Retrofitting oxy-fuel technology in a semi-industrial plant: flame characteristics and NOX production from a low NOX burner fed with natural gas

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Introduction

The “Friendly Coal” project is founded by the EU within the framework "Research Fund for Coal and Steel". The partners of the project are: ENEL, Technische Universität München (TUM), Austrian Energy and Environment (AEE), Technical University of Denmark (DTU), Technische Universität of Graz (TUG).

This presentation will show the results of the first phase of the experimental programme of this project; within this phase IFRF was in charge of the in-flame measurements

The objective of the experimentation is to run experiments with the existing low-NO_X burner in order to obtain a characterization of the combustion process with oxygen and recycled flue gas, with both natural gas and coal as fuels, and to produce data for computer modeling validation.

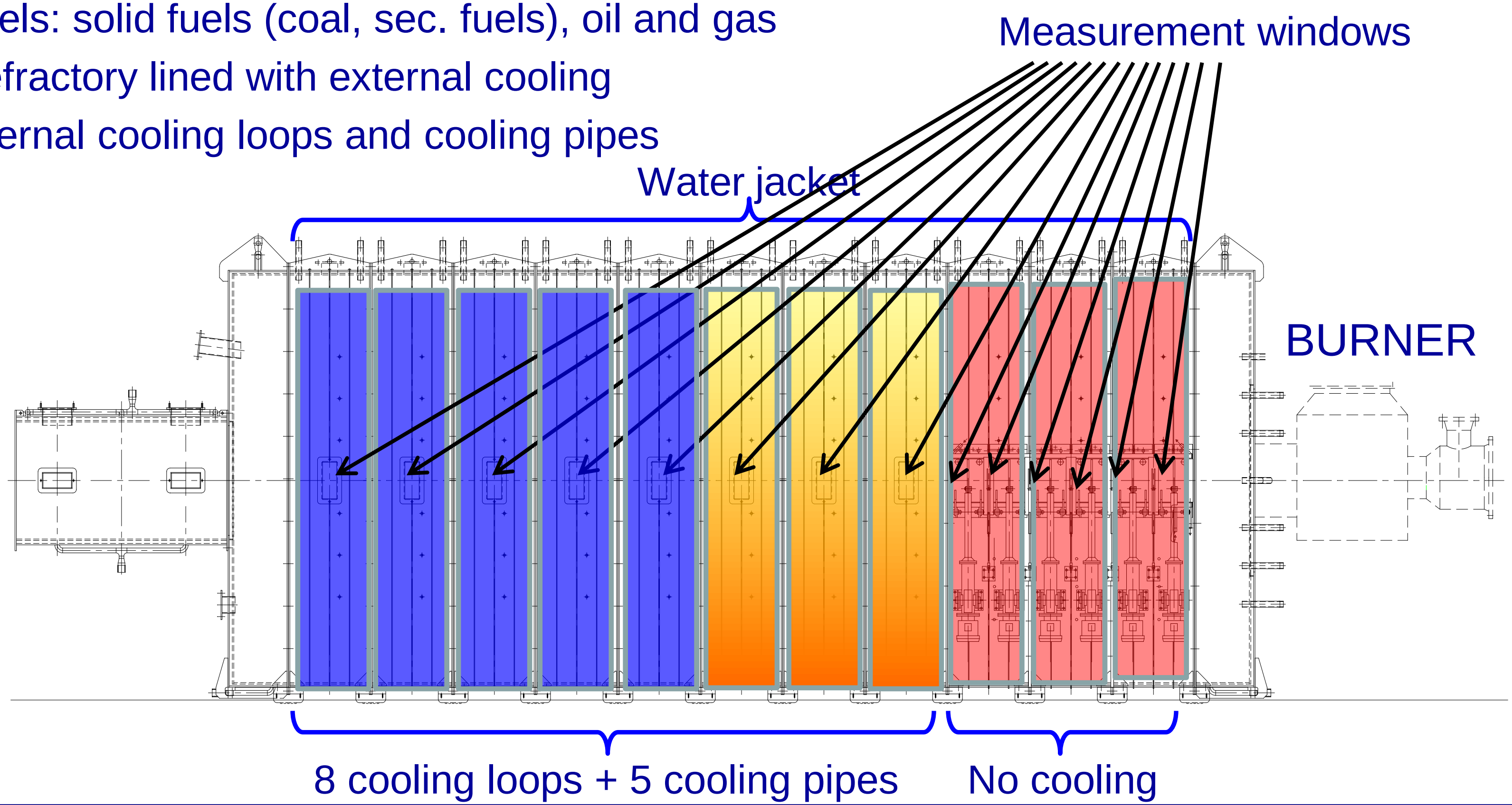
Experimental Setup

- The furnace
- The burner
- Modifications of the plant for oxy-combustion
- Measurements probes

The furnace

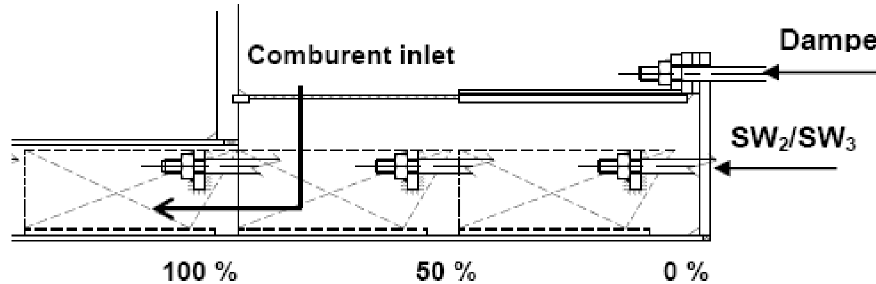
FOSPER (FOrnace SPERimentale – Experimental Furnace) is a replica of the former IFRF furnace number 1

- Dimensions: 2 m x 2 m x 6,25 m
- Fuels: solid fuels (coal, sec. fuels), oil and gas
- Refractory lined with external cooling
- Internal cooling loops and cooling pipes



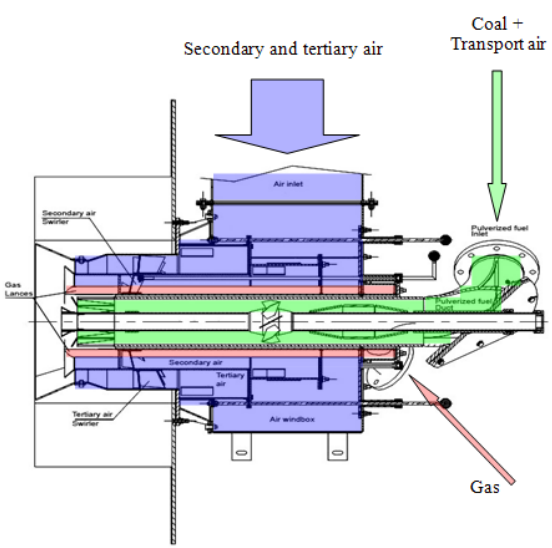
TEA-C Burner

Low-NO_X Burner
Secondary and tertiary air with independent swirler
Fuels: NG, oil, coal

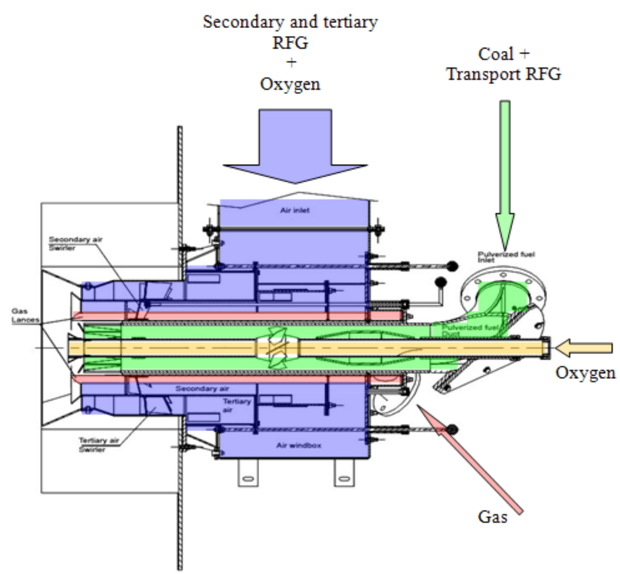


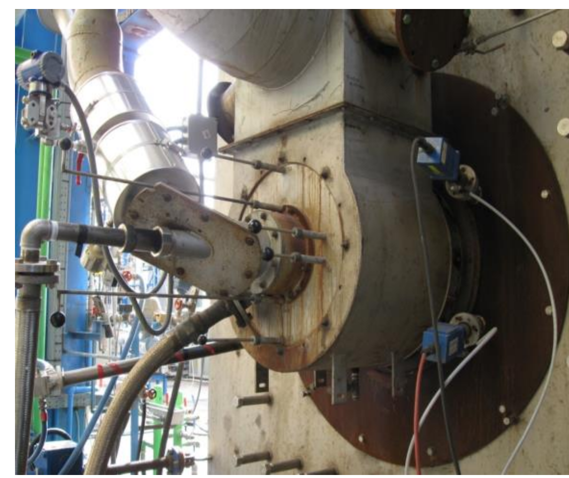
Swirler positions

Conventional combustion

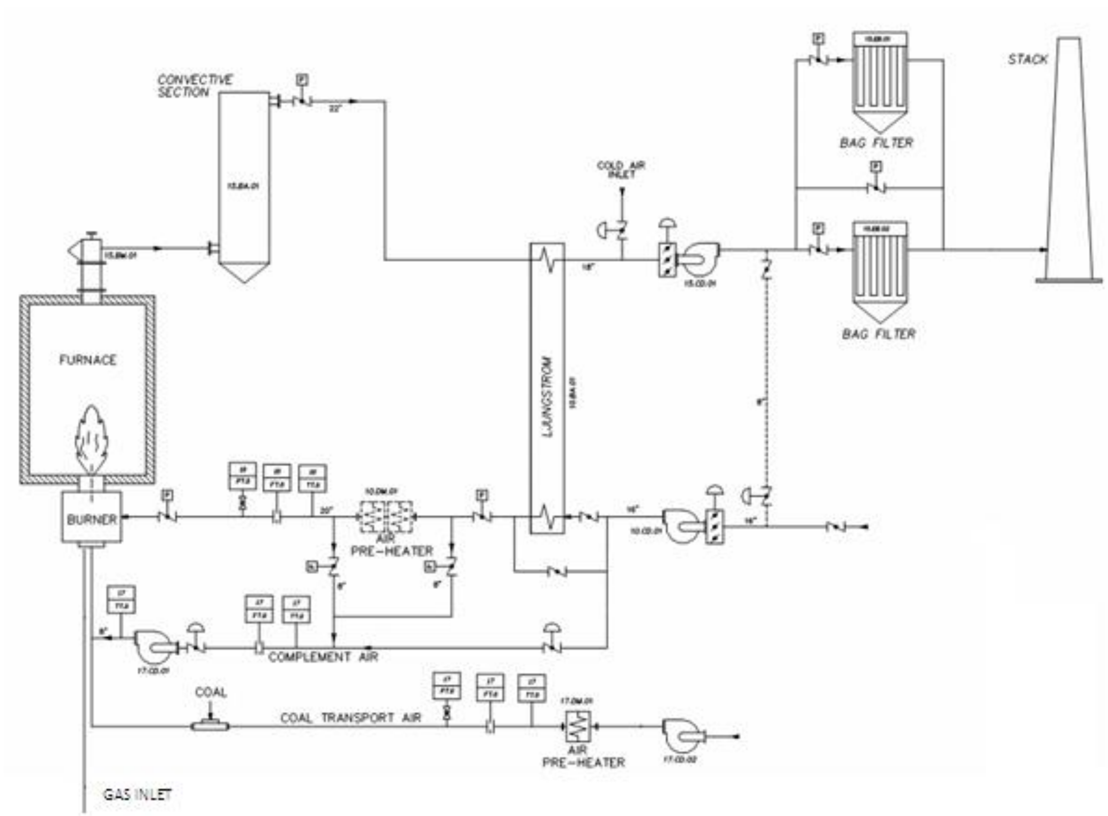


Oxy-combustion with RFG

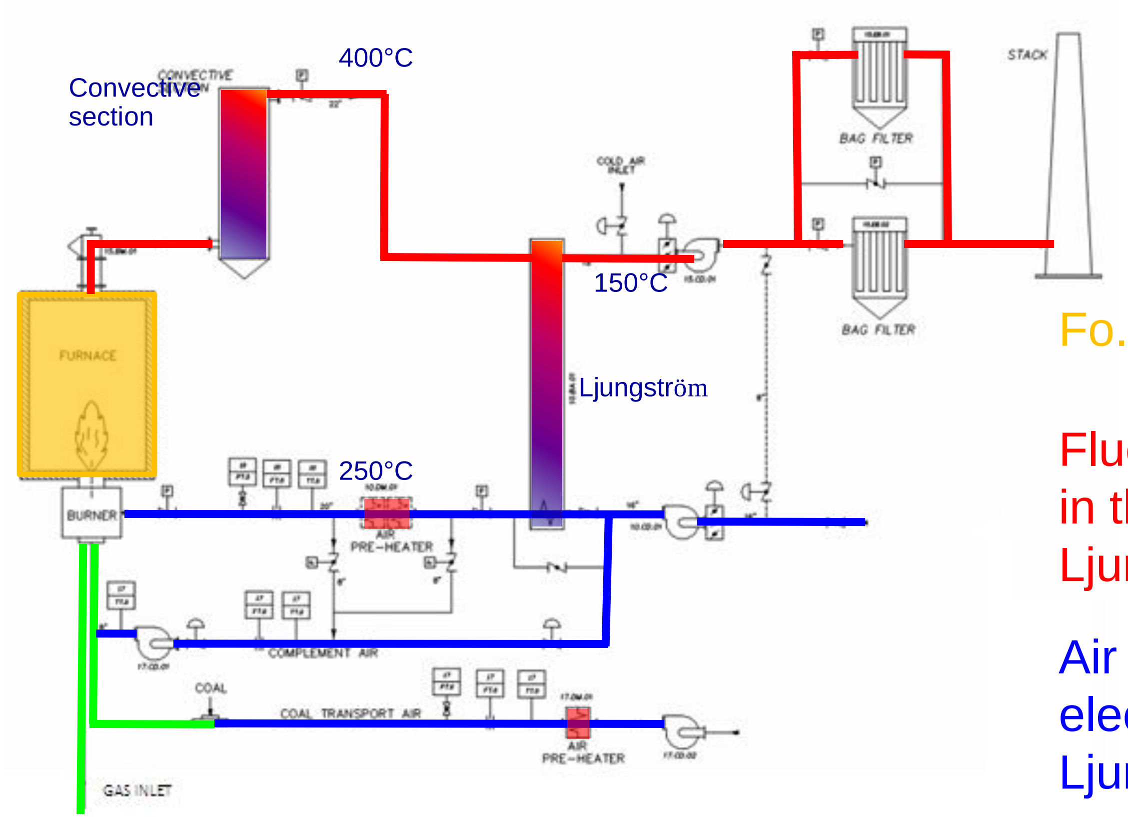




Plant scheme for conventional combustion



Plant scheme for conventional combustion



Fo.Sper. : combustion chamber

Flue gas line: the FG is cooled down in the convective section and by the Ljungström heat exchanger

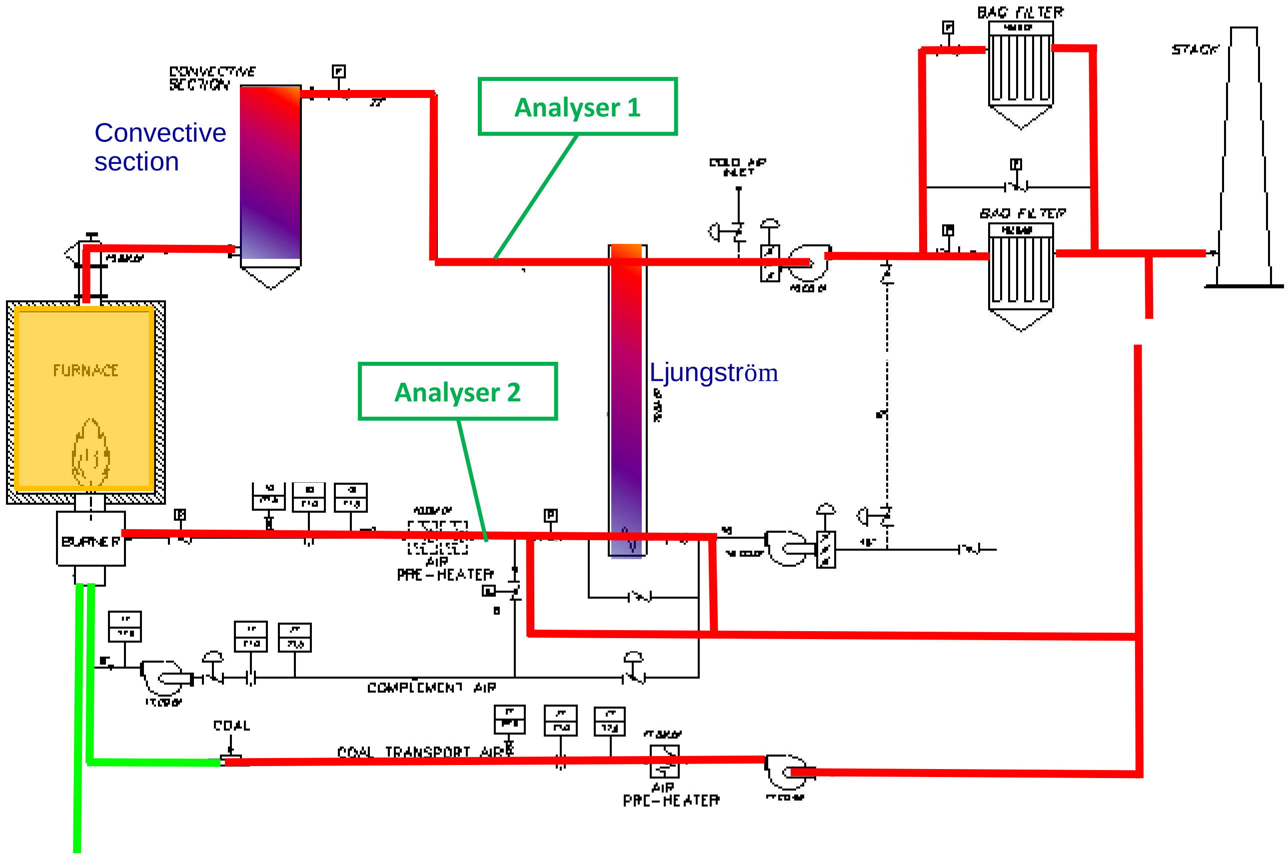
Air lines: the air is heated up by two electrical pre-heaters and by the Ljungström

Fuel lines: for natural gas and coal

Plant scheme for oxy – combustion

Blu lines: oxygen injection

Pink lines: recycled flue gas

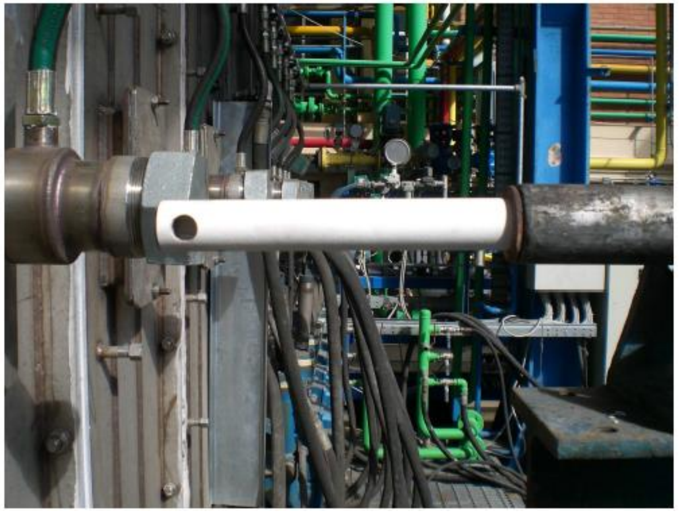


Measurements probes

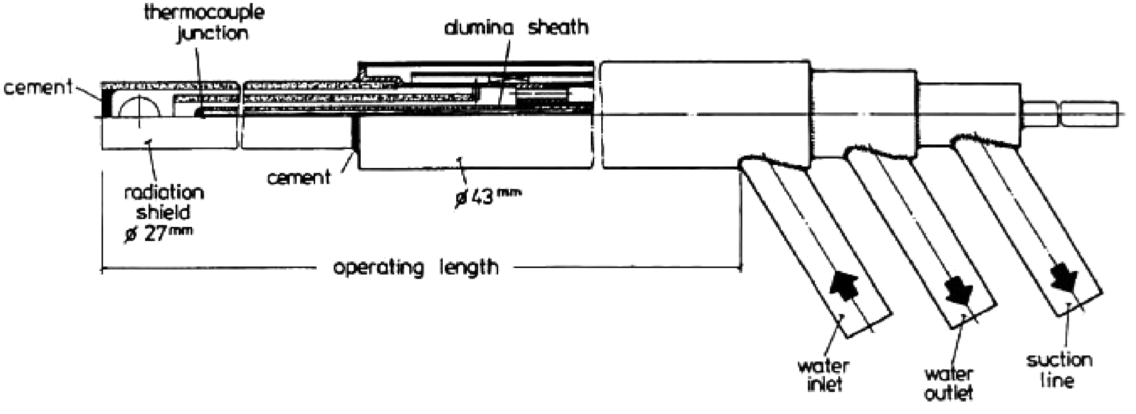
Water cooled suction pyrometer

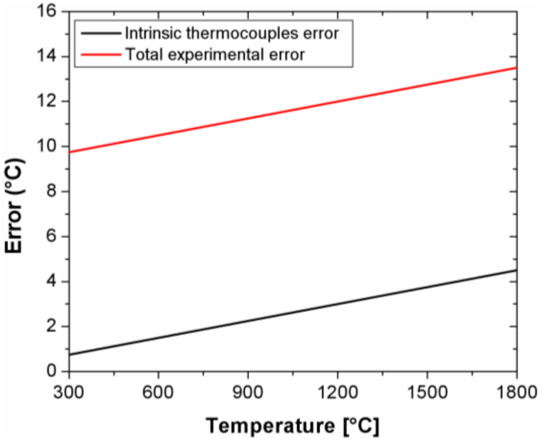
In the standard suction pyrometer a platinum-rhodium thermocouple, protected from chemical attack by a sintered alumina sheath, is surrounded by two concentric radiation shields.

The gases are drawn between the shields and over the sheath with high velocity so that the equilibrium thermocouple temperature is nearly that of gases without the need for correction.



Max temperature: thermocouple S ~ 1750°C
thermocouple B ~ 1820°C
ceramic shield (Alsint 99.7%) ~ 2050°C





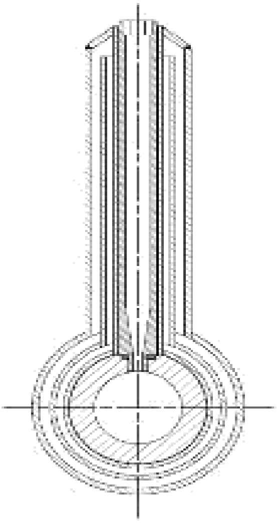
Intrinsic error for B and S thermocouples and total experimental error

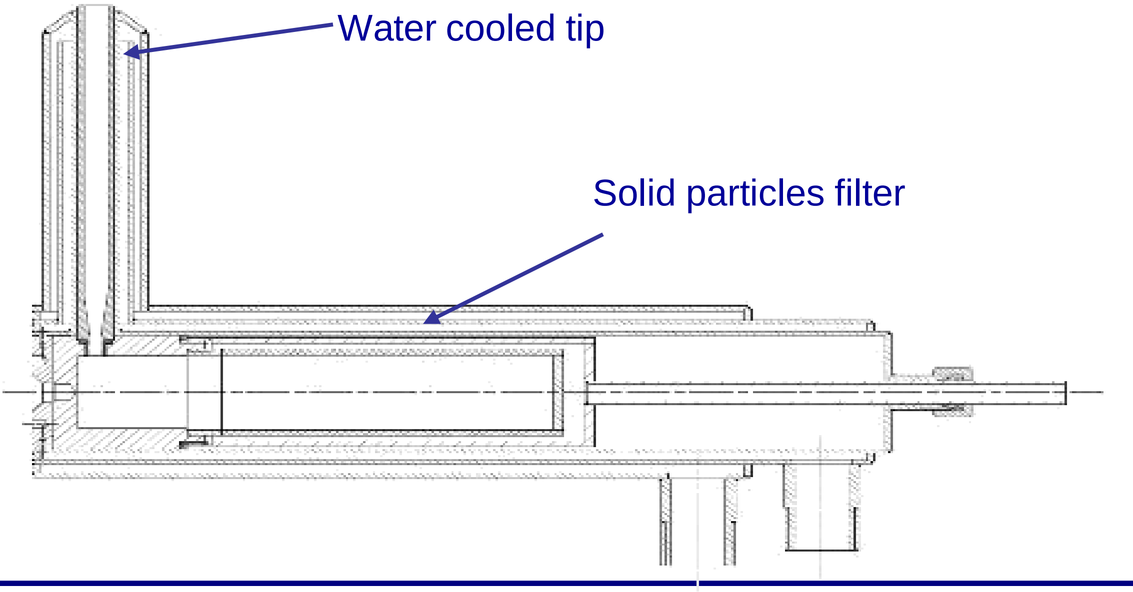
Gas/solid sampling probe

- Gas species concentration profiles (O_2, CO_2, NO, CO)
- Solid sampling

The accuracy of the analyzers is normally below 1ppm but the total error of the data is conditioned by the method of sampling.

A study about experimental errors introduced with different sampling techniques is currently ongoing at the IFRF.



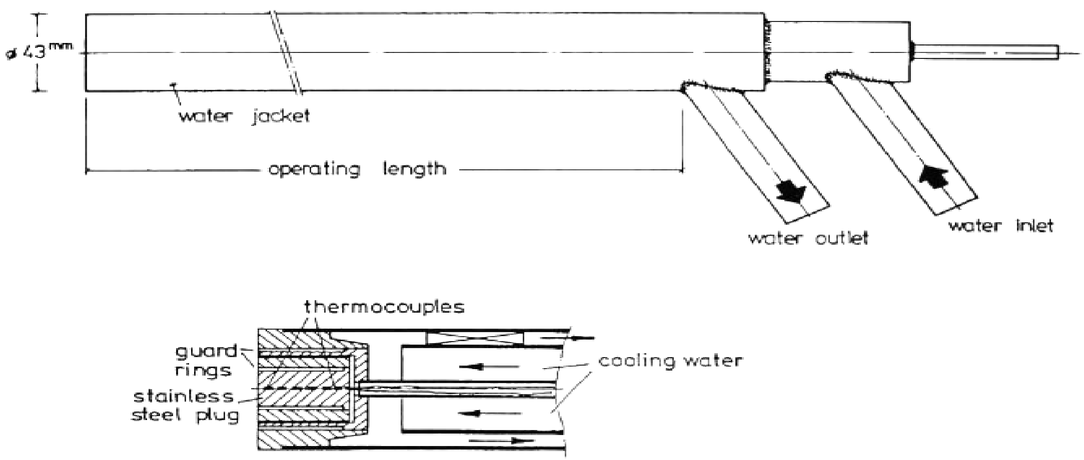


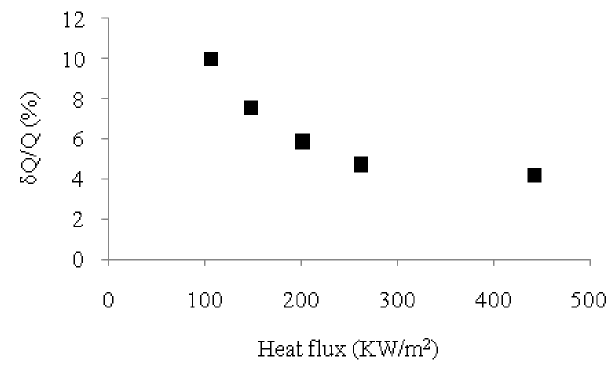
Total heat flux meter

The IFRF heat flux meter is designed to measure the total heat transfer (conduction + convection + radiation) from the combusting flow to its front surface.

The principle of the total heat flux measurement is based on the measurement of the temperature gradient through a steel plug of know thermal conductivity mounted at the tip of the probe.

The response time for this instrument is in order of 10 minutes.





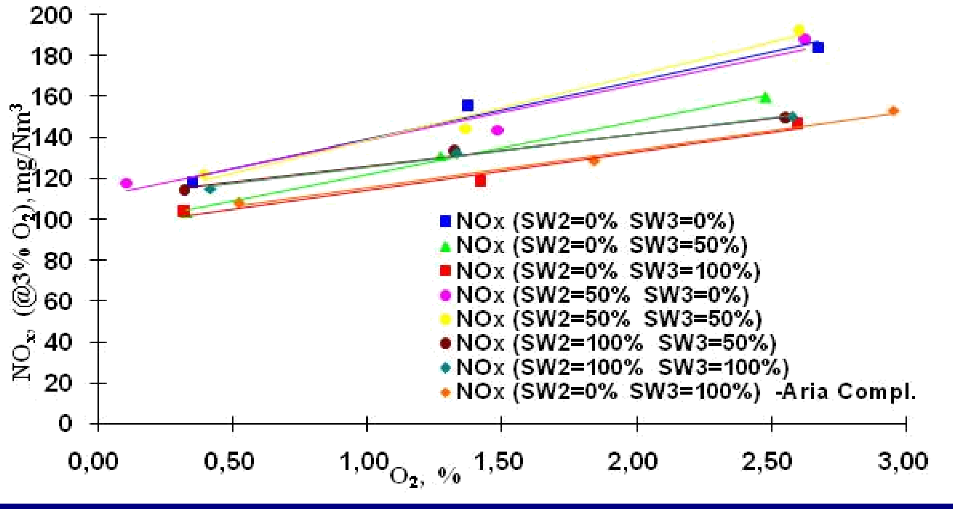
Relative error in the heat flux measurements

Burner settings

The driving guidelines for the assessment of the best settings were the following:

- **Flame stability.**
- **Minimize NO_X emissions**
- **Maximize flue gas CO_2 concentration.**
- **Comparison needs (heat transfer)**

In conventional combustion the best setting of the swirlers was the one that produced less NO_X emissions



Burner settings

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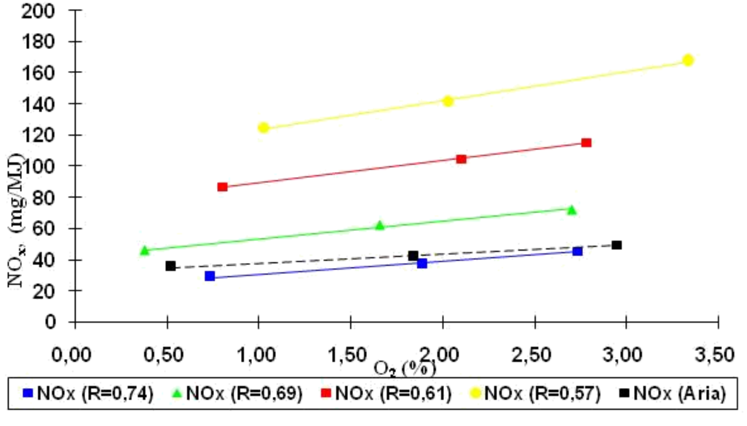
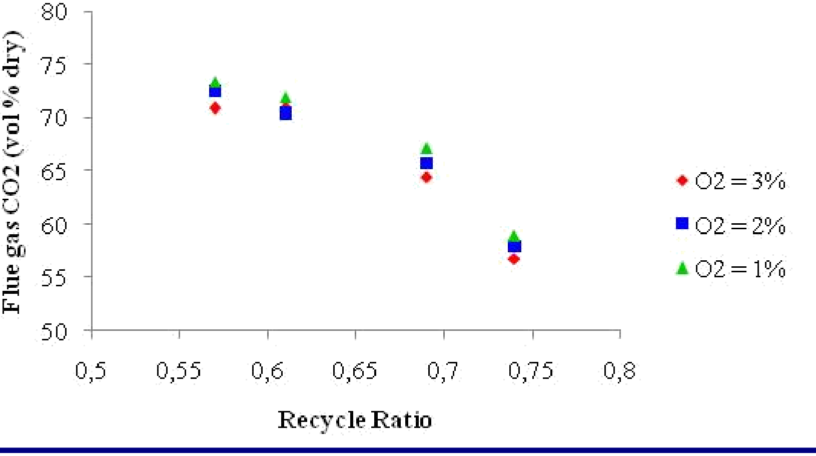
- **Flame stability.**
- **Minimize NO_X emissions**
- **Maximize flue gas CO_2 concentration.**
- **Comparison needs (heat transfer)**

In oxy-combustion the best setting of the swirlers was the same used for conventional combustion and the optimum recycle ratio was the best compromise between NO_X and CO_2 emissions





In flame measurements

Temperature and chemical species (O_2, CO_2, NO_X, CO) in-flame measurements were carried out in the following conditions:

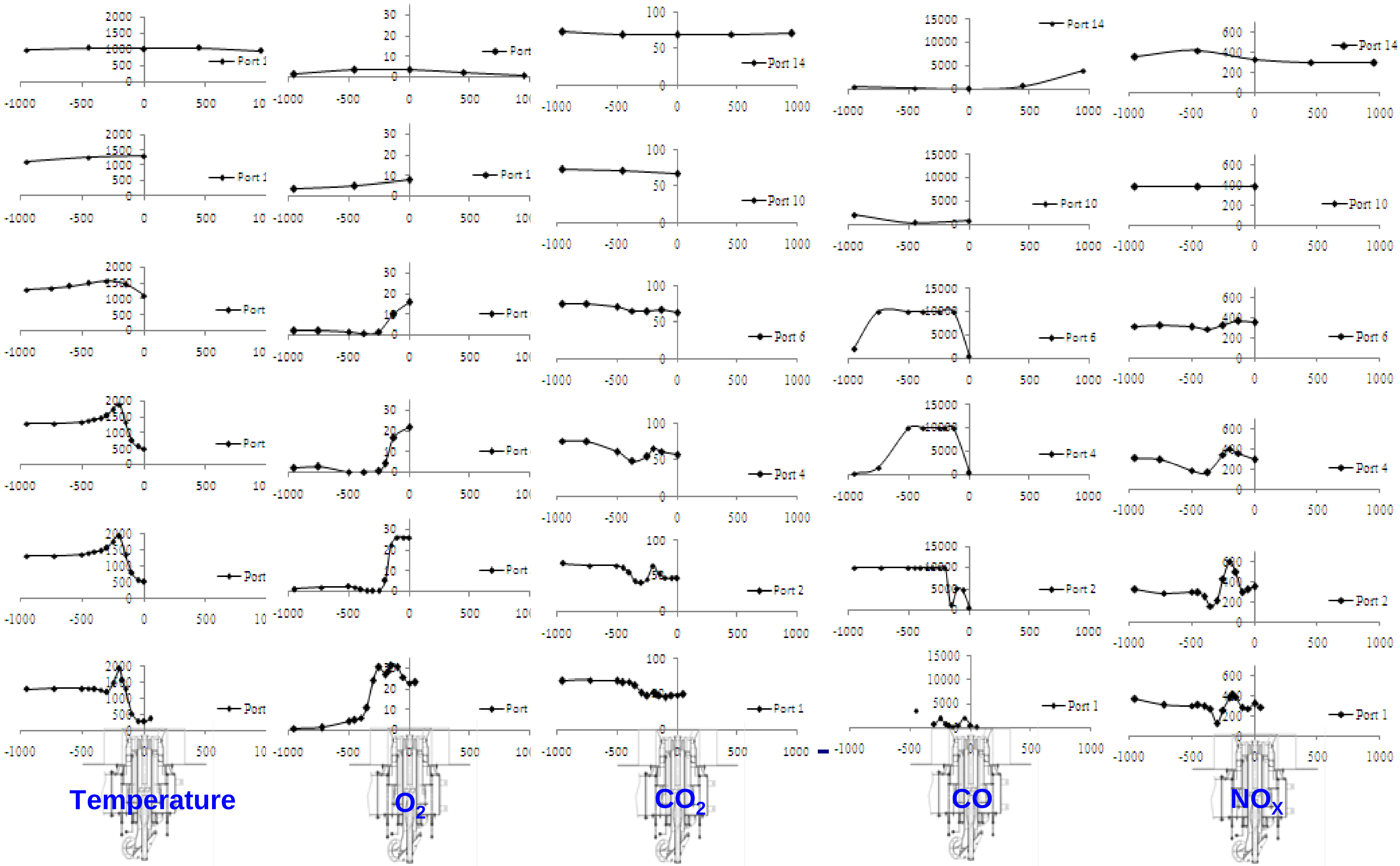
- **Conventional gas-air combustion**
- **Natural gas with pure oxygen and recycled flue gas combustion, R=0.61 and R=0.69**
- **Conventional coal-air combustion**
- **Coal with pure oxygen and recycled flue gas combustion, R=0.61**

Input-Output conditions

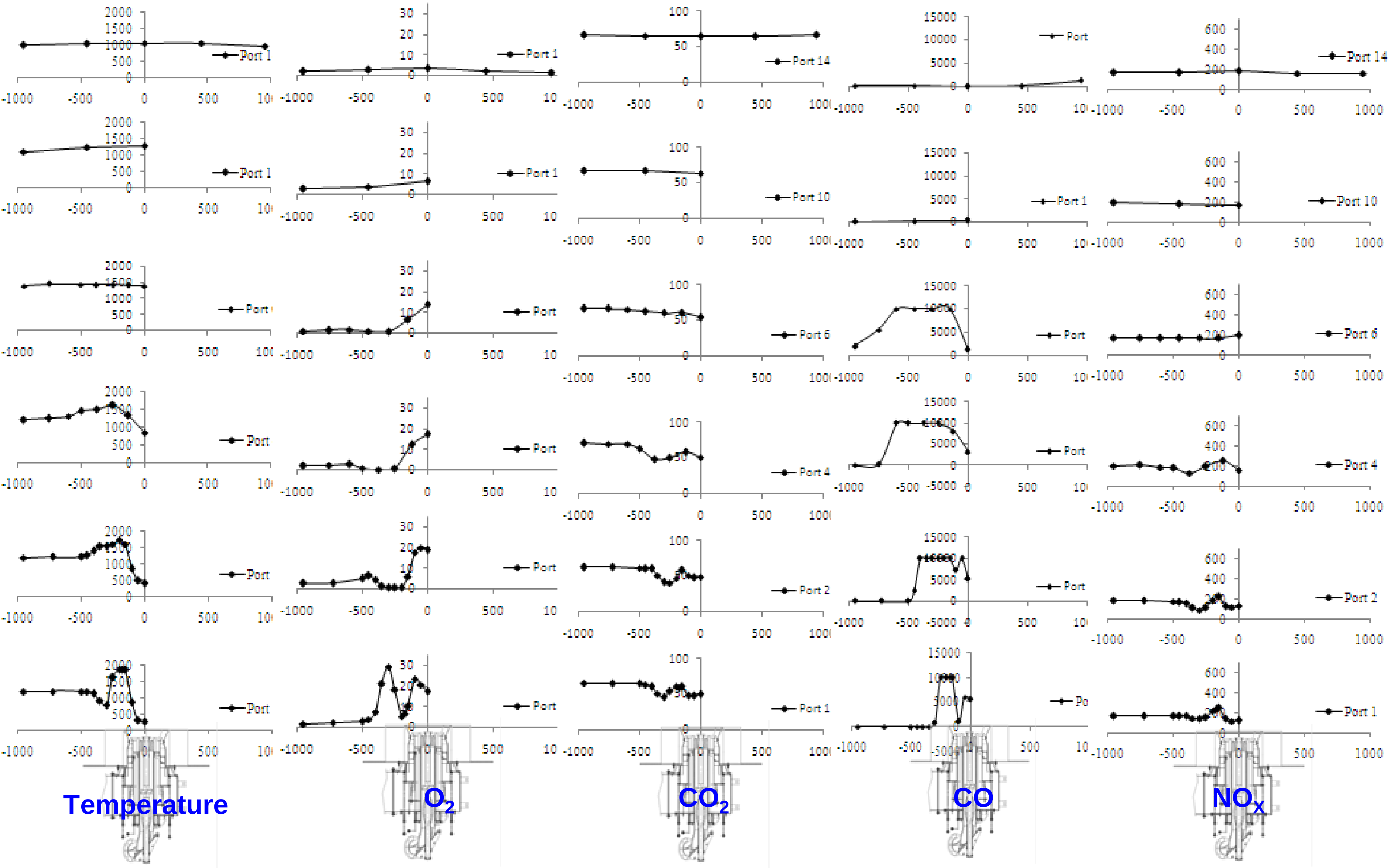
INPUT CONDITIONS					
	NATURAL GAS			***COAL***	
	AIR	OXY		AIR	OXY
Natural gas flowrate	272 Nm^3/h	267 Nm^3/h	265.9 Nm^3/h	-	-
Coal flowrate	-	-	-	360 kg/h	360 kg/h
Primary air	538 kg/h	-	-	501.8 kg/h	-
Primary air temperature	149°C	-	-	77°C	-
Sec/tert air	2798 kg/h	-	-	3100 kg/h	-
Sec/tert air temperature	251°C	-	-	250°C	-
Oxygen	-	729 kg/h	731.1 kg/h	-	718 kg/h
Primary RFG	-	700 kg/h	693.4 kg/h	-	700 kg/h
Sec/tert RFG	-	1447 kg/h	871 kg/h	-	1063 kg/h
Recycle ratio	-	0.69	0.61	-	0.61
Thermal input	2.5 MW_t	2.5 MW_t	2.5 MW_t	2.5 MW_t	2.5 MW_t

OUTPUT CONDITIONS					
	NATURAL GAS			***COAL***	
	AIR	OXY		AIR	OXY
Flue gas temperature	1100°C	1050°C	1025°C	1130°C	1250°C
Total heat extraction	1.115 MW	1.186 MW	1.28 MW	0.873 MW	0.93 MW
O_2	1.9%	3.2%	3%	3.9 %	2.76 %
CO	-	11 ppm	12 ppm	0 ppm	19 ppm
CO_2	10.8%	68.7 %	73.7%	14.57 %	76.22 %
NO_x	66 ppm	120 ppm	268 ppm	171 ppm	238 ppm
SO_2	-	-	-	314 ppm	646 ppm

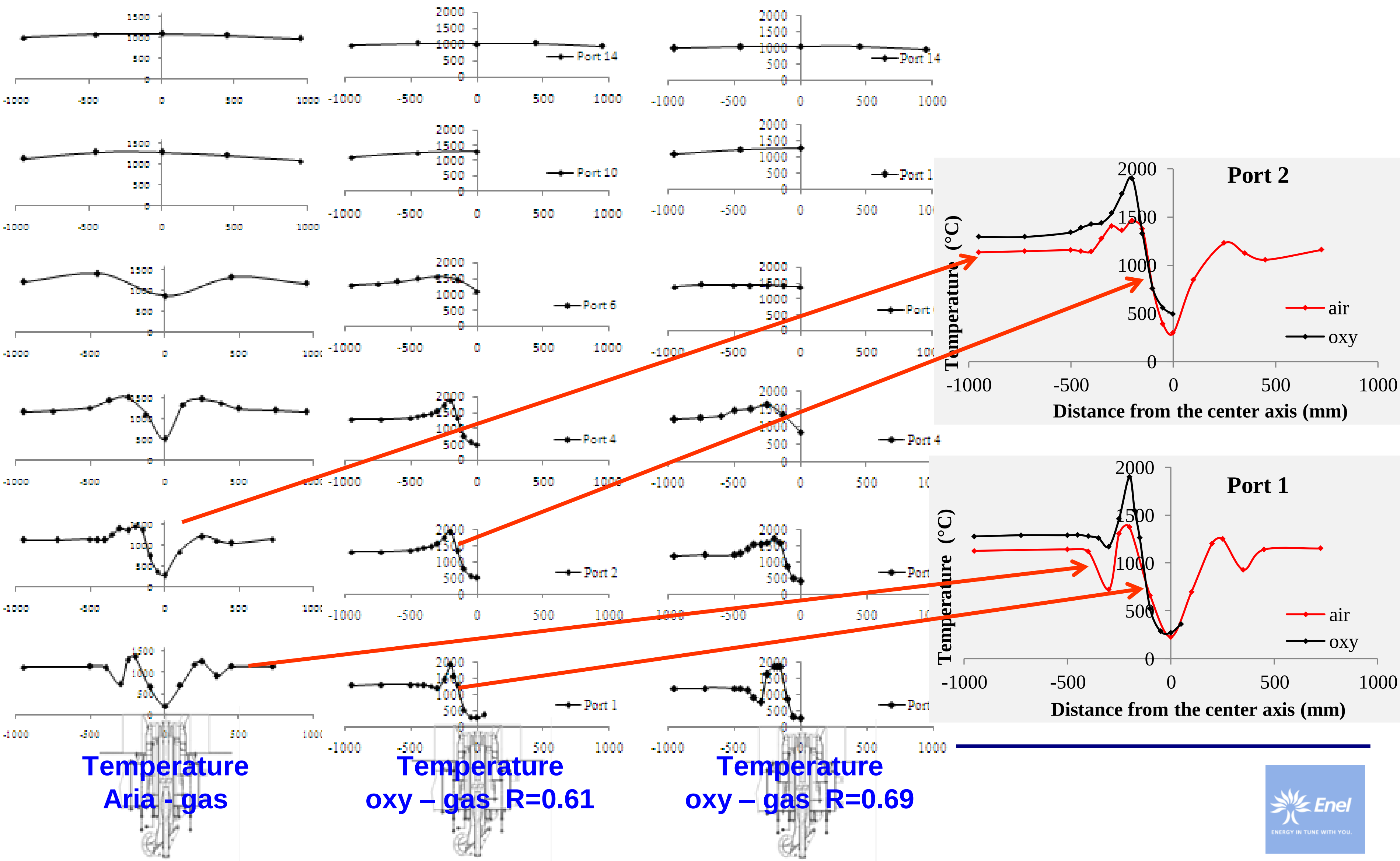
Mesurements results: oxy-gas, R=0.61



Mesurements results: oxy-gas, R=0.69



Gas firing temperature comparison

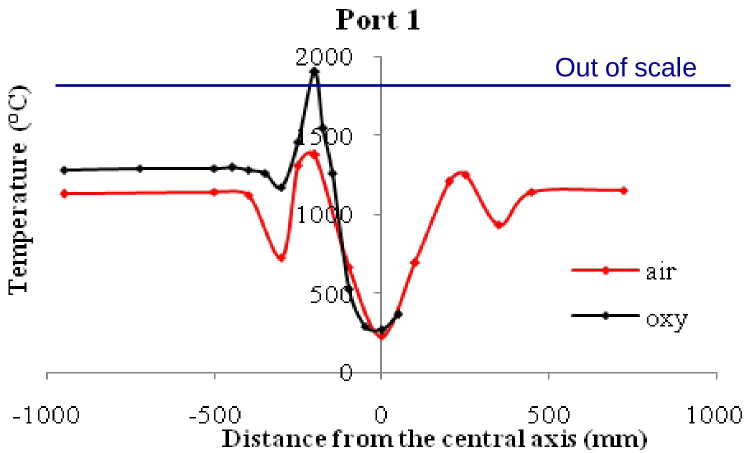


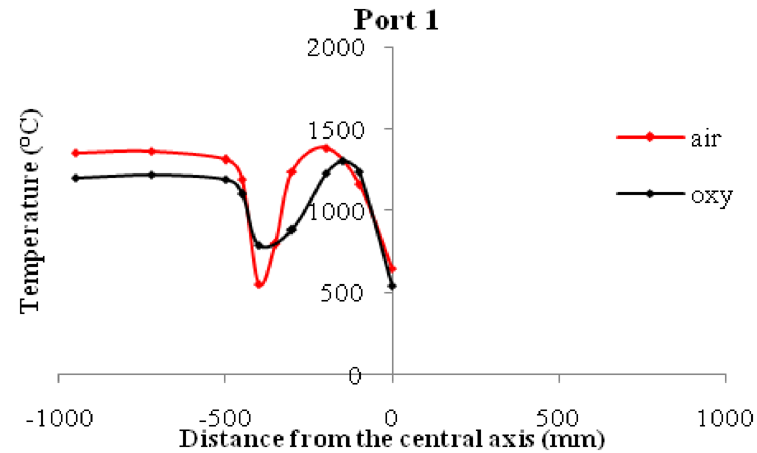
Temperature
Aria - gas

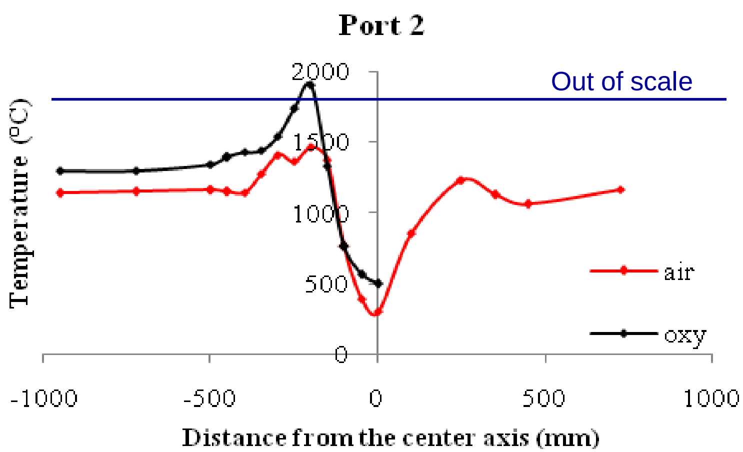
Temperature
oxy – gas R=0.61

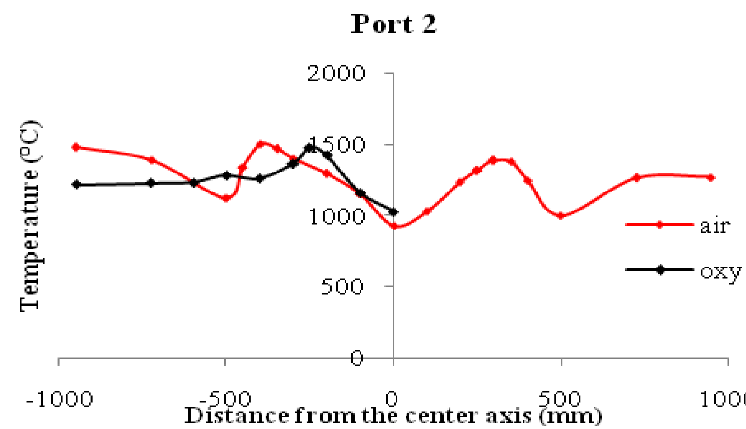
Temperature
oxy – gas R=0.69

Air and oxy temperature comparison







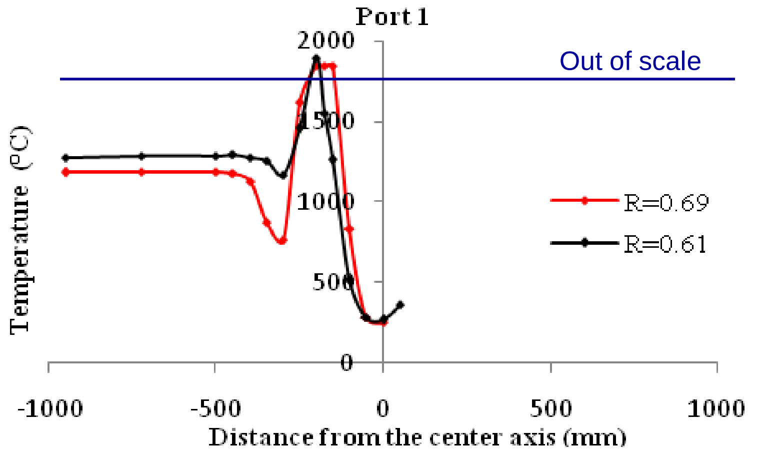


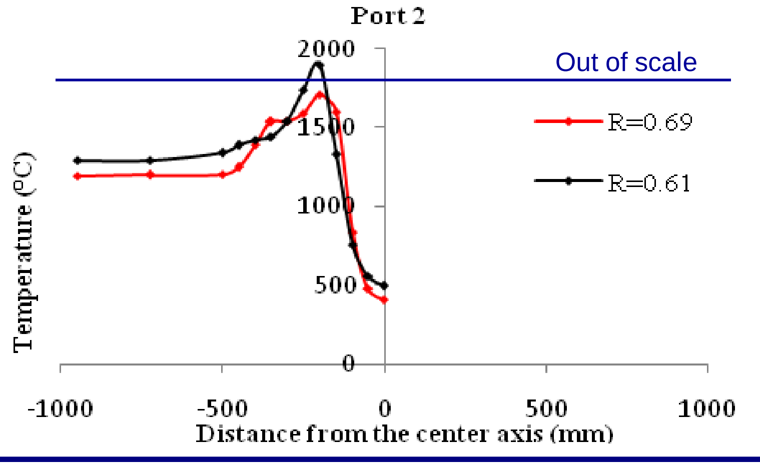
Gas firing

Coal firing

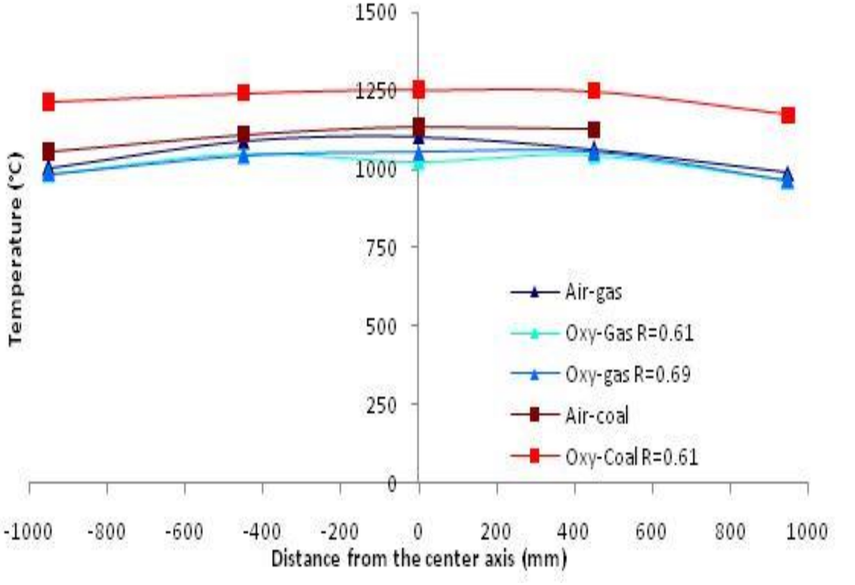
Temperature results

Effect of the recycle ratio





Temperature at the end of the furnace



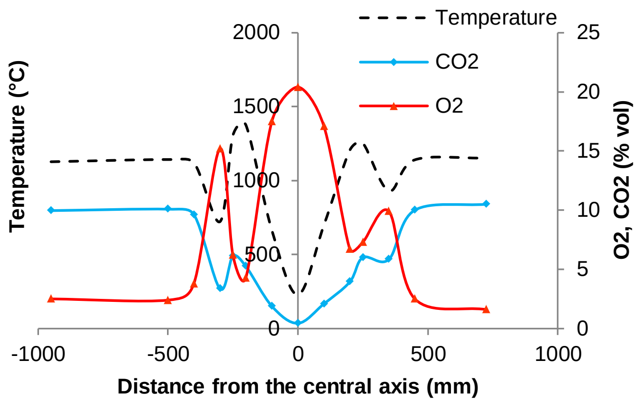
Chemical species

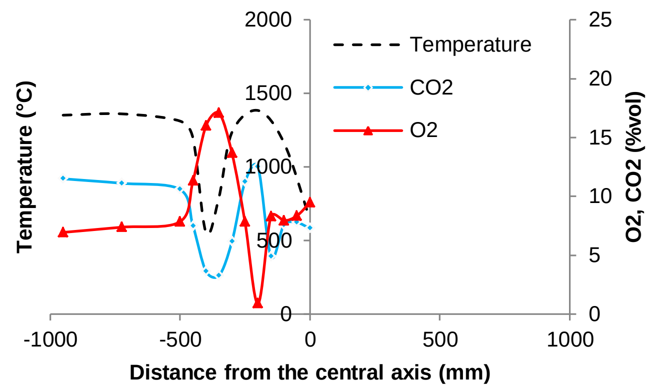
Gas composition profiles at the burner exit (port 1)

Gas firing

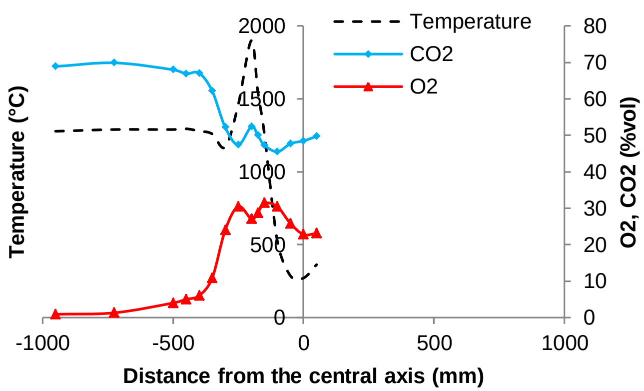
Coal firing

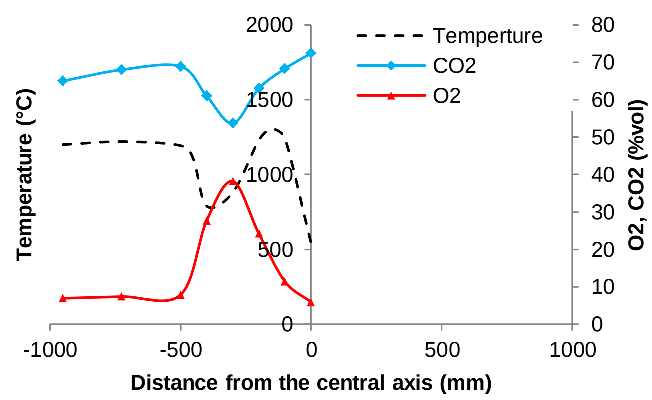
Conventional combustion





Oxy-combustion, R=0.61

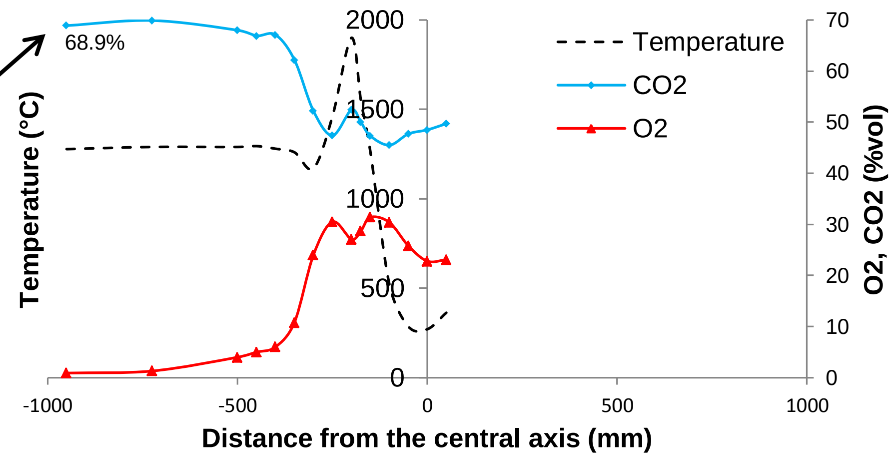




External recirculation zone

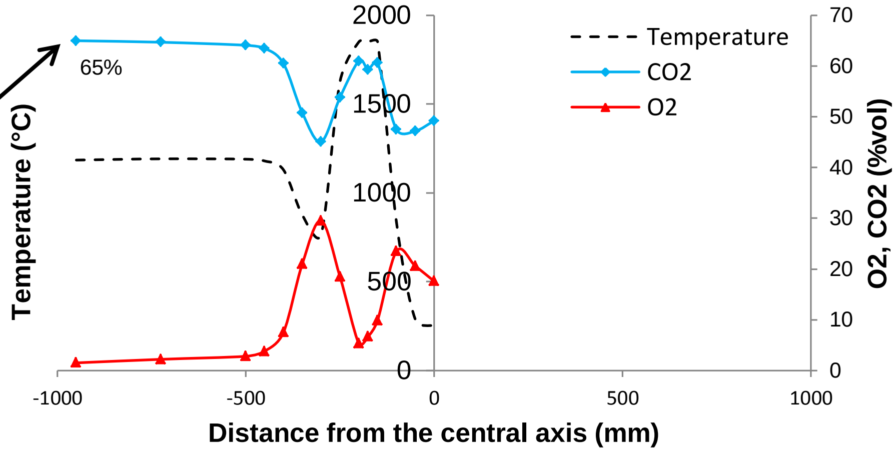
Output conditions

Recycle Ratio R	0.61
Temperature	927 °C
O_2	3%
CO_2	73.7%
NO_X	268 ppm
CO	12 ppm



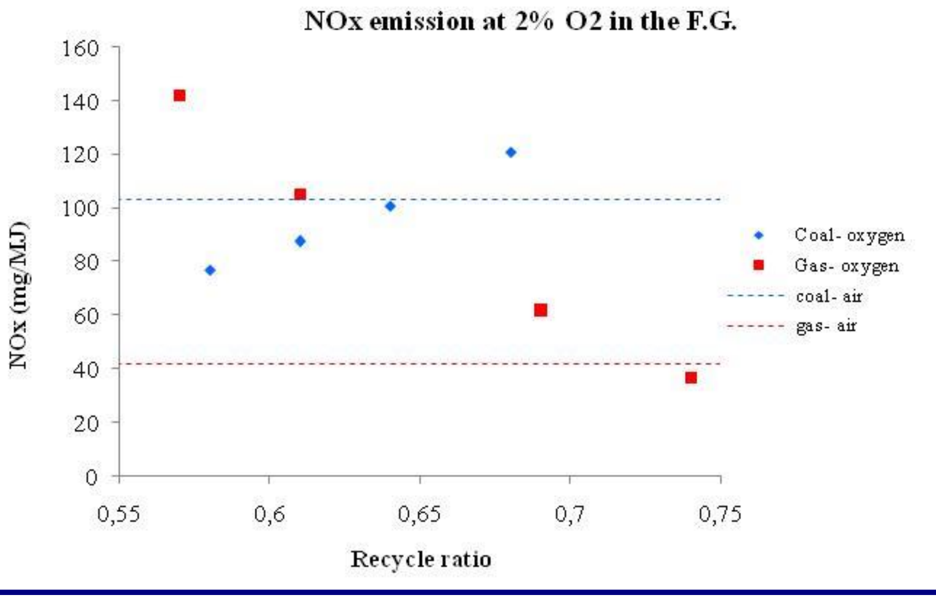
Output conditions

Recycle Ratio R	0.69
Temperature	919 °C
O_2	3.2%
CO_2	68.7%
NO_X	120 ppm
CO	11 ppm



NO_X emissions

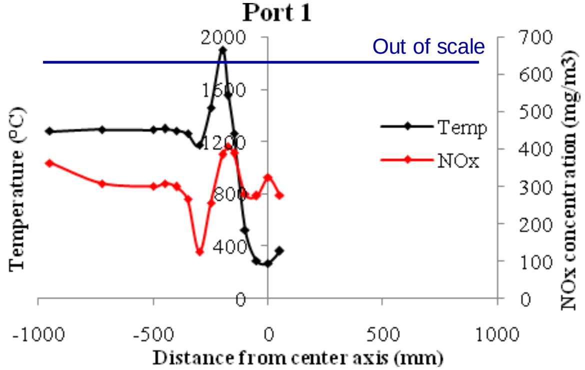
- NG-oxy combustion. The NO_X emission decreases as the recycle ratio increases. The emissions in oxy-combustion are generally higher than in conventional combustion
- Coal oxy-combustion. The NO_X emission increases as the recycle ratio increases. The emissions in oxy combustion are lower than conventional combustion for R<0.64.

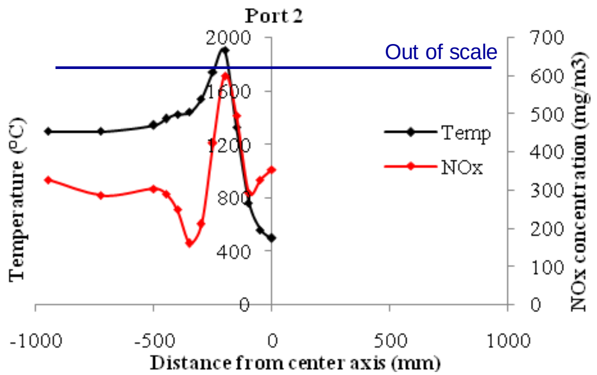


NO_X emissions

Oxy-gas

Thermal NO_X emissions predominant

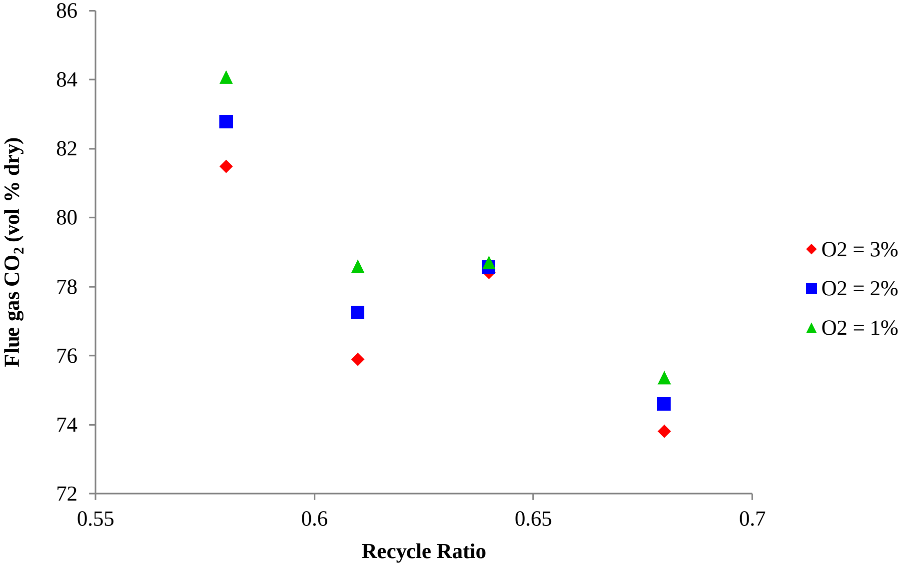




Oxy-coal

Air-in leakage effect predominant

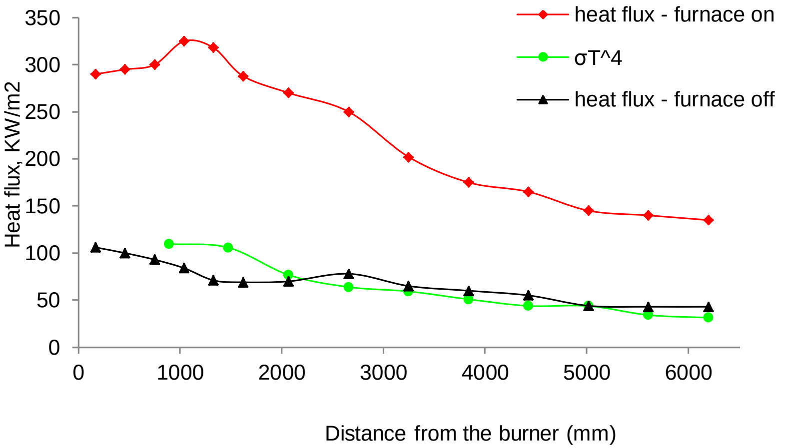
As the recycle ratio increase the air in-leakage in the system increase



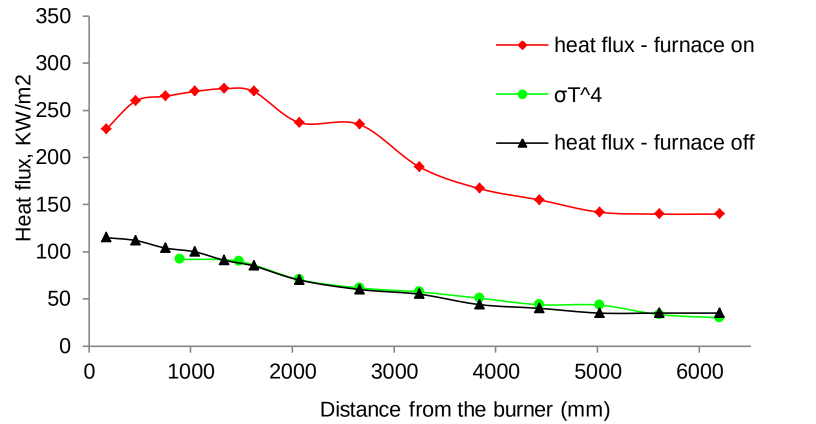
Total heat flux hitting the walls

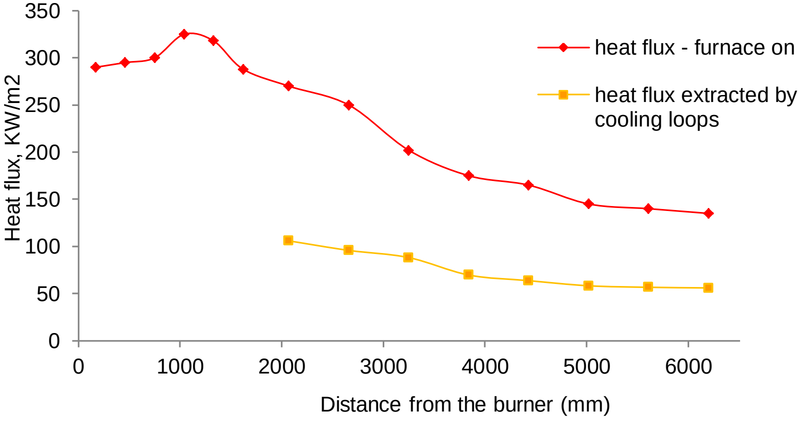
Oxy-gas combustion

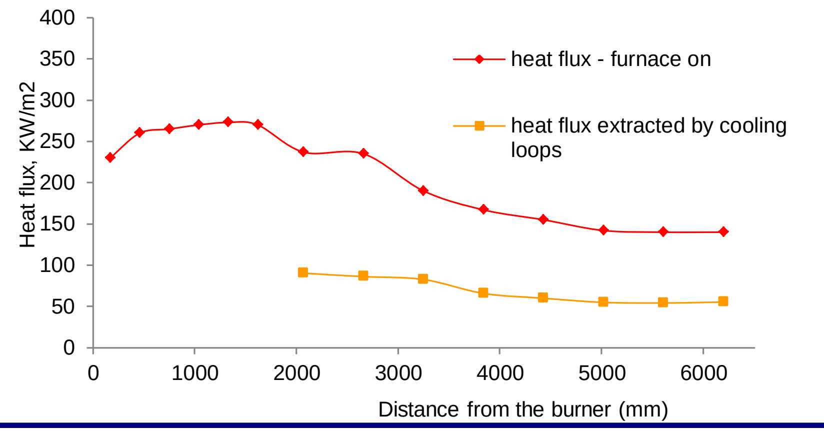
R=0.61



R=0.69







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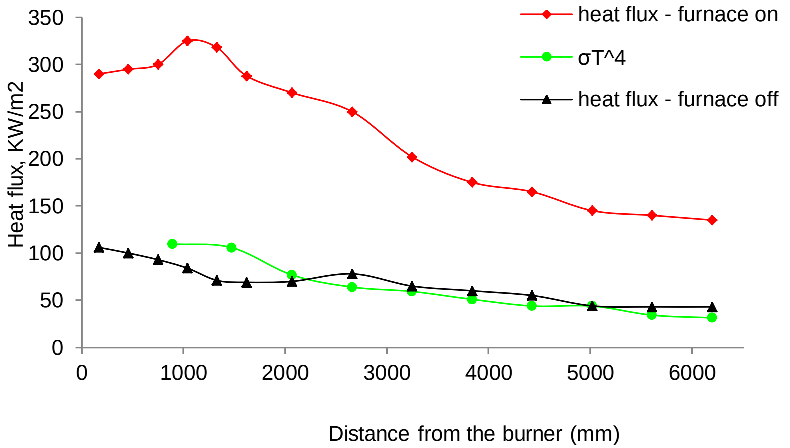
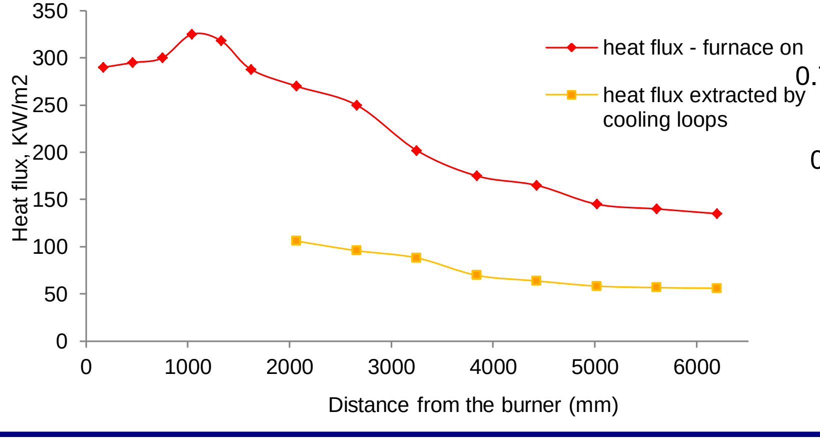
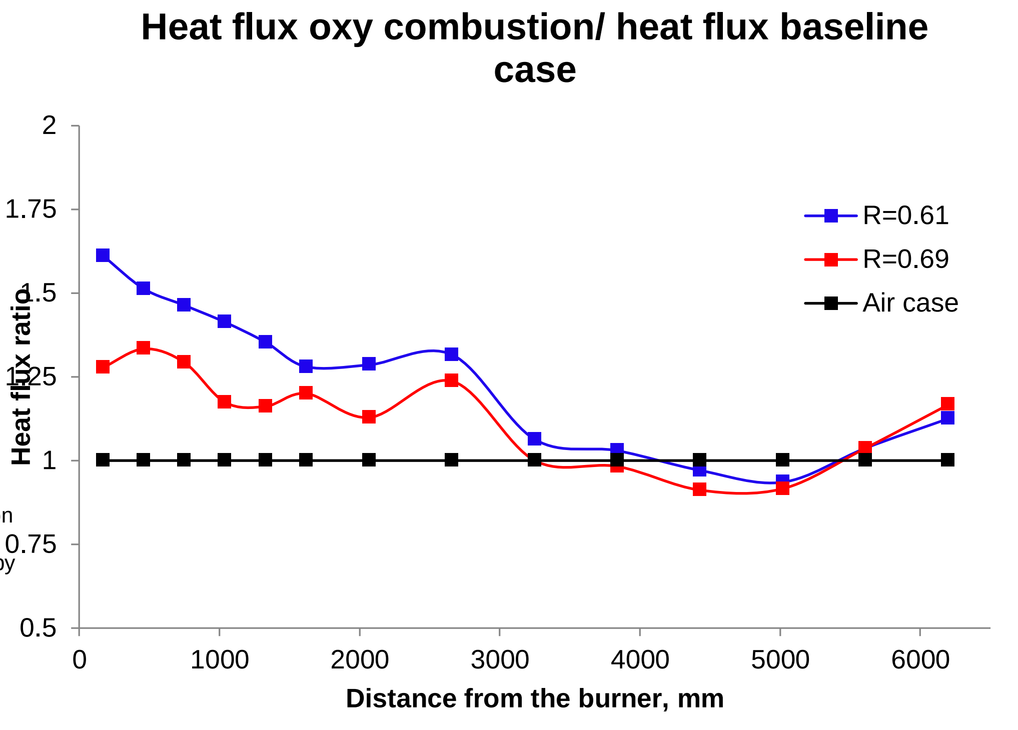


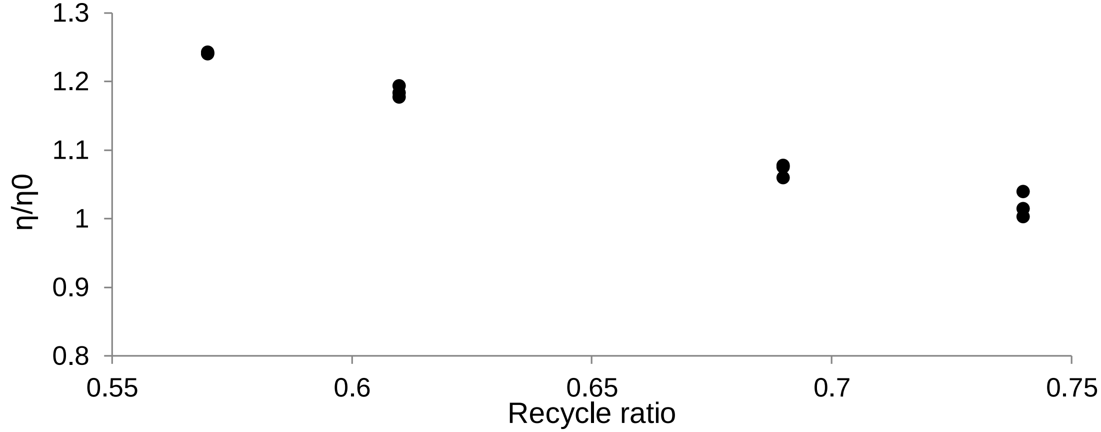




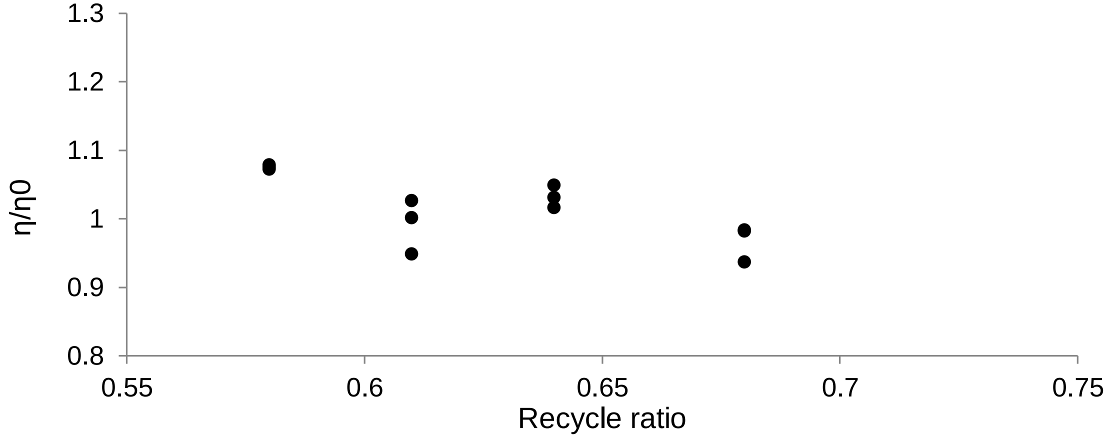
Heat transfer efficiency

Total heat exctracted by cooling loops / total heat extracted by cooling loops in the baseline case

Oxy-gas



Oxy-coal



Conclusions (1)

- Modified FoSper plant is OK for oxy-combustion studies
- Important **air in-leakage** is present at high R
- The process of retrofitting the FOSPER rig was studied. Some of the issues arisen in this work can give a good indication about what would be the problems if an industrial scale plant would undergone the same treatment.
- In particular the problem of the air in-leakage was the major cause of the level of the CO_2 in the flue gases lower than theoretically expected.
- Near future work: try to reduce in-leakage down to acceptable levels
- **TEA C burner**: good stable performances in oxy-RFG conditions, both with NG and coal *(no primary oxygen)*

Conclusions (2)

- The influences of the recycle ratio on the NO_X emission both in NG and coal oxy combustion were studied.

- The *in-flame* data collected during the campaigns are to be published in an IFRF report, and may be used to develop a better understanding of the changes in the chemical and physical processes involved in this kind of combustion. *Overall and In-flame measurements provide good sets of data for more fundamental analysis (flame structure, NOx, carbon in ash, etc.)*

- They can also provide modelers with a starting hint for the development of oxy-combustion flame mathematical simulation.

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