Experimental Study on Pollutant Formation in low-pressure Flames of Furanic Biofuels

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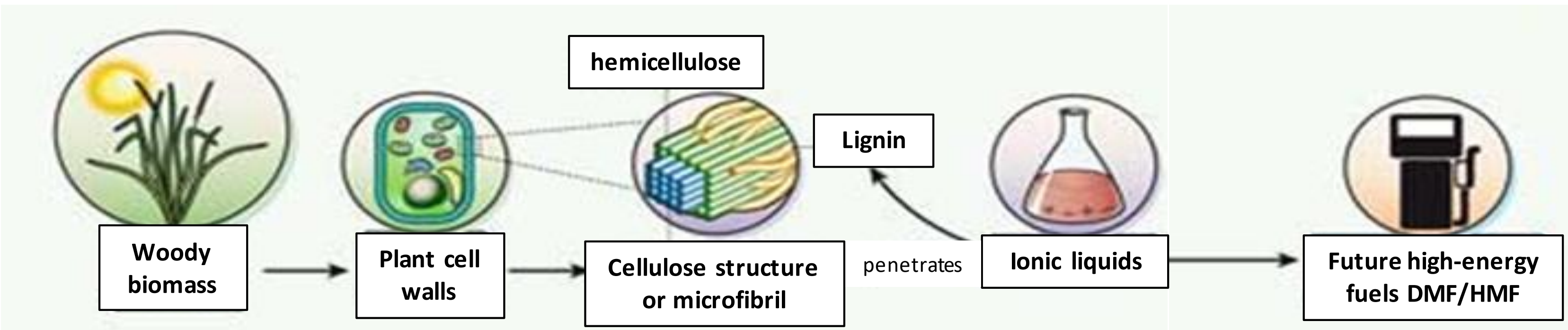
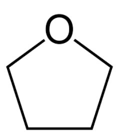
PhD Thesis financed by ***Region Hauts-de-France*** and ***Université de Lille***

Motivation

Biofuels are seen as an interesting and promising alternative to fossil fuels.

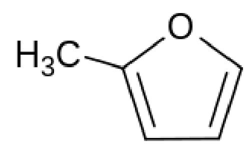


Furan family

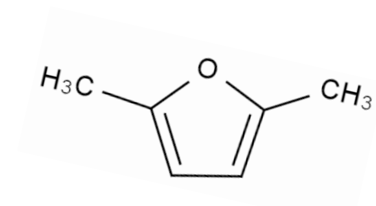


Tetrahydrofuran (THF)

Furan (F)



2-Methylfuran (MF)



2,5-Dimethylfuran (DMF)

- from **ligno-cellulosic biomass**
- **oxygenated fuels** comparable to commercial fuels
- What is **their impact on the formation of pollutant** emissions?

"Furan family" in literature...

➢ Oxidation in laboratory condition:

❖ Shock Tube

(Ignition delay time)

- SOMERS, K., et al." Proc. Combust. Inst., 34, (2013) **MF**
- XU, N., et al. Energy Fuels 29. (2015) **DMF, F, MF.**
- ...

❖ Premixed Laminar Flame

(Kinetics at High T)

- LIU, D., et al. Combust. Flame, 161, (2014) **F**
- TIAN, Z. et al. Combust. Flame ,158, (2011) **F**
- TRAN, L., et al. Combust. Flame, 162, (2015) **THF**
- TOGBÉ,C., et al.. Combust. Flame ,161, (2014) **DMF**
- ...

❖ Isothermal quarz flow reactor

(Kinetics at High T)

- ALEXANDRINO, K., et al., Proc. Combust. Inst ,35,(2015) **DMF**
- ...

➢ Oxidation in real condition:

❖ Rapid Compression Machine

(Kinetics at Low T - Ignition delay time)

- VANHOVE, G., et al. Energy Fuels 29 (2015) **THF**
- FENARD, Y. et al., Combust. Flame, 178 (2017) **MTHF**
- ...

➢ Nitrogen Oxides:

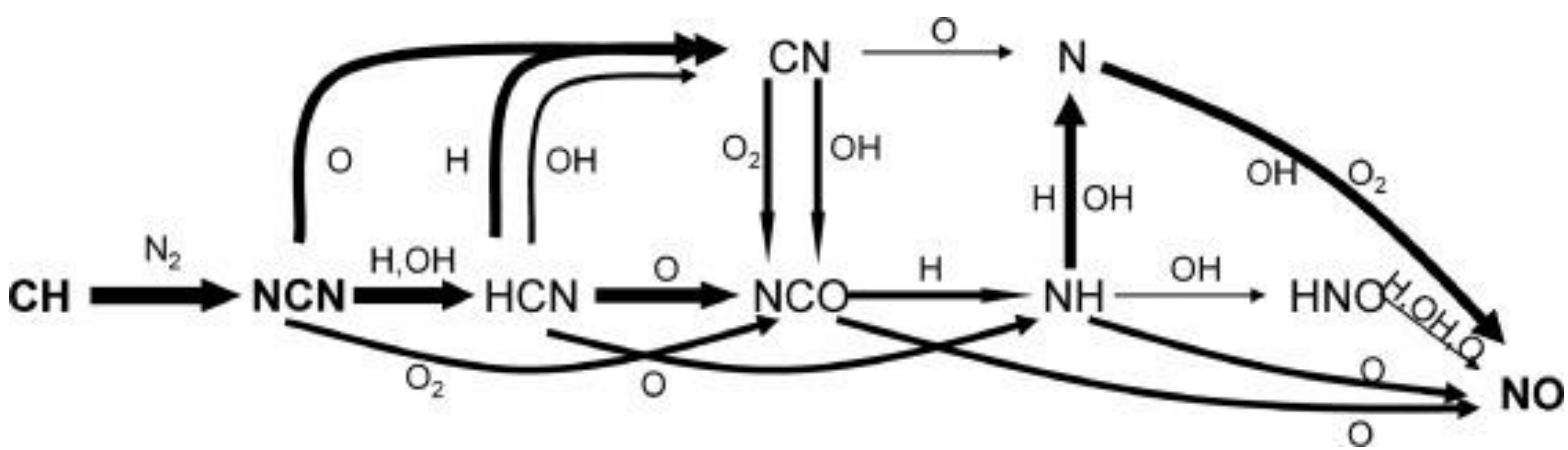
- ALEXANDRINO, K., et al. Energy Fuels, 28, (2014) **DMF, NO**

Nitrogen Oxides

NO is one of the regulated pollutants formed during combustion. It is produced according to different, more or less well-known, pathways :

Thermal - NO *Prompt - NO* *Fuel - NO*

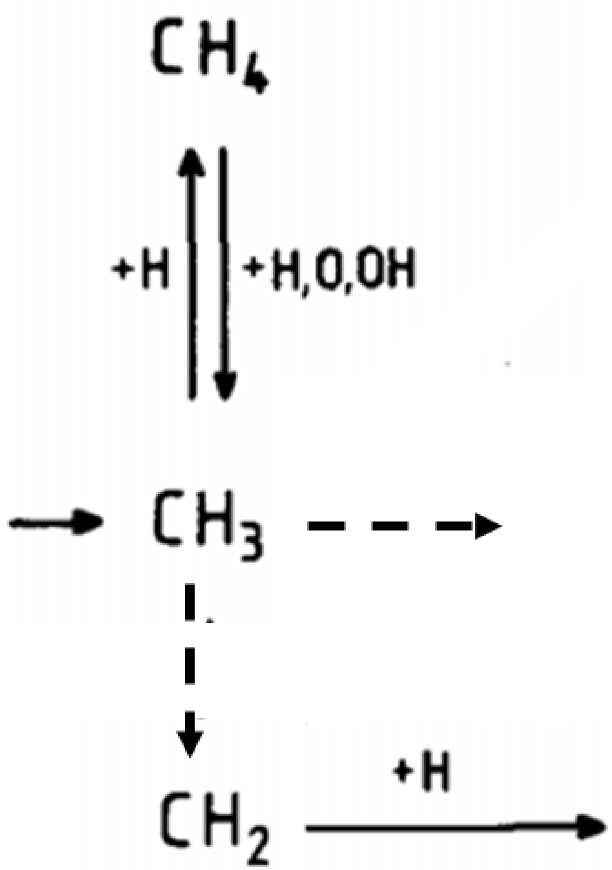
It involves intermediate hydrocarbon fragments, particulary CH, reacting with N_2 under fuel rich conditions.

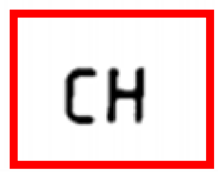


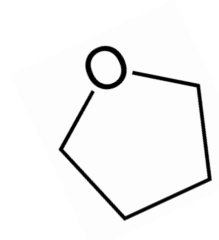
(Lamoureux et al., *Combustion and Flame* 157.10 (2010): 1929-1941.)

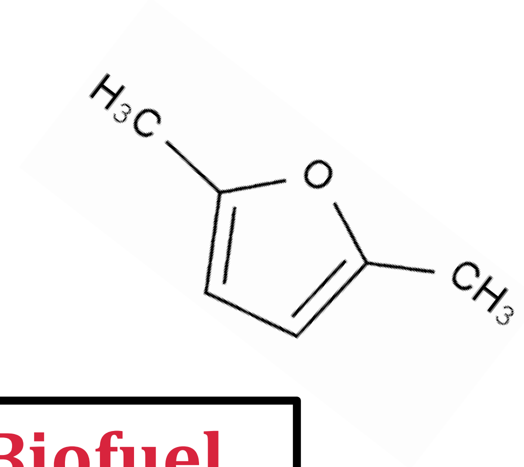
Fuel Oxidation

Methane oxidation







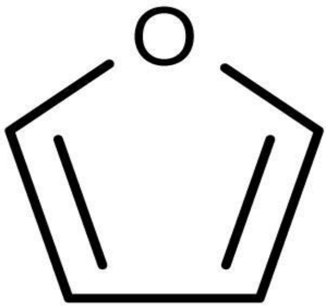


Biofuel Oxidation

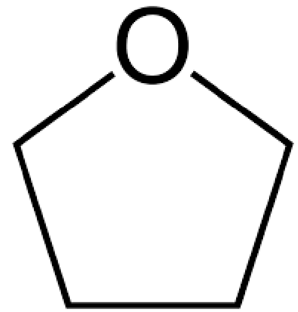
NO

Objectives

Considered fuels :



Furan



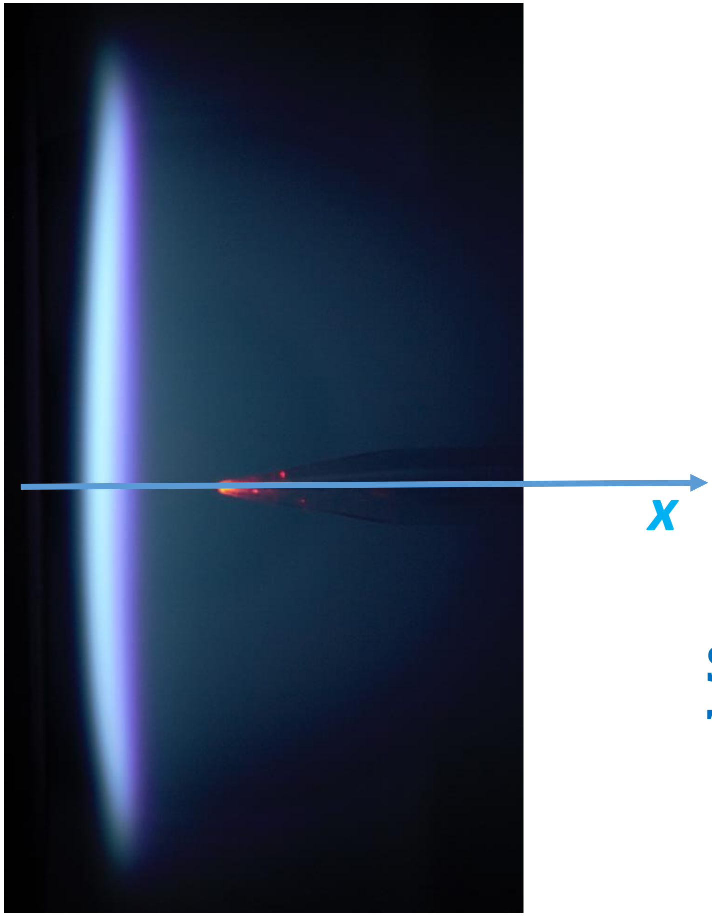
Tetrahydrofuran (THF)

Aims of this study :

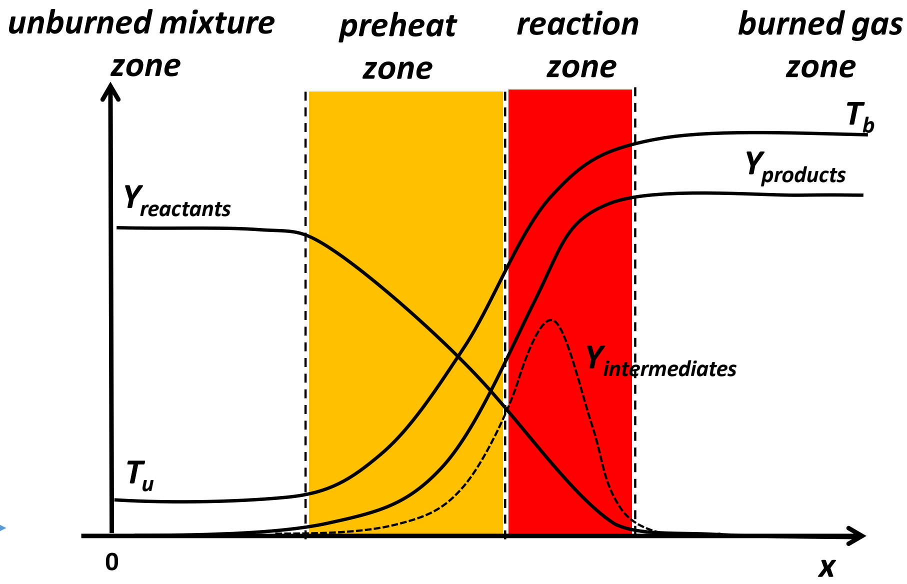
- **Experimental characterization** of NO formation during Furan and THF combustion
- **Development of a model** for NO formation during Furan and THF combustion
- Discussion on **NO formation routes**

Laminar Premixed Flame

Low pressure Flame



Flame structure



Species mole fraction
Temperature → **x=HAB**

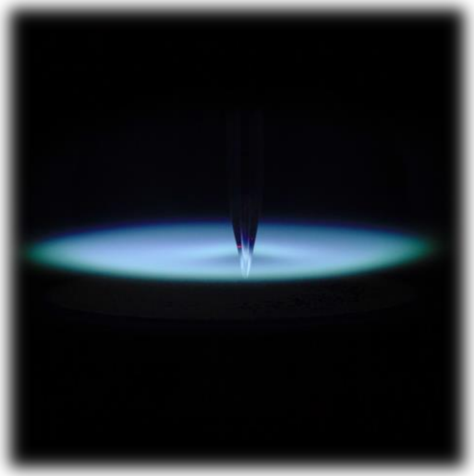
HAB = Height Above the Burner

Operating conditions

Flames	φ	*%CH4	*%F	*%THF
M1.0	1.0	100	0	0
M1.2	1.2	100	0	0
FM1.0	1.0	50	50	0
FM1.2	1.2	50	50	0
THFM1.0	1.0	50	0	50
THFM1.2	1.2	50	0	50

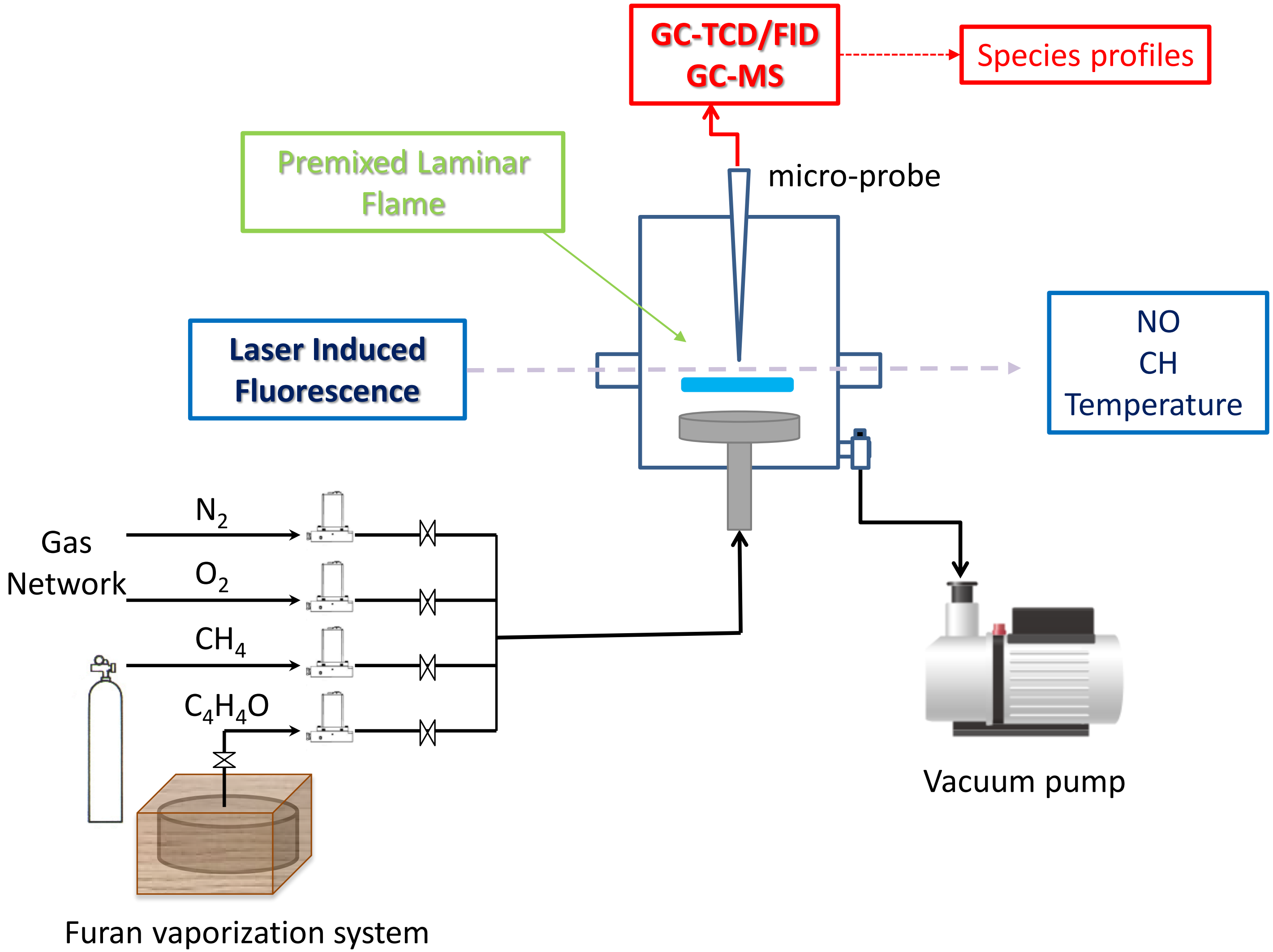
**** Fuel composition***

Pressure
5.3 kPa



Total Flow
5 sL/min

Experimental set-up



Combustion products and stable intermediates

Gas-Chromatography Results

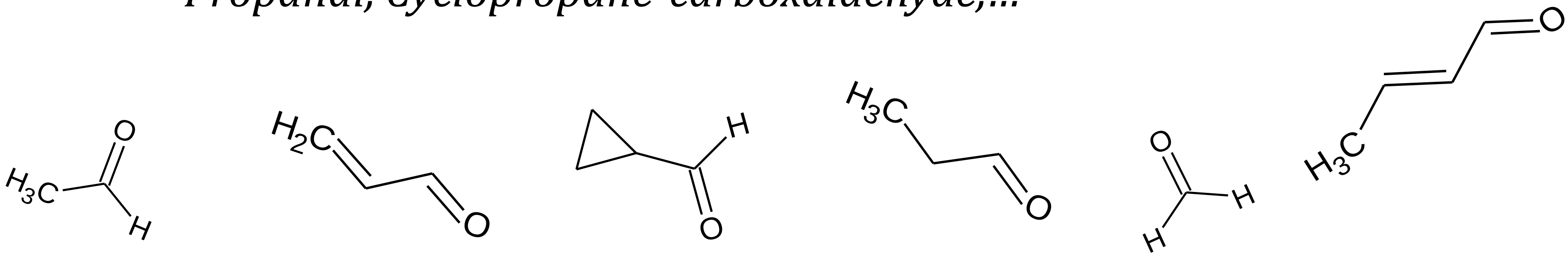
- 6 flames analyzed by gas chromatography equipped with:
  - **MS detector**
  - **FID detector** coupled with methanizer
  - **TCD detector**

- 63 species have been detected globally:
  - *14 in Methane flames*
  - *47 in Furan doped flames*
  - *49 in THF doped flames*

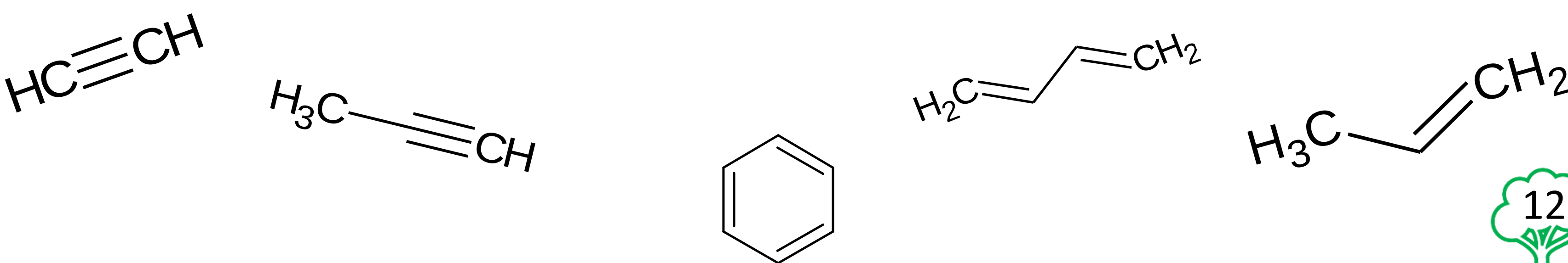
Gas-Chromatography Results

Different pollutants found in Furan and THF flames :

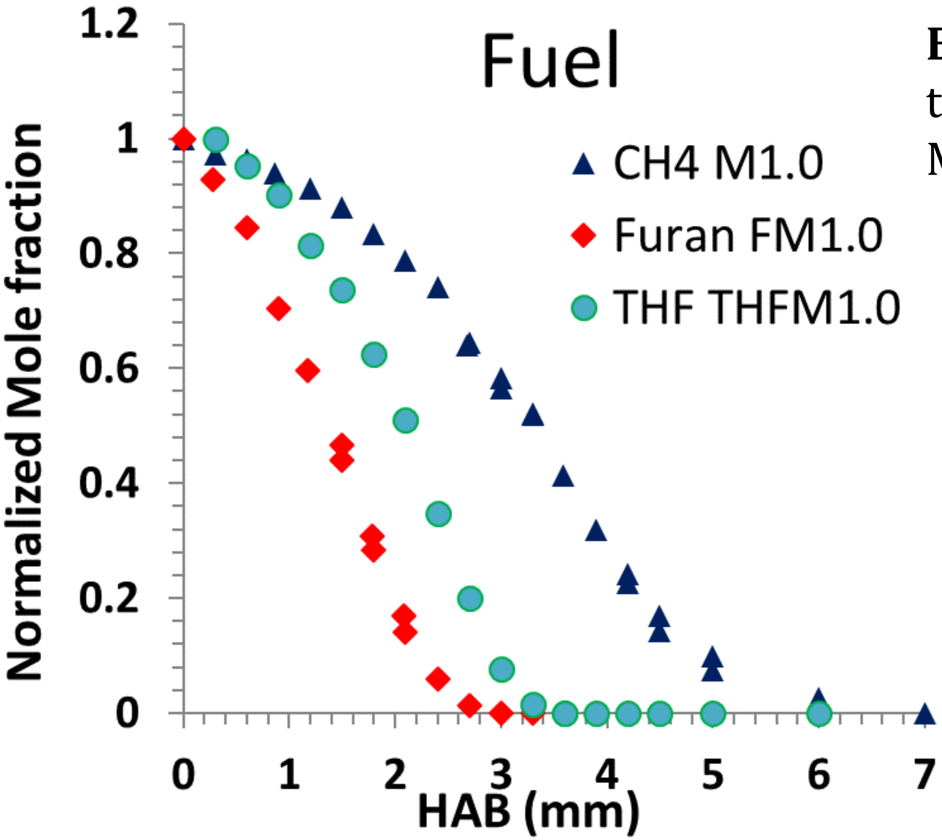
- **Aldehydes** : *Formaldehyde, Acetaldehyde, Acrolein, 2-Butenal, Propanal, Cyclopropane-carboxaldehyde,…*



- **PAH Precursors :** *Acetylene, Propene, Propyne, Allene, 1.3Butadiene, Cyclopentadiene, Benzene,…*



Species profiles



Biofuels flames are stabilized closer to the burner surface with respect to Methane flames

Furan is consumed faster than THF

Burning velocity

P=101kPa T=298K ϕ= 1

CH_4[a] : Su_{CH4} =36.3 $cm.s^{-1}$

THF[b] : S_{uTHF} =41.4 $cm.s^{-1}$

Furan[c] : S_{uFuran} =62.5 $cm.s^{-1}$

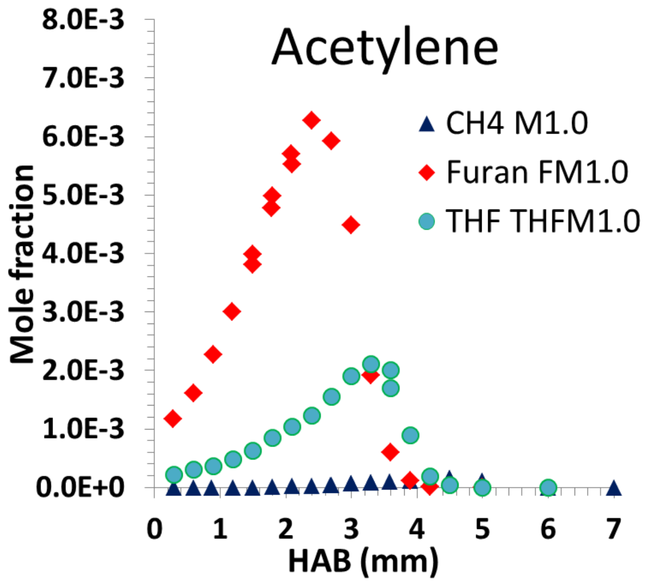
$S_{uFuran} > S_{uTHF}$

[a]Dirrenberger et al., Energy Fuel, 25 (2011) 3875-3884

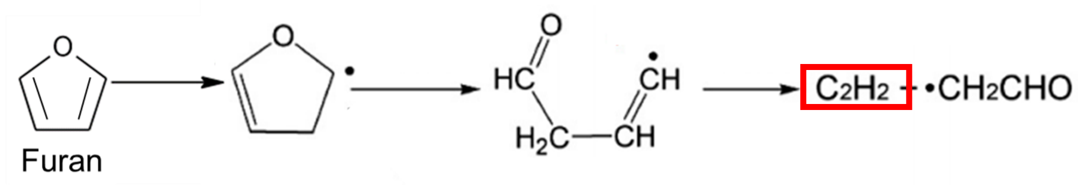
[b] Tran et al., Combustion and Flame, 162 (2015), 1899-1918

[c] Gibbs and Calcotte, J. Chem. Eng. Data, 4 (1959), 226-237

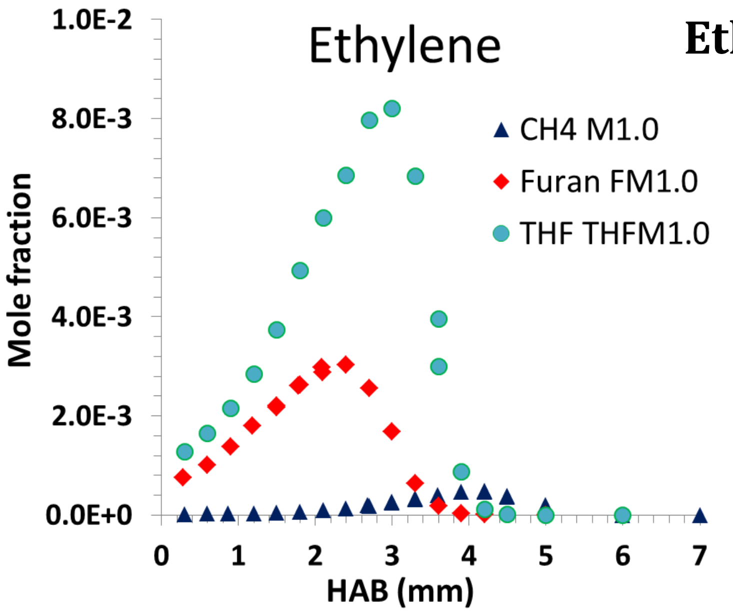
Species profiles



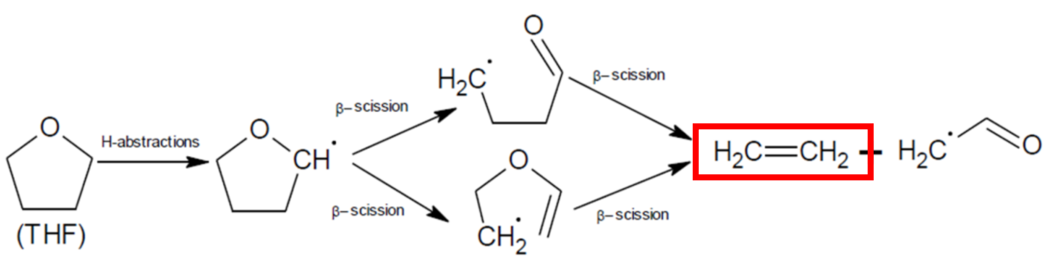
Acetylene formation is enhanced in furan oxidation



Liu et al., Combust. Flame, 61, (2014) 748-7651



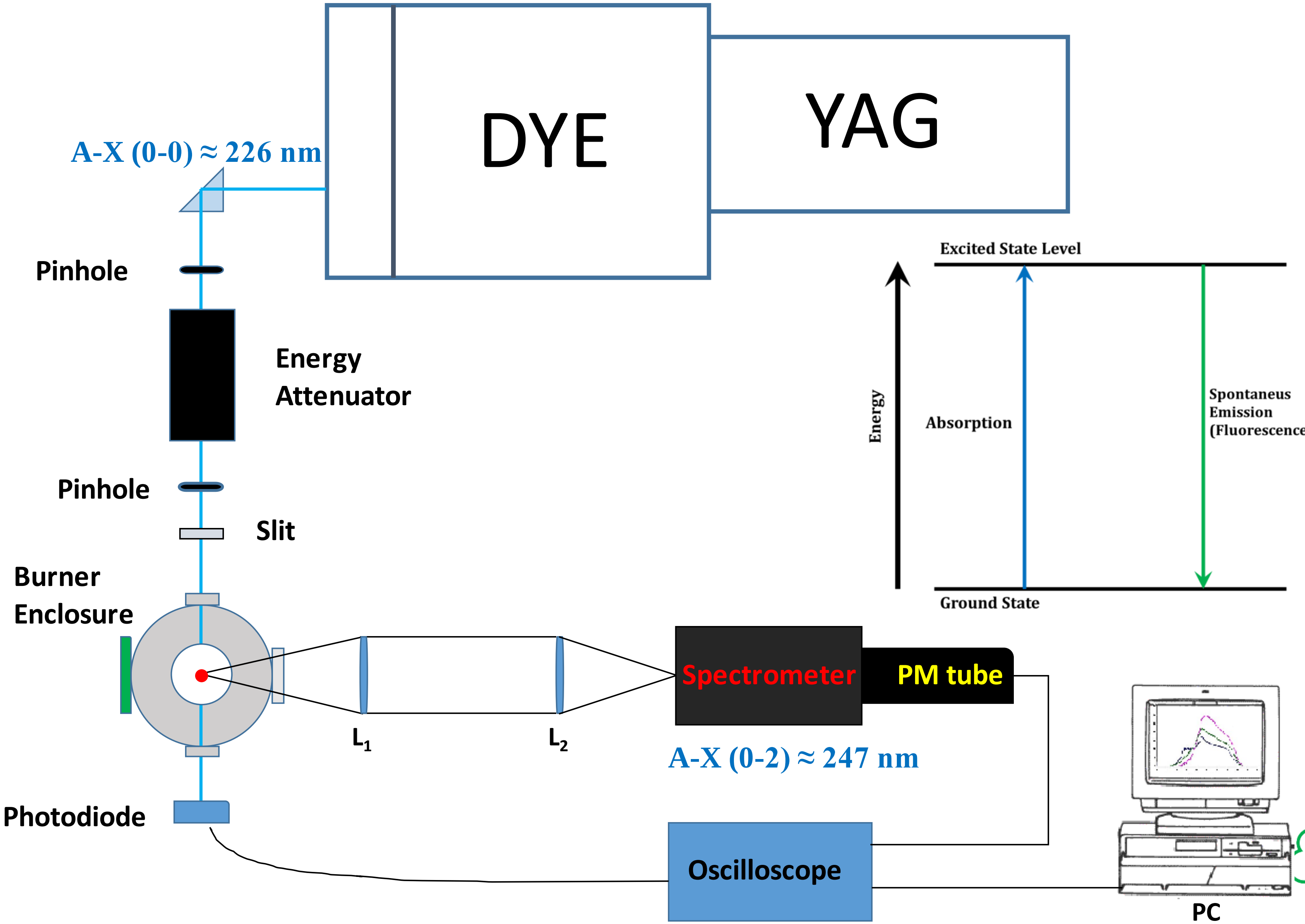
Ethylene formation is enhanced in THF oxidation



Tran et al., Combustion and Flame, 162 (2015), 1899-1918

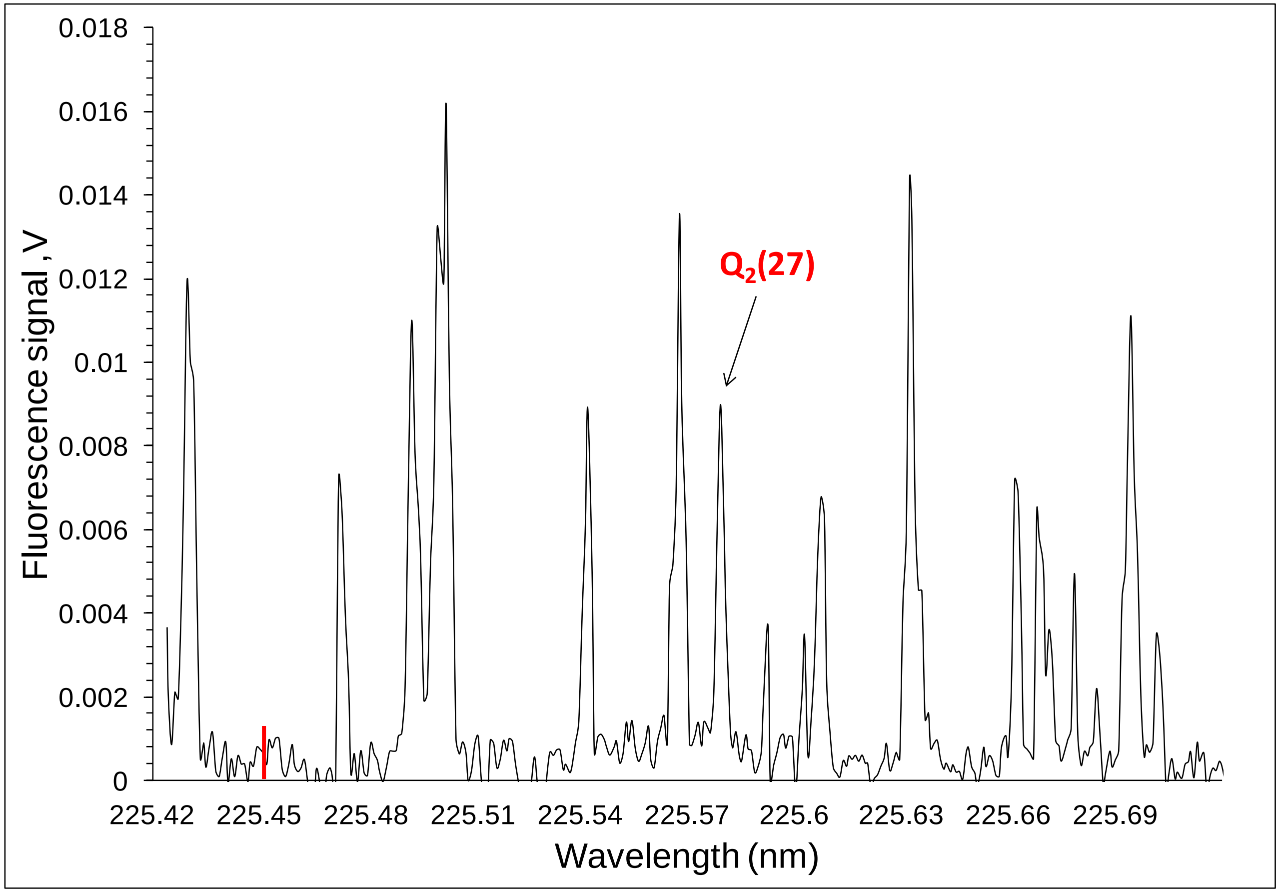
NO measurements

Laser Setup


DYE
YAG
A-X (0-0) ≈ 226 nm
Pinhole
Energy
Attenuator
Pinhole
Slit
Burner
Enclosure
Photodiode
L1
L2
Spectrometer
PM tube
A-X (0-2) ≈ 247 nm
Oscilloscope
PC
Excited State Level
Energy
Absorption
Spontaneus
Emission
(Fluorescence)
Ground State

Excitation-Detection scheme

Experimental NO LIF excitation spectra.



NO molecules are excited by using the $Q_2(27)$ transition of the A-X(0,0) at 225.58 nm

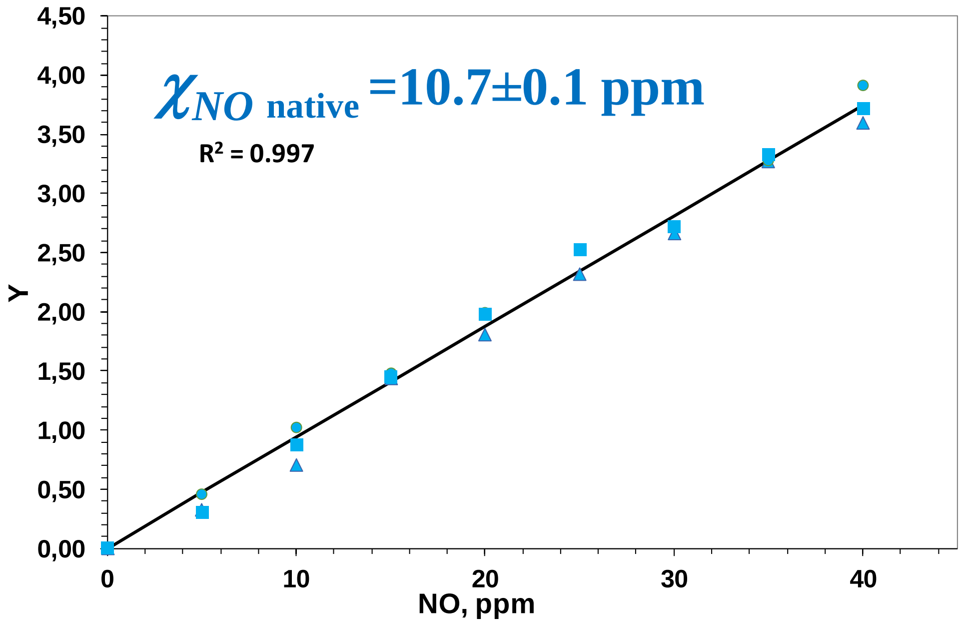
NO LIF signal profile

- **NO LIF relative profile**

Concentration of NO molecules

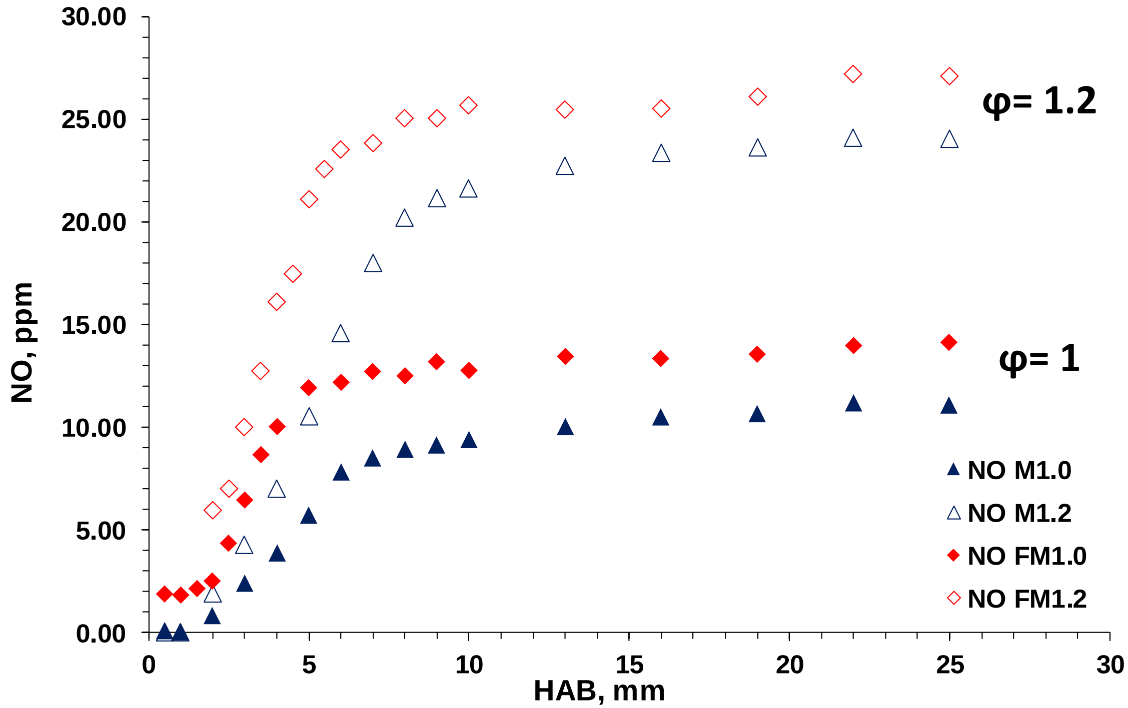
$$\Phi(t) = \frac{GV\Omega}{4\pi} N_{tot} f_b(J^{"}, v^{"}, T) B_{12} U_\nu \frac{A_{21}}{A_{21}+Q_{21}}$$

- **NO doping calibration method in flame M1.0**



Calibration curve obtained in flame M1.0, HAB=19 mm

NO mole fraction profiles



- NO formation is enhanced in **fuel-rich conditions**

- NO formation is enhanced in **Furan flames :**

  +27% at **φ=1** and **+11%** at **φ=1.2**

(with respect to Methane flames in same operating conditions)

Perspectives....

- Measurement of the NO in THF flames and CH profiles in flames by LIF

- Measurement of the temperature profiles in the flames by NO–LIF thermometry

- Detailed chemical kinetic modeling helps the interpretation of the data

BioFuel oxidation mechanism	available in literature
+	
NO mechanism NOMecha2.0*	developed in PC2A laboratory

*Lamoureux et al. Combust. Flame 163, 2016

Thanks for the attention