FUEL-OIL-TO-GAS CONVERSION IN INDUSTRIAL-SIZE BOILERS DRIVEN BY CFD

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Antonio Gómez

agomez@nabladot.com

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NABLADOT

Introducing nablaDot

¿What is nablaDot?

www.nabladot.com

It is a company at Zaragoza (Spain) that offer **simulation services (CFD)** to other companies in the energy, industrial, civil and wáter sectors

What we do?

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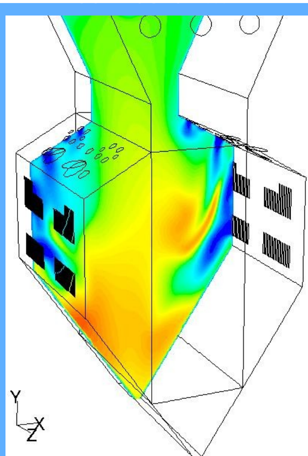
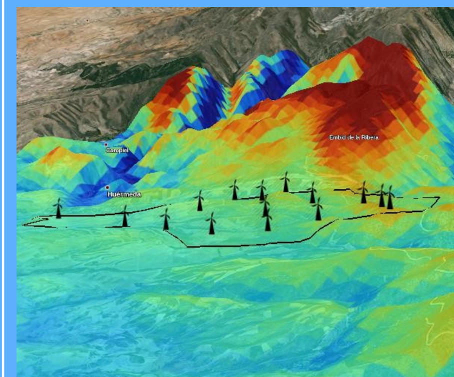
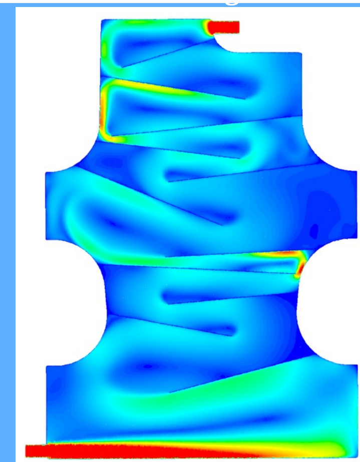
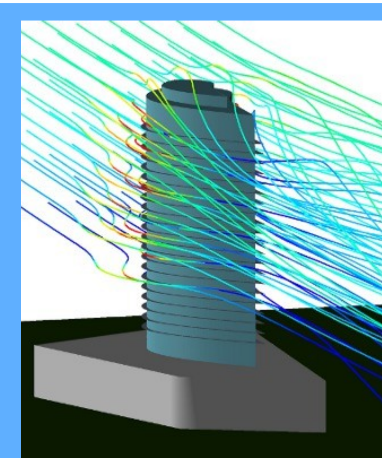
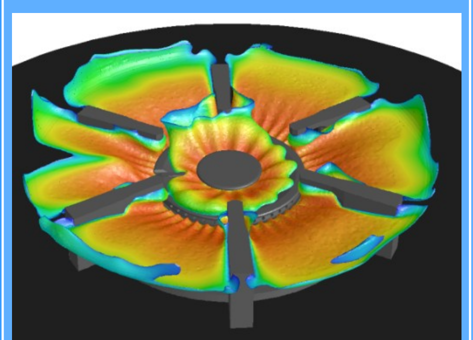
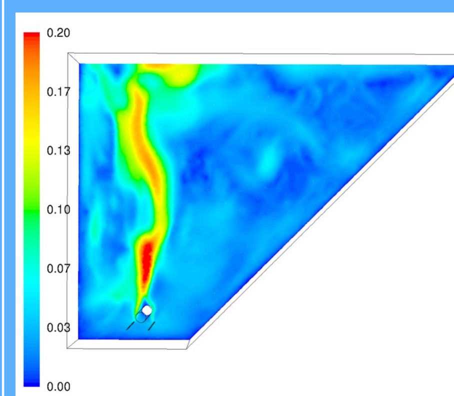
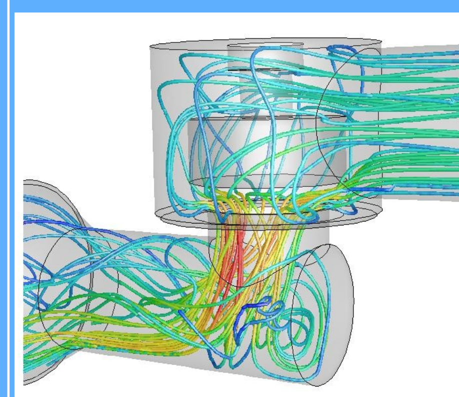
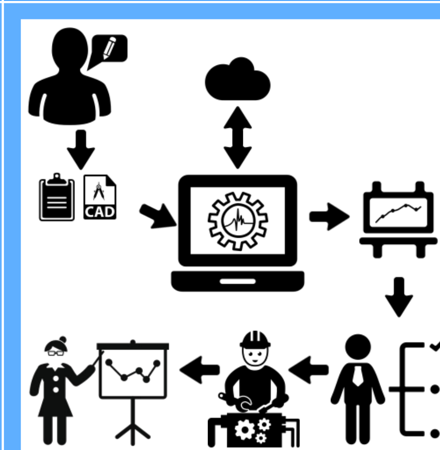
Energy Combustion, pollutants emissions, heat transfer, corrosion	Environment Weather forecast, wind fields, pollutants dispersion, wind farms optimization...	Industrial processes Valves, equipment design, separation processes, flue gas cleaning...	Others Arquitecture, built environment, external flow
			
Combustion in the furnace of a coal power plant	Optimization of the location of wind turbines	Flow (residence time and mixing) in a tank	Wind loads on buildings
			
Combustion in a gas domestic burner	Design of an aerobic digestor	Design of valves	Industry 4.0

What we do? - Expertise

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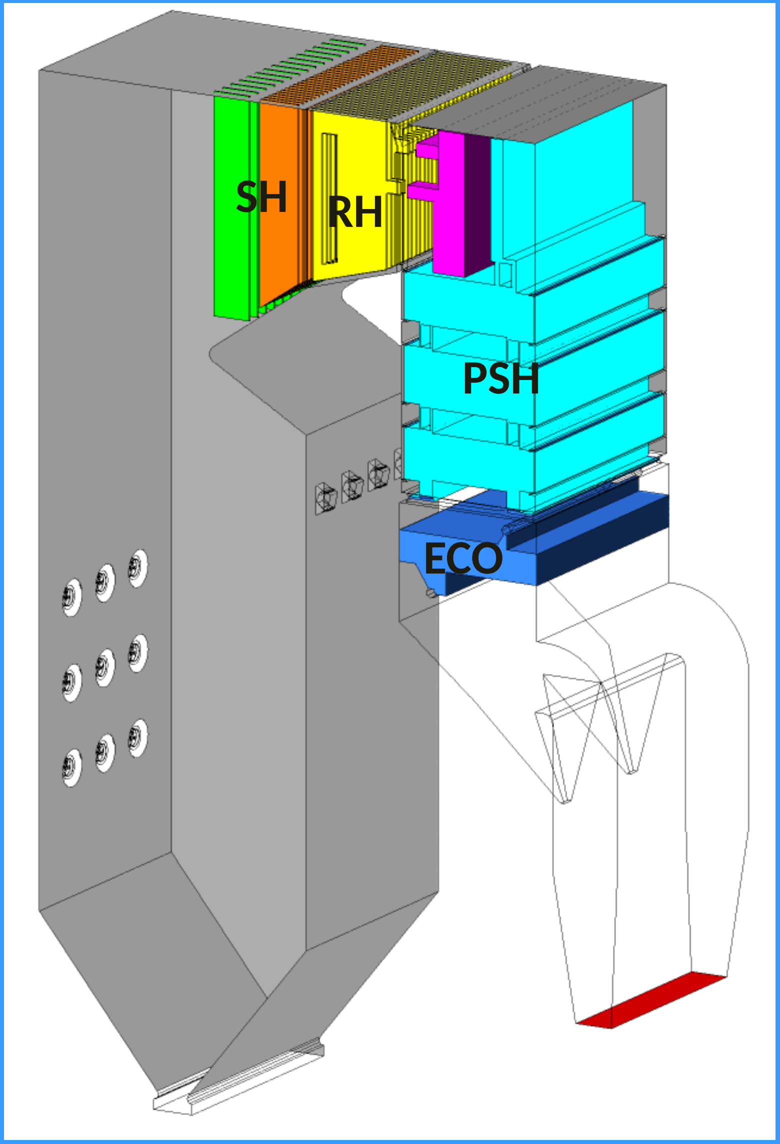
- High expertise in combustion and heat transfer
- Thermal power plants simulated ~10 GWe
- Coal, fuel-oil, natural gas, biomass, waste
- Ad-hoc simulation models for:
  - Air primary & secondary systems
  - Burners
  - Furnaces
  - Heat recovery zones
  - SCR
  - Wet scrubbers (flue gas desulfurization units)

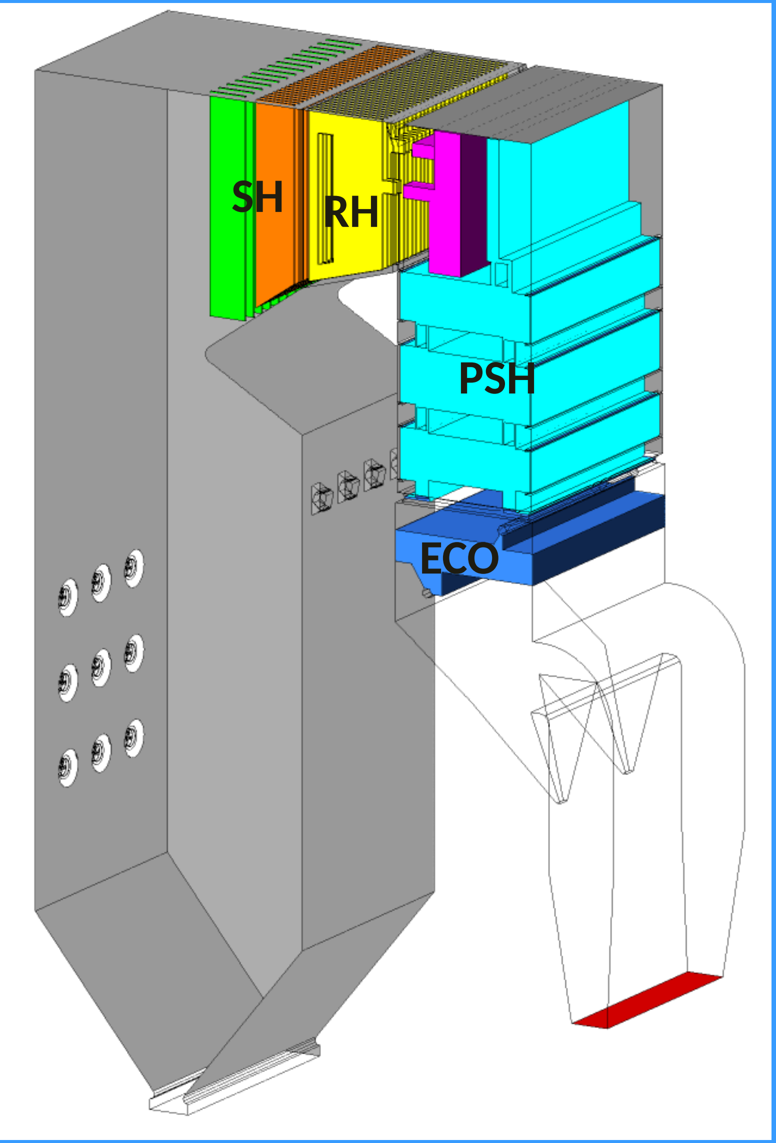
THE PROBLEM

- Replace fuel oil by natural gas in a thermal power plant
- What we expect?
  - Furnace exit gas temperatura is likely to increase (NG flame emissivity is lower that that for Fuel-Oil)
  - Lower Boiler efficiency (higher H2O content in flue gas)
  - Heat Transfer characteristics will be impacted (highly dependent on unit design and configuration)



Questions

- Impact of the gas conversion in the boiler performance (flue gas and steam temperatures, heat distribution)
- New configuration of the boiler operation (Secondary Air System)?
- New design of the burner?
- New design of the radiant furnace?
- New design of the convective pass heat transfer?
- New attemperator steam mass flow?



THE APPROACH

Integral CFD model of the boiler

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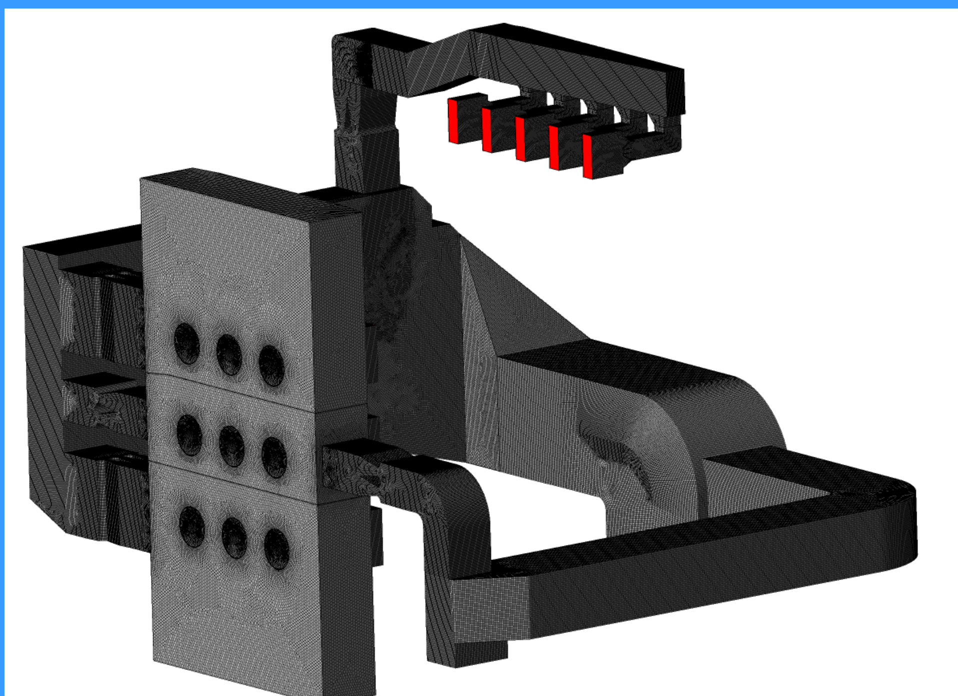
- Reduced-Physics model secondary air system +
- CFD furnace & convective pass model



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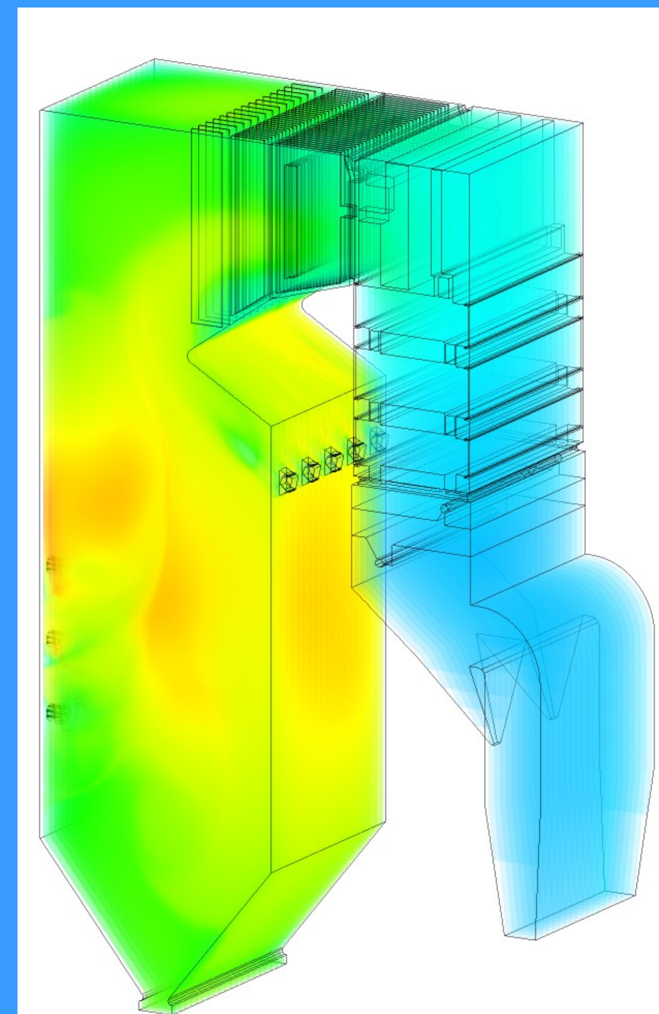
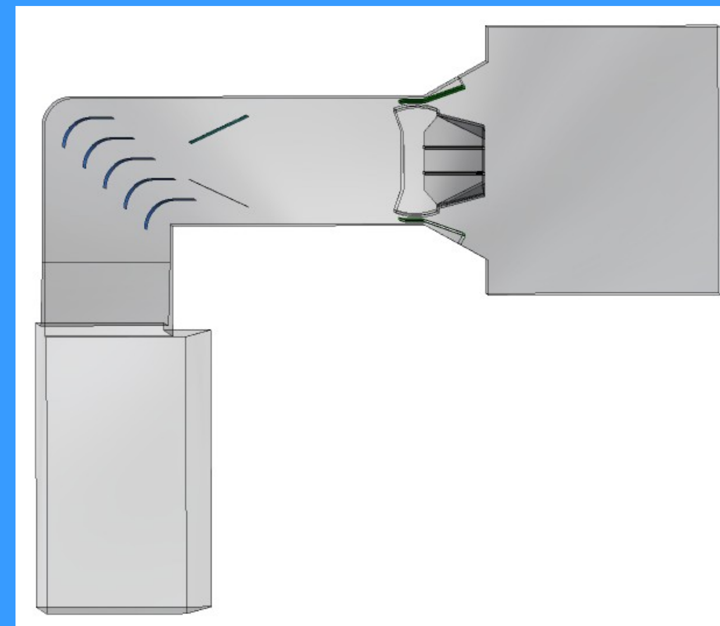
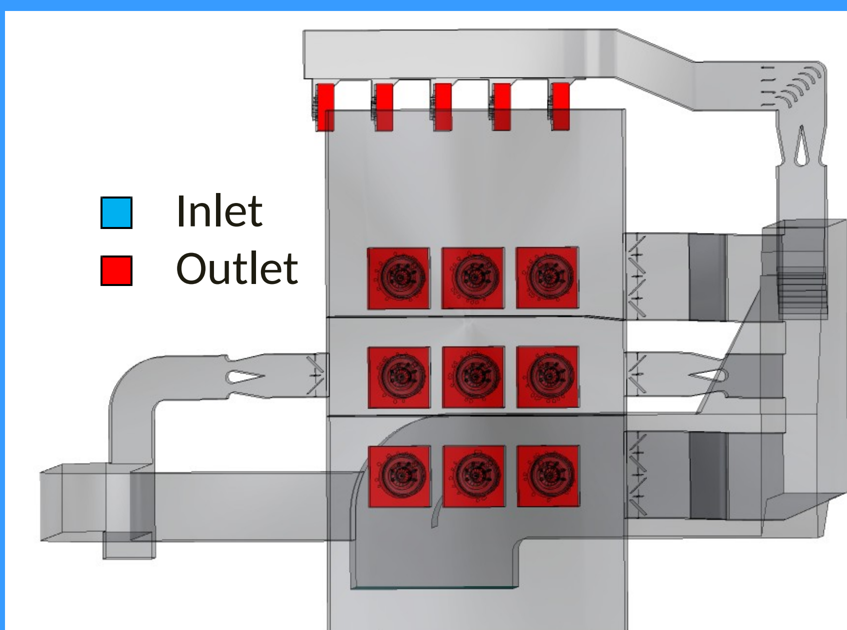
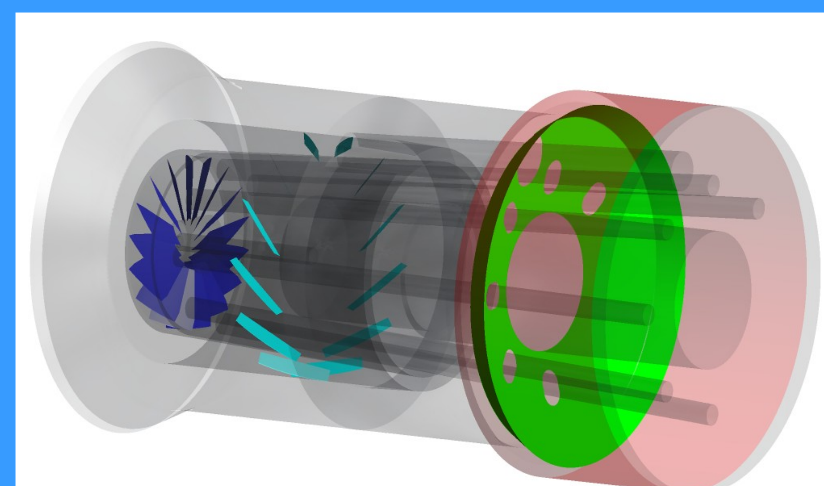


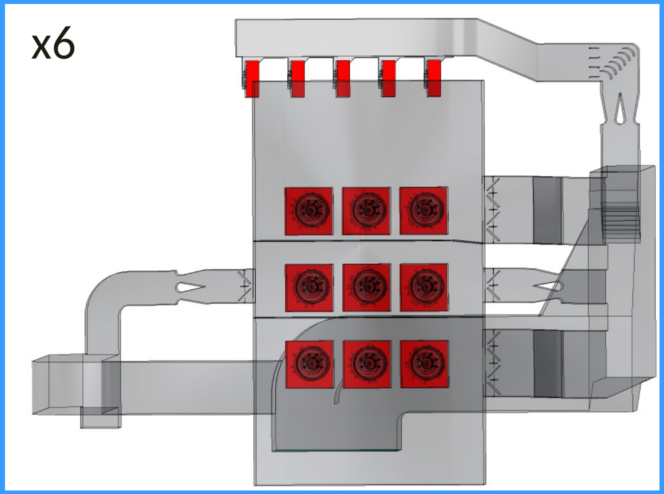
- Secondary air system:
  - General conducts
  - OFA conducts
  - OFA inlets to furnace
  - Burners
  - Multiple dampers

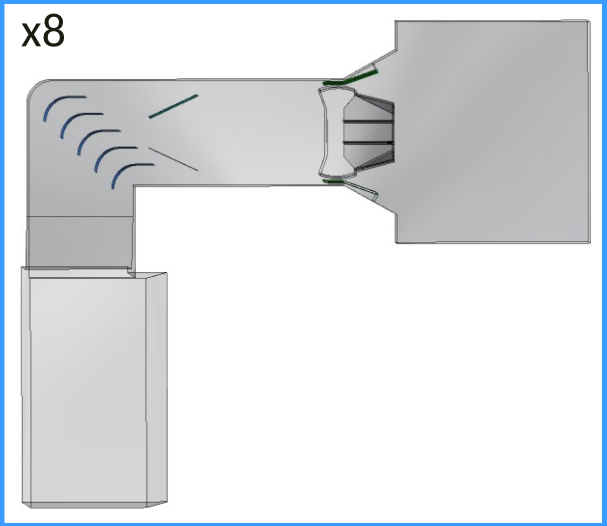


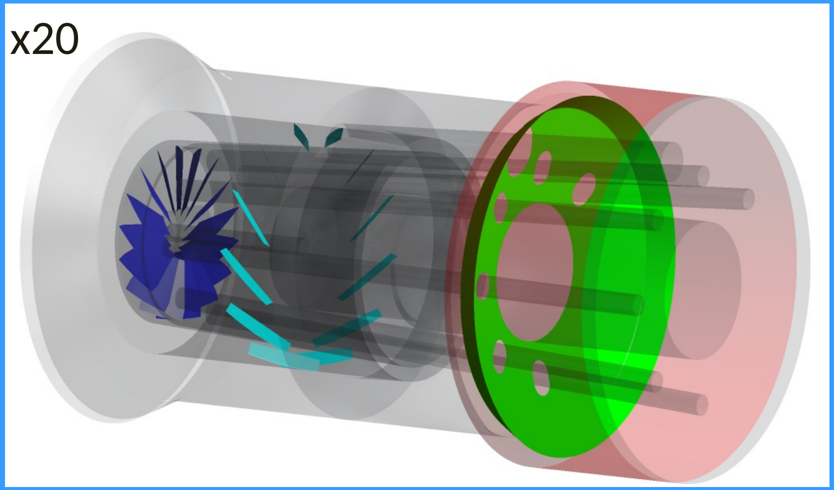




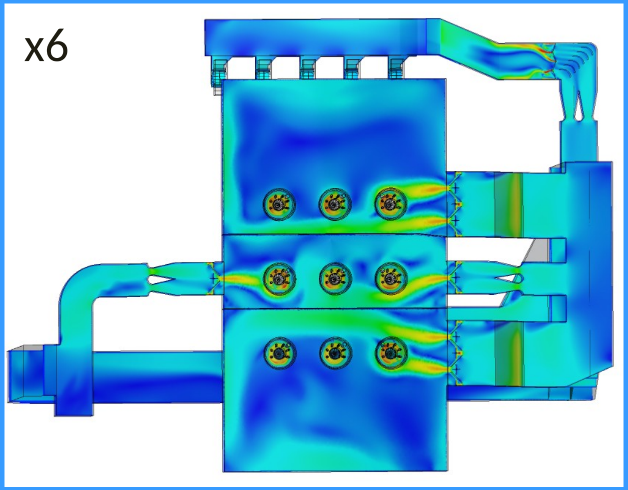
- Characterisation of the air secondary system through multiple simulations (combination of dampers position)

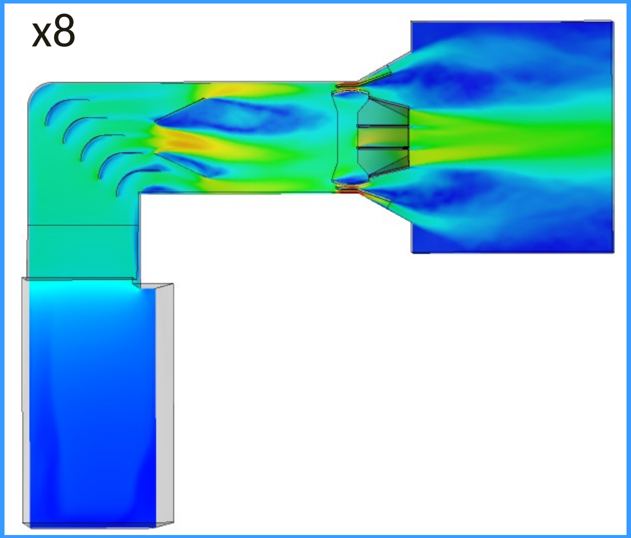


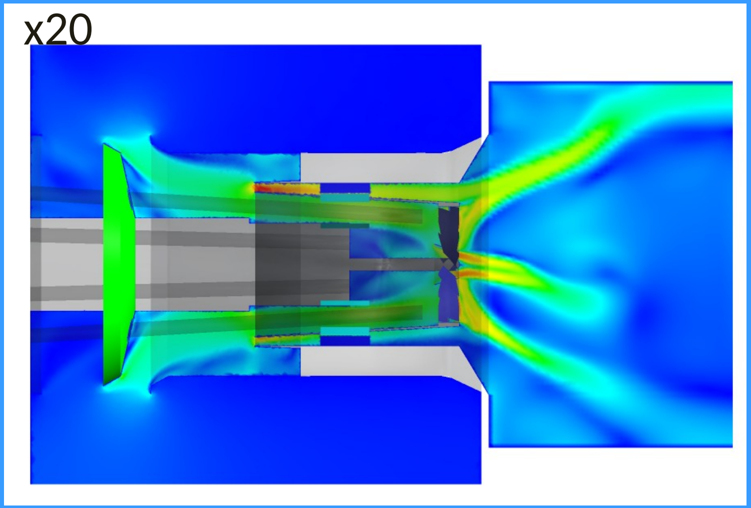




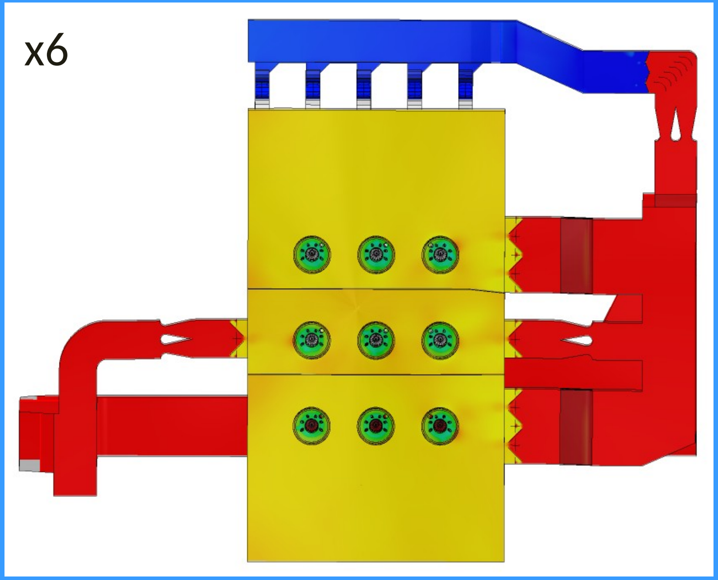
o CFD results (velocity)

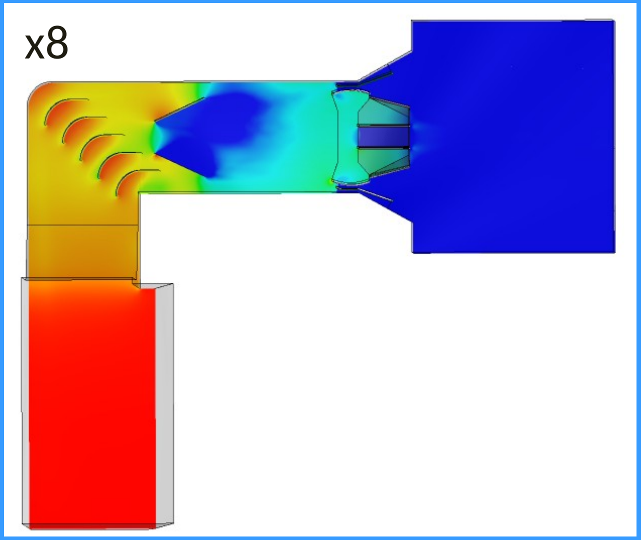


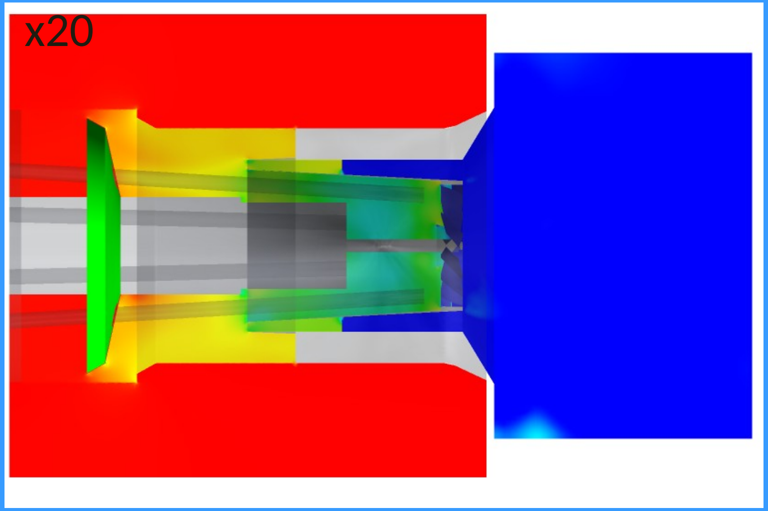




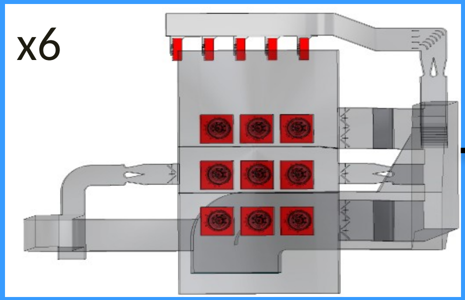
o CFD results (static pressure)

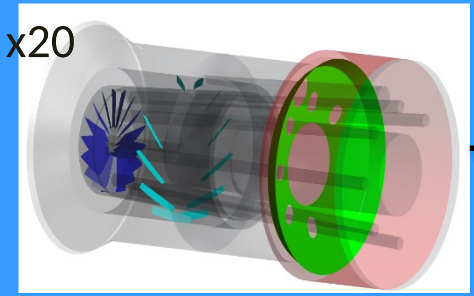


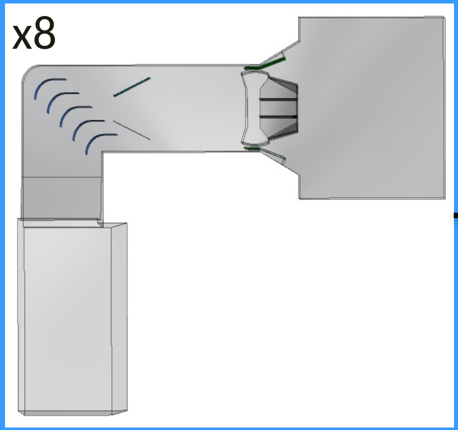




o Building RPM







Adimensional pressure drop factors as a function of dampers position and duct geometry

1D model

RPM Secondary Air System

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- Real-time calculation
- Deviation ~ 10-15%

INPUT

Pressure	1013	mbar
Furnace Pressure	-0.5	mbar
Air Temperature	315	ºC
Mass flow	255	t/h

Dampers position (%)

Level B	40%
Level C1	44%
Level C2	43%
Level A	49%
OFA	80%

Central damper

	1	2	3
Level B	200	200	200
Level C	200	200	200
Level A	200	200	200

Damper Duct (%)

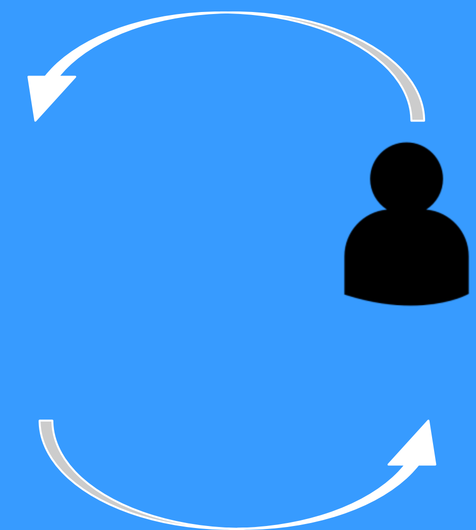
	1	2	3
Level B	100%	100%	100%
Level C	100%	100%	100%
Level A	100%	100%	100%

Inner vanes position

	1	2	3
Level B	175	175	175
Level C	175	175	175
Level A	175	175	175

OFA	1	2	3	4	5
damper	63%	75%	100%	87%	63%

Dampers position
Air mass flow, temperature



OUTPUT

Burner's Inner Inlet (t/h)

	1	2	3
Level B	9.86	9.58	10.05
Level C	10.08	10.33	10.54
Level A	10.20	10.27	10.17

Burner's Outer Inlet (t/h)

	1	2	3
Level B	11.57	11.24	11.79
Level C	11.83	12.12	12.36
Level A	11.96	12.05	11.93

Total burners (t/h)

	1	2	3
Level B	21.4	20.8	21.8
Level C	21.9	22.5	22.9
Level A	22.2	22.3	22.1

Air Rotation

	1	2	3
Level B	0.63	0.63	-0.63
Level C	0.63	0.63	-0.63
Level A	0.63	0.63	-0.63

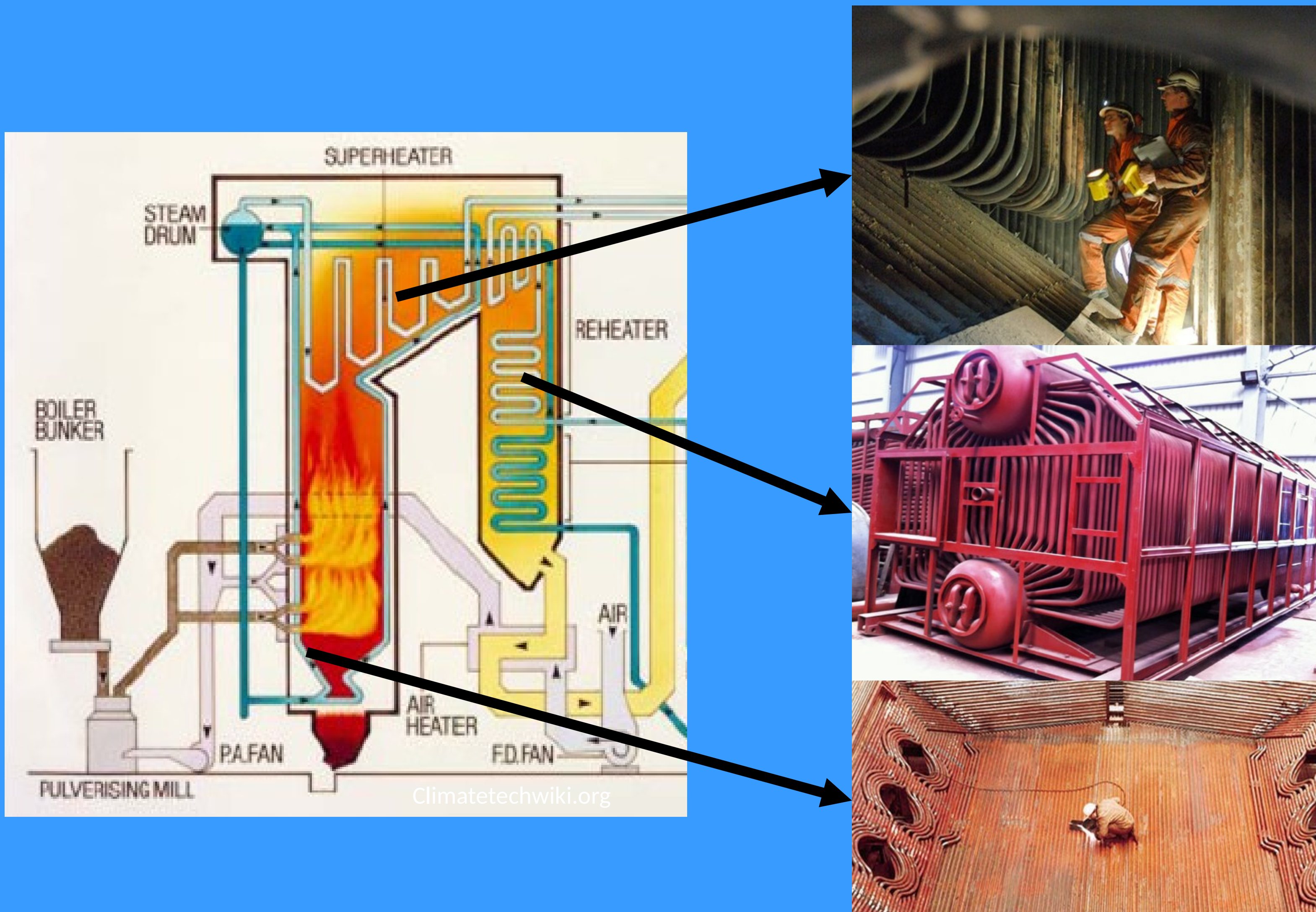
OFA (t/h)	1	2	3	4	5
total	9.85	11.76	12.98	12.61	9.87
main	6.61	8.22	9.29	8.96	6.65
refrig-main	0.36	0.52	0.75	0.66	0.36
refrig-interm	1.32	1.41	1.36	1.41	1.32
refrig-ext	1.55	1.61	1.58	1.59	1.55

Pressure

CRA outlet	19.0	mbar
Windbox B	12.6	mbar
Windbox C	13.8	mbar
Windbox A	13.6	mbar

Air mass flow for each inlet
Air rotation
Pressure drop in the SAS

Coupling furnace and convective pass



o Our model

	Chamber	Chamber, then HRZ	Chamber & HRZ	Our model
Tubes properties	Constant	Iterate betwen models	Coupled	Coupled
Influence of combustion in the tubes	✗	≈	✓	✓
Influence of tubes in the combustion	✗	≈	✓	✓
Efficiency	✗	≈	✓	✓
Equations to transport	9	9 + 6+wS	9 + waterS	9
Mesh cells	~ 2 Million	~ 3M + 400M	~ 500 Million	~ 4 Million
Computational cost	X	(100X)*i	100000X	X

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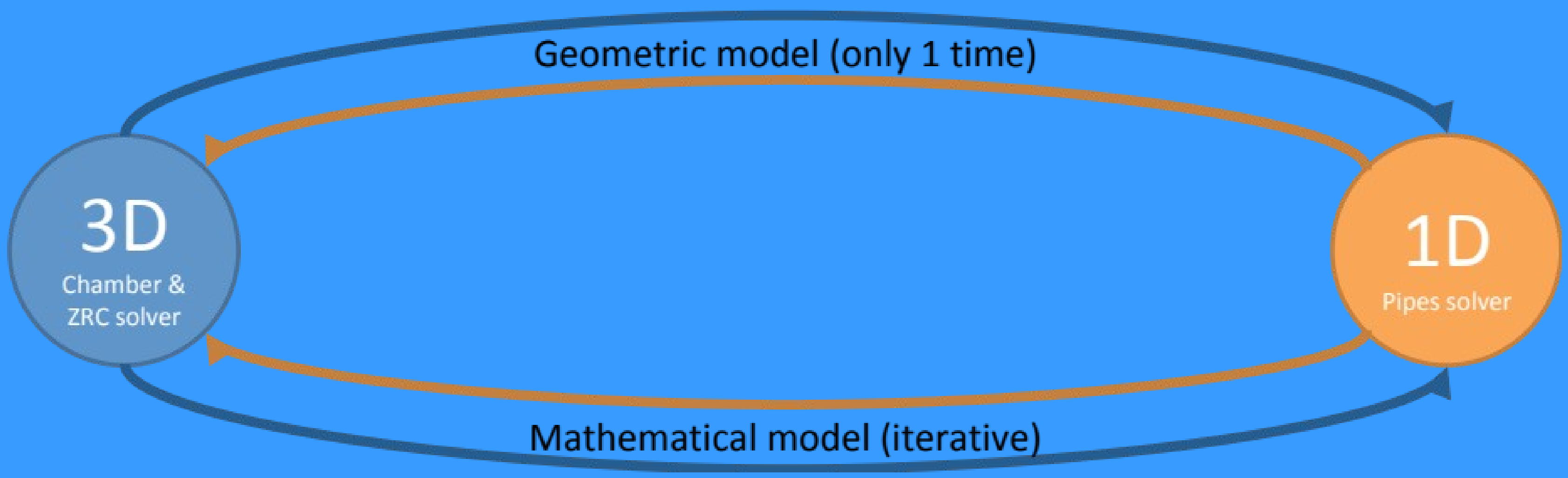
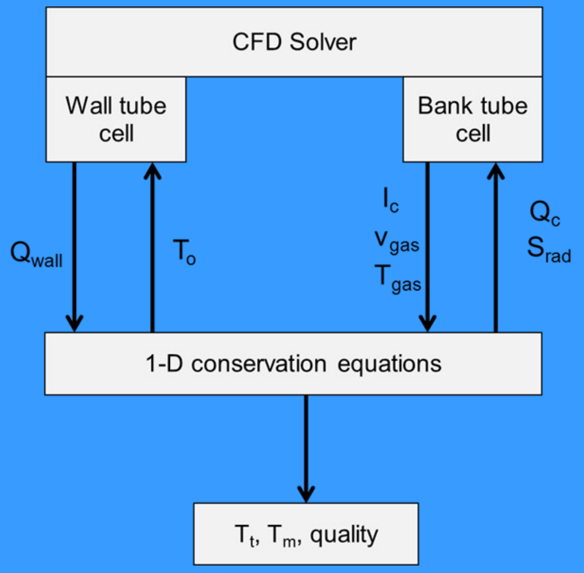
o How it works?

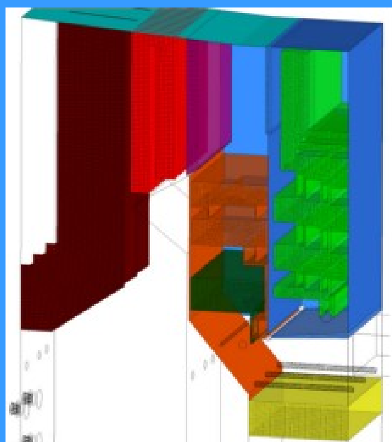




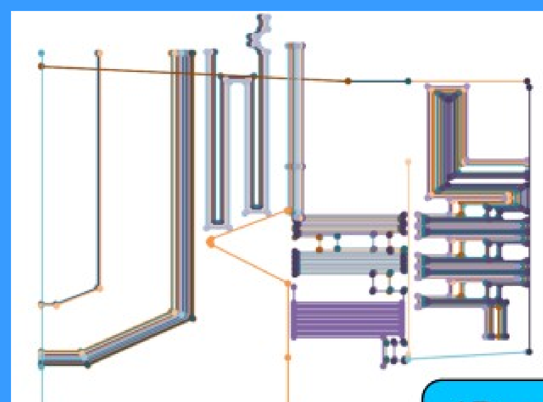
Implemented through UDF Ansys Fluent: ~3000 lines of code

o Geometric model

3D geometry → Ad-hoc subroutines → Sub-grid information & conectivity



Tube bank database → 1D mesh of tube banks → Ad-hoc subroutines



- 3D mesh:
  - Which cells contain the tube banks?
  - Tubes data: diameter, pitch…
- 1D mesh:
  - Which 3D cell contains each tube cell?
  - Which 1-D cell the water/steam comes from

Tube bank database:

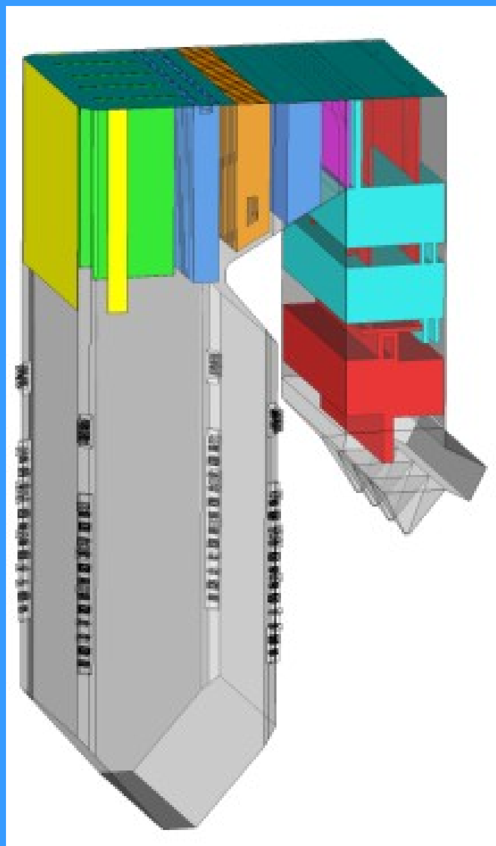
- Geometrical information
- Physical properties
- Topological properties

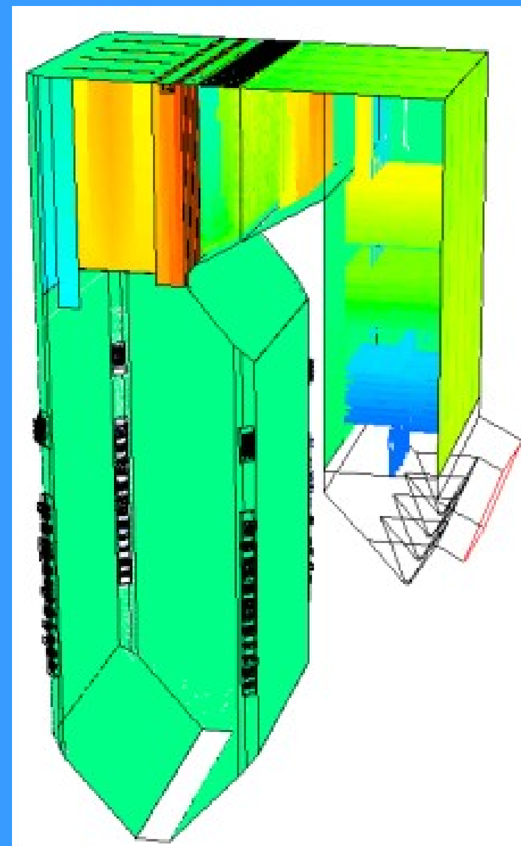
1D mesh of tube banks:

- Automatic generation
- Resolution: 5 cm

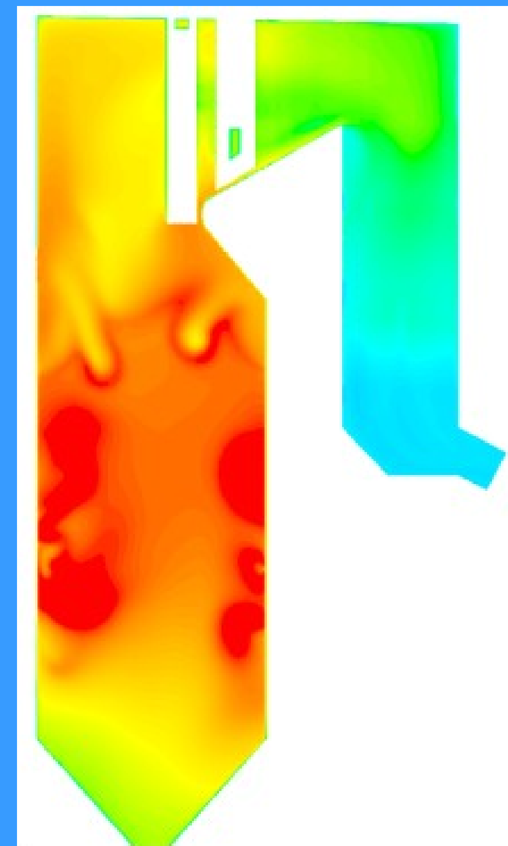
- 3D mathematical model
  - Conservation equations for:
    - Mass
    - Momentum
    - Enthalpy
    - Mixture fraction
  - k-ε realizable turbulent model
  - Equilibrium PDF
  - Langrangian framework for particles (if it is needed)
  - DO radiation model (WSGGM for absorption coefficients)

o Results obtained: integral assessment





Steam temperature
Tubes (metal) temperature
Heat transfer



Flue gas temperature
Flue gas velocity
O2 concentration
NOx concentration

APPLICATION & RESULTS

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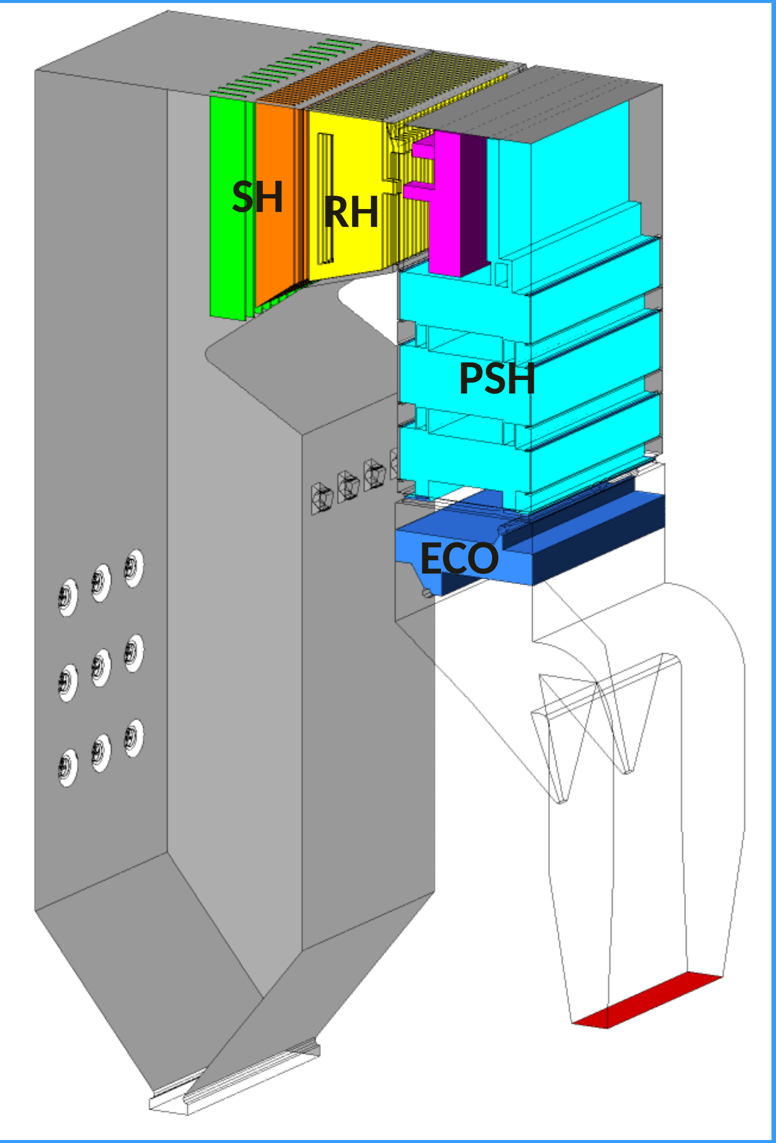
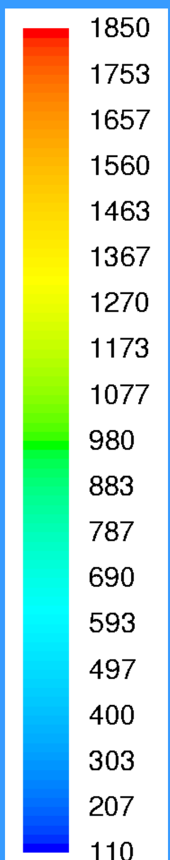
Questions

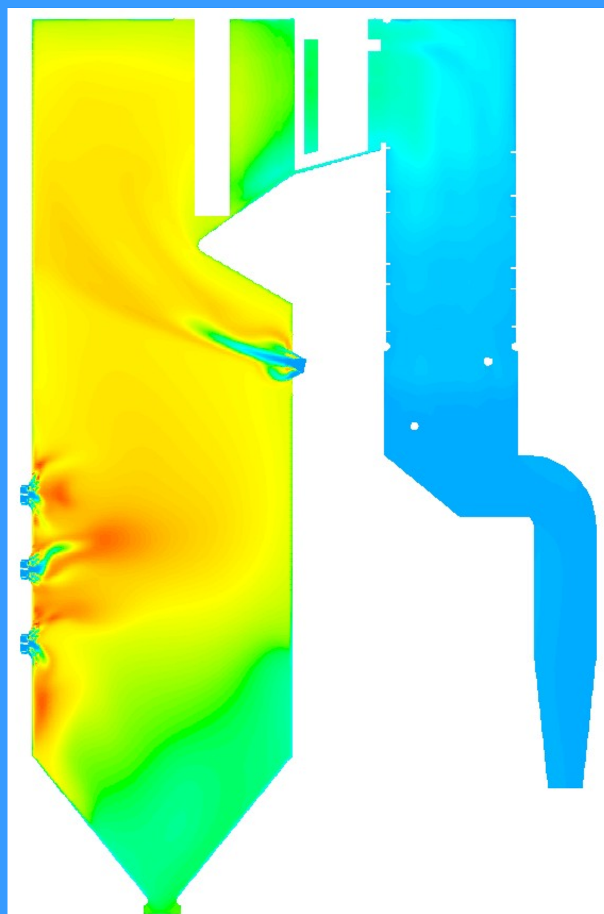
- Impact of the gas conversion in the boiler performance (flue gas and steam temperatures, heat distribution)
- New configuration of the boiler operation (Secondary Air System)?
- New design of the burner?
- New design of the radiant furnace?
- New design of the convective pass heat transfer?
- New attemperator steam mass flow?



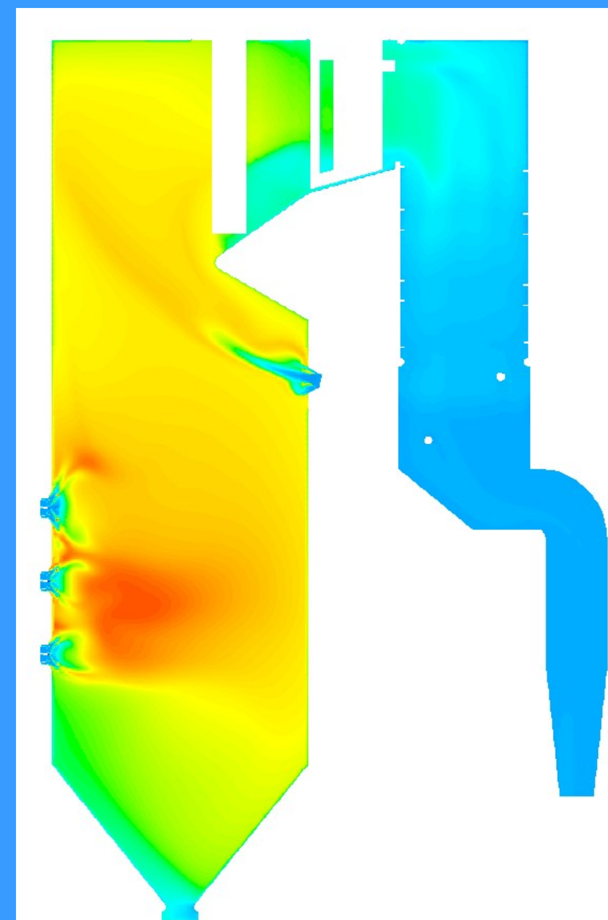
Natural gas vs. Fuel Oil – Temperature (ºC)

- Lower temperatures at the furnace
- Shorter flame



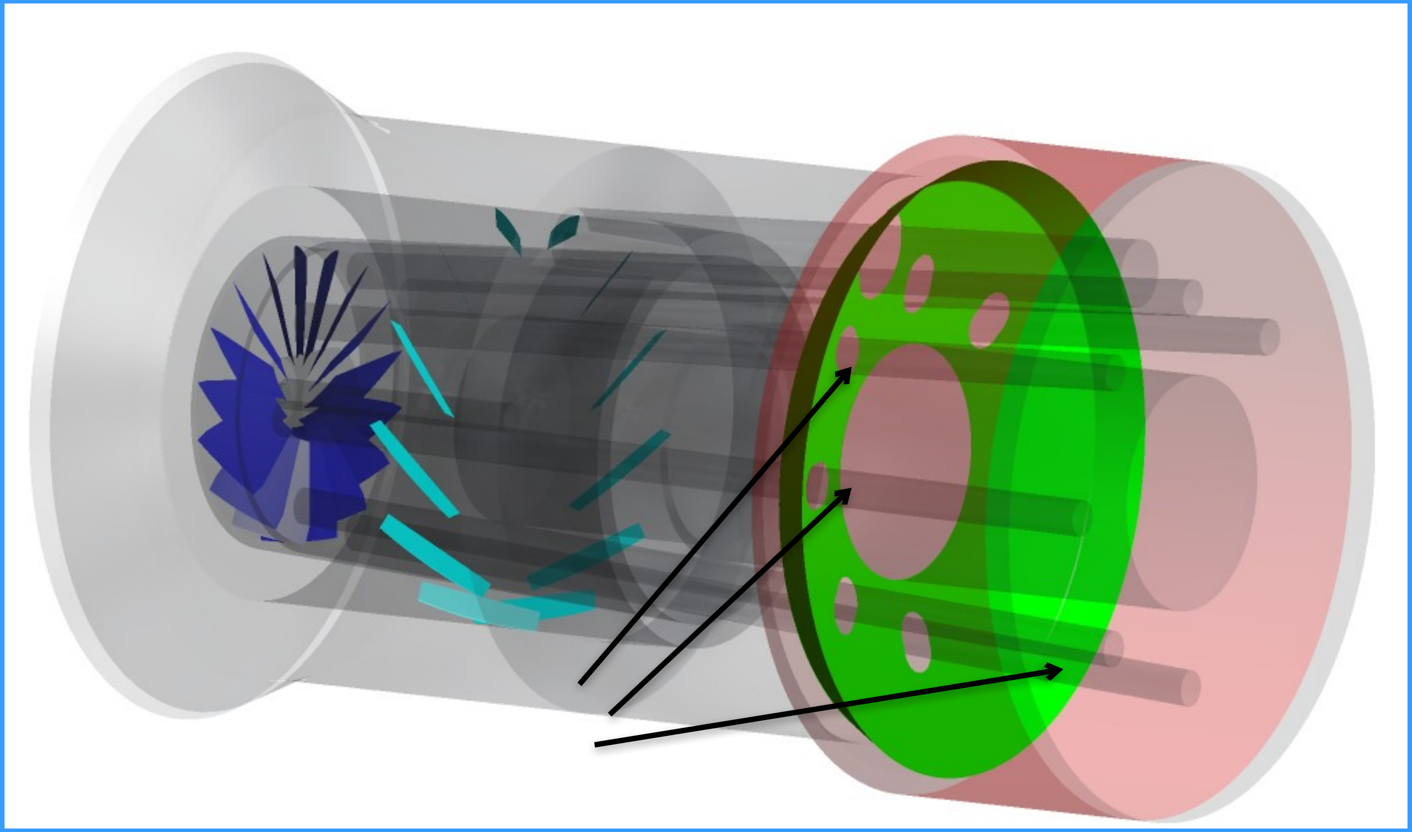


Natural gas

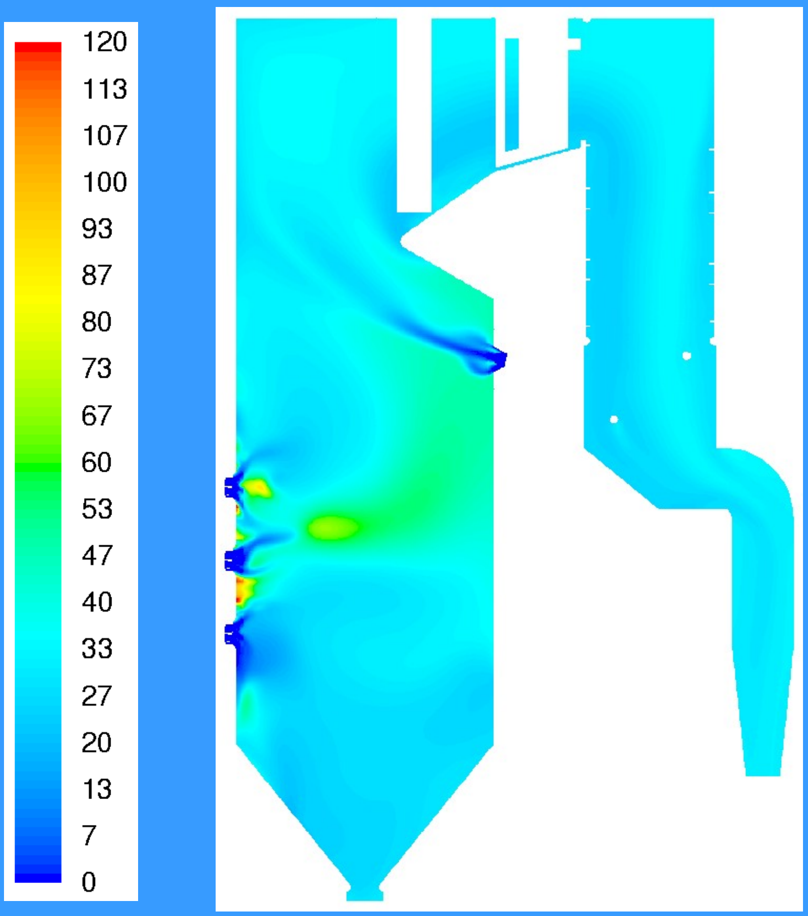


Fuel-Oil

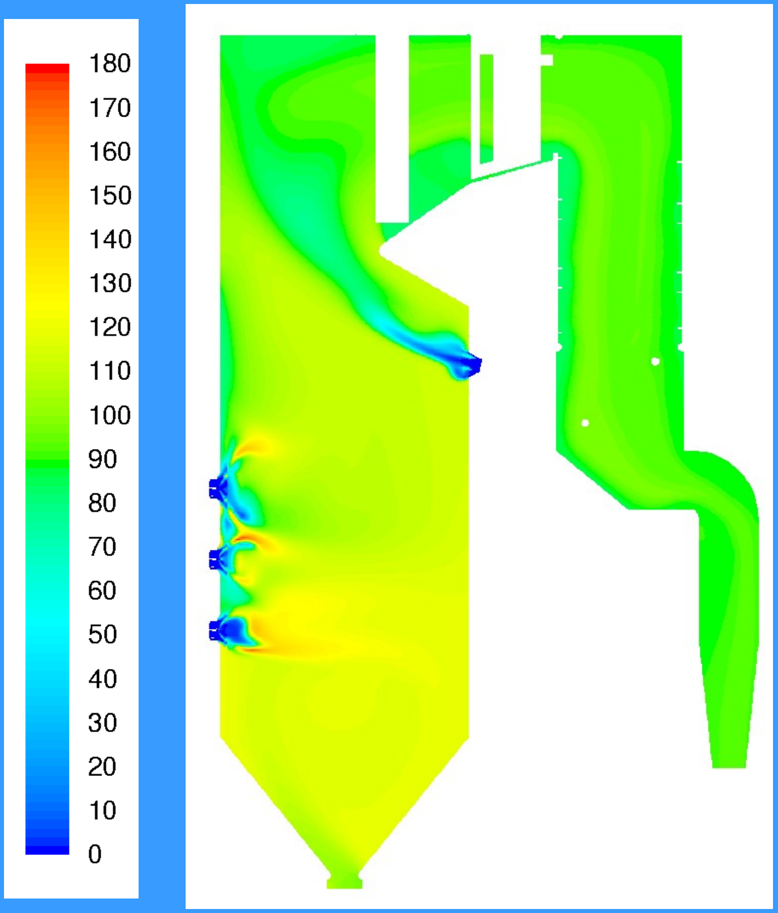
- Shorter flame
- Gas injectors end before the swirler



- Lower NOx



Natural gas

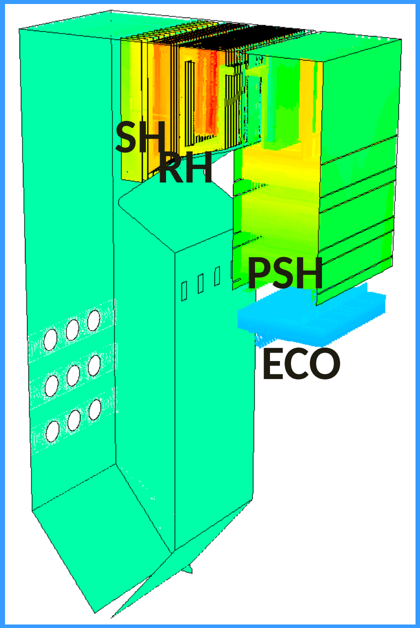


Fuel-Oil

Combustion results

Variable	Gas Natural (CFD)	Fuel-Oil (CFD)
O_2 outlet concentration (% vol)	1.06%	1.32%
Flue gas outlet temperature (°C)	382	357
NOx outlet concentration (mg/Nm3, dry, 3%O2)	73	192

- Lower efficiency



Steam /Liquid Mass flow	kg/s - Gas	kg/s - FO
Economizer	58.1	61.8
Steam generated at water walls	58.1	61.8
Attemperator	7.5	6.4
Superheater	65.6	67.0
Reheater	65.6	67.0

Bank tubes	Heat Transfer (Gas) (MW)	Heat Transfer (FO) (MW)
Economizer	5.6	5.3
Superheater	63.0	62.0
Reheater	27.6	28.2
Water walls	86.3	91.6
Total	182.5	187.1

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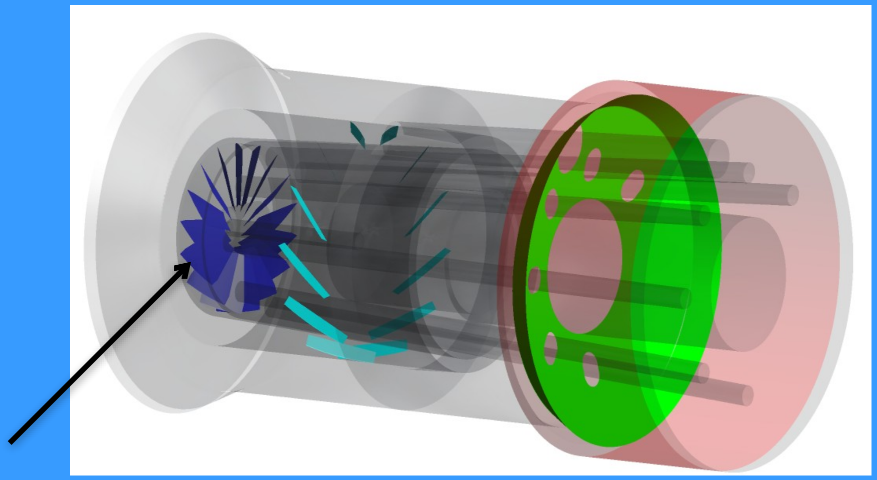
- Remove burner swirler



- Increase air through burners changing dampers position (ROM SAS). TA through OFA is reduced from 22.4% to 14.2%
- Longer flame and more intense combustion at the furnace

Natural gas vs. Fuel Oil – New case - Temperature (ºC)

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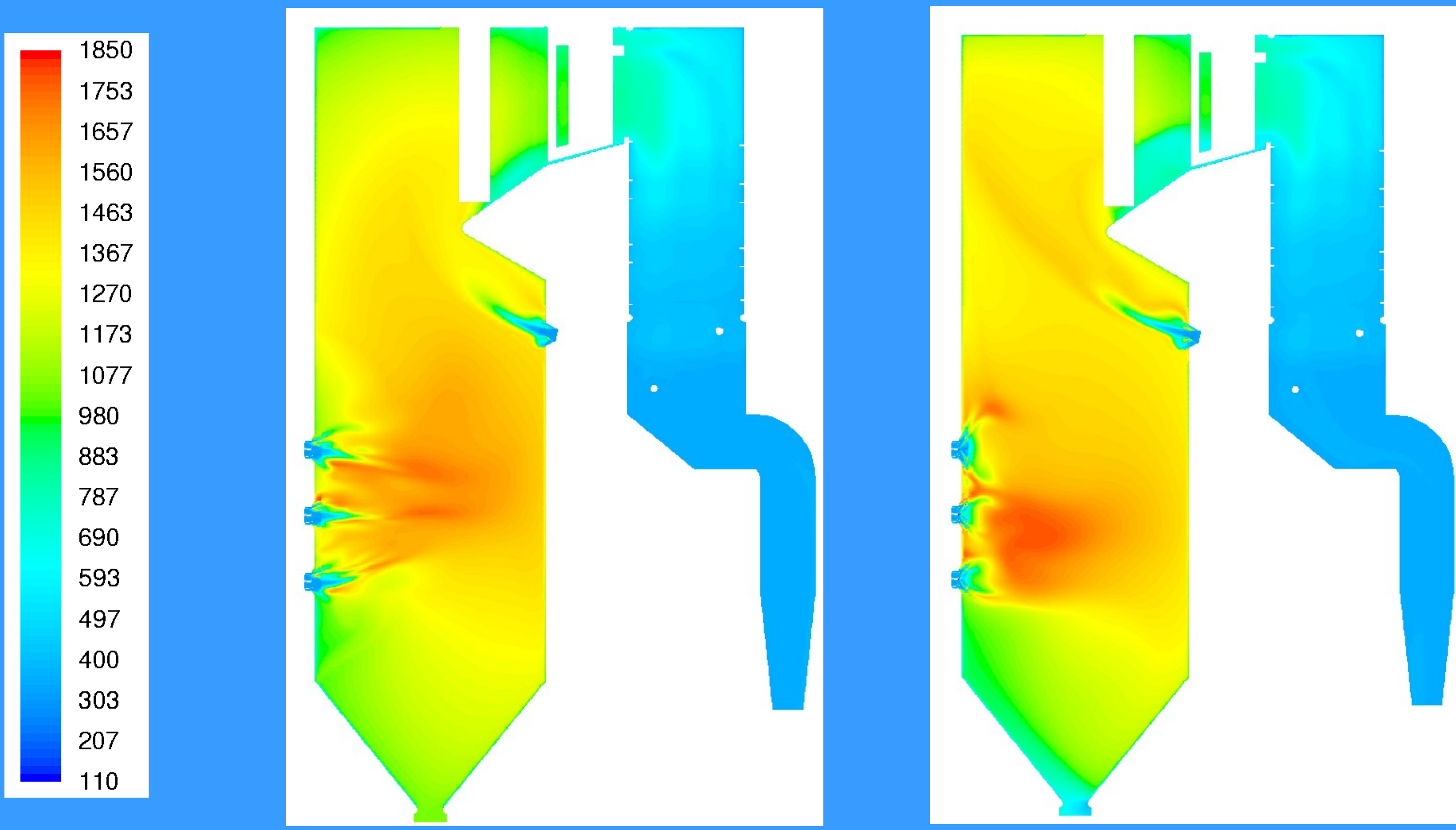
- More intense combustion at the furnace
- Longer flame



Natural gas

Fuel-Oil

Natural gas vs. Fuel Oil – New case - NOx (ppmv)

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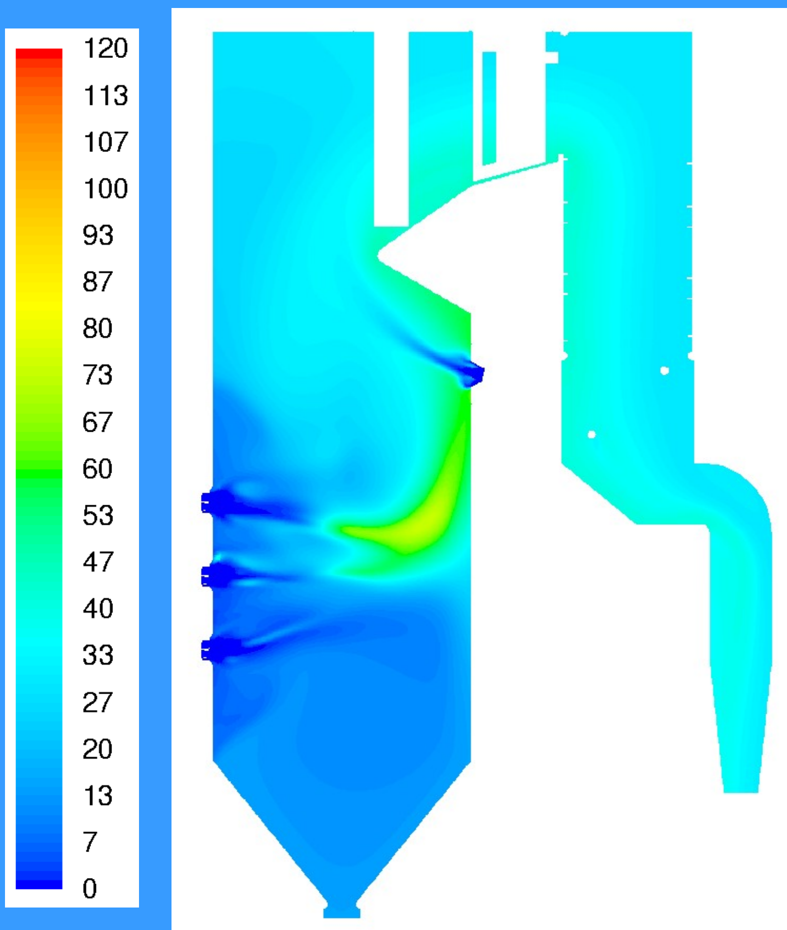
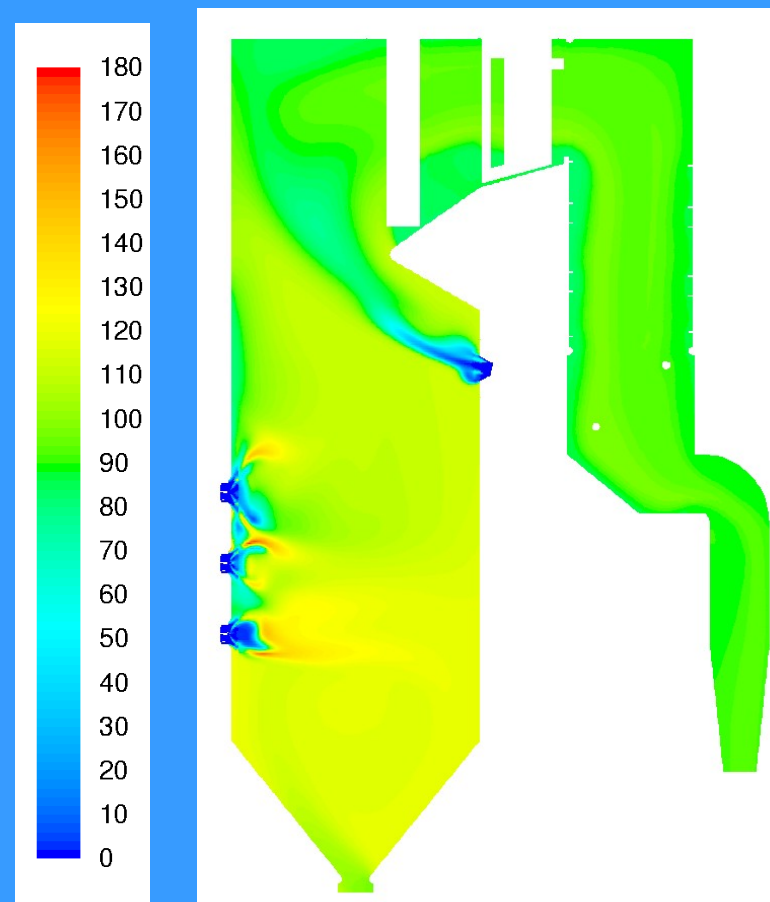
o Lower NOx



Natural gas



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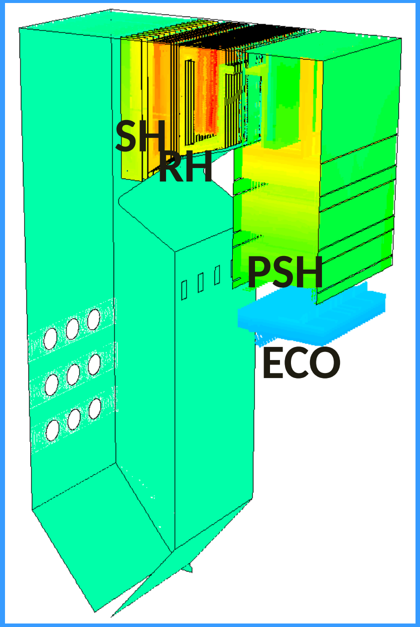
- Lower efficiency



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Attemperator	7.5	6.4
Superheater	65.6	67.0
Reheater	65.6	67.0

Bank tubes	Heat Transfer (Gas) (MW)	Heat Transfer (FO) (MW)
Economizer	5.2	5.3
Superheater	61.7	62.0
Reheater	29.6	28.2
Water walls	88.0	91.6
Total	184.5	187.1

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CONCLUSIONS

Questions

- Impact of the gas conversion in the boiler performance (flue gas and steam temperatures, heat distribution)
  - Lower heat transfer at the furnace. Efficiency decreases by 3.0%. More heat transfer at the convective pass.
- New configuration of the Secondary Air System?
  - It will be needed to improve the heat transfer at the furnace. Furthermore, there are margin to low the TA by OFA since NOx emissions are lower with natural gas.
- New design of the burner?
  - Yes, the current burner can introduce natural gas but only as an auxiliary support. The flame is too short, and removing the swirler reduces the control of the flame
- New design of the radiant furnace?
  - Probably not. Adjusting the configuration of the SAS, we can improve the heat transfer at the radiant furnace.
- New design of the convective pass heat transfer?
  - Probably not. Adjusting the configuration of the SAS and the attemperator steam mass flow, we can control the effects of a higher heat transfer at the convective pass.
- New attemperator steam mass flow?
  - Yes, we have to increase the attemperator steam mass flow to avoid an excessive steam temperature due to higher heat transfer at the convective pass

Q&A

Nabladot, S.L.
www.nabladot.com
agomez@nabladot.com

WTCZ torre Oeste planta 11, Avenida María Zambrano, Zaragoza

http://www.nabladot.com

976 076 623

hablemos@nabladot.com