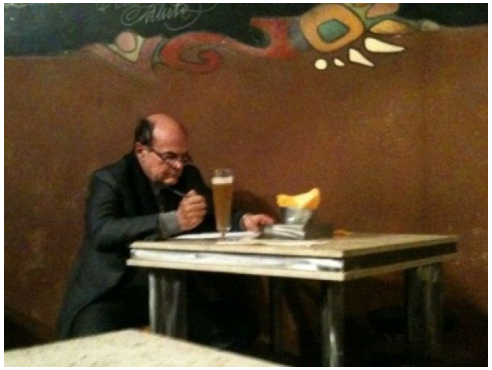
CFD Analysis of a MILD Low-Nox Burner for the Oil and Gas industry

Alessandro Atzori

Supervised by:
Vincent Moreau

Framework: Industria 2015



Bill on competitiveness and industrial policy, approved on 22 September of 2006 by the Italian Ministry of Economic Development.

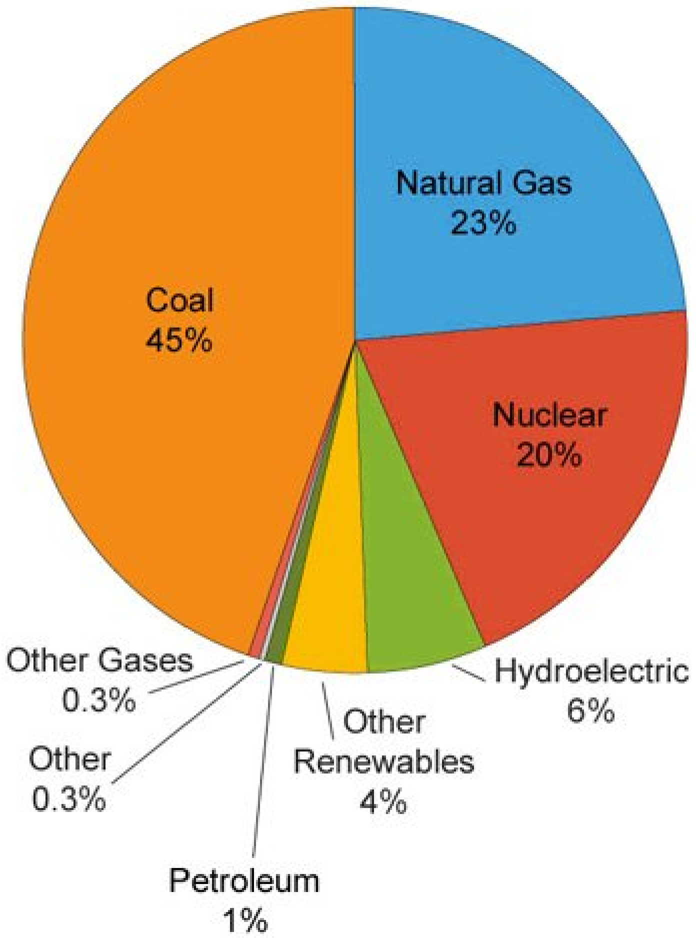
MILD Technology Integration in innovative combustion system characterised by low emissions

Steam Generator for electricity generation: realization of a 30 MWth multi fuel burner (oil-gas) SOFINTER-Macchi Boilers S.p.a.

74	F3	RI	Development of the boiler natural gas fuelled 3D hot MILD burner model	CRS4
75	F4	RI	Development of the boiler oil fuelled 3D hot MILD burner model	CRS4
76	F5	RI	Numerical functional optimisation of the MILD burner for boiler	CRS4

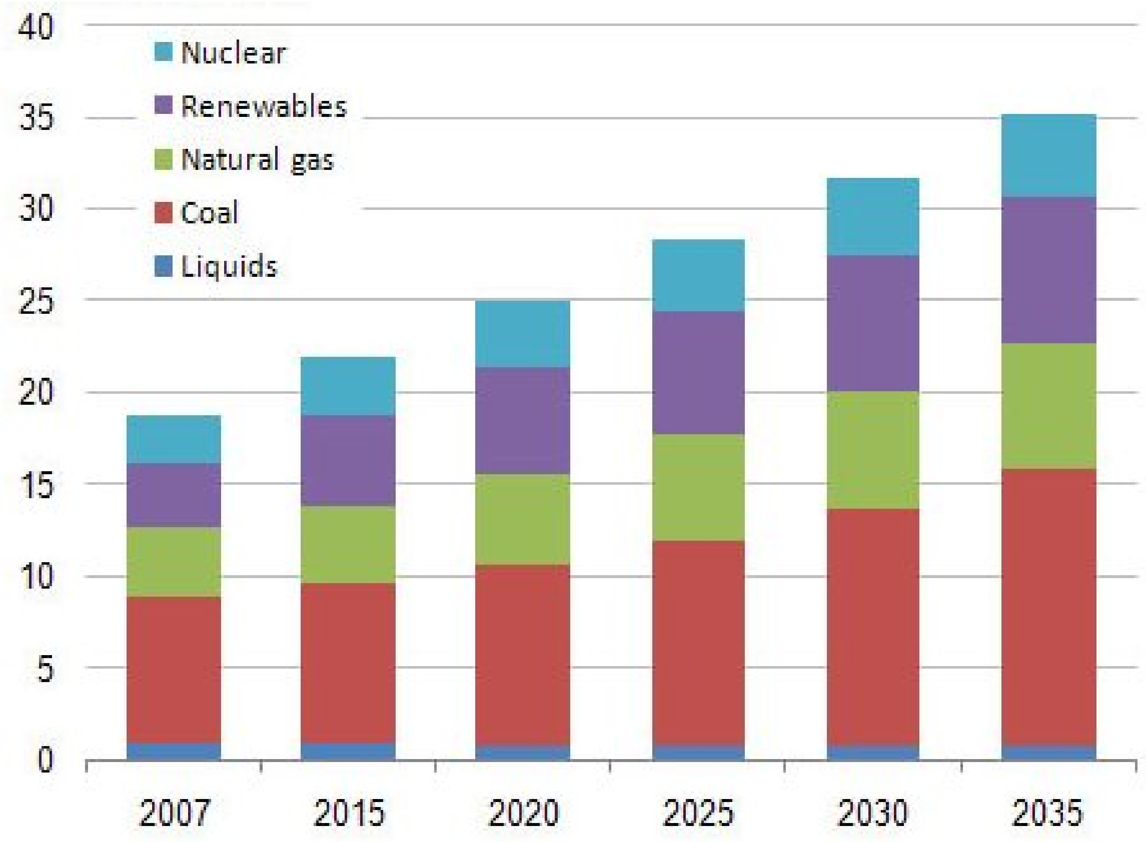
Why do we care?

U.S Net Electricity Generation by Fuel, 2010



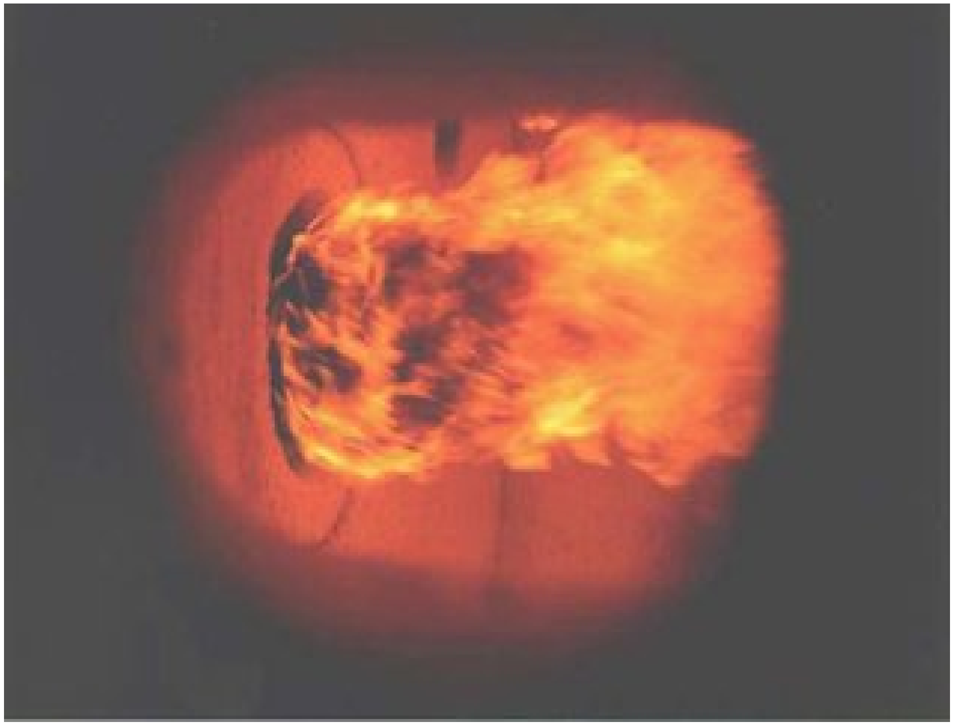
Source: US Energy Information Administration, Electric Power Monthly, Table 1.1 (March 2011), preliminary data.

World Net Electricity Generation by Fuel (trillion kilowatt-hours)

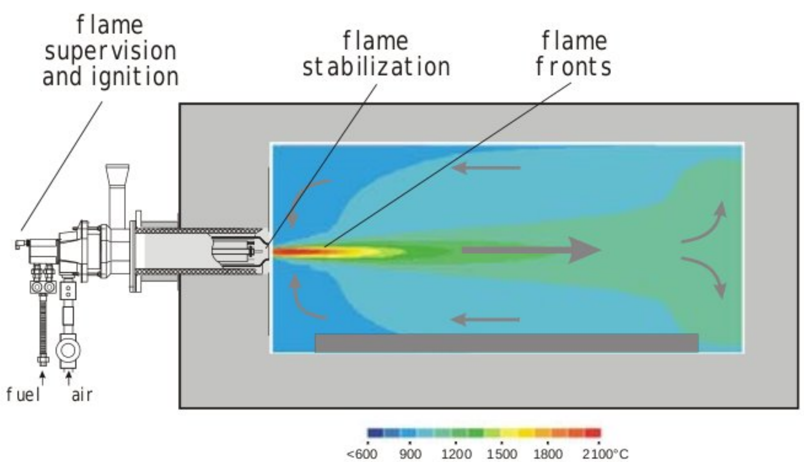


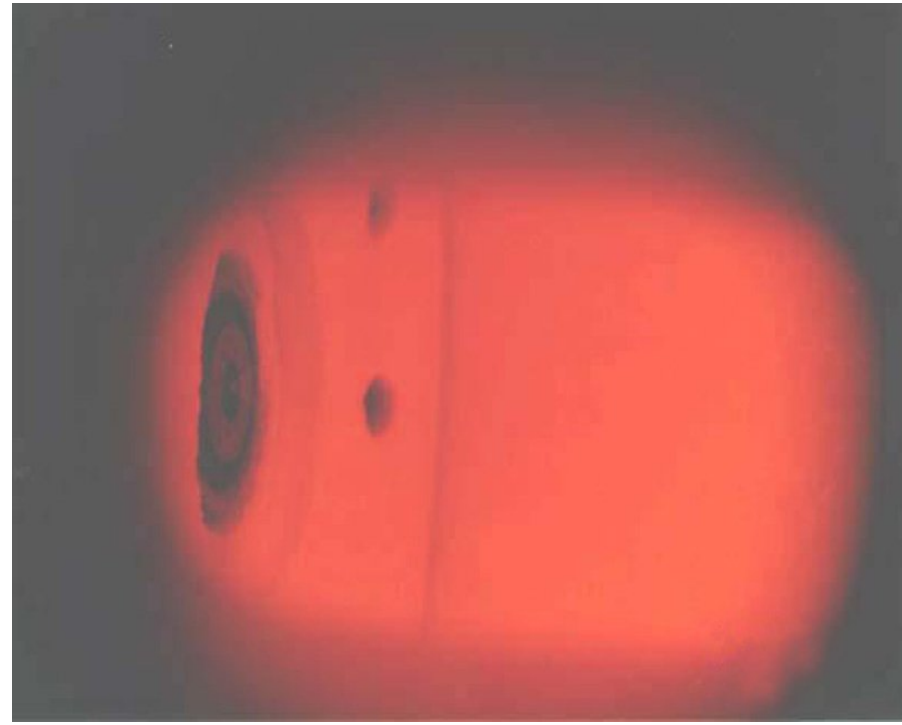
Source: US Energy Information Administration, International Energy Outlook 2010 – Highlights

MILD: Moderate and Intensive Low oxygen Diluted

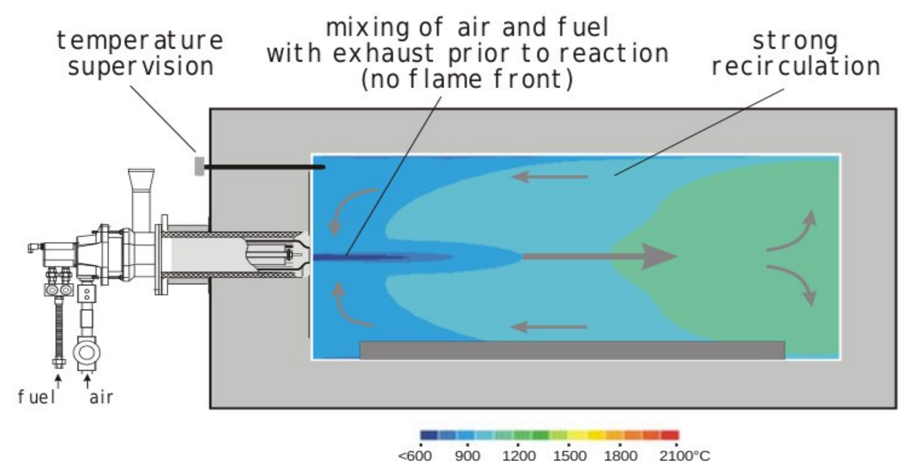


Standard Combustion





Flameless Combustion

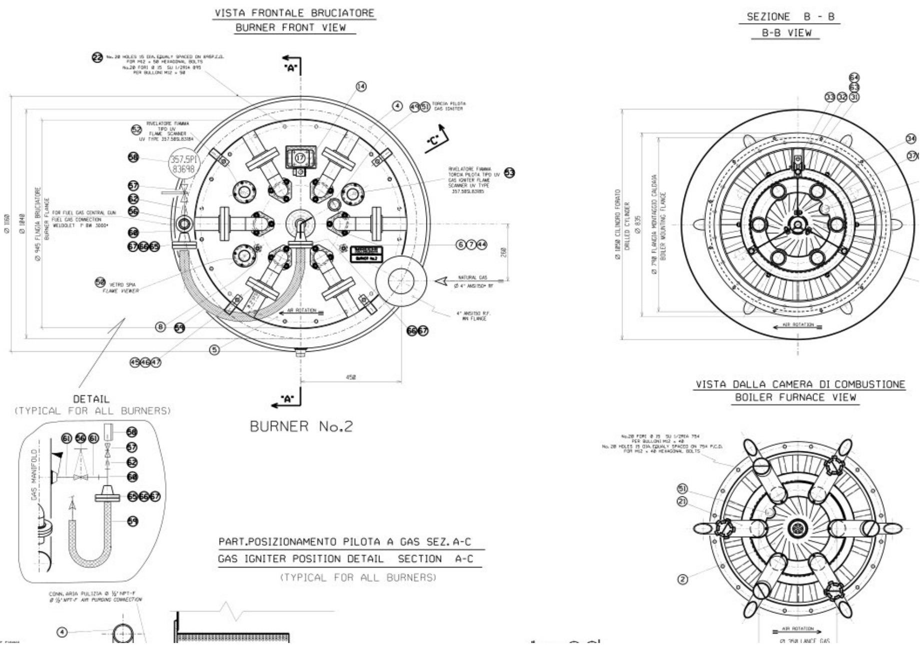


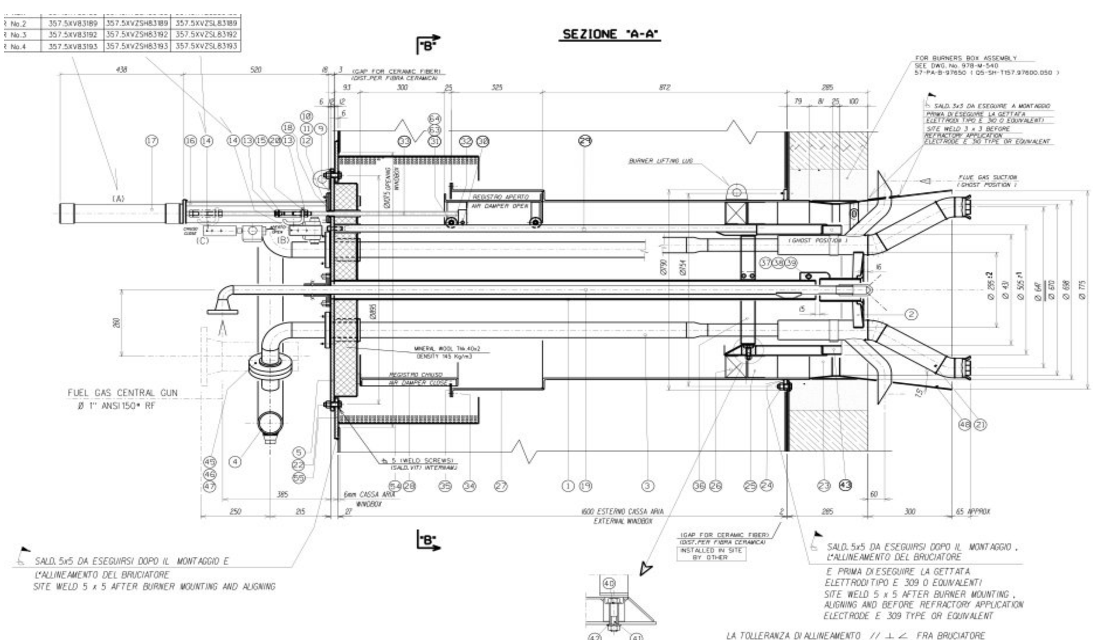
Flameless vs. Flame

In flameless mode, reactions take place at temperatures above the self-ignition temperature, in a distributed large volume instead of being concentratedinto a thin, highly convoluted and stretched flame front . With flameless combustion, there is no flame front, no visible flame, no UV or ionisation detection, and no noise or roar. This translates into:

- higher combustion efficiency (~30%)
- more homogeneous temperature distribution
- reduced thermal stress for the burner
- reduction in nitrogen oxide emissions (ten times less)
- reduction in soot

Macchi Mars I: what we had





-------- Original Message --------
Subject:R: disegni bruciatore MARS I
Date:Fri, 21 May 2010 14:25:33 +0200
From:Morandi Lorenzo <lorenzo.morandi@macchiboiler.it>
To:Vincent Moreau <moreau@crs4.it>
CC:Ernesto Bonomi <ernesto@crs4.it>, Vladimir Zimont <zimont@crs4.it>, <alessandro.saponaro@ansaldoboiler.it>

Caro Dott. Moreau,

Sono felice di fare la sua conoscenza anche se solo per e-mail.

Ho potuto osservare gli screenshots che mi ha inviato e devo dire che il modello del bruciatore appare molto dettagliato. Oltretutto non mi s
vedere quale dettaglio riuscirà a mantenere nella geometria di calcolo, visto che i conti che abbiamo eseguito noi a suo tempo erano senz'alt

Per quanto concerne la geometria della cassa d'aria e della camera di combustione le allego dei disegni anche se penso che l'Ing. Saponaro si
tenute presso il CCA di Gioia del Colle...Sono sicuro che l'equipe del CCA sarà in grado di fornirle ogni dettaglio.

Riguard[illegible] condizioni al contorno g[illegible]li, rif[illegible] al massimo carico del bruciatore, faccia riferimento alle seguenti indicazioni.

```
Portata Gas Naturale                      3650    Nm3/h
Densità Gas Naturale                      0.8     kg/Nm3
Pressione al collettore principale        1.2     barg
Pressione allo stabilizzatore      0.4    barg

Protata aria comburente                   47.8 T/h
Temperatura aria comb.                    37      °C
O2 dry analiz siemens                     2.5%
Delta P bruciatore                        190     mm H2O

Temperatura fumi uscita camera     1200 °C
```

[illegible]ero di essere stato esaustivo nelle mie risposte, ad [illegible] modo non esiti a contattarmi per ulteriori informazioni

Cordiali saluti

P.S.

....e un grande saluto al Prof. Zimont

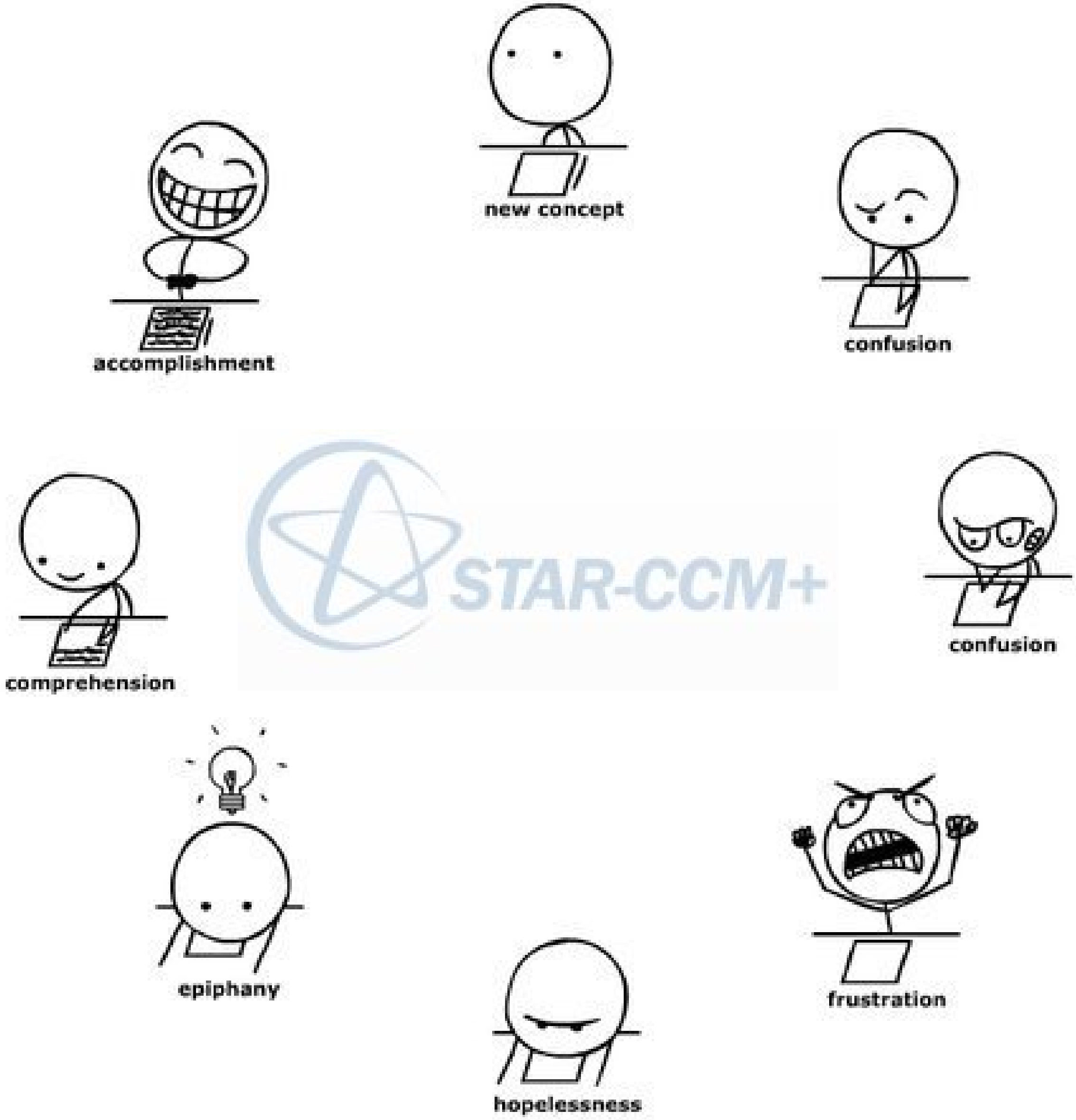
Aim

To simulate the compressible reacting flow field in the boiler by combining HPC and a state of the art CFD solver.

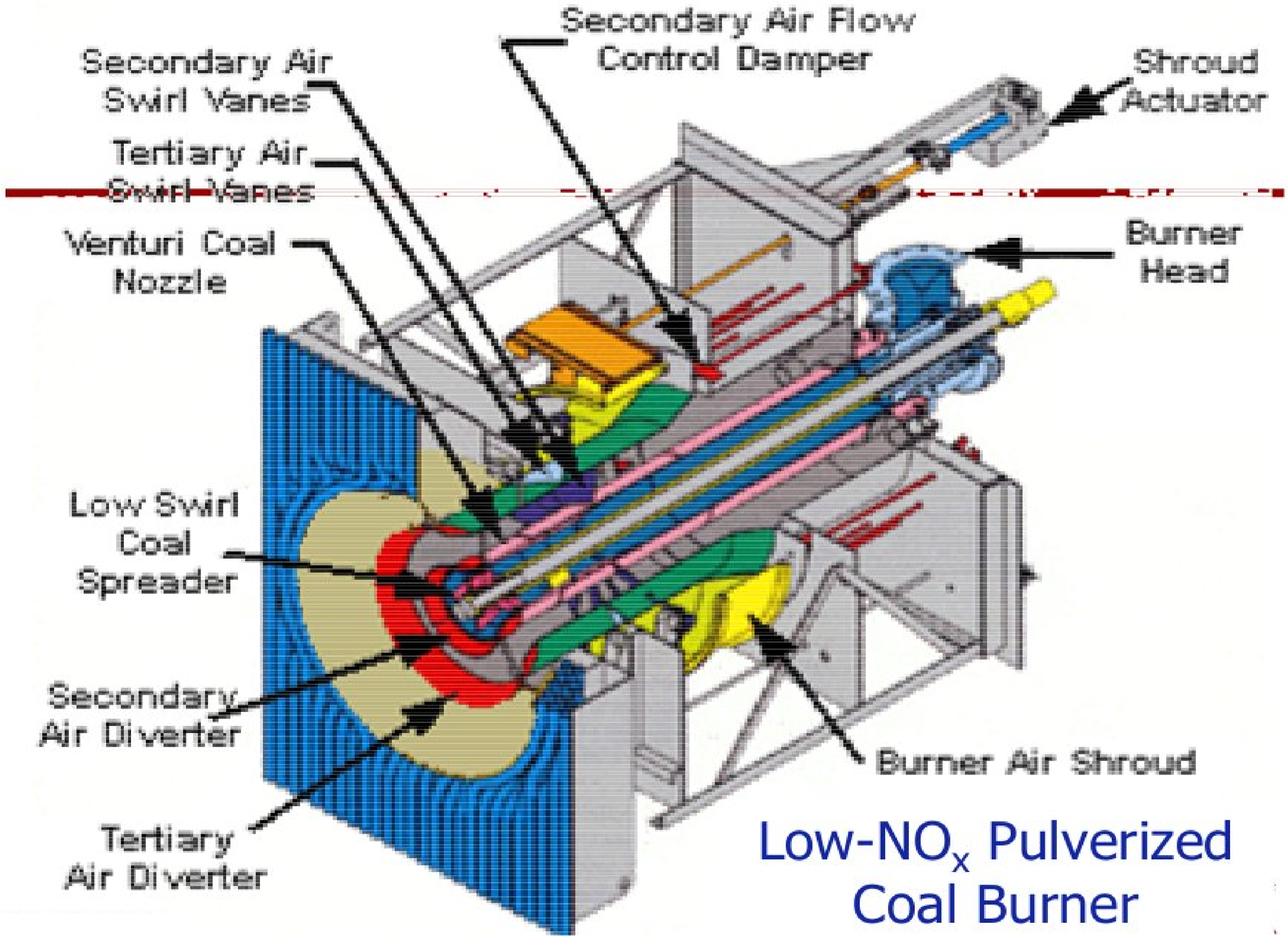
To validate the simulation by comparison with the data provided by the manufacturer.

Identify a process to implement to have a detalíled description of the behaviour of the burner in the furnace (problem breakdown).

How we did proceed



How is an industrial burner for boilers made?



Macchi Mars I: What we had.

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Riguardo alle condizioni al contorno generali, riferite al massimo carico del bruciatore, faccio riferimento alle seguenti indicazioni

Portata Gas Naturale	3650	Nm3/h
Densità Gas Naturale	0.8	kg/Nm3
Pressione al collettore principale	1.2	barg
Pressione allo stabilizzatore	0.4	barg
Protata aria comburente	47.8	T/h
Temperatura aria comb.	37	°C
O2 dry analiz siemens	2.5%	
Delta P bruciatore	190	mm H2O
Temperatura fumi uscita camera	1200	°C

Spero di essere stato esaustivo nelle mie risposte, ad ogni modo non esiti a contattarmi per ulteriori informazioni

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Component		Italian	Dutch	Russian	Algerian	Libyan
Volume composition (%)						
Methane	CH_4	99,63	89,44	93,27	83,69	74,15
Ethane	C_2H_6	0,07	3,28	3,32	7,60	13,27
Propane	C_3H_8	0,04	0,69	0,83	1,86	2,60
N-Butane	C_4H_{10}		0,29	0,37	0,38	0,13
Iso Butane	C_4H_{10}				0,26	0,13
N-Pentane	C_5H_{12}		0,09	0,15	0,08	0,01
Isopentane	C_5H_{12}				0,07	0,01
Esane	C_6H_{14}			0,15	0,08	
Hydrogen	H_2					7,08
Helium	He				0,17	
Carbon Diox.	CO_2	0,01	0,70	1,00	0,18	1,50
Nitrogen	N_2	0,25	5,51	0,91	5,63	0,45
Other						0,67
Heating Value (kcal/Sm³)						
HHV		9005	8866	9365	9400	9700
LHV		8108	7996	8450	8500	8768
Density (kg/Sm³)		0,682	0,752	0,742	0,790	0,778

Table 2: Composition of natural gas imported in Italy [2].

Natural Gas Flow Rate: 3650 Nm^3/h
Natural Gas Density: 0.8 kg/Nm^3
Pressure Drop at Collector: 1.2 barg

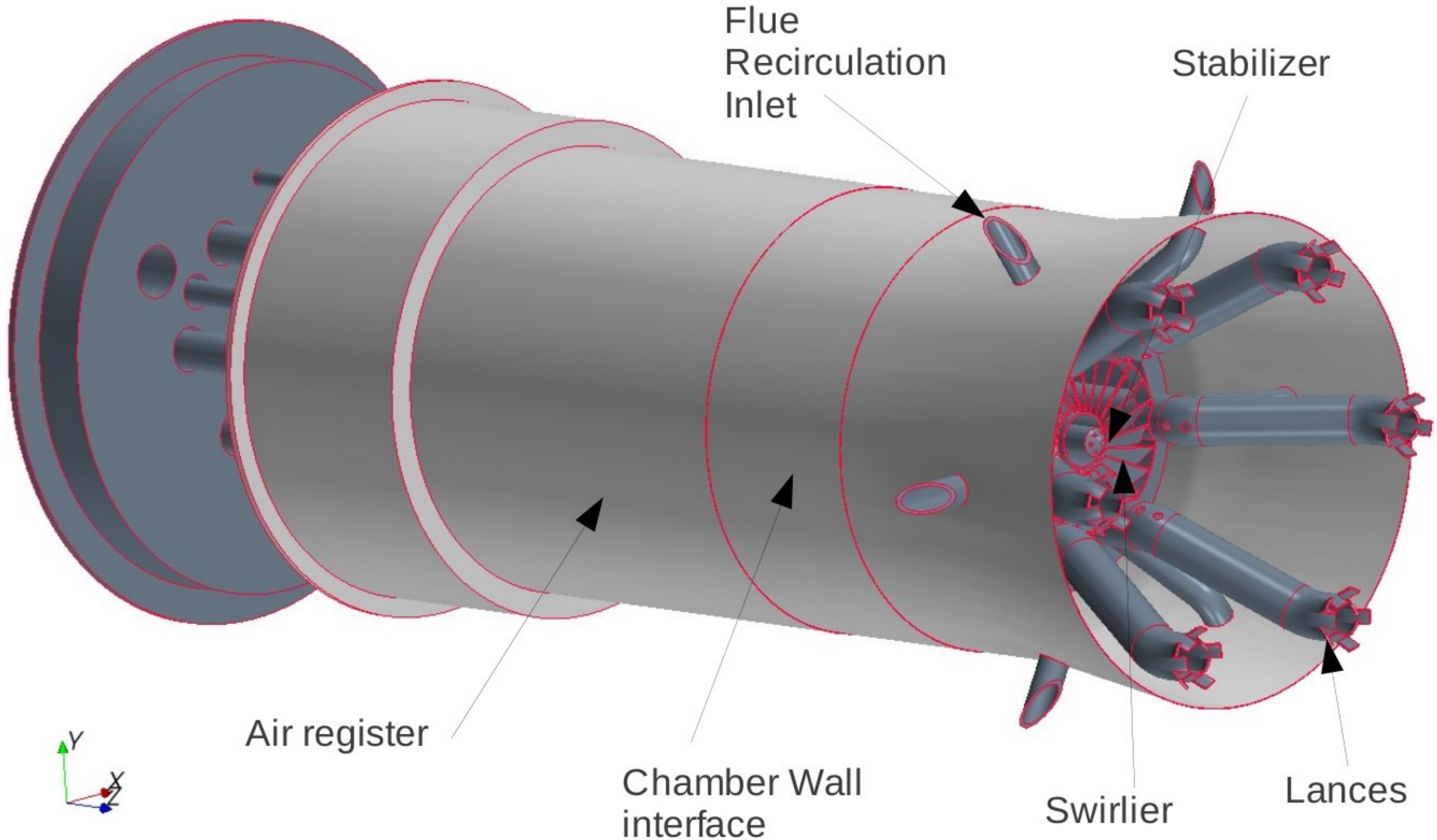
Air Flow Rate: 48 Tons/h
Air Flow Temperature: 37°C

O_2 dry analysis: 2.5%
Flue Out Temperature: 1200°C

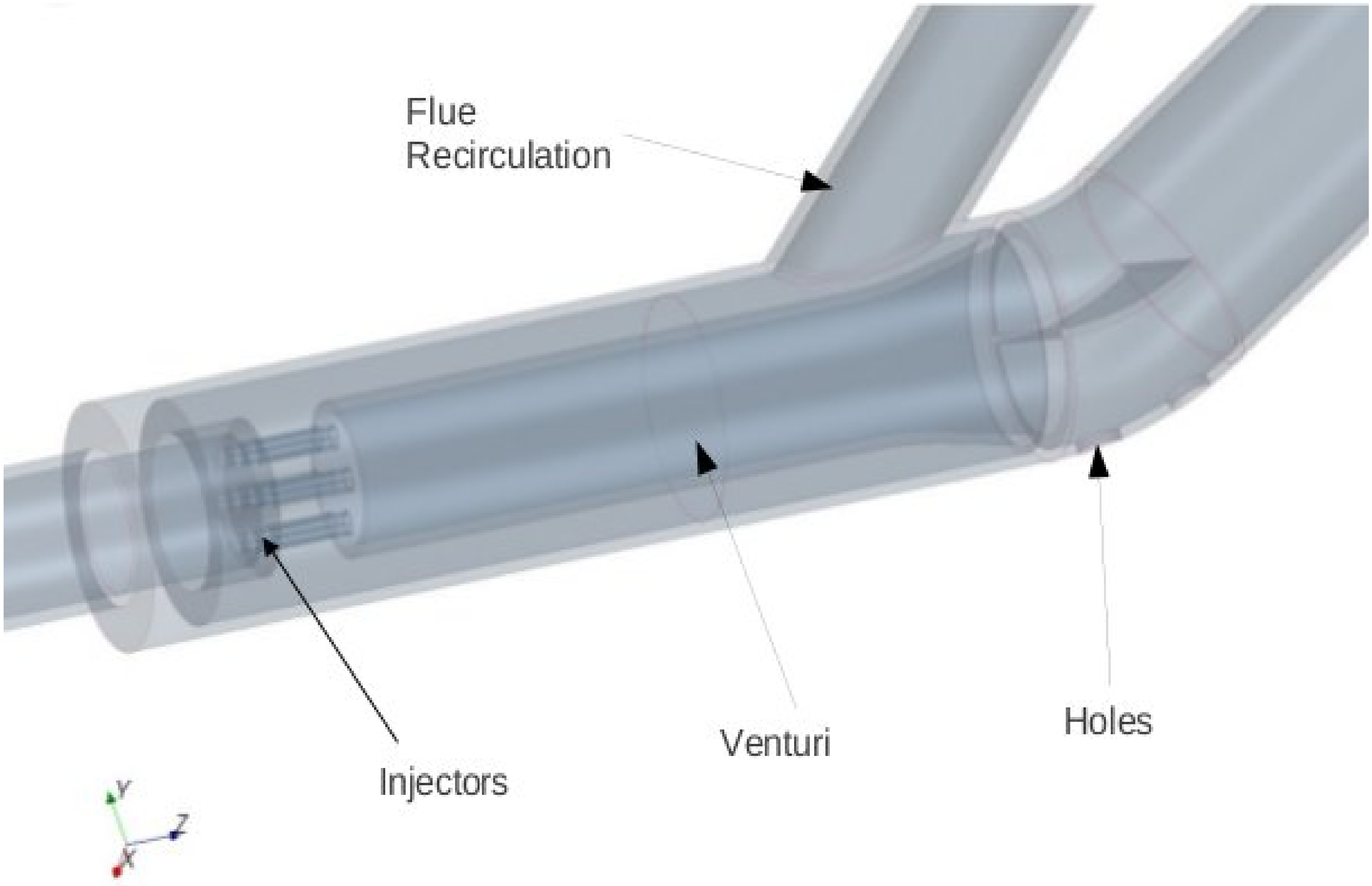
Simulated mixture (in volume):

Methane CH_4 85%,
Ethane C_2H_6 6%,
Nitrogen N_2 9%.

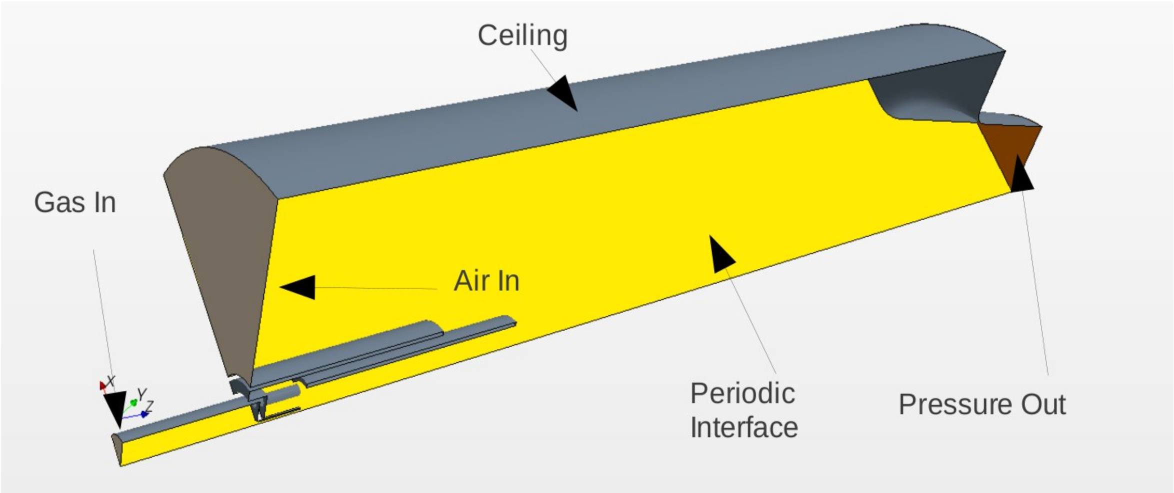
CAD model of the burner from 2D sketches



Injection system and recirculation



Simplified geometry to study the injection system

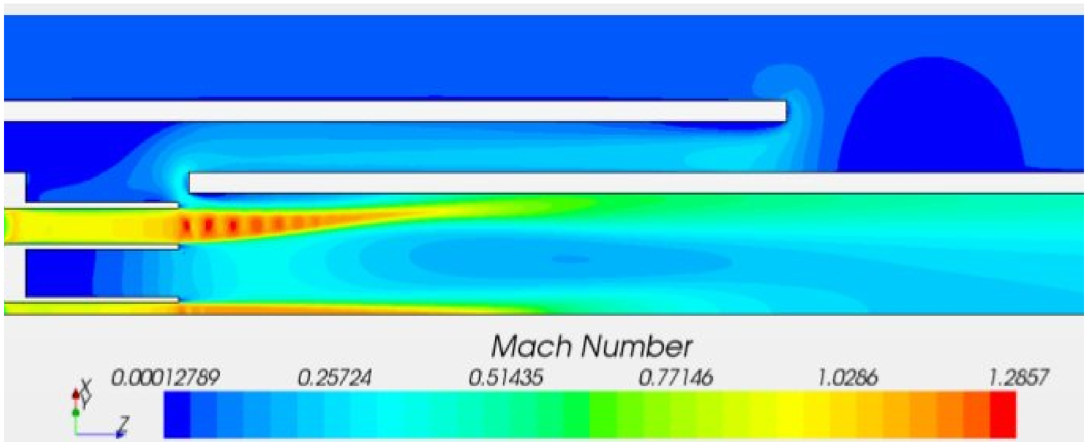


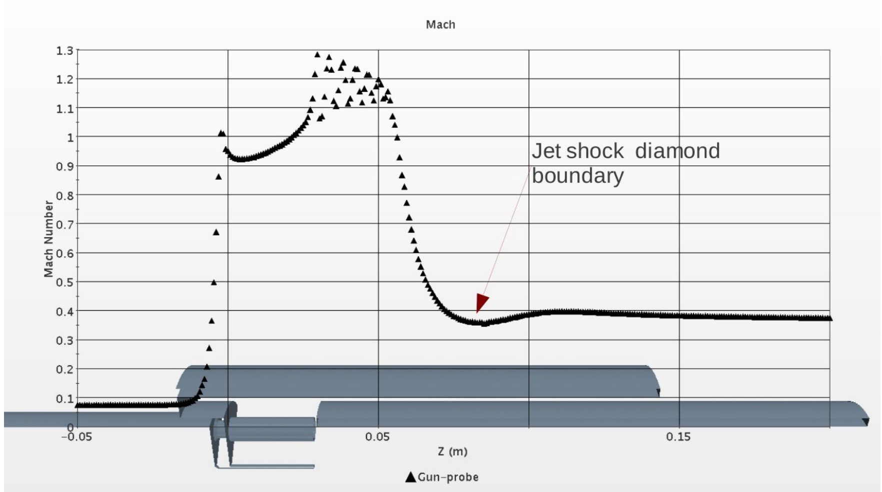
200000 cells

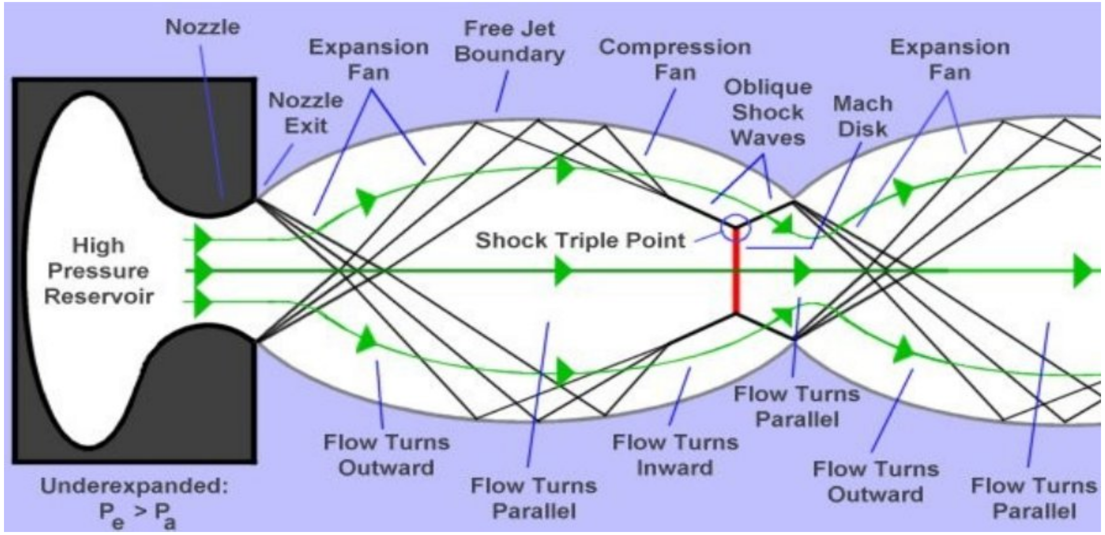
RANS Steady State
Realizable k-epsilon

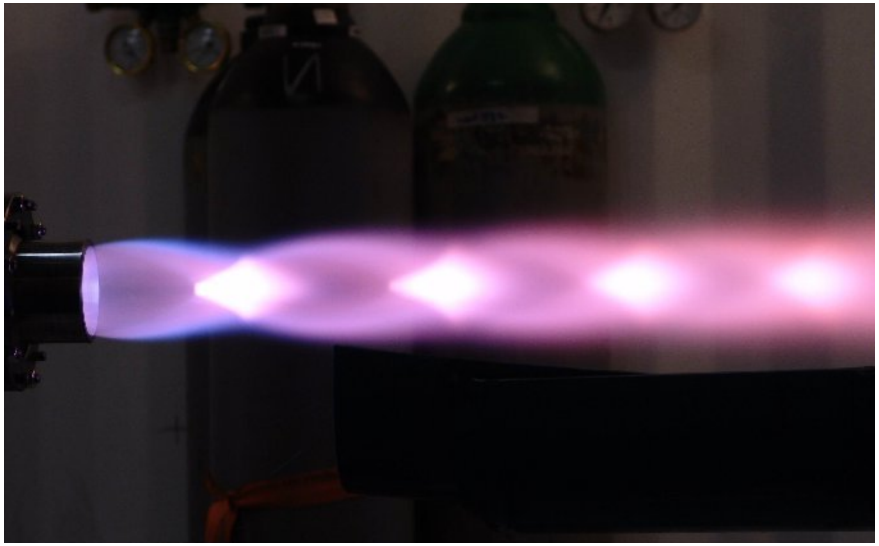
Non Reacting

Under expanded exit of the natural gas at the nozzle









Reacting Flow + Radiation Modeling for a single lance

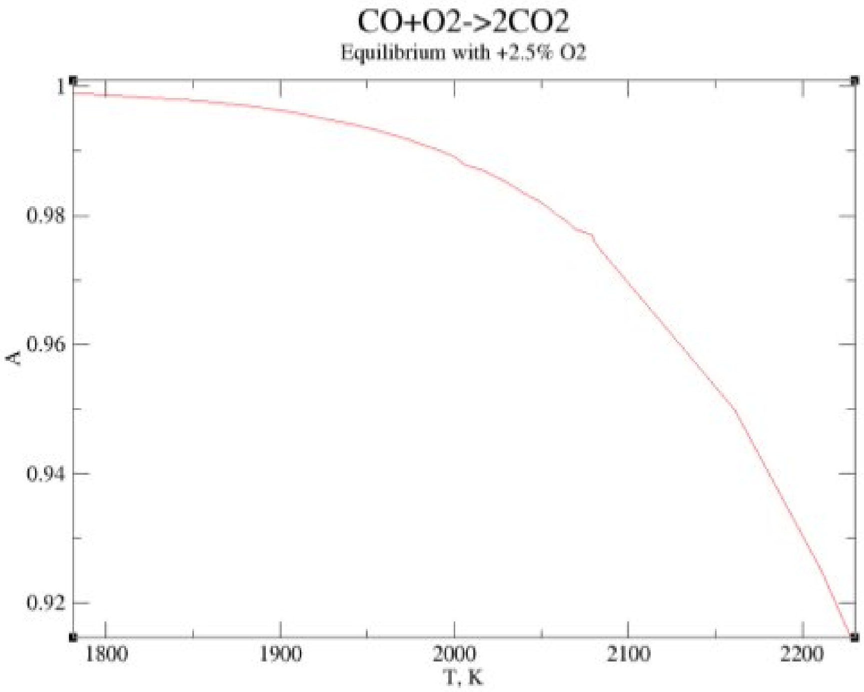
260000 cells

RANS Steady State (k-epsilon)

Single step global reactions

$$(g)\, CH_4 + 2\,O_2 \rightarrow CO_2 + 2H_2O\,;$$

$$(h)\, C_2H_6 + 3.5\,O_2 \rightarrow 2CO_2 + 3H_2O\,;$$

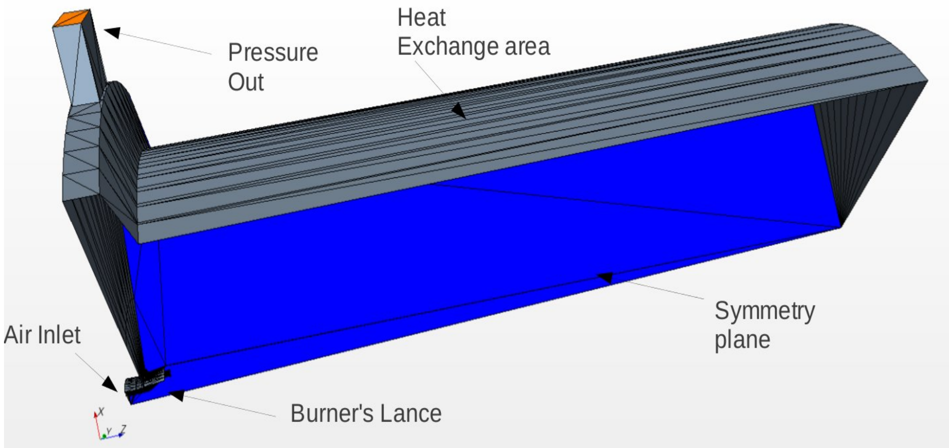


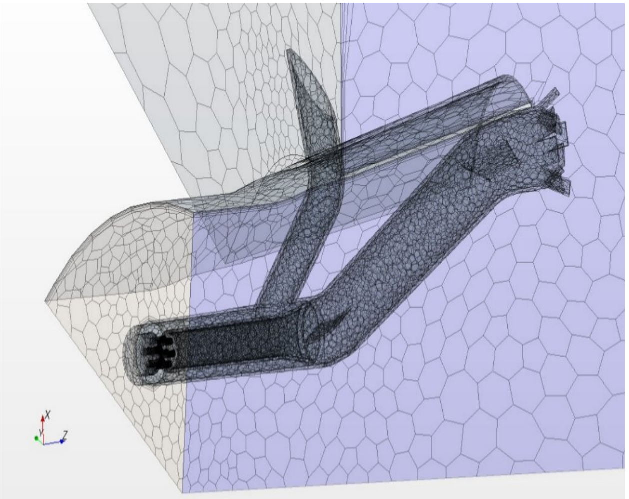
Hybrid EBU (mixed is burned + kinetics)

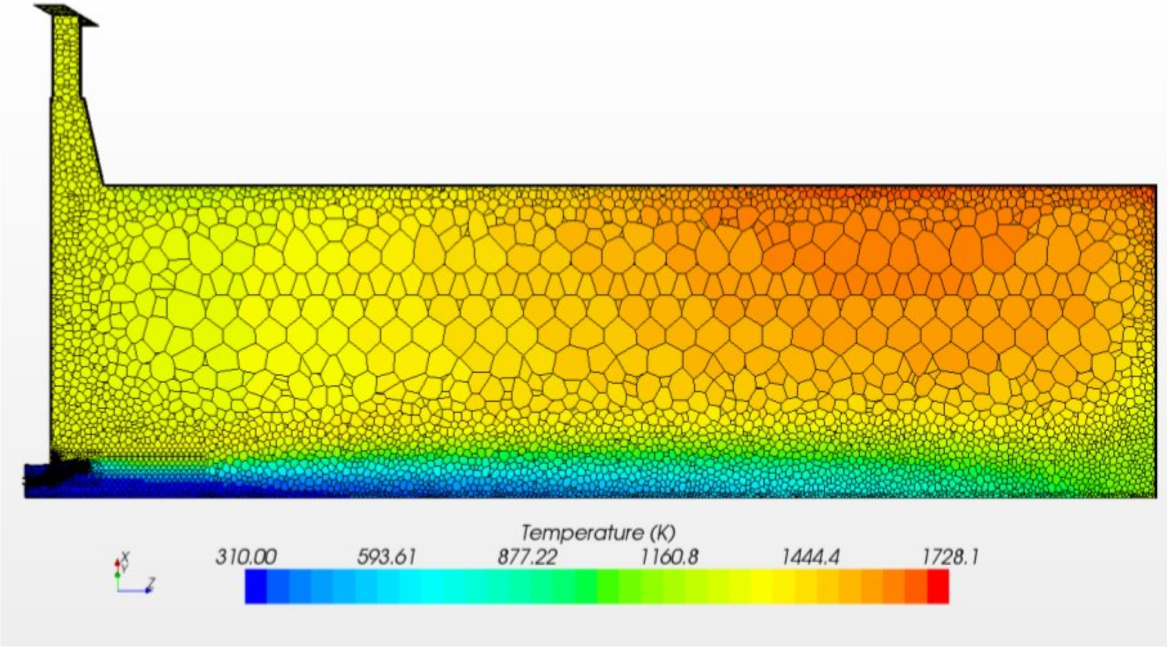
Participating Media Radiation, OPL=4.2m
gray gas (emissivity is constant for all the wavelength)

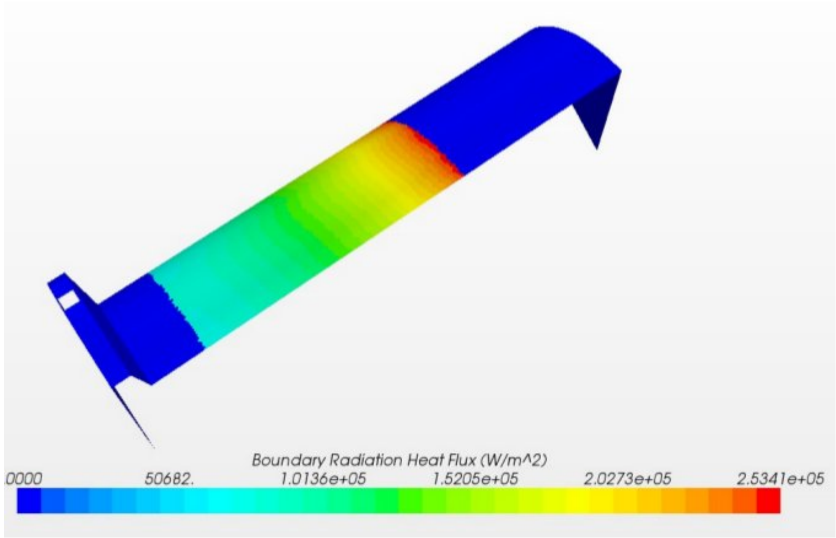
Radiation accounts for 80% of the Heat Flux!

Reacting Flow + Radiation Modeling for a single lance

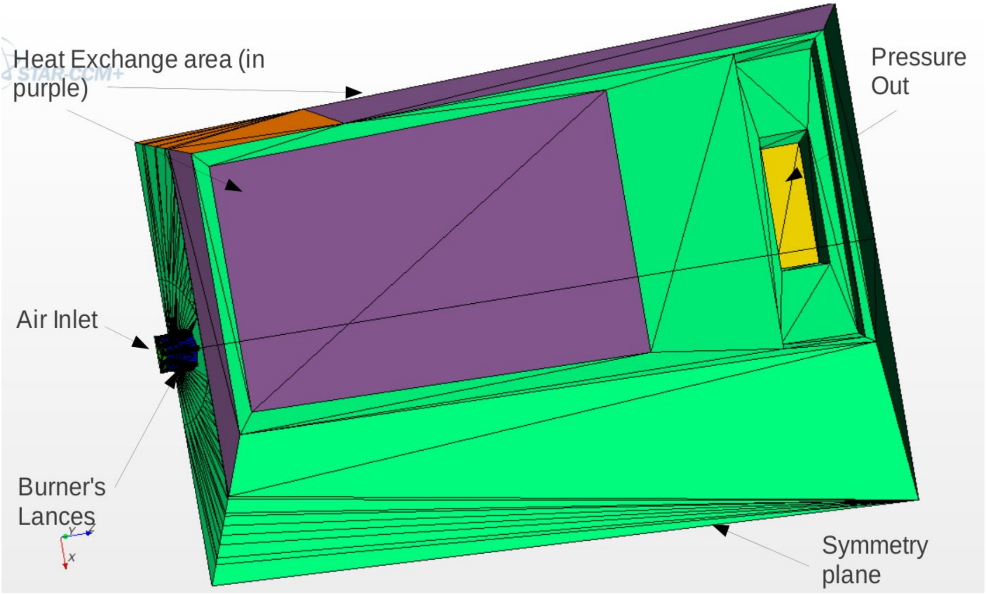


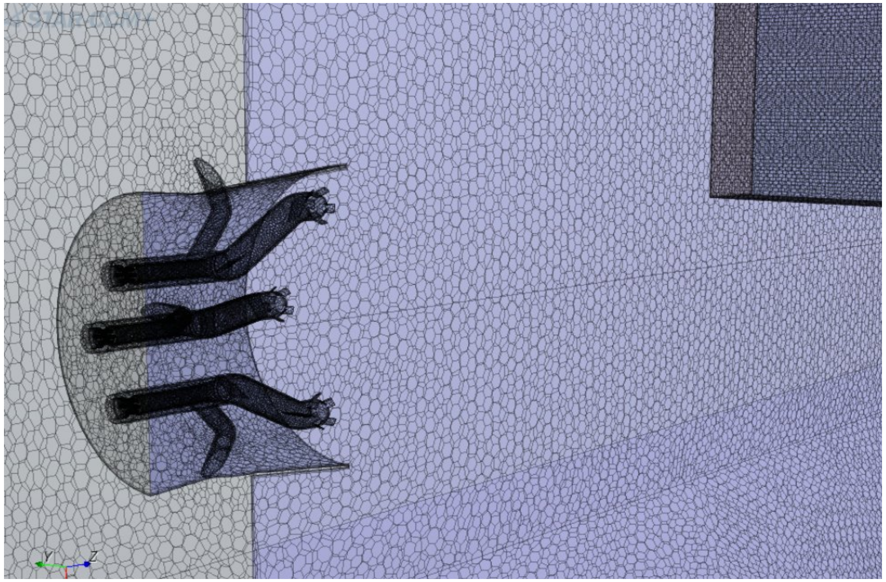


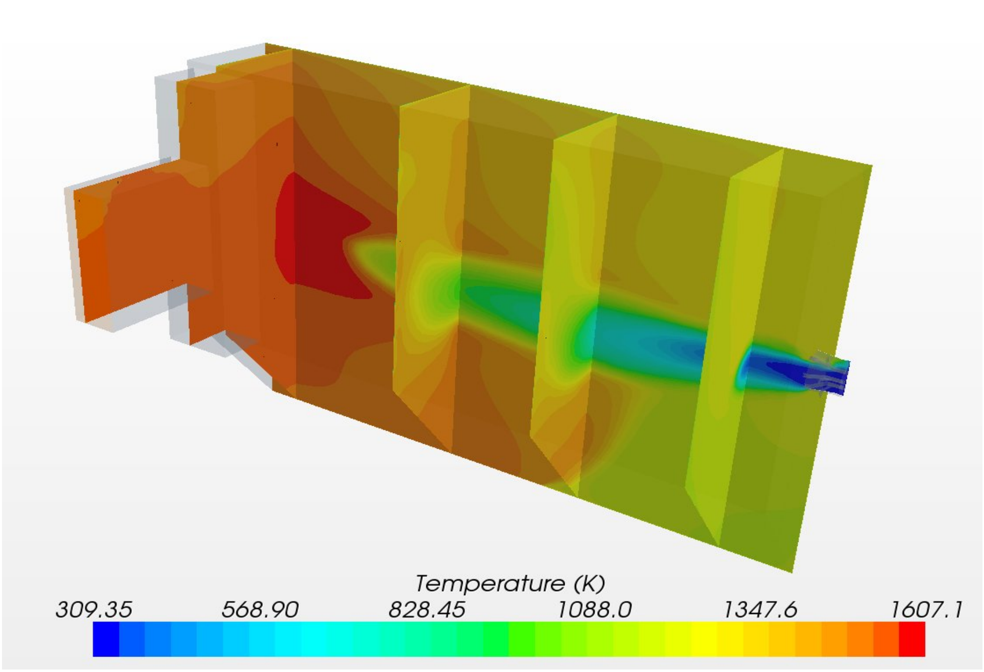


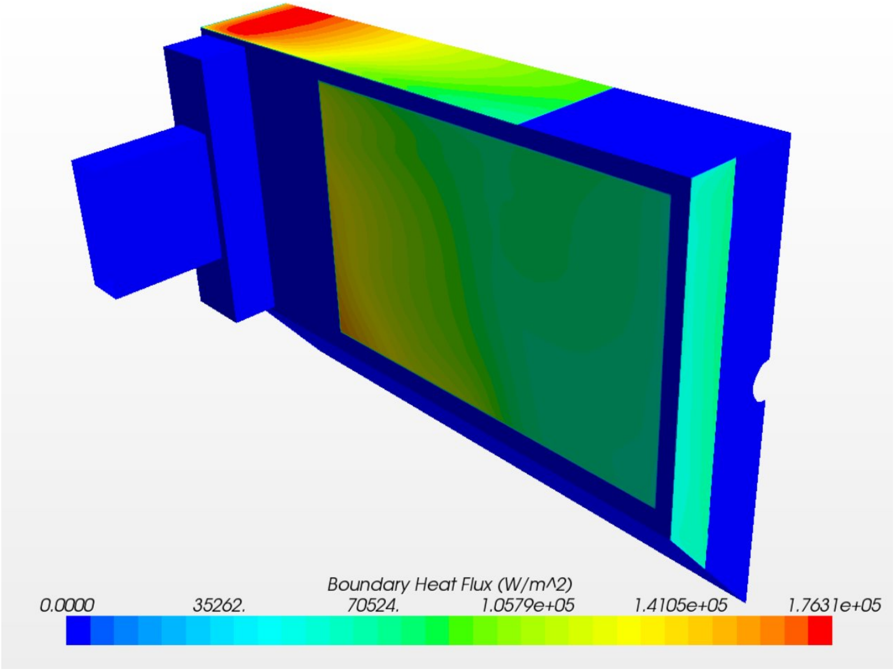


Reacting Flow + Radiation + Gravity (Half Furnace)









Half Furnace: Mass and Energy Balance

	CH_4	C_2H_6	CO_2	H_2O	O_2	N_2
Mass Flow [kg/s]	6.00E-008	5.40E-004	9.59E-001	7.61E-001	1.62E-001	5.110
Mass Fraction	8.57E-009	2.45E-005	1.36E-001	1.08E-001	2.40E-002	0.728
Volume Fraction	0.000	0.000	0.086	0.167	0.0204	0.725

Table 4: *Mixture components at the exit.*

	CH_4	C_2H_6	CO_2	H_2O	O_2	N_2
Mass Flow [kg/s]	2.76E-004	5.73E-006	3.19E-001	2.54E-001	5.43E-002	1.700
Mass Fraction	1.18E-004	2.45E-006	1.36E-001	1.08E-001	2.40E-002	0.728
Volume Fraction	0.000	0.000	0.086	0.167	0.0204	0.725

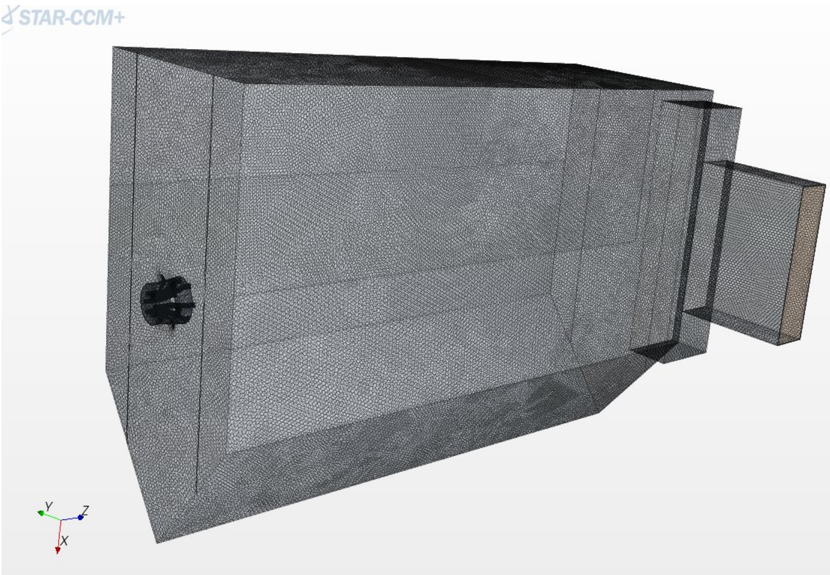
Table 5: Mixture components at the exit for the single lance case.

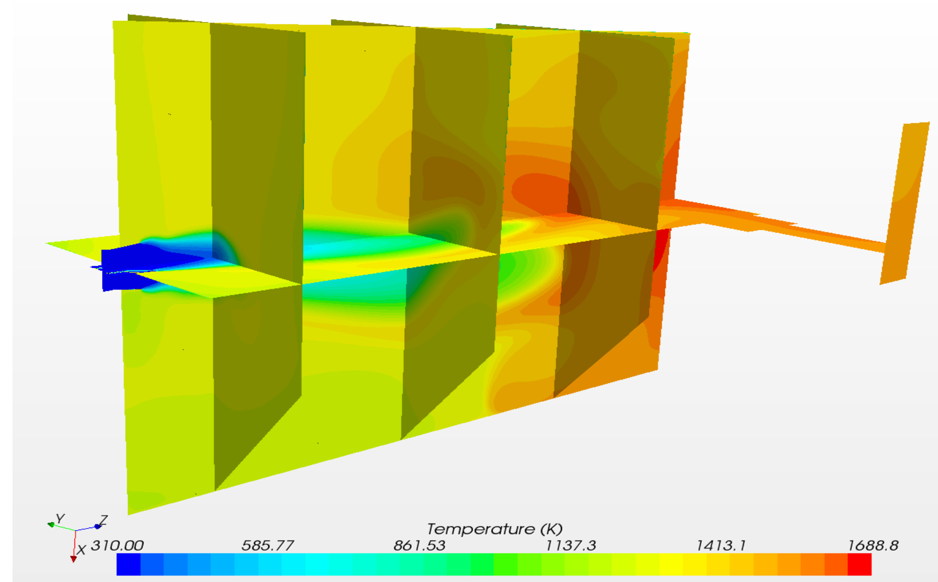
2.5% on dry basis!

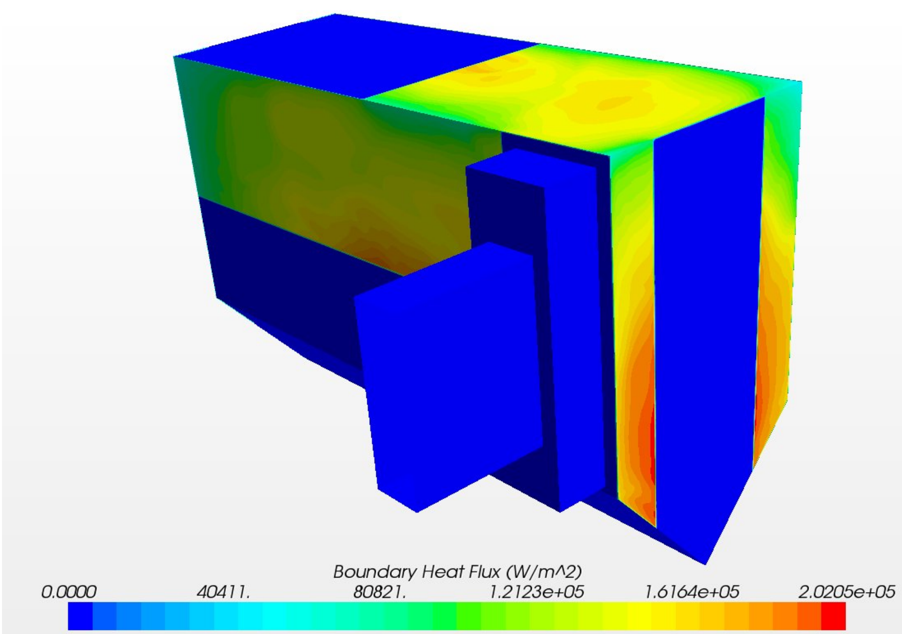
	Power (kW)
Air Inlet	-75.81
Adiabatic wall	0
Injectors	1560.48
Burner	0
Symmetry	0
Heat Exchanger	6432.72
Pressure Outlet	-7895.83
Total	21.56

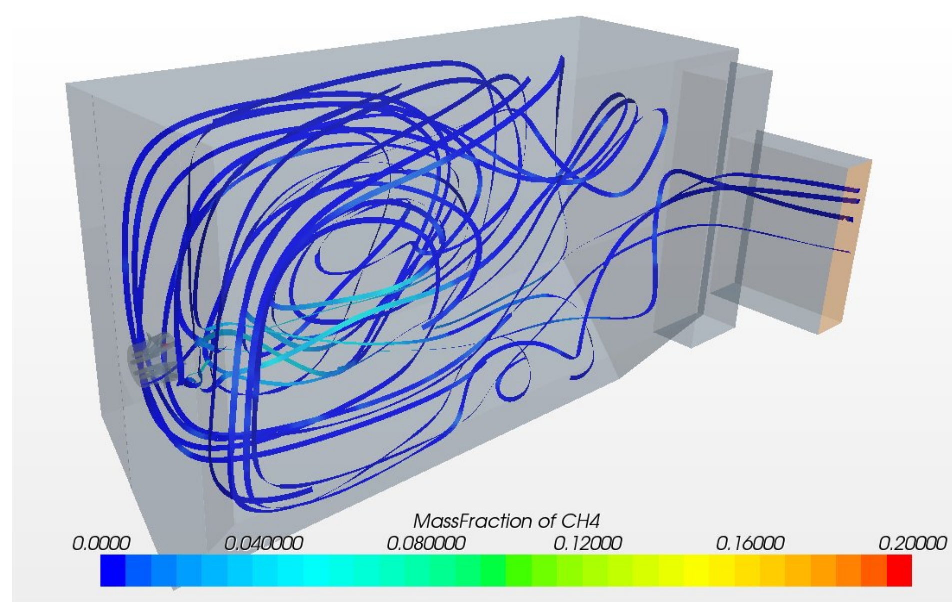
Table 7: Power exchange at boundaries (fuel mass flow rate 0.4045 kg_c/s).

Reacting Flow + Heat Exchange + Gravity + Nox (Furnace)









Furnace: Mass and Energy Balance

kg/s	Mass Flow	C	H	O	N
In	14.079	5.28E-001	1.70E-001	1.53E+000	10.29E+00
Out	14.078	5.28E-001	1.70E-001	1.53E+000	10.29E+00
Difference %	0.0	0.0	0.0	0.0	0.0

Table 8: Total mass and single species balance for the entire furnace.

	CH_4	C_2H_6	CO_2	H_2O	O_2	N_2
Mass Flow [kg/s]	5.68E-010	1.58E-003	1.92E-000	1.53E-000	3.33E-001	10.300
Mass Fraction	0	1.1E-004	1.36E-001	1.08E-001	2.38E-002	0.728
Volume Fraction	0.000	0.000	0.086	0.167	0.0205	0.725

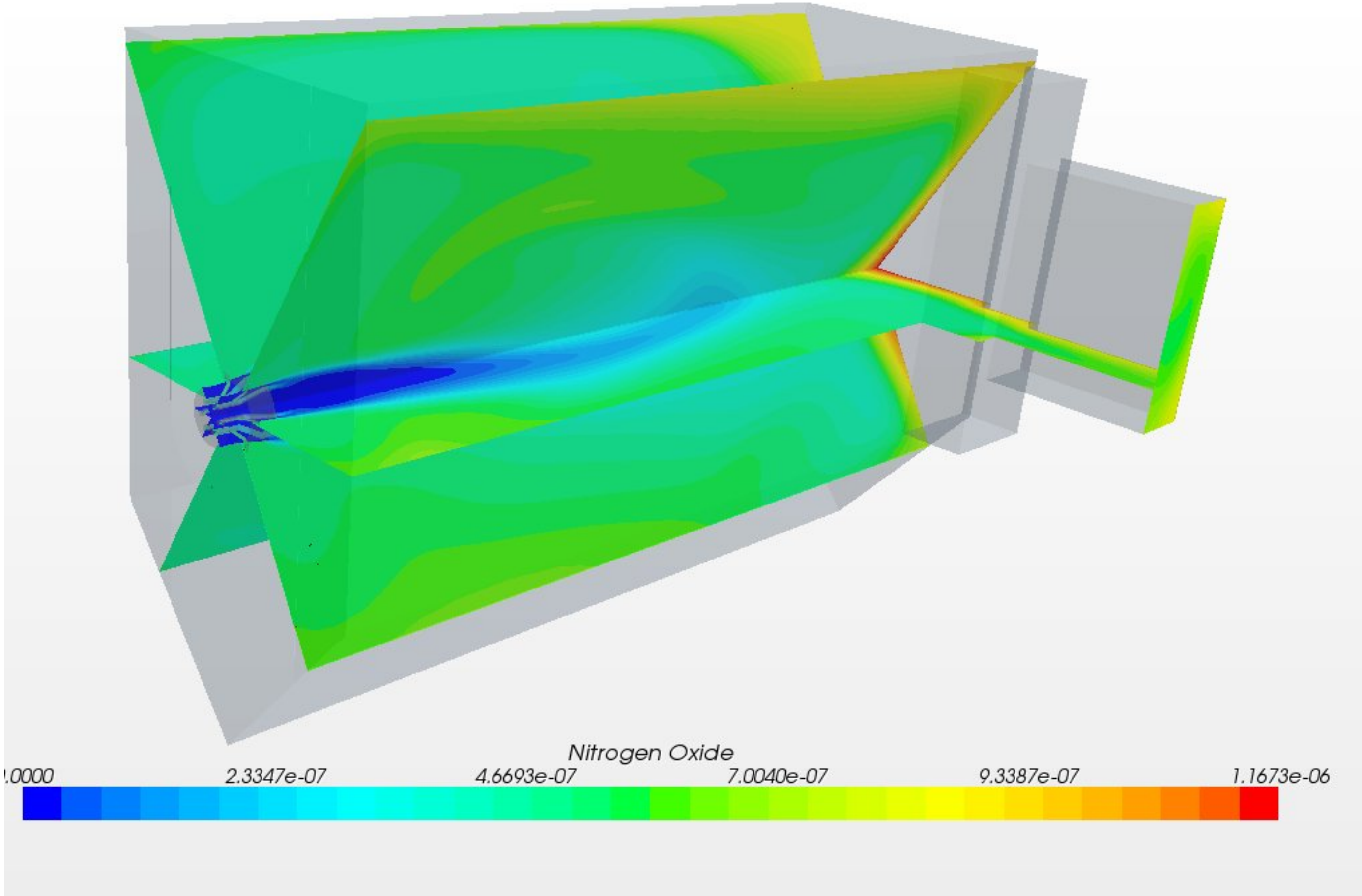
Table 9: *Mixture components at the exit.*

	Power (kW)
HHV_d (Gaur and Reed 1995)	38085
HHV_p (Gaur and Reed 1995)	34495
Chemical heat Release (Volume Integral)	34530

Table 10: Fuel HHV and volume enthalpy (fuel mass flow rate 0.81 kg_c/s).

Boiler 30MWth!

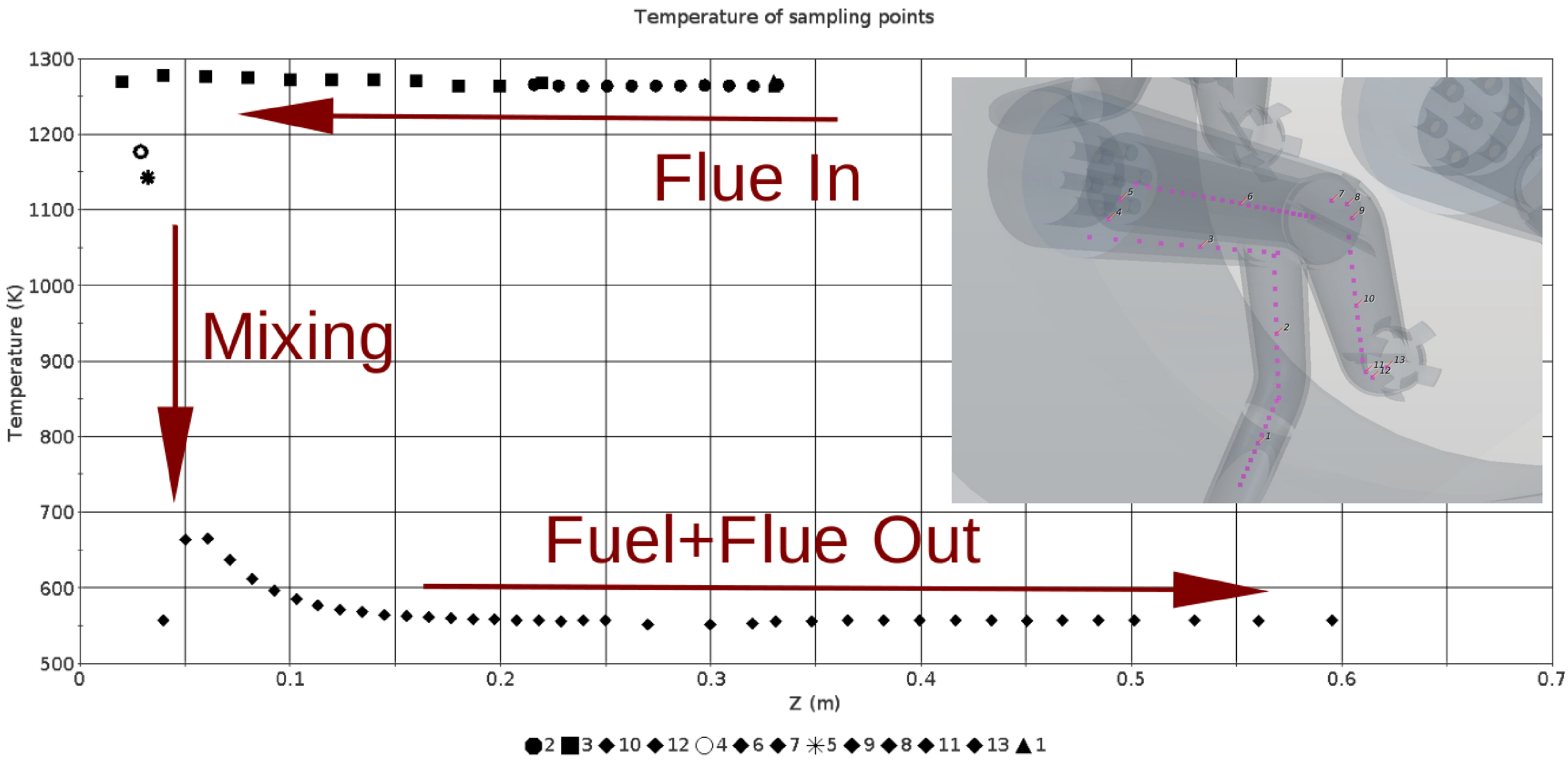
Nox Emission



"*MACCHI BOILERS and BURNERS, thanks to new Burner technology, have achieved successful operation handed over a Boiler rated 335 t/h, 28 barA, 235°C with NOx emissions certified at 14 ppm at Ras Abu Fontas, Qatar*" (SOFINTER-Website)

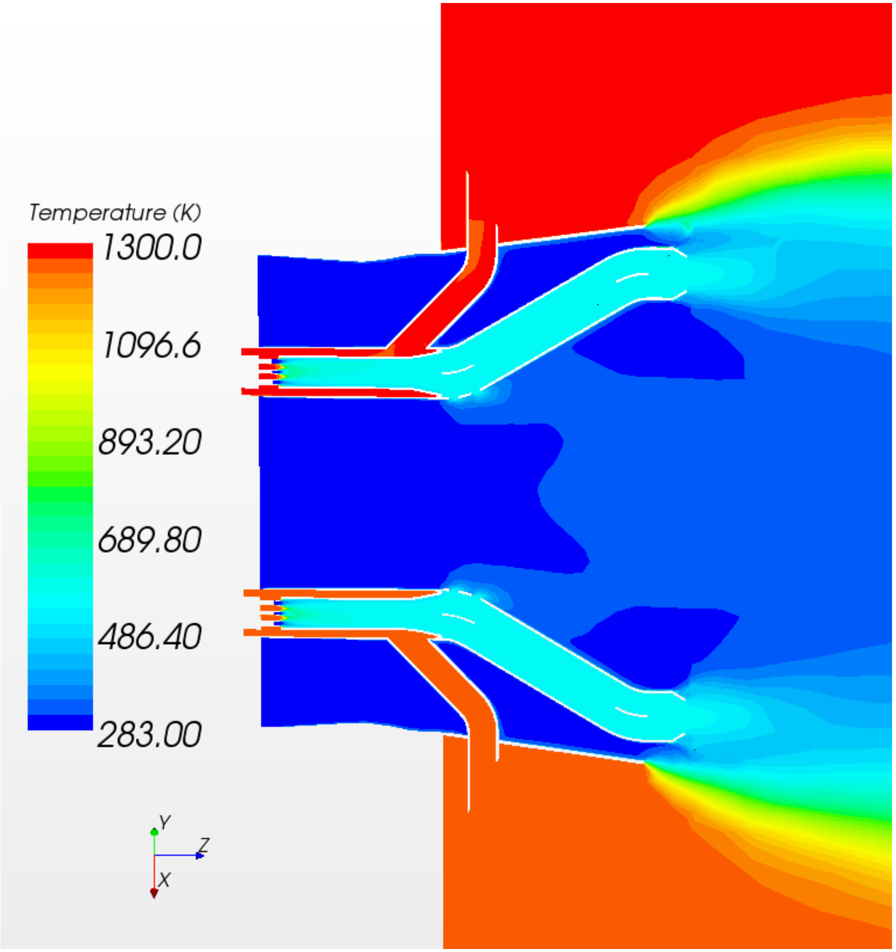
Our result: at the stack ~ 1 ppm

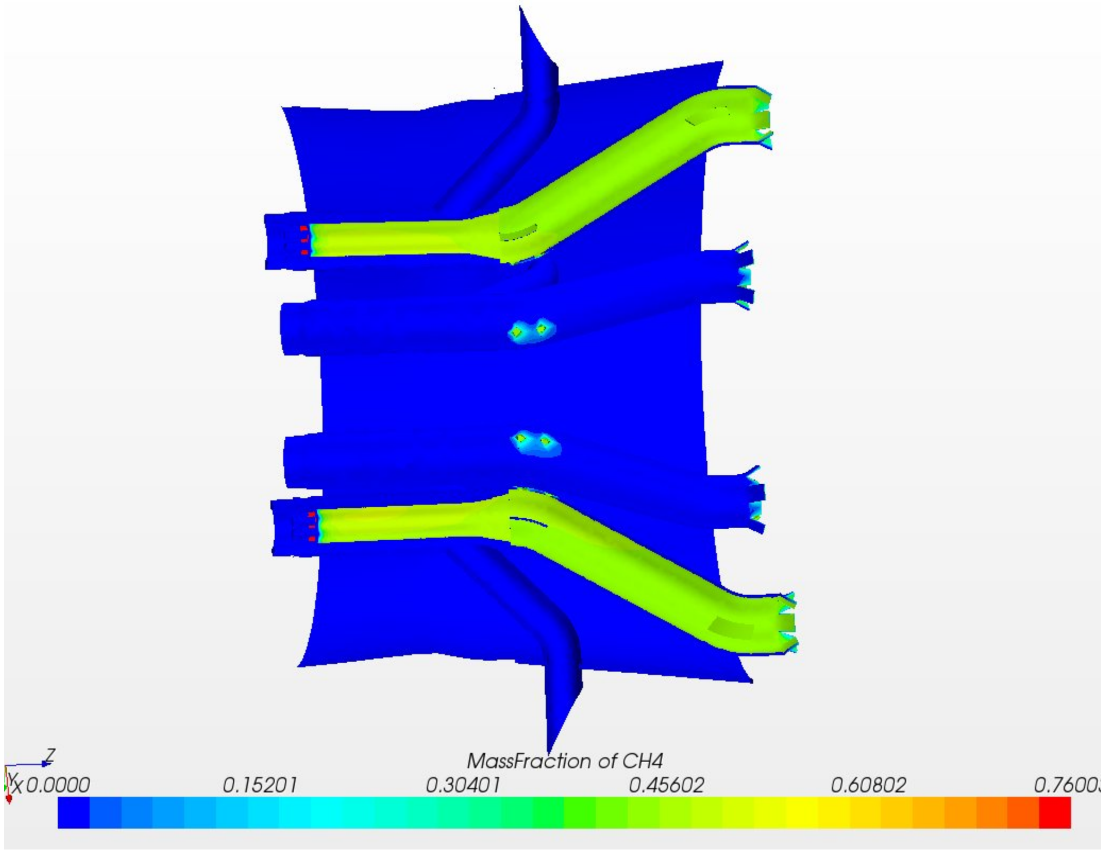
Flue Gas Recirculation



Our result for the single injector with air at 1200K: T= 510K

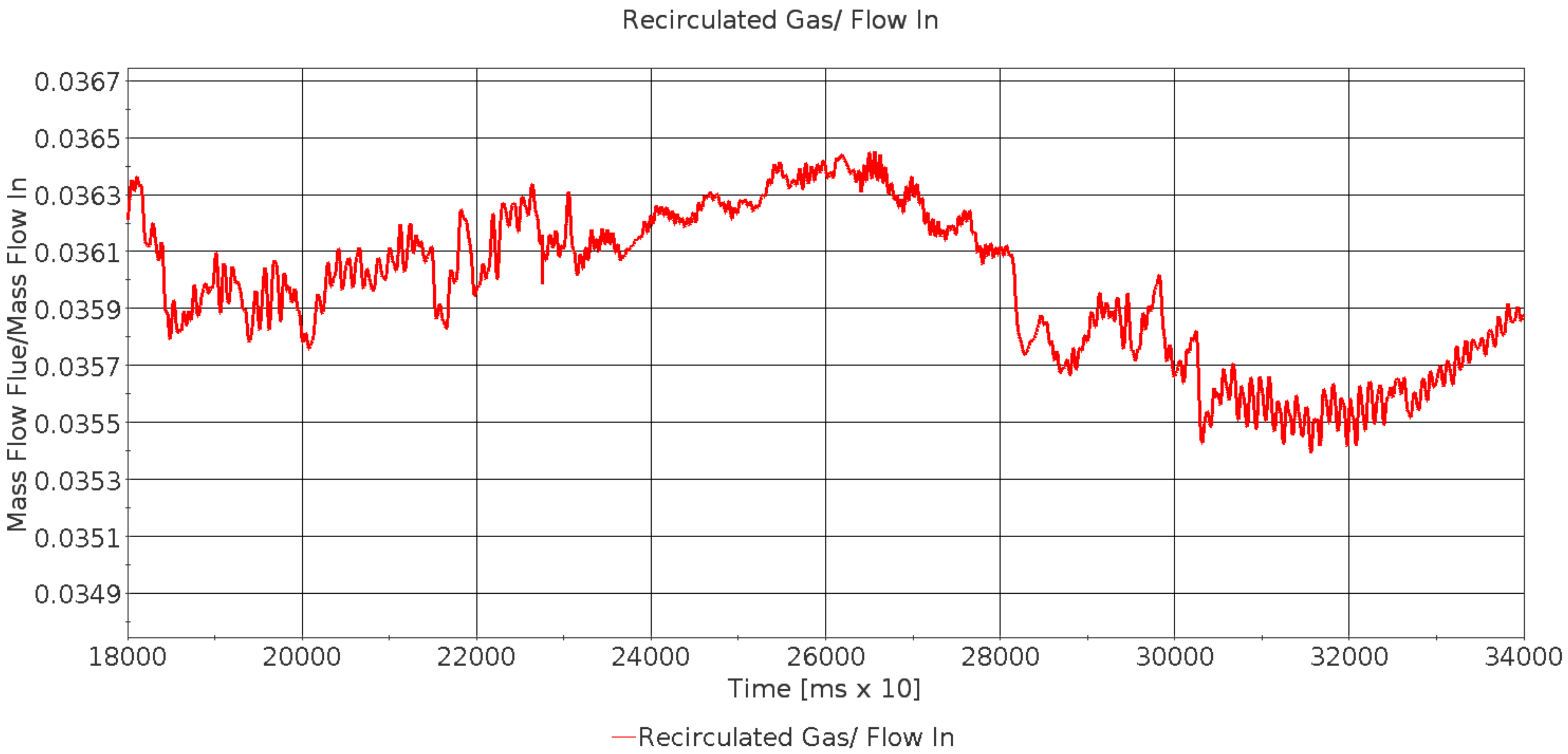
Flue Gas Recirculation Temperature



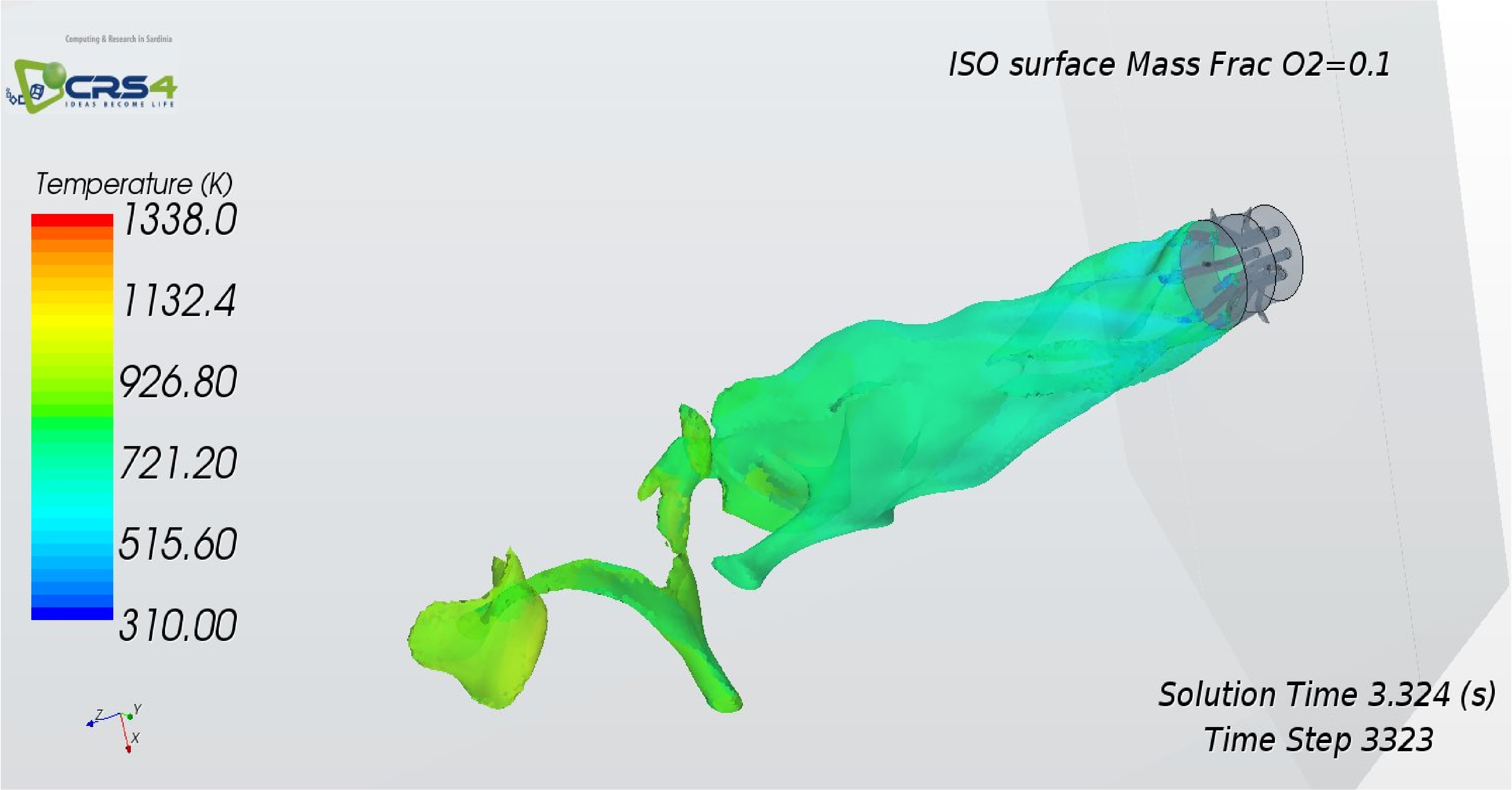


Temperature stratification due to gravity effects at flue recirculation inlet: ΔT~30K

Transient (URANS & DES)



But time of residency in the furnance ~ 14 s!


Computing & Research in Sardinia
CRS4
IDEAS BECOME LIFE
ISO surface Mass Frac O2=0.1
Temperature (K)
1338.0
1132.4
926.80
721.20
515.60
310.00
Z
Y
X
Solution Time 3.324 (s)
Time Step 3323

Movie 1: Streamlines

Streamlines.avi

The movie shows the flow strealmlines coloured with temperature scalars for a steady state RANS simulation.

Highest temperatures in red.

Movie 2: Pressure Waves in the Lance

Pressurewave.avi

The movie shows the pressure waves propagating in the lances due to the injection of the natural gas.

URANS simulation. Time step 1 ms.

Iso-Q surfaces coloured with O_2 mass fraction.

Movie 3: Swirl

Swirl.avi

The movie shows iso surfaces of O_2 mass fraction and the reacting flow swirling.

Detached Eddy Simulation (DES). Time step 1 ms.

Movie 4: Flow Temperature

FlowTemperature.avi

The movie shows the contours of temperature in the furnace.

Detached Eddy Simulation (DES). Time step 1 ms.

Conclusions

CFD simulations are in good agreement with the theoretical, experimental and numerical results found for the field variables.

Star-CCM+ is a robust and reliable integrated CFD platform for the simulation of a compressible, reacting, non-adiabatic flow field.

Our problem breakdown is suitable for the simulation of the boiler fuelled by natural gas with the MILD burner implementation (74-F3-RI Industia 2015).

Behaviour of the burner feeded with oil can be determined if data from the manufacturer is provided (75-F4-RI Industia 2015).
Numerical functional optimization can be implemented by using in UDF in Star-CCm+ (75-F6-RI Industria 2015).

Thanks.
Q&A?