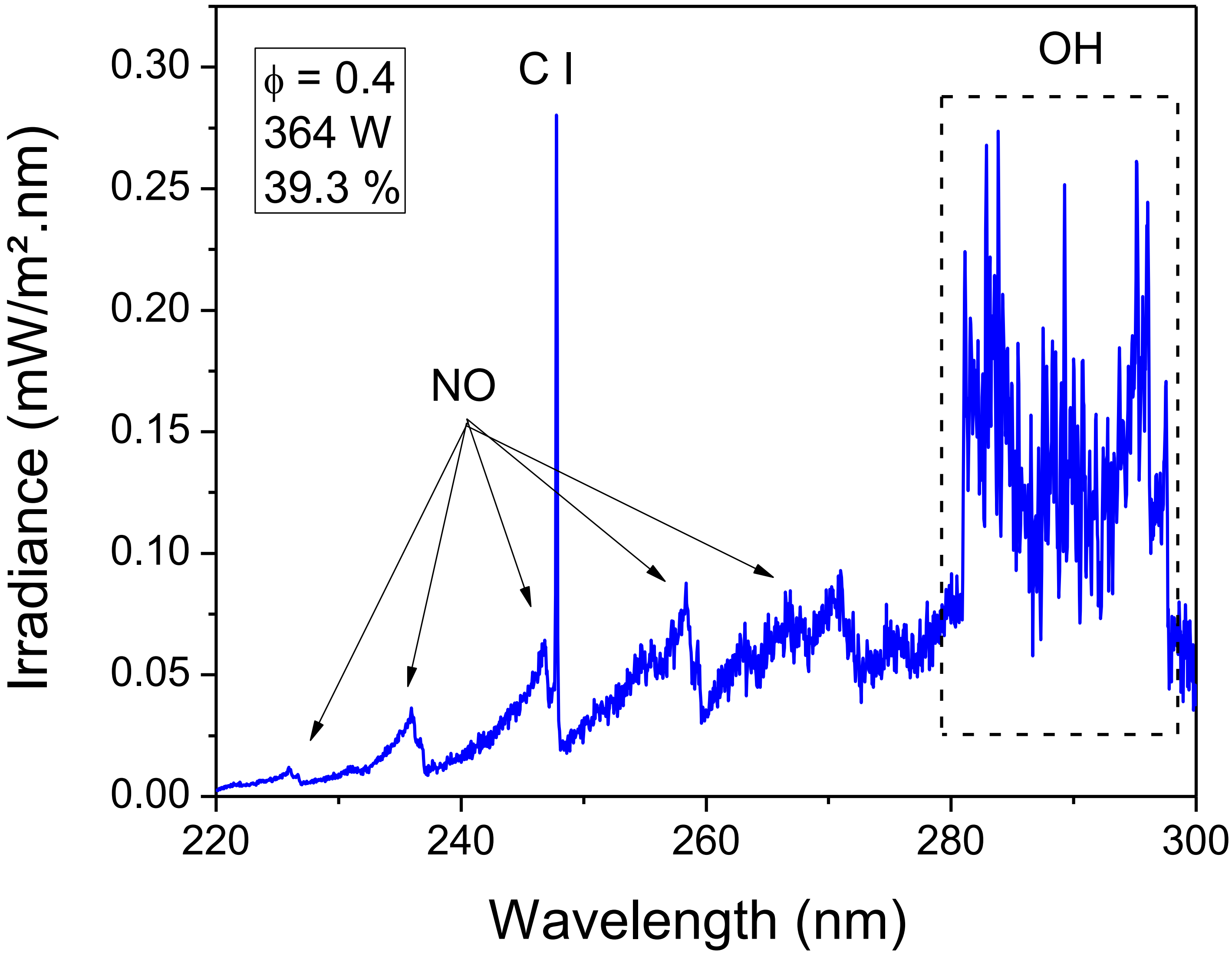


$$\chi = \frac{\Delta I}{I_0}$$



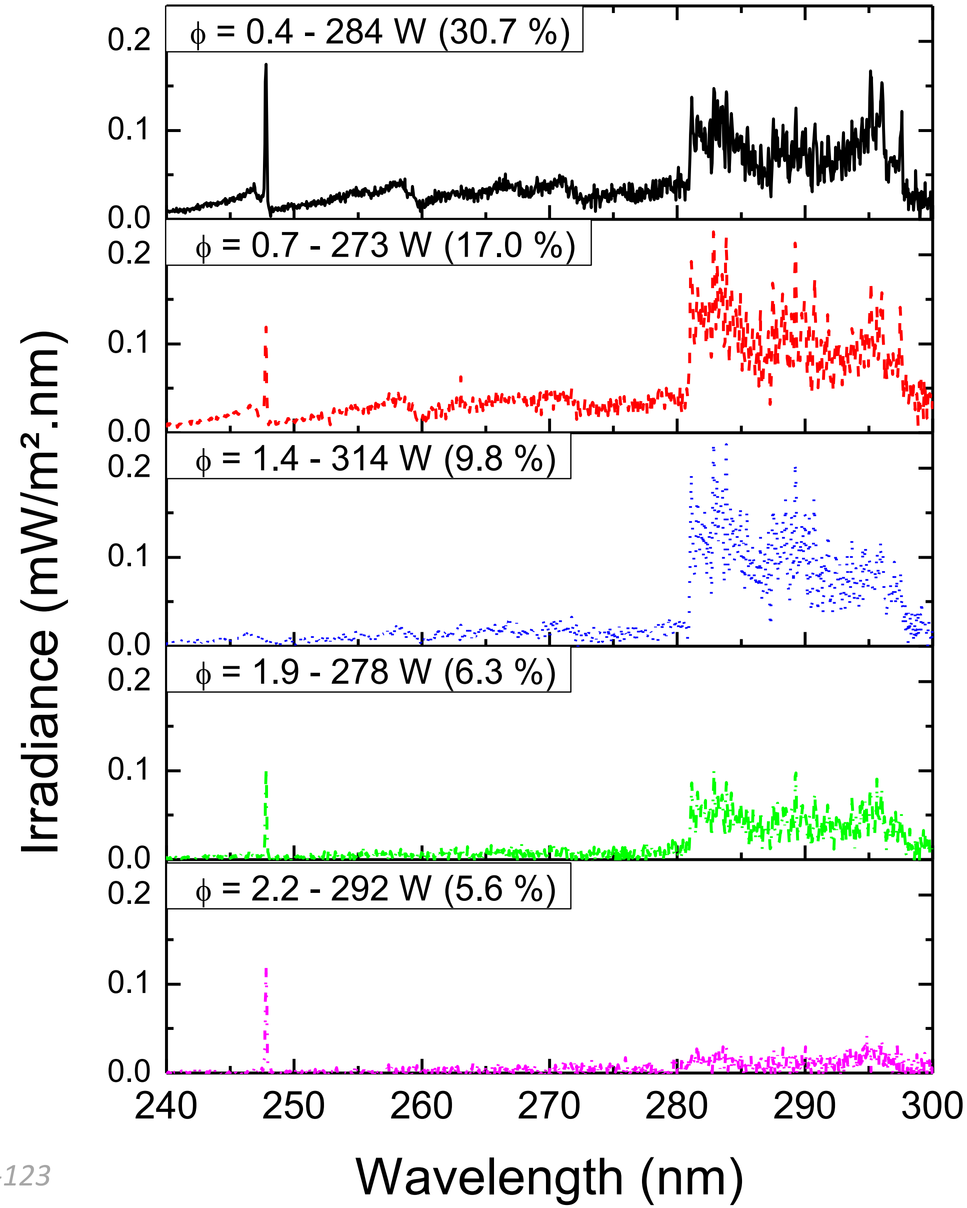
Sagás et al. Fuel 182 (2016), 118-123

OES in UV range



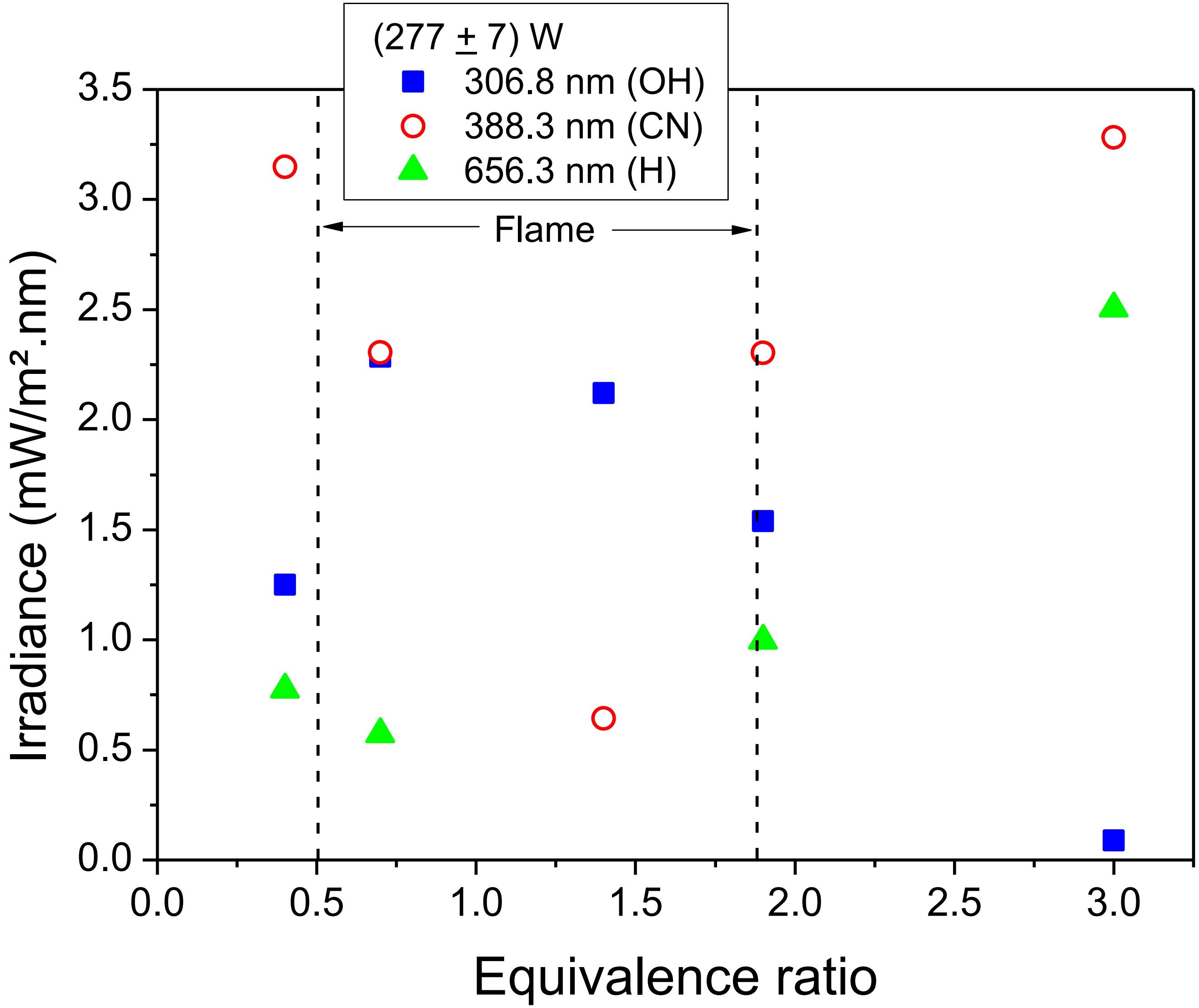
Sagás et al. Fuel 182 (2016), 118-123

OES in UV range



Sagás et al. Fuel 182 (2016), 118-123

OES in visible range



Sagás et al. Fuel 182 (2016), 118-123

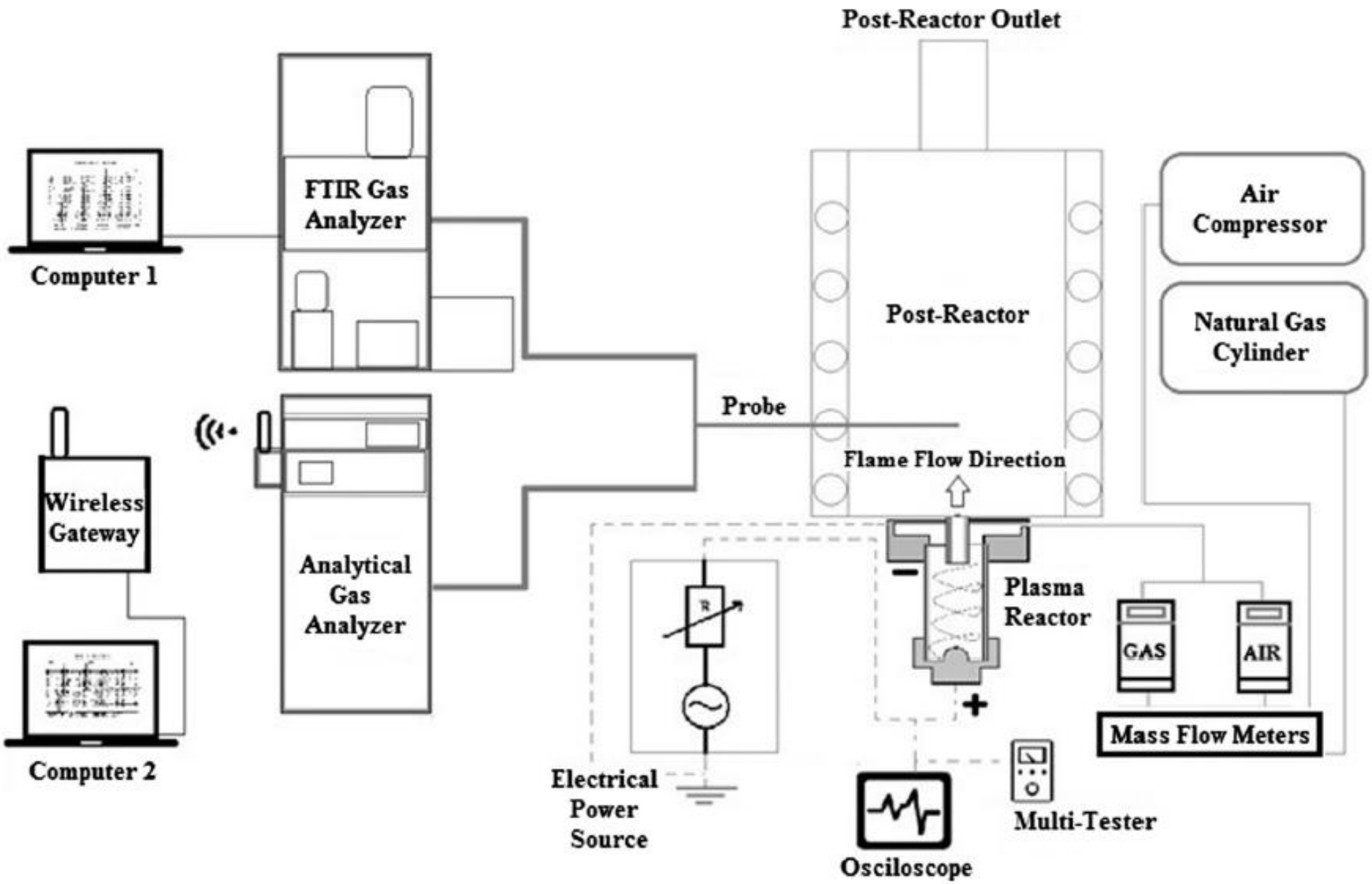
Conclusions – Part I

- The discharge is the main source of H_2 molecules, which are burned in the flame.

- The flame occurs in cycles.

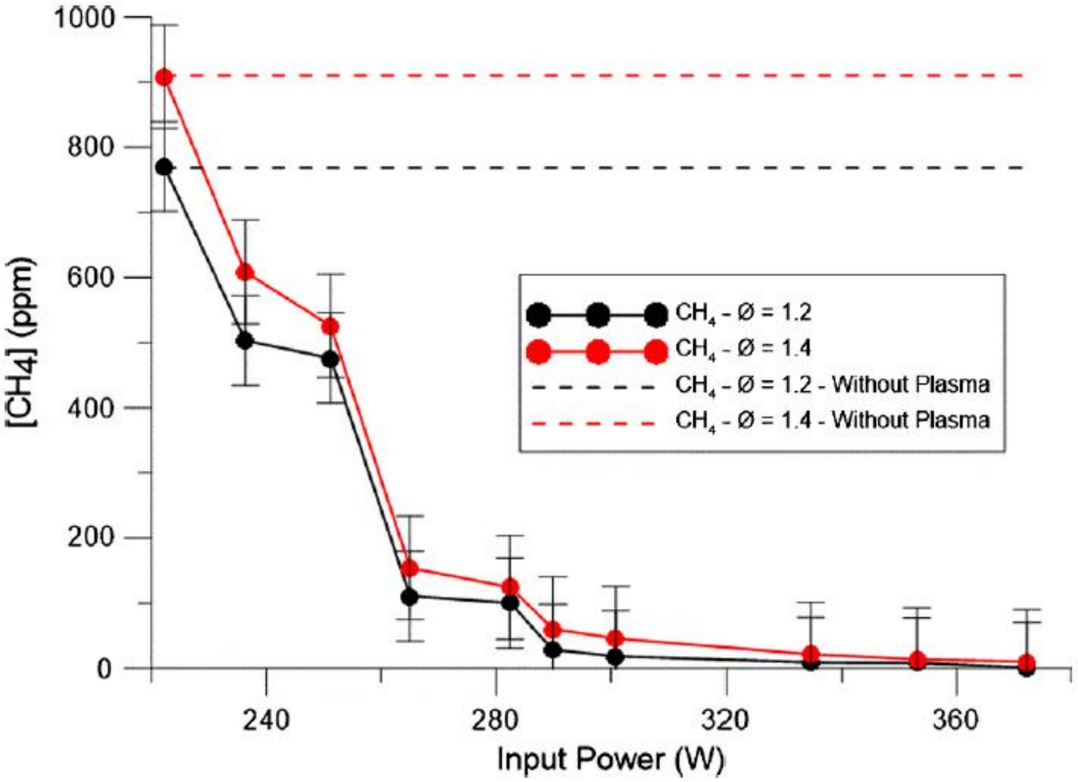
- Under plasma, the position of the flame is strongly dependent of the equivalence ratio in this setup.

Experimental setup – Part II



Varellaet al. Fuel 184 (2016), 269-276

HC emissions



CH_4 consumption

$$OH^* + CH_4 \Leftrightarrow CH_3^* + H_2O$$

$$H^* + CH_4 \Leftrightarrow CH_3^* + H_2$$

$$OH^* + H_2 \Leftrightarrow H^* + H_2O$$

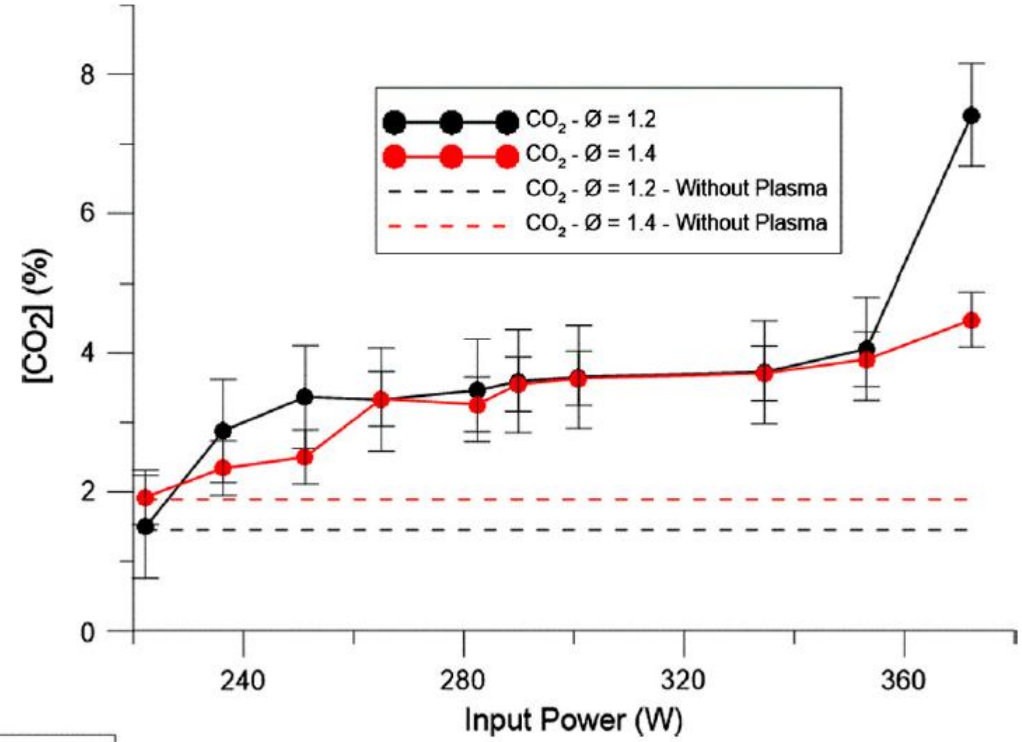
$$H^* + O_2 \Leftrightarrow OH^* + O^*$$

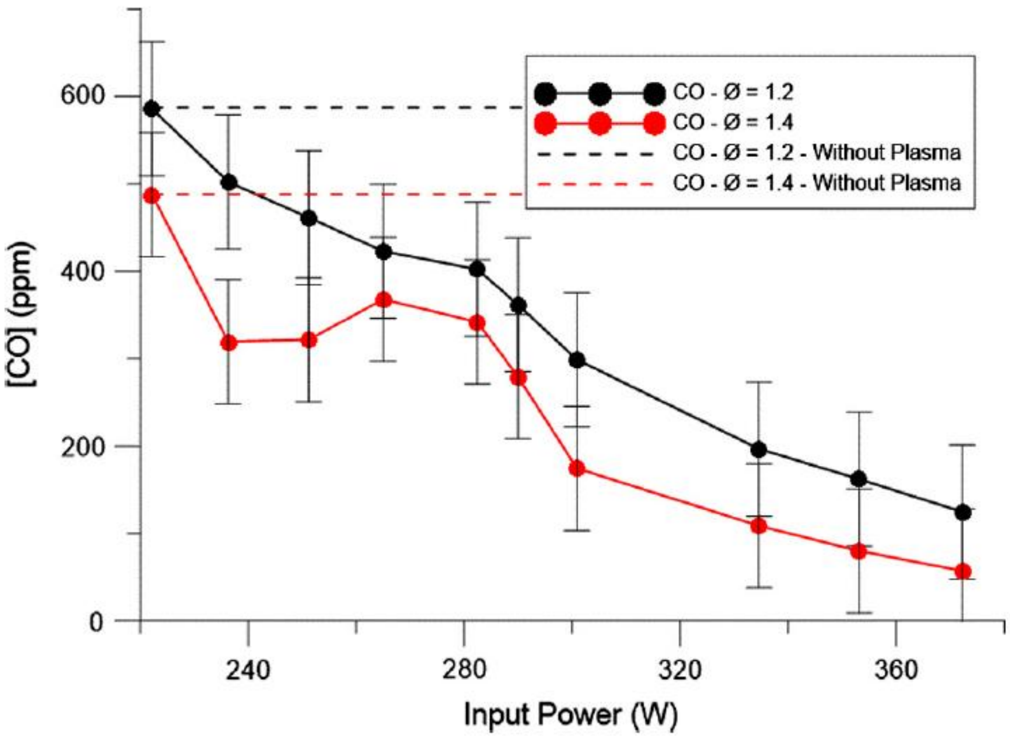
H and H_2 addition reduces CH_4 concentration

Varellaet al. Fuel 184 (2016), 269-276

CO and CO_2 emissions

$$CO + OH^* \Leftrightarrow CO_2 + H^*$$





$$CO + O_2 \Leftrightarrow CO_2 + O^*$$

$$O + H_2O \Leftrightarrow OH^* + OH^*$$

$$H + O_2 \Leftrightarrow OH + O^*$$

$$O + H_2 \Leftrightarrow OH^* + H^*$$

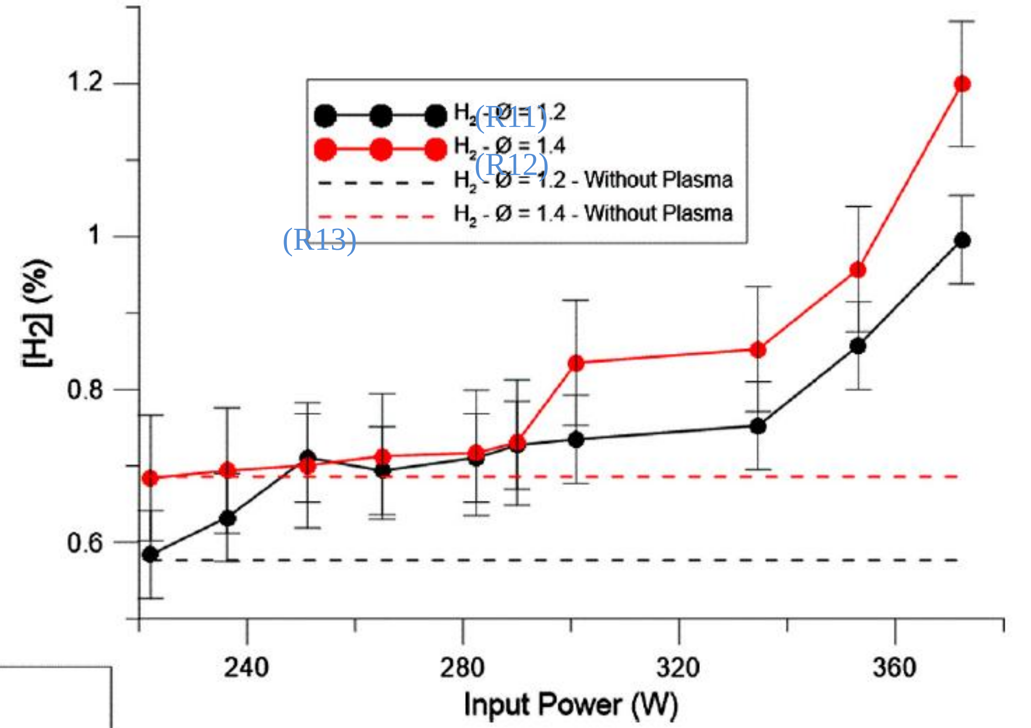
$$CO + HO_2 \Leftrightarrow CO_2 + OH$$

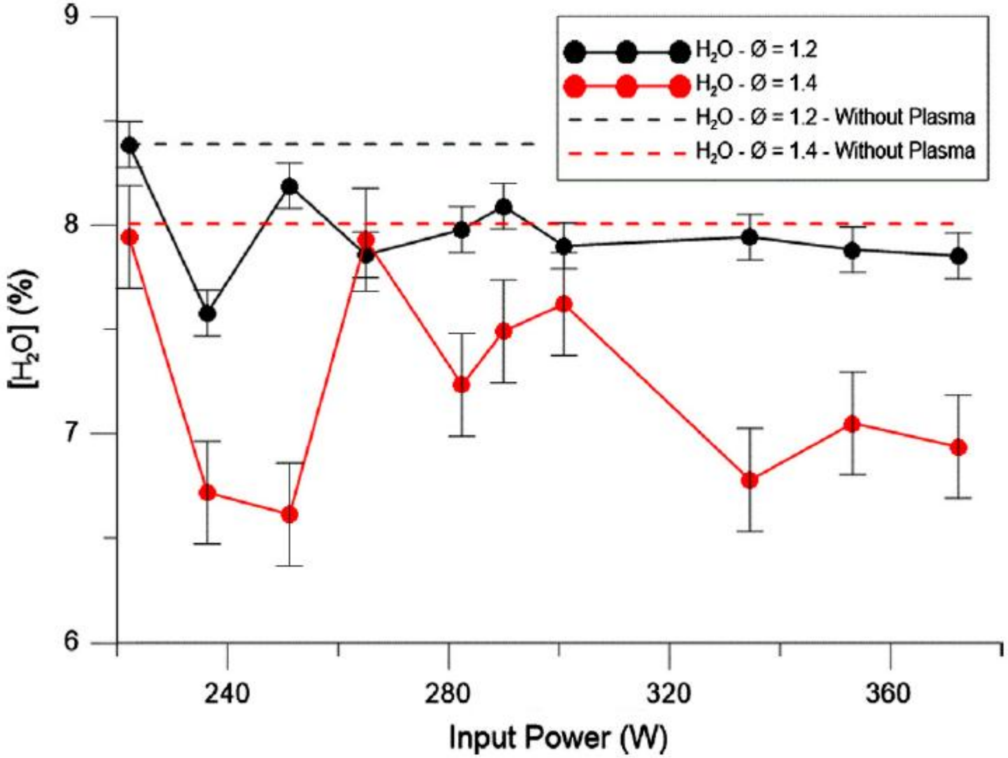
With H_2

Varellaet al. Fuel 184 (2016), 269-276

H_2 production

- *Hydrocarbon dissociation*
- *Dissociation of H_2O?*





$$CH_4 + H \Leftrightarrow CH_3 + H_2$$

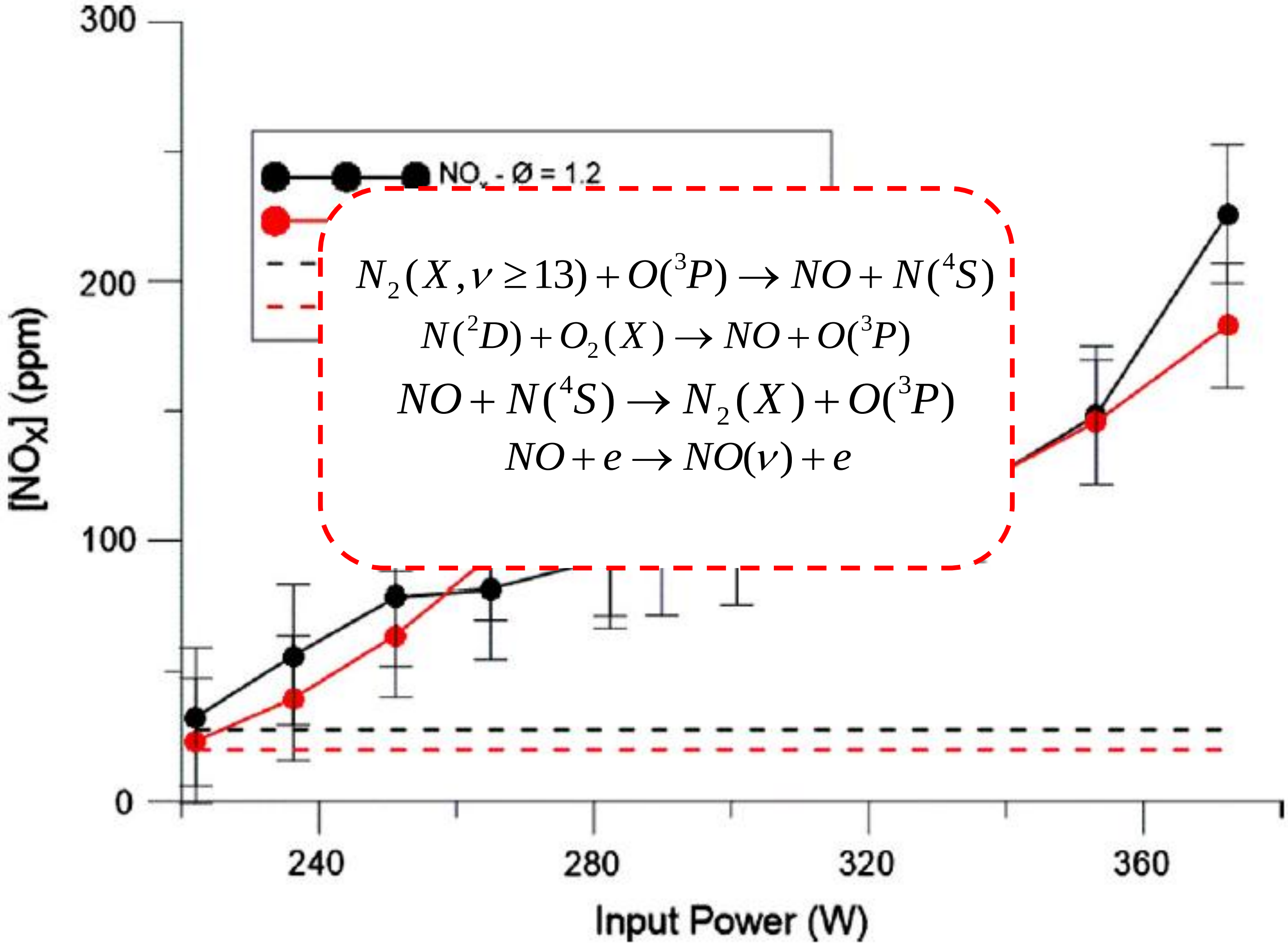
$$C_2H_6 + H \Leftrightarrow C_2H_5 + H_2$$

$$C_2H_4 + M \Leftrightarrow C_2H_2 + H_2 + M$$

$$C_2H_4 + H \Leftrightarrow C_2H_3 + H_2$$

Varellaet al. Fuel 184 (2016), 269-276

NO_x emissions



$$N_2(X, v \geq 13) + O(^3P) \rightarrow NO + N(^4S)$$

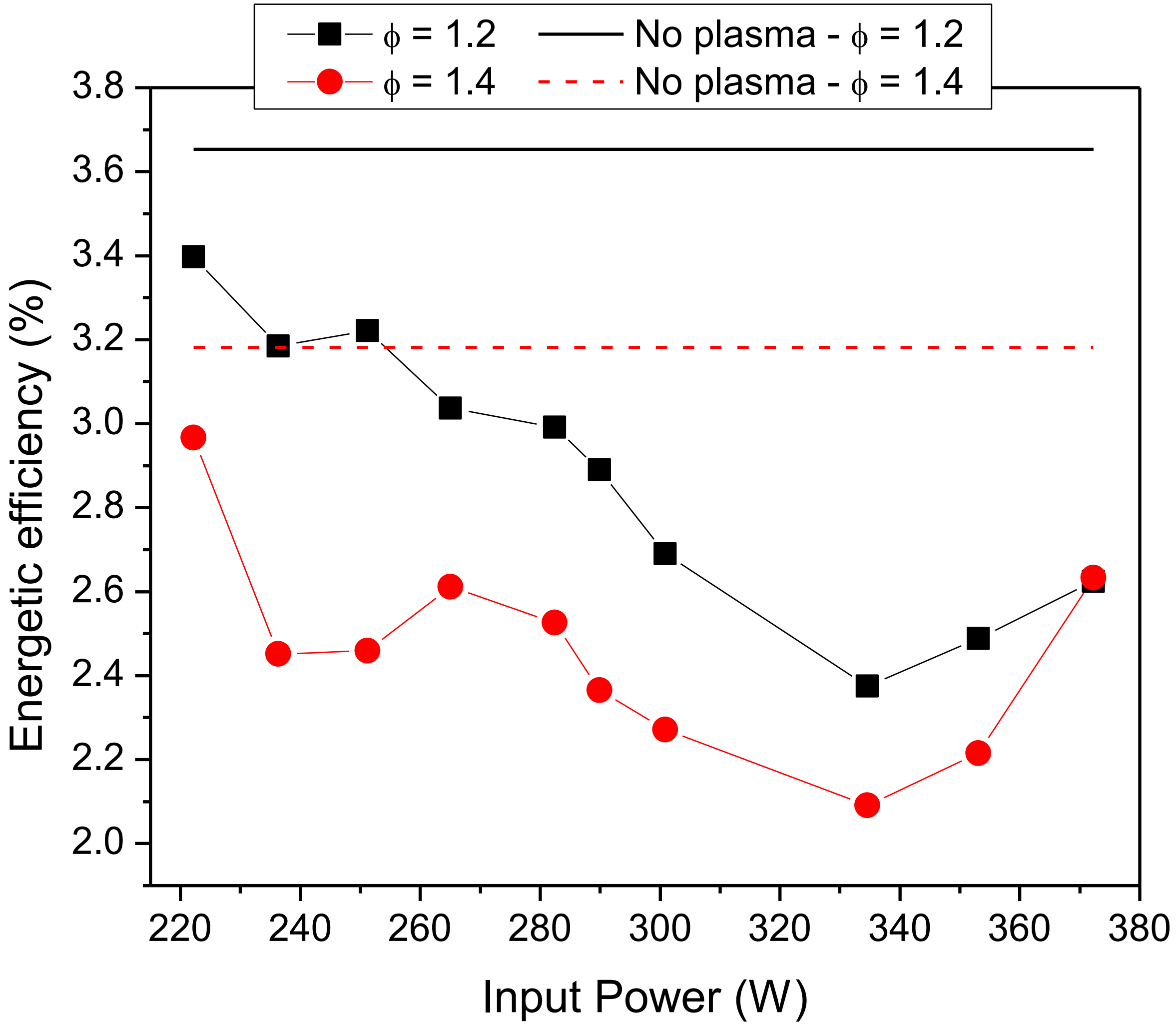
$$N(^2D) + O_2(X) \rightarrow NO + O(^3P)$$

$$NO + N(^4S) \rightarrow N_2(X) + O(^3P)$$

$$NO + e \rightarrow NO(v) + e$$

Varellaet al. Fuel 184 (2016), 269-276

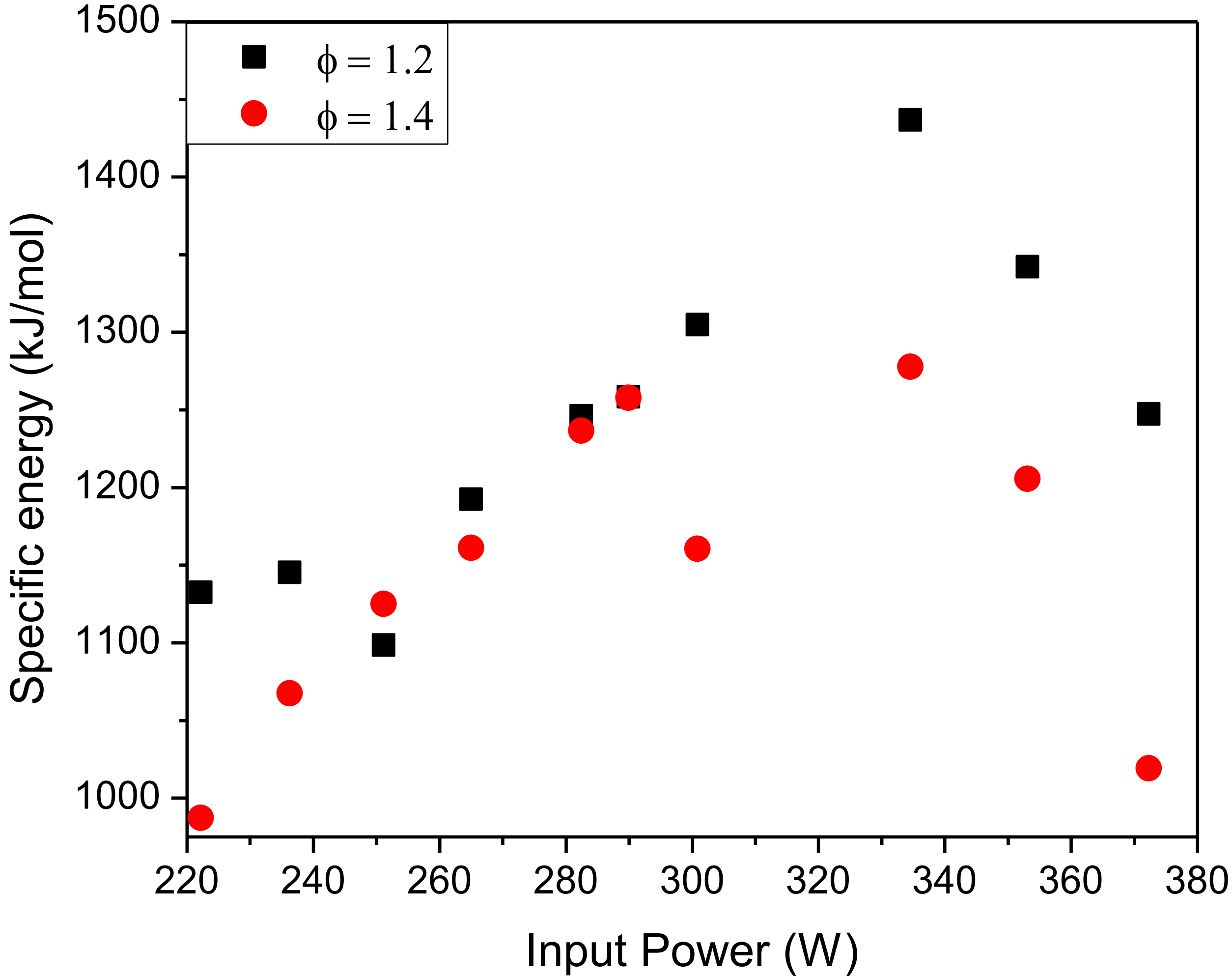
Energetic efficiency



$$\eta = \frac{[H_2 + CO]_{produced} \times LHV(H_2)}{Input\_plasma\_energy + fuel\_injected \times LHV(fuel)}$$

Varellaet al. Fuel 184 (2016), 269-276

Specific energy



$$\nu = \frac{Input\_plasma\_energy}{[H_2 + CO]_{produced}}$$

Varellaet al. Fuel 184 (2016), 269-276

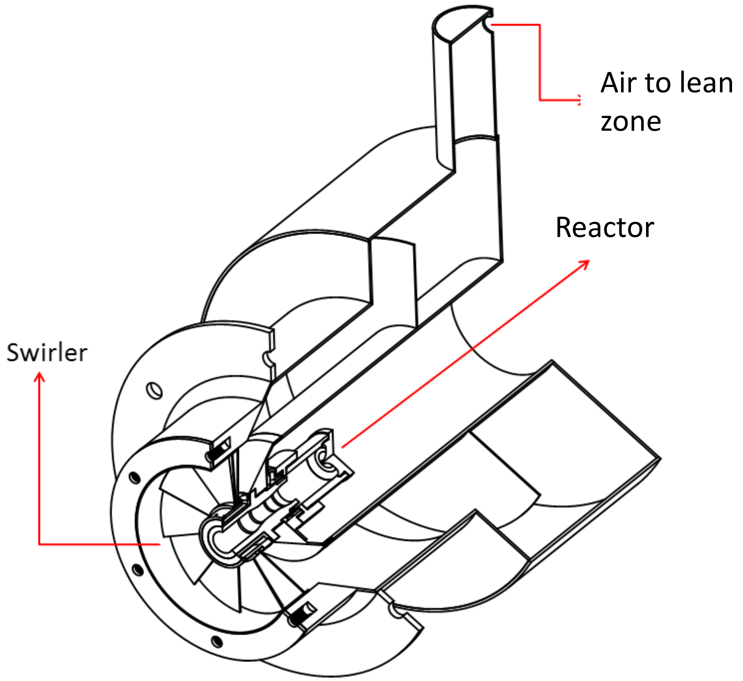
Conclusions – Part II

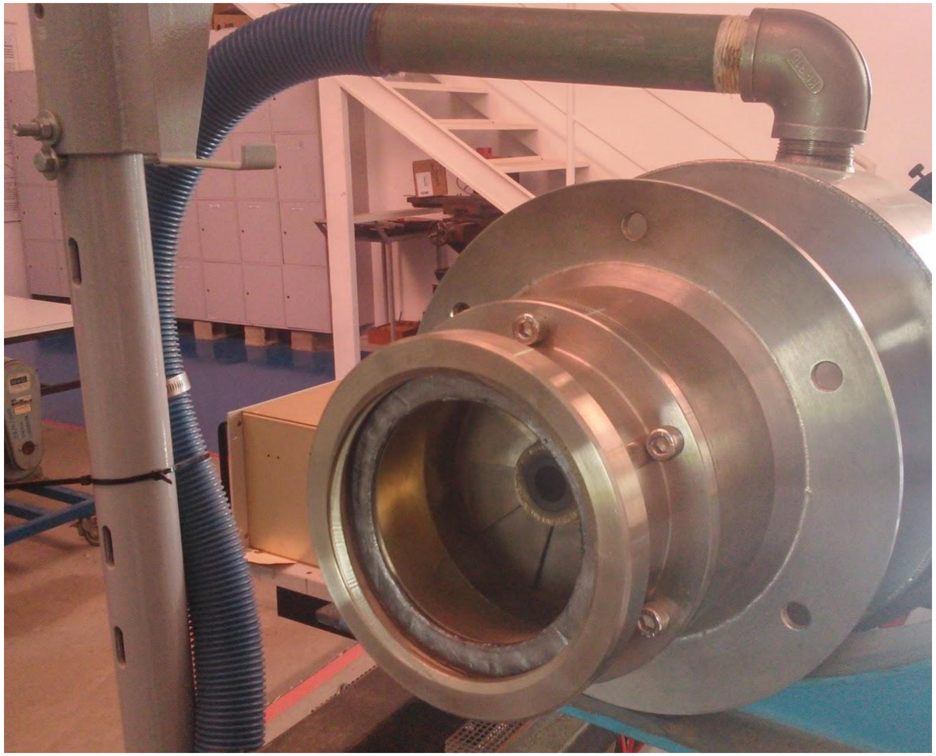
- Plasma causes a faster fuel oxidation.

- A selectivity to H_2 is observed.

- In plasma assisted combustions the pollutant emissions are reduced, except by $NO_{x.}$

In progress





Acknowledgments

C A P E S

CNPq

Project CNPq/Universal 477328/2012-1

FAPESP

PRONEX 11/50773-0

LabPlasma
UDESC-Joinville - CCT

THANK YOU

Contact: julio.sagas@udesc.br
www.cct.udesc.br/?id=1862