Characterization of 30 MW_{th} Circulating Fluidized Bed Boiler under Oxy-Combustion Conditions

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Outline of presentation

- Introduction
- Development approach from small to large scale
- CFB boiler, test programs and fuels
- Research priorities
- Furnace heat transfer
- Process performance generally
- Summary of operational experiences
- Conclusions

Acknowledgement

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The Compostilla Project OXYCFB300

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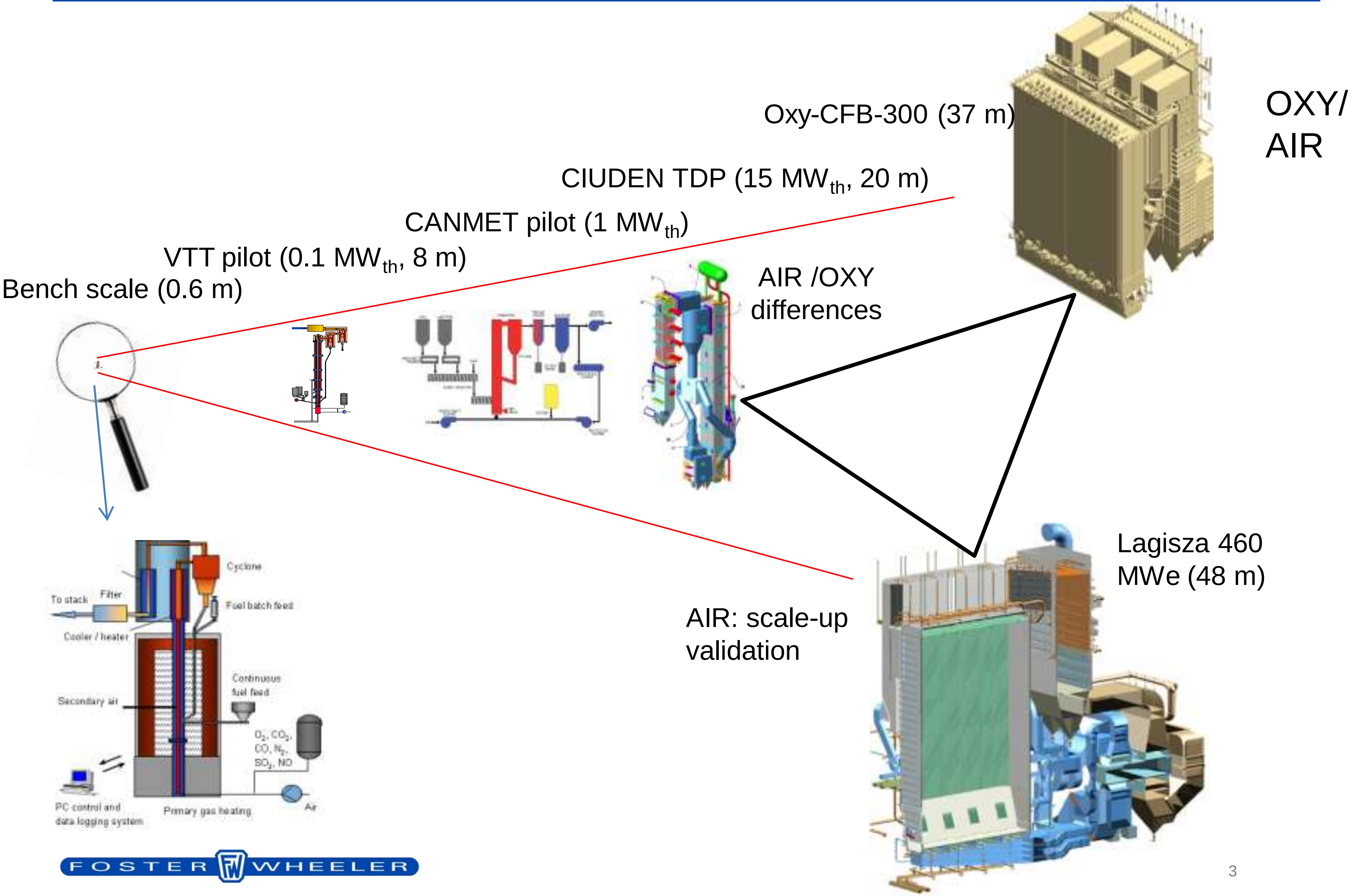
SEVENTH FRAMEWORK PROGRAMME

Co-financed by the European Union
European Energy Programme for Recovery

Introduction

- Prior to the CIUDEN CFB facility, Foster Wheeler has conducted several oxy combustion test campaigns at smaller pilot scale
  - VTT´s 100 kWth CFB test rig
  - CanmetEnergy´s 1 MWth oxy-CFB pilot plant
- Several feasibility studies to develop the Flexi-Burn CFB boiler concept
- The Oxy-CFB-300 Compostilla project to develop 300 MWe scale air/oxy flexible CFB boiler design has been a major driving force for vast R&D activities since 2010.
- CIUDEN 30 MWth Oxy-CFB pilot plant was commissioned in 2011-2012, and formed an important platform in testing activities
- Two EU projects, FP7 and EEPR funded, formed the frame for partnering and funding of this development.

Development approach from small to large scale



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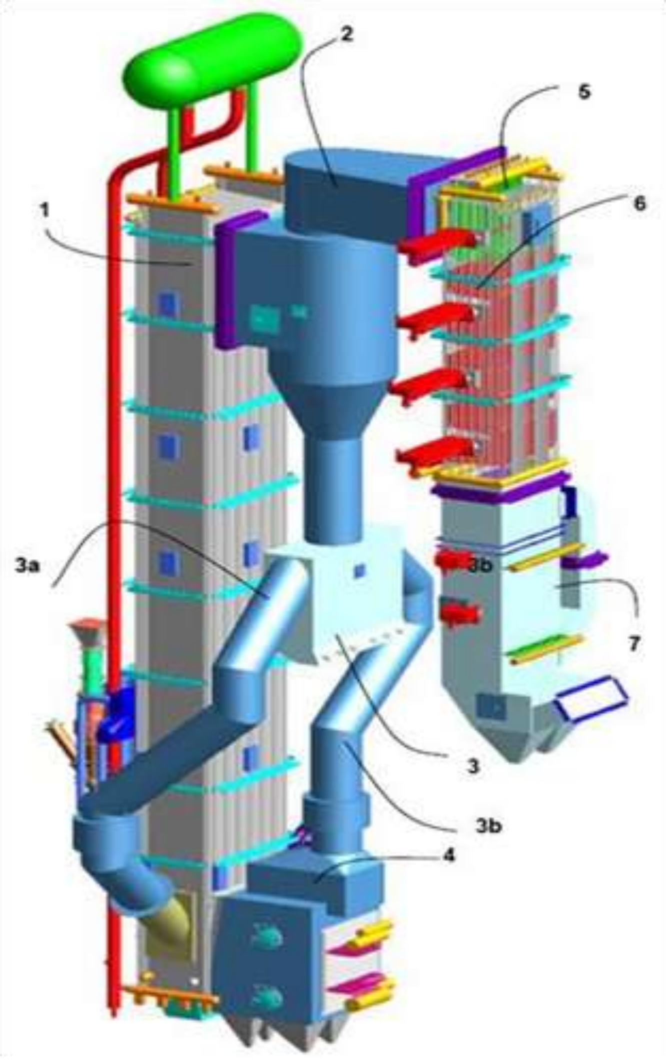
CIUDEN 30 MW_{th} Oxy-CFB Boiler



1. *Water tubes*
2. *Cyclone*
3. *Loop-seal*
    a. *Direct material recirculation*
    b. *Intrex material recirculation*
4. *Intrex*
5. *Heat recovery zone*
6. *Convective evaporator*
7. *Economizer*

Test programs at the CIUDEN Oxy-CFB Boiler

General objectives:

- Demonstrate air/oxy CFB combustion in large scale(Flexi-Burn CFB)
- Generate process data on various fuels for design verification and validation of models and design tools (1D and 3D CFB furnace models, 1D CFB dynamic model, emission models)
- Scale-up effects
- Gain operating experience in oxy combustion process and auxiliary equipment
- Demonstrate integrated operation of CFB and CPU
- Indentify needs for future development

TEST PERIOD	Oper. mode	Air tests	Oxy tests	Oxy hours	Schedule
Preliminary testing					
Anthracite	Air/Oxy	1	11	105	3/2012
Anthracite/petcoke	Air/Oxy	3	6	104	4/2012
FLEXI BURN CFB					
Anthracite (steady & dynamic)	Air/Oxy	-	12	126/41	7/2012
Anthracite/petcoke blend (70/30 %)	Oxy	-	13	314	7/2102
Anthracite/petcoke (various mixtures)	Air/ Oxy	3	10	190	8/2012
Sub-bituminous, Biomass co-firing with anthracite	Air/Oxy	3	13	290	9/2012

TEST PERIOD	Oper. mode	Air tests	Oxy tests	Oxy hours	Schedule
EEPR TESTS (1.10.-17.12.2013)					
Anthracite/petcoke blend (70/30 w-%)					
Session 2: Boiler parametrical testing; FU & FP7 + EEPR(steady & dynamic)	Oxy	2	6	82	10/2012
Session 1: CPU parametrical testing (steady & dynamic)	Air/Oxy	-	3	76	10/2012
Session 3: Changes in emissions and disturbance testing (dynamic)	Oxy	-	5	98	11/2012
Session 4: S-A bituminous coal (steady & dynamic)	Air/Oxy	1	9	92	12/2012

Tested fuels

FLEXIBURN CFB

	Unit	Anthracite	Anthracite/ petcoke (70/30 w-%)
Proximate analysis			
Total moisture	w-% (a.r.)	5.41	4.77
Ash content (815°C)	w-%, d.s.	31.92	22.95
Volatile matter	w-%, d.s.	6.05	7.03
Fixed carbon	w-%, d.s.	62.03	70.02
Ultimate analysis			
Carbon	w-%, d.s.	60.53	70.12
Hydrogen	w-%, d.s.	1.83	2.20
Nitrogen	w-%, d.s.	0.88	1.07
Sulphur	w-%, d.s.	1.01	2.17
Oxygen	w-%, d.s.	2.73	1.50
Gross calorific value	MJ/kg (d.s.)	22.98	26.49
Net calorific value	MJ/kg (d.s.)	22.58	26.02

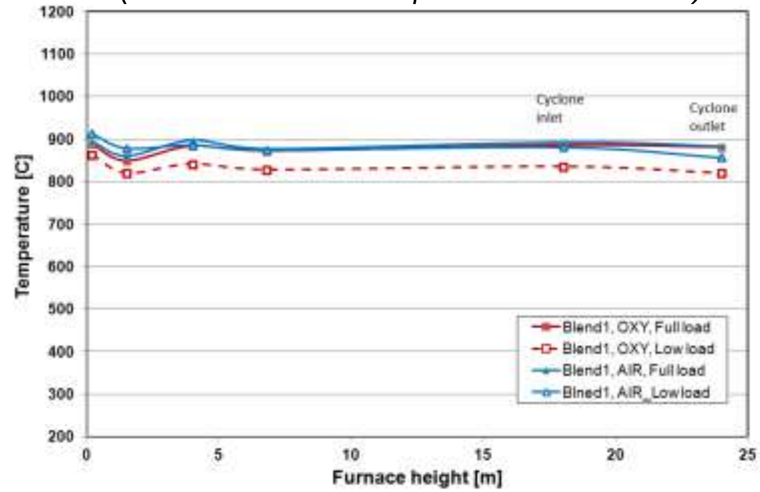
Priorities in CFB process evaluations

- Knowledge on differences between air and oxy combustion
  - Extend validity of existing models for oxy-fuel combustion
  - Analysis of process data by using 1D CFB, 3D CFB and 1D Dynamic models
- Heat transfer in furnace and backpass (→thermal design of large boiler)
- Combustion performance, unburned carbon in ash
- Emissions (SO_2 & SO_2 control by limestone, NO_x & NO_x control by SNCR, CO, NH_3 slip) → Conclusions for the large scale design
- Effect of oxygen content in oxidant streams on process performance
- Limestone compounds in bed (related to sulphur capture mechanisms and bed behaviour in hot loop)
- Dynamic behaviour of the oxy-CFB process and validation of dynamic simulation model.
- Corrosion (esp. acid dew point in cold end), fouling, air ingress
- Operational aspects
- Performance of auxiliary equipment (any oxy combustion related issues)

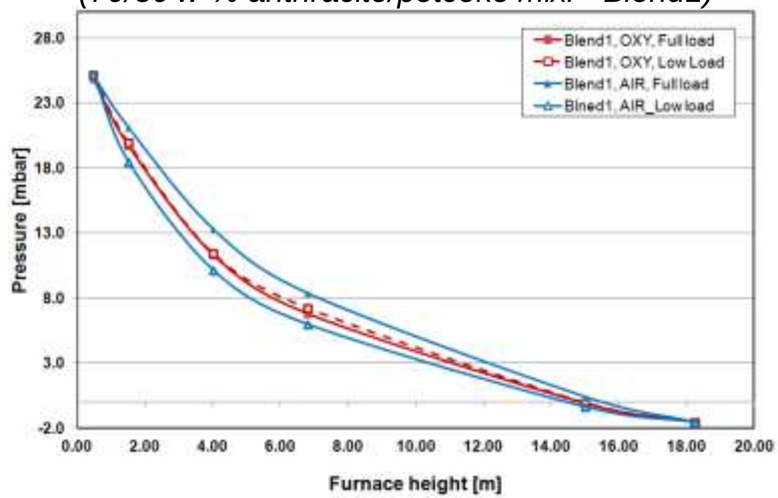
Procedure for furnace heat transfer evaluation

- Furnace vertical temperature, pressure and oxygen profiles
- Detailed analysis of solids composition and mass balance
- Solids density profile correlations
- Comparison of solids behaviour in air and oxy combustion
- Back calculations to verify the model accuracy with the test data
- If necessary, tune the model parameters to get the best fit with the test data
- Combustion profile
- Heat release profile
- Validation of 3D CFB model by CIUDEN CFB data
- Comparison of heat transfer in air and oxy combustion

Measured furnace temperature profile
(70/30 w-% anthracite/petcoke mix. =Blend1)

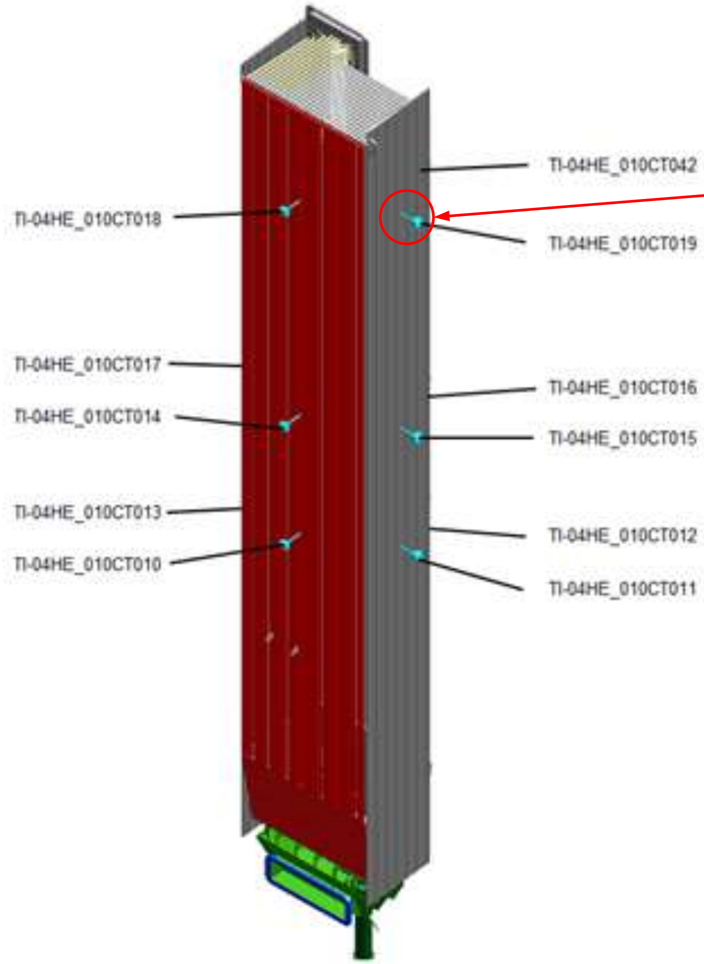


Measured furnace pressure profile
(70/30 w-% anthracite/petcoke mix. =Blend1)



Measurements for heat transfer analysis

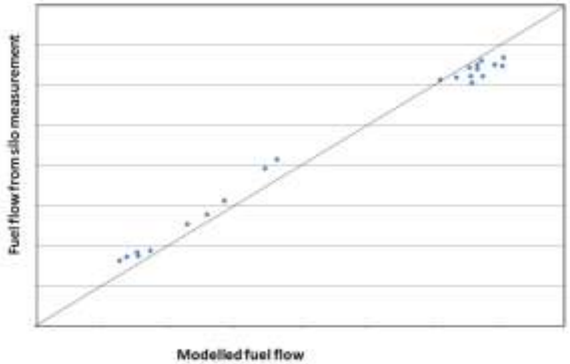
Heat flux sensors for direct heat transfer measurement

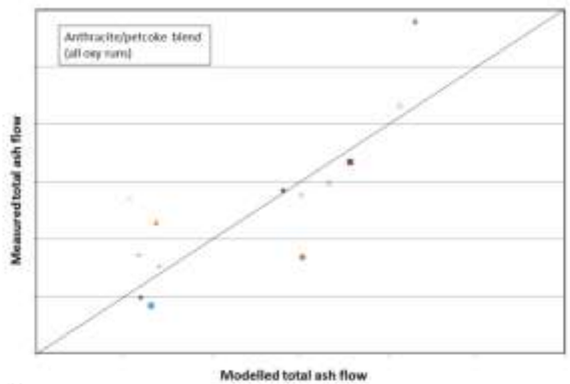


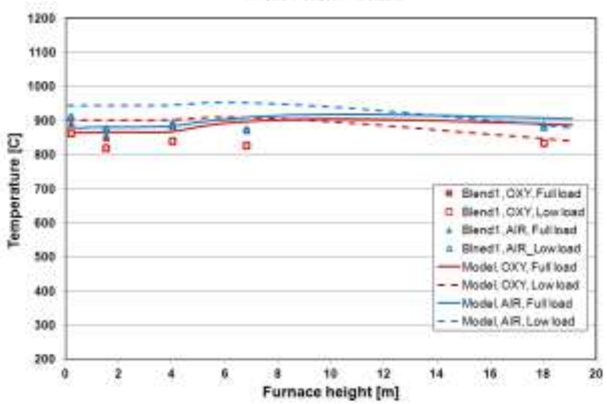
Chordal termocouple

- Measured furnace vertical temperature, pressure and oxygen profiles
- Fuel and limestone flow
- Ash weighing for determination of distribution between fly and bottom ash
- Solids sampling for their physical and chemical characterization
- Furnace profile measurements for solids and gas
- Heat flux measurements (integrated in membrane walls at three elevations) for direct monitoring of heat transfer (air vs. oxy)

Verification of 1D CFB model by back calculations







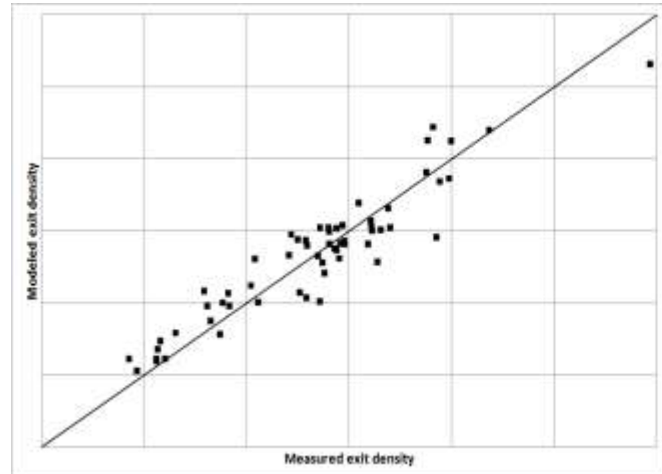
Examples

Modelled vs. measured fuel flow

Modelled vs. measured ash flow

Modelled vs. measured temperature profiles

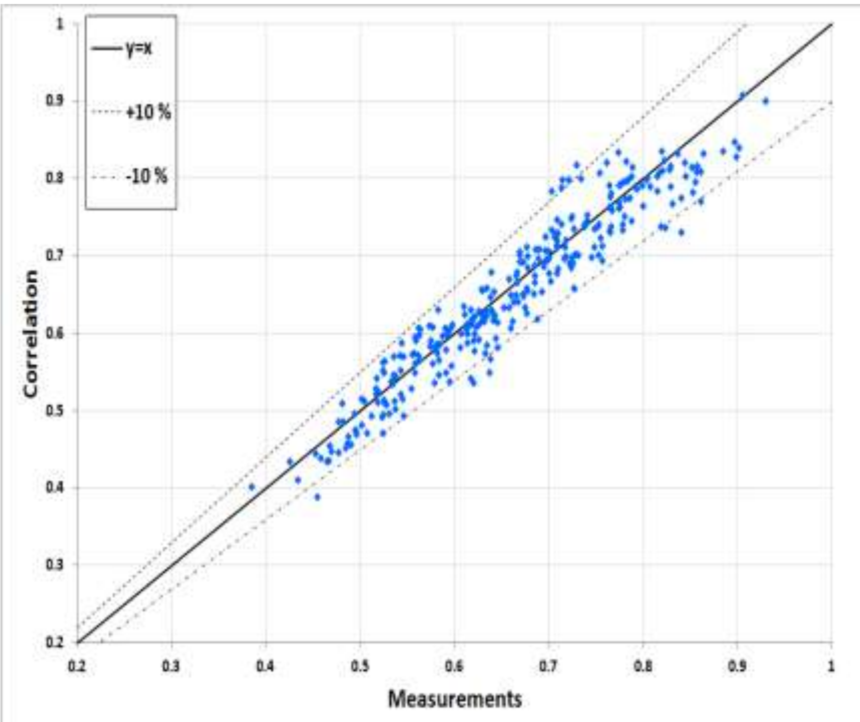
Modelled vs. measured solids exit density



- Particle convection is the primary mechanism of heat transfer in CFB furnace
- Solids material balance and solids density profile are key factors in particle convection.
- Correlation was developed for the CIUDEN CFB including
  - Fluidization velocities,
  - Furnace PSD and
  - Bed inventory (mass) in furnace
- Correlation predicts solids densities of both combustion modes well

Modeling of heat transfer

Measured vs. modelled heat transfer at different elevations

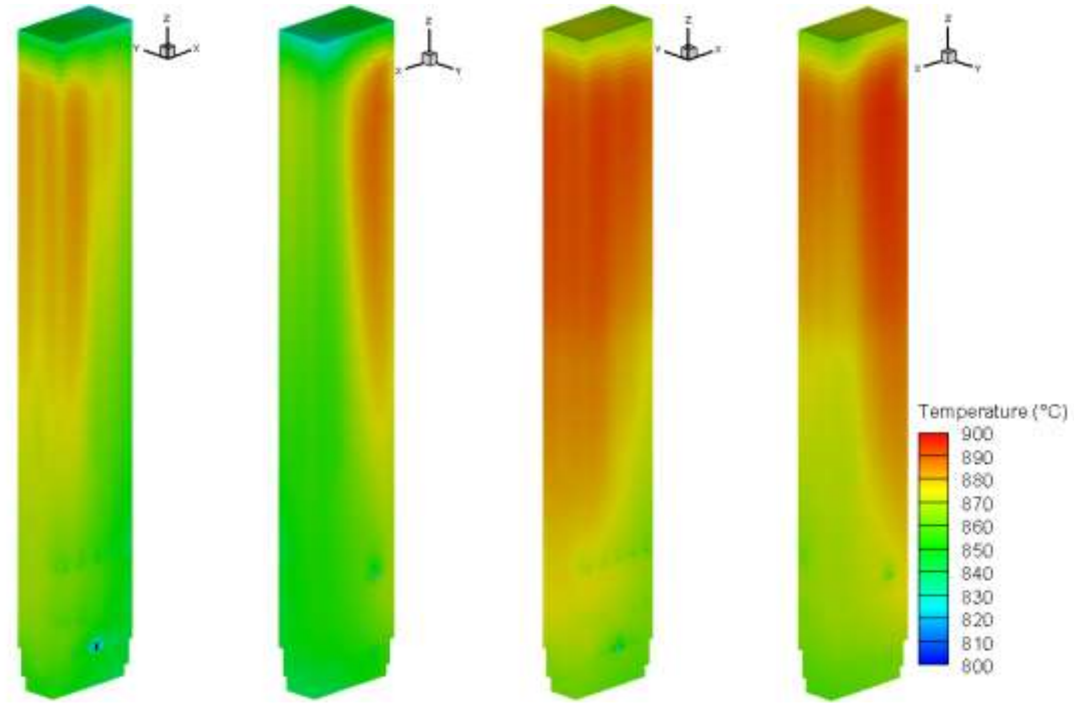


- Heatflux sensors installed at different elevation in furnace
  - ➔ Direct comparison of heat flux locally between air and oxy combustion
- Correlating heat transfer coefficient with key process parameters: solids density, temperature
- Tuning the parameters for all test data with different fuels.
  - ➔ Tool to compare heat transfer in air and oxy combustion mode in the CIUDEN CFB.

3D CFB furnace model

Comparison of furnace temperature in air and oxy combustion test points with near similar operating conditions

FB_S1_A_A1 (air) FB_S1_A_O1 (oxy)

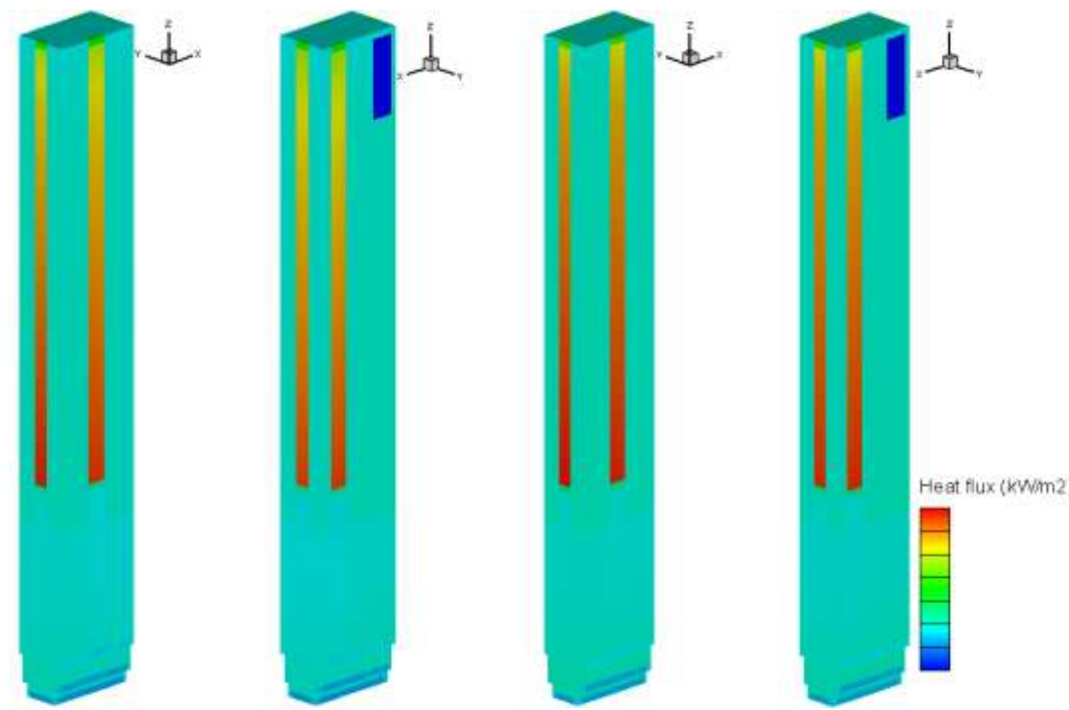


- The temperature level in oxygen-fired case is slightly higher due to higher fuel input.

3D CFB furnace model

Comparison of heat flux in air and oxy combustion test points with near similar operating conditions

FB_S1_A_A1 (air) FB_S1_A_O1 (oxy)



- The heat transfer panels are located at different walls. Other surfaces are refractory lined.
- The heat flux in oxygen-fired case is slightly higher due to higher furnace temperature

Conclusions of process performance in oxy combustion relative to air combustion

	Oxy compared w/ air combust-ion[1)]	Remarks [1)] Conclusions and remarks are valid for ppm's. When expressed as mg/MJ, all are lower in oxy combustion.
Furnace temperature	Equal	Oxidant O2 level can be used for temperature control in oxy → adds up flexibility in oxy control over the load range
Solids density profile	Equal	With same fuel/limestone particle size
Furnace heat transfer	Equal	Furnace temperature, solids density profile and feed material characteristics are the primary variables.
Unburned carbon in ashes	Equal	Generally higher at low load and lower in high load oxy operation
CO emission	Slightly higher	
SO2 capture by limestone	Higher	Higher in oxy combustion due to higher SO2 concentration Retention is reduced at low temperature/load due to direct sulphation mode (i.e. below calcination temperature)
NOx emission	Equal / lower	Lower at high load/high temperature
N2O emission	Higher/Equal	Fuel dependent, similar temperature dependence as in air combustion

Summary of operational findings

- Boiler operation and performance generally not outstandingly different (oxy vs. air)
- Furnace control with oxidant O_2 demonstrated; ~similar oxidants used as in planned OXY-CFB-300 boiler concept
- Switches between the operating modes (air&oxy) can be done smoothly by automated sequence. No process technical issues originating from the oxy combustion conditions have been experienced.
- Correct PSD (crushing) of anthracite is important due to hard ash.
- Optimal furnace operating parameters (e.g. temp.) with the design fuel were determined
- No clear re-carbonization issues encountered, however conditions in fluid bed heat exchanger (INTREX™) were not fully representative (low solids outlet T)
- No significant fouling has been observed. Neither any corrosion issues were observed in the CFB hot loop and heat recovery area.
- Acid dew point issues avoidable through limestone feeding, control of surface temperatures and elimination of leaks (important also for flue gas CO_2). Test duration was obviously too short to experience boiler tube degradation.

Conclusions

- An extensive process database was accumulated during the boiler commissioning and two test projects at the CIUDEN Oxy-CFB boiler in 2011-2012.
- Major focus in data evaluation and modeling activities was to understand the impact of oxy combustion condition on combustion, emissions and heat transfer.
- An important result was that with the same operating parameters, furnace heat transfer appears to be at the same level as of air combustion.
- The tests confirmed the previous findings from smaller scale pilots that there is no major difference in process operation compared to air combustion.
- Valuable experience on operation of the oxyfuel CFB process was gained.

➔ **OXY-CFB-300 boiler design verification**

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Thank you

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