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IGNITION DELAY OF COAL PARTICLE JETS IN OXY-FUEL CONDITIONS

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Introduction

- Clean coal technologies →oxy-fuel combustion (CCS)

- Need to improve the understanding of coal combustion in oxy-fuel conditions through the use of advanced experimental facilities able to provide data under operating conditions (i.e. temperatures and heating rates) similar to industrial ones.
  - Entrained flow reactors (EFR):
    - They usually provide conversion as a function of operating conditions
    - They need sophisticated experimental techniques or tedious procedures to derive kinetics

- Most of EFR studies focuses on single solid fuel particle behaviour…but in industrial furnaces, pulverised coal particles are fed in dense streams

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Objectives

- To use a simple optical technique (Optical Diagnostics for Combustion - ODC) and related analysis to derive information on the combustion of coal clouds in air and oxy-fuel conditions in an entrained flow reactor (Isothermal Plug Flow Reactor - IPFR) thus with temperatures and heating rates similar to industrial ones.

- So far ODC has been successfully applied to gas combustion, especially to study thermo-acoustic instabilities in gas turbines. However it is the first time that ODC is applied for the characterisation of coal combustion.

→feasibility of the technique for coal combustion?

→'clever' design of the experiments?

→quantitative information?

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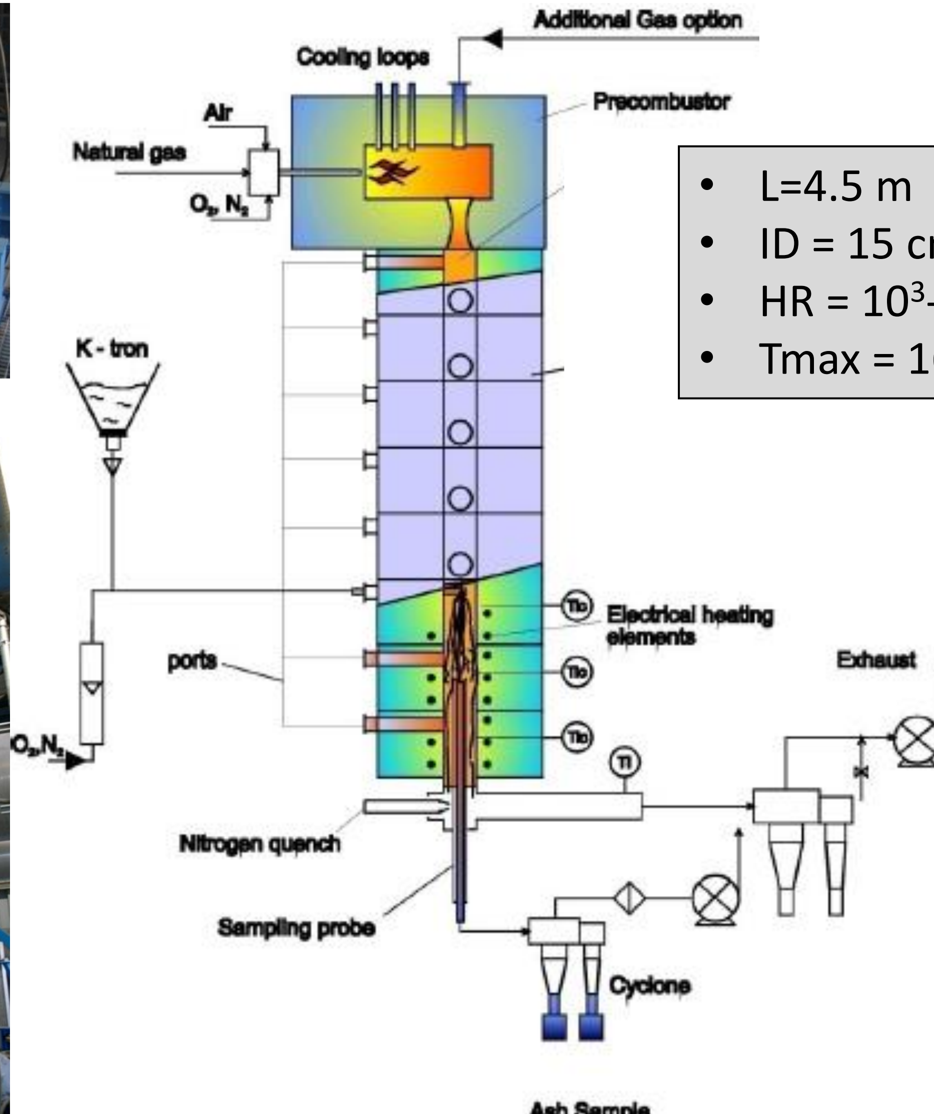
Isothermal Plug Flow Reactor



- L=4.5 m
- ID = 15 cm
- HR = 10^3-10^4 K/s
- Tmax = 1673 K

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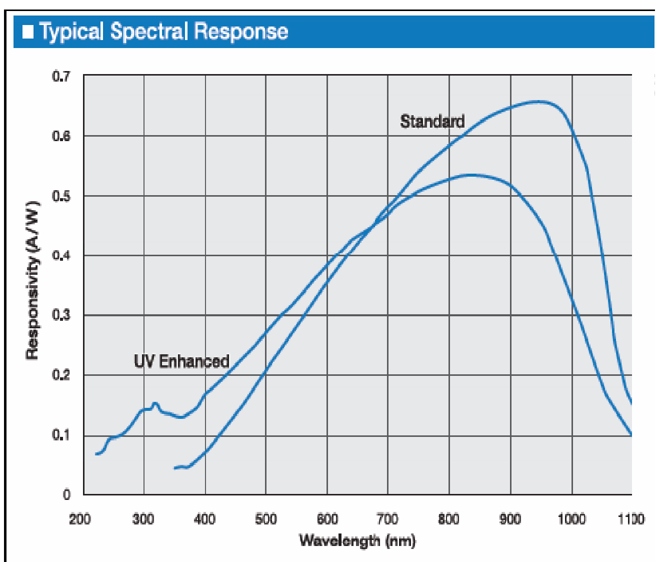
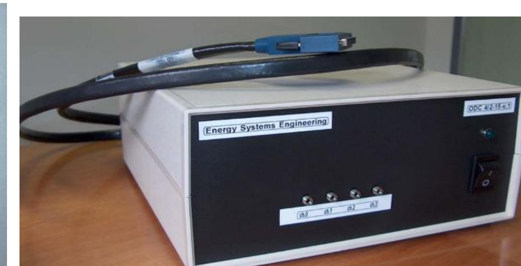
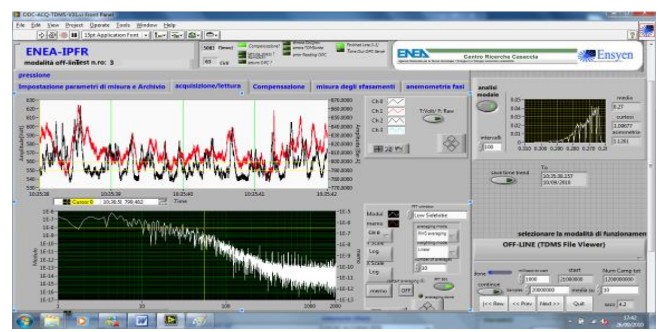
Optical Diagnostic of Combustion (ODC)

- Developed by ENEA
  - based on a photodiode which detects the radiant energy in the spectral range from UV to near IR (200 nm to 1100 nm).
  - very high sampling frequency, i.e. 5 MHz.
- Signal processing through sub-routines in Matlab® package.







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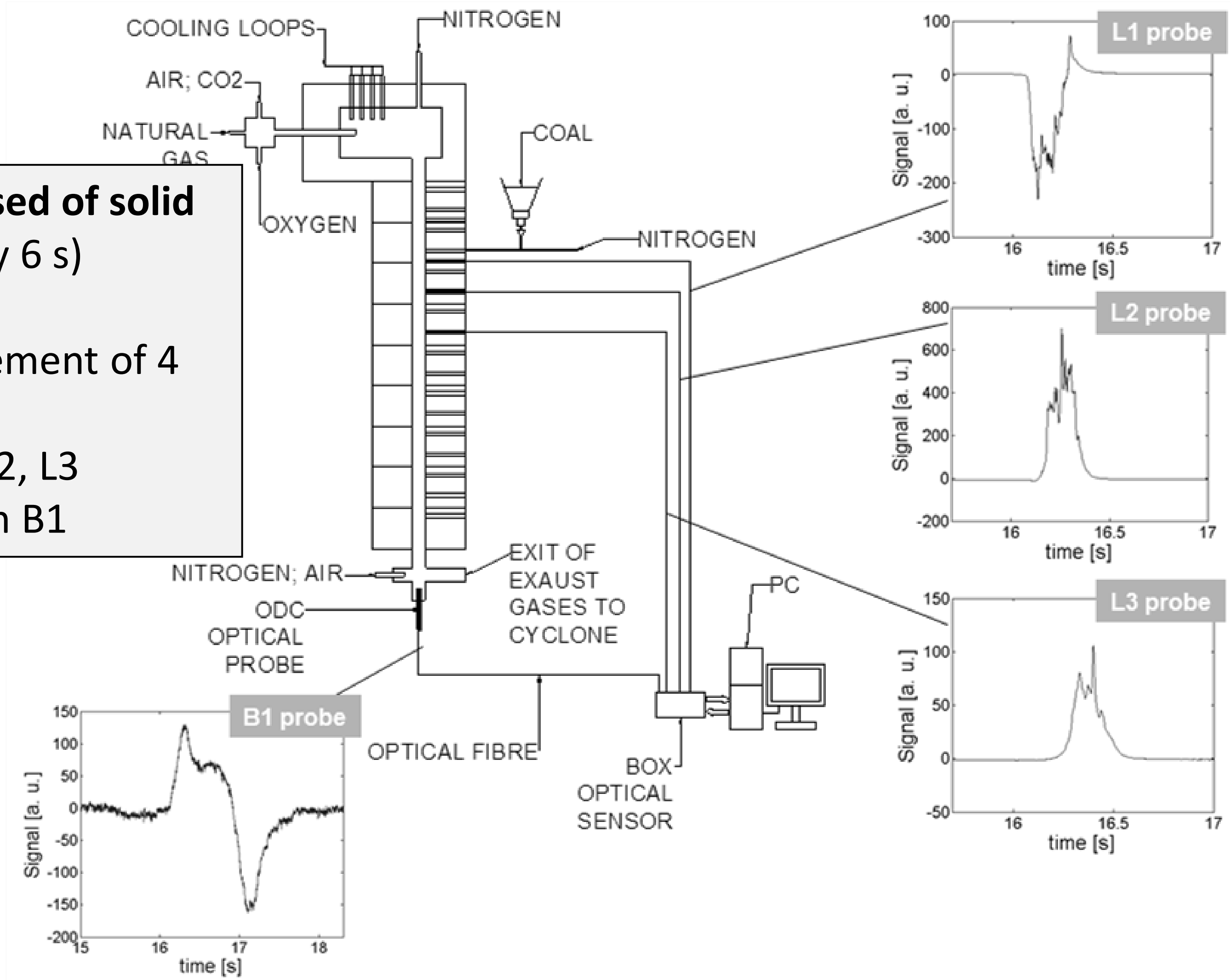
Design of Experiments

Feeding of **pulsed of solid particles** (every 6 s)

Special arrangement of 4 probes
- 3 lateral L1, L2, L3
- 1 from bottom B1



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Experimental campaigns

			pre-heating combustion section			Carrier			measurements			
d_p [μm]	T [K]	nominal Y_{O2} [% dry]	F_{GN} [Nm³/h]	F_{AIR} [Nm³/h]	F_{O2} [Nm³/h]	F_{CO2} [Nm³/h]	F_{N2} [Nm³/h]	F_{AIR} [Nm³/h]	CO_2 [% vol]	CO [ppm]	O_2 [% vol]	Φ [-]
38-90	1173	0	2.24	22.6			1.2		8.5	0.24	0.7	
		3	2.29	27.3			1.2		7.2	0.15	3.15	1.4
		6	2.19	30.3			1.2		7.6	0.13	6.31	0.75
	1373	0.5	2.17	21.5			1.2		10.1	1.06	0.41	
		3	2.17	24.9			1.2		8.8	0.26	3.05	1.75
		6	2.17	30			1.2		7.5	0.21	5.96	0.74
		9	2.17	35.8			1.2		6.9	0.15	9.15	0.47
		0	1.69		3.65	9	1.2		+	3.02	0.81	
		3	1.69		3.95	9	1.2		+	2.2	3.7	2.58
		6	1.69		4.3	9	1.2		+	2.12	6.63	2.13
		9	1.69		4.75	9	1.2		+	2.2	9.45	0.66
>125	1173	0	2.19	21.4			1.2		11.6	0.31	0.54	
		3	2.19	24.8			1.2		9.3	0.16	3.2	1.86
		6	2.19	30.3			1.2		7.8	0.08	6.32	0.75
	1373	0.5	2.17	21.4			0.6	0.6	10	0.53	0.73	
		3	2.14	24.9			1.2		8.7	0.25	3.12	1.78
		6	2.14	29.8			1.2		7.5	0.21	5.99	0.76
		9	2.14	35.4			1.2		6.9	0.17	9.09	0.48

Effect of reactor temperature, Y_{O2}, particle size and atmosphere (diluent)

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Feeding of groups of particles

- Group number

$$G = \frac{3 * \rho_g * R_c^2}{a^2 * \rho_p * \dfrac{\dot{m}_g}{\dot{m}_p}}$$

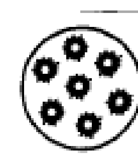
- ρ_g = carrier gas density
- ρ_p = solid fuel particles density
- R_c = radius of the cylinder of the carrier gas
- a = adius of the solid fuel particles
- m_g = massive flow of the carrier gas
- m_p = massive flow of the solid fuel particles
- n = numerical particle density.

All gas parameters are evaluated for the cold carrier gas.

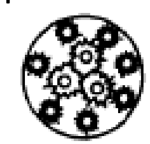
G = 9.7 for dp >125 μm

G = 40.1 for dp = 38-90 μm

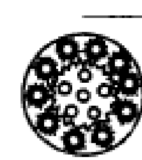
G<0.3 individual flame combustion



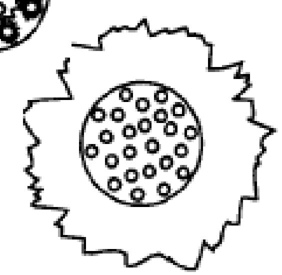
0.3<G<2 Incipient group combustion



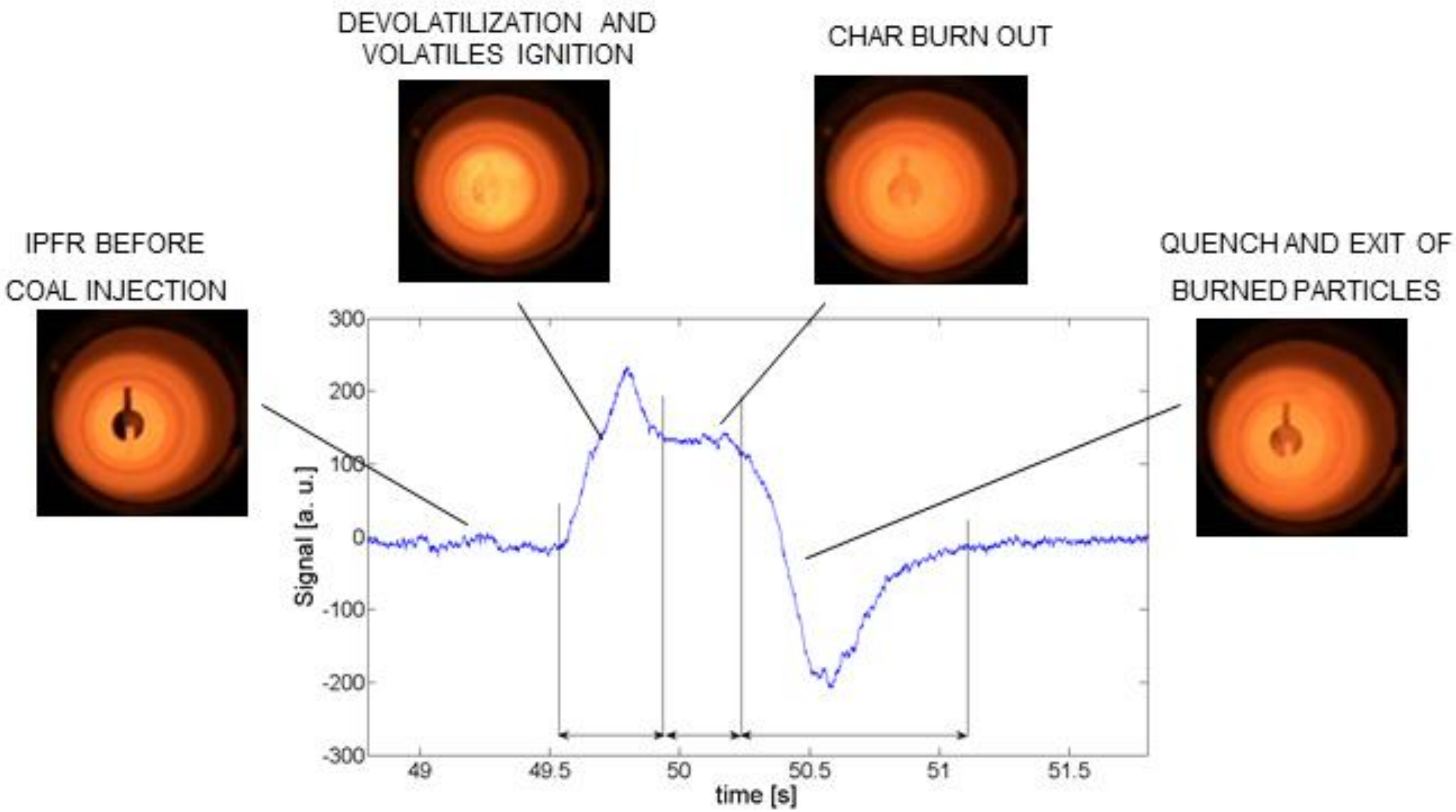
2<G<4 partial group combustion



4<G<100 group combustion



Results: signal from B1 probe



Results: effect of O_2 fraction

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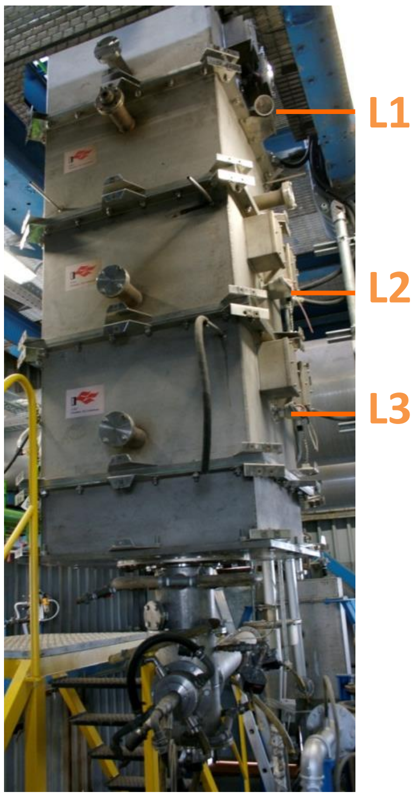
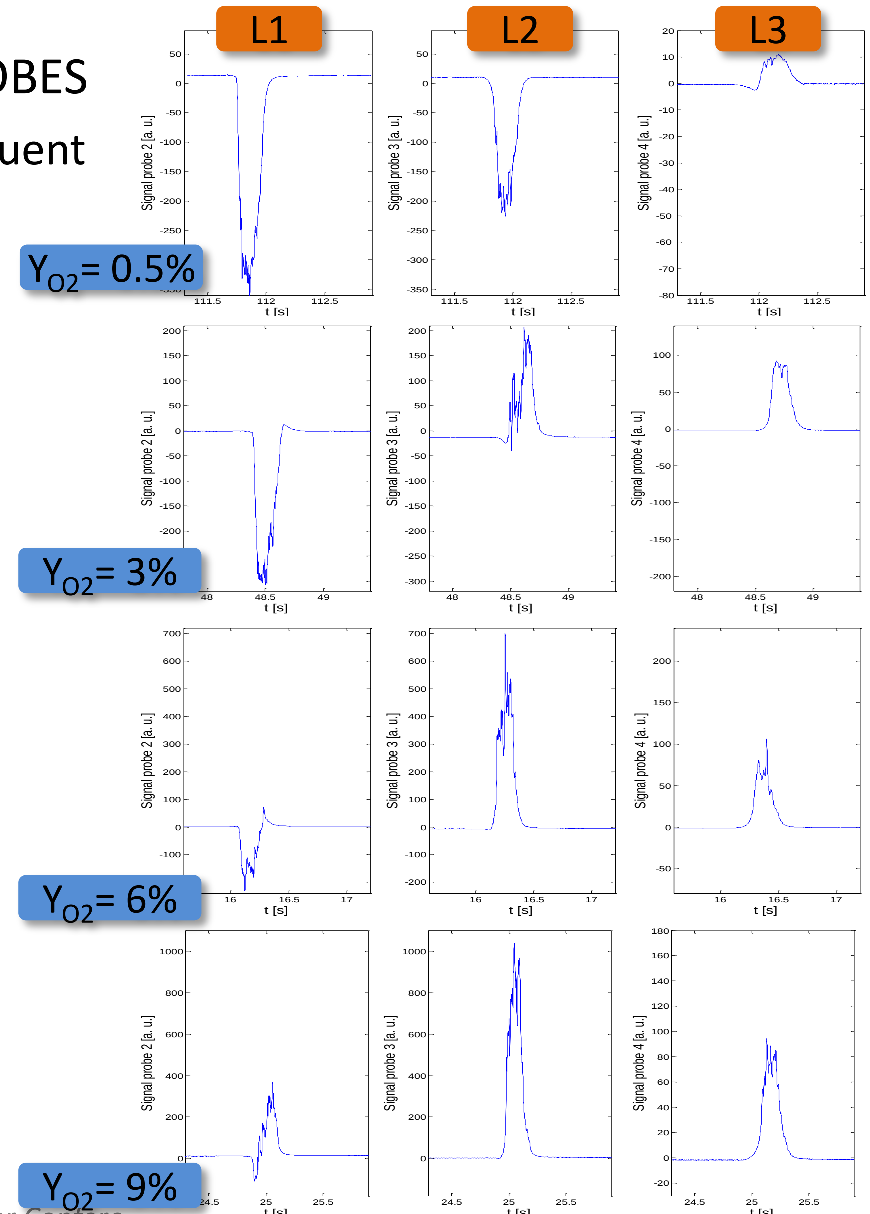
Signal vs. time from LATERAL PROBES

- T = 1373 K, dp = 38-90 μm, N_2 diluent





The occurrence of the first positive signals (related to volatiles oxidation) is anticipated with increasing Y_{O2}.

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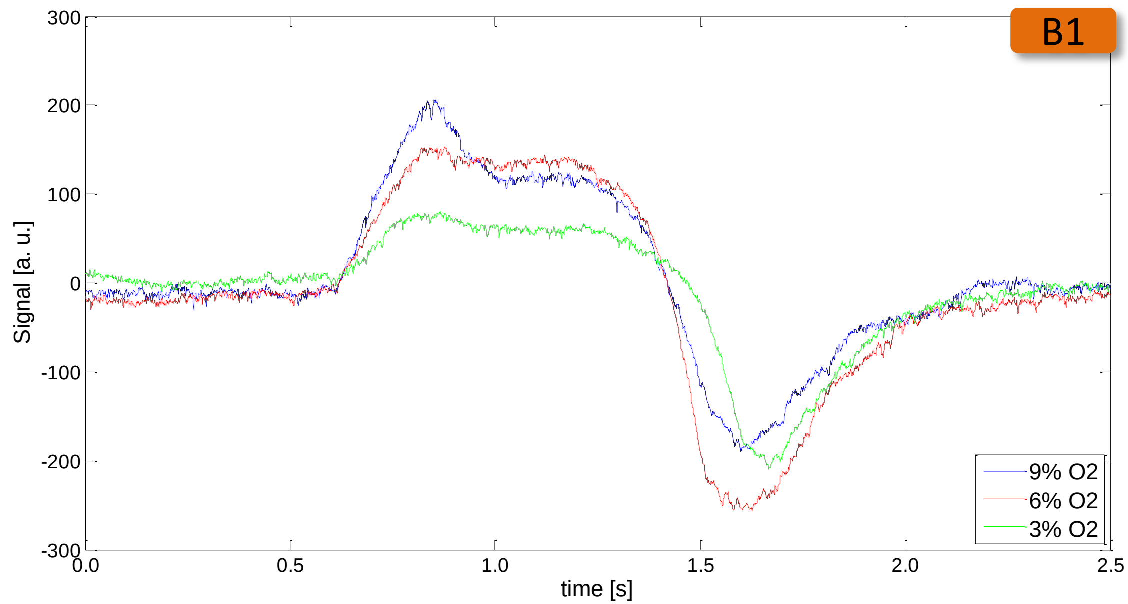
Results: effect of O_2 fraction

Signal vs. time from BOTTOM PROBE

- T = 1373 K, dp = 38-90 μm, N_2 diluent



- the intensity of the maximum of the signal corresponding to volatiles oxidation increases with increasing Y_{O2}
- the slope of the signal in the initial stage of volatiles oxidation increases with the increasing Y_{O2}
- signal of test with Y_{O2}=9% shows a marked different intensity between the volatiles oxidation and the char oxidation stages

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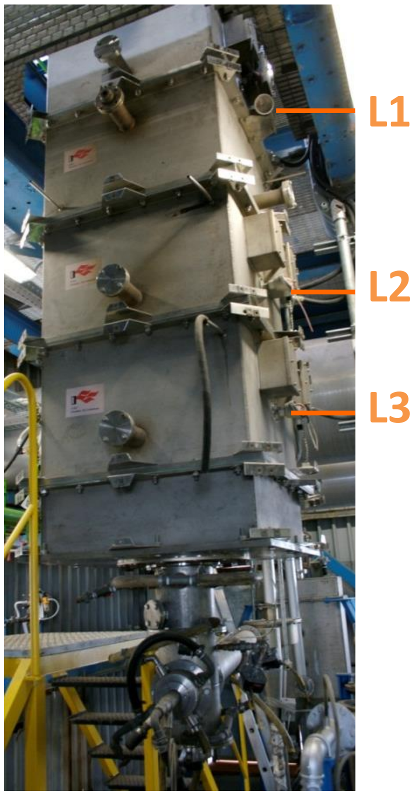
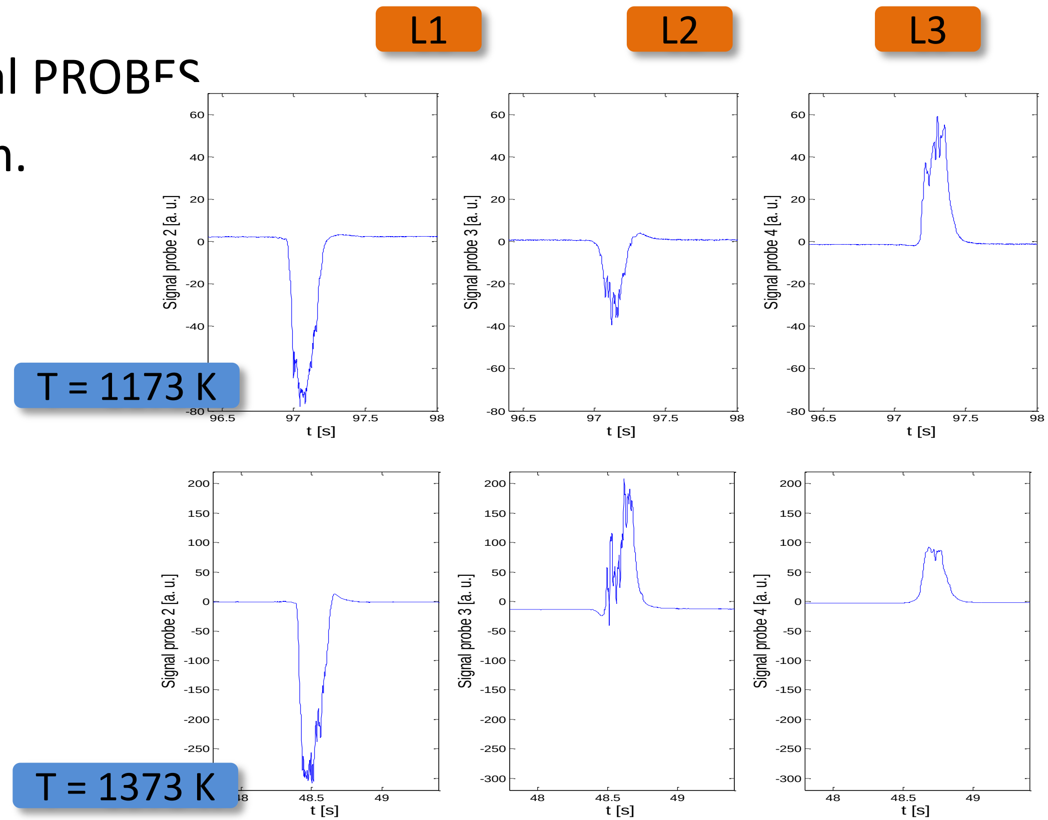
Results: effect of reactor temperature

Signal vs. time from lateral PROBES

- Y_{O2}=3%, dp = 38-90 μm.





Volatiles ignition occurred as the coal reached the first probe location for T = 1373 K, whereas it was just started at the second probe position for T = 1173 K.

Results: effect of particle size

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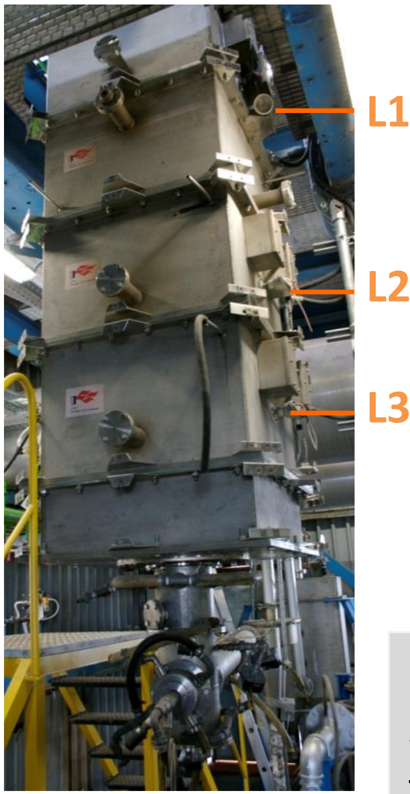
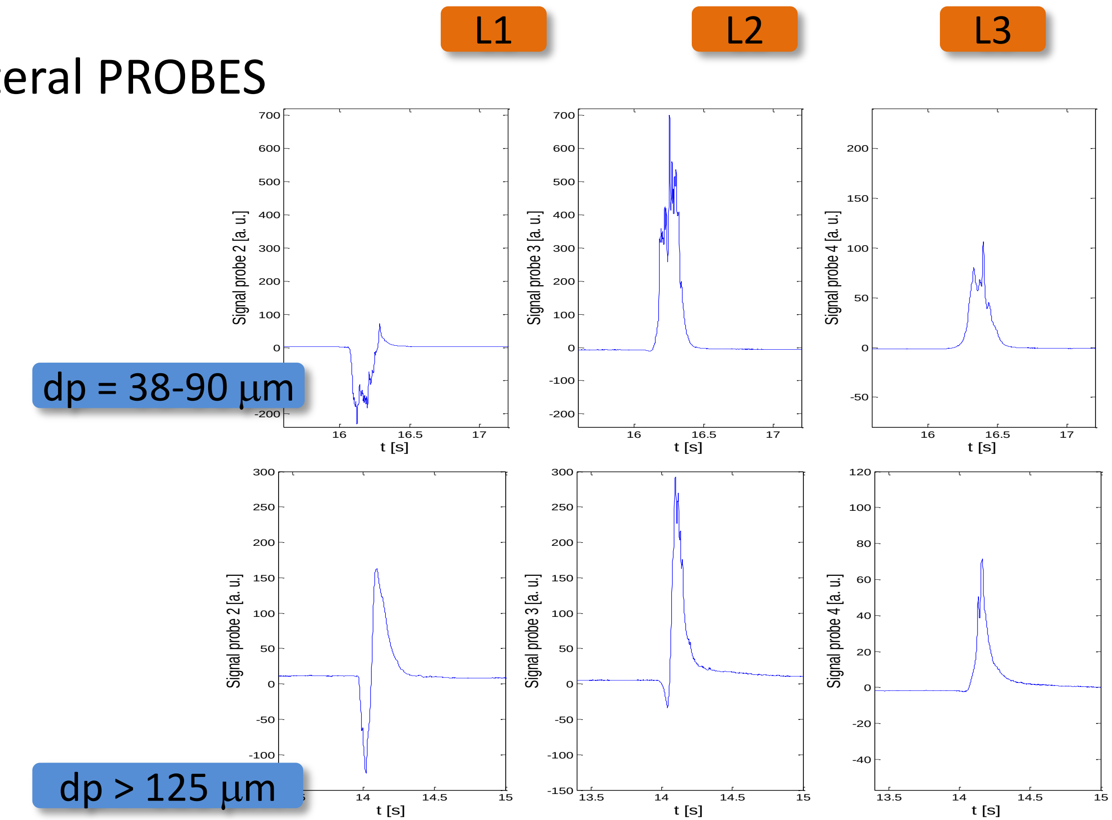
Signal vs. time from lateral PROBES

- Y_{O2}=6%, T = 1373 K.





Signals show surprisingly that L1 probe reveals emission for the bigger particles and no for small ones.
Such differences may not be explained with a difference in group number

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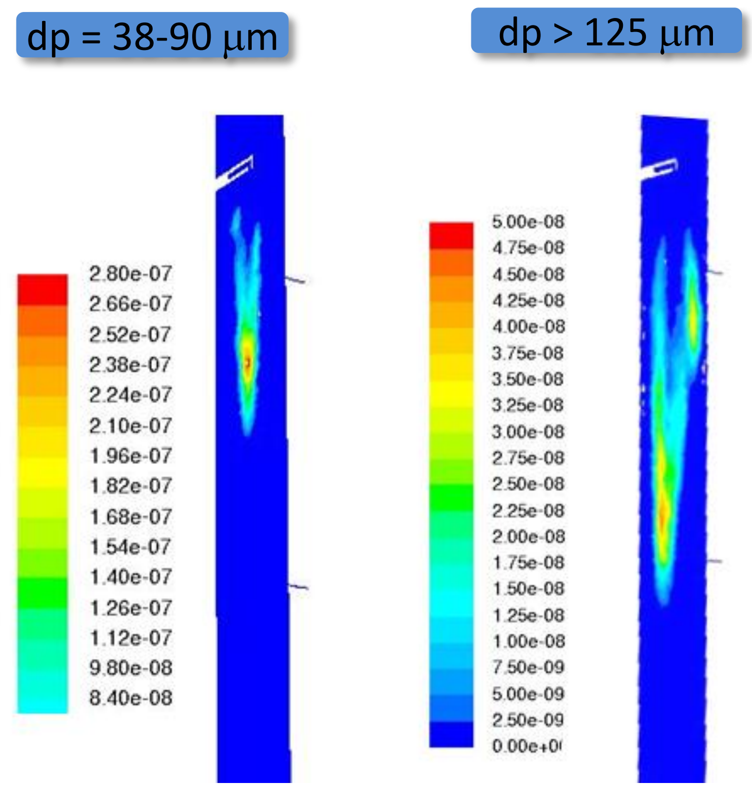
Results: effect of particle size

- CFD simulations (Ansys 13) to elucidate the behaviour of different particles
- Lagrangian tracking
- Domain: 1/2 IPFR (900k elements)
- Physical model
  - Turbulence mod κ-ε RNG
  - Combustion model: EDM
  - Radiation model: P1/WSGGM
  - Volatiles oxidation: 2-step scheme
  - 1-step devolatilization mode

Distribution of devolatilization rate



- Bigger particles spread more towards the reactor walls thank to the feeding probe geometry. These coal particles are slower, so that volatiles oxidation occurs at the same time of the inner particles but for shorter distances from the coal injection point, as revealed by the L1 lateral probe.
- Smaller particles tend to follow closely the carrier gas flow and volatiles oxidation occurs near the rector axis at further distances.

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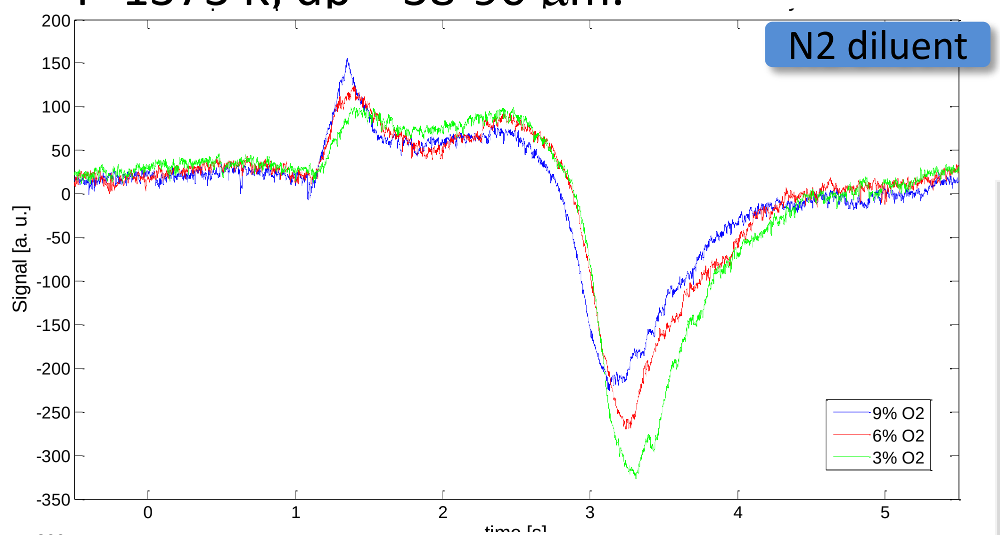
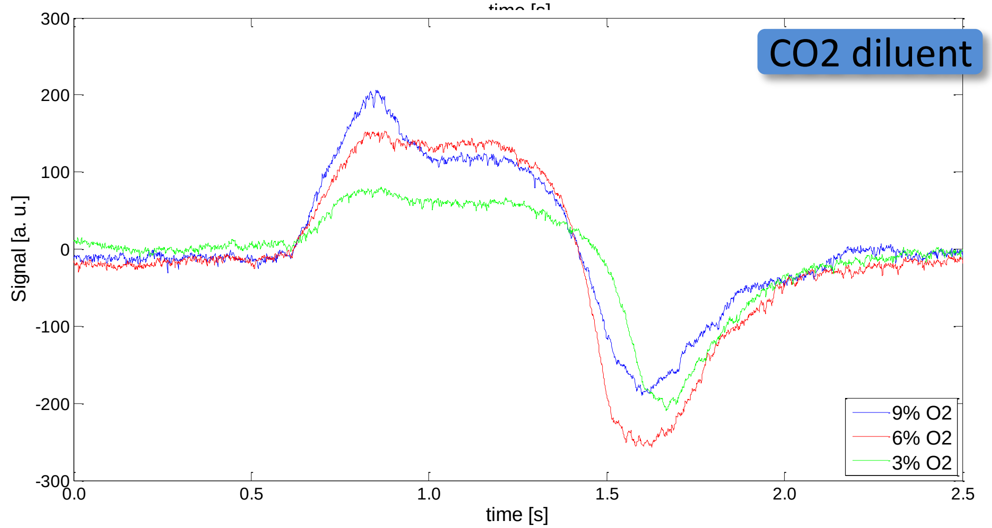
Results: effect of diluent gas

Signal vs. time from BOTTOM PROBES

- T=1373 K, dp = 38-90 μm.





- Lateral probes, showed that in case of CO2 atmosphere positive signals (i.e. emission) occurred at larger distances from the injections than for N2 atmosphere.
- Oxy-fuel combustion (in CO2 atmosphere) is slower than combustion in N2

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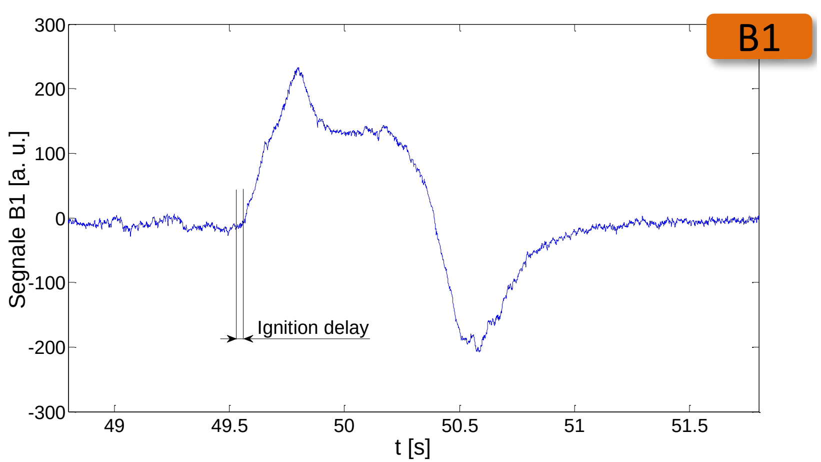
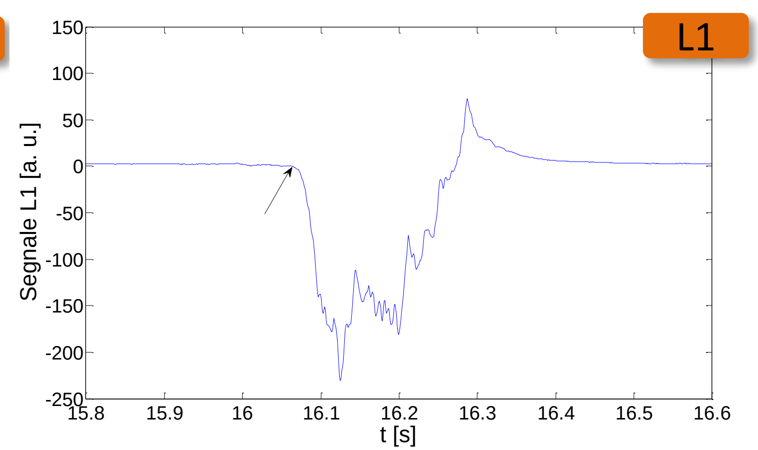
Ignition delay

- Calculation procedure: from both signals from bottom (B1) and lateral (L1) probes

- Ignition delay = time at which B1 signal increases – time of coal injection

- Time at which B1 signal increases: OK from B1 signal!
- Time of coal injection:
  - not from B1 signal as the fed coal particles are too little and too far (4 m) from the B1 probe to cause an important decrease of the signal.
  - Injection time determined with the aid of the first lateral (L1) probe (placed only 0.1265 m below of the coal injection)





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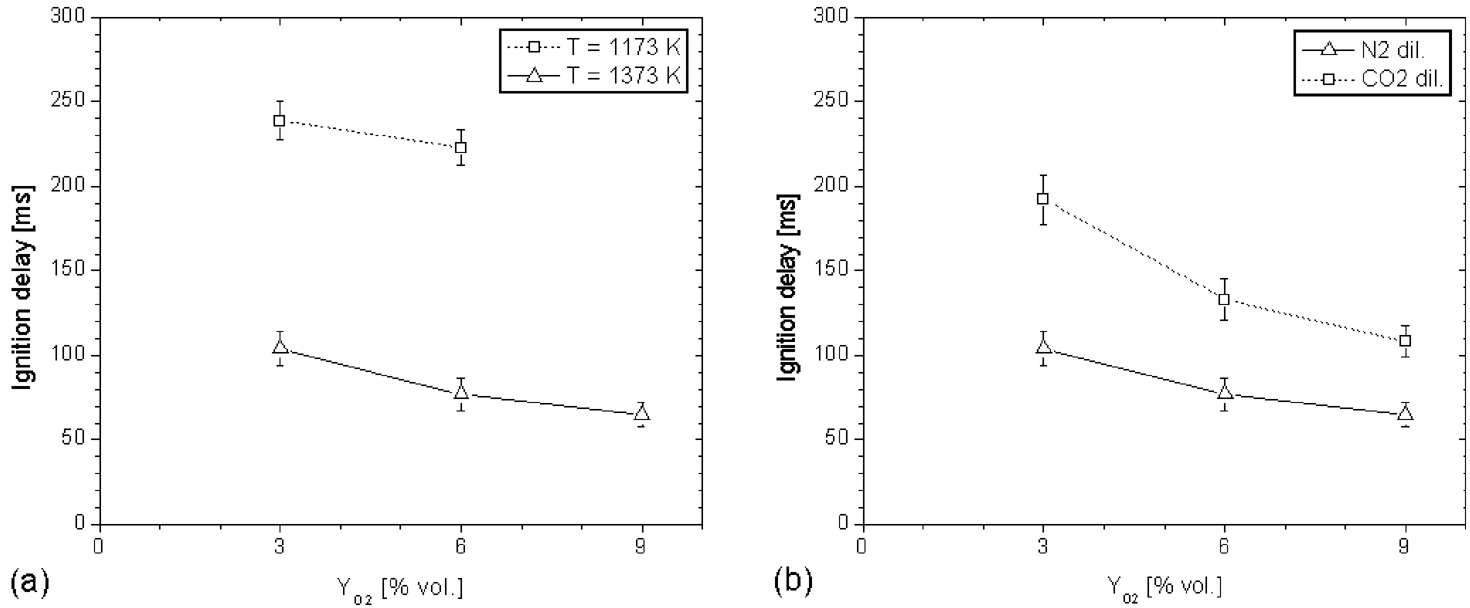
Ignition delay

- Ignition delay vs. Y_{O2} for different (a) reactor temperatures (N2 diluent) and (b) diluents (T = 1373 K). dp = 38-90 μm.



- the ignition delay decreases with Y_{O2} fraction.
- larger ignition in oxy-fuel conditions than air-fuel

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Conclusions

- Optical ODC probes have been applied to study coal combustion for the first time
  - able to capture the passage of coal streams and to identify different phenomena (e.g. volatiles ignition, char oxidation).
  - the use of more probes and a planning of their spatial arrangement as well as the feeding conditions, may provide quantitative information, such as particle velocity, ignition delay and devolatilization time.
- The data that can be derived from such technique may help the determination of kinetics from EFRs without the need of sophisticated diagnostics
  - development of heterogeneous combustion CFD sub-models
- Results are encouraging, especially because the low intrusiveness of the probe suggests its use for industrial application
  - ODC experimental campaigns in FoSper