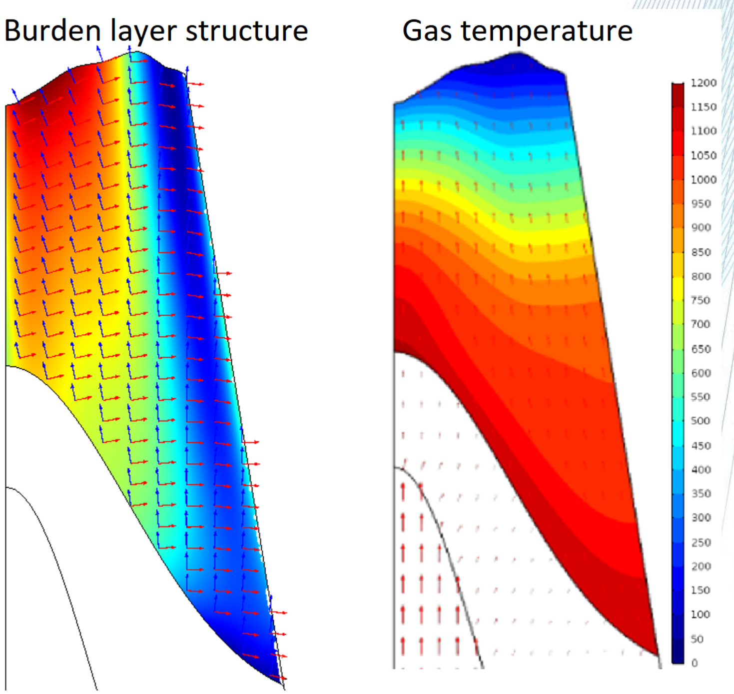
A complex online model for the iron ore reduction in the blast furnace



A complex online multiphysics model of the blast furnace shaft for various operational conditions and charging programs

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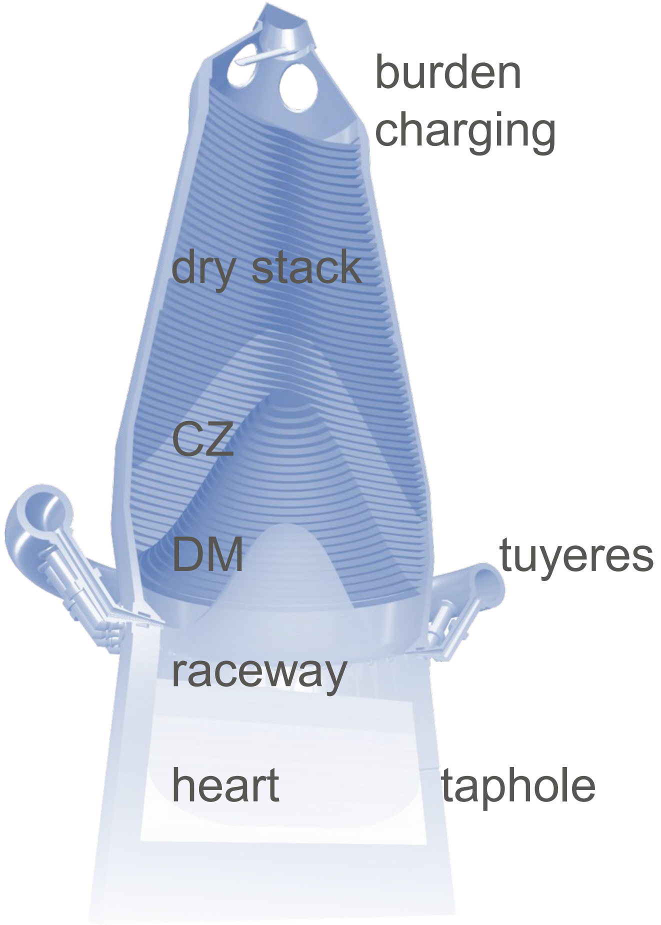
Stahl

Short Introduction of Blast Furnace

- Blast furnace is a huge counter-flow reactor
- Iron ore (pellet or sinter) and coke feed from top using advanced charging programs to for a controlled layered structure
- Usually O_2-enriched hot air injected through tuyeres (pulverized coal, natural gas, or oil can be also injected to reduce coke rate)
- Hot blast gas mostly converted to CO and H_2 in the raceway which then react with the ore particles and remove Oxygen
- As the burden descending, a sponge formed iron forms, which then starts melting and dripping in the cohesive zone (CZ)
- Below CZ only remains cokes (relatively stationary deadman: DM)
- This study focuses on the ore reduction above CZ.



Model set-up and assumptions

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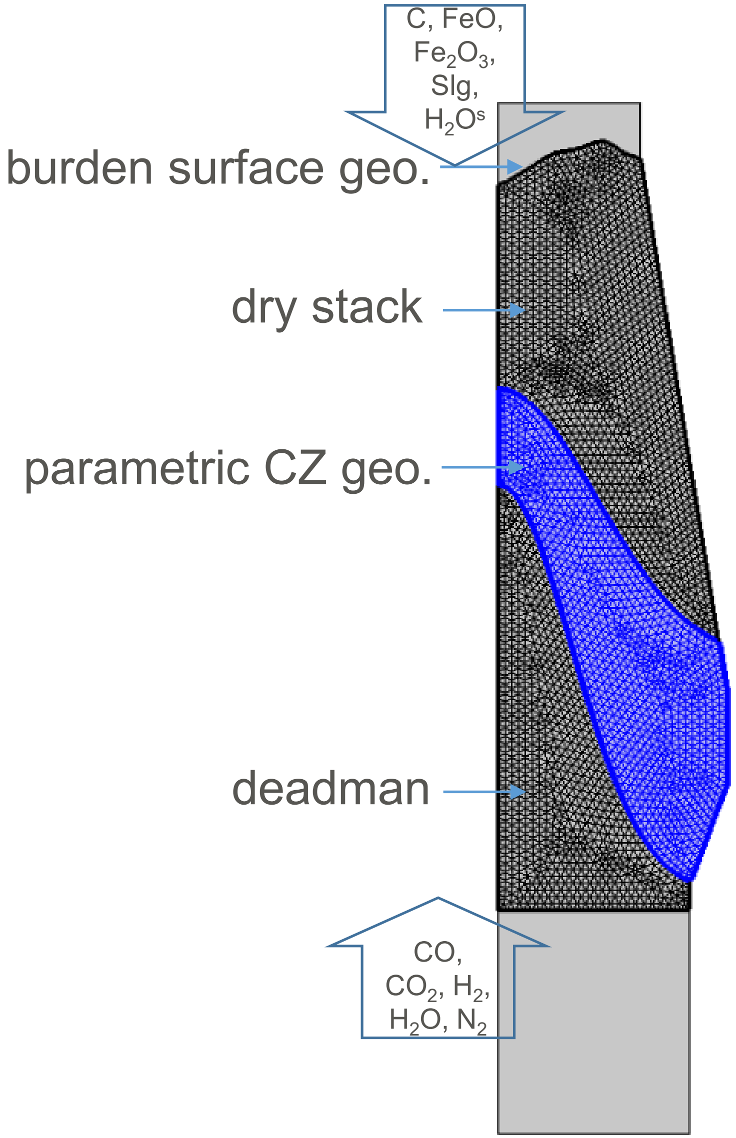
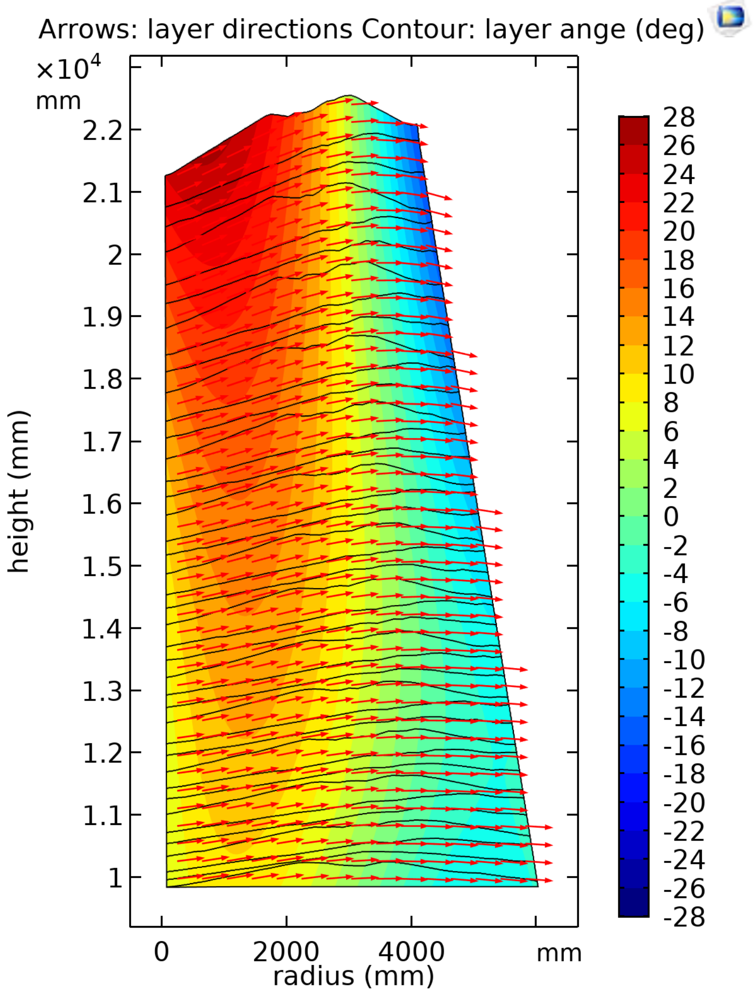


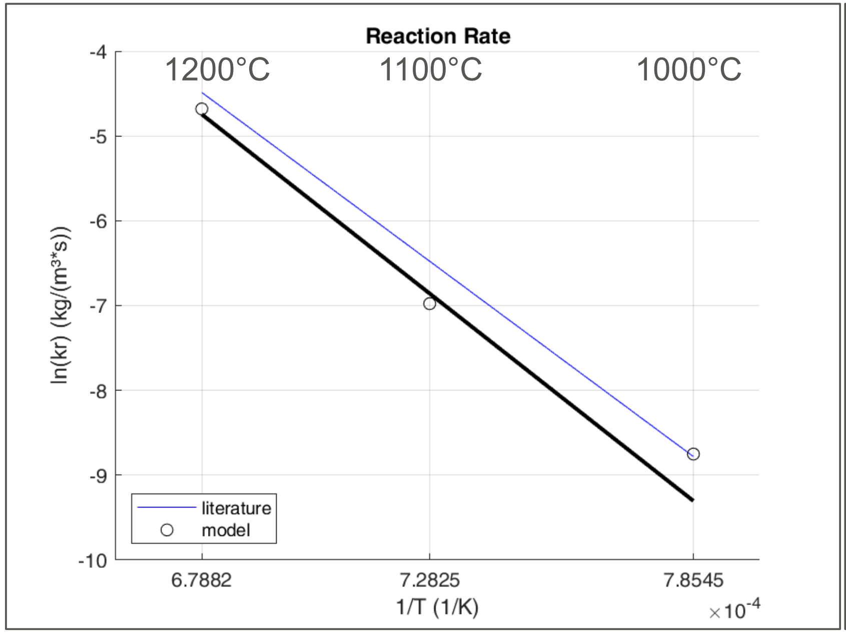
- Model covers reactions and gas-solid heat exchange at the dry stack region
- Burden moisture given by H_2O^s
- Coke is composed of mainly C and rest contributes to Slg
- Ore is composed of mainly Fe_2O_3, some FeO and rest is called Slg
- Gas is composed of CO, CO_2, H_2, H_2O and N_2
- Burden structure (ore/coke layers) are implemented by anisotropic permeability

Burden Structure

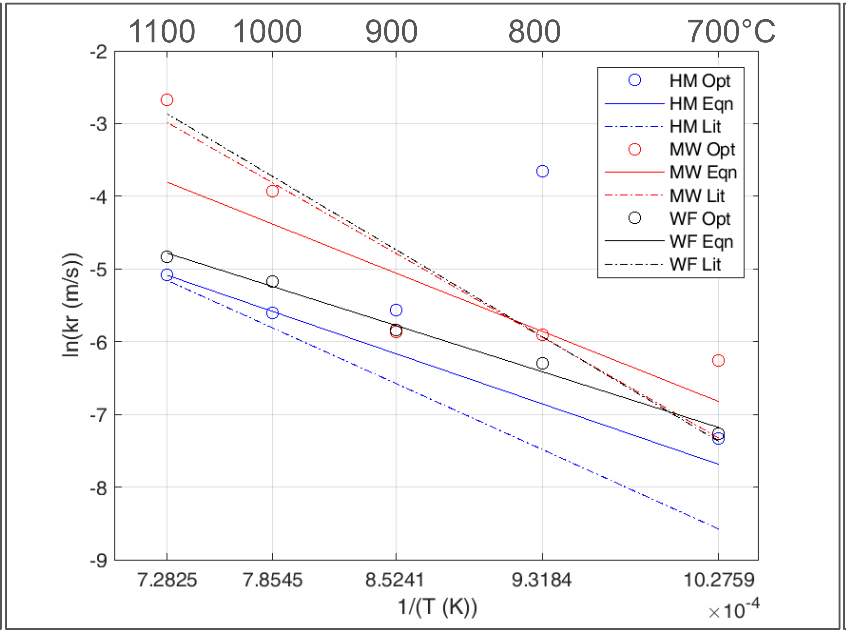


Model calibration by experiments (CO and H_2)

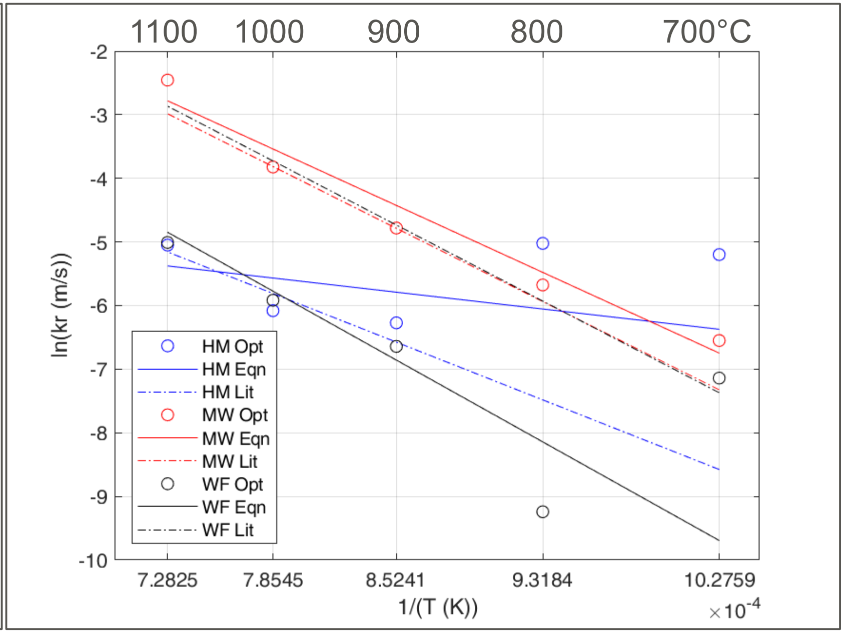
coke gasification



sinter reduction by CO



pellet reduction by CO



*) kr_lit = exp(22.84 – 40258[K]/T); % m³/(kg*s)
kr_mod = exp(24.27 – 42740[K]/T);

*) I. Muchi, Mathematical model of blast furnace, ISIJ, Vol. 7, 1967.

**) Murayama, T.; Ono, Y.; Kawai, Y.: Step-wise Reduction of Hematite Pellets with CO-CO2 Gas Mixtures. Tetsu-to-Hagané 63 (1977), pp. 1099/1107

**) krHM_lit= 23.63*exp(-1.2*9520[K]/Ts)[m/s];
krMW_lit= 1948.5*exp(-14500[K]/Ts)[m/s];
krWF_lit= 3277.5*exp(-15050[K]/Ts)[m/s];

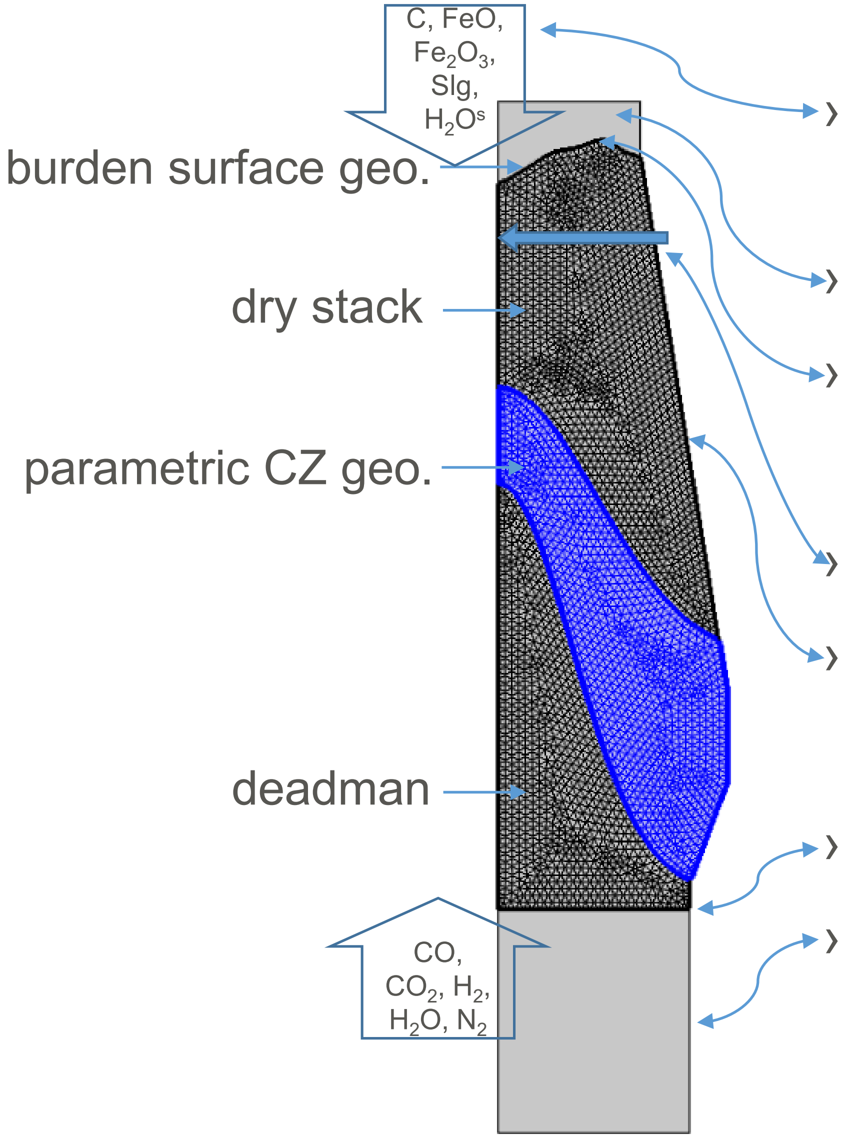
krHM= exp(1.24-8688[K]/Ts)[m/s];
krMW= exp(3.535-10080[K]/Ts)[m/s];
krWF= exp(1.05-8008[K]/Ts)[m/s];

krHM_lit= 23.63*exp(-1.2*9520[K]/Ts)[m/s];
krMW_lit= 1948.5*exp(-14500[K]/Ts)[m/s];
krWF_lit= 3277.5*exp(-15050[K]/Ts)[m/s];

krHM= exp(-2.952-3329[K]/Ts)[m/s];
krMW= exp(6.869-13251[K]/Ts)[m/s];
krWF= exp(6.942-16189[K]/Ts)[m/s];

Legend: Opt → from single isothermal experiment
Eqn → regression line to Opt
Lit → literature equation

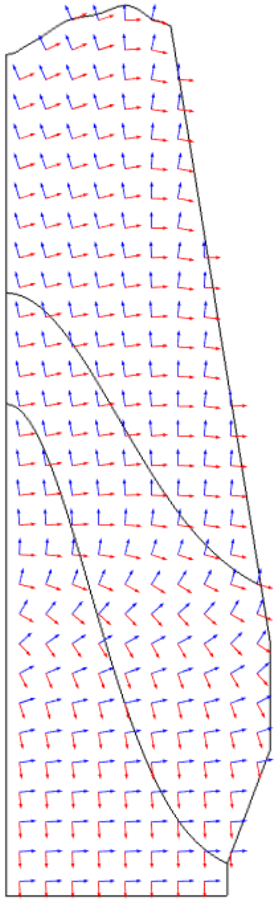
Online model connections to blast furnace operational data



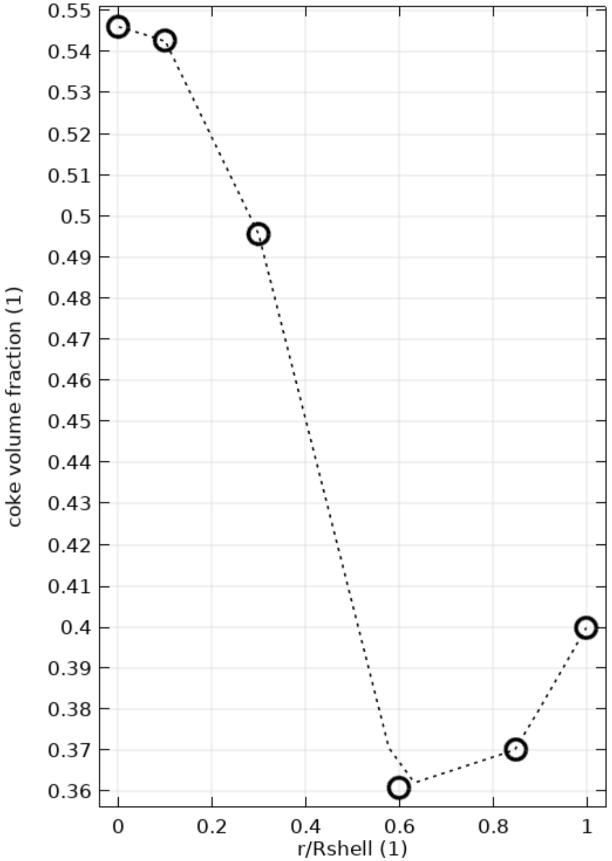
- BF charging data + chemical analysis of charging material average coke and ore size
- Top gas temperature and gas compositions
- Surface decent velocity and burden top surface shape
- In burden probe (temperature, gas compositions)
- Wall pressure measurements (permeability)
- Blast data (temperature, volume, O_2 enrichment, PCI rate)
- Production rates (HM and slag) + HM and slag analysis

2d simulation example (online process model for Dillinger BF4)

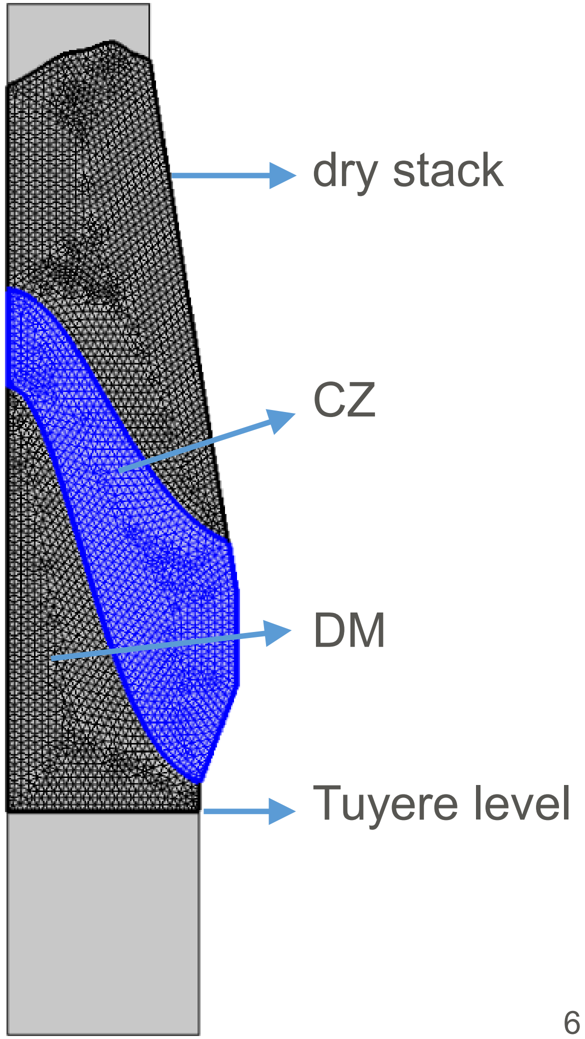
- variation of layer angles via polynomial regression



- variation of coke volume fraction via piecewise linear interpolation



- typical FEM mesh



Dillinger BF4 operational data

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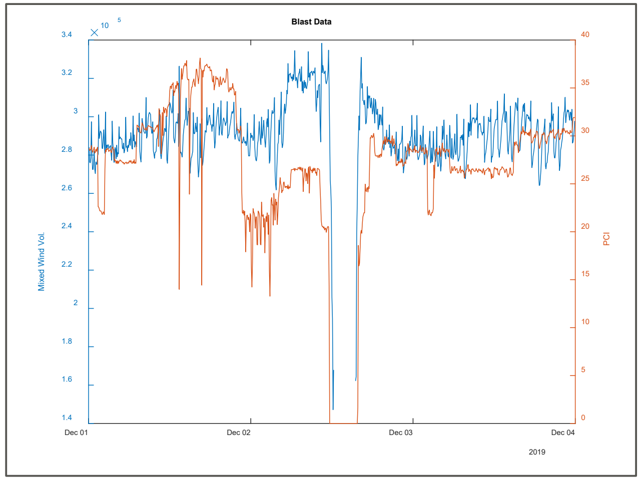
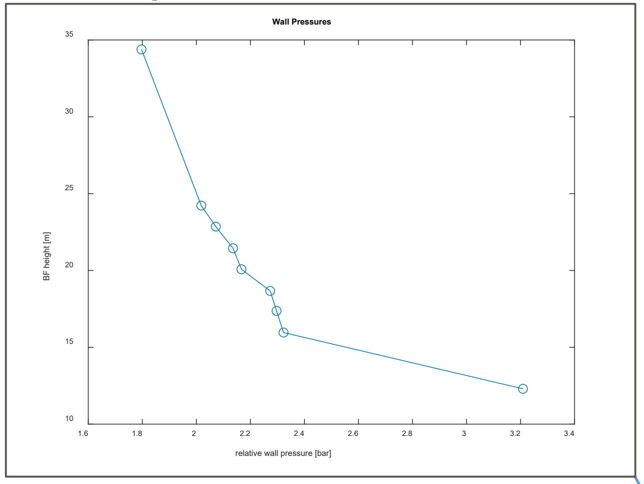
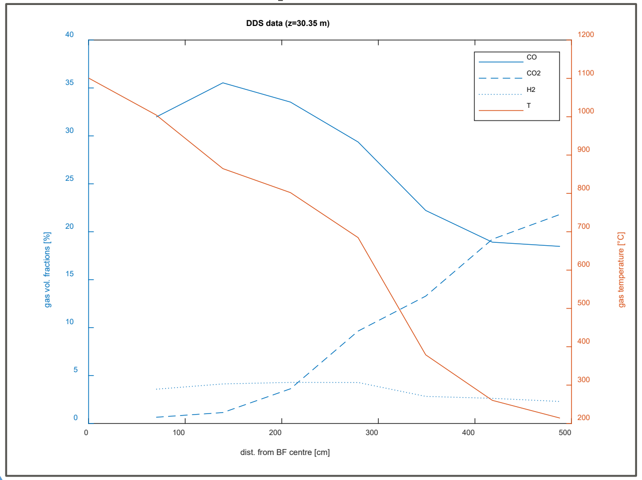
blast data



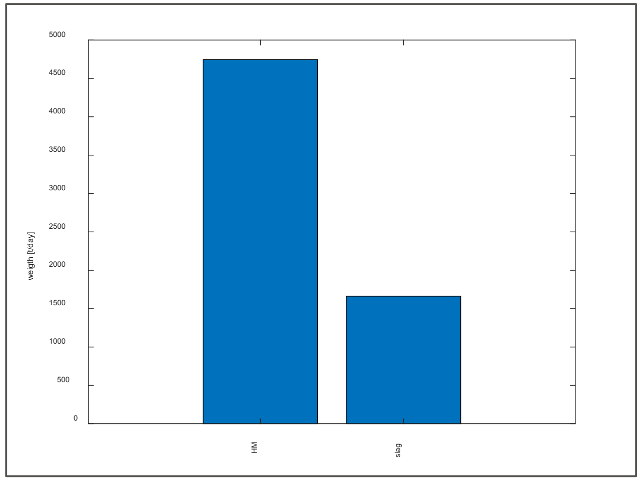
wall pressure



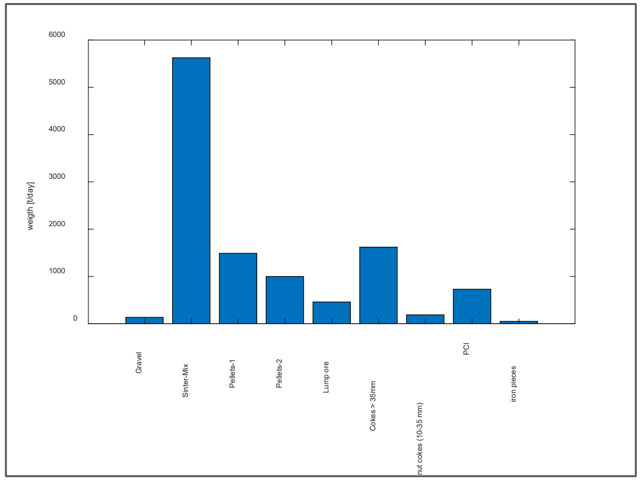
in-burden probe



production HM and slag



charging material types

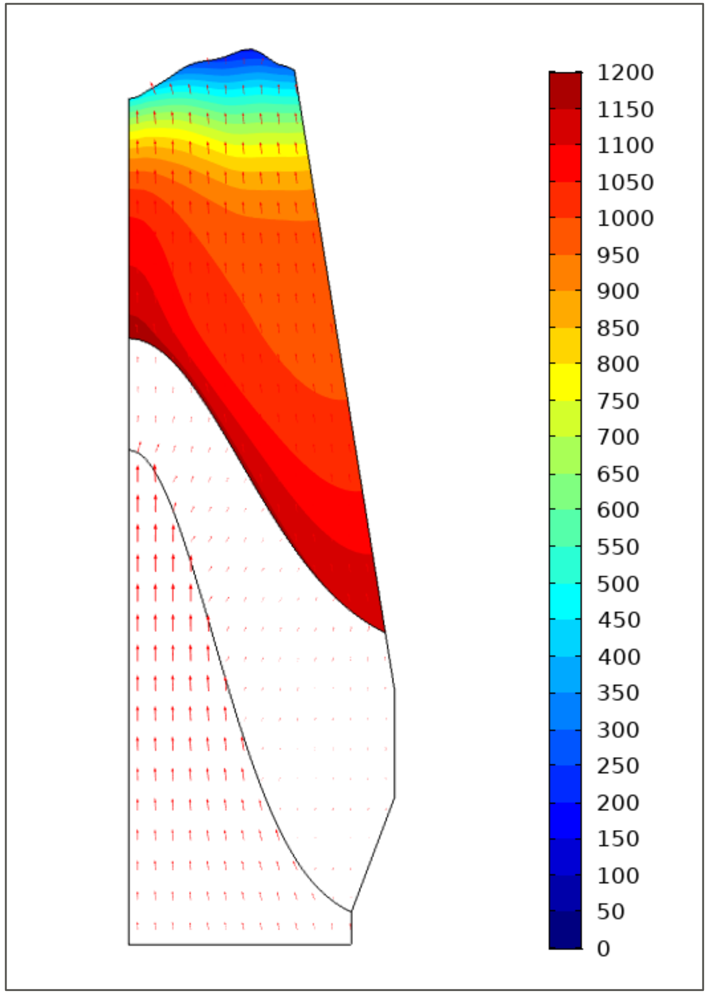


Remarks:

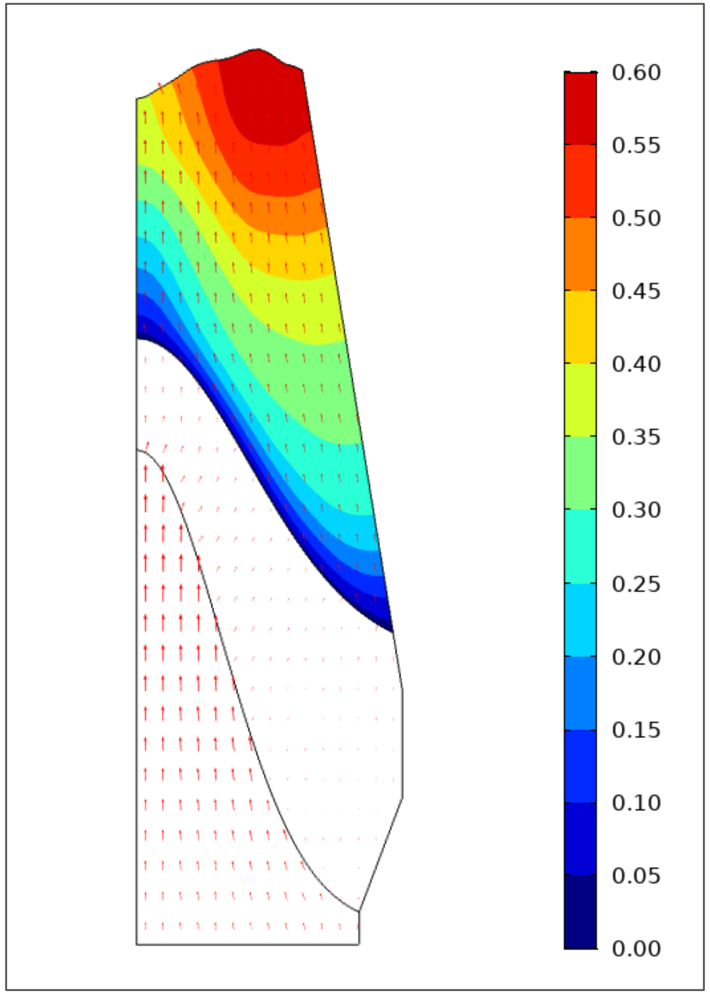
- It can be difficult to see the CZ position in the wall pressure measurements
- The CO volume fraction at center region is not measured correctly by in-burden probe as T>1100°C.

Results of Dillinger BF4 model

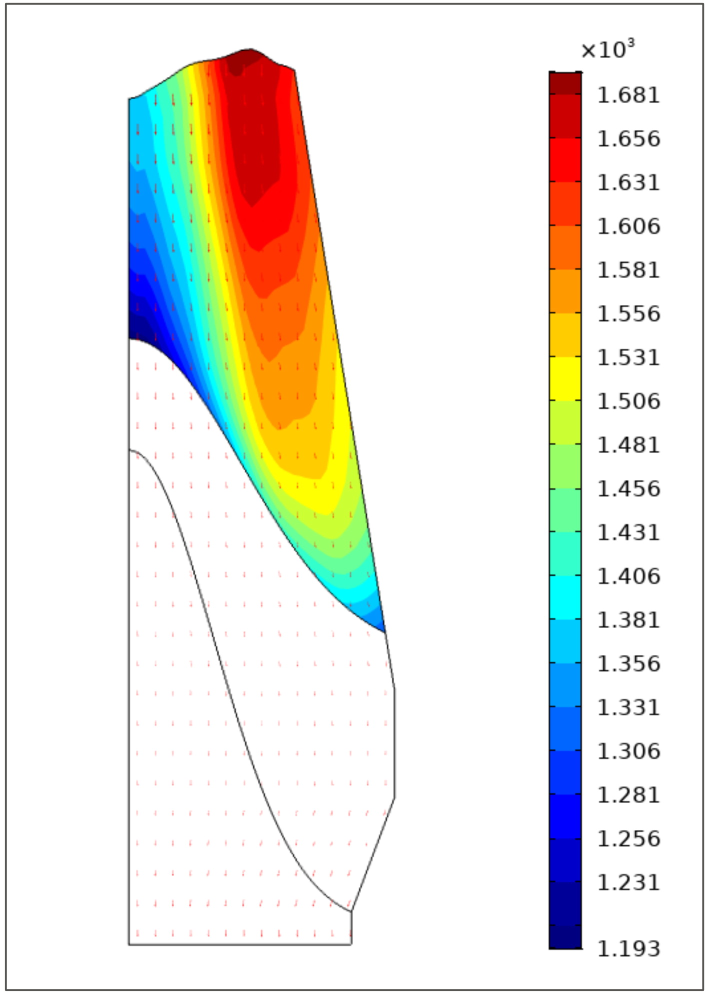
- gas temperature (°C)



- $\eta_{CO} = \frac{CO_2}{CO_2 + CO}$ utilization

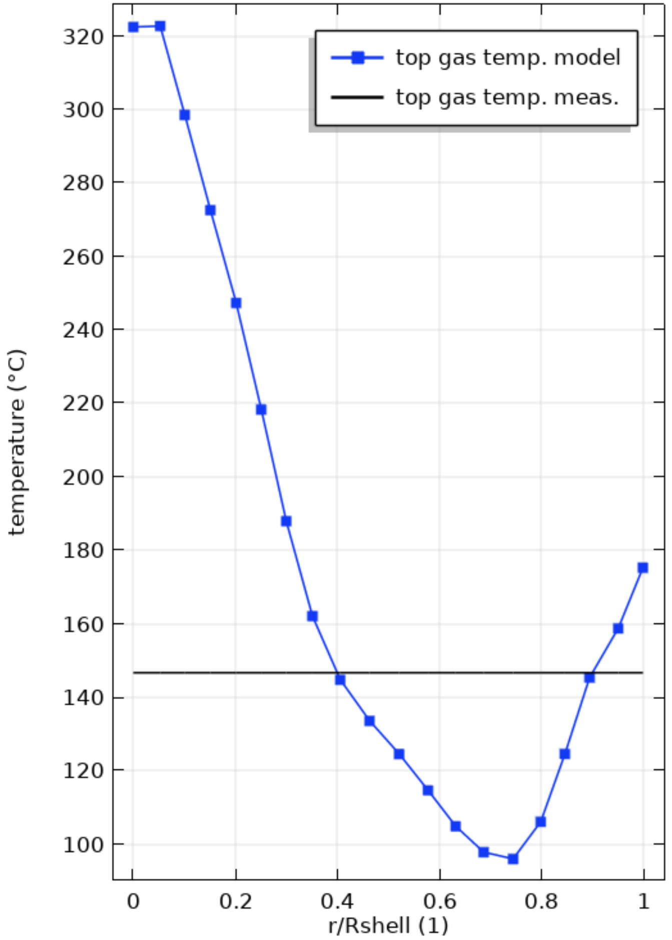


- solid density (kg/m³)

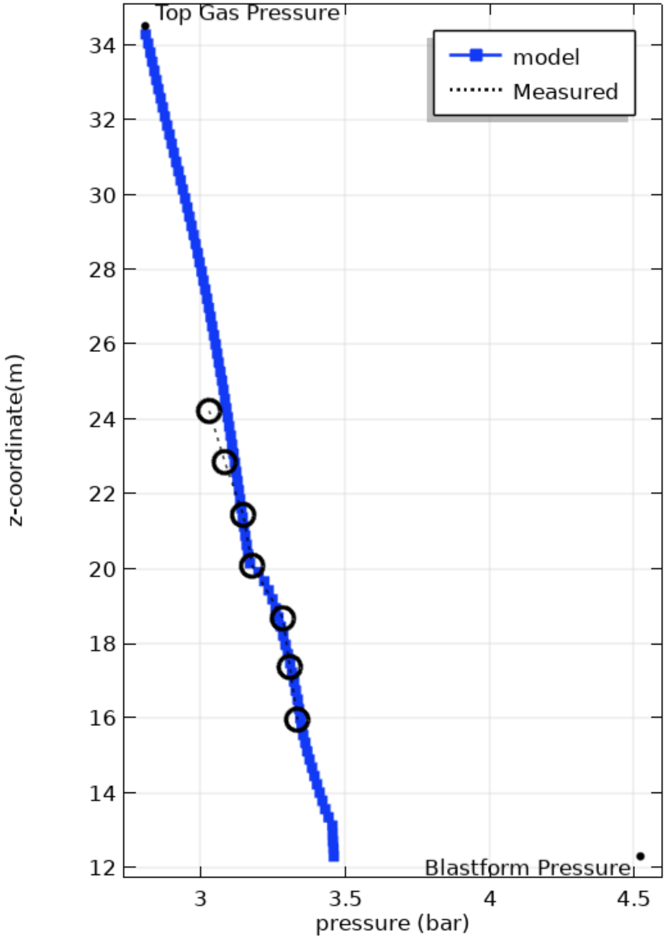


Results of Dillinger BF4 model vs. operational measurements

- top gas temperature (°C)



- wall pressure (bar)



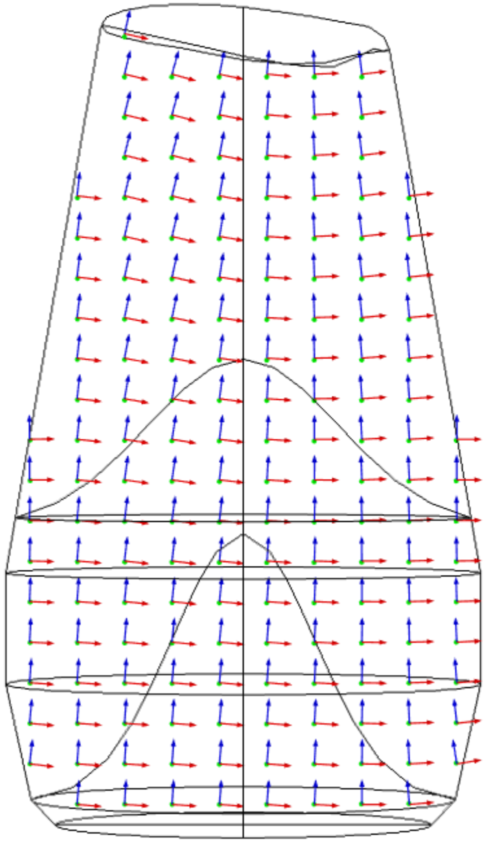
The model estimation for wall pressure fits quite well.

General top temperature level fits well.

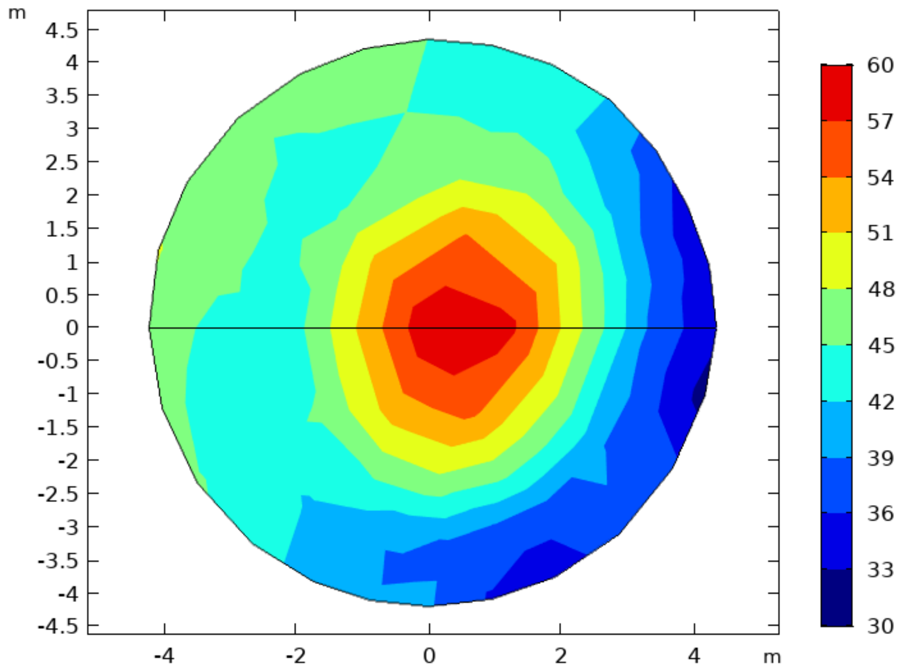
Comparison to SOMA and DDS data not done yet.

3d simulation example

› Variation of layer angles via polynomial regression

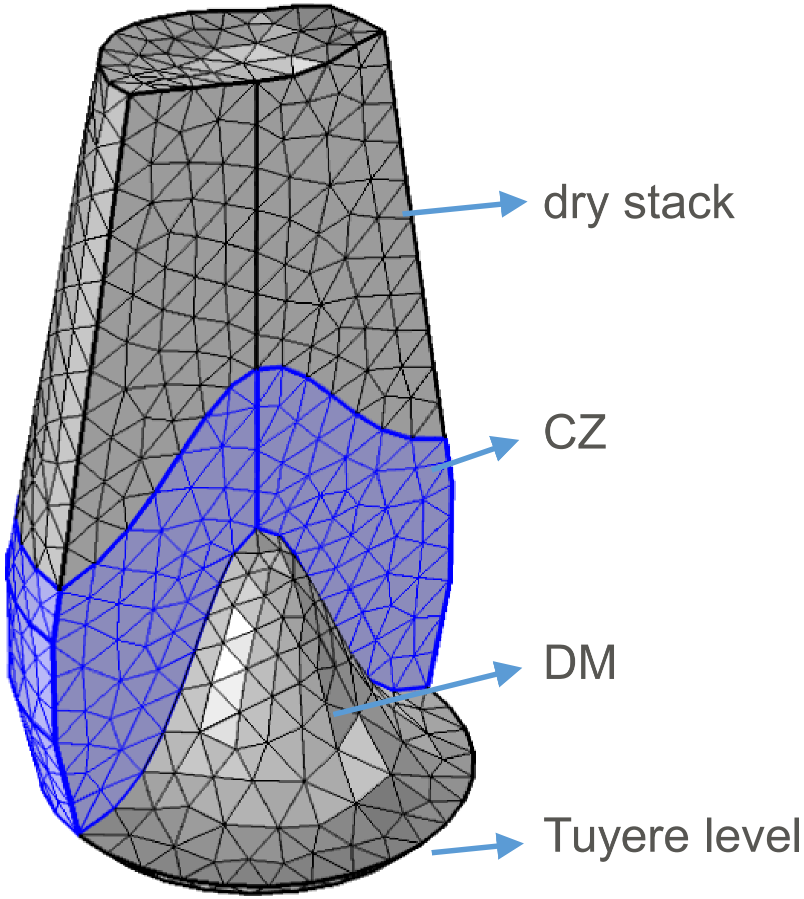


› Variation of coke volume fraction via polynomial regression



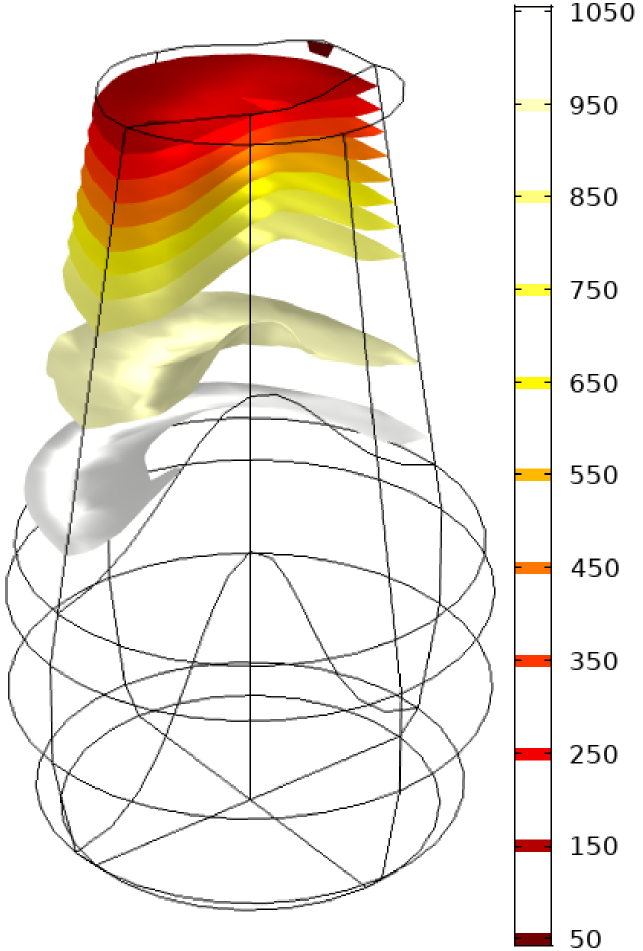
› Mid-surface inclination and layer thickness data is utilized to obtain regression functions

› Typical FEM mesh

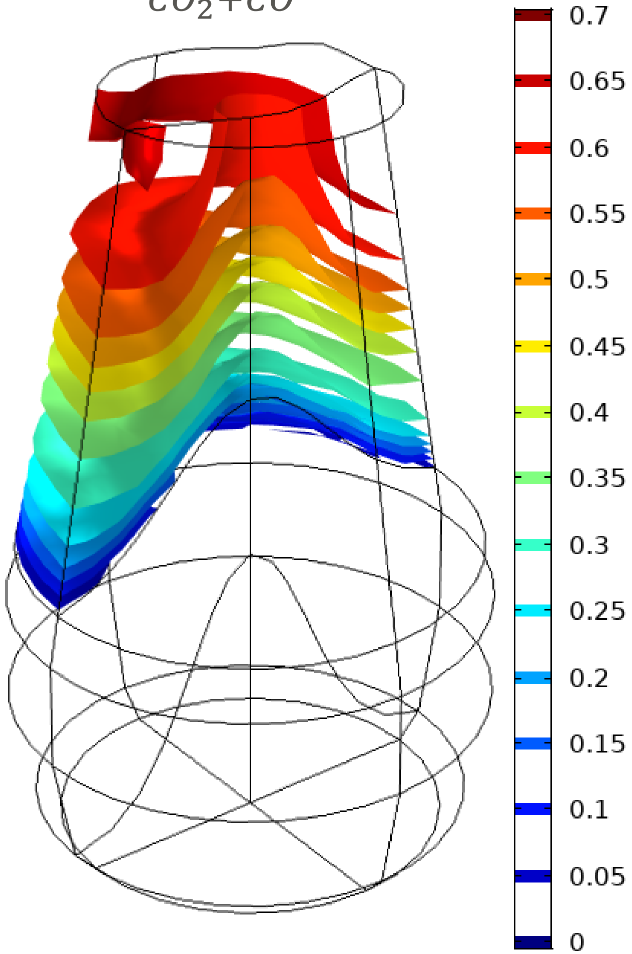


Results of 3d BF model

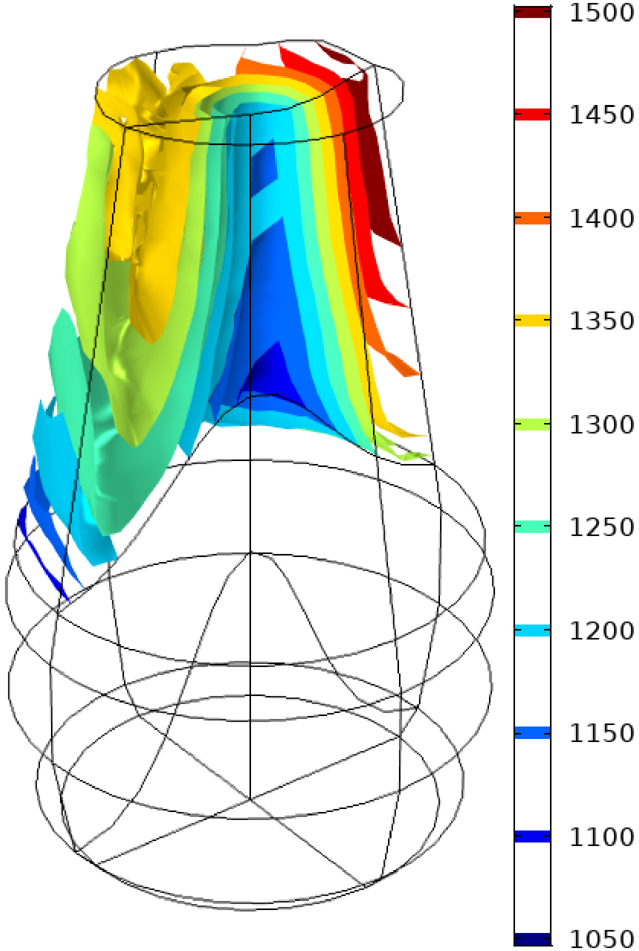
› gas temperature (°C)



› $\eta_{CO}=\frac{CO_2}{CO_2+CO}$ utilization



› solid density (kg/m³)



Conclusions on BF model of the dry stack zone

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- Multi-physics-based stack monitoring model (“virtual BF”) developed
- Main results of the model describes the state of the dry stack (temperature, flow distribution, compositions, reduction degree, etc.)
- Various BF operational data can be used as input to the model (charging material types, blast data, tapping data, etc.)
- Operational measurements can be used to calibrate the model (top gas measurements, SOMA and 3D radar, wall pressures, etc.)
- Results of operational measurements are not always plausible and may cause implausible model results → a careful check needed

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