Review of ICARE-CNRS activities on facilitating CO_2 capture from the combustion of fossil fuels

Centre National de la Recherche Scientifique - CNRS
Institut de Combustion, Aérothermique, Réactivité et Environnement - ICARE

Iskender GÖKALP
Director

Outline

- Few words about ICARE-CNRS @ Orléans
- Basic chemical kinetic studies on the oxydation of methane, ethylene and propene in the presence of CO2 and H2O (ANR project TACOMA)
- Combustion of methane in oxygene enriched air coupled with membrane capture of CO2. Basic and pilot system studies (CNRS Energy Program project COCASE)
- Retrofitting a pulverised coal power plant into a oxyfuel system. (FP7 TREN demonstration project SOMALOX)
- Interdisciplinary and comparative analyses of the acceptability of new energy technologies: the case studies of CCS in France and Canada (CNRS Energy Program project ALICANTE)
- 10th ICCEU

ICARE in Orléans

- Institut de
- Combustion
- Aérothermique
- Réactivité et
- Environnement

- Institute for Combustion, Aerothermal sciences, Reactivity, Environnement

Where is ICARE ?

ICARE is in Orléans,
125 km from Paris

ICARE – CNRS
Institut de **C**ombustion, **A**érothermique
Réactivité et **E**nvironnement
1c, avenue de la Recherche Scientifique
45071 Orléans – Cedex 2 – France

Total staff : 120
26 Researchers and faculty
21 Engineers and technicians
39 PhD students and post-docs
34 Various trainees

Main research domains and areas

Two main research domains:

Energy & Environnement
Space & Propulsion

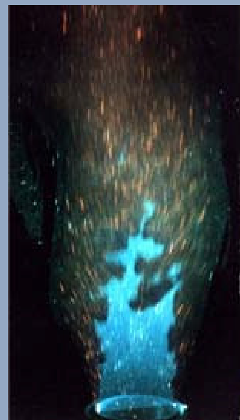
Four main research thematics:

Chemical kinetics of combustion and reactive systems
Dynamics of combustion and reactive systems
Atmospheric chemistry
Supersonic, hypersonic, rarefied, ionized flows

Research domains of ICARE

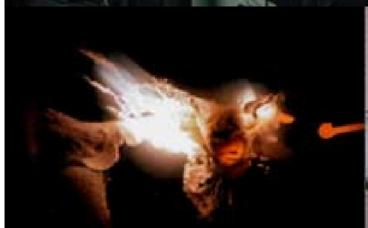
Energy & Environment
Propulsion & Space

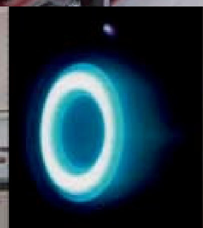
- Combustion
  - Chemical kinetics
    - Plasmas physics
      - Fluid mechanics, turbulence
        - Two phase flows
          - Supersonic, hypersonic flows
            - Ionized, rarefied flows












Application domains

- Aerospace propulsion
- Electric propulsion
- Liquid and solid propulsion
- Atmospheric reentry
- Atmospheric chemistry
- Energy production
- Alternative fuels, biofuels, hydrogen
- Pollutant emissions reductions
- Industrial risk prevention

Main contractual cooperations

ADEME

esa

cnes

cea

INERIS

IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE

AREVA

EDF

GDF SUEZ

AIR LIQUIDE

TOTAL

IFP

PSA PEUGEOT CITROËN
PEUGEOT

ONERA

EADS

MBDA MISSILE SYSTEMS

Roxel

Snecma SAFRAN Group

Turbomeca SAFRAN Group

AIRBUS

SNPE MATÉRIAUX ÉNERGÉTIQUES GROUPE SNPE

Main international cooperations: UE, Russie, USA, Canada, Chine, Japon, Ukraine, Turquie, Argentine, etc

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Project TACOMA
(GDF SUEZ; TOTAL; IFP; ICARE-CNRS)

- A new combustion mode for glass, petrochemistry, steel industries to concentrate CO_2 in the flue gases
- Combustion of heavy oil and natural gas diluted with recirculation of burnt gases
- Ethylene and propene are the main products of the cracking of heavy oil
- Oxydation of C_2H_4 and C_3H_6 in $O_2/N_2/CO_2/H_2O$ at atmospheric pressure, over a wide range of initial concentrations, temperatures and equivalence ratios. A detailed chemical kinetic reaction mechanism was used to simulate the experiments and analyze the results.

Project TACOMA-ICARE CNRS Conclusions

- The oxidation of ethylene is inhibited by water and the effect decreases with the increasing equivalence ratio. Carbon dioxide accelerates slightly the consumption of C_2H_4 under fuel-rich conditions. The oxidation of ethylene in presence of water vapor yields reduced formation of carbon monoxide and increased acetylene production. Carbon dioxide participates to the production of CO when initially present in ethylene-O_2-N_2 reacting mixtures.
- The oxidation of propene is less affected by the presence of CO_2 or H_2O in the reacting mixture under the present JSR conditions.

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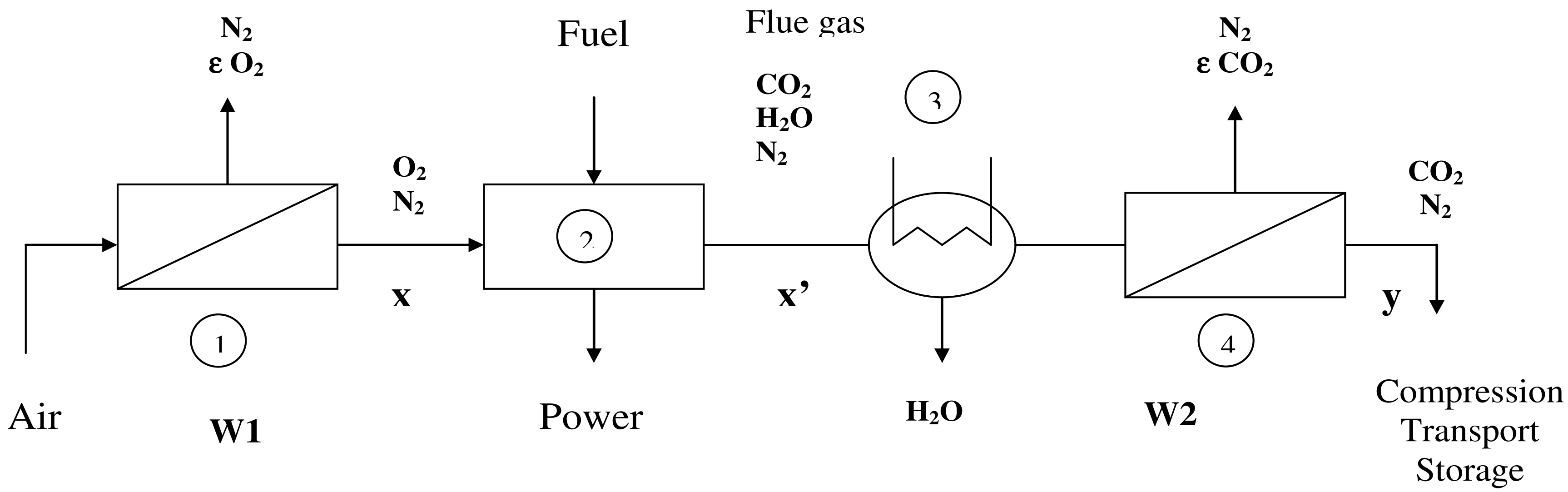
Oxygen enriched air combustion of methane in relation with membrane capture of CO2
Project COCASE (CNRS Energy Program)

- Membrane capture of CO_2 is a promising technology but needs a minimum of 20% CO_2 concentration in the flue gases.
- Combustion of CH_4 in oxygen enriched air with CO_2 recirculation is investigated to optimise the O_2 concentration, the CO_2 recirculation rate, the CO_2 concentration rate and the membrane properties

Project COCASE: Global principle

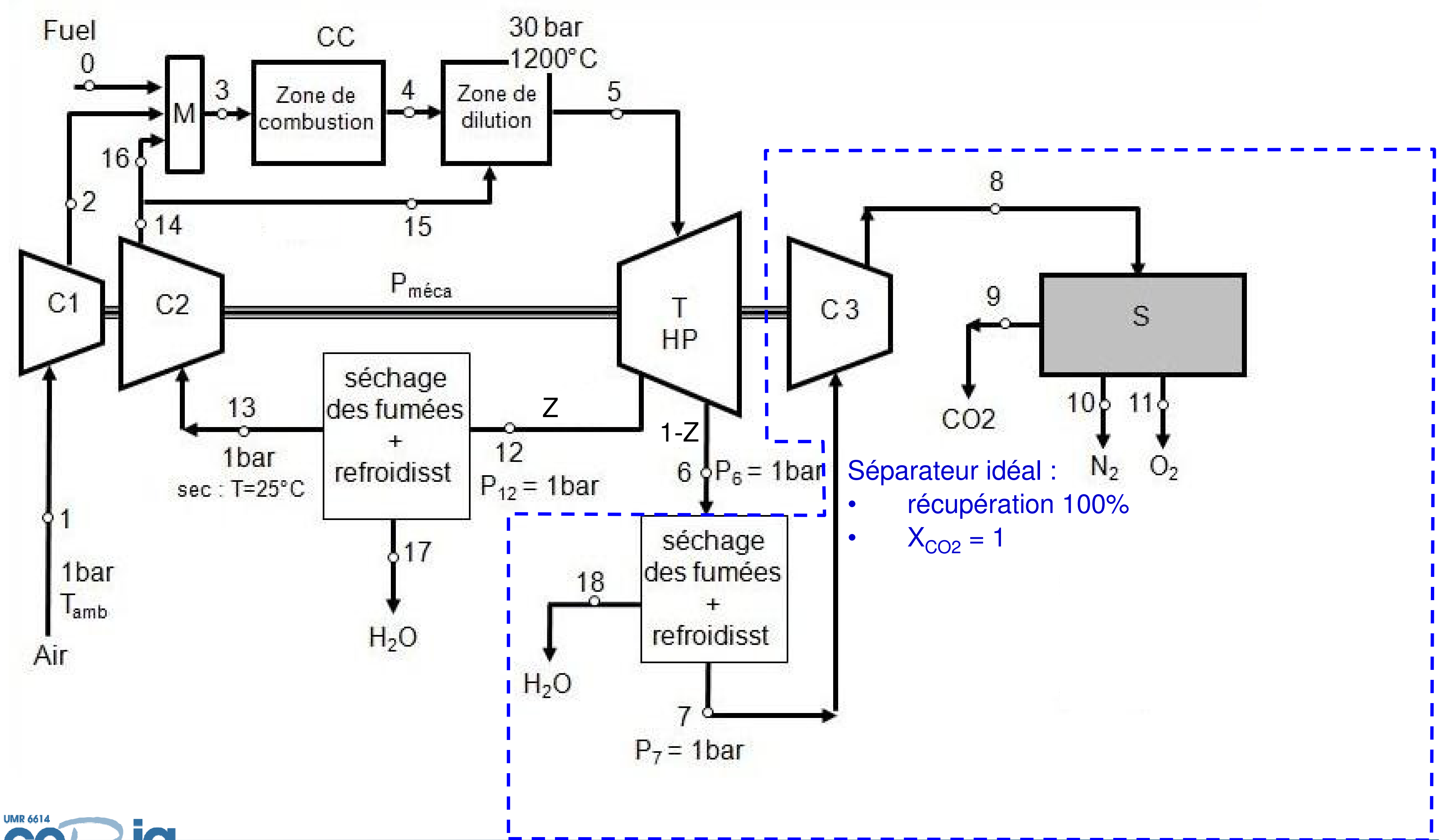


Impact énergétique de la récupération du CO_2

Cycle turbine réaliste + recyclage + recompression - capture CO_2(idéal)

: P_3 = HP= 30bar, P_1=P_2 = P_{atmo}, T_4 = 1200°C

$\eta_{is\text{-}compresseur}$ = 0.9, $\eta_{is\text{-}turbine}$ = 0.9, $\Delta P_{Ch\ Comb}$ = 5%

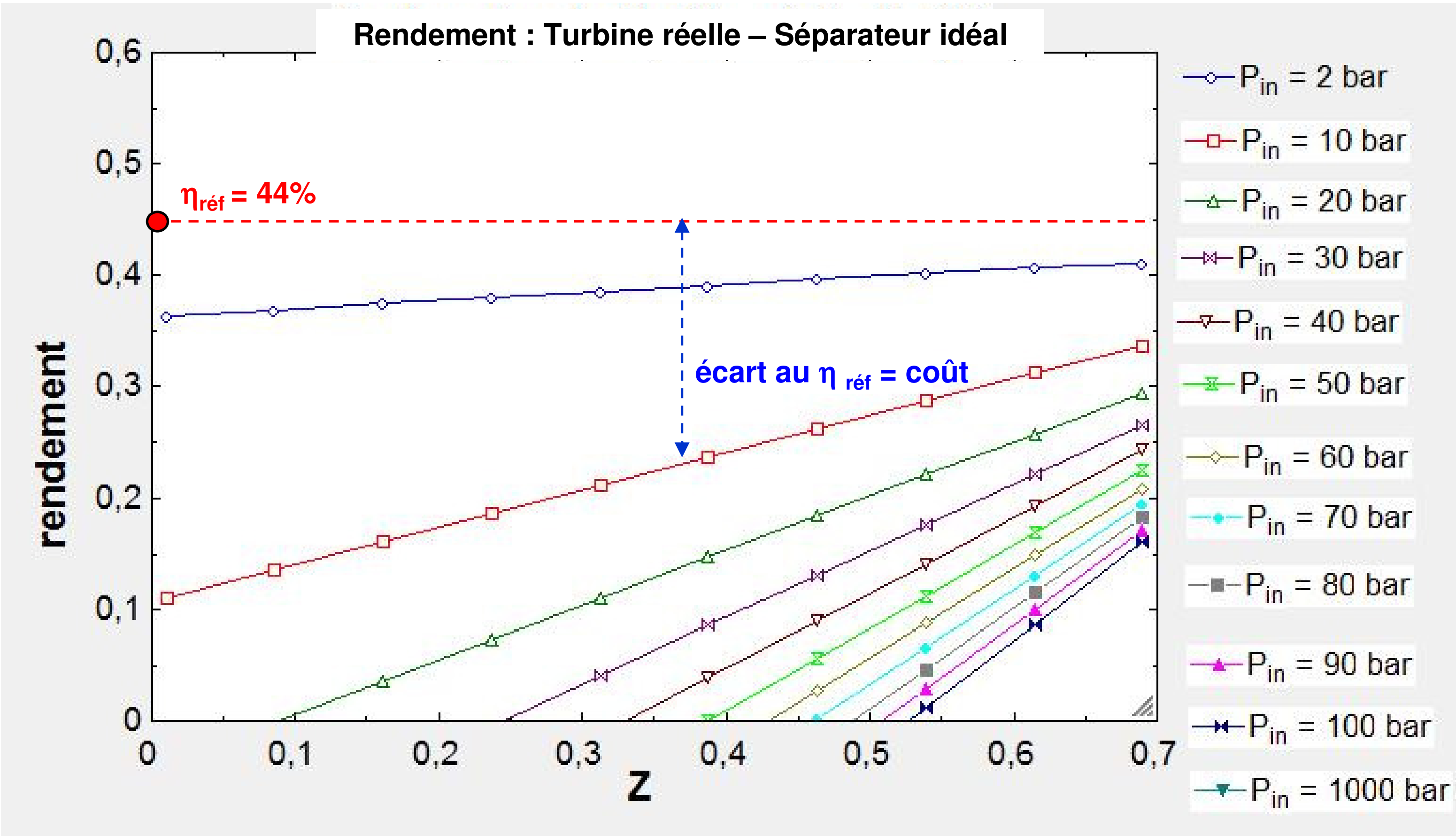


Séparateur idéal :

- récupération 100%
- X_{CO2} = 1

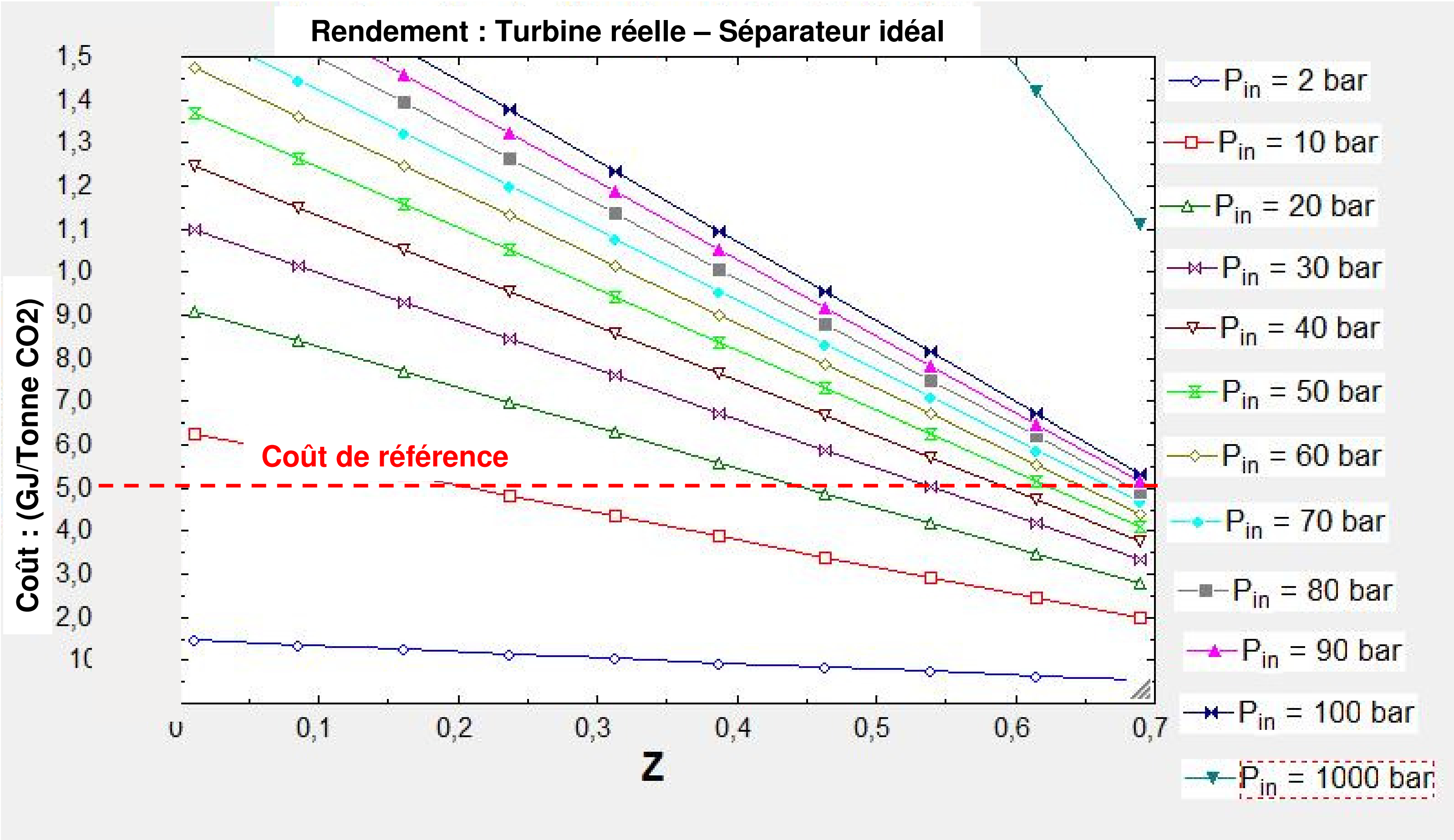
Impact énergétique de la récupération du CO_2

Impact du taux de recirculation Z et de la pression P_{in} en entrée du séparateur sur le rendement



Impact énergétique de la récupération du CO2

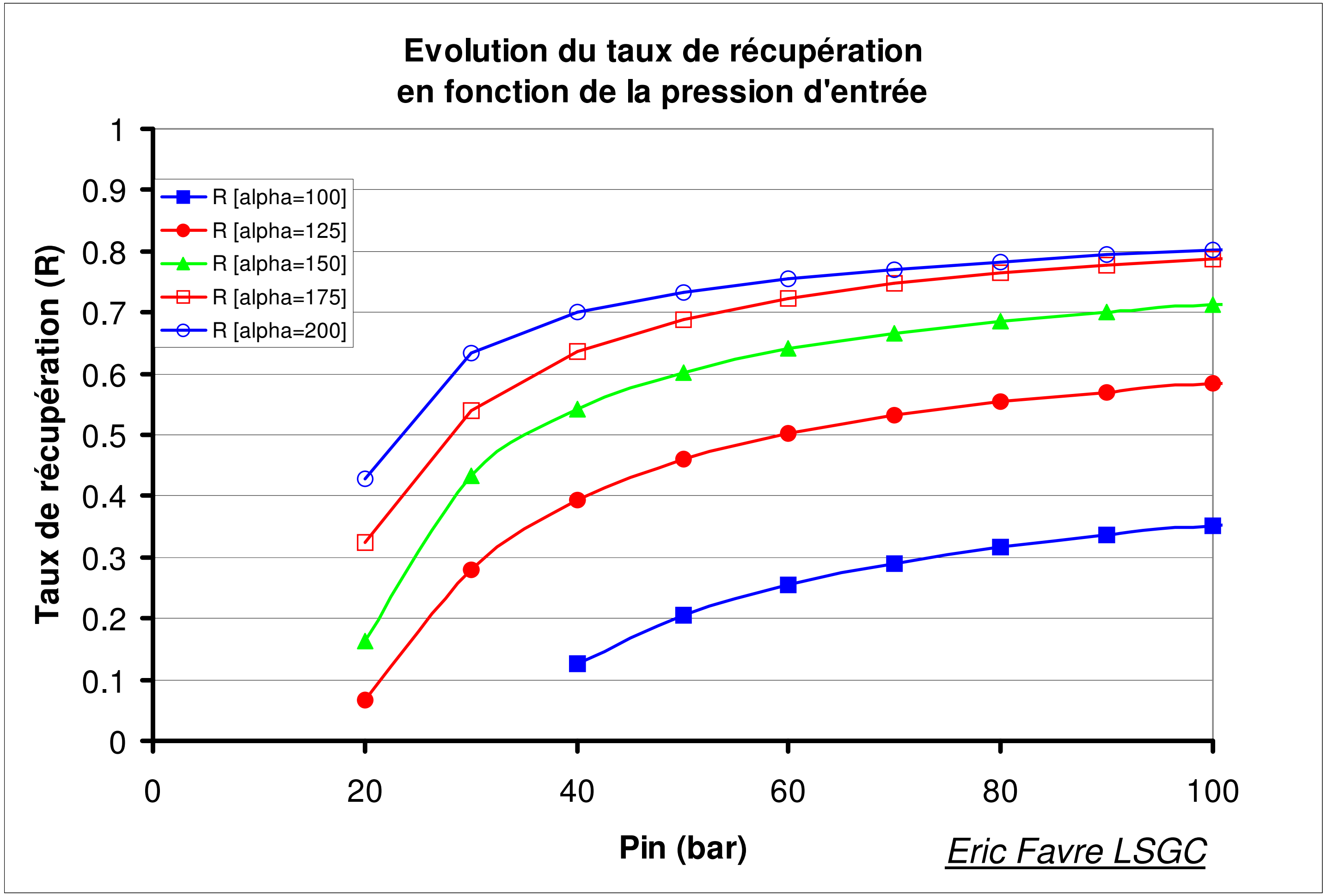
Impact du taux de recirculation Z et de la pression P_{in} en entrée du séparateur sur le cout de capture du CO_2



Impact énergétique de la récupération du CO2

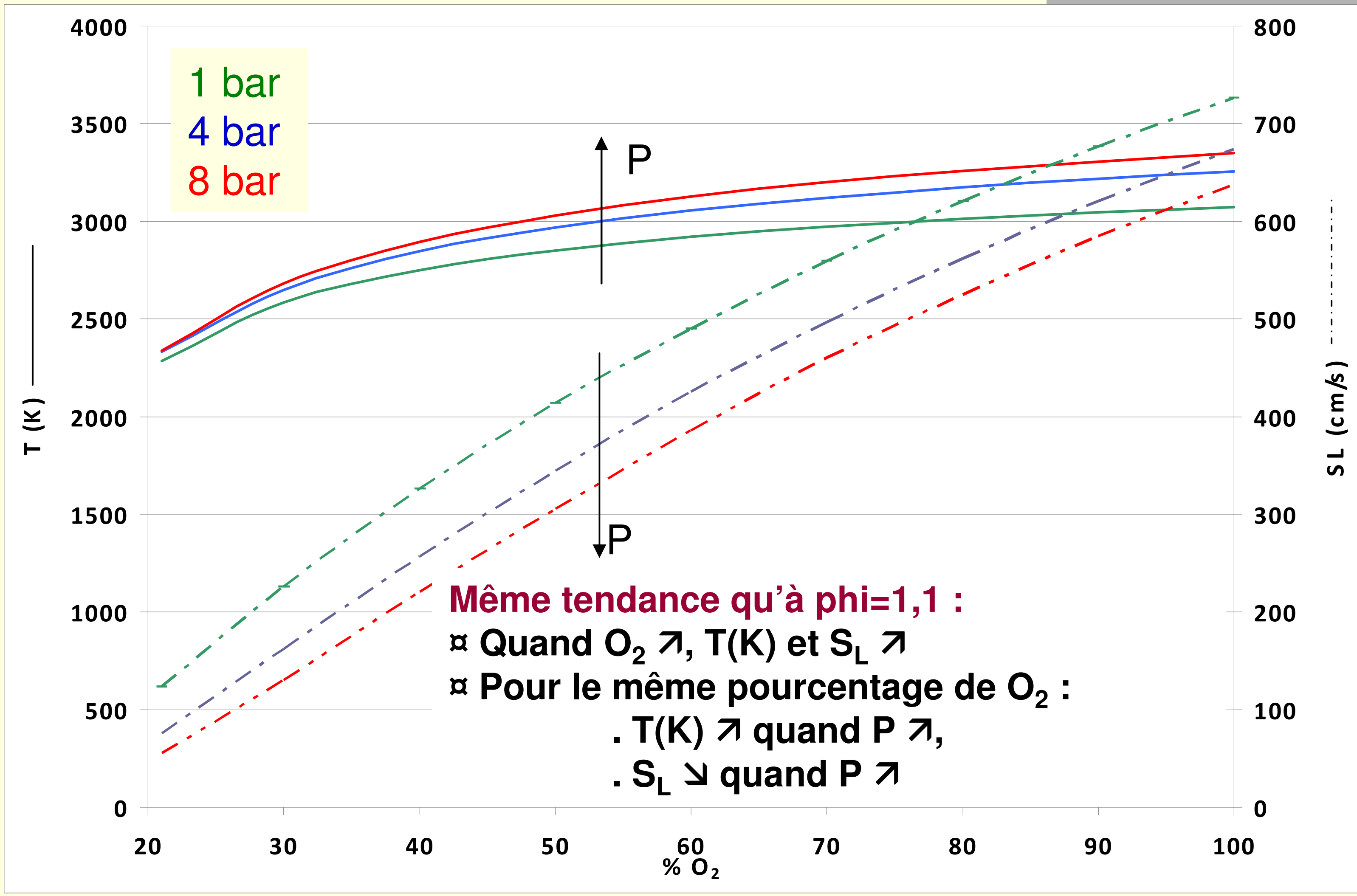
Taux de récupération de la membrane
en fonction de la sélectivité de la membrane et de la pression Pin (entrée membrane)

X_{in} = 0.11 maximale avec taux de recirculation maximale (0.7)
X_{out} = 0.9



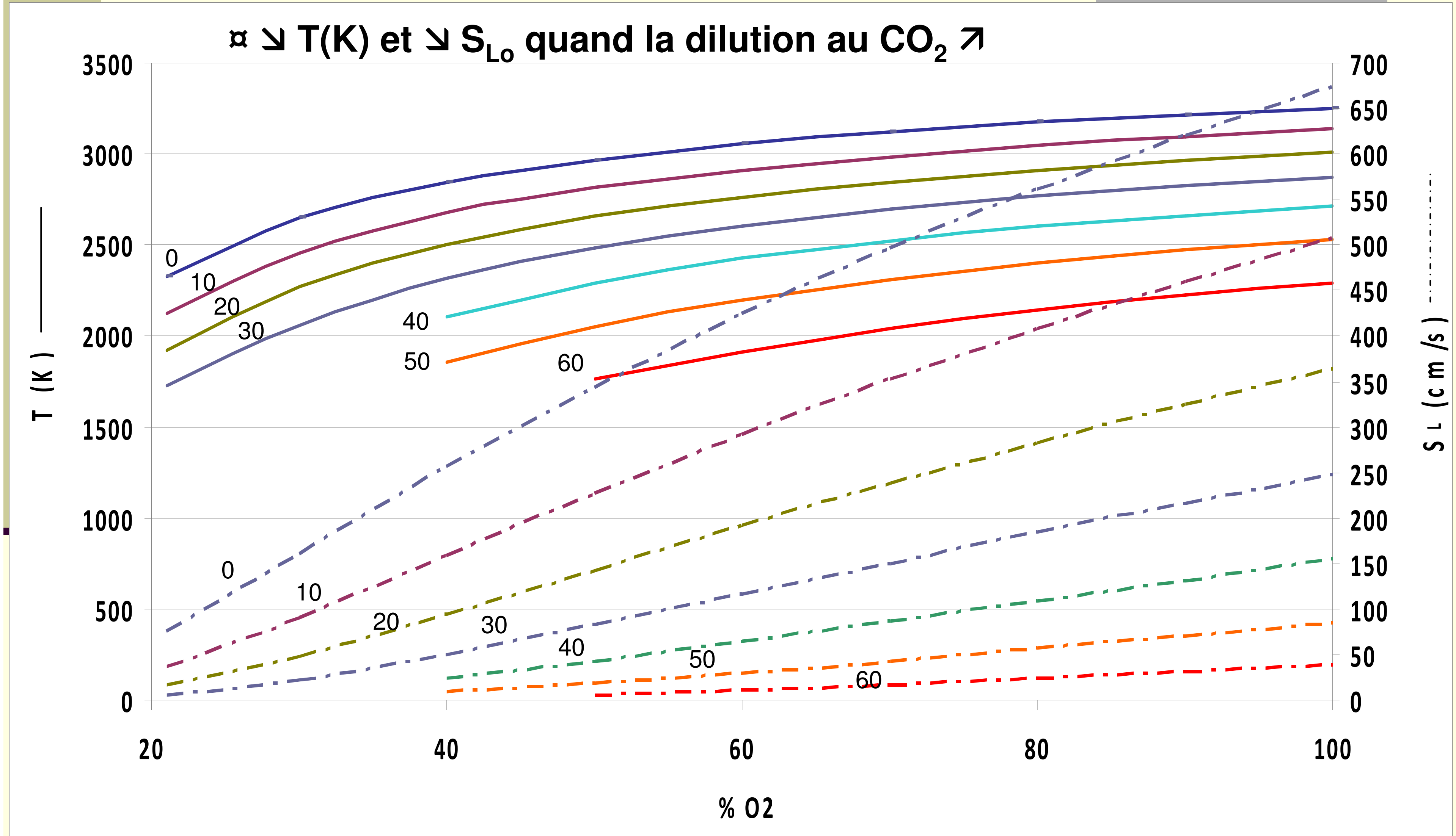
Résultats à phi=0,9 (condition n°1 : enrichissement seul)

Température et vitesse de flamme en f° du %O_2 dans l'air (1, 4, 8 bars), T_o=600K



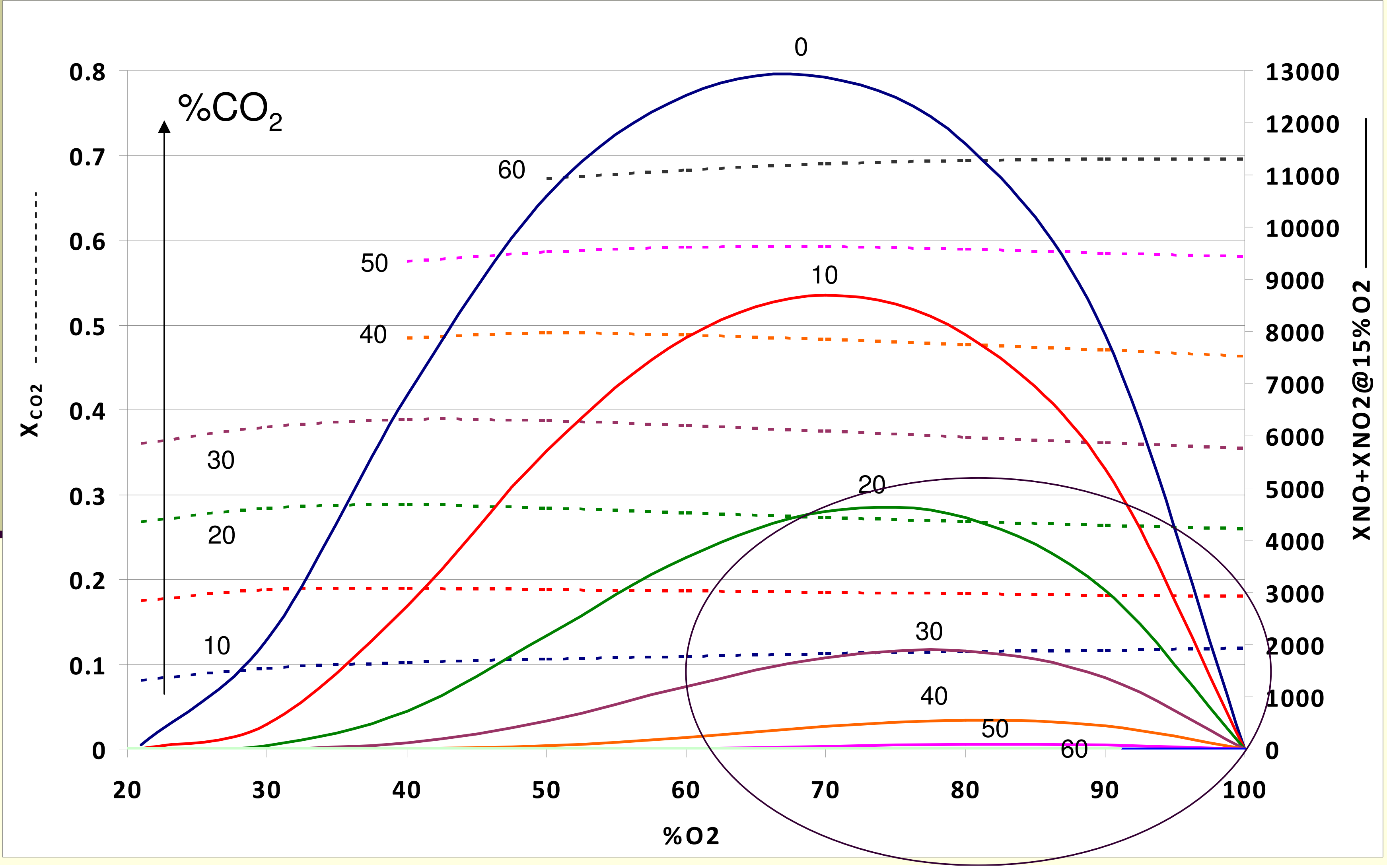
Résultats à phi=0,9 :

Température et vitesse de flamme en f° du %O_2 dans l'air, T_o=600K, avec ou sans dilution (4 bars)



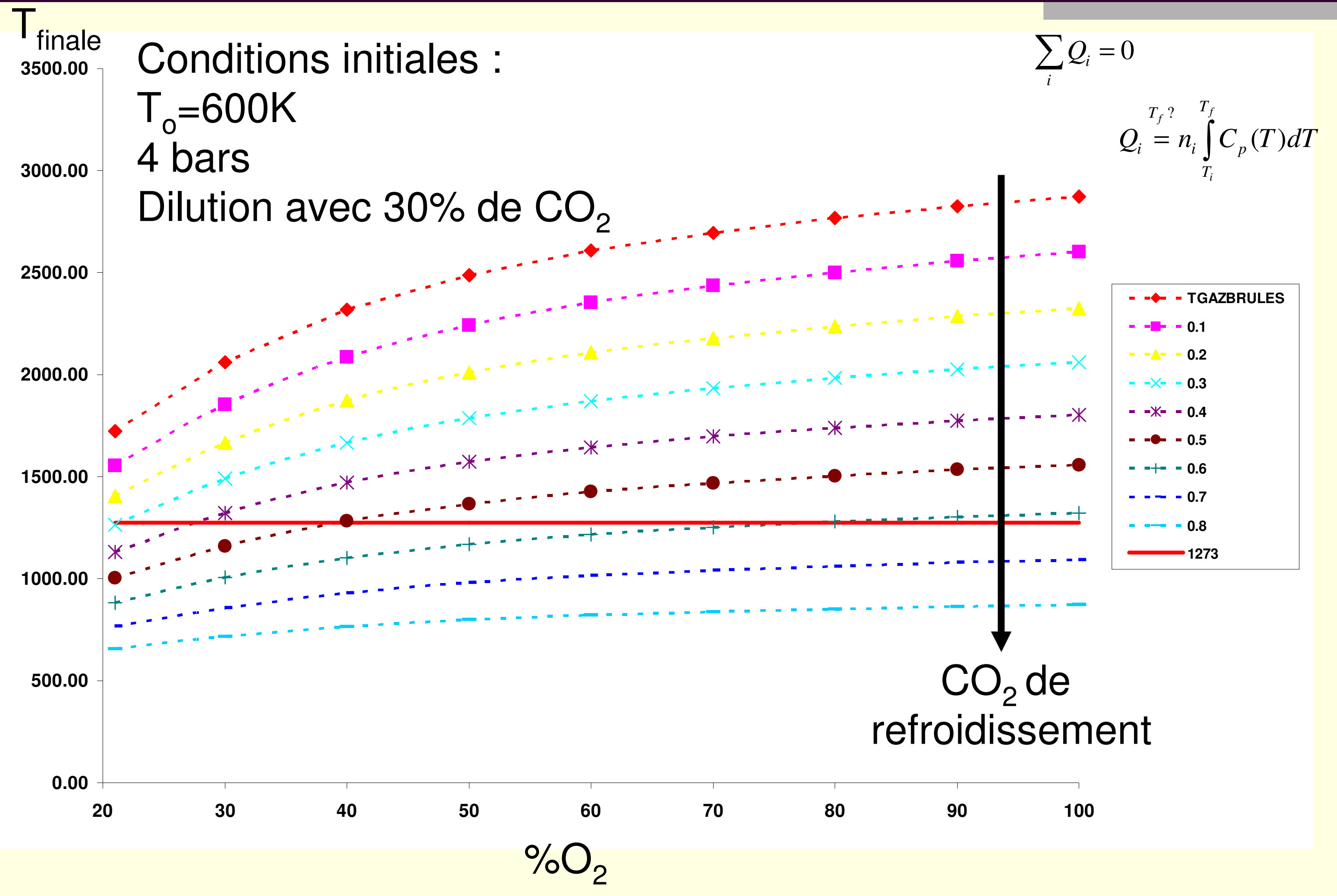
Résultats à phi=0,9 :

CO_2 et NOx (Thomsen) en f° du %O_2 dans l'air, T_o=600K, avec ou sans dilution (4 bars)



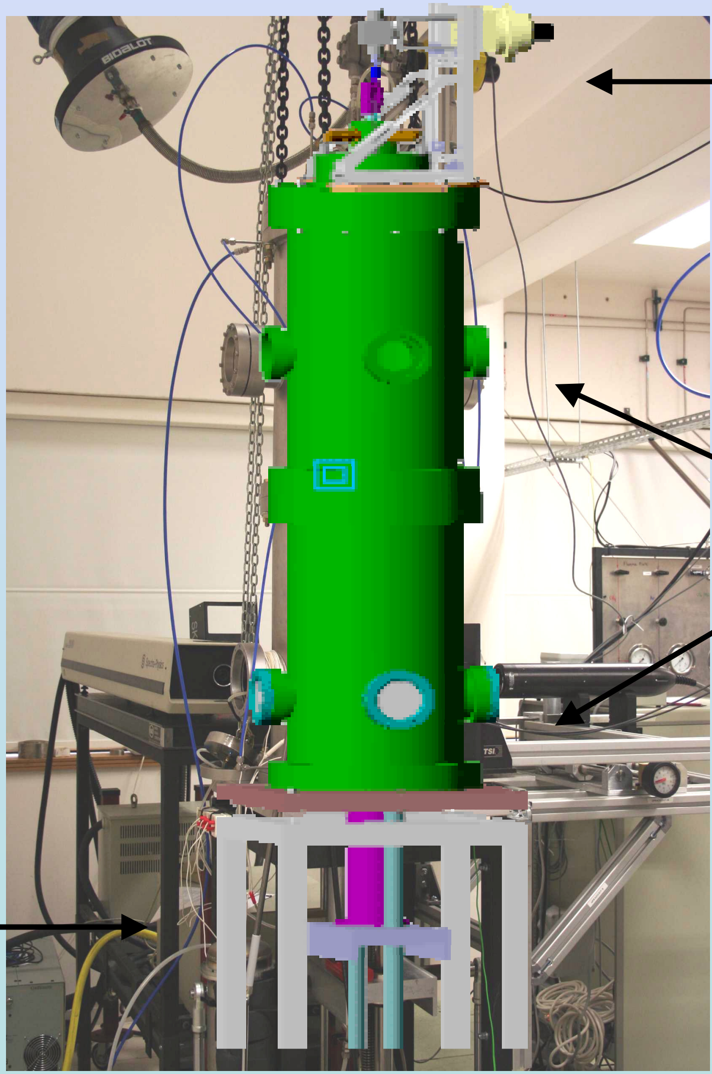
Résultats à phi=0,9 :

Refroidissement : environ 60% de CO_2 froid (300K) nécessaire quelle que soit la pression et les conditions



High Pressure Chamber

- H = 1.2 m
- D_{int} = 0.3 m
- Water cooling system
- Windows heating system
- Laser light absorbing paint



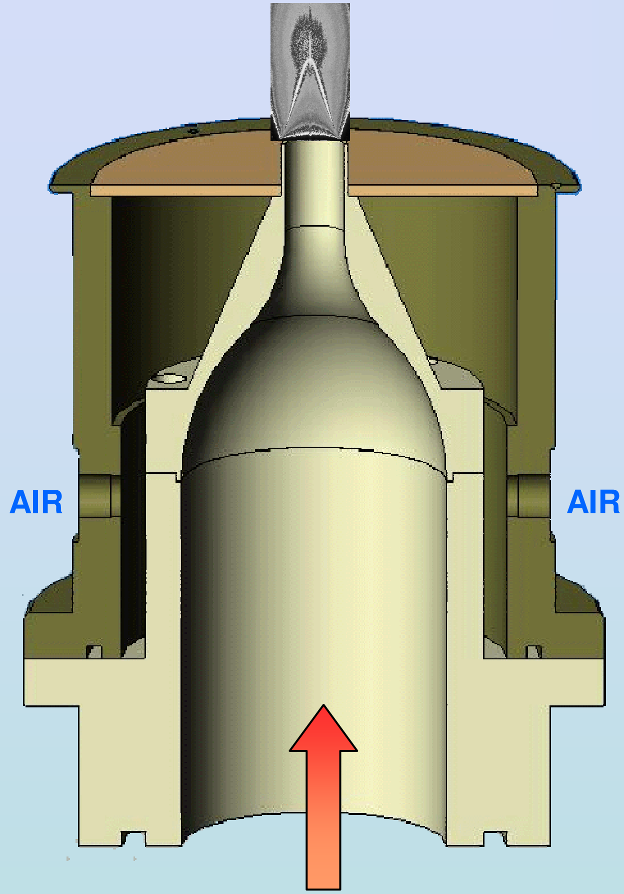
Laminar Burner

Experimental conditions

- U_0 = 0.7 à 1 m/s
- ϕ = 0.9 à 1.05
- P < 0.2 MPa
- Re < 1300

Characteristics

- Bunsen Burner
- D = 12 mm



Objectives

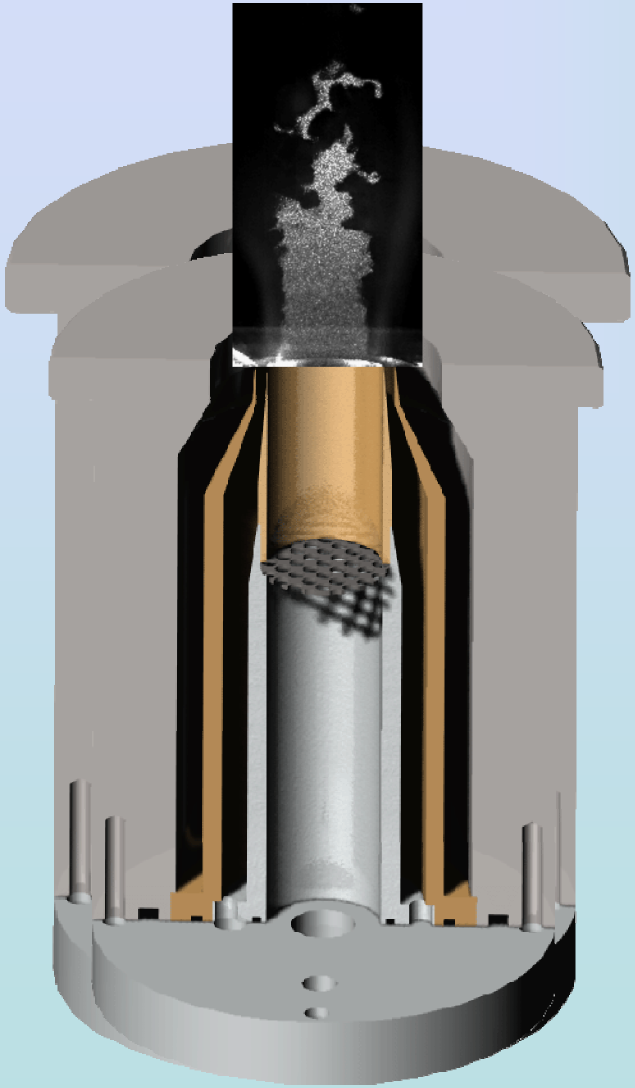
Study of the Flickering

High Pressure

Turbulent Burner

<u>Experimental conditions</u>

- $U \approx$ 2.1 m/s
- ϕ = 0.6 à 0.7
- P = 0.1 à 0.9 MPa
- Pilot flame flow < 7% Main flow
- T = 300 K
- u' et L_U cste



Flow conditions

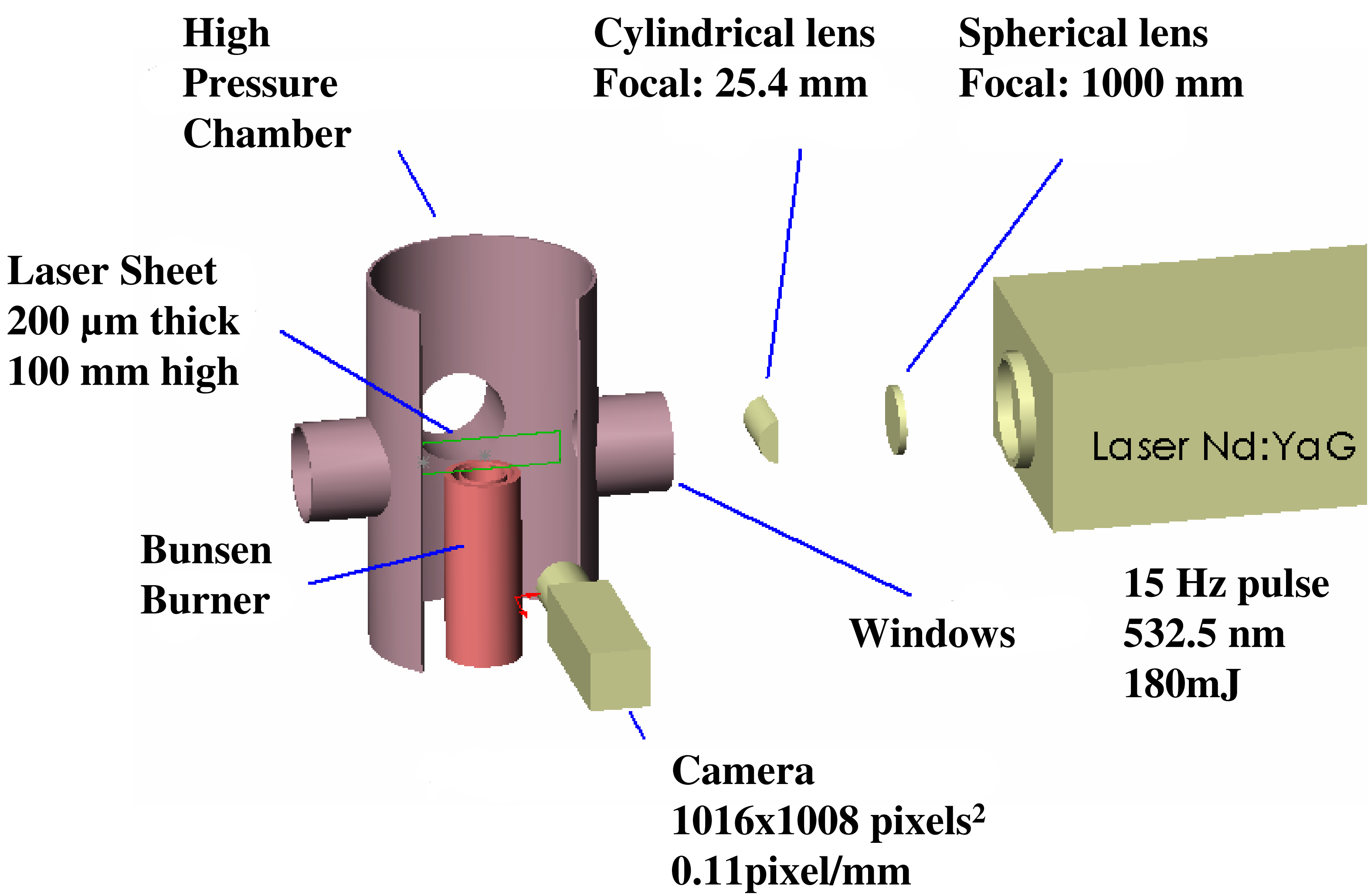
- Mean flow velocity :
  - U_0 = 0.7 to 1 m/s (Laminar)
  - $U \approx$ 2.1 m/s (Turbulent)
- Equivalence ratio :
  - ϕ = 0.9 to 1.05 (Laminar)
  - ϕ = 0.6 (Turbulent)
- CO_2 addition :

$$(1-\beta)\left[CH_4 + (2+x)(O_2 + 3.78N_2)\right] + \beta CO_2$$
$$\rightarrow CO_2 + 2(1-\beta)H_2O + 7.56(1-\beta)N_2 + x(1-\beta)(O_2 + 3.78N_2)$$

where $\beta = \dfrac{n(CO_2)}{n(CH_4) + n(CO_2)}$ and x the air excess

- Pressure :
  - P < 0.2 MPa (Laminar)
  - P < 0.9 MPa (Turbulent)
- Temperature of fresh gases : 300 K

Laser diagnostics

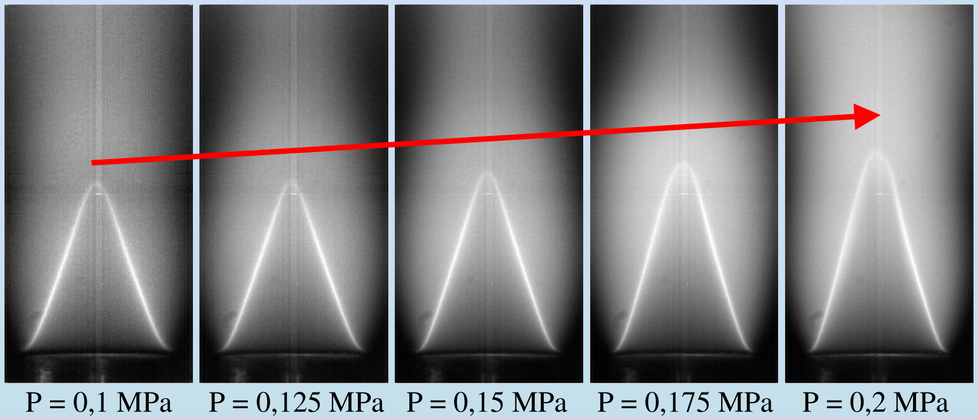


Methodology

- Camera CCD : 40 Hz – Resolution : 34.8 µm/pixel
- 500 images for each experimental condition

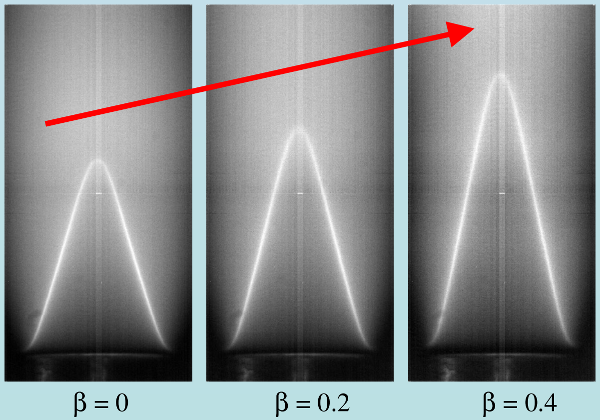
Pressure effect

(U_0=1 m/s et ϕ= 1)

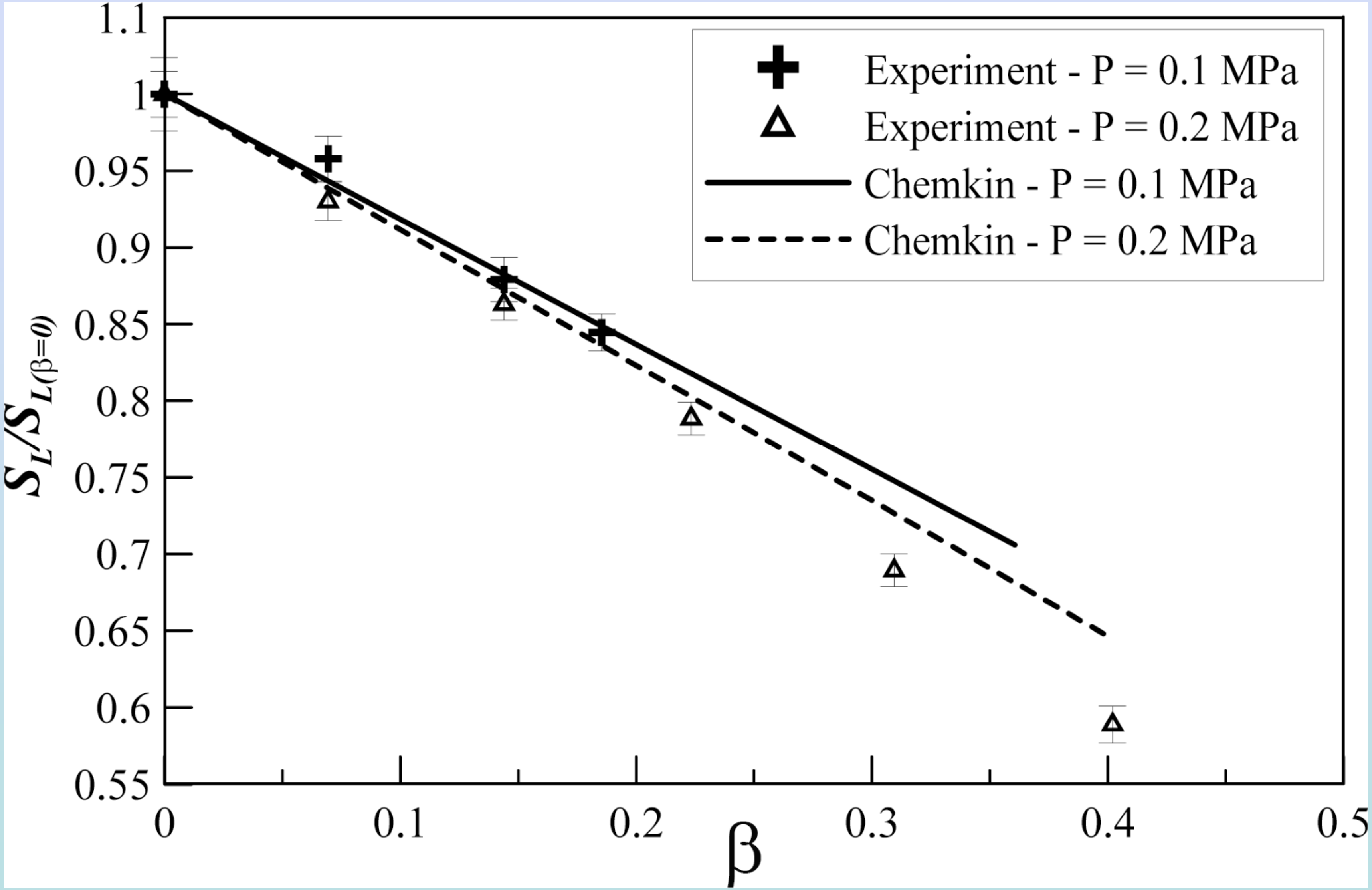


CO_2 addition effect

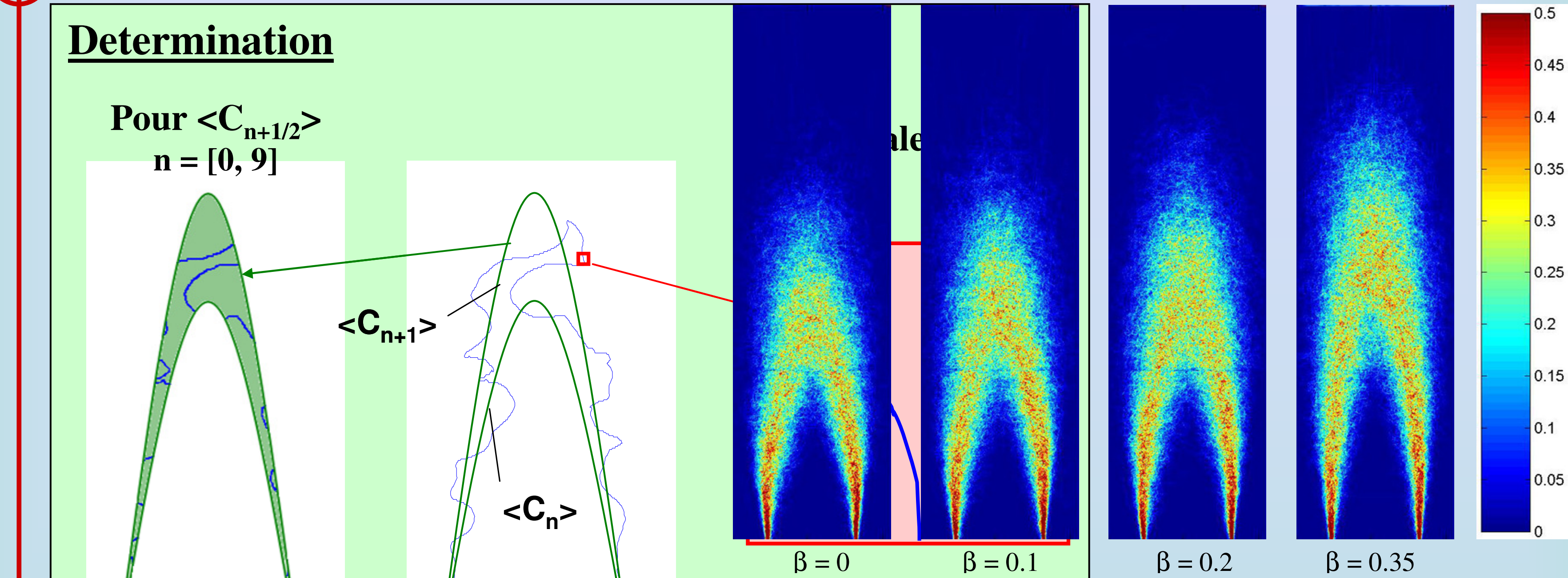
(P=0.1MPa - ϕ=0.95 - U_0=1.2m/s)

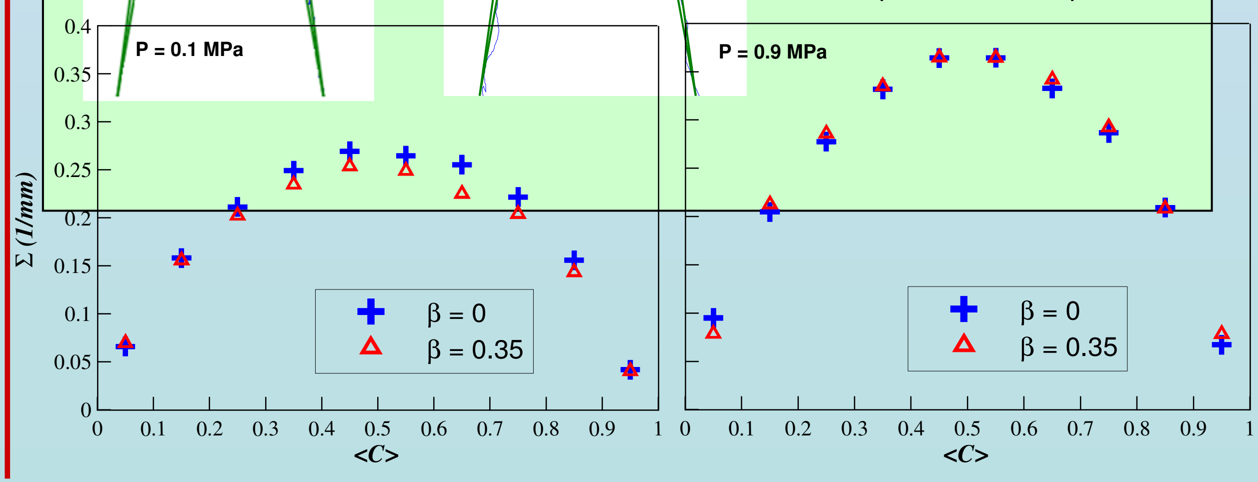


Laminar flame velocities



Flame surface density



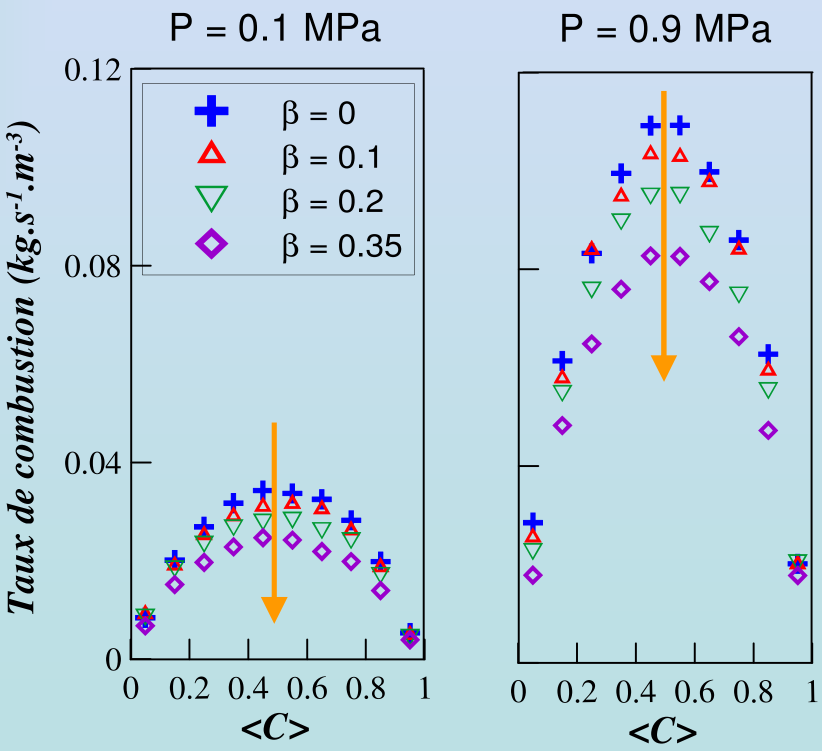


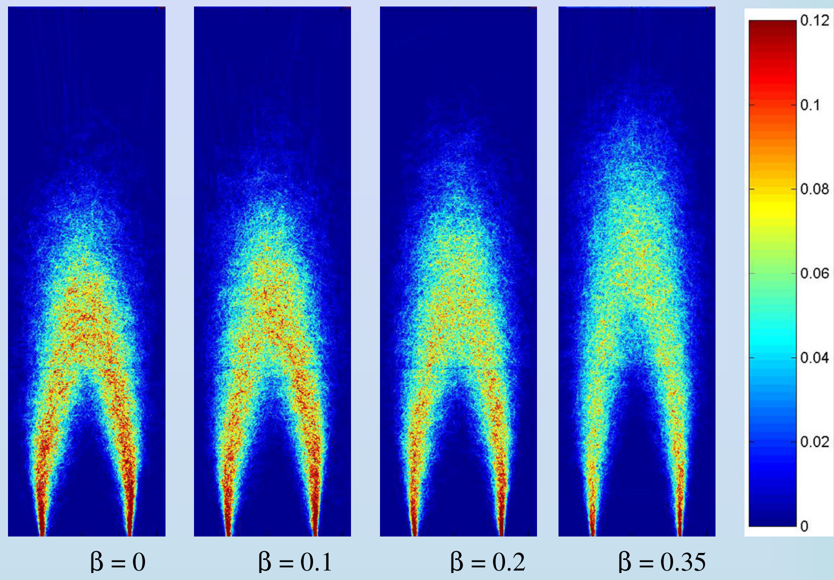
The CO_2 dilution has no effect on the flame surface density.

BML Model

Mean reaction rate

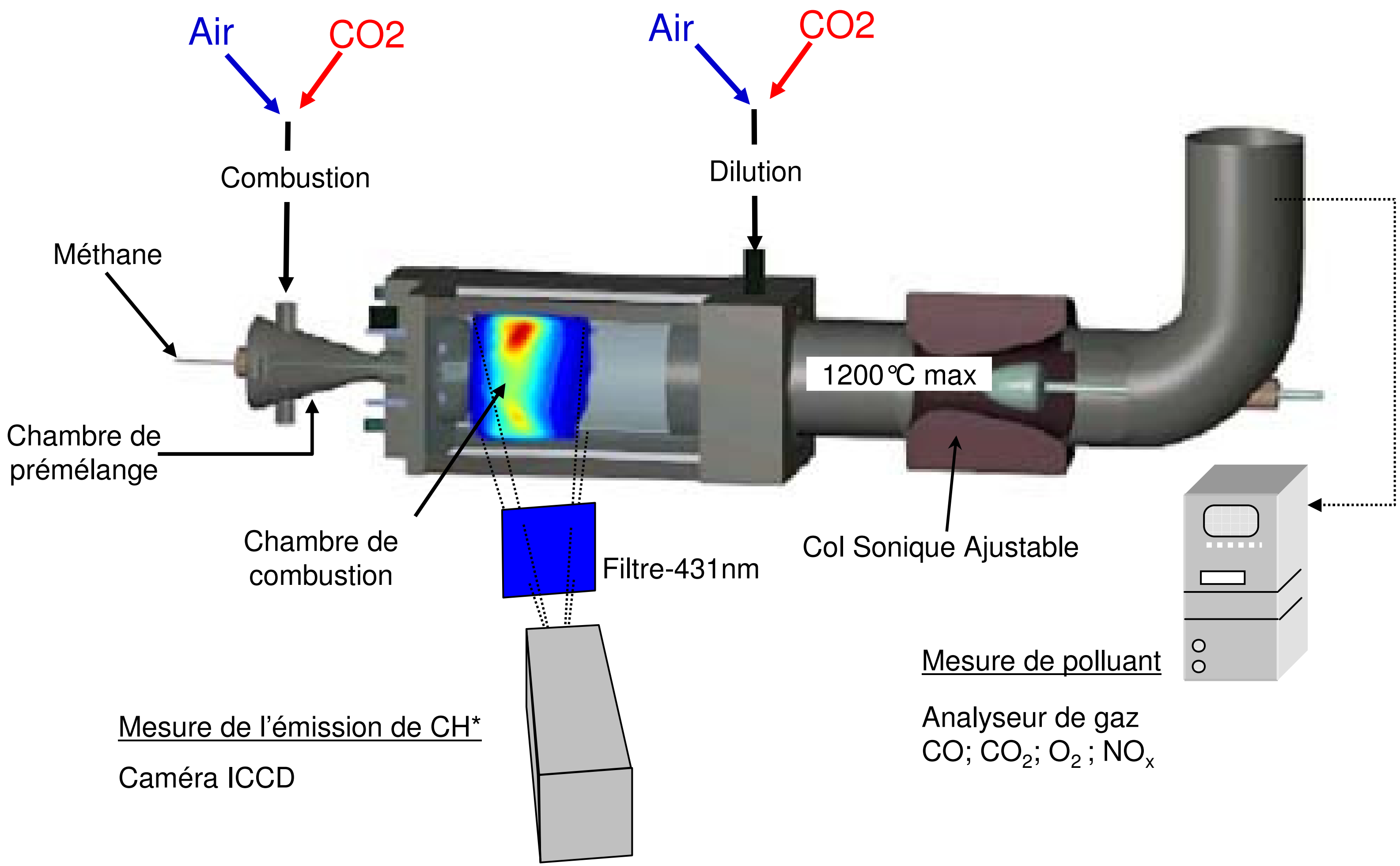
$$\langle w \rangle = \rho_{GF} \cdot S_L^0 \cdot I_0 \cdot \Sigma$$





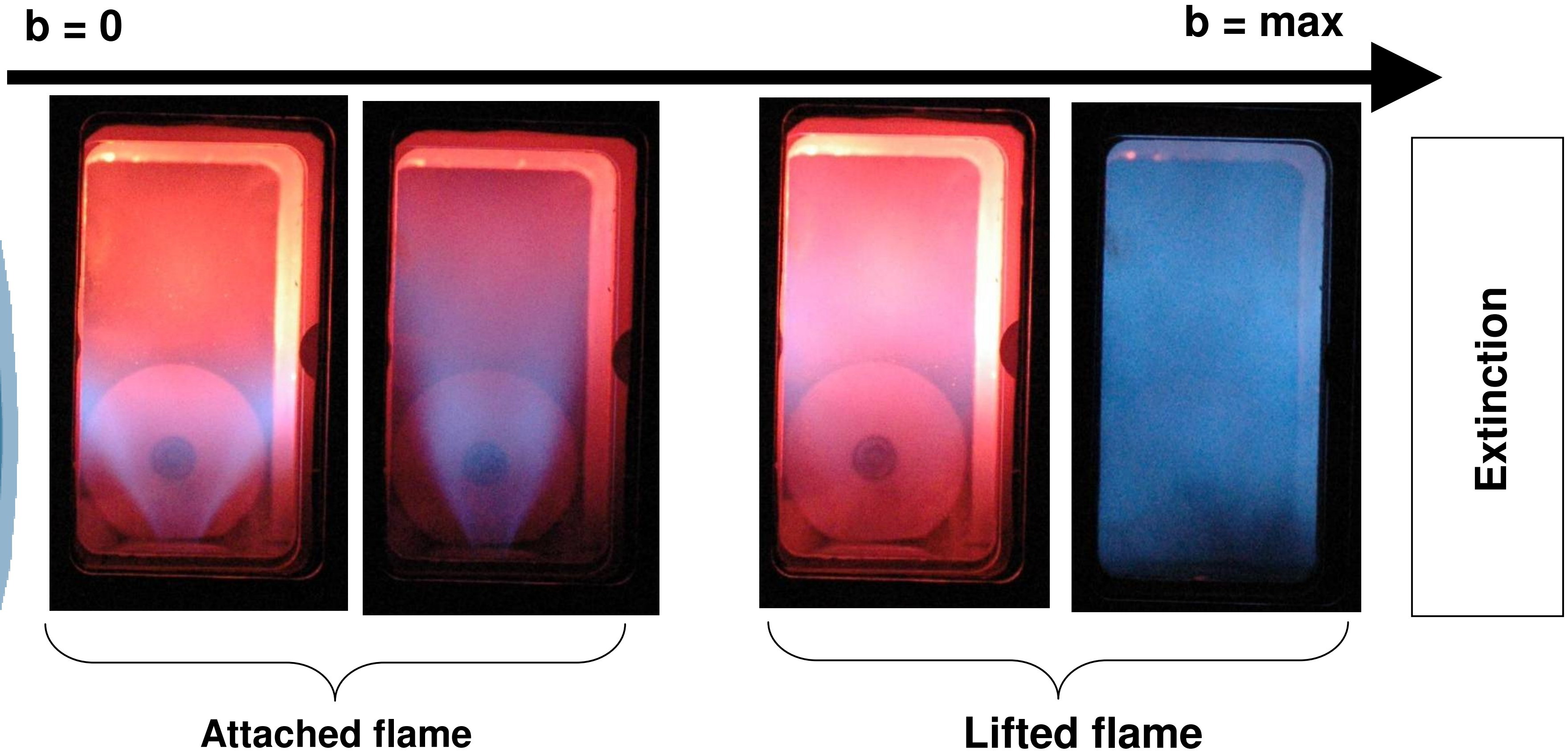
- Mean fuel consumption rate decrease with the dilution rate
- Power at 0.1 MPa = 2.2 kW (theoretical = 2 kW)
- Power at 0.9 MPa = 12 kW (theoretical = 14 kW)

Gas turbine combustion chamber facility of CORIA-CNRS, Rouen



$$CH_4 + (1+e)\ 2\ (\ O_2 + 3.78\ N_2 + b\ CO_2\ )$$

Evolution of turbulent flame structure with CO2 dilution rate, at contant equivalence ratio



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Topic ENERGY.2008.6.1.3: Efficiency Improvement of Oxygen-based combustion

Content/scope: Further research and demonstration work is needed on oxygen based combustion technologies in respect to the CO2 capture process to make this technology available for large scale power plants. Work in this area should include – but not be limited to - issues like advanced burner designs as well as slagging, fouling and corrosivity of flue gases, the identification of the optimal CO2 capture rate, combination of CO2 capture with other gas cleaning processes and processes for separation, compression and conditioning of CO2. It is envisaged that a project under this topic will test, demonstrate and further develop existing technologies in a medium sized test environment. Scalability of the results to large scale power plants has to be in the focus of the activities.

Funding scheme: Collaborative project with a dominant demonstration component.

Expected impact: Oxygen-based combustion technologies can play an important role for CCS. Projects under this topic shall further develop these technologies and test them in small scale demonstration plants and thereby pave the way for their use in industrial scale power plants.

Open in call: FP7-ENERGY-2008-2

Why oxy-fuel lignite combustion ?

- To improve the efficiency of lignite combustion; retrofitting possible; rapid benefits for electricity production for countries such as Turkey and Greece
- To ease CO2 capture
- less NOx as recycled NO (fuel NO) is burned out and no thermal NOx (no N2)
- EOR
- Enhanced CBM

Issues (1)

- Retrofit is possible and demonstrated in pilot scale systems. O_2 is mixed with a fraction (important about 65%) of the flue gases (CO_2 and H_2O mainly or if after condensation mainly only CO_2). This helps to reduce the flame temperature and obtain flame conditions equivalent to air burning. As the CO_2 and H_2O thermal capacities are higher than that of N_2, more O_2 concentration is needed to obtain full conversion. It is possible to adjust the O_2 and flue gas concentration to match the heat transfer parameters to that of air burning

Issues (2)

- As the flow physical parameters are different between air and recycled flue gas and oxygen mixture, if we want to match the heat transfer rate, the flow rates will be different. Therefore a new burner design is necessary
- SO_2 SO_3 emissions may increase, corrosion should be handled
- Heat transfer parameters may also need adjustment; no air in leakage should be allowed, so the boiler should be very well sealed

Issues (3)

- ASU (air separation unit) is the most energy consuming part, 95% O_2 is generally used to reduce the cost penalty
- Also for CO_2 recycling and capture compressors are necessary
- Therefore, oxy-fuel coal burning with CCS gives clearly a lower energy efficiency compared to air burning
- But CCS with air burning and amine based systems is even more costly; then we have to compare comparable issues

Issues (4)

- The efficiency issue should be considered globally. With oxy-fuel combustion we shall burn much more efficiently the lignite. Combustion studies should be done
- Captured CO2 should be used intelligently: for EOR, for ECBM, for inclusion into cement and concrete production, for ex-situ carbonation etc. We have to increase the value of the whole chain by using CO2 as a commodity

Issues (5)

- We need to chose a demonstration site for oxy-fuel lignite combustion: SOMA A: EUAS, TKI
- Compatible power level with the FP7 requirements: 22 MW with several burners of the MW level
- Pulverized lignite with oxy-fuel retrofitting, dissemination and scalability potential
- Enhanced CBM potential in the area…

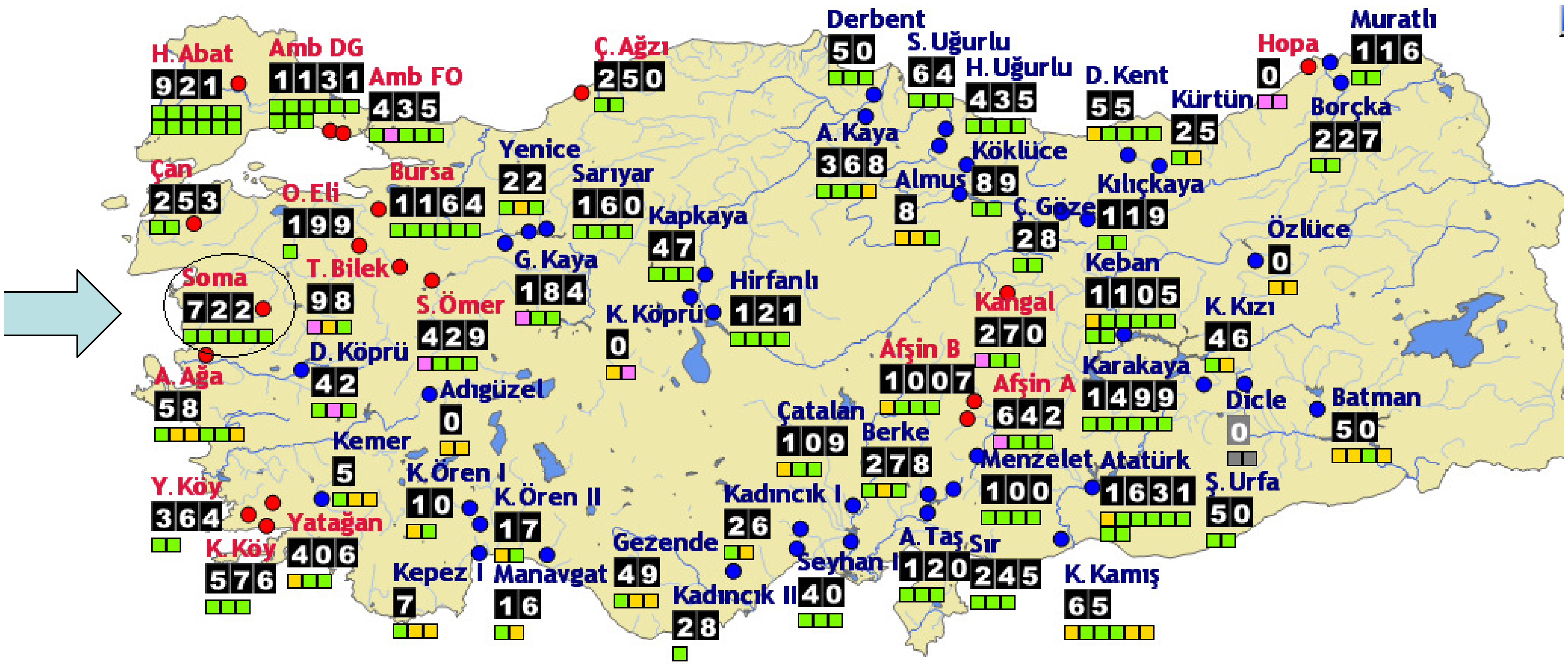
SOMALOX

- A proposal for FP7 ENERGY TREN 2008 to demonstrate retrofitting the SOMA A pulverized lignite power plant (22 MW) to oxy-fuel combustion

- Partnership: AEE, RWE NPower, CKD Export, ENEA, TKI, EUAS, HABAS, CNRS, NTUA, JRC-IE, Cottbus, Nottingham…

Where is SOMA ?

150 km north-east of Izmir



SOMALOX Work package structure

- WP I: Simulation of the optimisation of the SOMA A power plant for oxy-fuel lignite combustion retrofitting
  Simulation of the global process
  Optimisation of the lignite preparation for oxy-fuel combustion
- WP II Optimisation of oxygen production, gas cleaning, CO_2 capture
- WP III Optimisation of the oxy-fuel lignite burner
- WP IV Retrofitting and Demonstration at the plant level
- WP V Economic, Environmental, Dissemination, Scalability analysis

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THE NINTH ASIA-PACIFIC INTERNATIONAL SYMPOSIUM ON COMBUSTION AND ENERGY UTILIZATION (9th APISCEU)

November 02-06, 2008
Beijing, China

Organized by
Beijing Society of Thermophysics and Energy Engineering, China
Institute of Engineering Thermophysics, Chinese Academy of Sciences
Beijing Shenwu Thermal Energy Technology Co, LTD, China
Yanshan Petro-Chemical Industry Corporation, China
The Combustion Institute, USA
Sponsored by
Beijing Association for Science and Technology, China

Internet: http://www.APISCEU9.org.cn

10th ICCEU

- 10th International Conference on Combustion and Energy Utilisation
- Will be organized at the University of Mugla, Turkey, on 4-8 May 2010
- Main topic: Clean fossil fuel technologies : (technical and socio-economic aspects)
- Contact: Iskender Gökalp

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