



Dynamic model of a TSL furnace, developed with SimuSage™ software

RF van Schalkwyk,

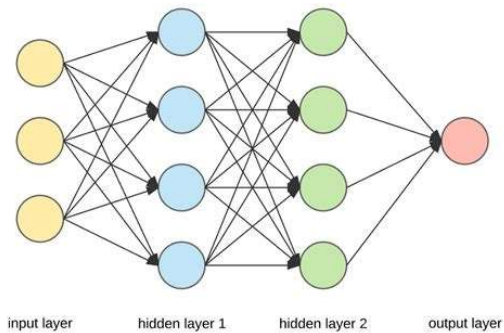
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Helmholtz Institute Freiberg for Resource Technology

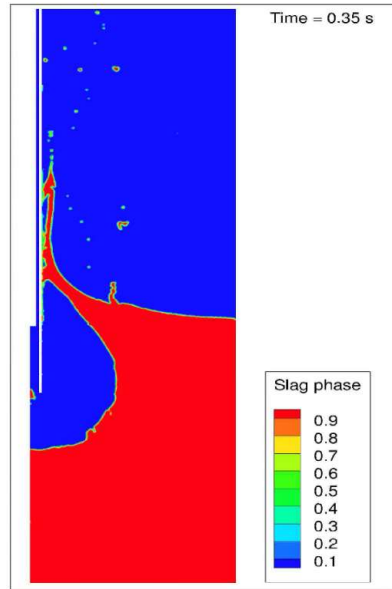


Dynamic Modeling Methods



Neural Networks coupled with Autoregressive model

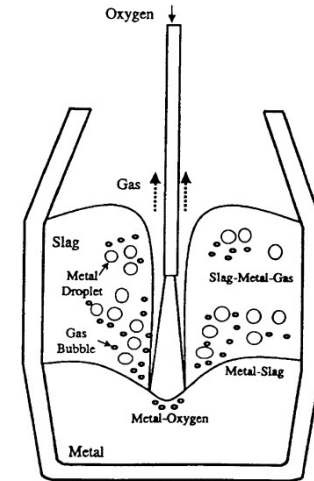
Georgalli et al. (2002) Minerals Engineering: Ni-Cu TSL



CFD coupled with reaction kinetics

Huda et al. (2012) MMTB: Zinc fuming in TSL

Obiso et al. (2019) MMTB: TSL CFD, viscosity & surface tension in slag



Compartmentalised model, coupled with kinetic rate equations

Rout et al. (2018) MMTB: Basic Oxygen Steelmaking Process

Connected Local Equilibria Method (Compartmentalised model)

Logic

- Furnace consists of well-mixed zones.
- Zones are in internal equilibrium.
- Mass transfer controlled reactions.
- Interface areas and reaction mechanisms are not described

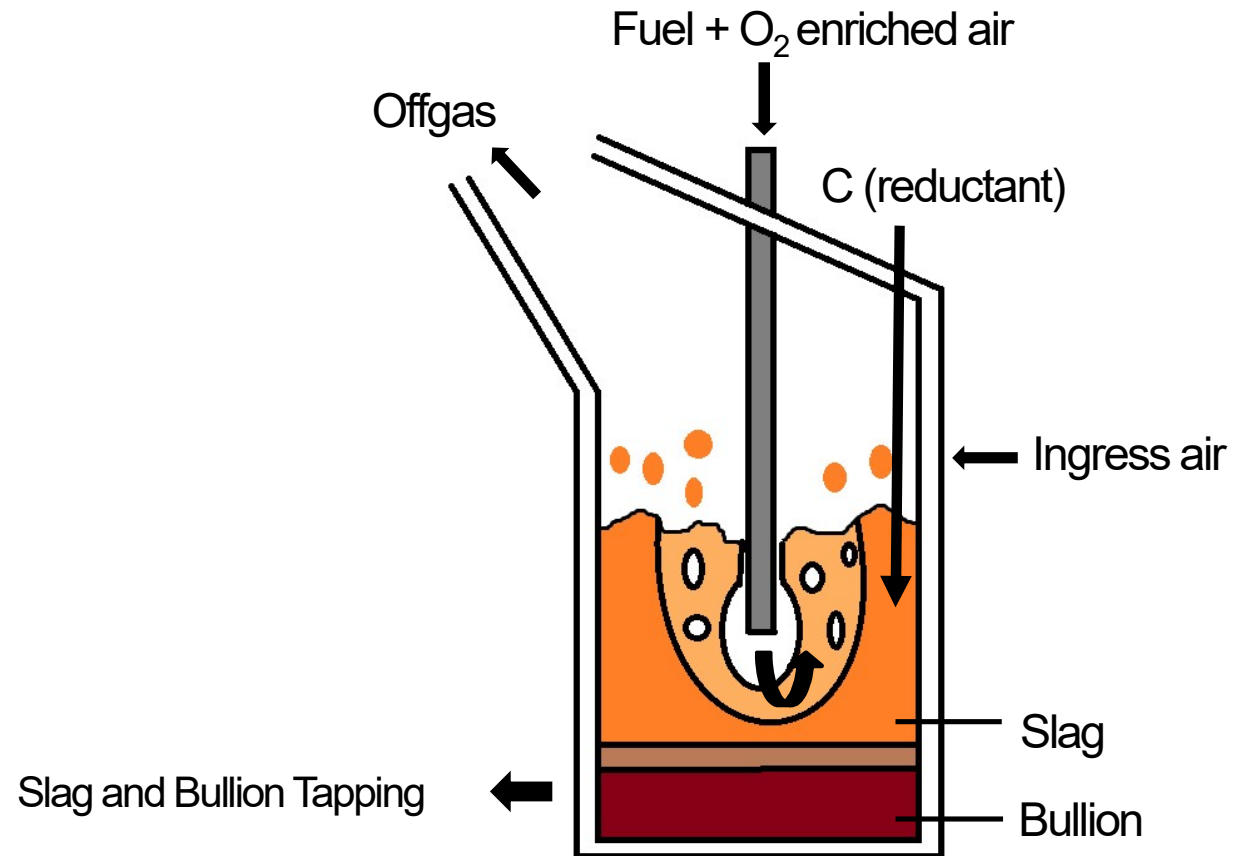
FactSage

- Thermodynamic database.
- Pure components and optimised solutions.
- Calculates equilibrium according to composition and temperature.

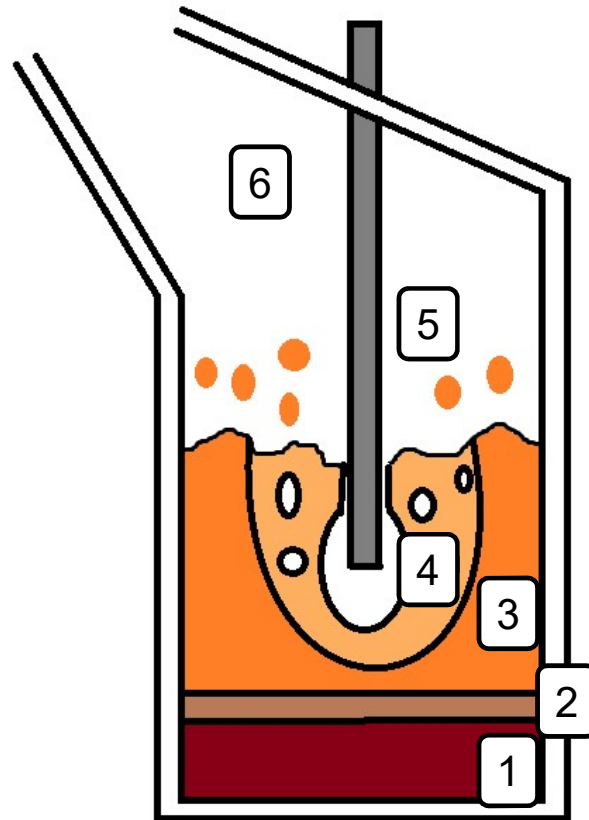
SimuSage

- Flowsheet with connected Equilibrium Zones.
- Mass transfer between zones can be specified.

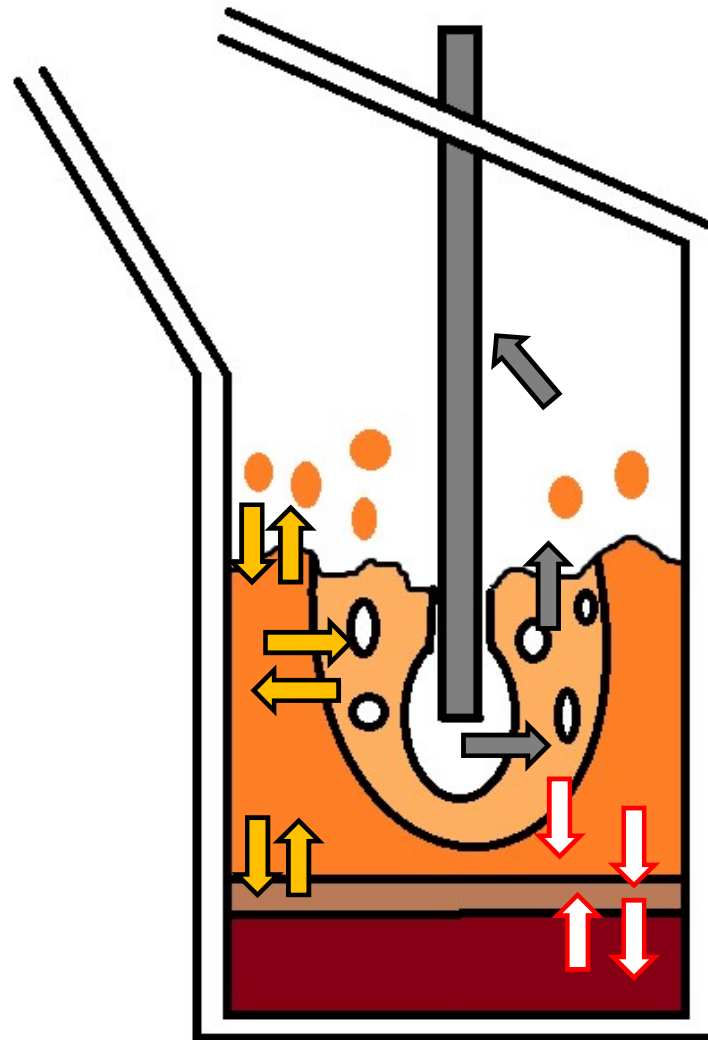
Top Submerged Lance Furnace (TSL)



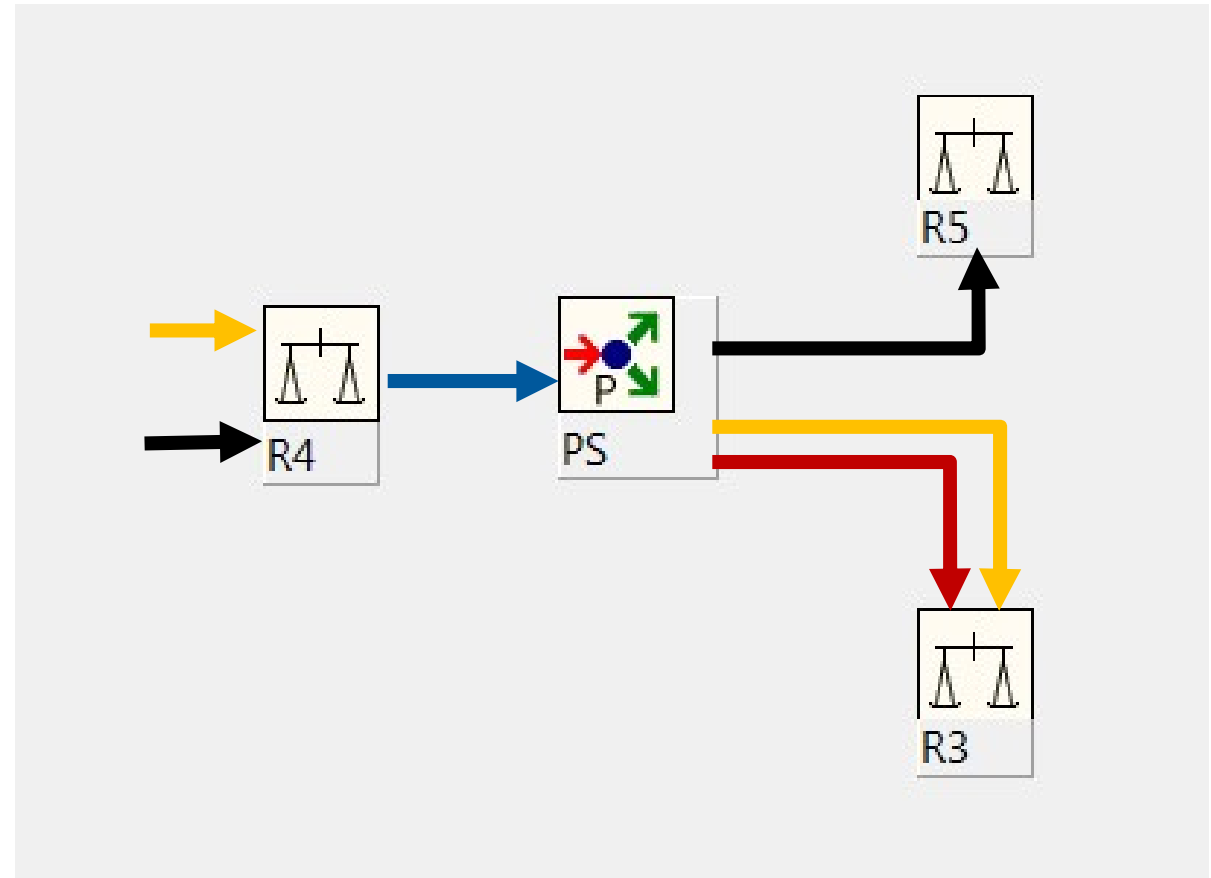
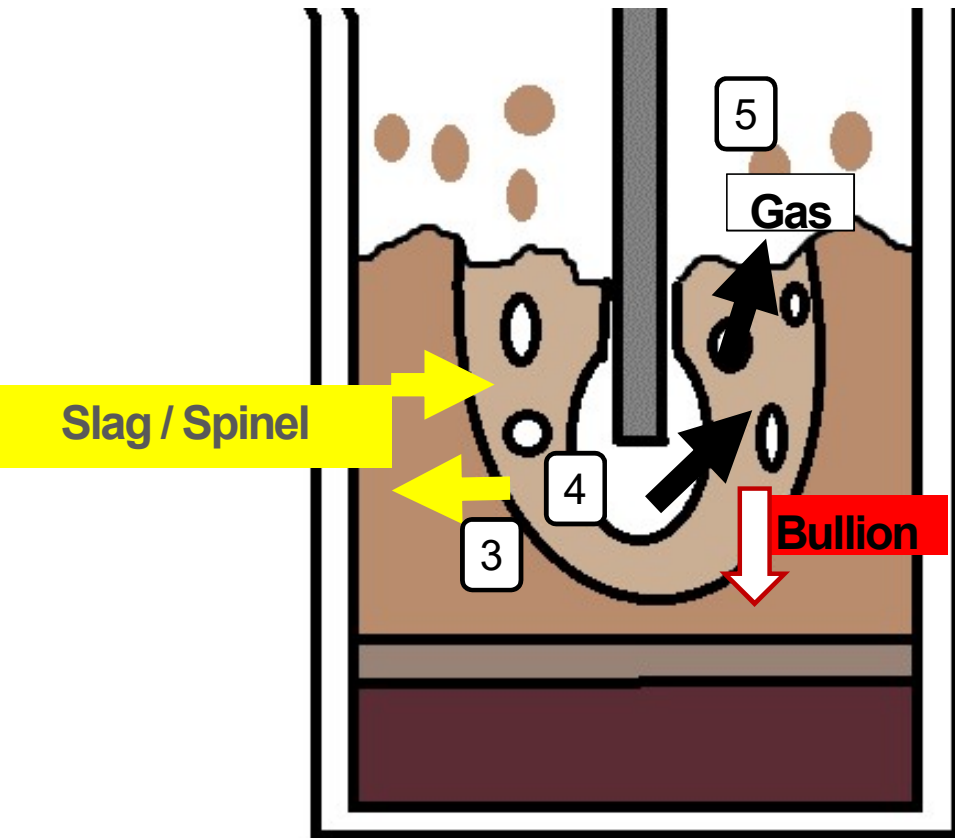
Reactor Zones



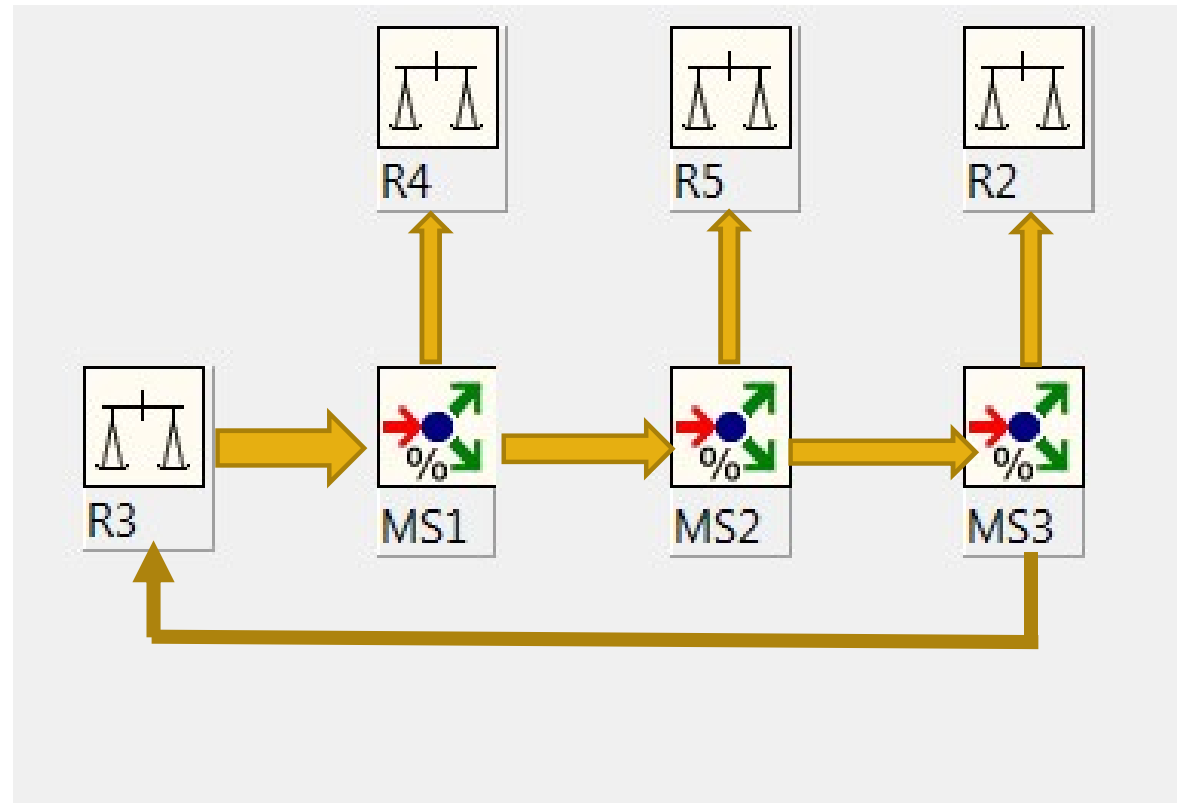
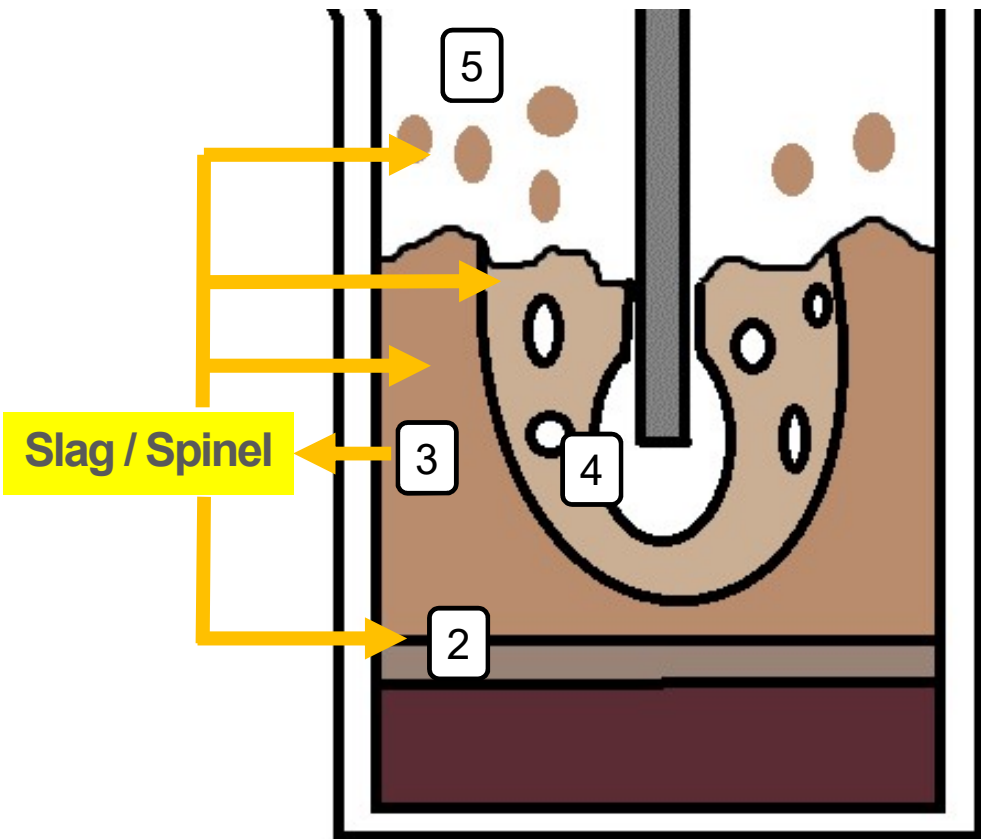
Reactor Zones



SimuSage: Phase Splitters



SimuSage: Mass Splitters



SimuSage Interface

The screenshot displays the SimuSage software interface for a process simulation. The main window, titled 'TForm1', contains a process flow diagram with the following components:

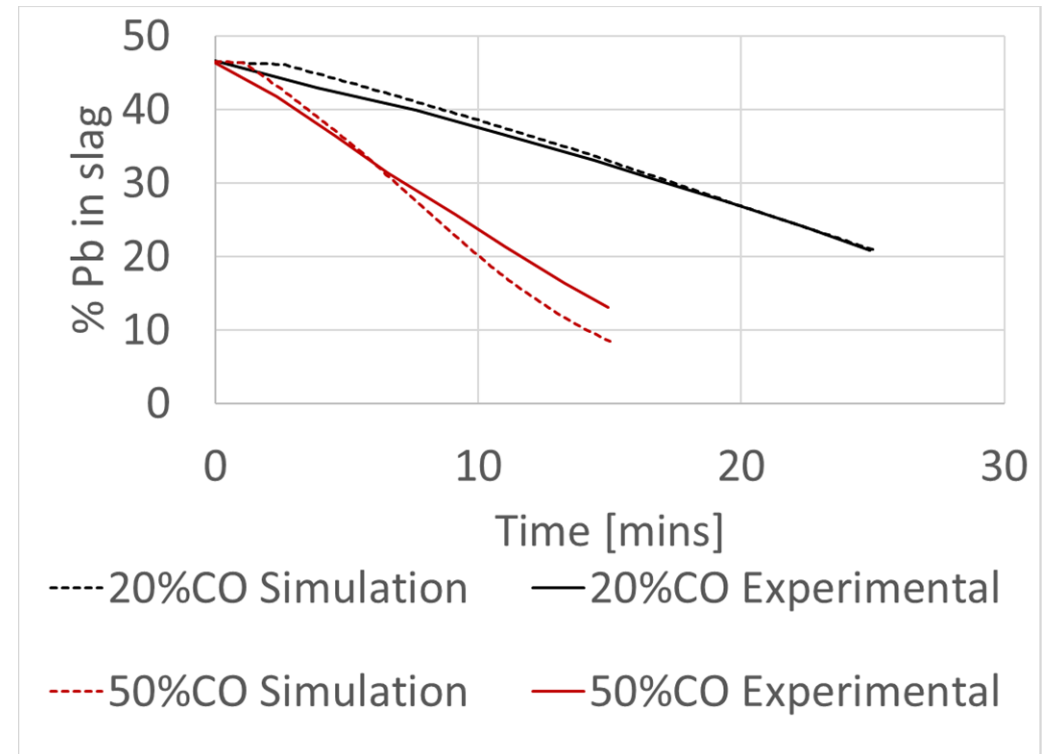
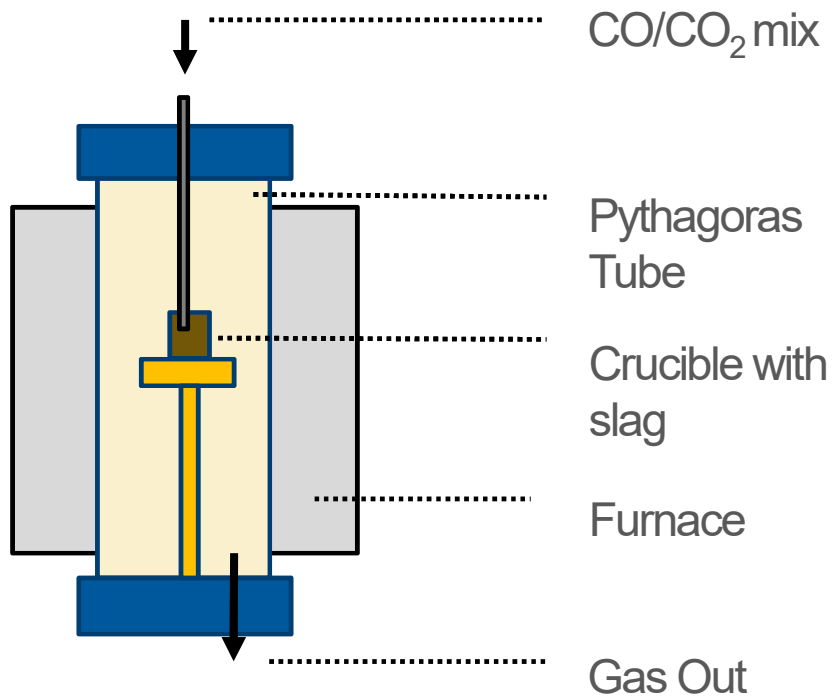
- Reactor R1: Metal Eq Reactor**
 - Inputs: InR1_It2 (0 kg), InR1_It1 (0 kg)
 - Outputs: MTS_Out (0 kg), R1_MTS (2700 kg rate, 19000 kg limit), R1_FrSp (1 kg min limit), R1_It2 (0.1 kg, absolute value going to R2), R1_R2 (1000 kg)
- Reactor R2: Metal/Slag Eq Reactor**
 - Inputs: InR2_It8 (0 kg), InR2_It3 (0 kg)
 - Outputs: R2_PhSp, PhSpR2_M, PhSpR2_SG
- Reactor R3: Slag Eq Reactor**
 - Inputs: InR3_It5 (0 kg), InConc (968 kg), InR3_It4 (0.0001 kg)
 - Outputs: R3_PhSpR3, PhSpR3_M, R3_STS (2400 kg rate, 1700 kg limit, 1 kg min limit), PhSpR3_G_F (968 kg/iteration)
- Reactor R4: Carbon/Splash Zone**
 - Inputs: InR4_It6 (0 kg), InR4_It7 (0 kg)
 - Outputs: R4_PhSp, PhSpR4_MS_FrSp, PhSpR4_G_F
- Other Components**
 - R3_It3**: 8 kg/iteration (Fuel), 332 kg/iteration (InGasCO2)
 - R3_It4**: 0.4, 3000 kg (absolute value going back to R2)
 - R3_It5**: 0.6
 - R3_It6**: 0.2, 6000 kg (absolute value going to R4)
 - R3_It7**: 0.2, 6000 kg (absolute value going to R4)
 - R3_It8**: 0.2, 6000 kg (absolute value going to R4)
 - R3_It9**: 0.2, 6000 kg (absolute value going to R4)
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 - R3_It98**: 0.2, 6000 kg (absolute value going to R4)
 - R3_It99**: 0.2, 6000 kg (absolute value going to R4)
 - R3_It100**: 0.2, 6000 kg (absolute value going to R4)

At the bottom of the interface, a status bar shows the following information:

- 10:32:54: P:\Research\Dundee_Precious_Metals\DPMT SimuSage\TSL DPMT Gas Split 24052019-backup\TSLv1P.exe started.
- 10:32:54: SimuSage version is 1.20.0 (Build 11) for Lazarus , ChemApp version is 7.2.2

PbO reduction example: comparison to literature

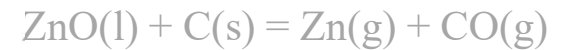
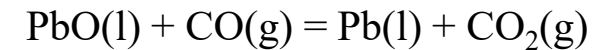
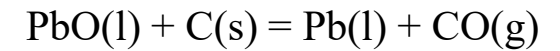
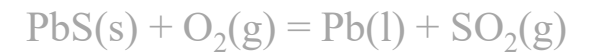
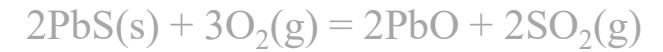
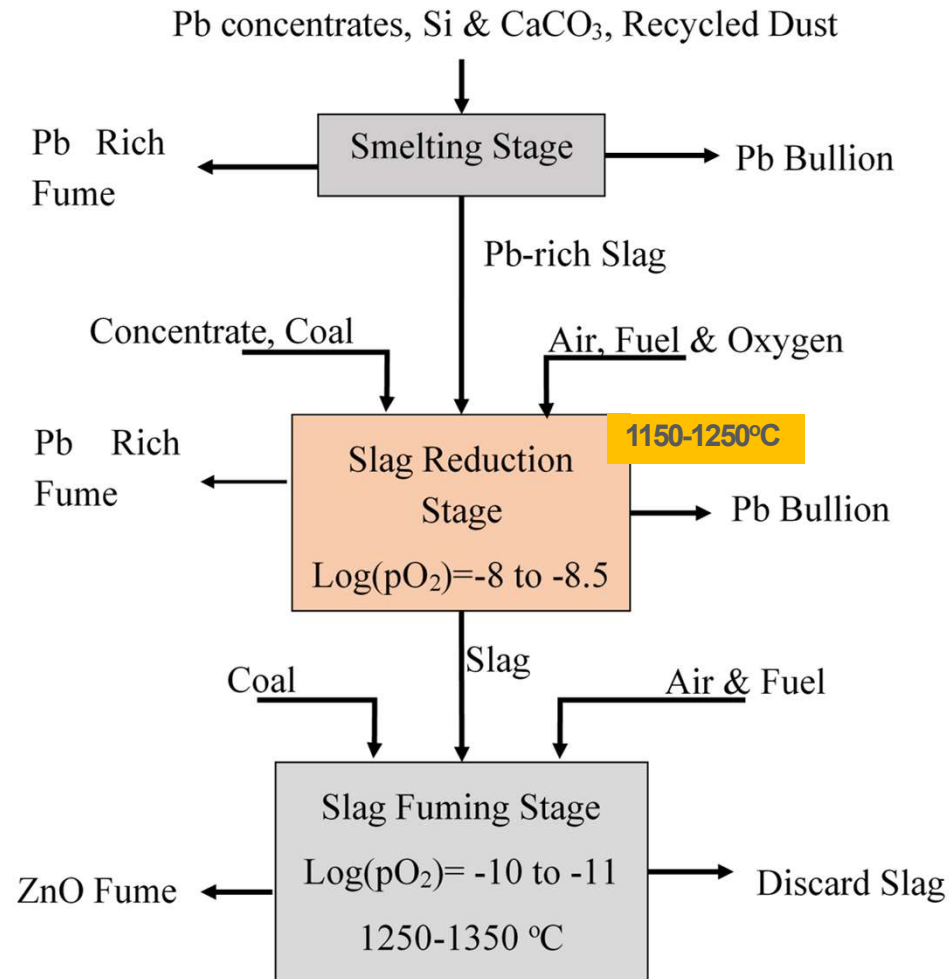
Reduction of PbO-FCS slag at 1220 °C



Experimental data from:
Jahanshahi & Wright (2017)

$$\dot{m} = k \cdot X_{Pb}$$

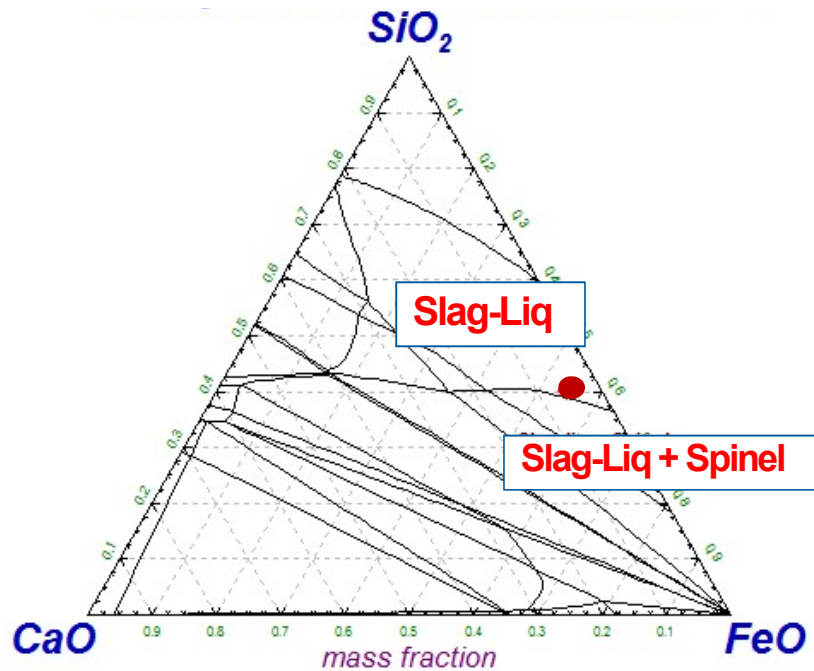
PbO Reduction Example



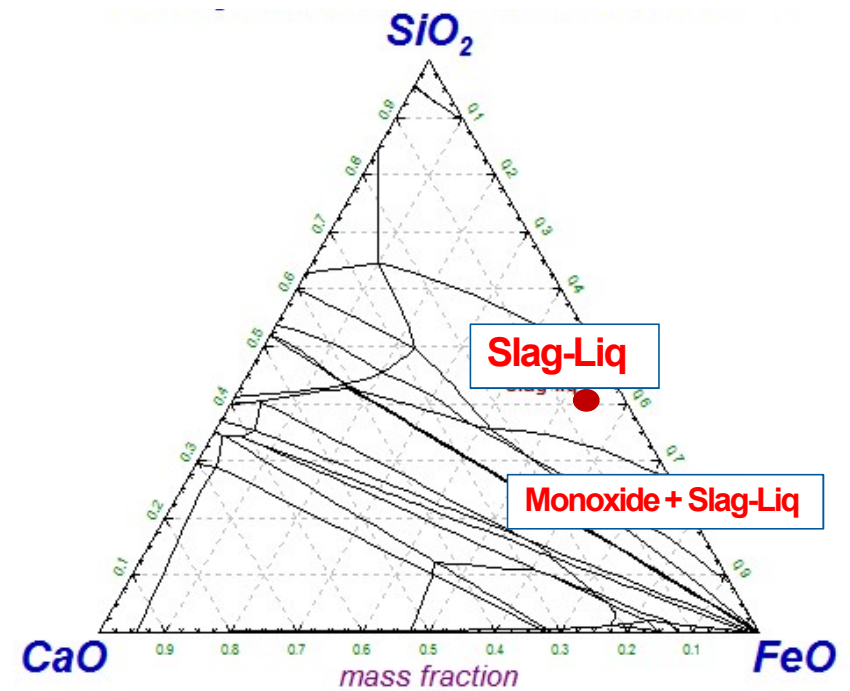
Gu et al. (2012)

PbO Reduction Slag Chemistry: Selection of databases and solutions

SiO₂-FeO-CaO
 ZnO = 9 %, PbO = 28 %, Log pO₂ = -8
 T = 1200 °C

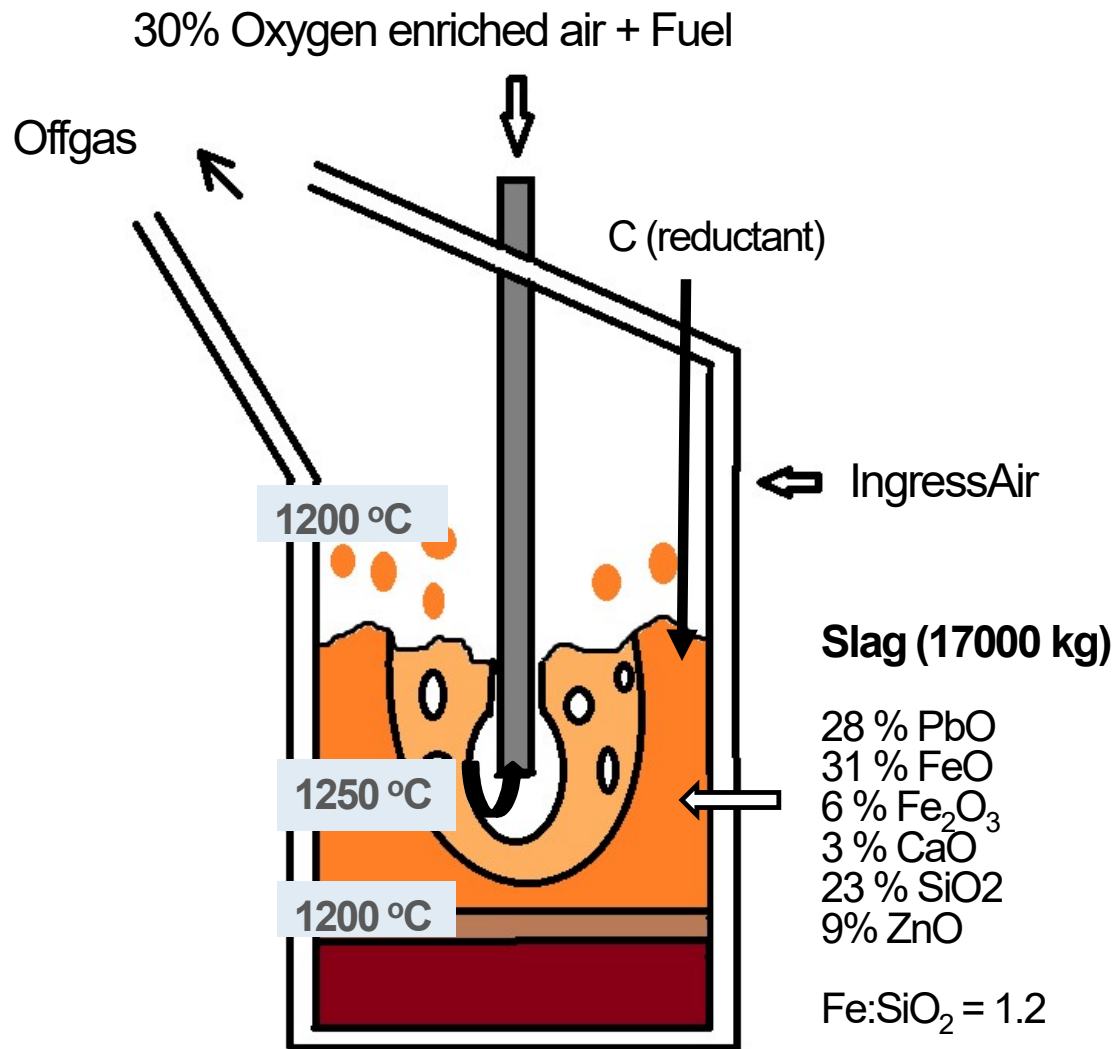


SiO₂-FeO-CaO
 ZnO = 11 %, PbO = 5 %, Log pO₂ = -9
 T = 1200 °C

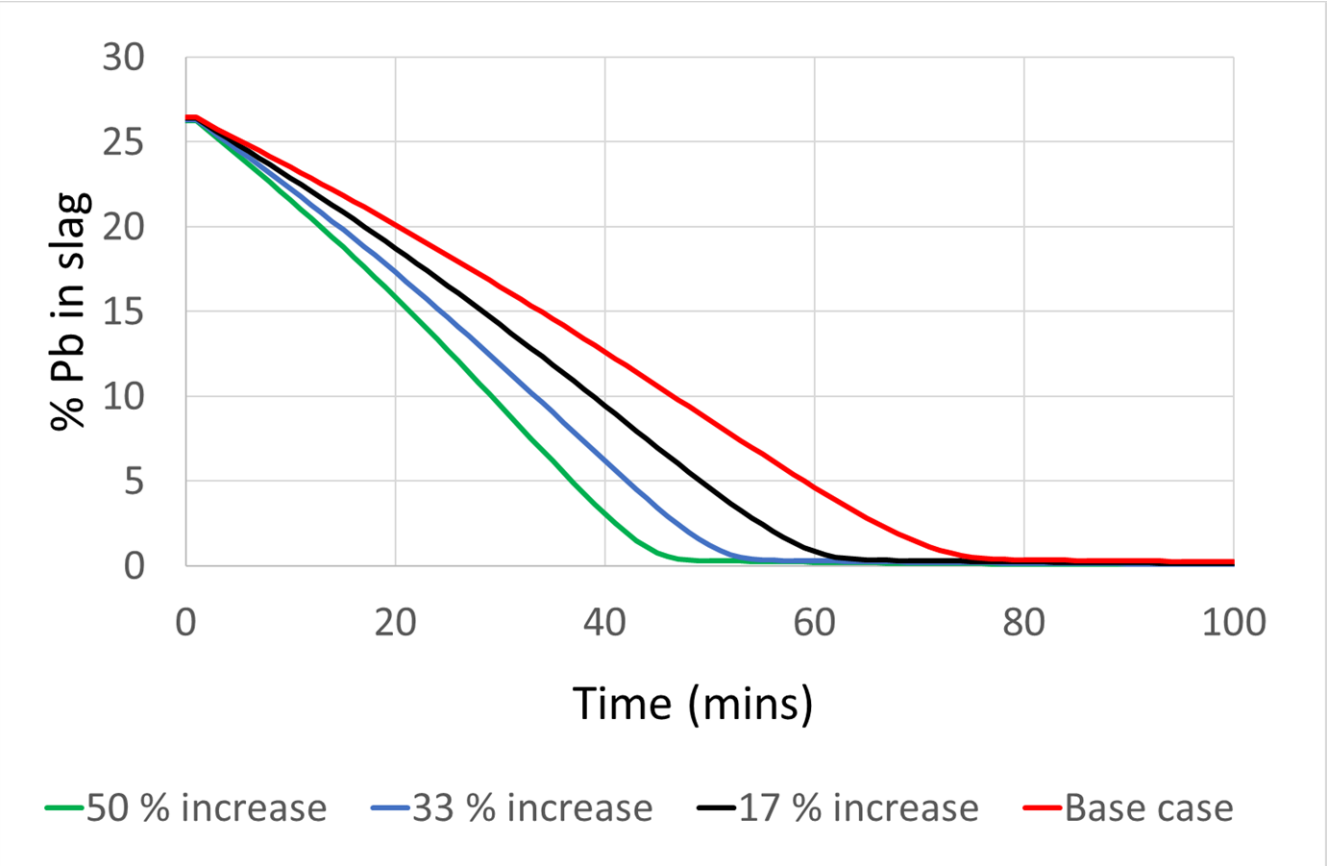


FactSage Study: main phases to form will be Bullion, Slag and Spinel

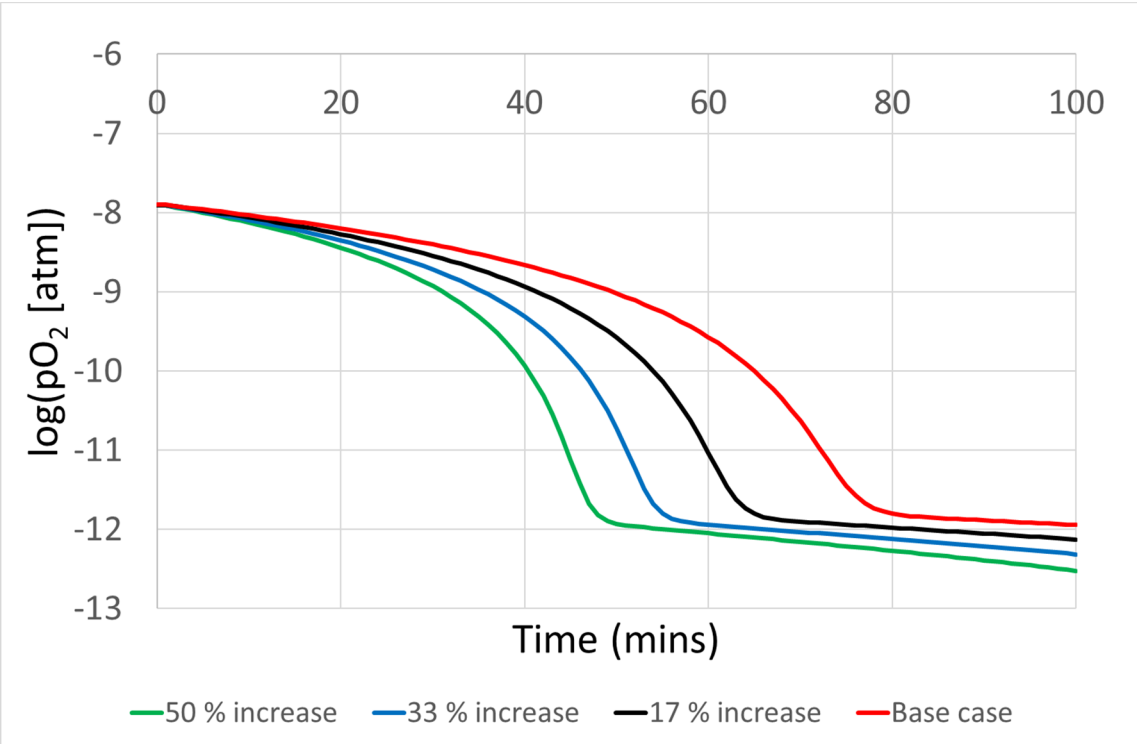
PbO slag reduction: Industrial size



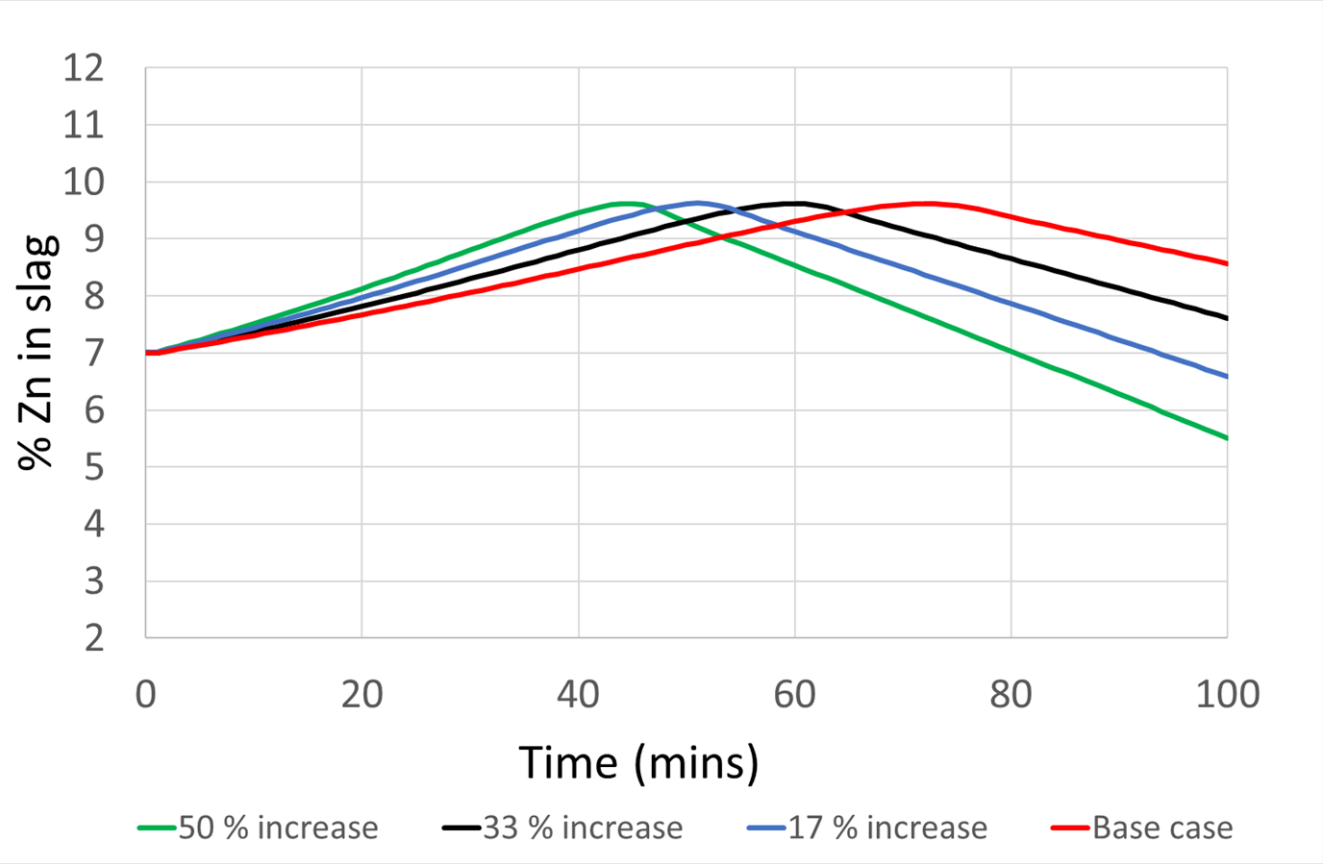
Effect of increased coal addition



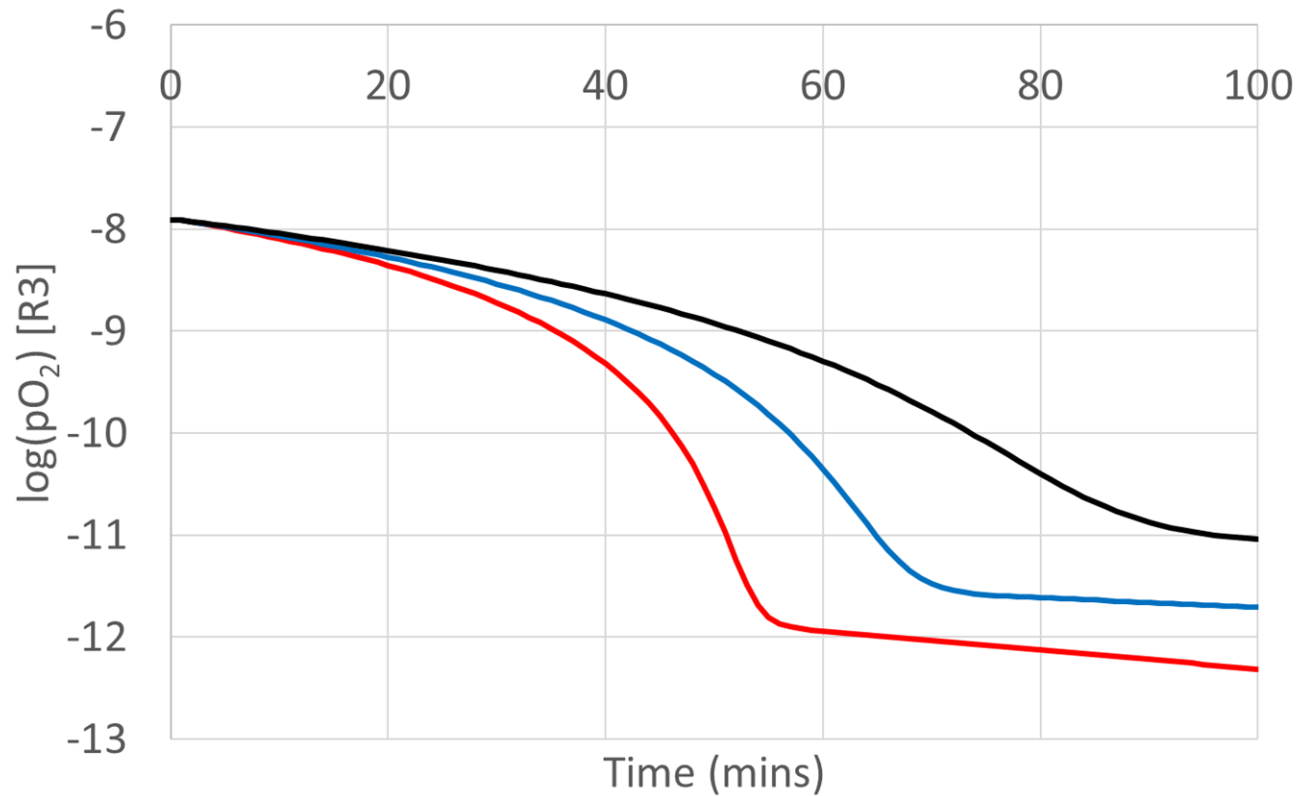
Effect of increased coal addition



Effect of increased coal addition



Effect of increased splash

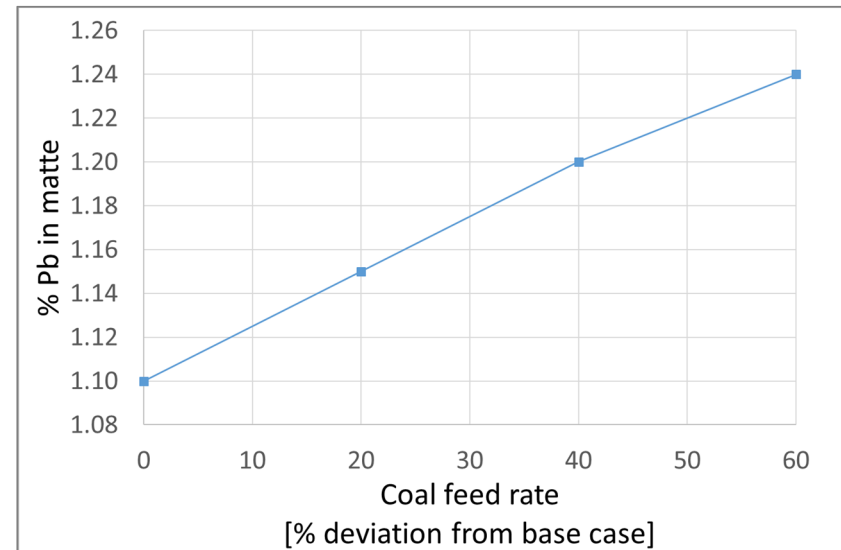
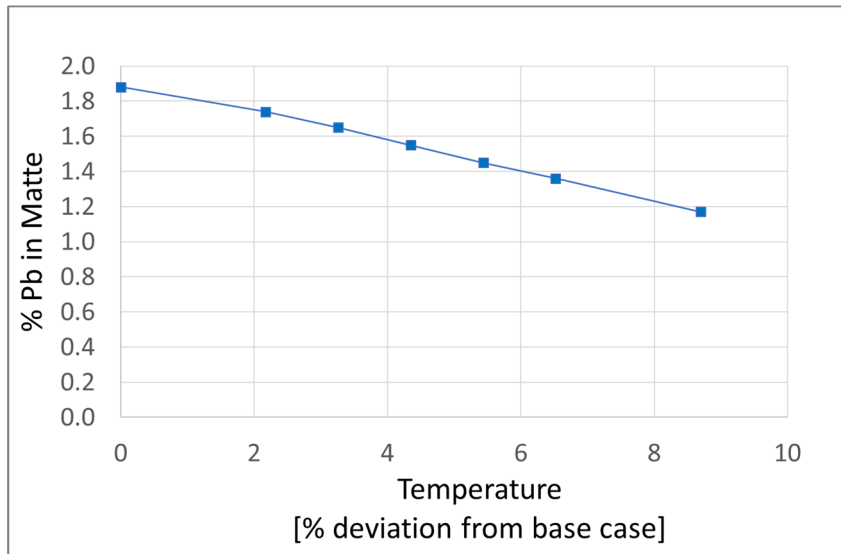


— Base case

— 100 % increase in splash

— 200 % increase

Industrial Cu Matte TSL Smelting Application – Calibrated on site



Conclusions

- Model applied to predict trends and test parameters in PbO reduction process – can be adapted for other processes as shown for industrial copper matte smelting.
- Model can be extended to consider more elements, if thermodynamic data are available.
- Model accuracy depends on suitable choices for mass transfer parameters i.e. the flow of material between the different zones.

Outlook

- Accuracy improvement: better flow modelling, link to CFD.
- Accuracy improvement: better thermal profile, link to measurements at TUBAF.
- Model Thermal profile by using temperature calculation in SimuSage.
- Validation of model vs. experimental data or operational data.

References

- Jahanshahi S, Wright S. Kinetics of Reduction of CaO-FeO x-MgO-PbO-SiO₂ Slags by CO-CO₂ Gas Mixtures. Metallurgical and Materials Transactions B. 2017 Aug 1;48(4):2057-66.
- Georgalli GA, Eksteen JJ, Reuter MA. An integrated thermochemical-systems approach to the prediction of matte composition dynamics in an Ausmelt® nickel–copper matte converter. Minerals Engineering. 2002 Nov 1;15(11):909-17
- Gu H, Song X, Lan X, Ross B, Ross A, Markus R. Design and commissioning of the Ausmelt TSL lead smelter at Yunnan Tin Company Limited. In International Smelting Technology Symposium: Incorporating the 6th Advances in Sulfide Smelting Symposium 2012 May 9 (pp. 11-21). The Minerals, Metals & Materials Society Orlando, Florida, USA
- Huda N, Naser J, Brooks G, Reuter MA, Matusewicz RW. Computational fluid dynamic modeling of zinc slag fuming process in top-submerged lance smelting furnace. Metallurgical and Materials Transactions B. 2012 Feb 1;43(1):39-55
- Rout BK, Brooks G, Rhamdhani MA, Li Z, Schrama FN, Sun J. Dynamic Model of Basic Oxygen Steelmaking Process Based on Multi-zone Reaction Kinetics: Model Derivation and Validation. Metallurgical and Materials Transactions B. 2018 Apr 1;49(2):537-57
- Obiso D, Kriebitzscha S., Reuter MA, Meyer B. The importance of viscous and interfacial forces in the hydrodynamics of the Top-Submerged-Lance furnace. . Metallurgical and Materials Transactions B 2019 (in press)