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MODELING OF FULL SCALE OXY-FUEL CEMENT ROTARY KILN

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- Methodology for optimization of the process modeling by integrating the CFD
- Full scale rotary cement kiln setup
- Results
  - Heat profiles to the clinker
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- Conclusions

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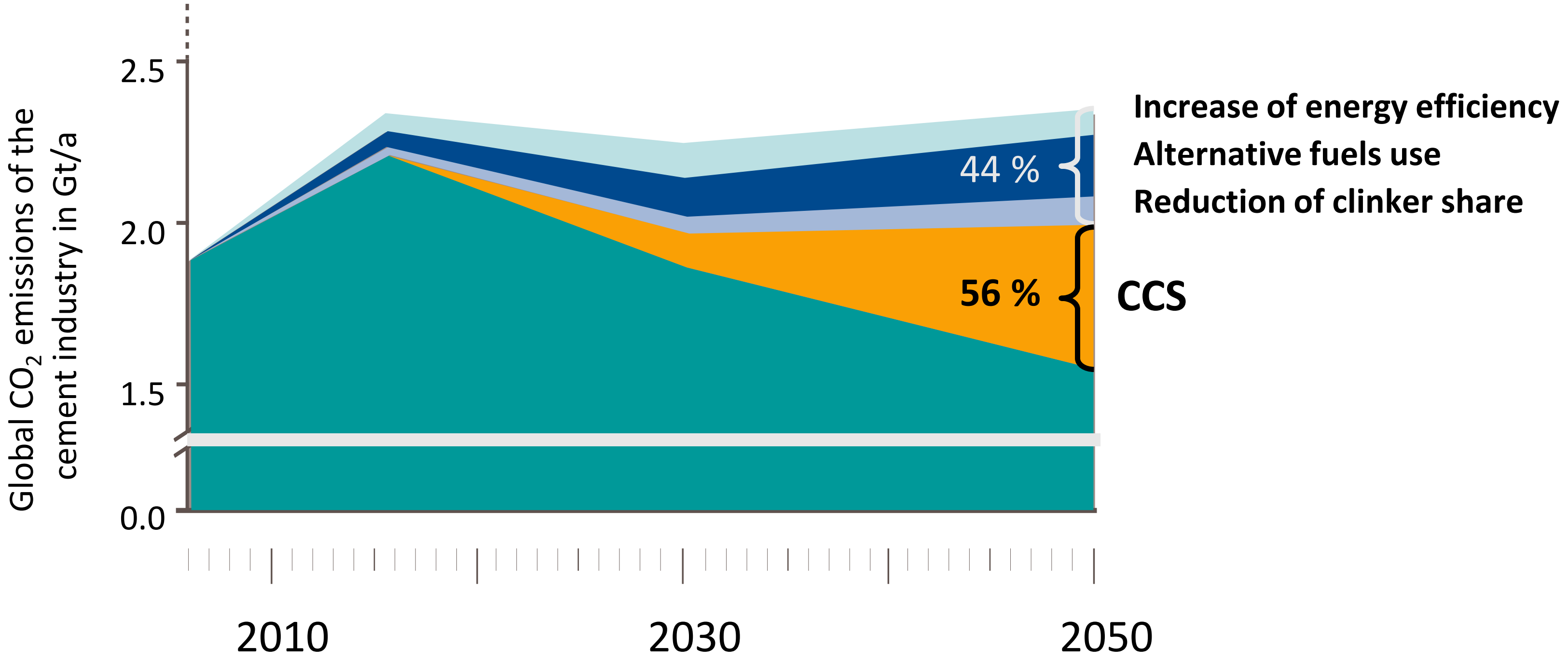
Introduction

CO2 emissions reduction targets from cement production



Source: IEA Cement Roadmap

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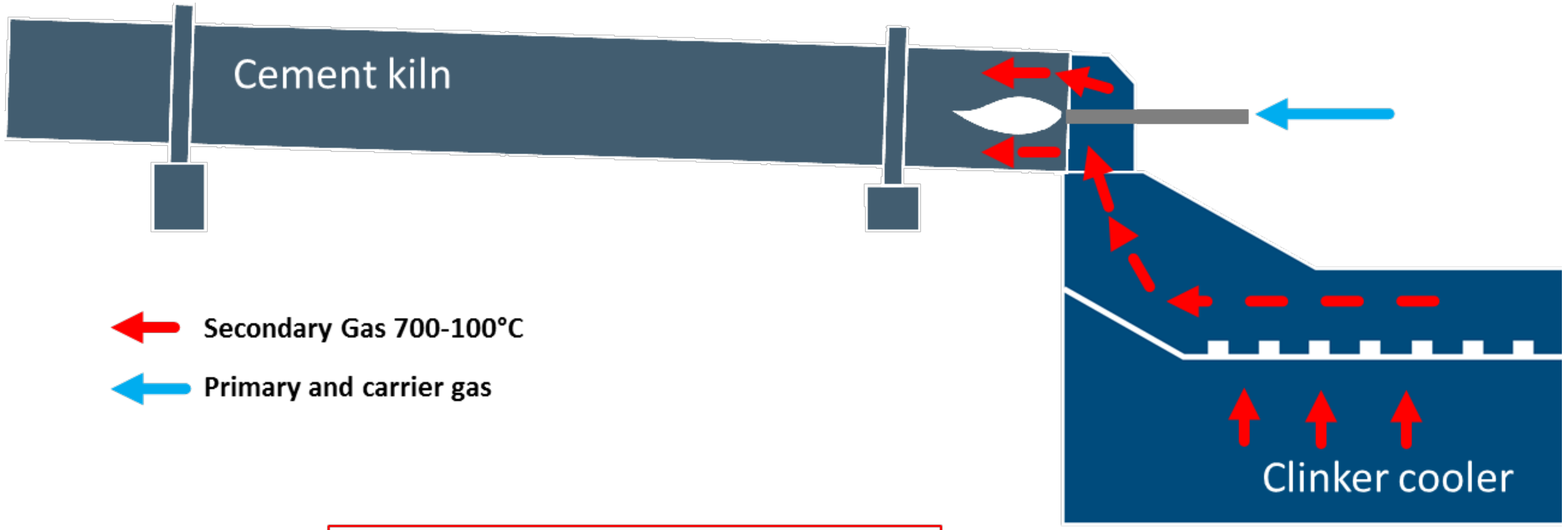
Introduction

Cement rotary kiln



- Preheating of secondary gas
- Dry secondary gas

CEMCAP - oxy-fuel combustion

Pilot testing adapted commercial burner

ThyssenKrupp

ThyssenKrupp Industrial Solutions

Universität Stuttgart ifk

CFD validation

CFD full scale rotary cement kiln inlet optimization

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Cement plant process optimization

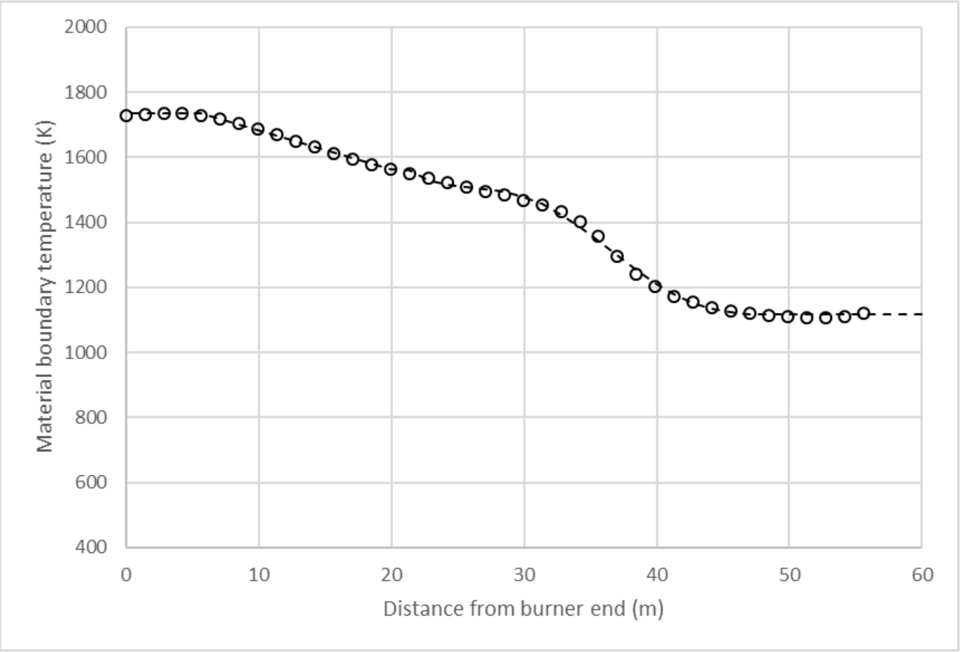
vdz.

CEMCAP - oxy-fuel combustion

Optimization methodology

- Objective of optimization: achieve a flame generating a heat profile in the kiln comparable to that of the reference BAT case: the material temperature profile must be preserved

- Reference BAT case: AIR



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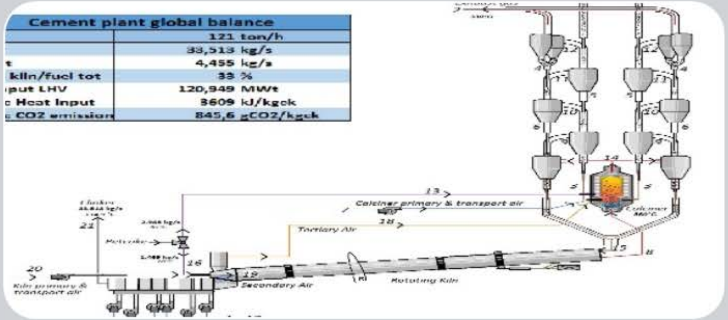
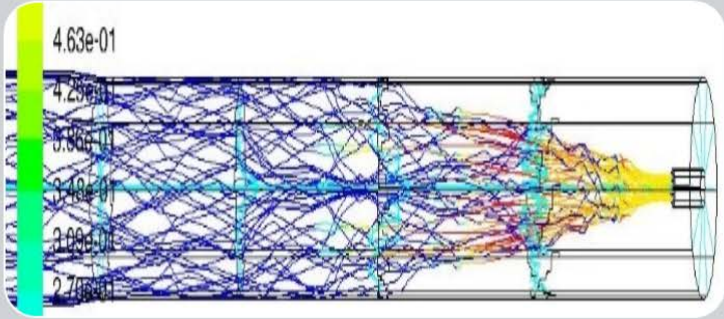
CEMCAP - oxy-fuel combustion

Optimization methodology





Process Modelling of Cement Plant (WP6)

- Kiln modelled as 1D with 40 cells

- Solves mass and energy balance, and material transformation across the whole plant

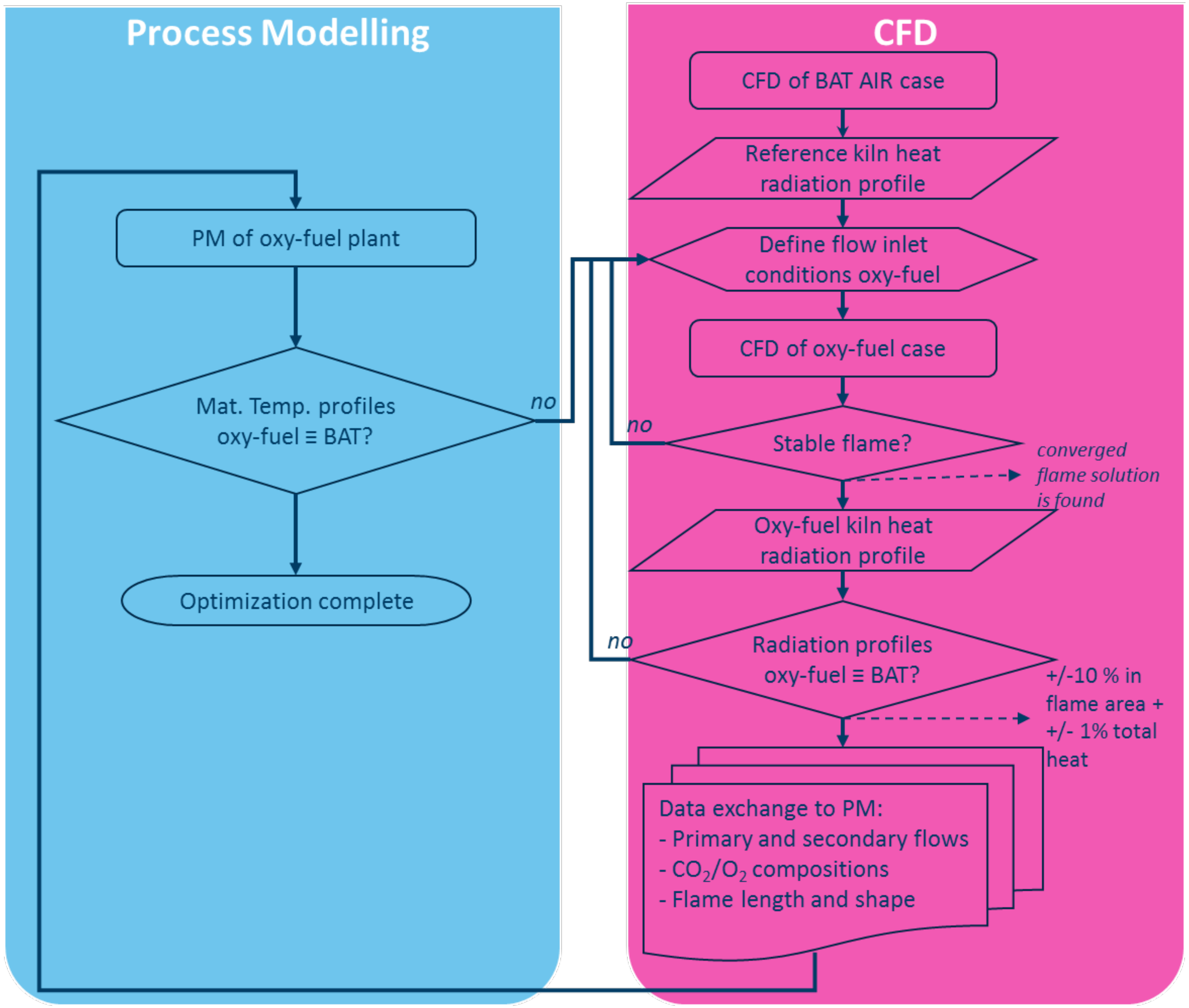
CFD of Rotating kiln (WP7)

- Kiln modelled as 3D with 16 millions cells

- Solves the turbulent fluid mechanic and combustion kinetic equations in the flame

CEMCAP - oxy-fuel combustion

Data exchange and process optimization



CEMCAP - oxy-fuel combustion

Constraints in the process optimization

Parameter	Constraint
O_2 % in primary stream	None
CO_2/O_2 composition in carrier stream	0% - 35 %
Primary / secondary flow	0.1 – 0.15
Primary CO_2 flow rate	No limitations, but overall efficiency will decrease with an increase of cold primary flow
Secondary CO_2 flow rate	34,000 to 40,000 Nm^3/h
Total primary	None
Overall kiln lambda	1 - 3 % O_2 in dry flue gases
Burner swirl angle	None
Velocities at burner outlets	
Nozzles	150 – 250 m/s, preferably greater than 200 m/s
Secondary	3 – 6 m/s
Carrier gas	15 – 20 m/s
Burner hardware	During the optimization step, a suggestion for burner hardware modification (nozzle size) may be made if a solution does not match the current burner specs

Full scale rotary kiln

Burner

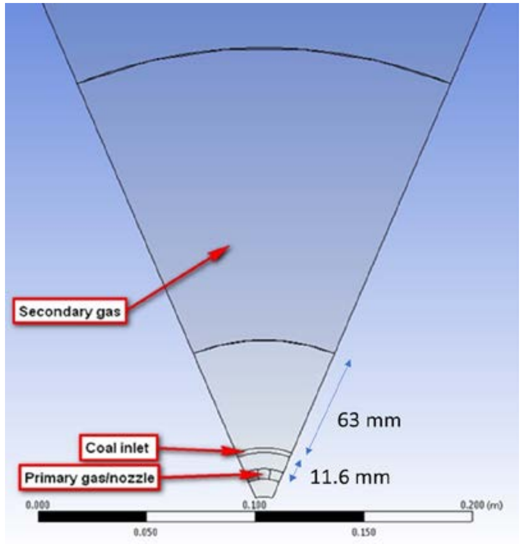
Source: ThyssenKrupp- POLFLAME

- Coal

Property	Value
HCV (J/kg)	27,150
Volatiles (%)*	27
Fixed C (%)*	56
Ash (%)	16.5
Moisture (%)	0.5
Coal size (µm)*	100 - 400
Coal feed rate (kg/s)	1.47
Coal ultimate analysis (waf)	
C (%)	83.15
H (%)	4.82
O (%)	10.85
N (%)	0.58
S (%)	0.60

- Clinker dust

Property	Value
Density (kg/m³)	1400
Cp (J/kg K)	Polynomial
Particle emissivity	0,9
Particle scattering factor	0,9
Inlet velocity (m/s)	Secondary flow
Particle diameter (µm)	150
Particle inlet temperature (K)	1073
Mass flow rate (kg/s)	0.28



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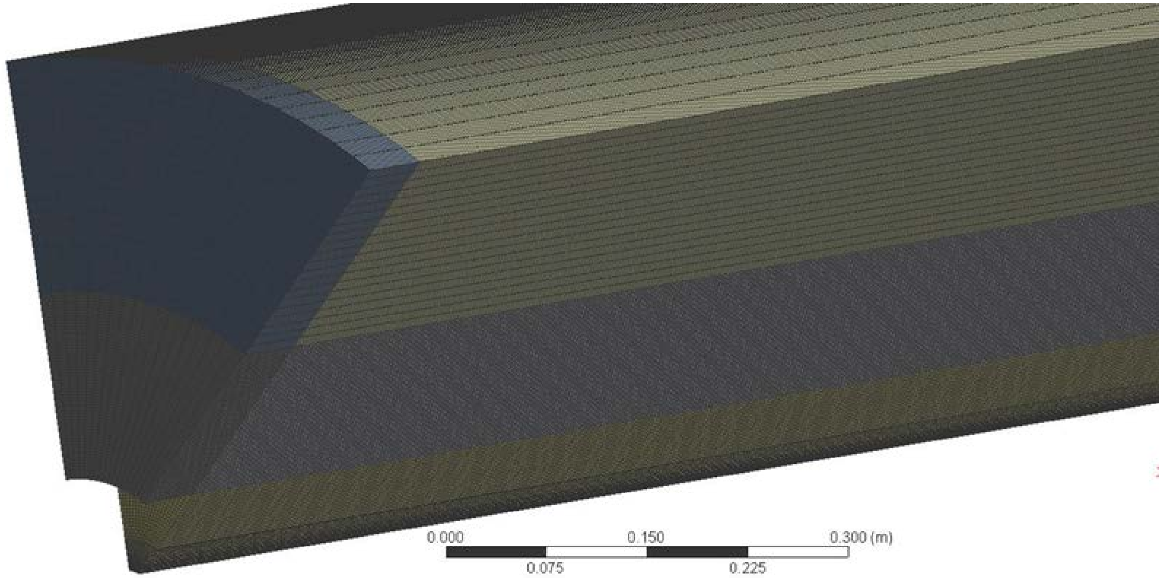
Full scale rotary kiln

CFD domain and setup



- Code: Fluent 17.2
- 3D domain 1/10th symmetry
- Mesh: of 1,648,500 cells
- Turbulence: k-omega SST
- Chemistry: Species transport, Finite rate/Eddy-Dissipation, 7-step reaction model
- Radiation model: Discrete Ordinates and WSGGM for gas radiation
- Geometry: 60 m long, Ø 3.76 m and Ø 3.56 m in the sintering zone
- Wall boundary: Forced temperature profile as in BAT profile
- Rotary kiln capacity: 3,000 t/d

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Full scale rotary kiln

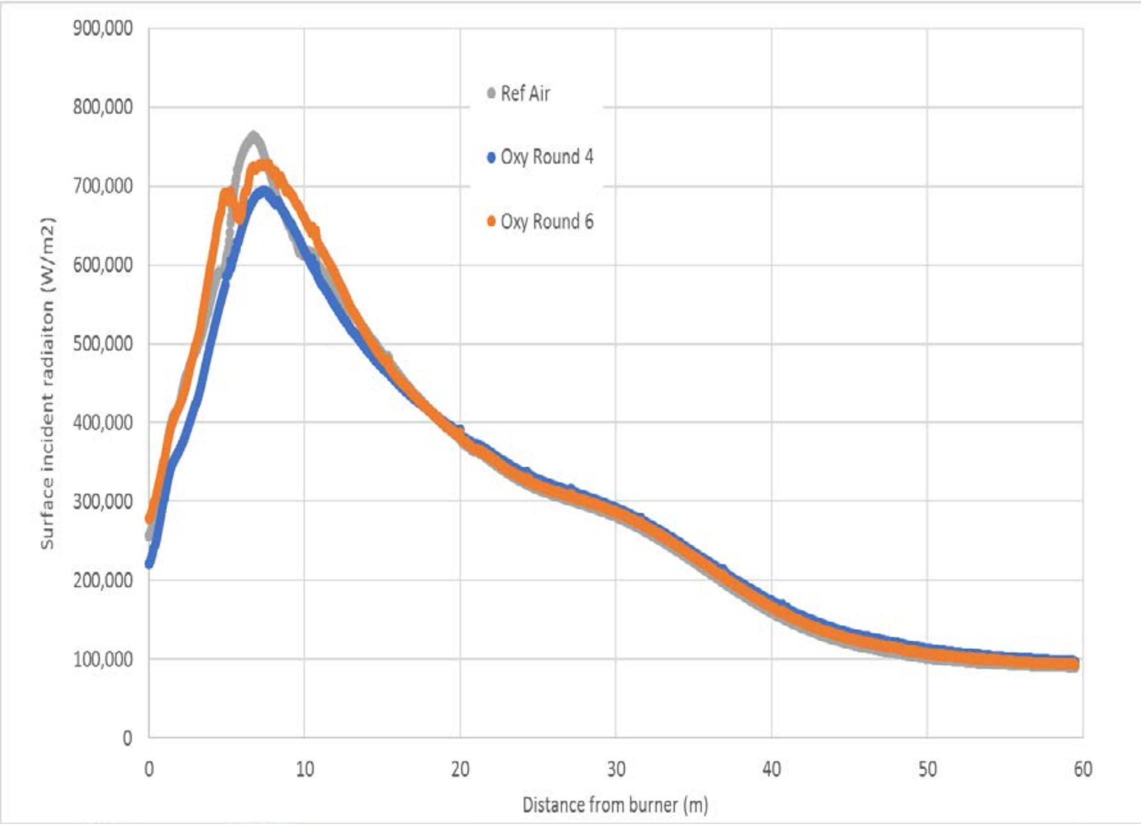
Inlet streams

- Constraint priority: retrofit (i.e. burner hardware)
- Total available gas in the primary stream is one third lower in the oxy-fuel case, compensated by higher swirl

Combustion cases:		AIR-Ref.	OXY-Round 3	OXY-Round 4	OXY-Round 6
Primary gas					
Volume flow rate	Nm^3/h	5,100	4,068	4,500	4,500
Temperature	K	323	323	323	323
Composition					
N2 or CO2		N2	CO2	CO2	CO2
O2	% by vol.	21	60	60	60
N2 or CO2	% by vol.	79	40	40	40
Swirl degree	angle	20° tangential	40° tangential	30° tangential	30° tangential
Velocity	m/s	250	200	221	221
Carrier gas					
Volume flow rate	Nm^3/h	4,040	1,600	1,600	1,050
Temperature	K	323	323	323	323
Composition					
N2 or CO2		N2	CO2	CO2	CO2
O2	% by vol.	21	30	30	18
N2 or CO2	% by vol.	79	70	70	82
Velocity	m/s	38.3	15.2	15.2	10.0
Fuel					
type		coal	coal	coal	coal
mass flow rate	kg/s	1.469	1.469	1.469	1.469
stoichiometric O2 mass	g_O2/g_fuel	2.070	2.070	2.070	2.070
Primary + Carrier					
Volume flow rate	*Nm^3/h*	*9,140*	*5,668*	*6,100*	*5,550*
Temperature	*K*	*323*	*323*	*323*	*323*
Composition					
N2 or CO2		*N2*	*CO2*	*CO2*	*CO2*
O2	*% by vol.*	*21.0*	*51.5*	*52.1*	*52.1*
N2 or CO2	*% by vol.*	*79.0*	*48.5*	*47.9*	*47.9*
O2	*Nm^3/h*	*1,919*	*2,921*	*3,180*	*2,889*
CO2 or N2	*Nm^3/h*	*7,221*	*2,747*	*2,920*	*2,661*
available combustion O2	*g_O2/g_fuel*	*0.518*	*0.789*	*0.859*	*0.780*
Secondary gas					
Volume flow rate	Nm^3/h	29,090	32,714	36,000	28,126
Temperature	K	1073	1073	1073	1273
Composition					
N2 or CO2		N2	CO2	CO2	CO2
O2	% by vol.	21.0	18.0	18.0	20.8
N2 or CO2	% by vol.	79.0	82.0	82.0	79.2
Velocity	m/s	3.7	4.2	4.6	4.3
Flue gas composition					
O2	*% dry by vol.*	*1.1*	*2.8*	*4.6*	*3.0*
N2	*% dry by vol.*	*80.8*	*0.1*	*0.0*	*0.1*
CO2	*% dry by vol.*	*18.1*	*97.1*	*95.3*	*96.9*
H2O	*% wet by vol.*	*6.0*	*6.1*	*5.5*	*6.9*

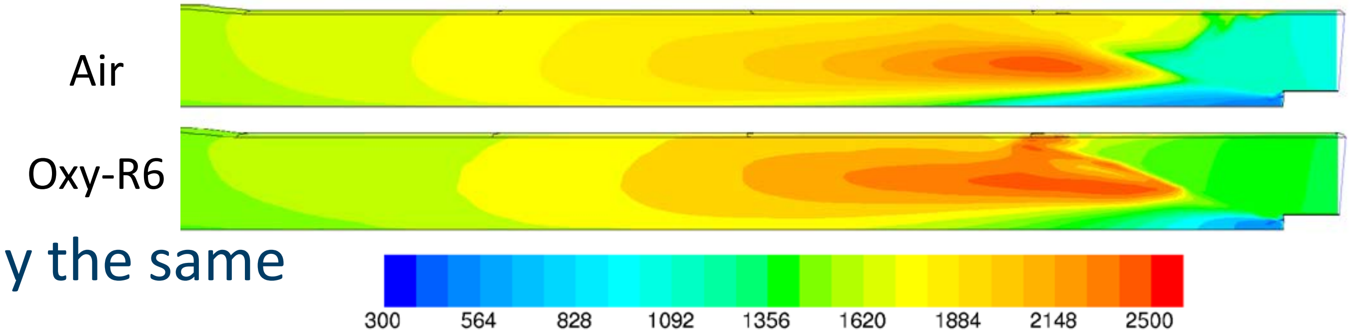
Clinker incident heat radiation

- Max deviation total heat: -0.8% and 2.1%
- Max deviation in near flame: -7.9 % and 2%
- Deviation O_2 flue gas +1.6 %-pt and 0
- Further matching peak radiation by:
  - enrich primary stream oxygen
  - increase swirl
  - decrease the carrier flow velocity
  - (Burner hardware modifications)

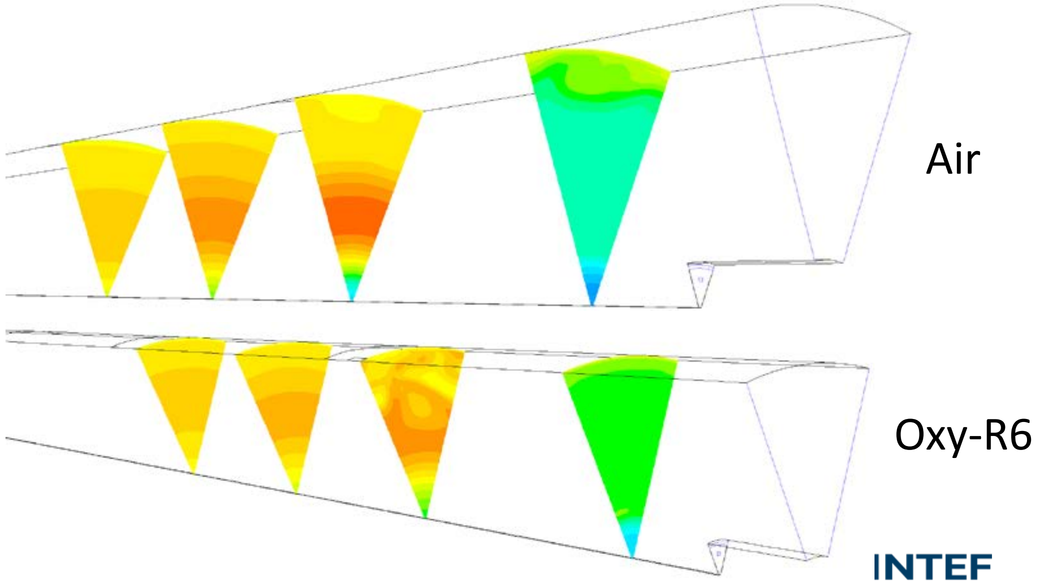


Flame field characteristics

Temperature

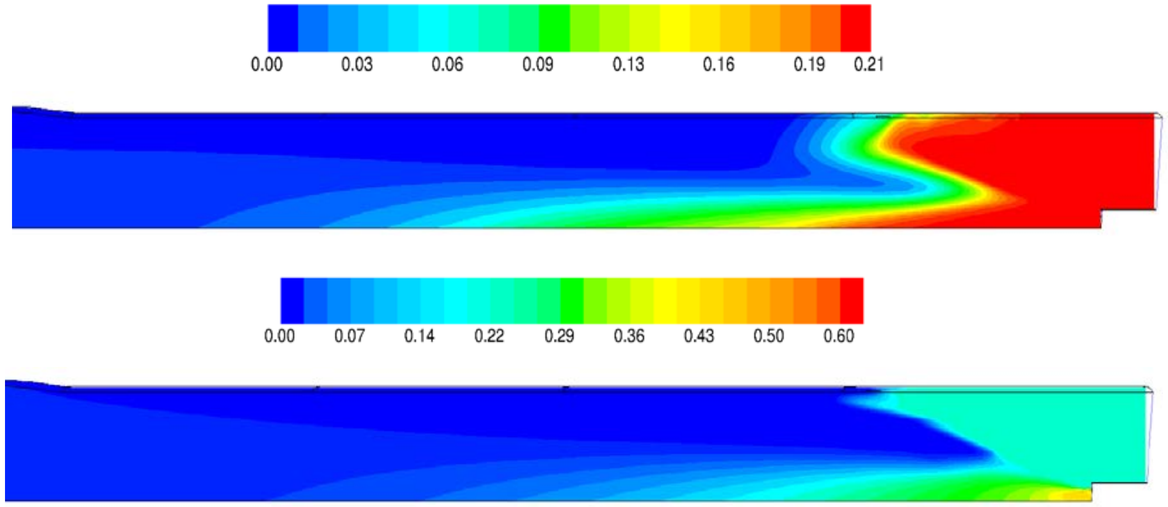


- Flame stabilization at approximately the same distance from the burner
- Flame front slightly more expanding in the oxy-fuel case
- Field homogeneity reached sooner in air
- Temperature paradox:
  - peak temperature in air 2360 K against 2239 K in oxy, although the primary gas O2 = 60%



Flame field characteristics

Oxygen



- Complex O2 pattern in oxy-fuel due to varying inlet compositions of the three gaseous mixtures (primary, carrier, and secondary streams)

- oxygen concentration of 60 % only at the primary gas outlet plan

- At flame anchoring position the O2 concentration is in fact ca. 25-29 % explaining the low temperature peak

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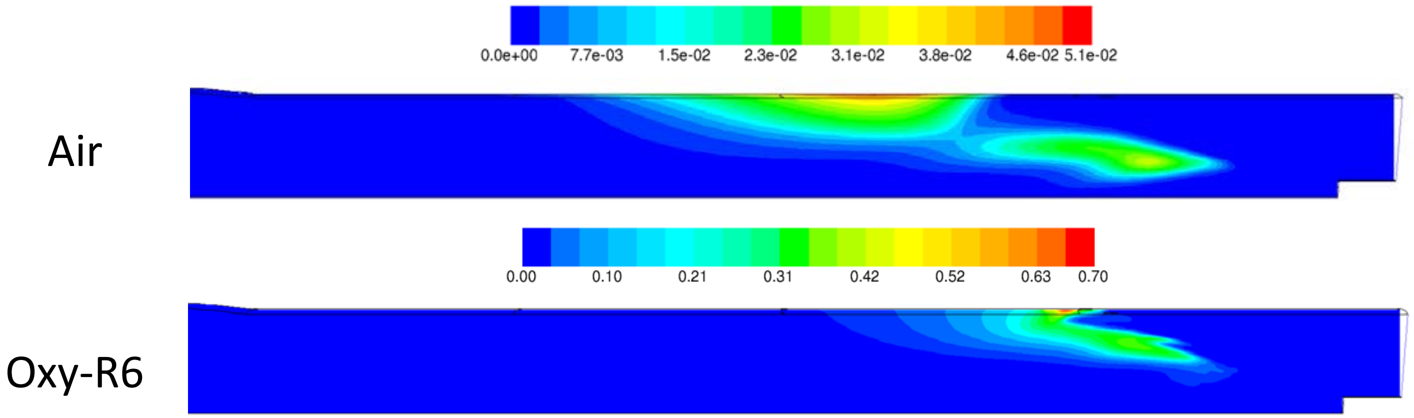
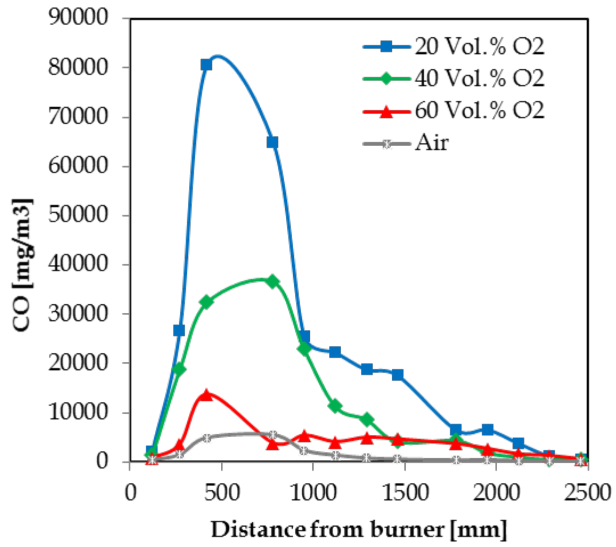
Flame field characteristics

CO





- Heterogeneous reactions of char (3) used are strong producers of CO with CO2 at large partial pressures (Boudouard reaction's net production reaction rate is two orders of magnitude larger in oxy-fuel)
- Also observed in the Univ. Stuttgart 500 kW pilot tests at varying oxygen concentration in the primary gas

Conclusions

- Study based on a defined reference BAT case and optimization methodology
- Most sensitive parameters to shape the required heat radiation profile:
  - Velocity at high speed nozzle
  - Swirl degree
- Least sensitive: carrier stream conditions (velocity and composition)
- Albeit similar heat radiation profile, the oxy-fuel flame characteristics in the kiln are different than in the reference air case
- Swirl angle at the burner (modulable in TKIS design) is a proper retrofitting tool when shifting from air to oxy-fuel mode

Acknowledgements

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