ONE-DIMENSIONAL MODEL OF HEAT-RECOVERY, NON-RECOVERY COKE OVENS

NUMERICAL MODELING OF THE COKING PROCESS FOR THE UHDE HR/NR - COKE OVEN DESIGNs

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Horizontal Chamber (HC-CO)

Heat Recovery (HR-CO)

Vertical Chamber (VC-CO)

Feedstock:

Horizontal Chamber (HC-CO)	Heat Recovery (HR-CO)	Vertical Chamber (VC-CO)
• Hard coking coal blends incl.: – high-volatile (gas) coals – lean coals – petrol coke & "coal": ~22% < VM (d. b.) < ~28%	• Hard coking coal blends incl.: – lean coals, anthracite ~ 20% < VM (d. b.) < ~ 26% • Petrol coking "coal" (PCC): 16% < VM (d. b.) < 20%	• Lignite (brown) coals: – ash ≤ 7% (d. b.) – sulfur ≤ 1% (d. b.) • Low-grade/-baking hard coals <22% < VM (d. b.) > ~28%

Product spectrum:

Horizontal Chamber (HC-CO)	Heat Recovery (HR-CO)	Vertical Chamber (VC-CO)
• Blast furnace/foundry coke • Sulfur, sulfuric acid • Ammonia, ammonium bicarbonate • Benzene, tar	• Blast furnace/foundry coke • Steam • Electricity • Gypsum	• Lignite coke for COREX/FINEX direct reduction of iron • Blast furnace coke • Synthetic natural gas • Methanol, dimethyl ether

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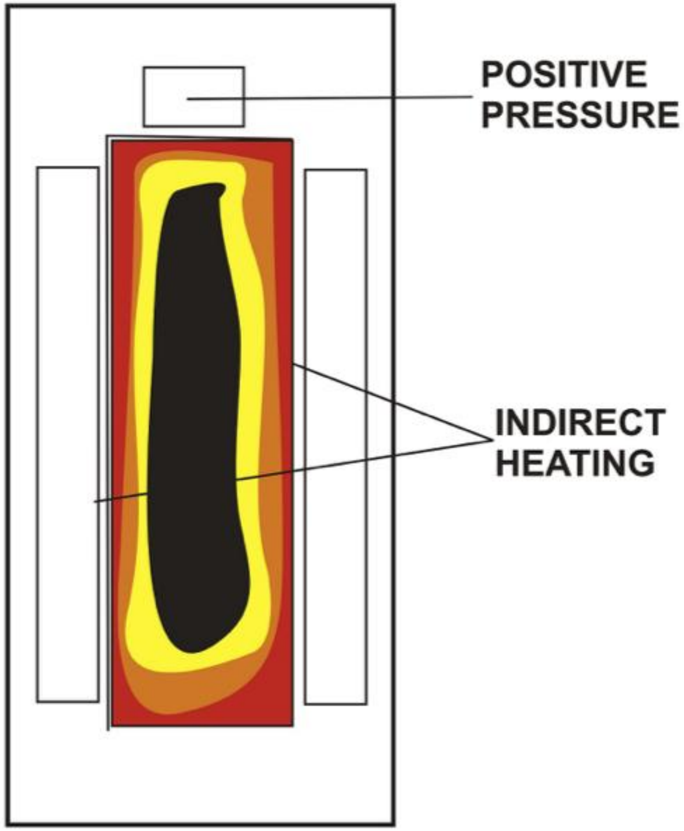
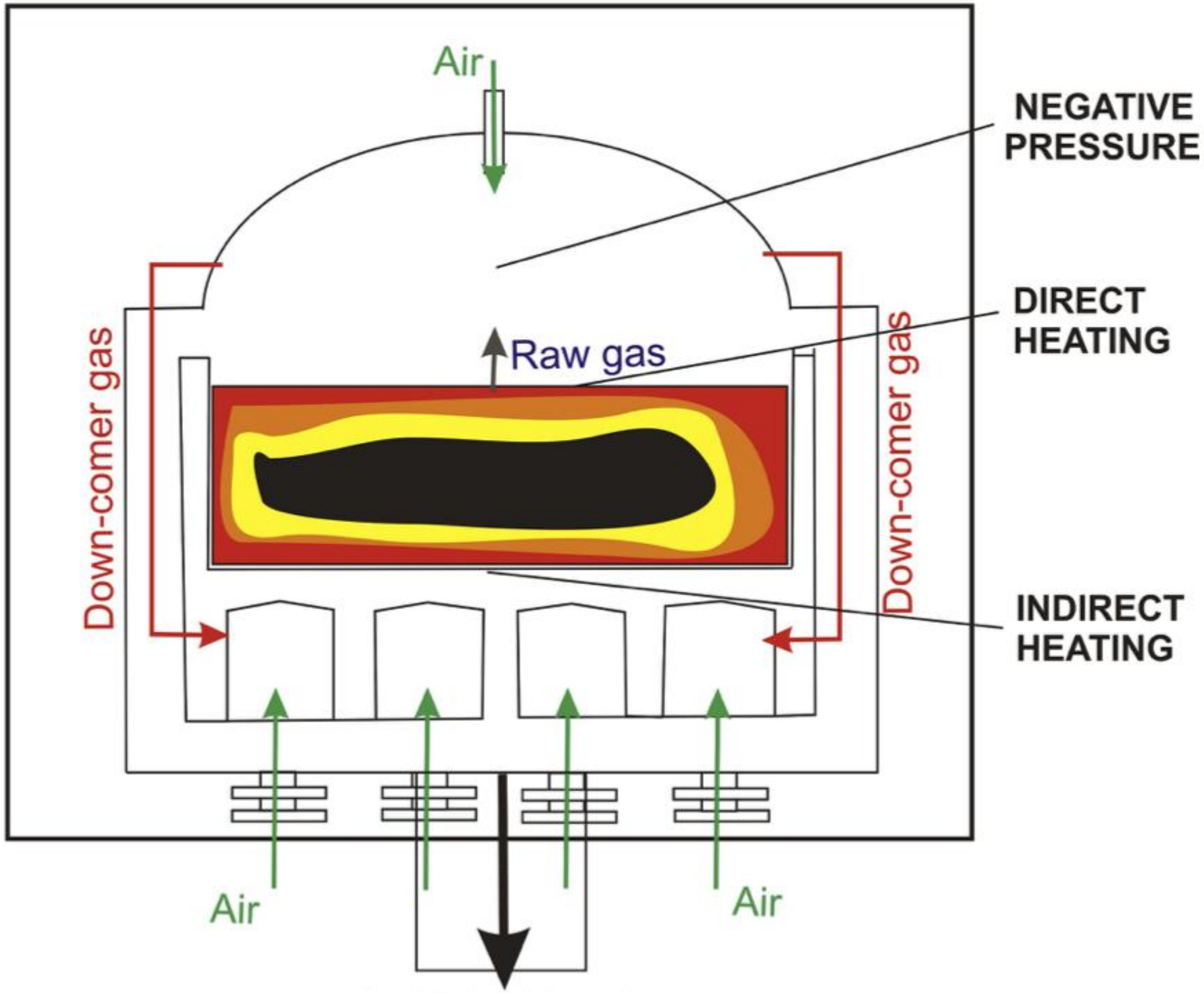
SLOT-TYPE COKE OVEN



NON/ HEAT-RECOVERY COKE OVEN



GOALS

1. to carry out numerical calculations of the combustion process inside the HR/NR - coke-oven sole-flue,
2. to improve the sole-flue design with the three specific aspects:

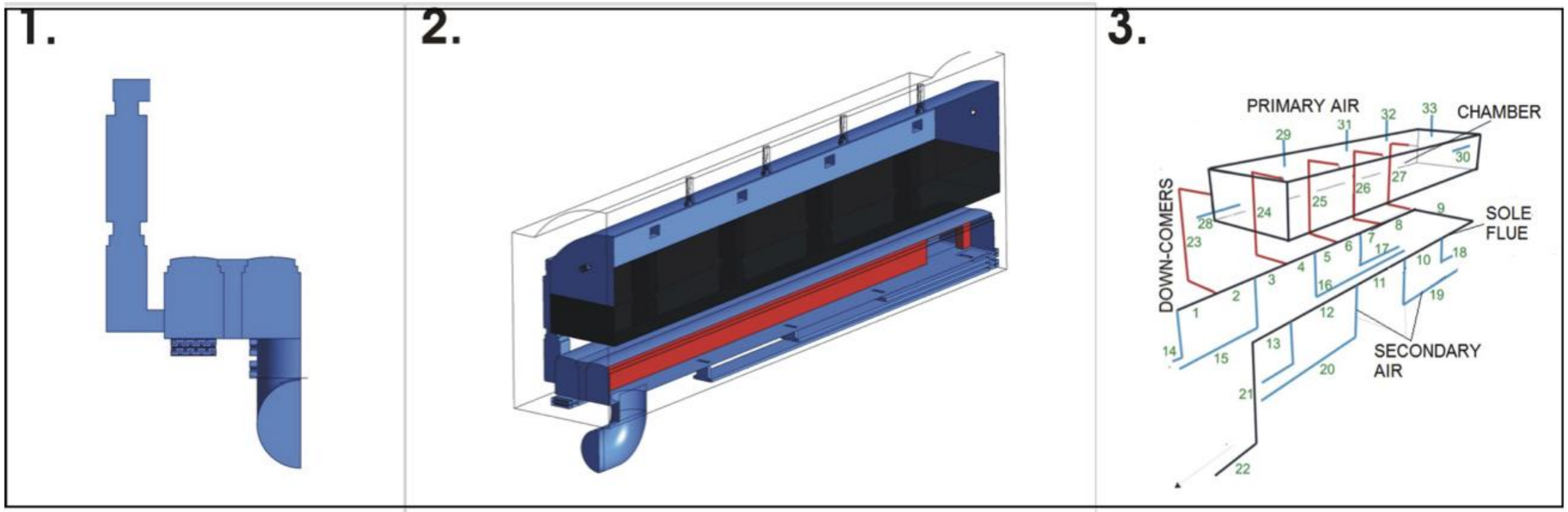
ASPECTS

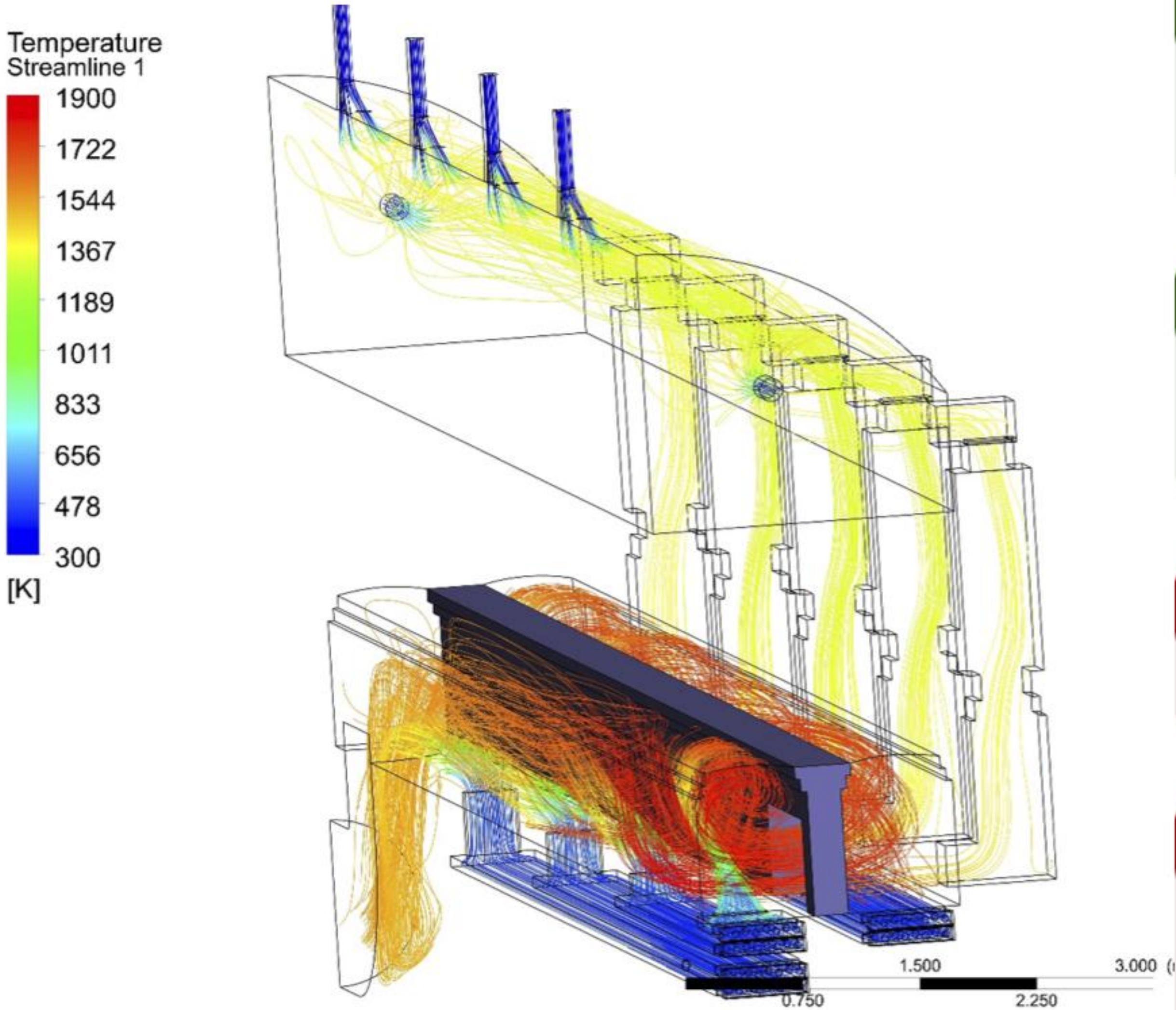
1. **Safety goal**
   - sole-flue ceiling temperature should be lower than $1500^{o}C$,
2. **Optimization goal**
   - the heat transferred through the ceiling to the upper oven should be uniform over the whole ceiling,
3. **Simplicity goal**
   - proposed modifications of the sole-flue design should be easy to implement, and should not impede the operation of the unit.

STRATEGY OF THE ANALYSIS

In order to find out the best design solutions a three mathematical models have been developed:

1. 3D CFD- based model - sole-flue only,
2. 3D CFD- based model - a half of the oven,
3. One-dimensional model of heat-recovery, non-recovery coke oven.





ADVANTAGE OF CFD

useful to understand processes inside the oven

ADVANTAGE OF CFD

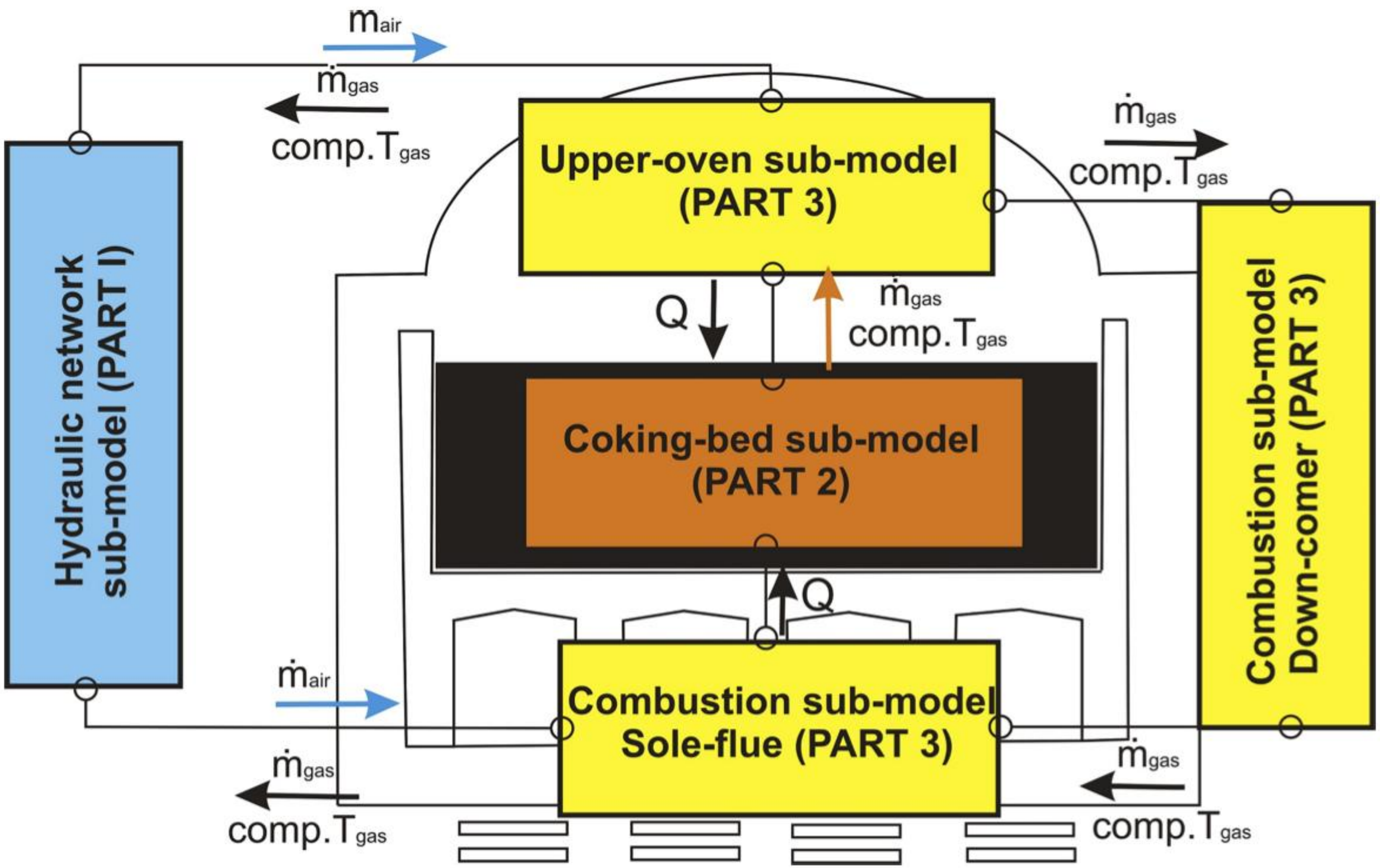
helpful when oven-design and construction are to be optimized

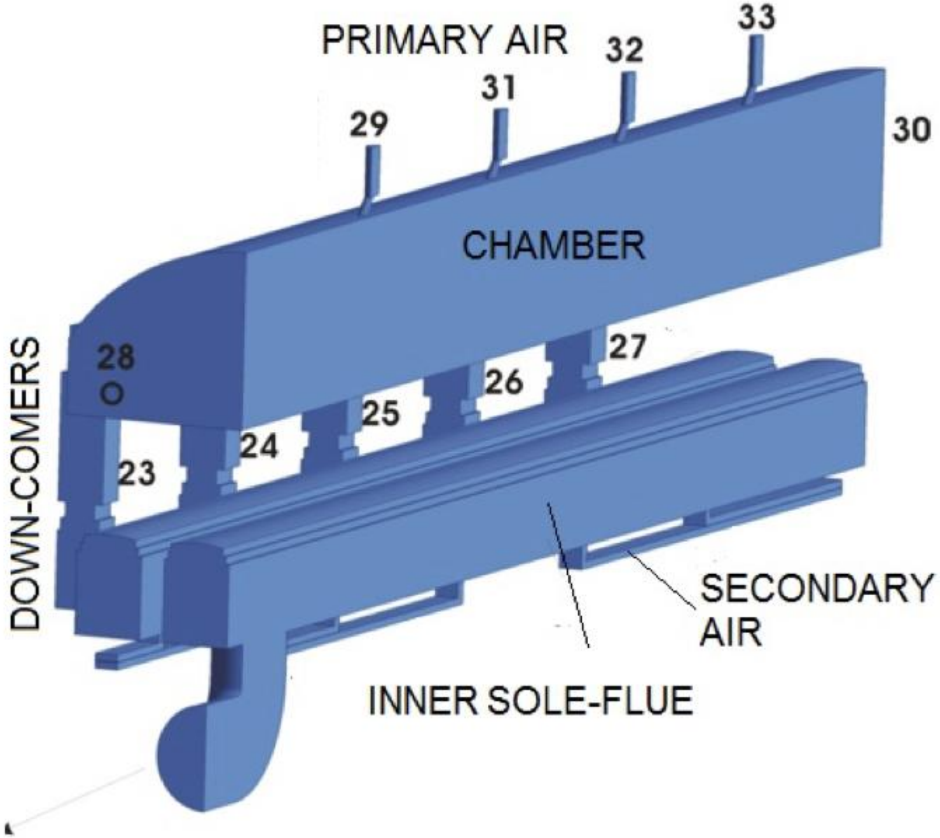
DISADVANTAGE OF CFD

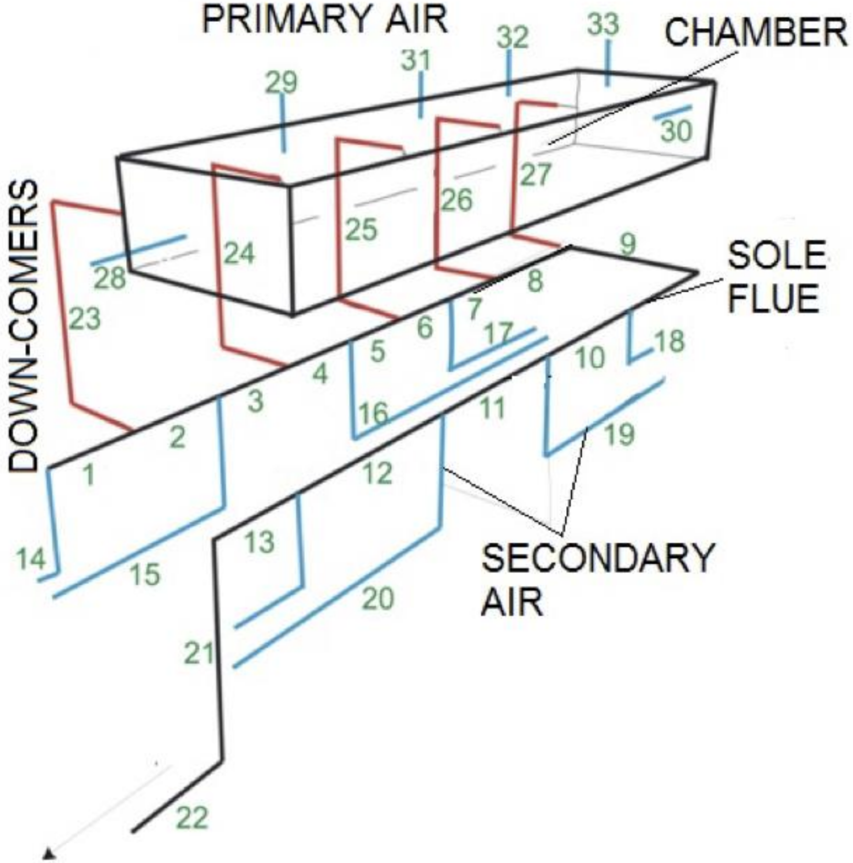
Long computation time

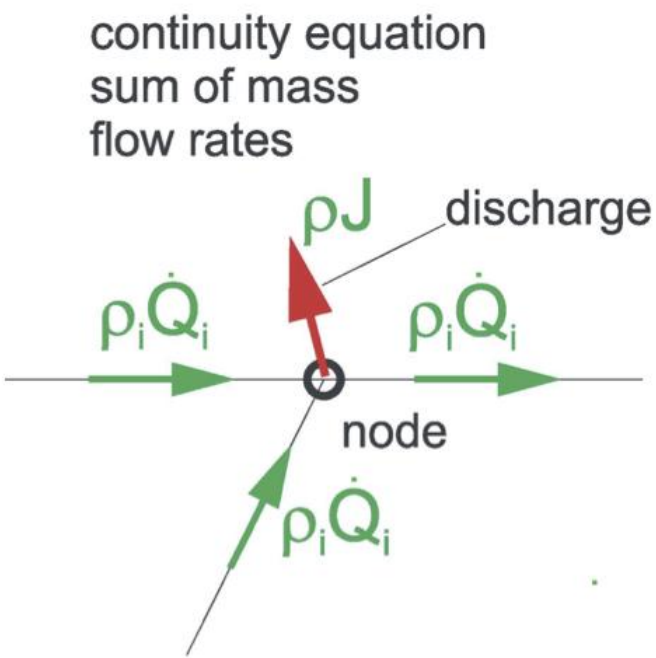
DISADVANTAGE OF CFD

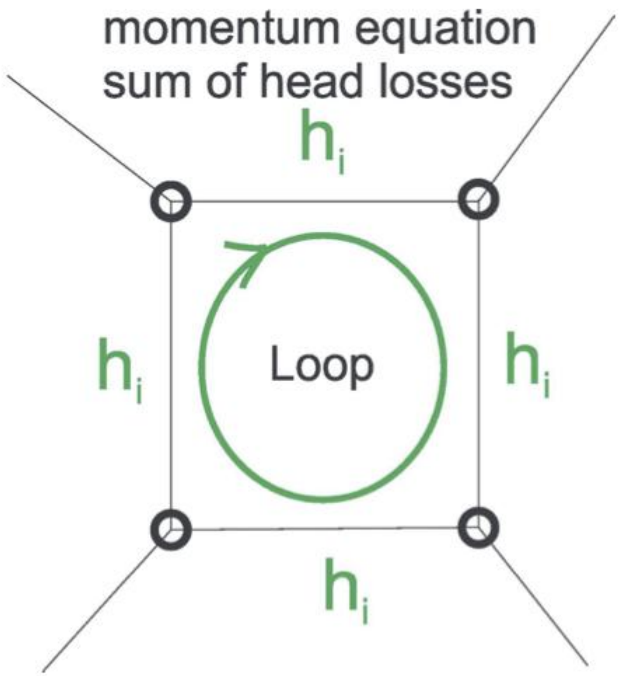
Transient calculations require super-computers !!!


$\dot{m}_{air}$
$\dot{m}_{gas}$
comp.T_{gas}
Upper-oven sub-model (PART 3)
$\dot{m}_{gas}$
comp.T_{gas}
Hydraulic network sub-model (PART I)
Q
$\dot{m}_{gas}$
comp.T_{gas}
Coking-bed sub-model (PART 2)
Q
Combustion sub-model Down-comer (PART 3)
$\dot{m}_{air}$
Combustion sub-model Sole-flue (PART 3)
$\dot{m}_{gas}$
comp.T_{gas}
$\dot{m}_{gas}$
comp.T_{gas}


PRIMARY AIR
29
31
32
33
30
CHAMBER
DOWN-COMERS
28
27
26
25
24
23
SECONDARY AIR
INNER SOLE-FLUE


PRIMARY AIR
29
31
32
33
CHAMBER
30
DOWN-COMERS
28
27
26
25
24
23
SOLE FLUE
9
8
7
6
5
4
3
2
1
17
18
10
11
16
19
12
13
14
15
20
21
22
SECONDARY AIR





The continuity equation: $\rho \dot{Q}_j - \sum \rho \dot{Q}_i = 0$

The momentum equation: $\sum h_{fi} = 0$, or $\sum h_{fi} = \triangle H$

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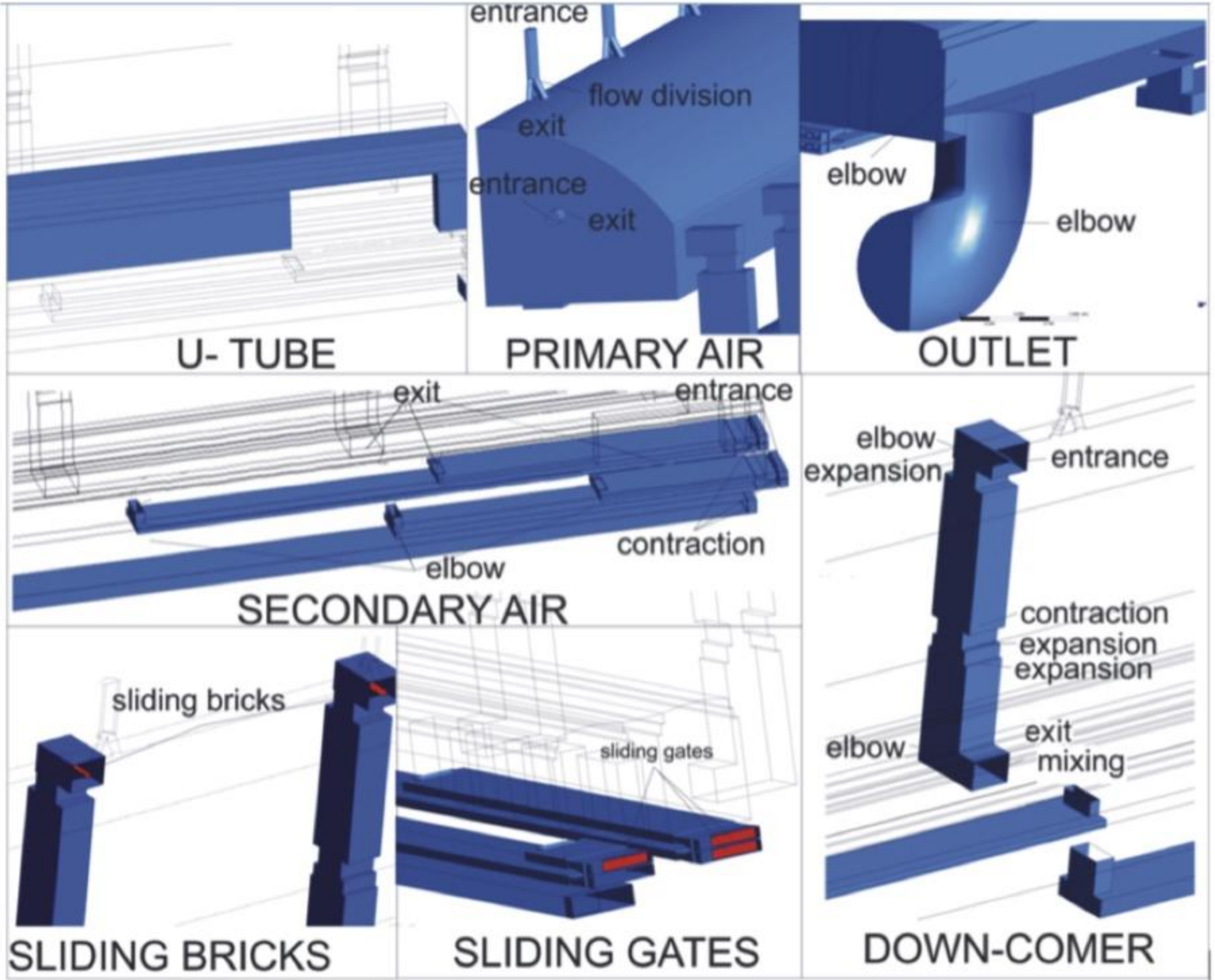
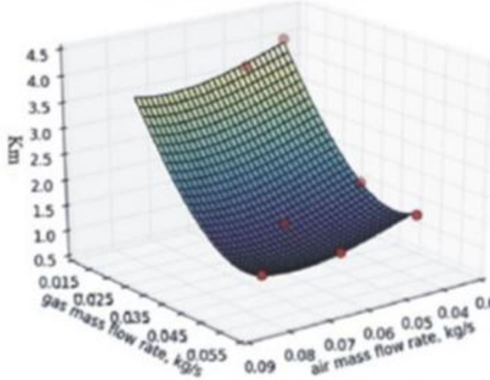
Minor loss coeffieicients due to obstacles

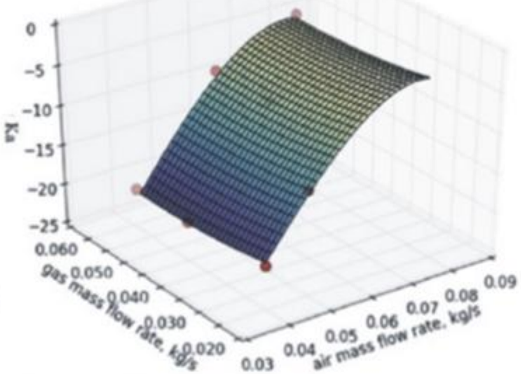


Minor loss coefficient due to mixing

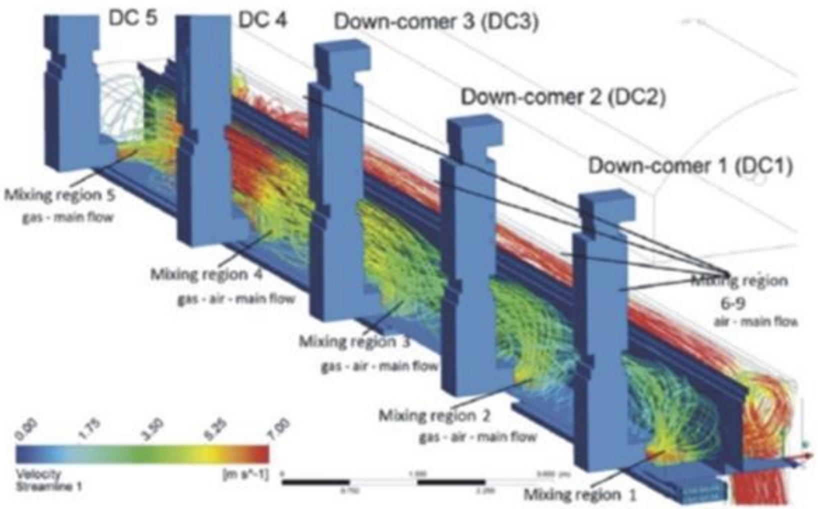
MAIN FLOW



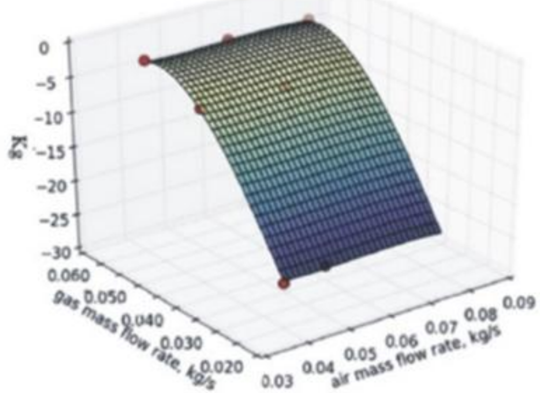
BRANCH FLOW - AIR

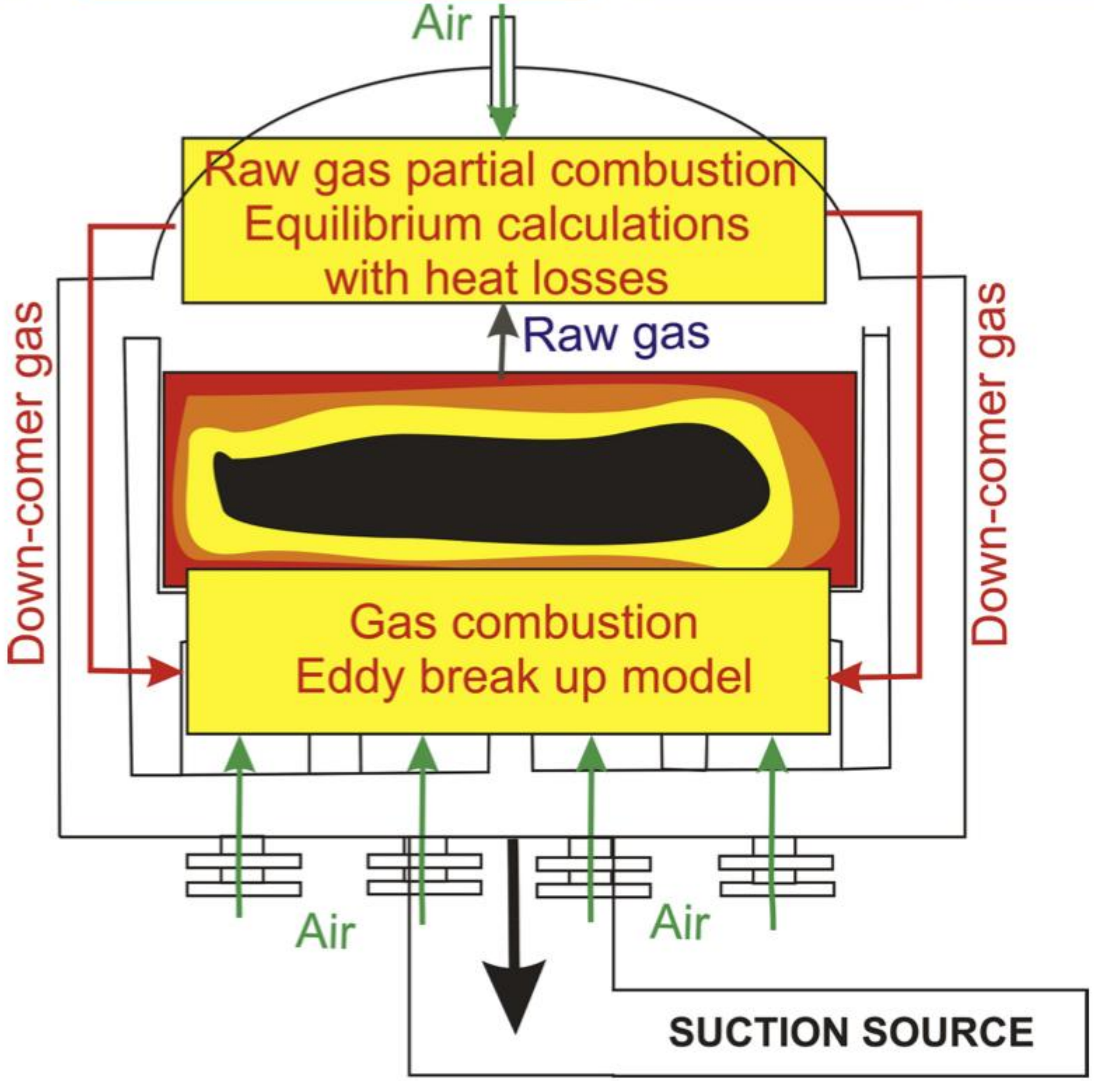


MIXING REGIONS IN THE SOLE-FLUE

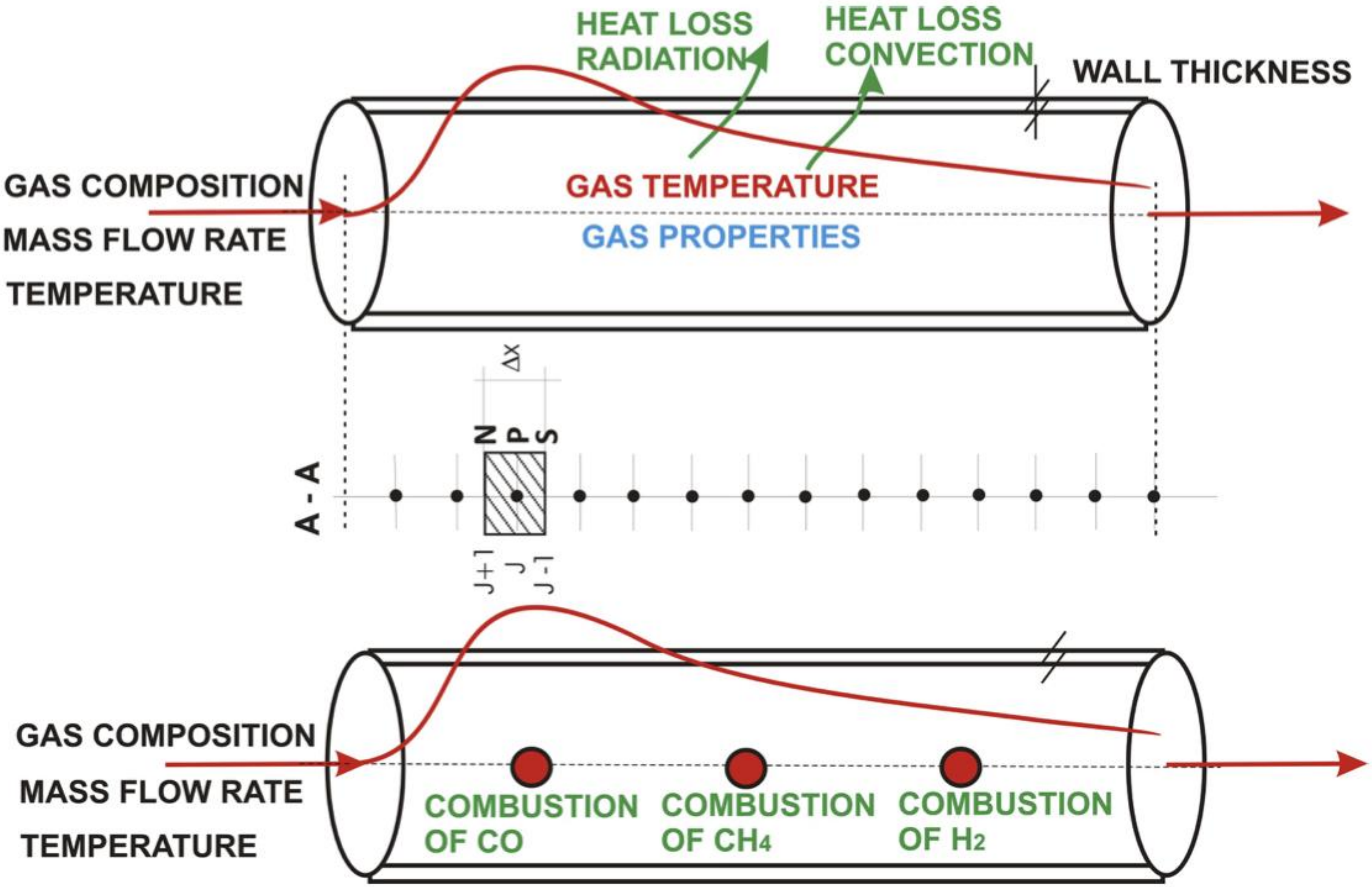


BRANCH FLOW - GAS

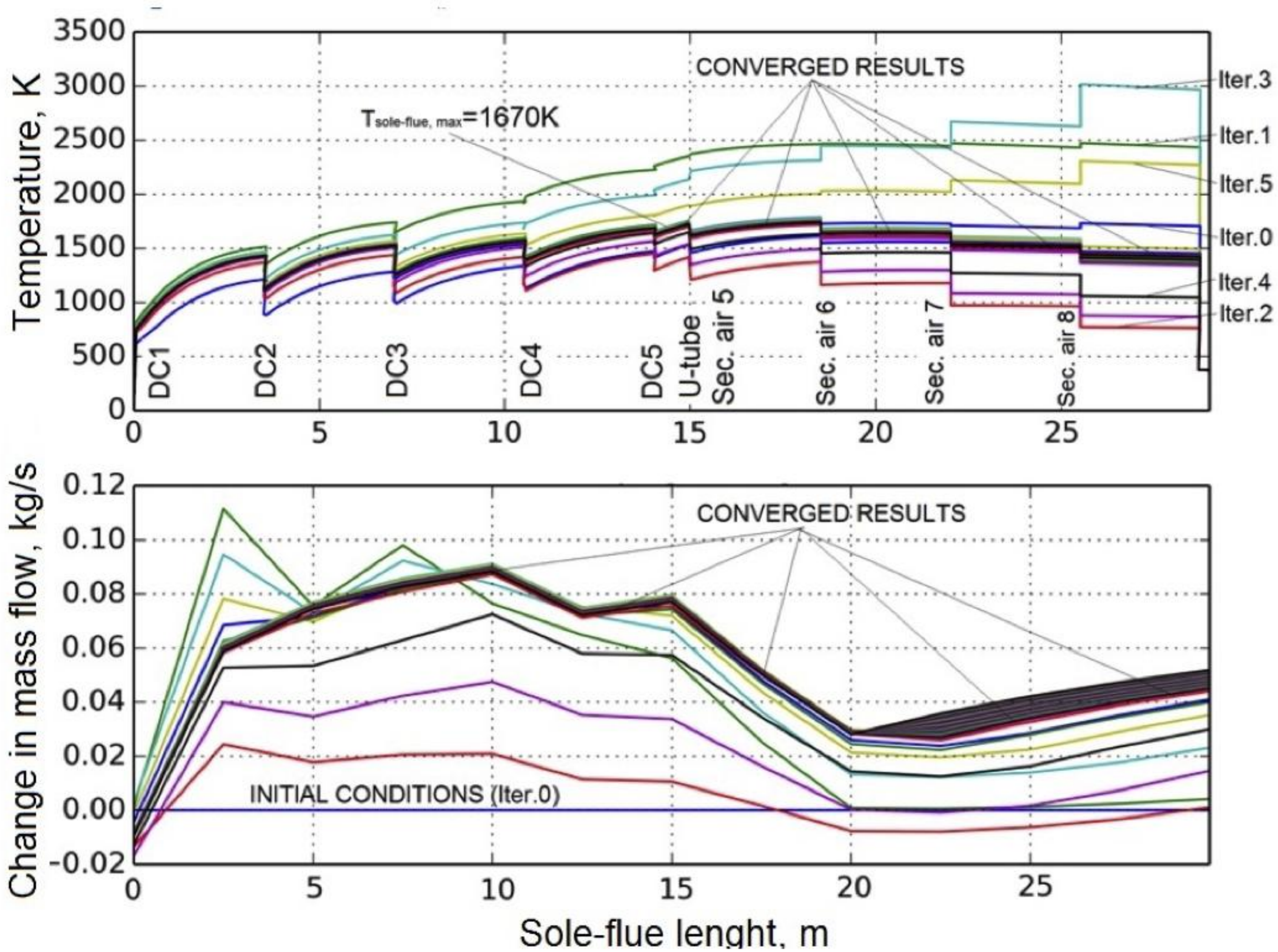



Air
Raw gas partial combustion
Equilibrium calculations
with heat losses
Raw gas
Down-comer gas
Down-comer gas
Gas combustion
Eddy break up model
Air
Air
SUCTION SOURCE

Combustion and heat transfer in the hydraulic network:



Iteration process



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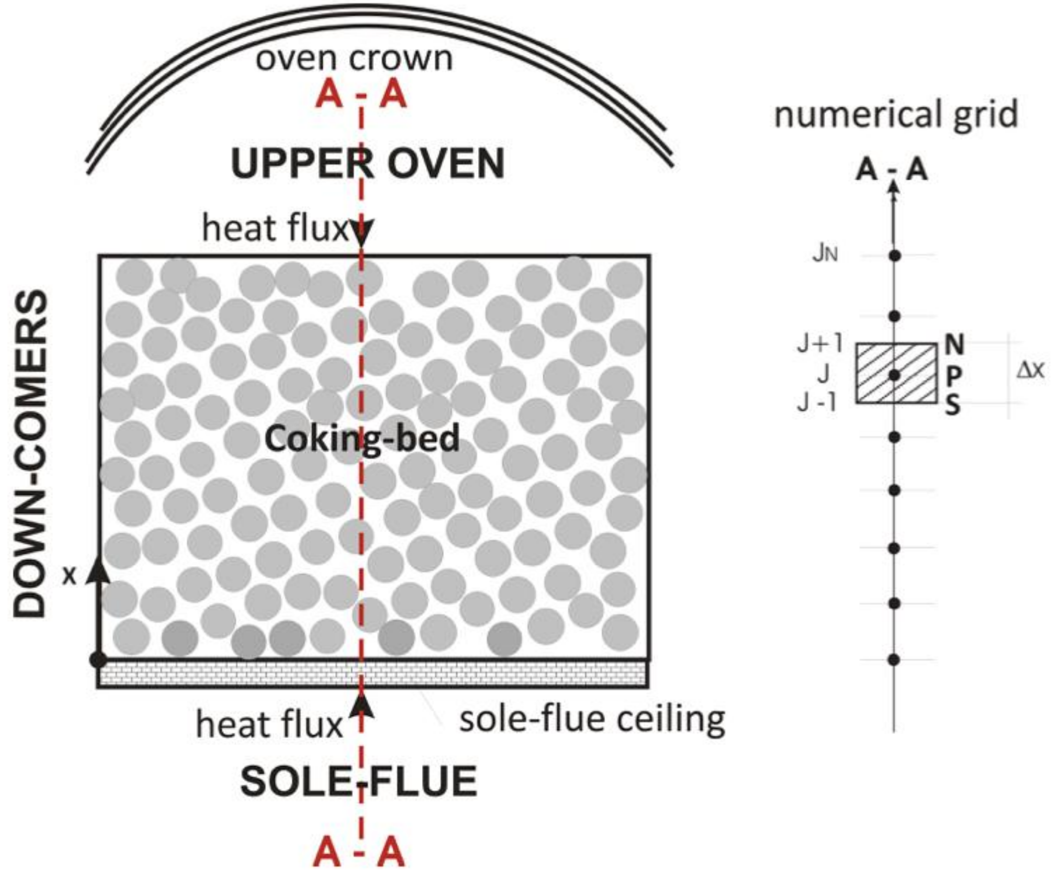
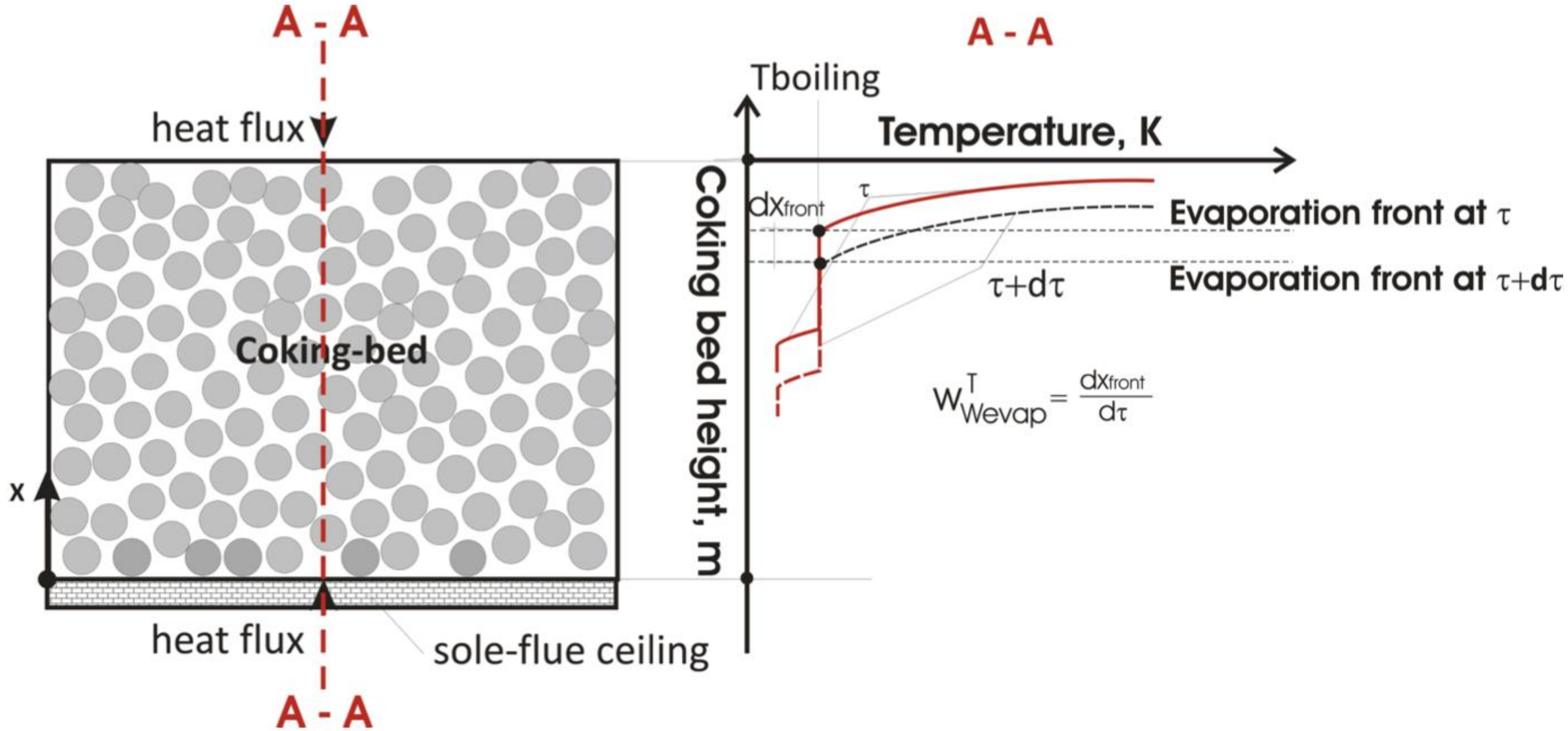
Assumption:

$$\rho_{bulk,s} \cdot c_s \cdot \frac{\partial T}{\partial \tau} = \frac{\partial}{\partial x}\left(k_{eff,s}\frac{\partial T}{\partial x}\right) + \dot{S}_{evap} + \dot{S}_{cond} + \dot{S}_{dev}, \qquad \frac{W}{m^3}$$



Evaporation of moisture



$$\dot{m}_{evap} = A \cdot w_{evap} \cdot \rho_{bulk,s} \cdot g_{water}, \frac{kg_{water}}{s}$$

$$\dot{m}_{cond} = \frac{\epsilon V \cdot M_{water}}{R \cdot T \cdot \Delta\tau} \left(p^{BOIL}_{sat} - p^{T}_{sat} \right), \frac{kg_{water}}{s}$$

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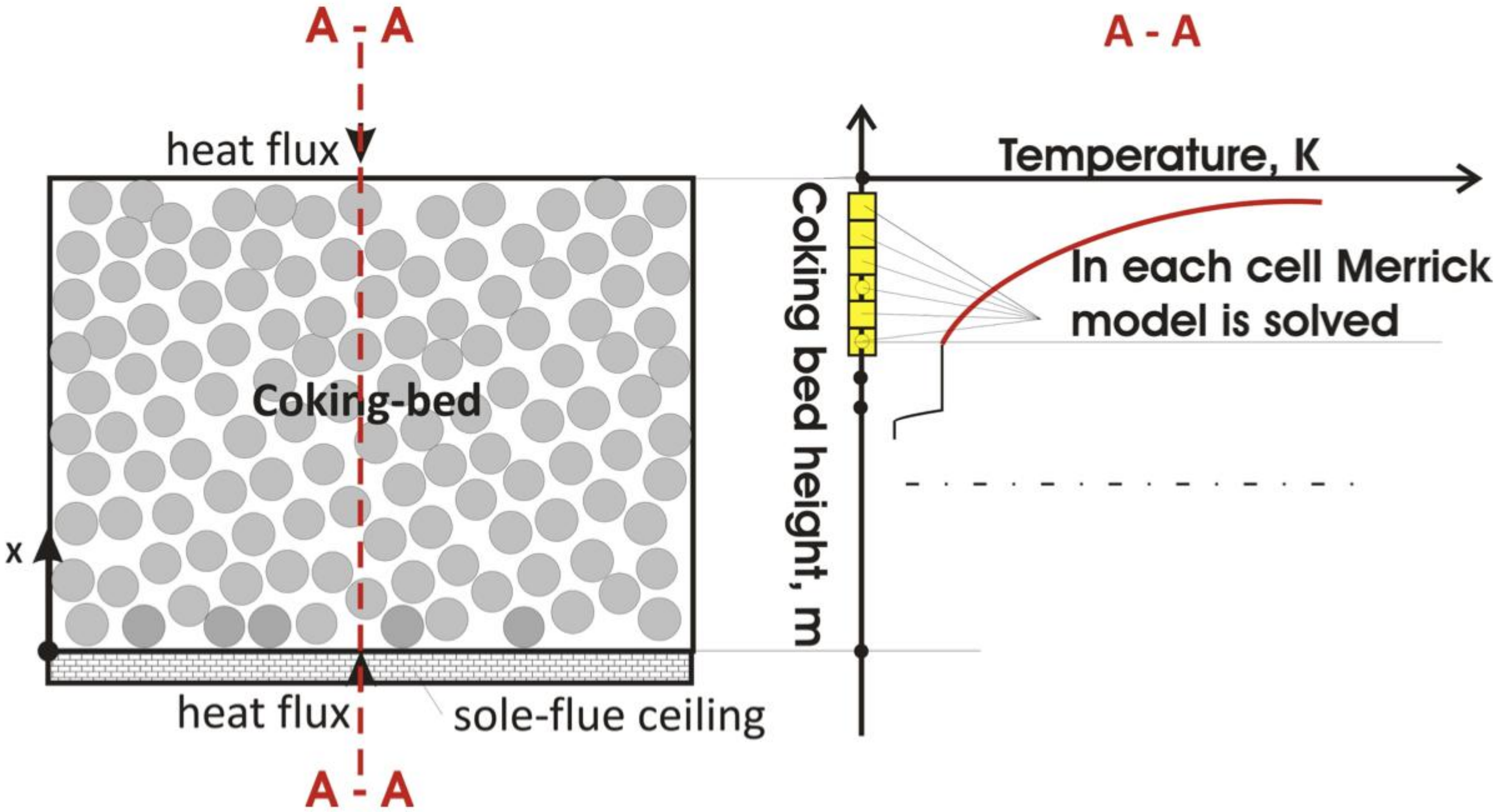
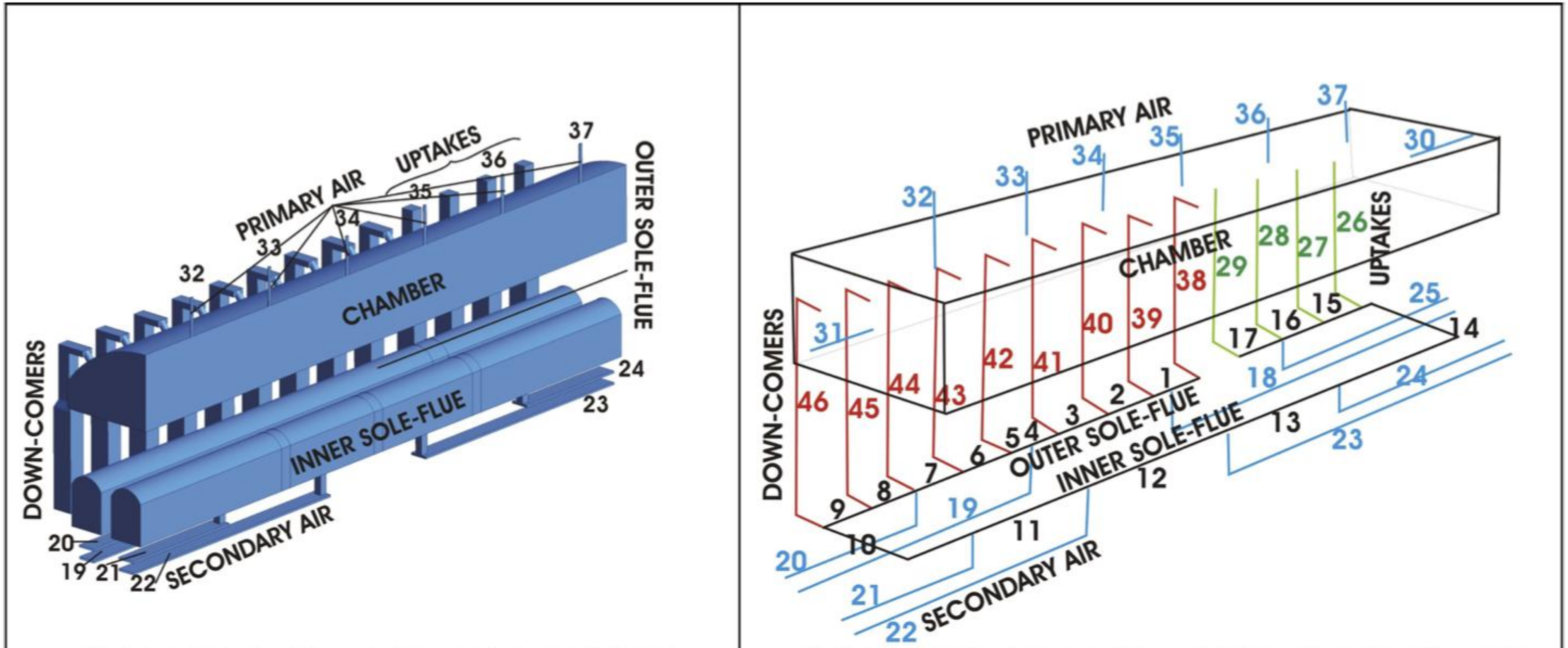
Devolatilization

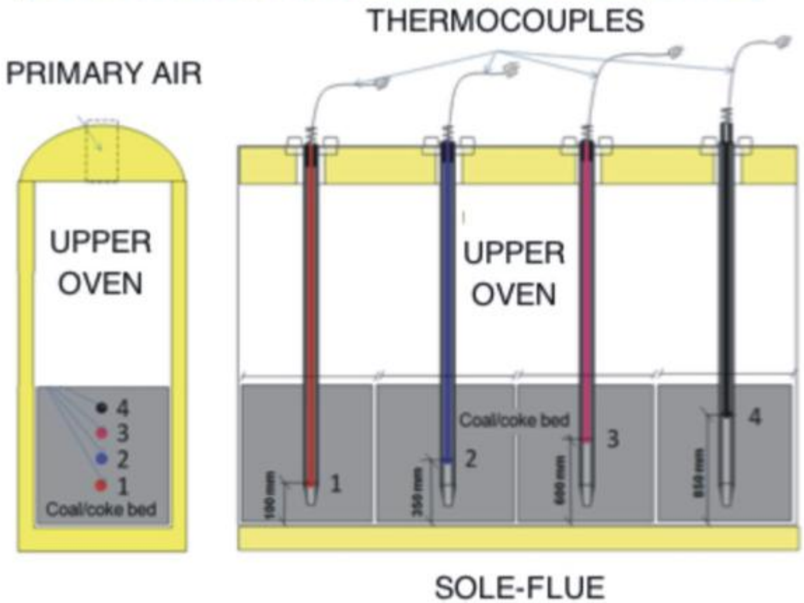


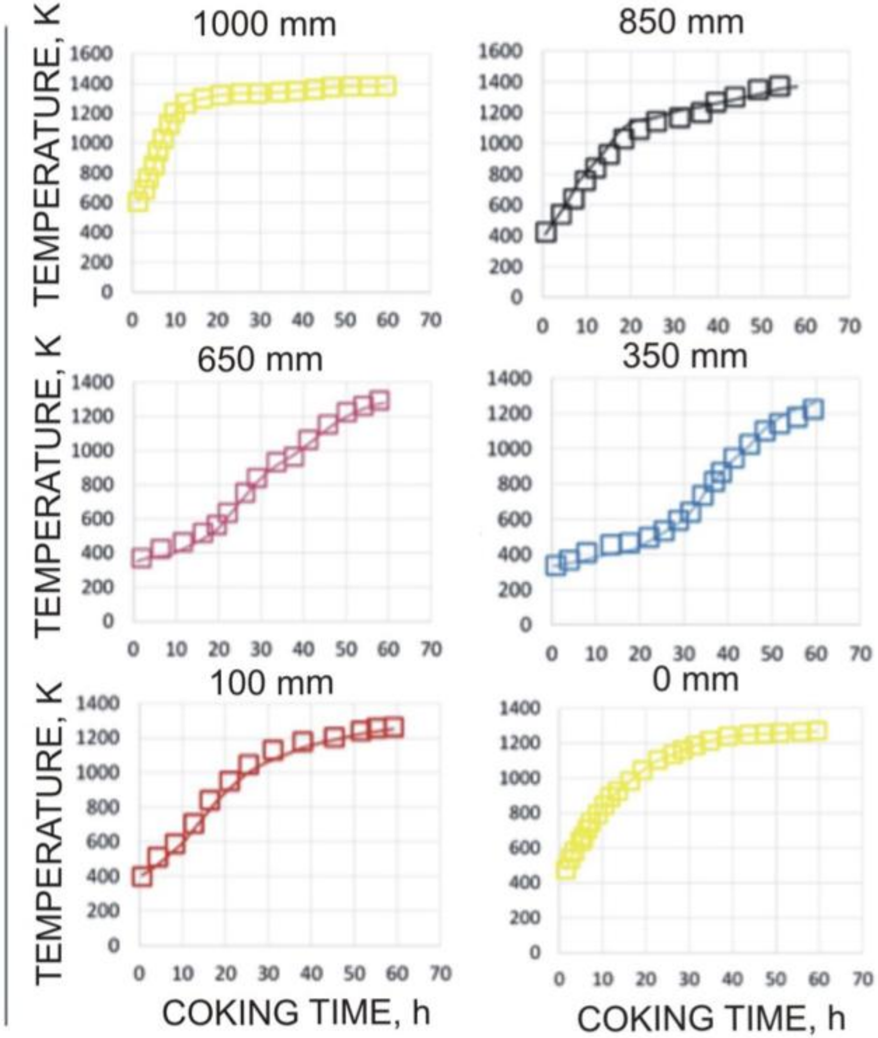
Hydraulic network of tkCSA - coke-oven (Brazil)

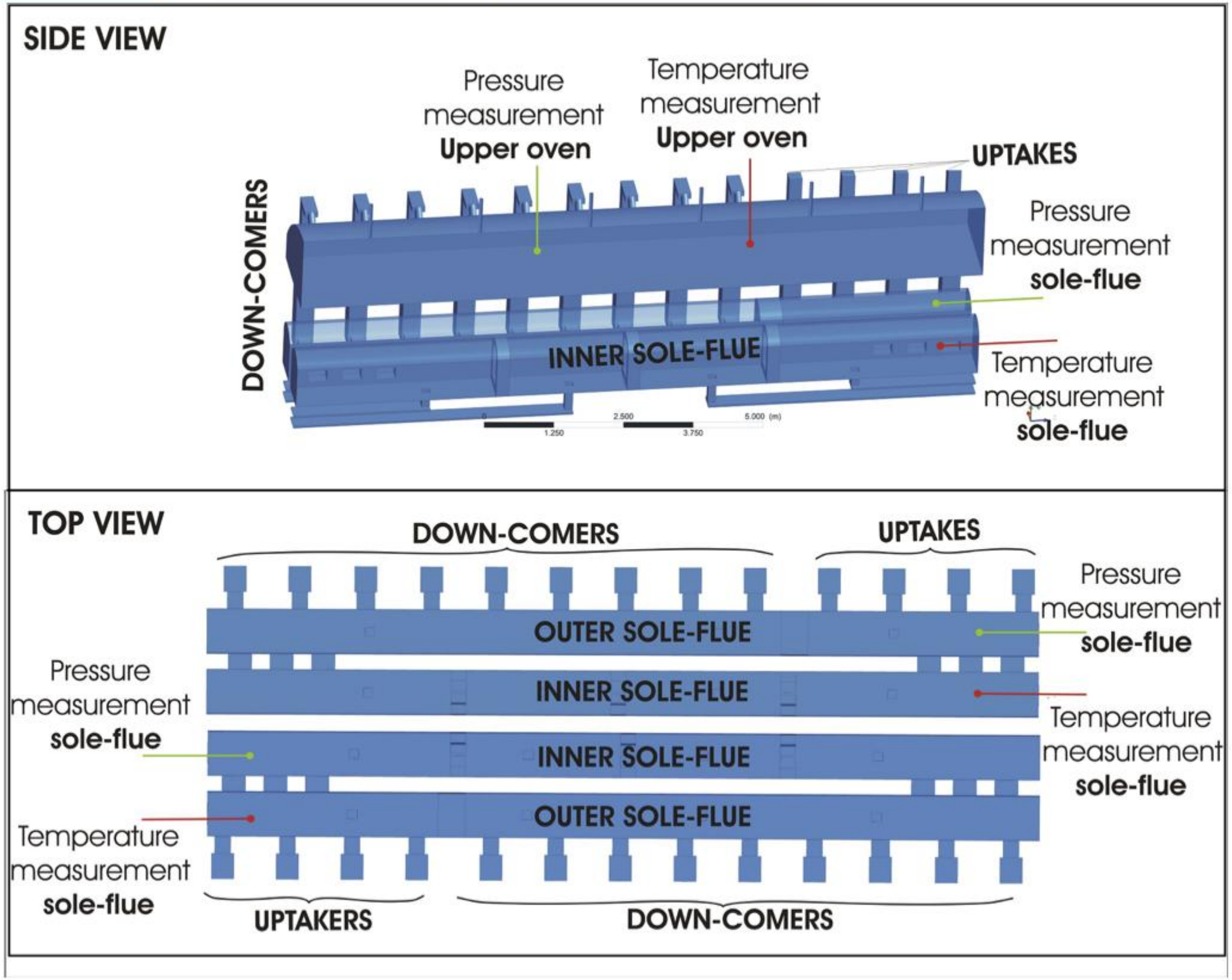


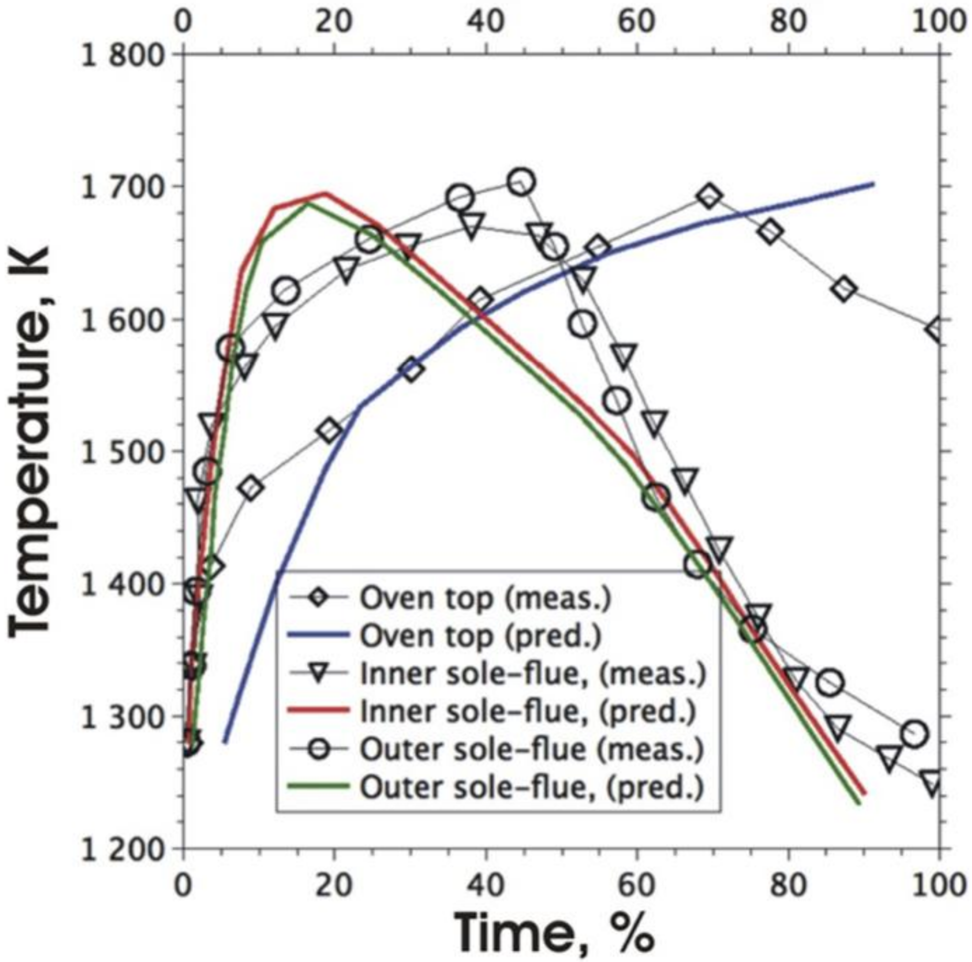
ISOMETRIC SIDE VIEW (3D MODEL) ISOMETRIC SIDE VIEW (NETWORK MODEL)

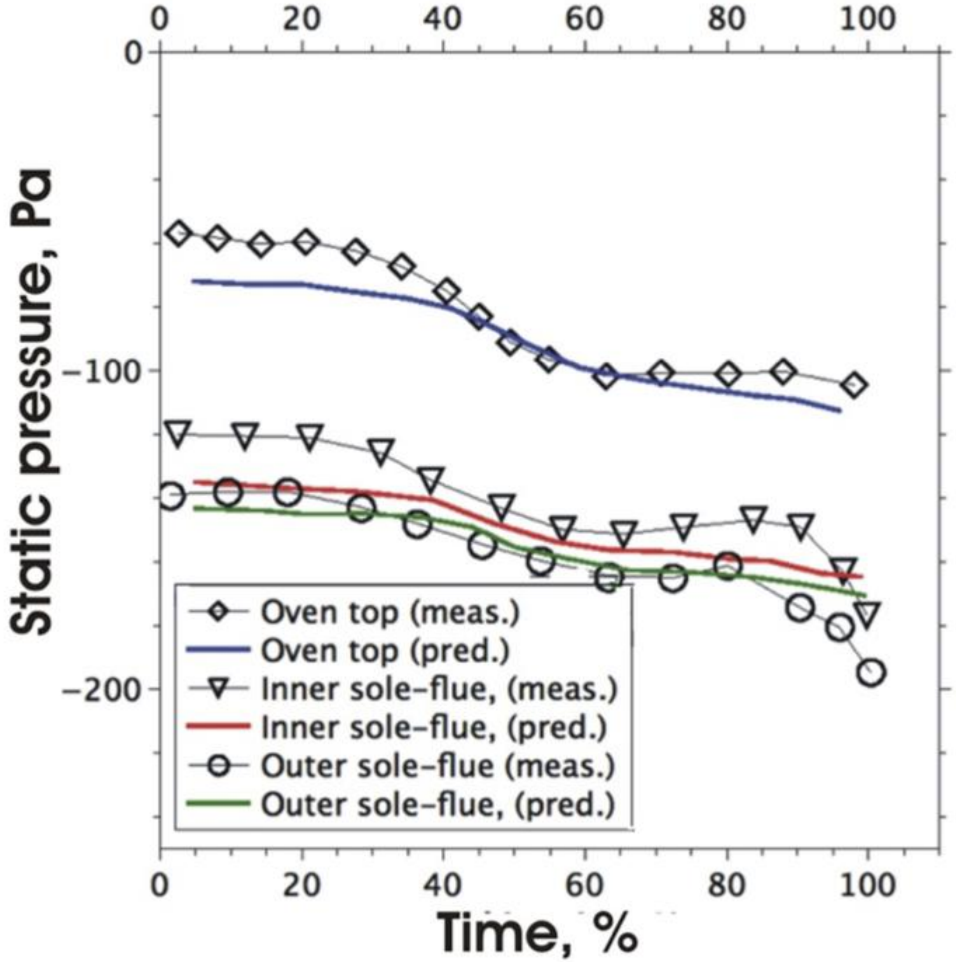
Validation (tkCSA - Brazil)

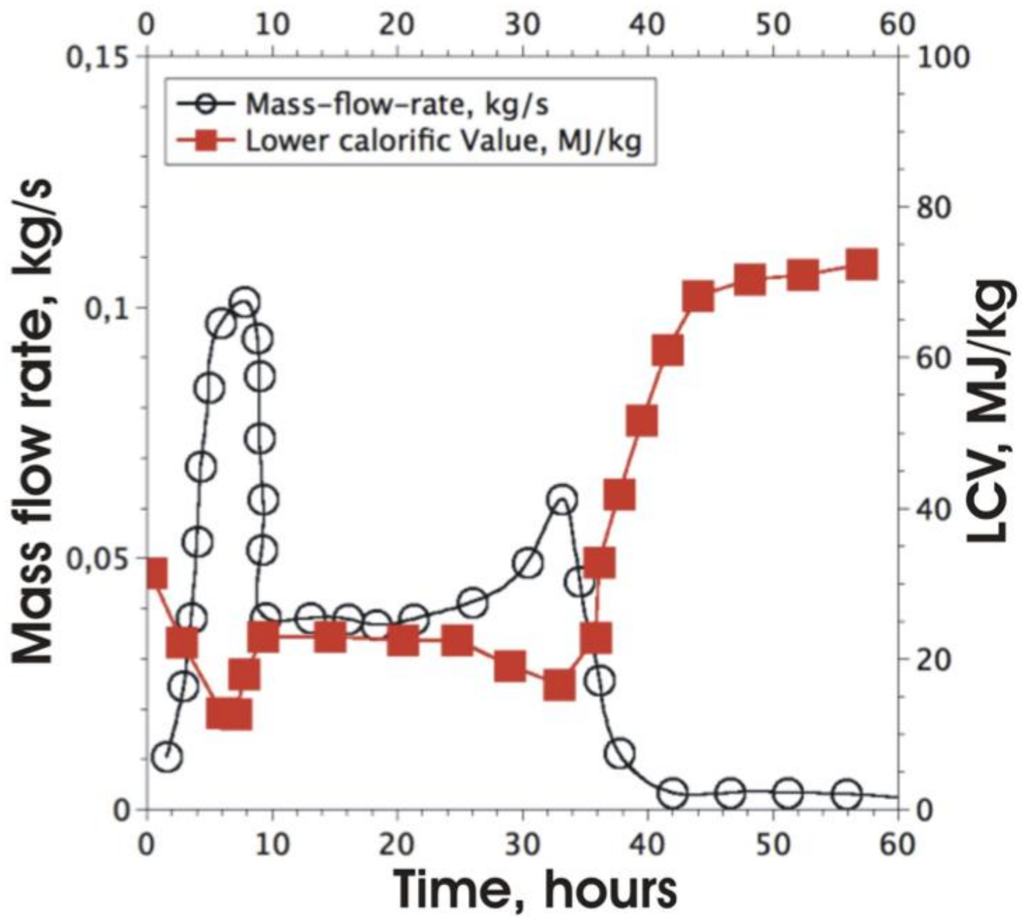


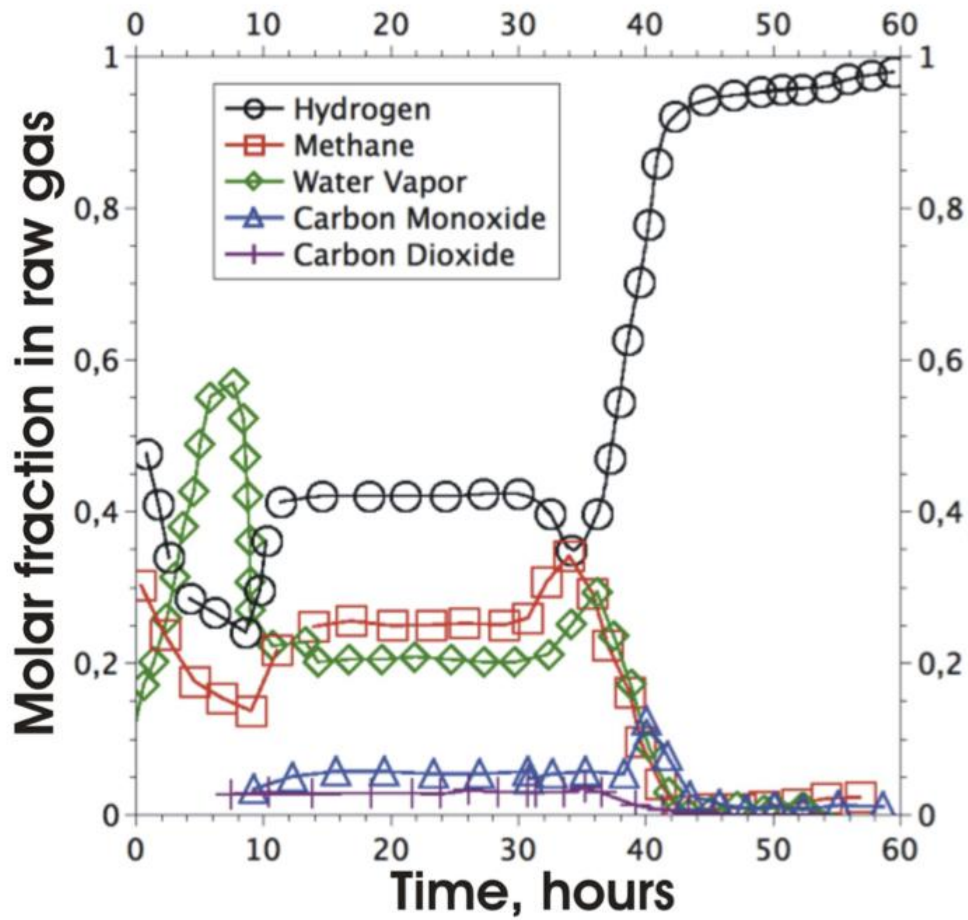


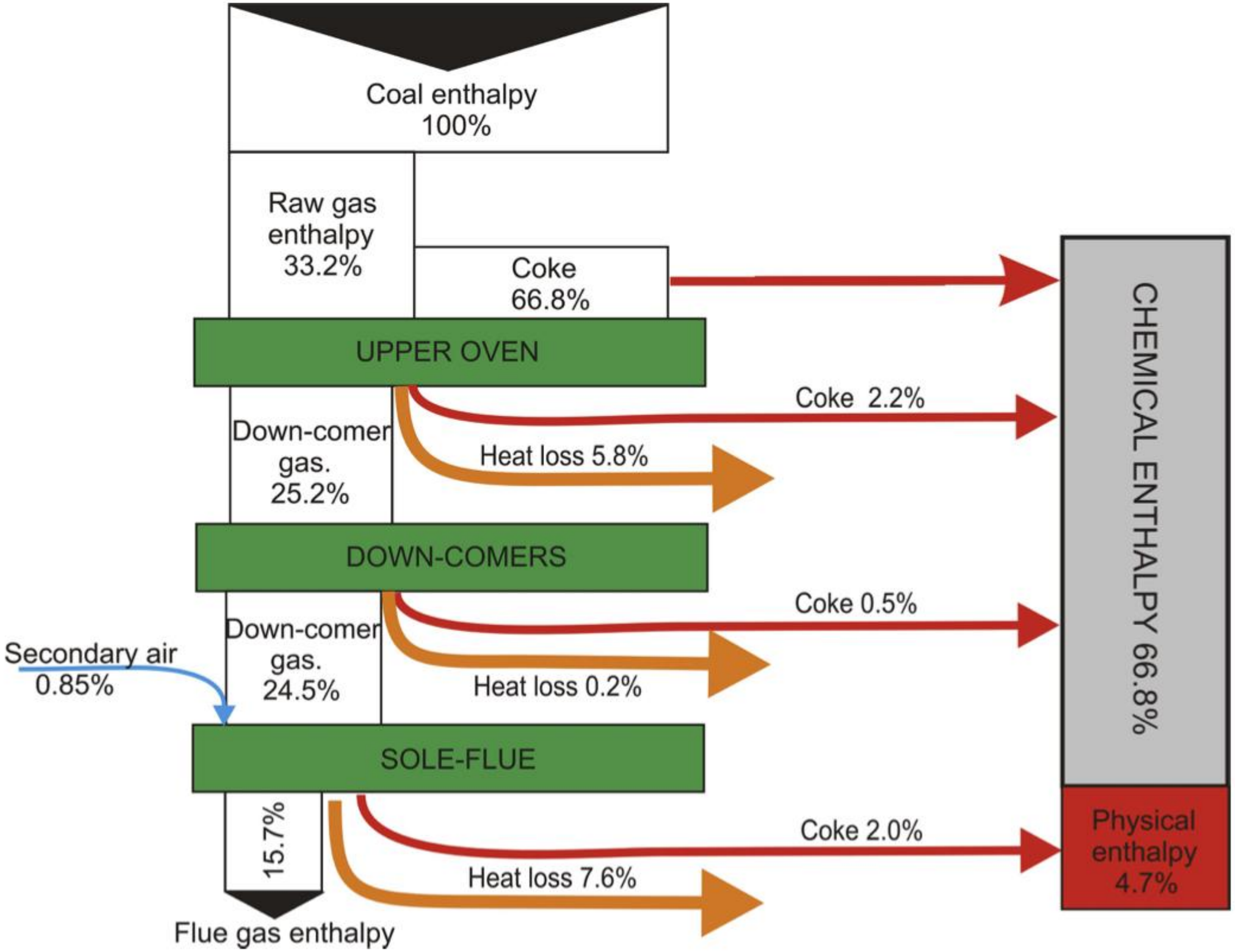

SIDE VIEW
Pressure measurement **Upper oven**
Temperature measurement **Upper oven**
UPTAKES
DOWN-COMERS
Pressure measurement **sole-flue**
INNER SOLE-FLUE
Temperature measurement **sole-flue**
TOP VIEW
DOWN-COMERS
UPTAKES
Pressure measurement **sole-flue**
OUTER SOLE-FLUE
INNER SOLE-FLUE
Pressure measurement **sole-flue**
Temperature measurement **sole-flue**
INNER SOLE-FLUE
OUTER SOLE-FLUE
Temperature measurement **sole-flue**
UPTAKERS
DOWN-COMERS


Temperature, K
Time, %
Oven top (meas.)
Oven top (pred.)
Inner sole-flue, (meas.)
Inner sole-flue, (pred.)
Outer sole-flue (meas.)
Outer sole-flue, (pred.)


Static pressure, Pa
Time, %
Oven top (meas.)
Oven top (pred.)
Inner sole-flue, (meas.)
Inner sole-flue, (pred.)
Outer sole-flue (meas.)
Outer sole-flue, (pred.)


Mass-flow-rate, kg/s
Lower calorific Value, MJ/kg
Mass flow rate, kg/s
LCV, MJ/kg
Time, hours


Hydrogen
Methane
Water Vapor
Carbon Monoxide
Carbon Dioxide
Molar fraction in raw gas
Time, hours


Coal enthalpy
100%
Raw gas
enthalpy
33.2%
Coke
66.8%
UPPER OVEN
Coke 2.2%
Down-comer
gas.
25.2%
Heat loss 5.8%
DOWN-COMERS
Coke 0.5%
Secondary air
0.85%
Down-comer
gas.
24.5%
Heat loss 0.2%
SOLE-FLUE
15.7%
Coke 2.0%
Heat loss 7.6%
Flue gas enthalpy
CHEMICAL ENTHALPY 66.8%
Physical
enthalpy
4.7%

- The one-dimensional time-dependent mathematical model has been used to simulate the performance of the industrial HR coke oven battery,
- The heart of the model is the hydraulic network sub-model which interacts with the coking-sub-model and the combustion sub-model,
- The temperatures measured inside the coking bed have been used to adapt the coking sub-model to the coal blend carbonized,
- The overall network model has predicted well the pressure and temperature distributions in the oven,
- The yield and composition of the raw-gas, the down-comer gas and the sole-flue gas have been well predicted for the whole 60-hours lasting process,
- The main advantage of the whole network model is in its short computation times,

1D COKE-OVEN MODEL IS USED TO:

- predict the optimal channels diameter,
- calculate position of the "sliding-bricks" and "sliding-gates",
- identify regions of excessive temperatures inside the upper-oven or sole-flues,
- estimate coking time.

Buczynski R et al. One-dimensional model of heat-recovery, non-recovery coke ovens. Parts I-IV. Fuel (2016).
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doi:10.1016/j.fuel.2016.01.086,
doi:10.1016/j.fuel.2016.01.087,
doi:10.1016/j.fuel.2016.05.033.