NUMERICAL SIMULATIONS OF OXY-COMBUSTION OF PULVERIZED COAL IN SWIRL BURNERS

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Oxy-fuel Combustion vs. Combustion in air

- Coal plays an important role in electricity production due to its large reserves around the world. To reduce the emission during coal combustion one may carry out the combustion process in oxy-combustion technology
- Combustion process carried out in O_2/CO_2 mixture differs from combustion in air (heat transfer, temperature distribution). This is due to differences in CO_2 and N_2 properties such as higher density and higher heat capacity of CO2

- Higher heat capacity of CO_2

  (T=1000 K: Cp_{CO2} = 54,3 J/(mol K), Cp_{N2} = 32,54 J/(mol K)),

- Higher density of CO_2

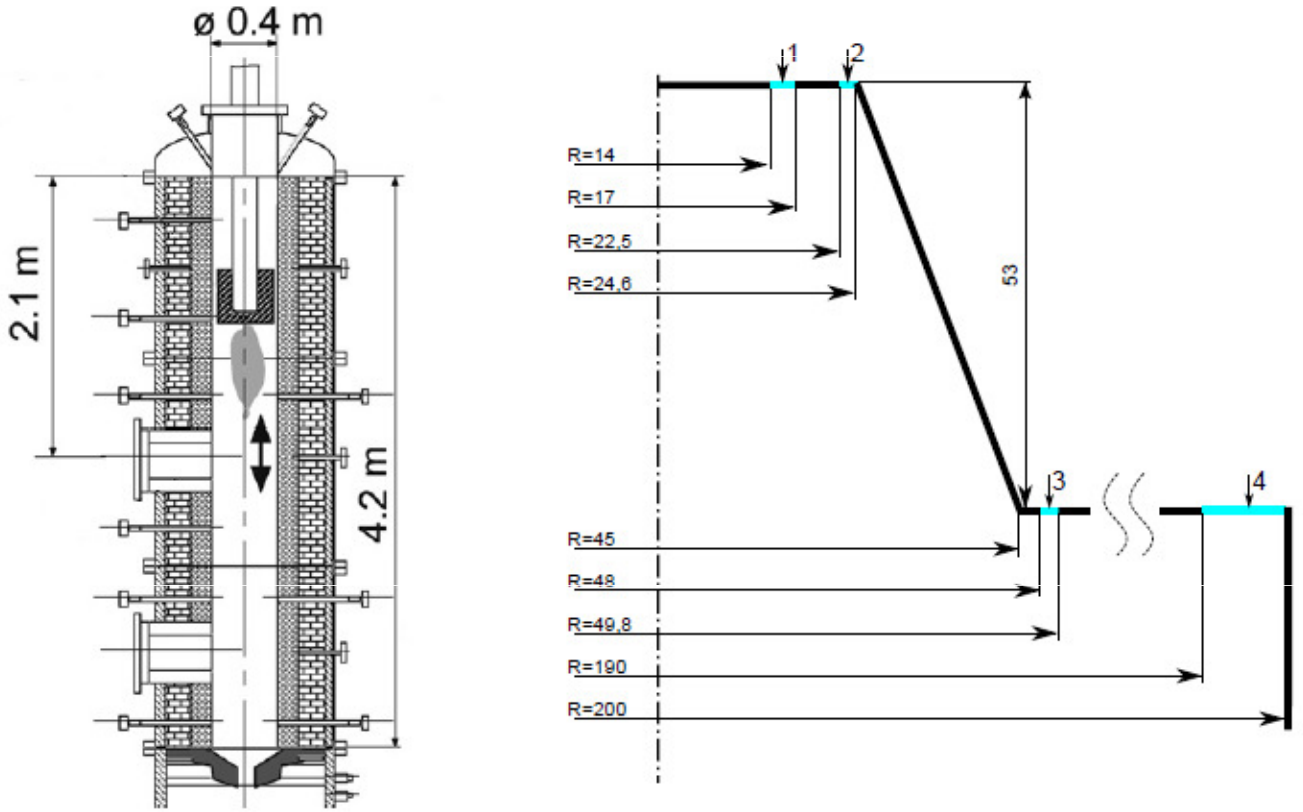
  (T=273 K, P=1 atm: ρ_{CO2}= 1,98 kg/m3, ρ_{N2}= 1,251 kg/m3),

- Lower diffusion coefficient of oxygen in CO_2,

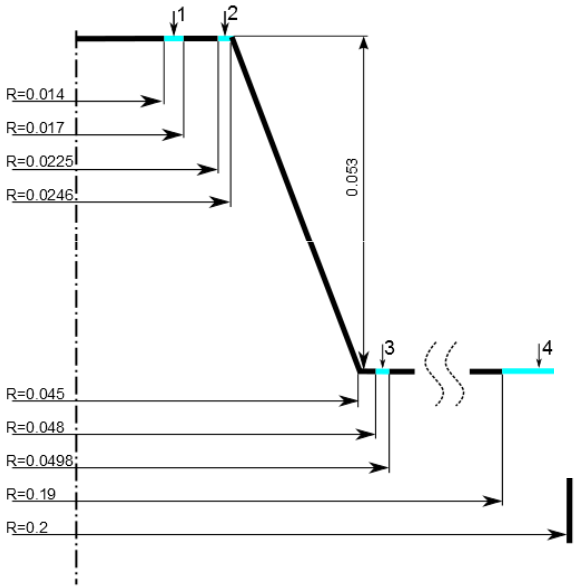
- Higher emissivity of tri-atomic gases – heat transfer by radiation

- In order to obtain adiabatic flame temperature similar to that for combustion in air, the proportion of oxygen should be about 30%

Scheme of the oxy-fuel test facility of Toporov et al.



Toporov D., Bocian P., Heil P., Kellermann A., Stadler H., Tschunko S., Foerster M., Kneer R. Detailed investigation of a pulverized fuel swirl flame in CO_2/O_2 atmosphere. Combustion and Flame, vol. 155 (2008) pp. 605-618.



Coal analysis

Proximate analysis [%]				Ultimate analysis [%]				
FC	Volatiles	Ash	Moisture	C	H	O	N	S
40.9	46.6	4.1	8.4	67.4	4.24	14.7	0.86	0.3

Test facility operating parameters

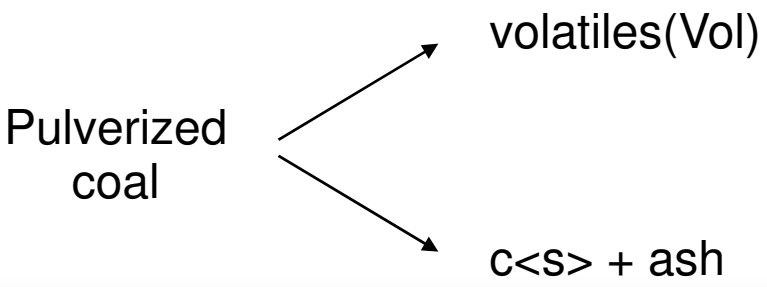
	Flow rate [kg/h]	O2 [% vol.]	CO2 [% vol.]	Temperature [K]
Coal	6.5	-	-	313
Primary stream (inlet 1)	17.6	19	81	313
Secondary stream (inlet 2)	26.6	21	79	333
Tertiary stream (inlet 3)	1.5	21	79	333
Staging stream (inlet 4)	54.9	21	79	1173
Burner temperature	-	-	-	573
Wall temperature	-	-	-	1273

- ANSYS Fluent 14
- Geometry: 2D/3D
- Turbulence modeling: RANS/LES
- Two-phase-Euler-Lagrange (DPM)
- combustion model:
  -Finite-Rate/Eddy-Dissipation
- devolatilization model:
  - Single Kinetic Rate Model
- Char combustion model:
  - Multiple Char Reactions
- Radiation model:
  - Discrete Ordinates

Chemical reactions

1. $C_xH_yO_zN_mS_n + (x/2 + n - z/2)\ O_2 \rightarrow x\ CO + y/2\ H_2 + n\ SO_2 + m/2\ N_2$
2. $CO + 0.5O_2 \rightarrow CO_2$
3. $H_2 + 0.5O_2 \rightarrow H_2O$
4. $C<s> + 0.5O_2 \rightarrow CO$
5. $C<s> + CO_2 \rightarrow 2CO$
6. $C<s> + H_2O \rightarrow CO + H_2$

Coal devolatilization

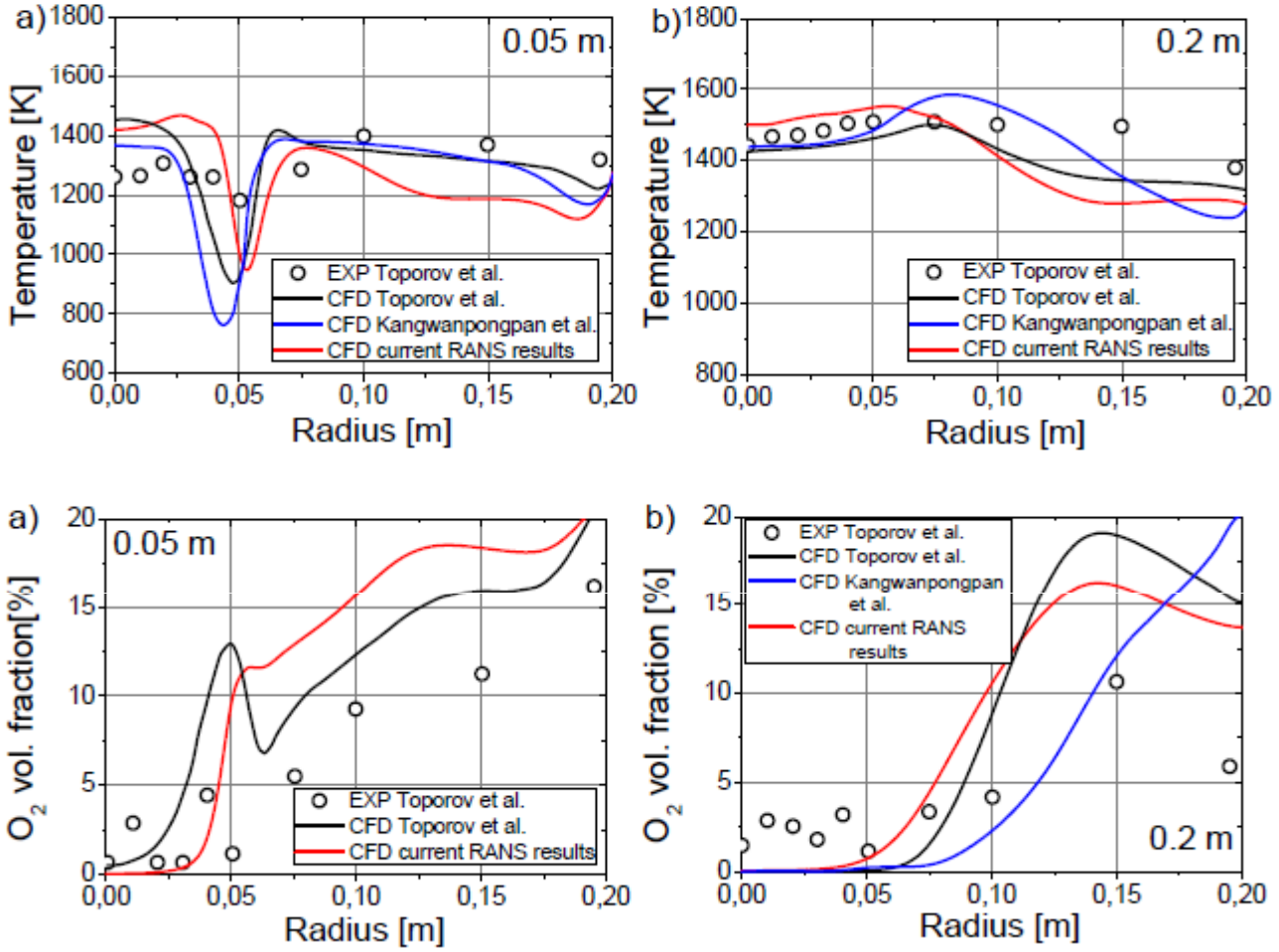


	Toporov et al.. (2008)	Kangwanpongpan et al. (2012)
CFD code	Fluent 6.2	ANSYS Fluent 12
Turbulence model	k-epsilon model	RSM
geometry	3D (1/6 of chamber)	3D (1/6 of chamber)
Mesh	590800 nodes	100000 nodes
Devolatilization model	CPD	CPD
Combustion model	FR/ED	FR/ED

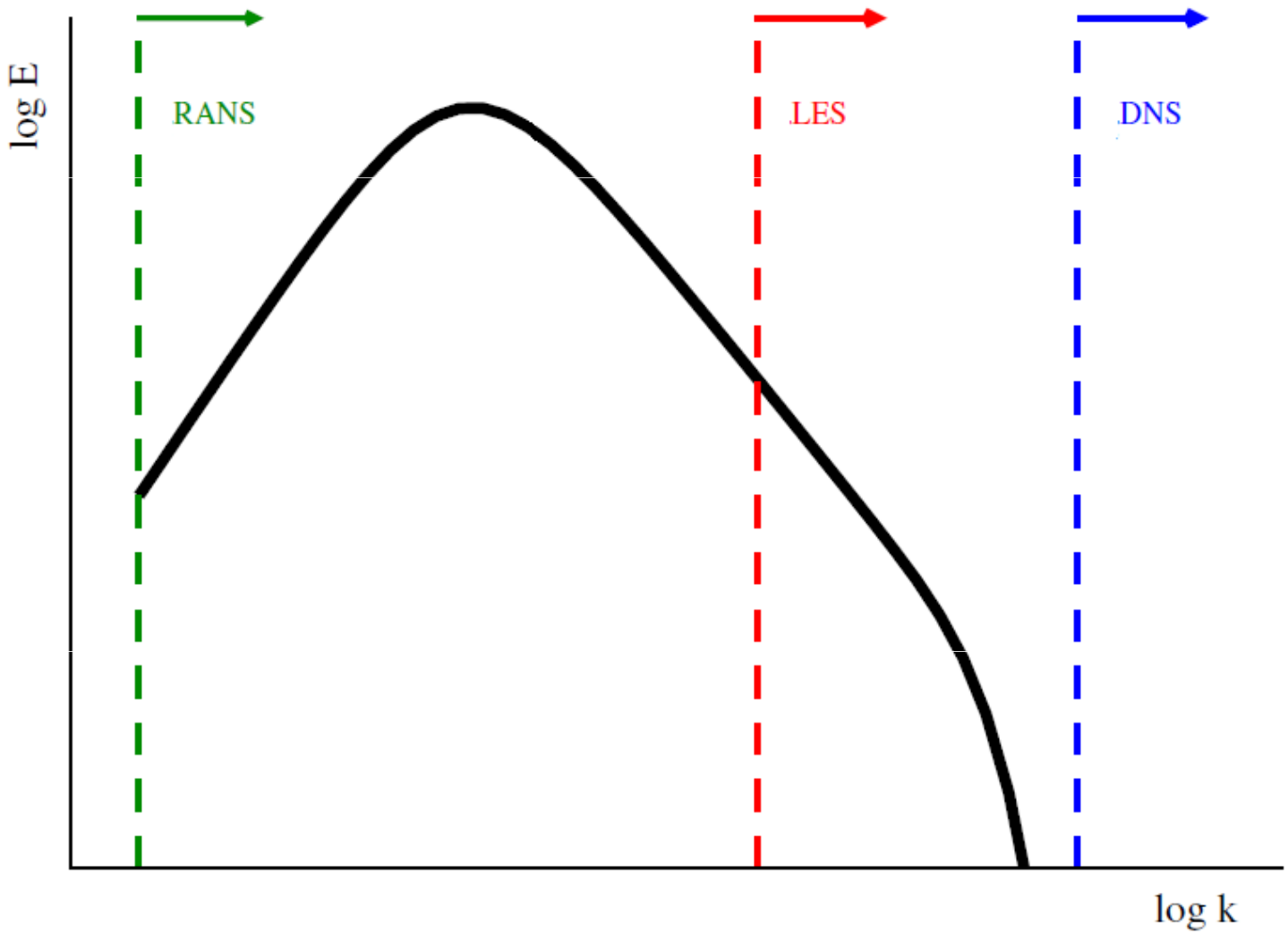
Toporov D., Bocian P., Heil P., Kellermann A., Stadler H., Tschunko S., Foerster M., Kneer R. Detailed investigation of a pulverized fuel swirl flame in CO_2/O_2 atmosphere. Combustion and Flame, vol. 155 (2008) pp. 605-618.

T. Kangwanpongpan, R. C. da Silva, H. J. Krautz, Prediction of oxy-coal combustion through an optimized weighted sum of gray gases model, Energy 41 (1) (2012) 244 - 251.

Temperature and oxygen volume fraction profiles



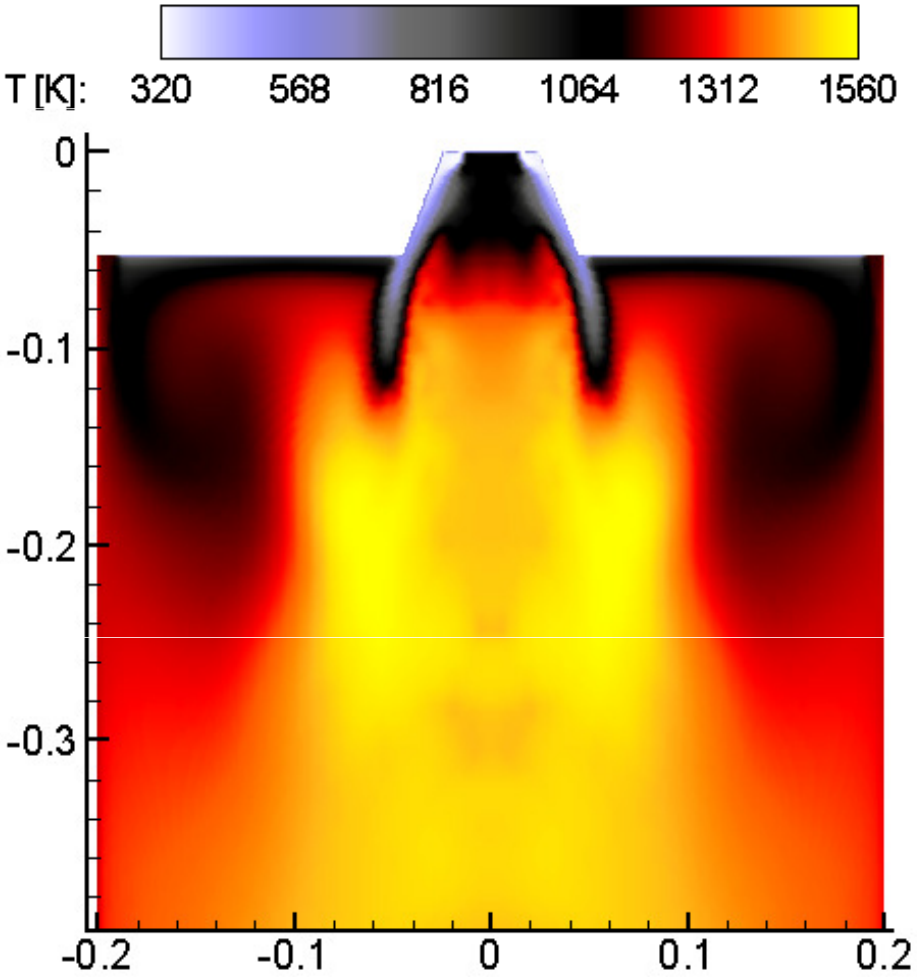
RANS, LES and DNS



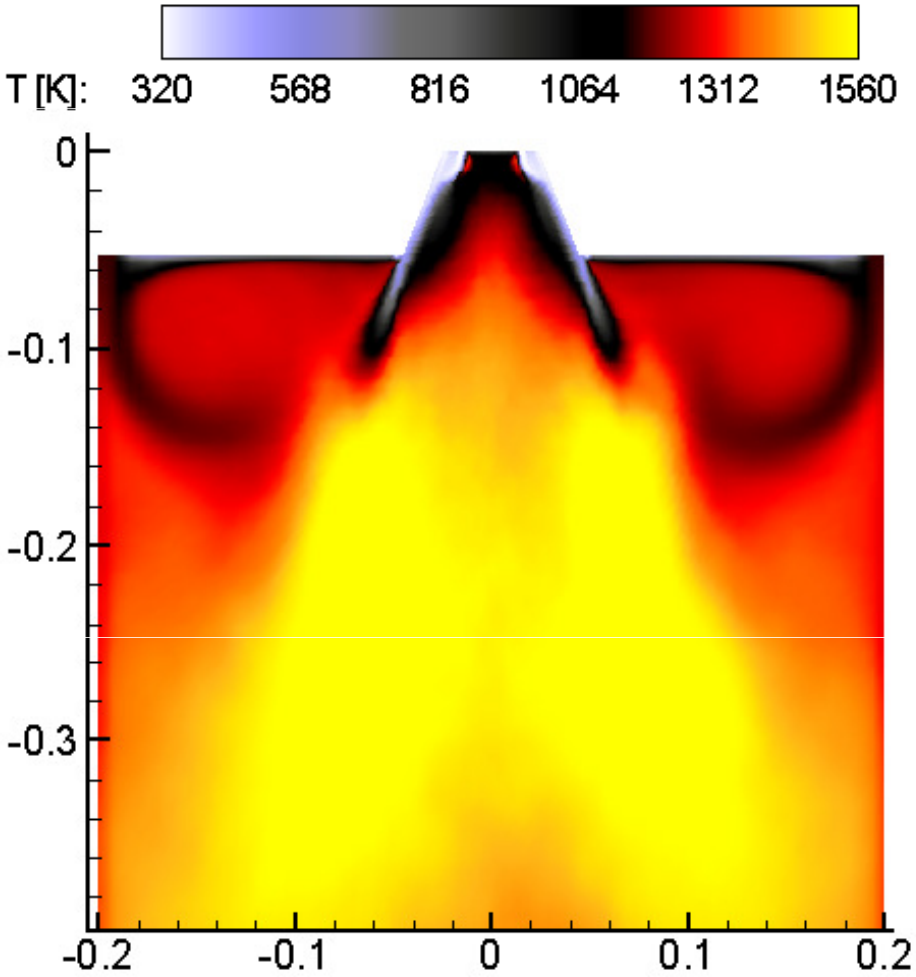
J. Froehlich, D. von Terzi: Hybrid LES/RANS Methods for the Simulation of Turbulent Flows. Progress in Aerospace Science, vol. 44 (2008) pp. 349-377

Mean temperature distributions :

RANS

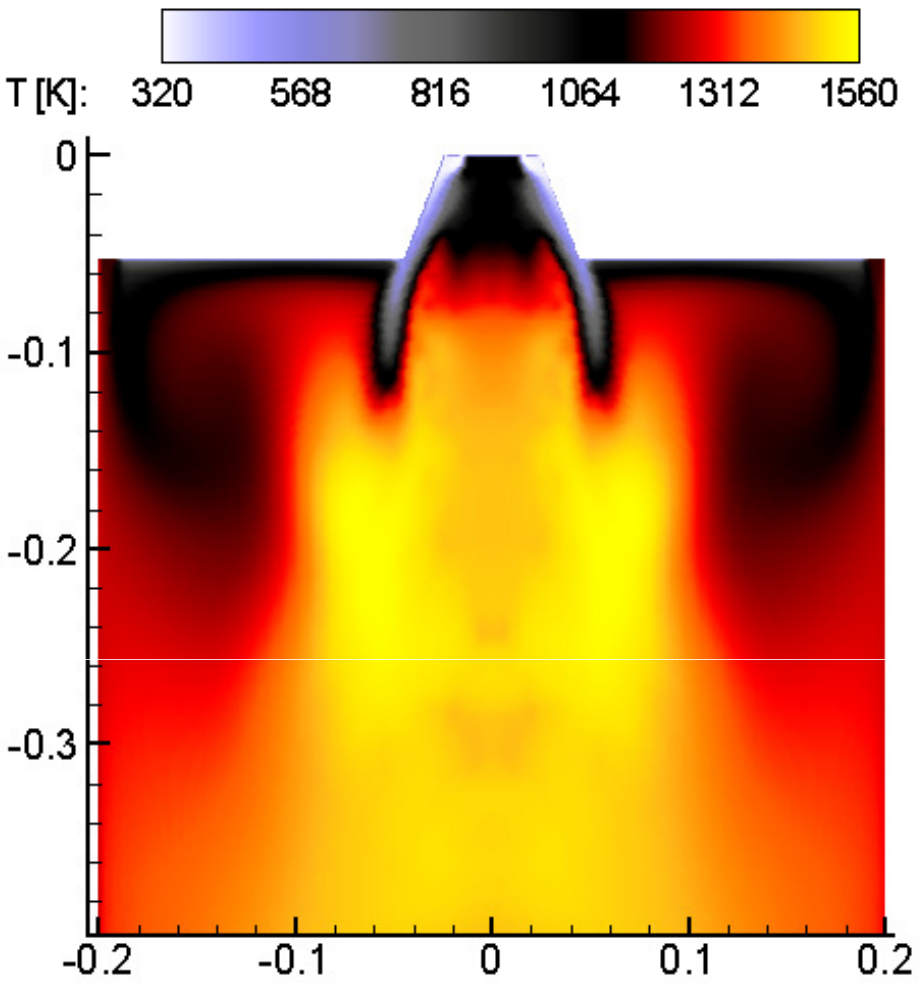


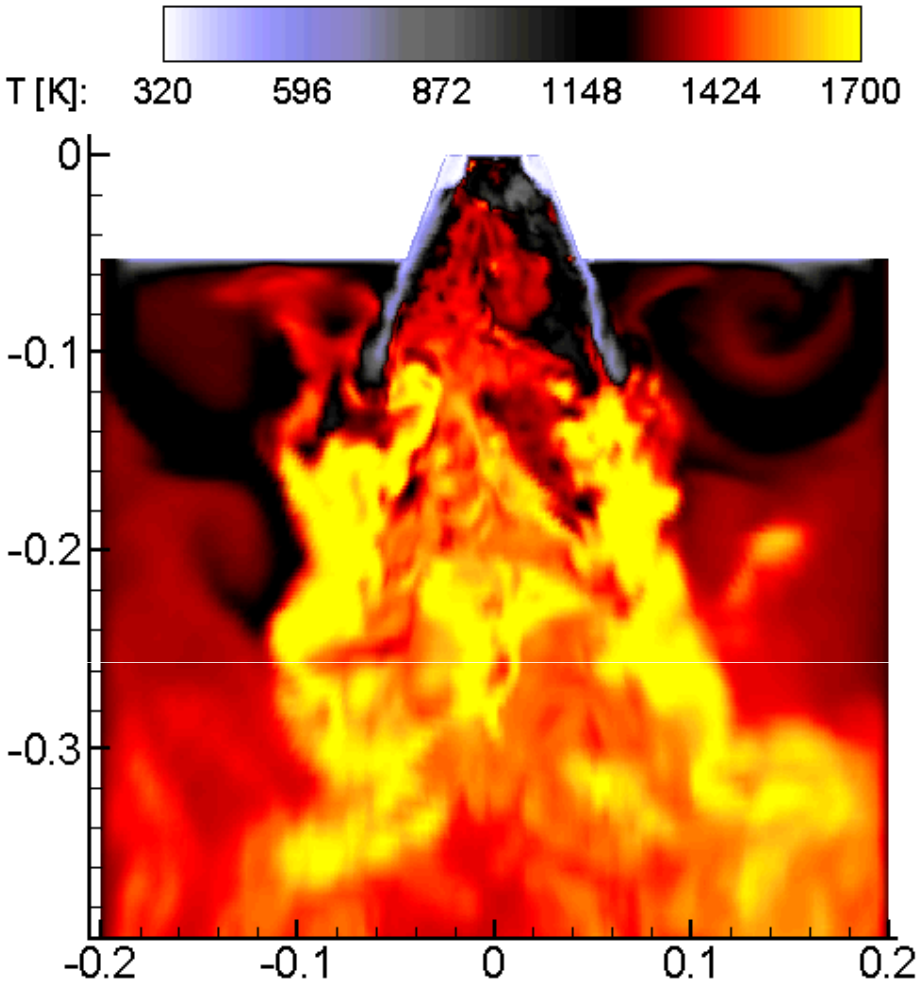
LES



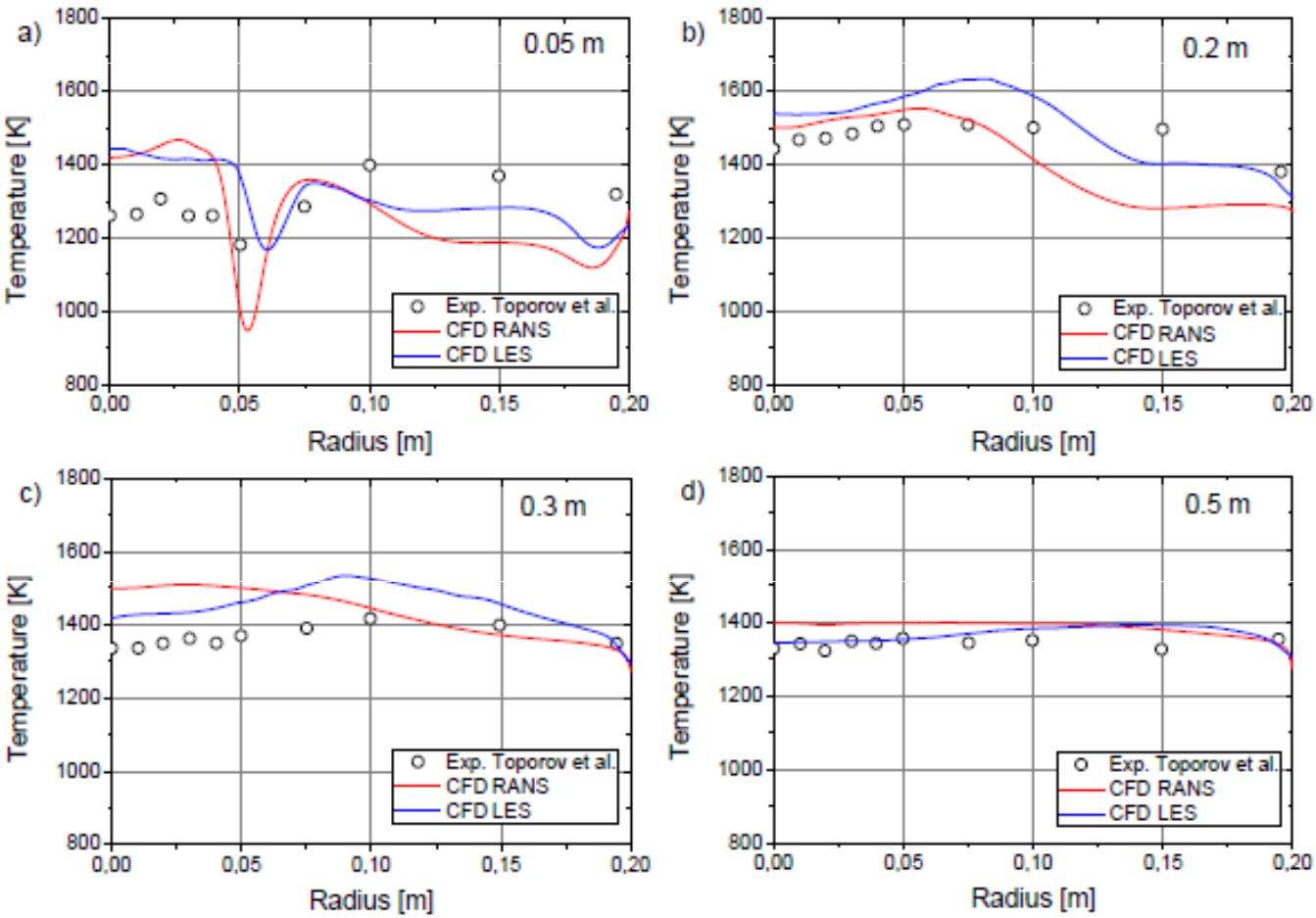
RANS: mean temperature

LES: instantaneous temperature field





Temperature profiles – RANS vs. LES



Combustion of pulverized coal in various O_2/CO_2 atmospheres

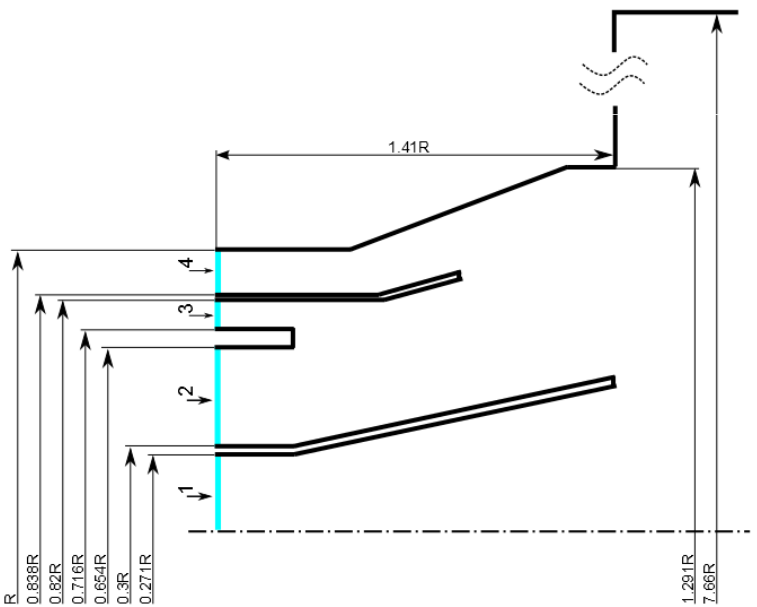


Table 1
Coal analysis.

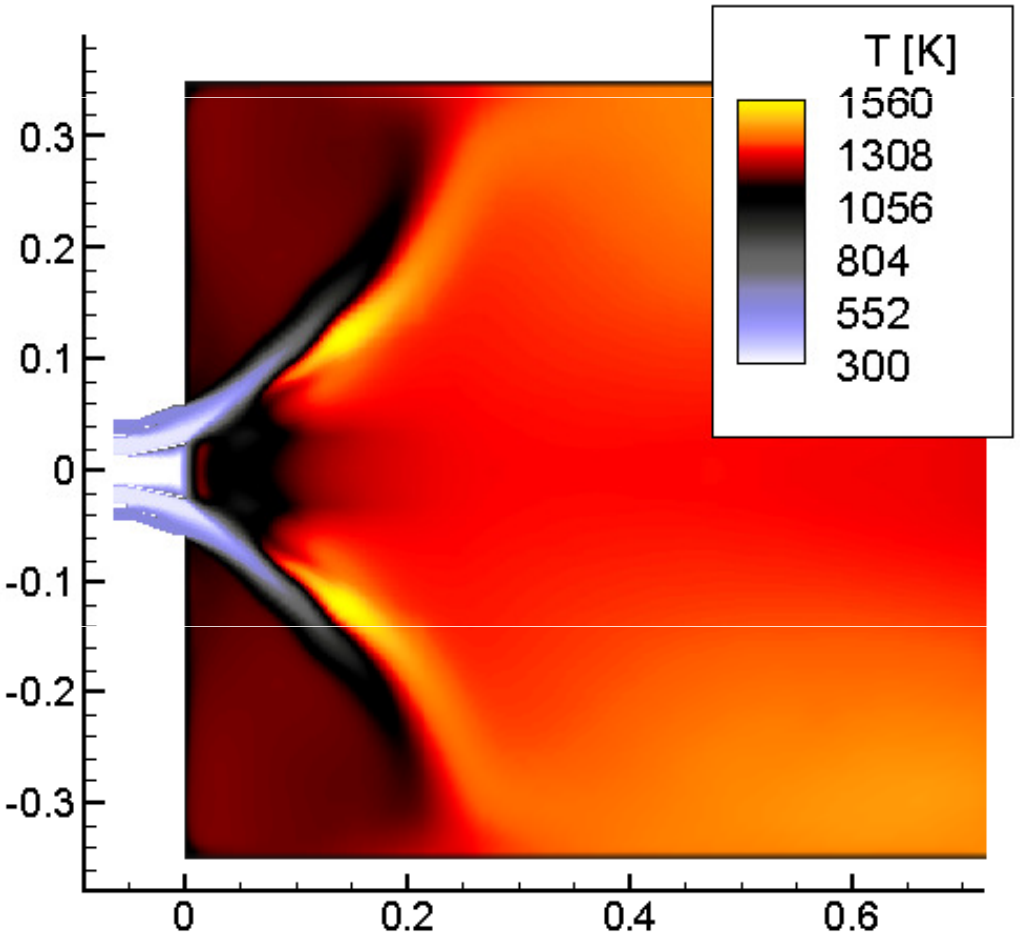
Proximate analysis [%]				Ultimate analysis [%]				
FC	Volatiles	Ash	Moisture	C	H	O	N	S
49.3	30.7	13.0	7.0	64.15	4.73	8.68	1.06	1.38

Table 2
Test facility operating parameters.

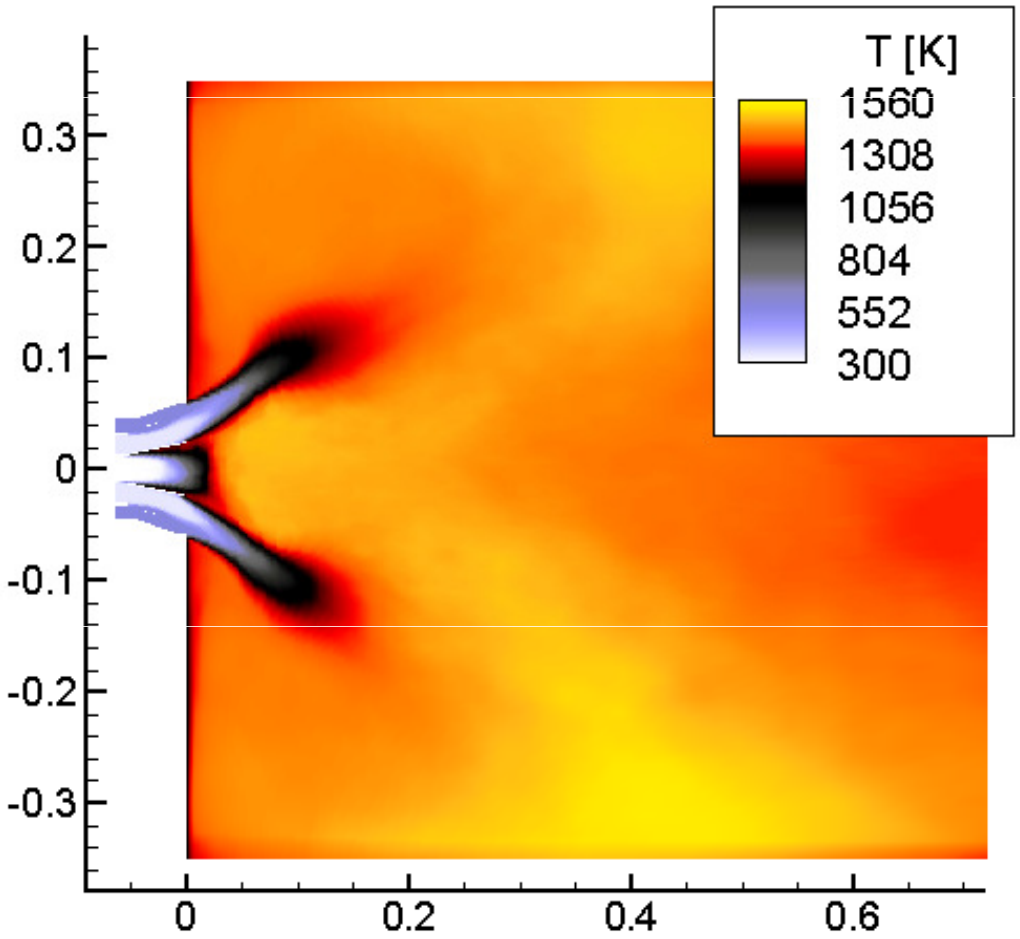
Parameter	Value
Temperature of the combustion chamber	1023 [K]
Mass flow rate of the core stream (inlet 1)	4.55 [kg/h]
Temperature of the core stream (inlet 1)	293 [K]
Mass flow rate of the primary stream (inlet 2)	120.6 [kg/h]
Temperature of the primary stream (inlet 2)	338 [K]
Mass flow rate of the secondary stream (inlet 3)	76.55 [kg/h]
Temperature of the secondary stream (inlet 3)	563 [K]
Mass flow rate of the secondary stream (inlet 4)	141.2 [kg/h]
Temperature of the secondary stream (inlet 4)	563 [K]
Fuel mass flow rate (inlet 2)	36 [kg/h]

Reference test case – combustion in air

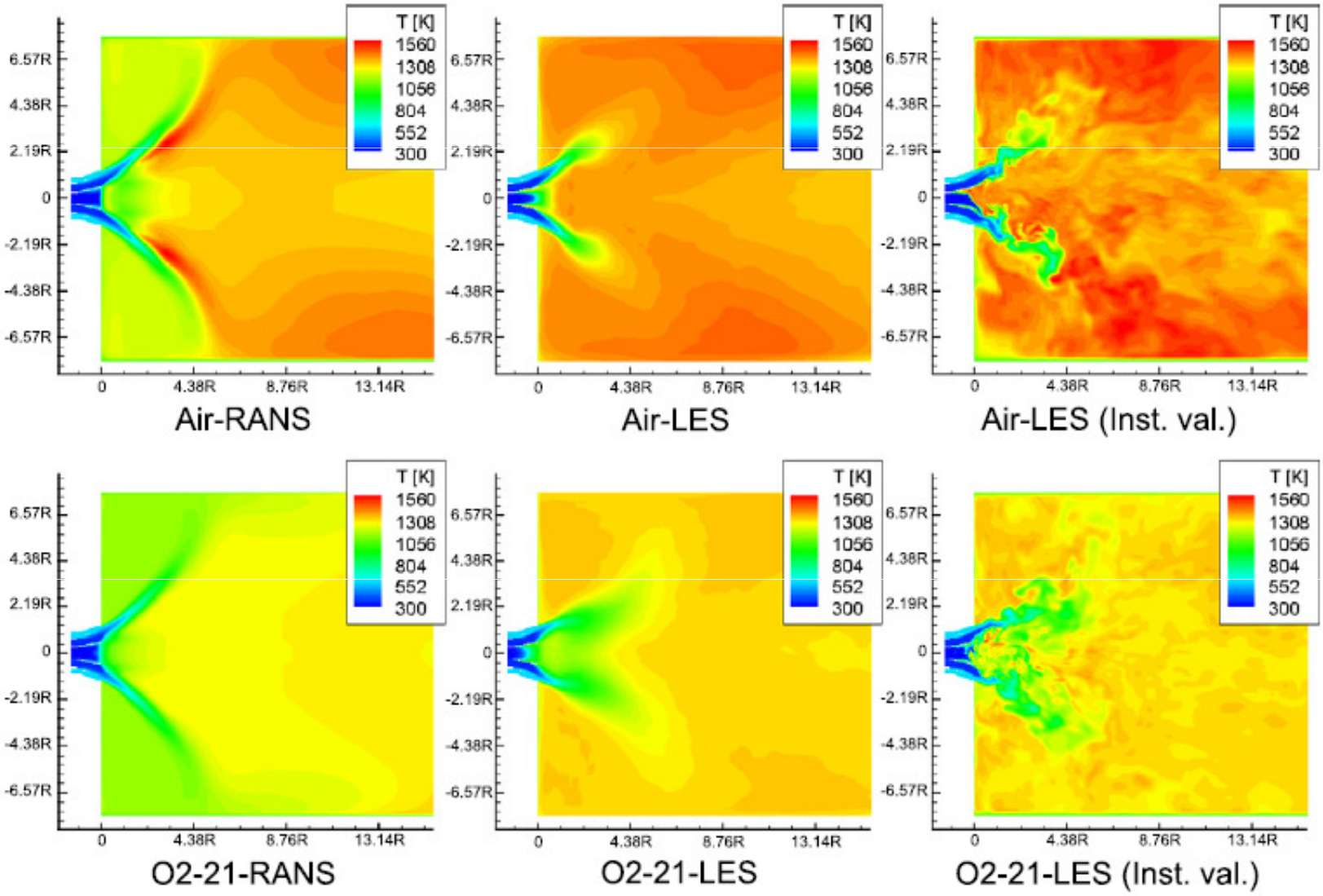
RANS



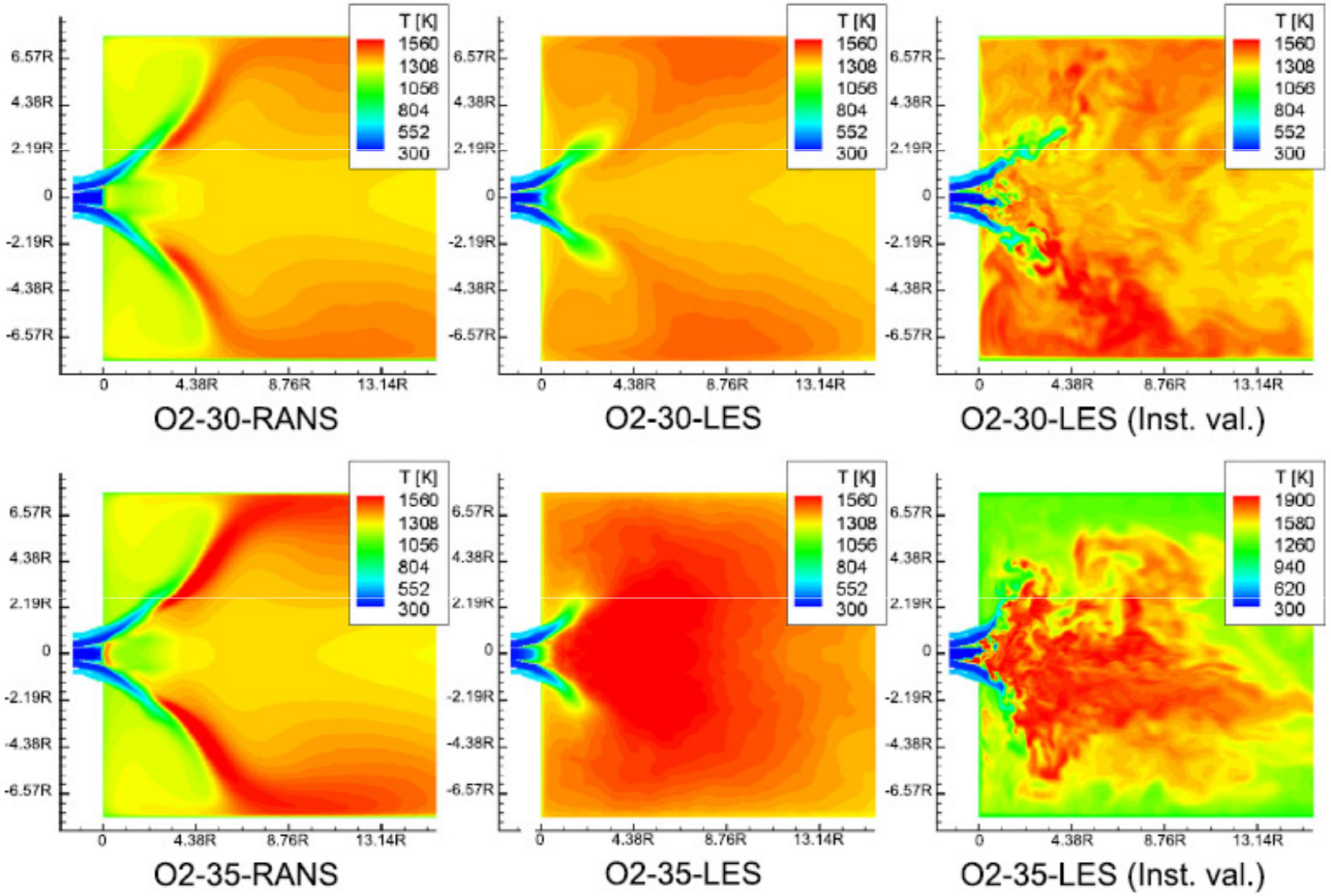
LES



Contour plots of temperature for RANS and LES methods for air and O_2 -21%

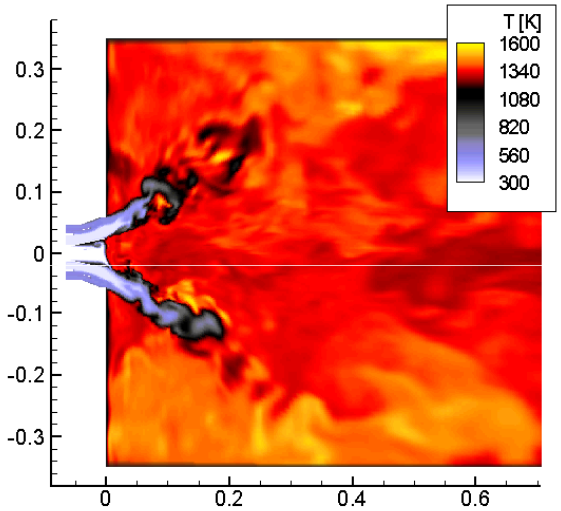


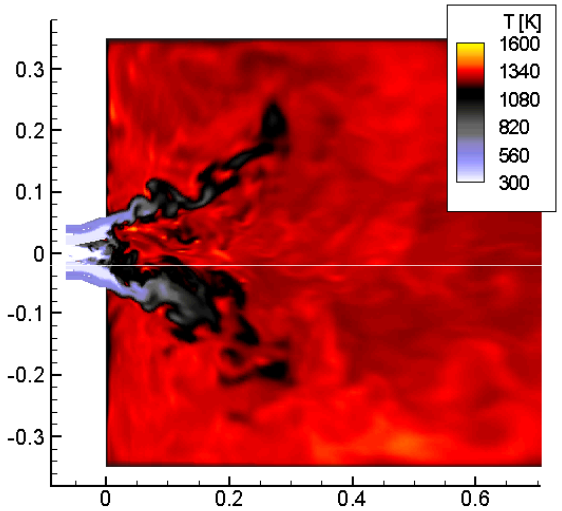
Contour plots of temperature for RANS and LES methods for O_2 -30% and O_2 -35%



Combustion of pulverized coal in various O_2/CO_2 atmospheres

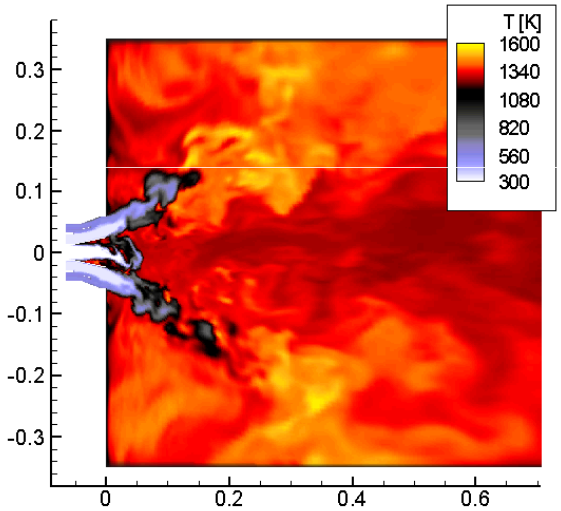
air

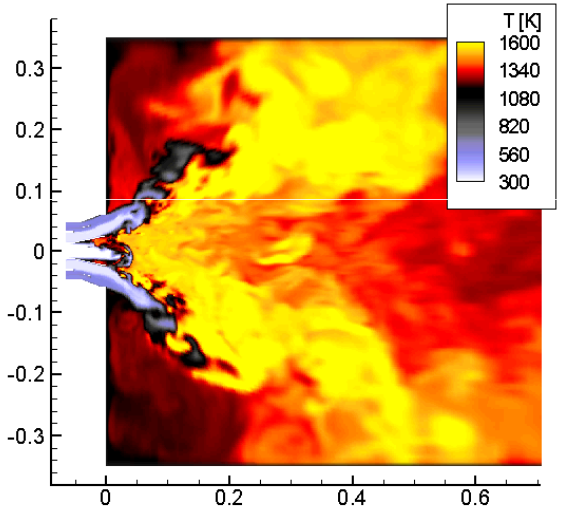




O_2=21%
CO_2=79%

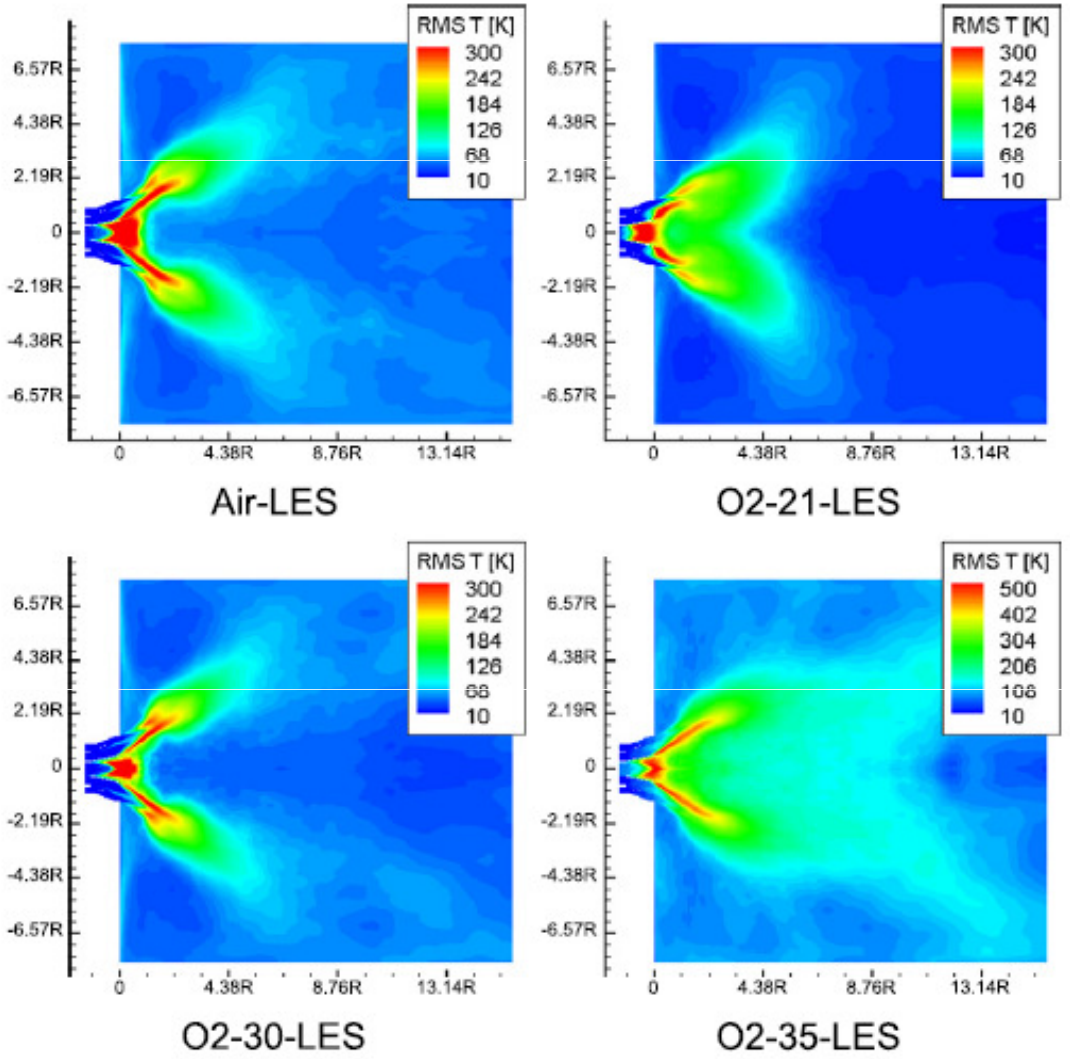
O_2=30%
CO_2=70%



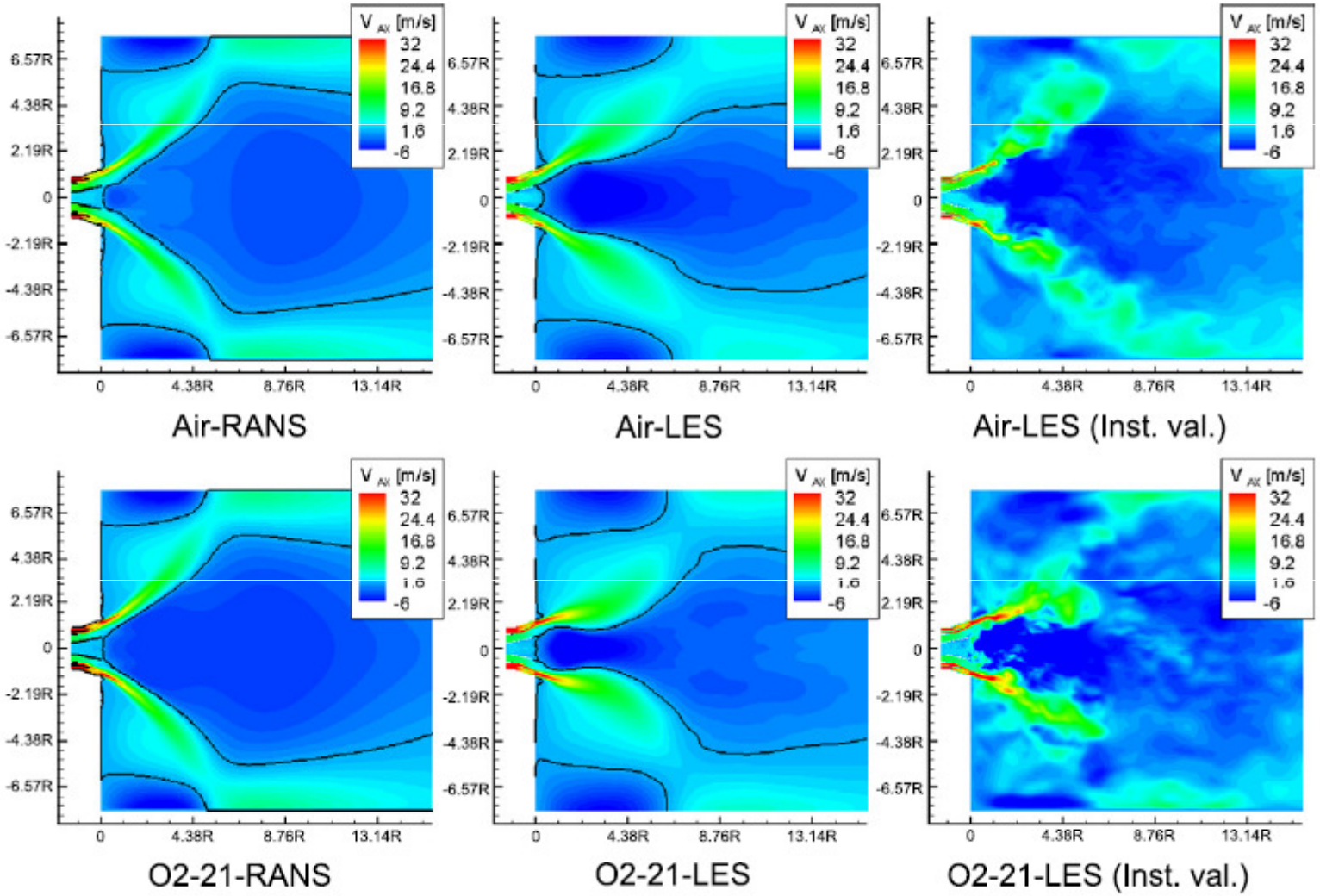


O_2=35%
CO_2=65%

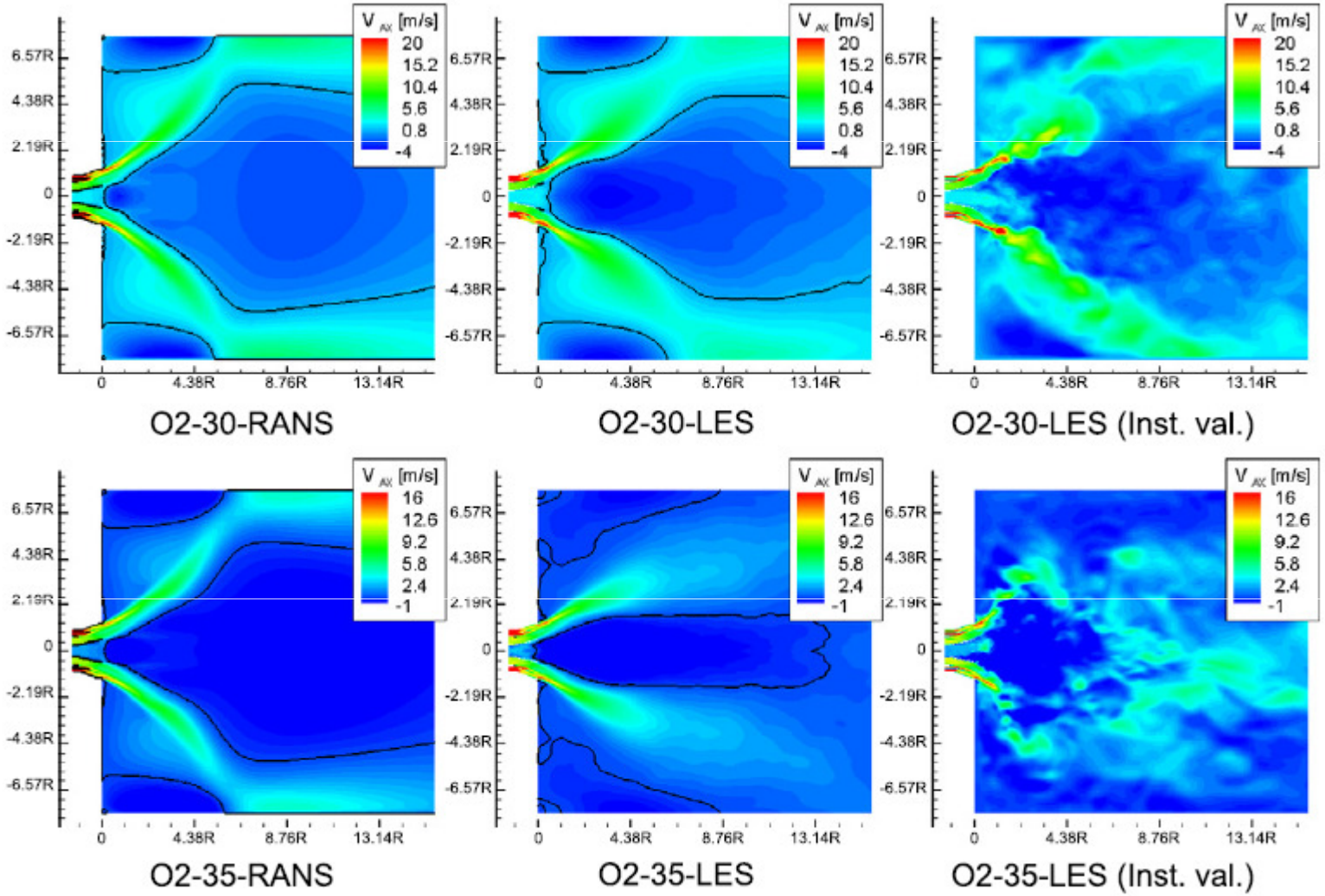
Contour plots of RMS of temperature for LES method for four analyzed test cases.



Contour plots of axial velocity for air and O_2 -21%



Contour plots of axial velocity for O_2 -30% and O_2 -35% .



Concluding remarks

- The results of the oxy-combustion process of pulverized coal were shown for swirl burners using RANS and LES methods for turbulent flow
- Comparisons of the results obtained from the two methods show differences in velocity and temperature fields inside the combustion chamber,
- In the case of RANS simulations a separation of the combustion chamber into two temperature zones can be observed. Such a behavior is not observed in the case of numerical simulations using LES method, where the temperature is more uniformly distributed inside the combustion chamber
- Nevertheless both methods show that in order to represent the conventional combustion in air, one should use the oxidizer that contains about 30% of oxygen with respect to carbon dioxide,
- For lower or higher oxygen concentration in the oxidizer one gets lower or higher temperature values inside the combustion chamber.,
- Additionally, the research performed with the use of numerical methods pointed out problems that can occur during the adaptation of the existing, conventional systems to burn pulverized coal in oxy-combustion technology

References:

1. Warzecha P., Bogusławski A., Simulations of Pulverized Coal Oxy-combustion in Swirl Burner Using RANS and LES Methods, Fuel Processing Technology, Vol. 119, pp. 130-135, 2014, **IF: 3.493**
2. Warzecha P., Bogusławski A., LES and RANS Modeling of Pulverized Coal Combustion in Swirl Burner for Air and Oxy-combustion Technologies, Energy, vol.66, pp. 732-743, 2014, **IF: 4.107**