GTT Annual Users' Meeting | July 2015

A Thermodynamic Model for the Waelz Kiln

Authors

Eng. Bruno Reis

Prof. Dr. Nestor Heck

Research by

NTCm

Nucleus for Computational Thermodynamics

UFRGS

Federal University of Rio Grande do Sul. Brazil

Summary

- Waelz Kiln
- Objective
- Methodology
- Results
- Conclusions
- Further Work

Waelz Kiln

- European Commission: “Best Available Technology”
- Recycling of Zn rich wastes
  - Metallurgical wastes
  - Obsolete scrap
  - Electric Arc Furnace Dust (EAFD) – 80% in 2009
- In Brazil: one plant in state of commissioning
  - Votorantim Group, Juiz de Fora, Rio de Janeiro
- Rotary Kiln
  - Length: 38.5 - 70m
  - Diameter: 2.5 - 4.5m
  - Slightly tilt
  - Revolution Speeds: 0.5 - 1.6rpm

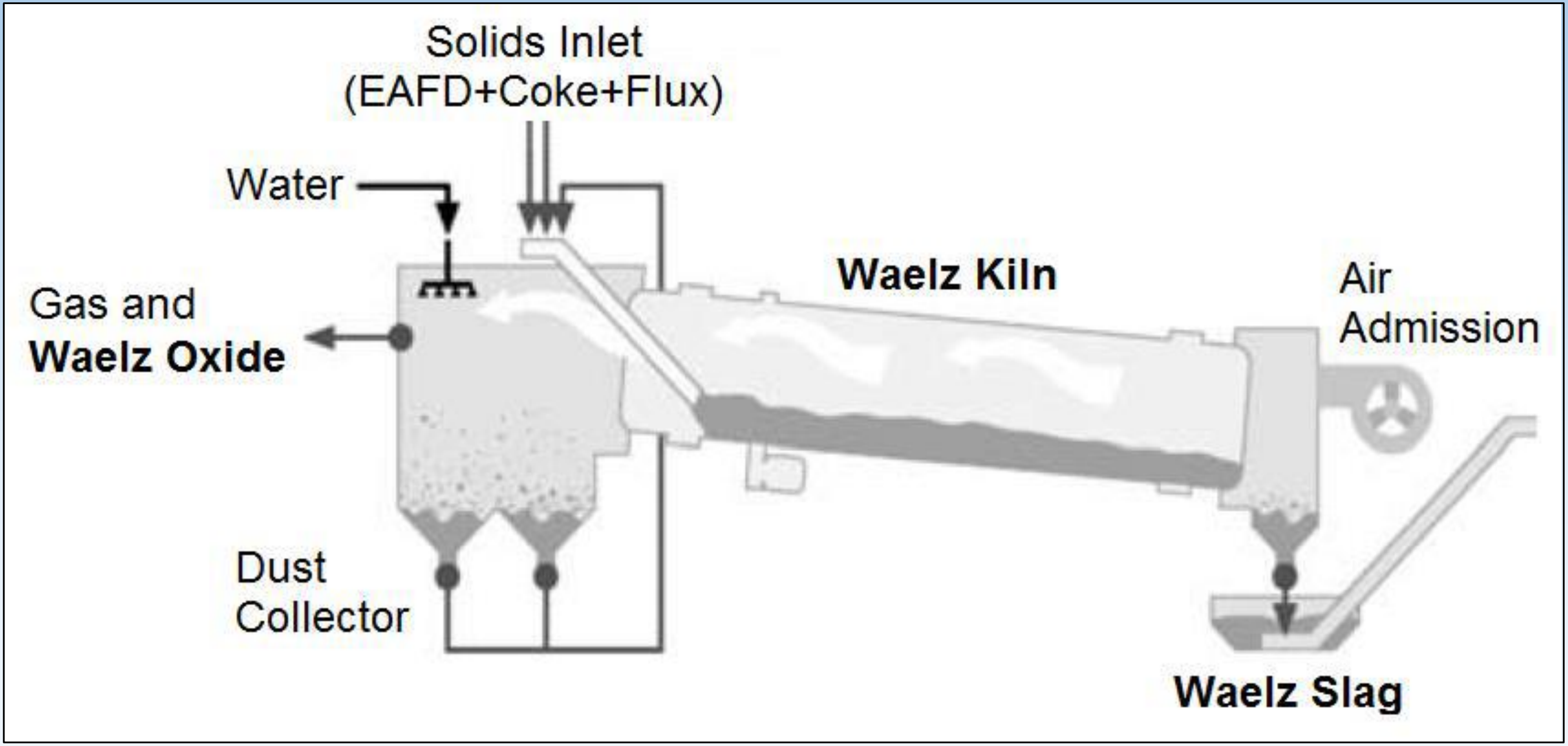
Waelz Kiln

- Load
  - Zn rich waste: pelletized EAFD
  - Coal reducing agent: Coke
  - Slagging agent: Lime or Silica

Operation	EAFD	Coke	Slagging Agent
Basic Mode	≈ 85%	≈ 6%	≈ 9% (Lime)
Acid Mode	≈ 50%	≈ 30%	≈ 20% (Silica)

- Oxygen (air) is injected counter-current
  - Reoxidation of Zn

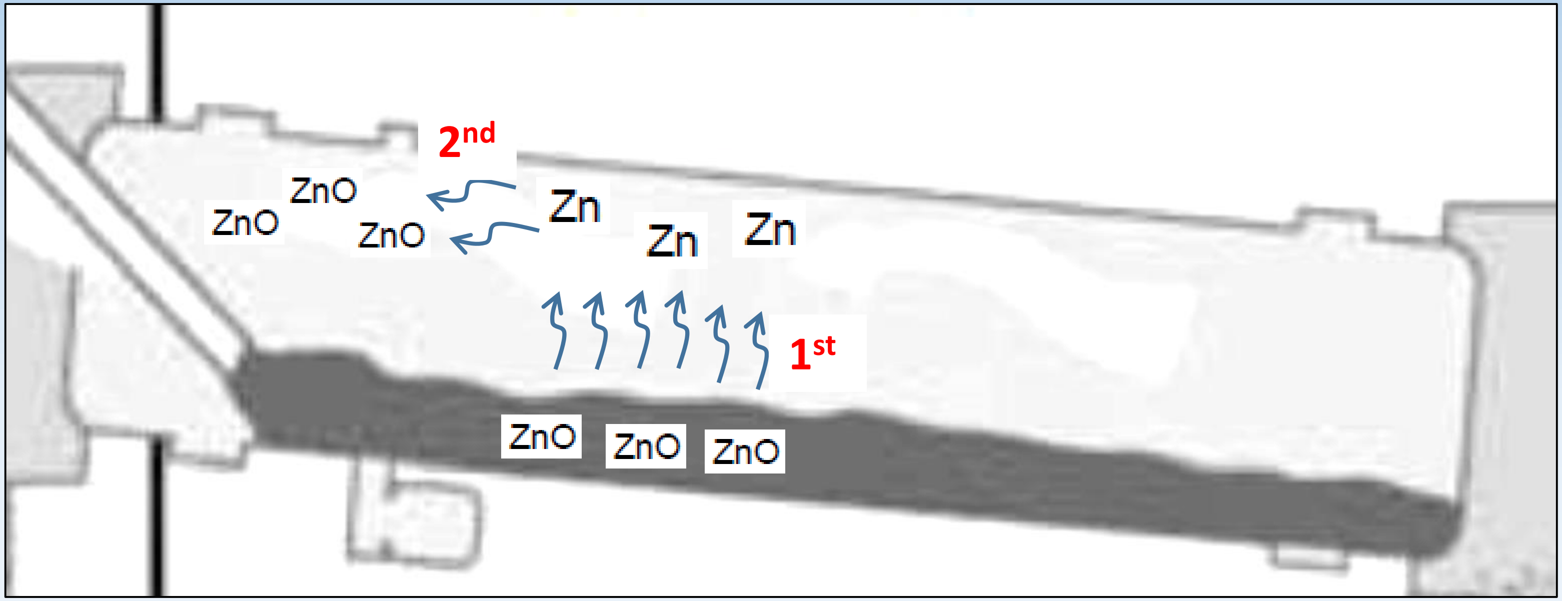
Waelz Kiln



Solids Inlet
(EAFD+Coke+Flux)
Water
Gas and
Waelz Oxide
Waelz Kiln
Air
Admission
Dust
Collector
Waelz Slag

Waelz Kiln

- Zn recovery principle

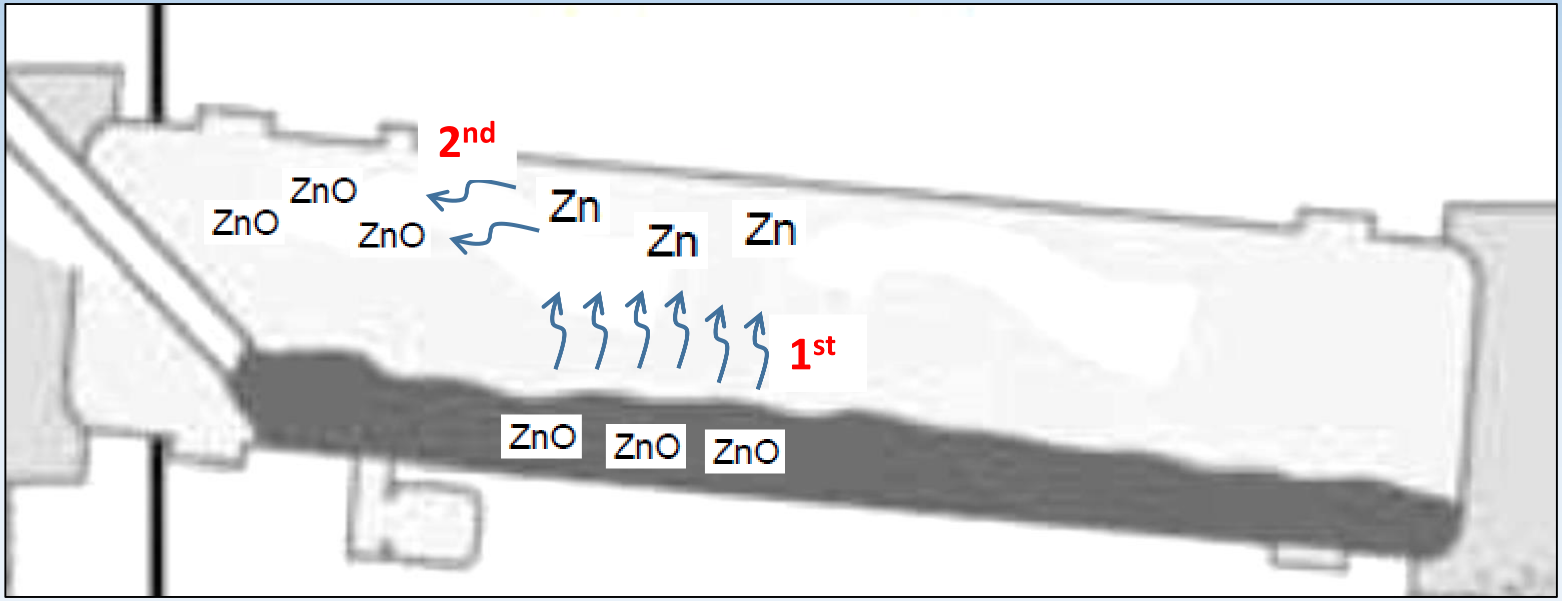


1st reaction: $ZnO + C \rightarrow Zn_{(g)} + CO$

2nd reaction: $Zn_{(g)} + CO + O_2 \rightarrow ZnO + CO_2$

Waelz Kiln

- Zn recovery principle



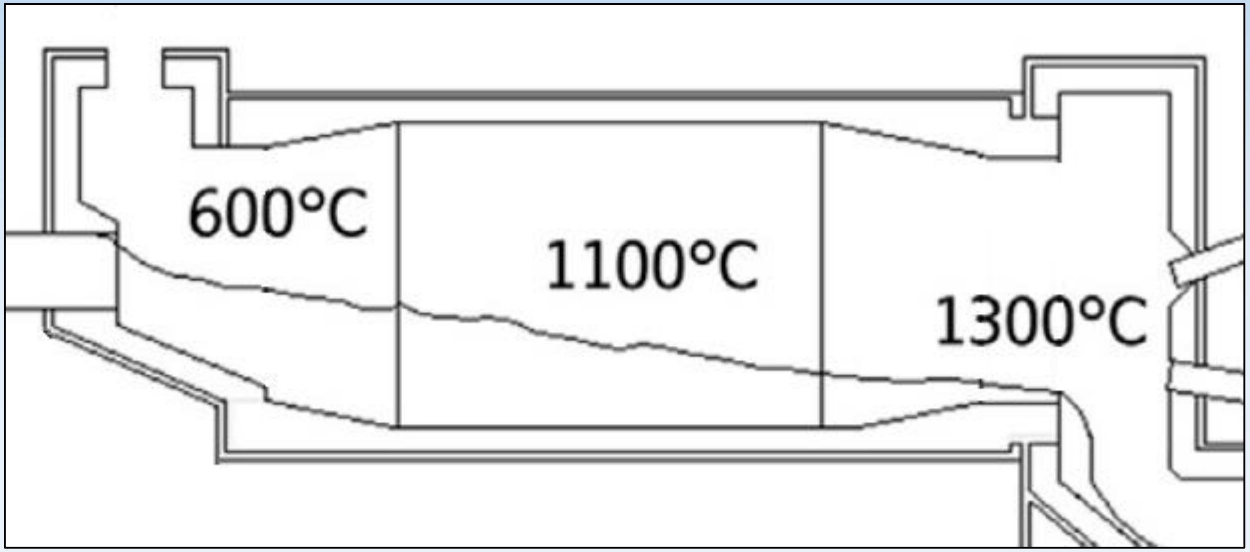
1st reaction: $ZnO + C \rightarrow Zn_{(g)} + CO$

2nd reaction: $Zn_{(g)} + CO + O_2 \rightarrow ZnO + CO_2$

Waelz Oxide

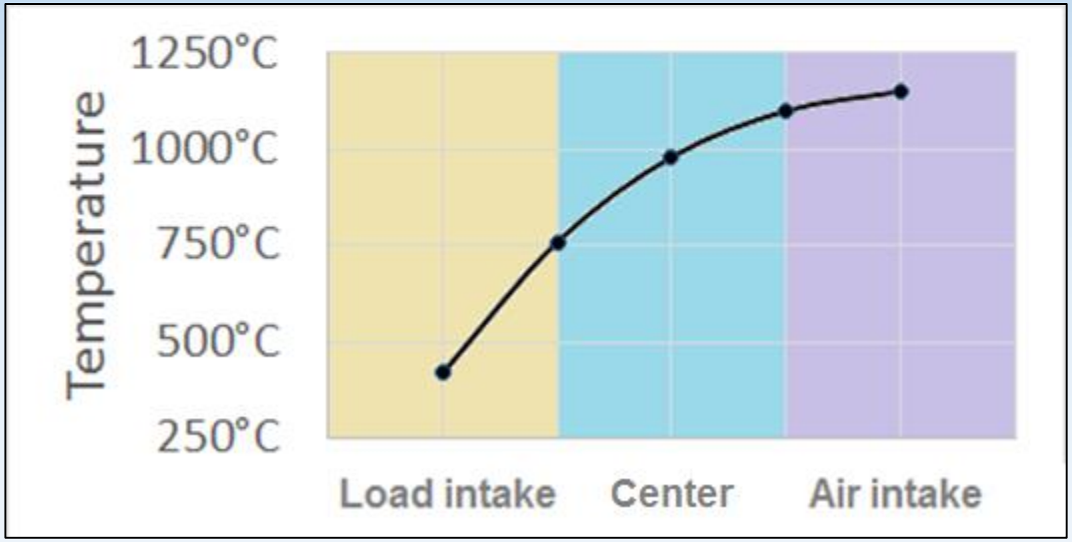
Waelz Kiln

- Temperature profile
  - [Mombeli *et al.*, 2014]



Waelz Kiln

- Temperature profile
  - Industrial plant [Clay and Schooraad, 1977]



Waelz Kiln

- Other possible reactions…

$ZnO + C \rightarrow CO + Zn\ (vapour)$ . . . . (1)

$Zn\ (vapour) + CO + O_2 \rightarrow ZnO + CO_2$ . . . . . . (2)

$C + O_2 \rightarrow CO_2$ . . . . (3)

$ZnS + CaO + C \rightarrow Zn\ (vapour) + CaS + CO$ . . . (4)

$ZnS + FeO + C \rightarrow Zn\ (vapour) + FeS + CO$ . . . (5)

$2\ (Zn, Fe, Mn)\ O + SiO_2 \rightarrow 2\ (Zn, Fe, Mn)\ O.\ SiO_2$ (6)

$2\ (Zn, Fe, Mn)\ O.\ SiO_2 + Fe \rightarrow Zn\ (vapour) + 2\ (Fe, Mn)\ O.\ SiO_2$ . . . . (7)

$ZnO + Al_2O_3 \rightarrow ZnO.\ Al_2O_3$ . . . . (8)

$ZnO\ Al_2O_3 + Fe \rightarrow Zn\ (vapour) + FeO.\ Al_2O_3$ . . (9)

$3ZnO\ Fe_2O_3 + 3C \rightarrow 3ZnO + 2Fe_3O_4 + 3CO$ . . . (10)

$ZnS + Fe(2Cu) \rightarrow Zn\ (vapour) + FeS\ (Cu_2S)$ . . (11)

$2ZnO.\ SiO_2 + 2C \rightarrow 2\ Zn\ (vapour) + SiO_2 + 2CO$. (12)

$ZnO + CO = Zn\ (vapour) + CO_2$ . . . . (13)

$2\ ZnO.\ SiO_2 + 2\ CO \rightarrow 2\ Zn\ (vapour) + SiO_2 + 2\ CO_2$ (14)

$C + CO_2 \rightarrow 2\ CO$ . . . . (15)

Objective

"Develop a computational thermodynamic model for the Waelz Kiln by means of the SimuSage tool, aiming the reproduction of results found in the literature."

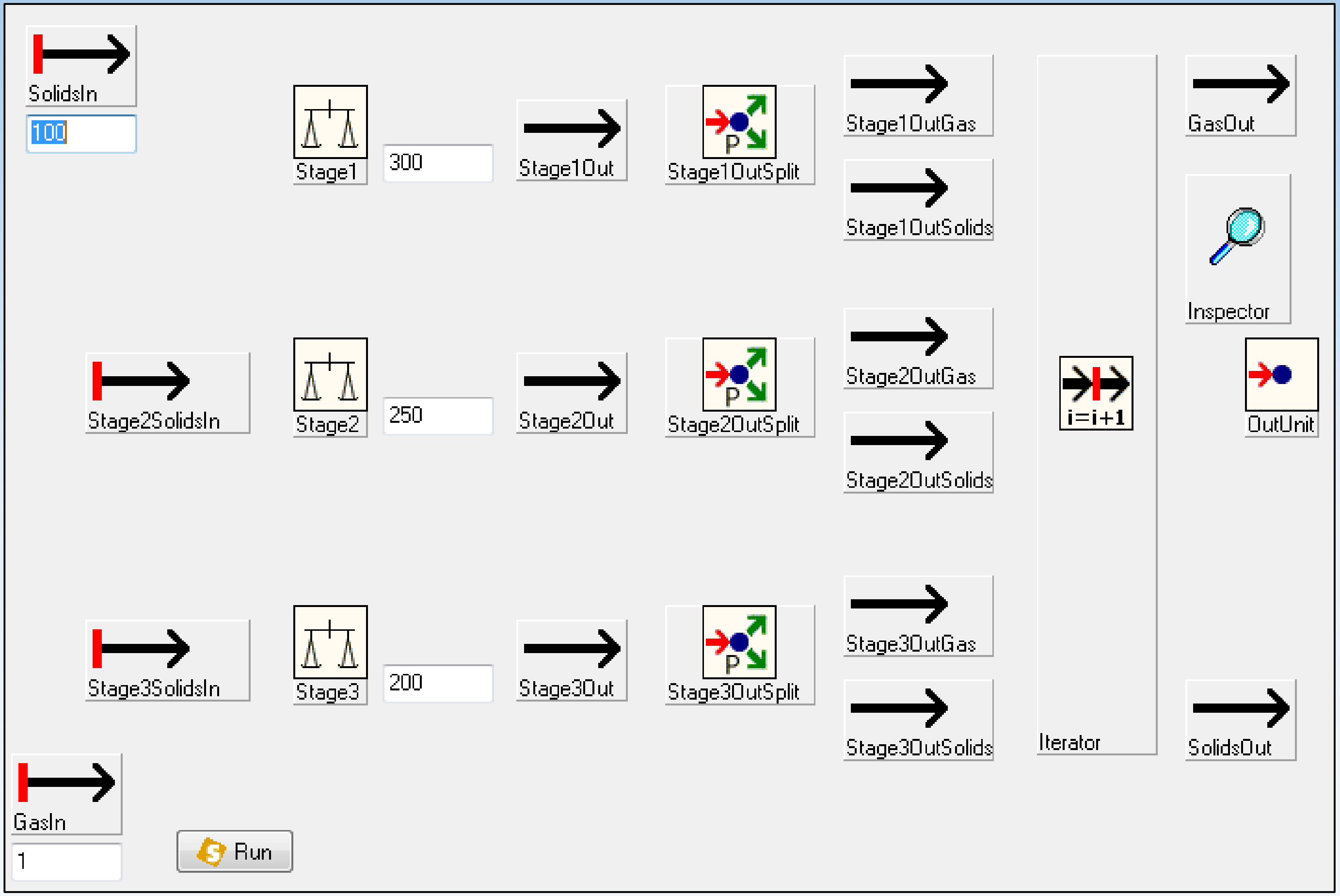
Methodology: Software

- FactSage 6.4 ➔ Thermodynamic data
  - FactPS – pure solids, liquids and gases
  - FToxid – pure solids + SLAGA (single phase)

- Lazarus 1.2.6 ➔ IDE (Integrated Development Environment)
  - Object Pascal language
  - SimuSage 1.12.7 package
    - Concept of using simple unit operations

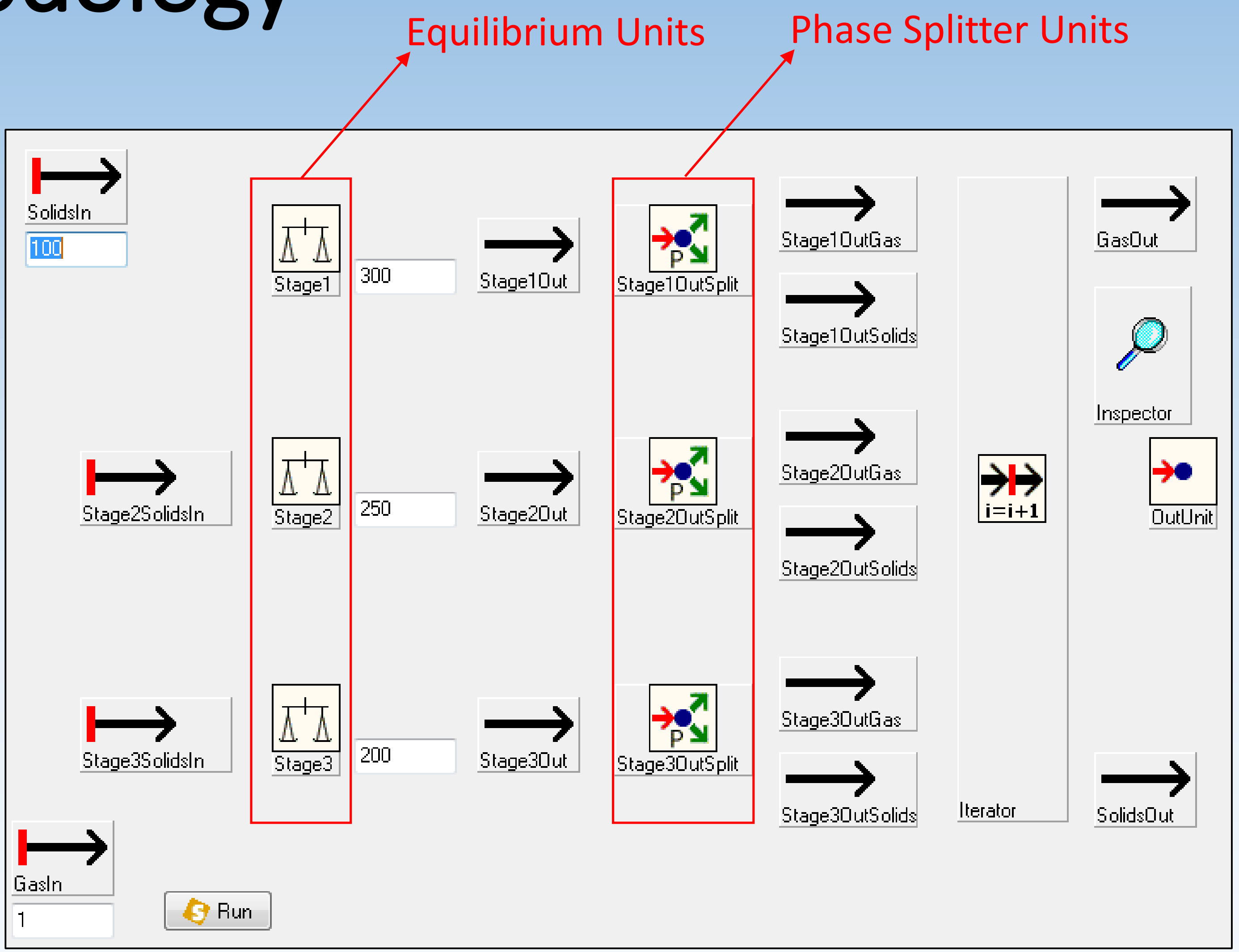
Methodology

SimuSage →

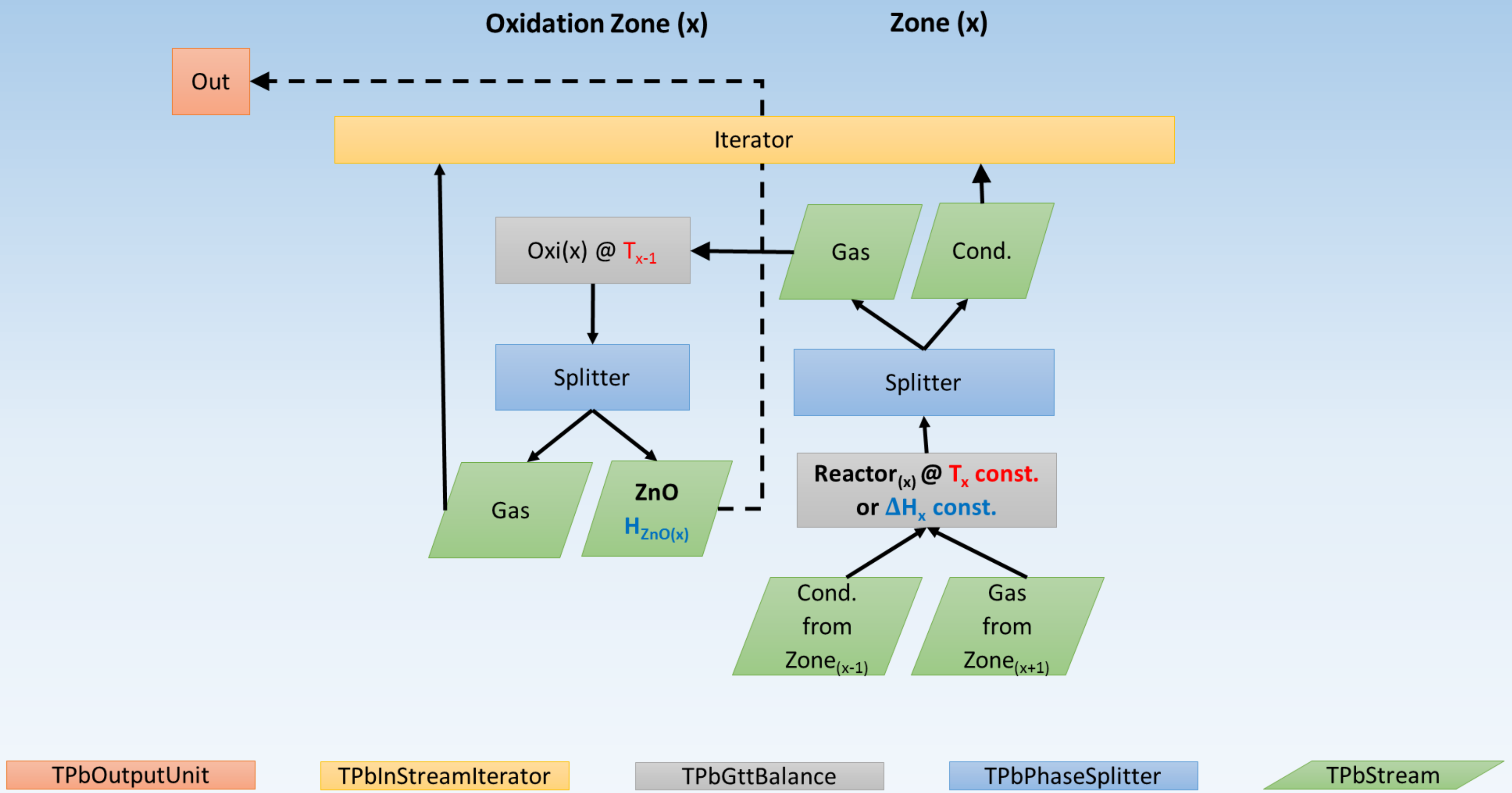


Methodology

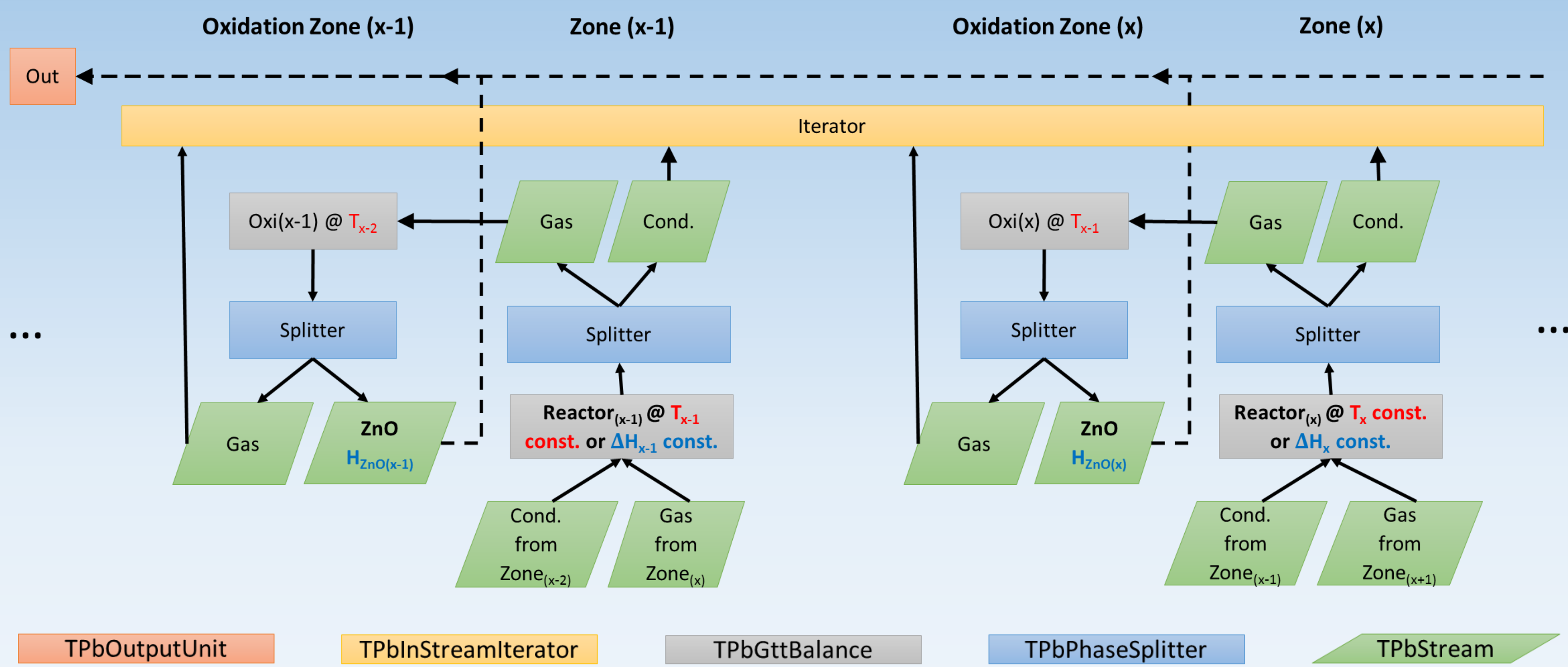
SimuSage ➔



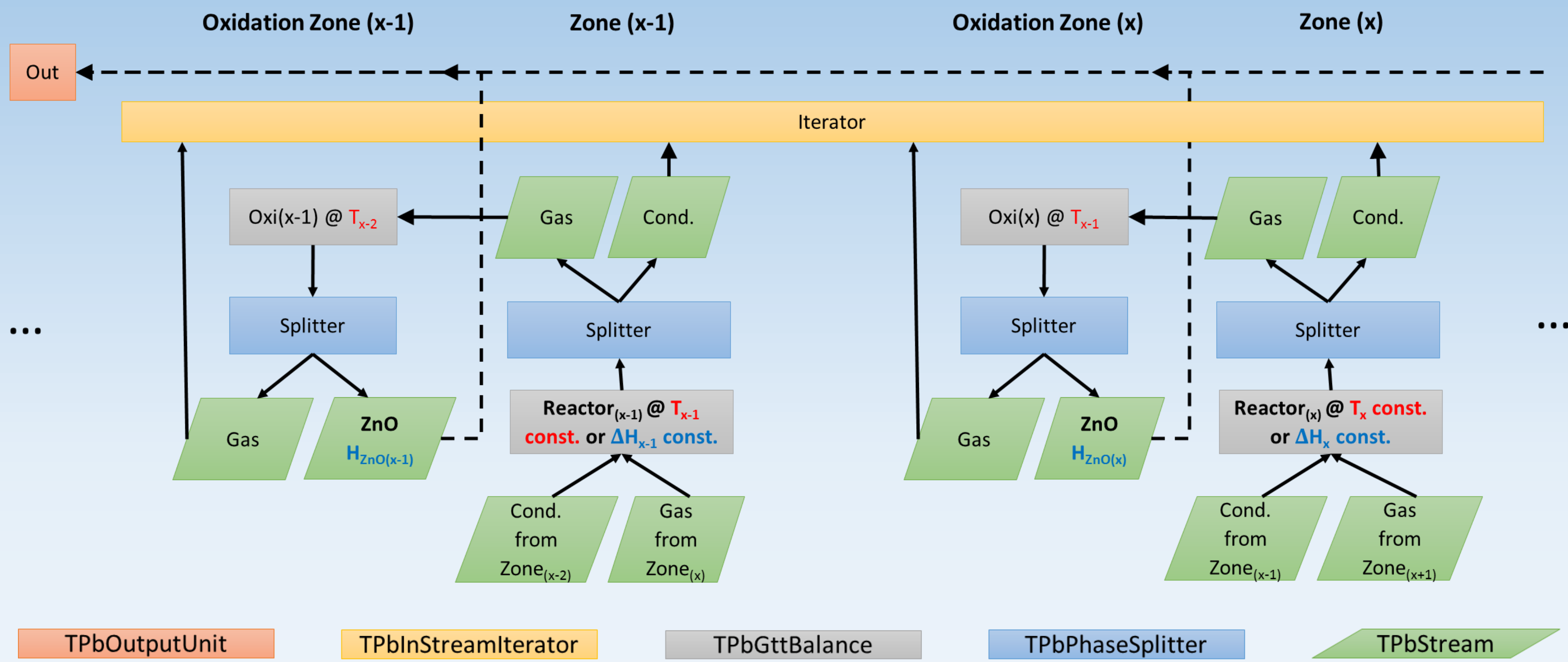
Methodology: SimuSage Modelling



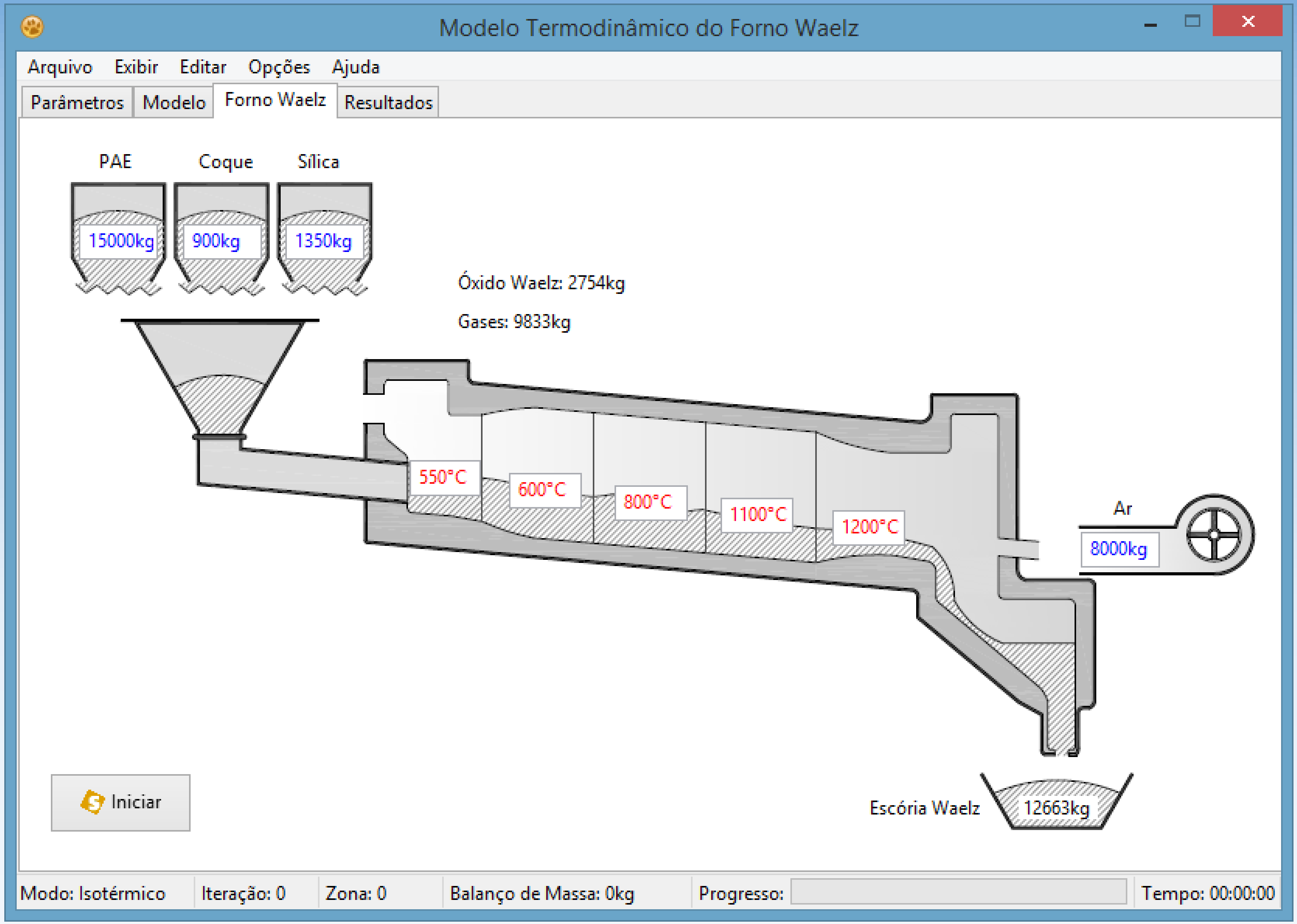
Methodology: SimuSage Modelling

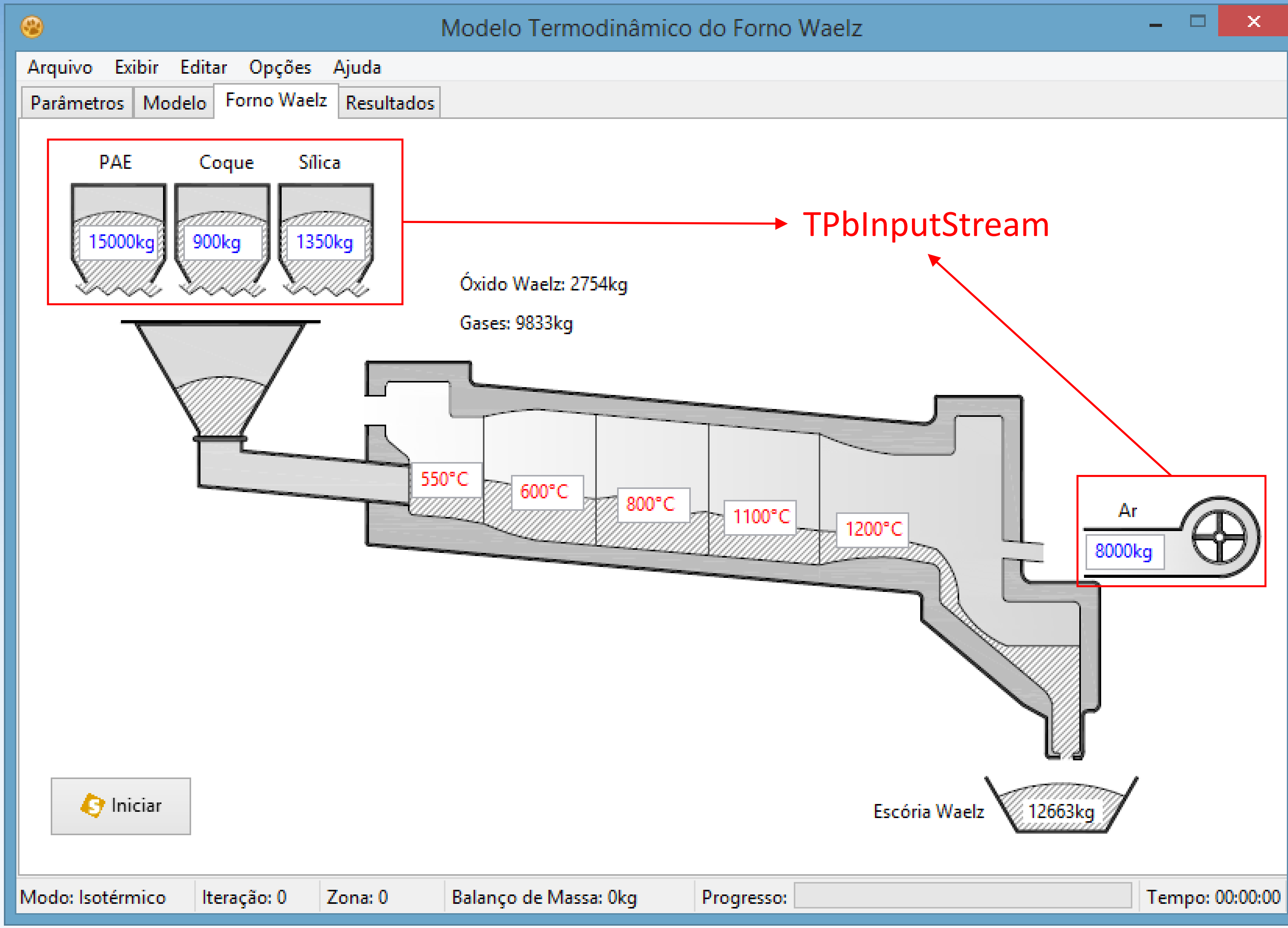


Methodology: SimuSage Modelling



If adiabatic, $\Delta H_{x-1}=(0 - H_{ZnO(x)})$ and $\Delta H_x=(0 - H_{ZnO(x+1)})$.


Modelo Termodinâmico do Forno Waelz
Arquivo
Exibir
Editar
Opções
Ajuda
Parâmetros
Modelo
Forno Waelz
Resultados
PAE
Coque
Sílica
15000kg
900kg
1350kg
Óxido Waelz: 2754kg
Gases: 9833kg
550°C
600°C
800°C
1100°C
1200°C
Ar
8000kg
Iniciar
Escória Waelz
12663kg
Modo: Isotérmico
Iteração: 0
Zona: 0
Balanço de Massa: 0kg
Progresso:
Tempo: 00:00:00


Modelo Termodinâmico do Forno Waelz
Arquivo
Exibir
Editar
Opções
Ajuda
Parâmetros
Modelo
Forno Waelz
Resultados
PAE
Coque
Sílica
15000kg
900kg
1350kg
TPbInputStream
Óxido Waelz: 2754kg
Gases: 9833kg
550°C
600°C
800°C
1100°C
1200°C
Ar
8000kg
Iniciar
Escória Waelz
12663kg
Modo: Isotérmico
Iteração: 0
Zona: 0
Balanço de Massa: 0kg
Progresso:
Tempo: 00:00:00

Methodology: Simulations

Ind. Plant [Beyzavi, 2000]		Simulations	
EAFD	wt%	EAFD	wt%
Zn	18.2	Si	2.150
Pb	2.5	Ca	5.003
Fe	30.5	Mg	1.206
SiO_2	4.6	Al	0.265
CaO	7	O	5.976
MgO	2	Zn	18.2
Cd	0.035	Fe	30.5
Al_2O_3	1	Ctot	2.1
Ctot	2.1	EAFD mass	6900 kg
Stot	0.45	Silica mass	1400 kg
Cl	4.5	Coke mass	2500 kg
F	0.3	Air volume	
Na	1.5	Case "a"	3882 Nm^3
K	1.05	Case "b"	7764 Nm^3
EAFD mass	6900 kg/h	Case "c"	8638 Nm^3
Silica mass	1400 kg/h	Case "d"	9705 Nm^3
Coke mass	2500 kg/h	Case "e"	14250 Nm^3
Air volume	19000 Nm^3/h	Case "f"	19000 Nm^3

Conditions	
Operation mode	Acid
Calculation mode	Adiabatic
Mass balance precision	1kg
Air inlet temperature	500°C
Other input streams T	25°C

Methodology: Simulations

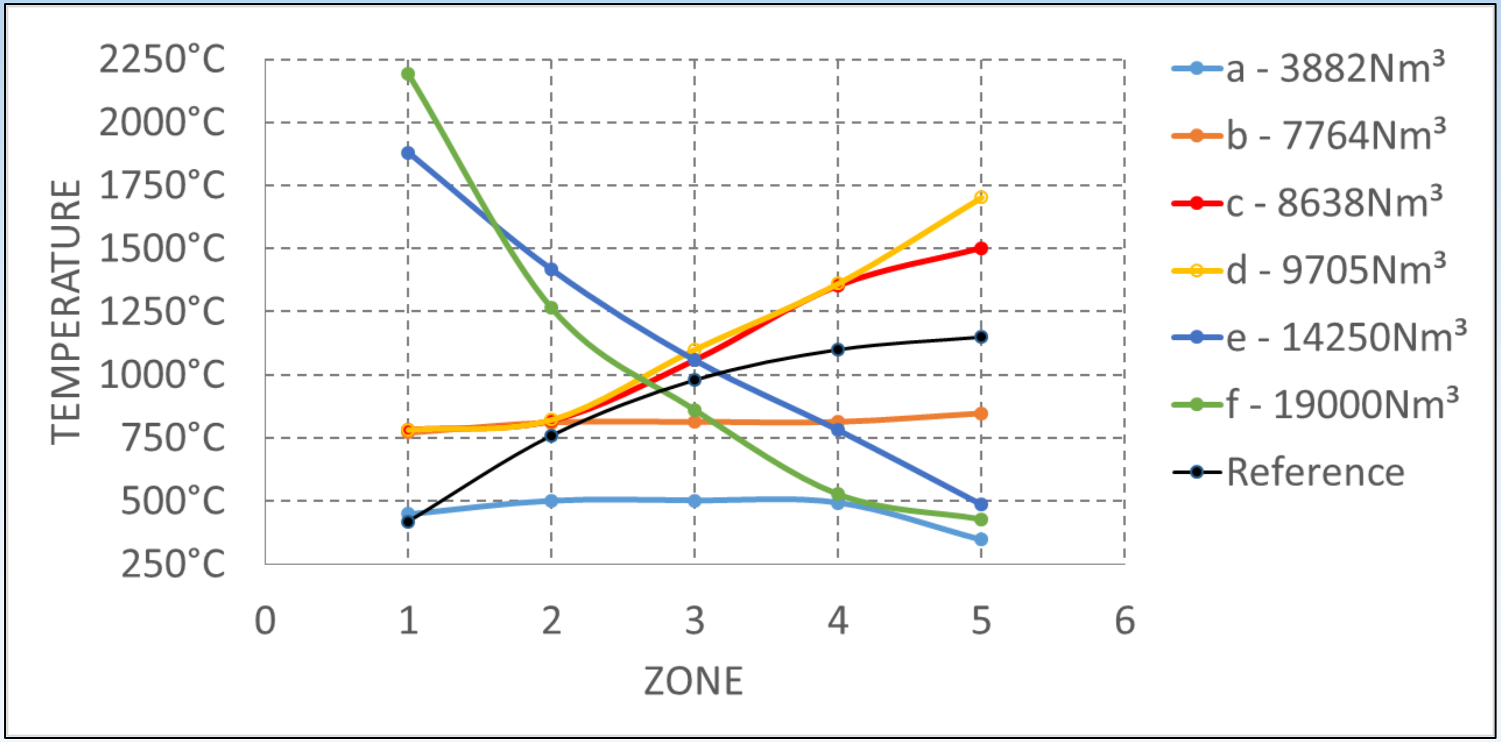
Ind. Plant [Beyzavi, 2000]	
EAFD	wt%
Zn	18.2
Pb	2.5
Fe	30.5
SiO_2	4.6
CaO	7
MgO	2
Cd	0.035
Al_2O_3	1
Ctot	2.1
Stot	0.45
Cl	4.5
F	0.3
Na	1.5
K	1.05
EAFD mass	6900 kg/h
Silica mass	1400 kg/h
Coke mass	2500 kg/h
Air volume	19000 Nm^3/h

Simulations	
EAFD	wt%
Si	2.150
Ca	5.003
Mg	1.206
Al	0.265
O	5.976
Zn	18.2
Fe	30.5
Ctot	2.1
EAFD mass	6900 kg
Silica mass	1400 kg
Coke mass	2500 kg
Air volume	
Case "a"	3882 Nm^3
Case "b"	7764 Nm^3
Case "c"	8638 Nm^3
Case "d"	9705 Nm^3
Case "e"	14250 Nm^3
Case "f"	19000 Nm^3

Conditions	
Operation mode	Acid
Calculation mode	Adiabatic
Mass balance precision	1kg
Air inlet temperature	500°C
Other input streams T	25°C

Results

- Temperature profile



Results

- Case “c”

Zn RECOVERY (%)		WAELZ SLAG CHEMICAL COMPOSITION (wt%)					
Ref.	Case "c"	Constituent	Ref.	Case "c"	Constituent	Ref.	Case "c"
96.6	100.0	Zn	1.2	0.0	Al_2O_3	1.9	0.7
Note: 'n.c.' denotes a non-considered constituent in the model		Pb	0.3	n.c.	C_{total}	11	0.4
		Fe	30.7	40.1	S_{total}	0.4	n.c.
		SiO_2	28.2	31.6	Cl	0.35	n.c.
		CaO	7.3	9.5	F	0.2	n.c.
		MgO	2.1	2.6	Na	0.9	n.c.
		Cd	0	n.c.	K	0.3	n.c.

Results

- Case "c"

RECOVERY OF ZN (%)		WAELZ SLAG CHEMICAL COMPOSITION (wt%)					
Ref.	Case "c"	Constituent	Ref.	Case "c"	Constituent	Ref.	Case "c"
96.6	100.0	Zn	1.2	0.0	Al_2O_3	1.9	0.7
Note: 'n.c.' denotes a non-considered constituent in the model		Pb	0.3	n.c.	C_{total}	11	0.4
		Fe	30.7	40.1	S_{total}	0.4	n.c.
		SiO_2	28.2	31.6	Cl	0.35	n.c.
		CaO	7.3	9.5	F	0.2	n.c.
		MgO	2.1	2.6	Na	0.9	n.c.
		Cd	0	n.c.	K	0.3	n.c.

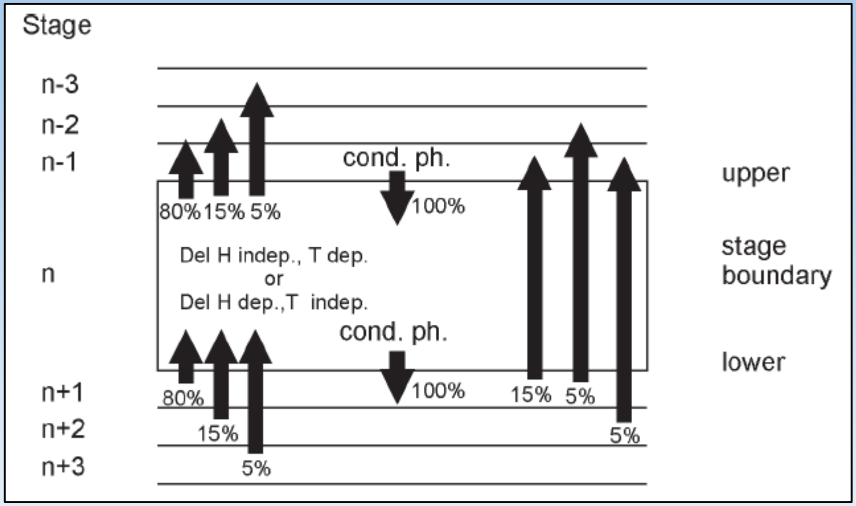
Conclusions

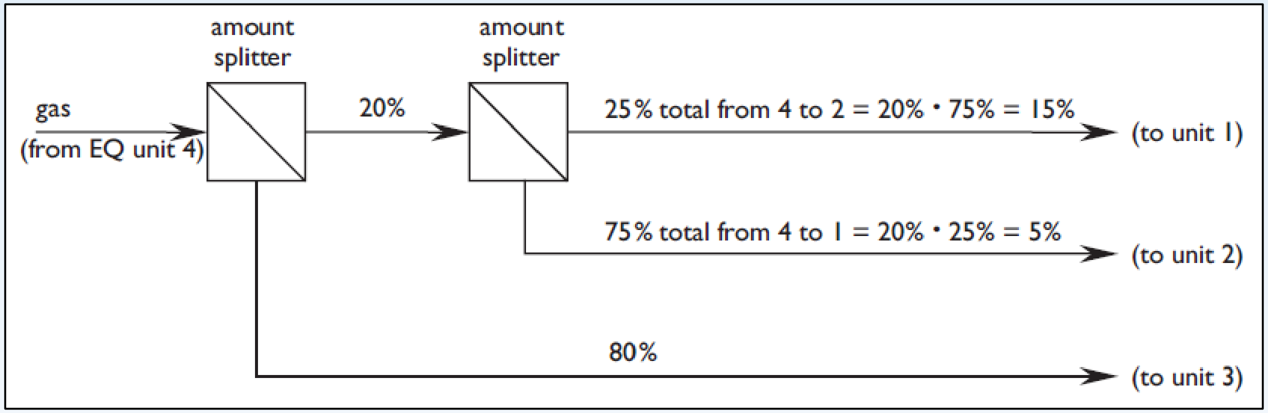
1. SimuSage enabled the creation of a thermodynamic model for the Waelz Kiln, providing:
   - Temperature profile (5 zones)
   - Percentage of zinc recovery
   - Chemical composition inside de kiln
   - Chemical composition of the products

Conclusions

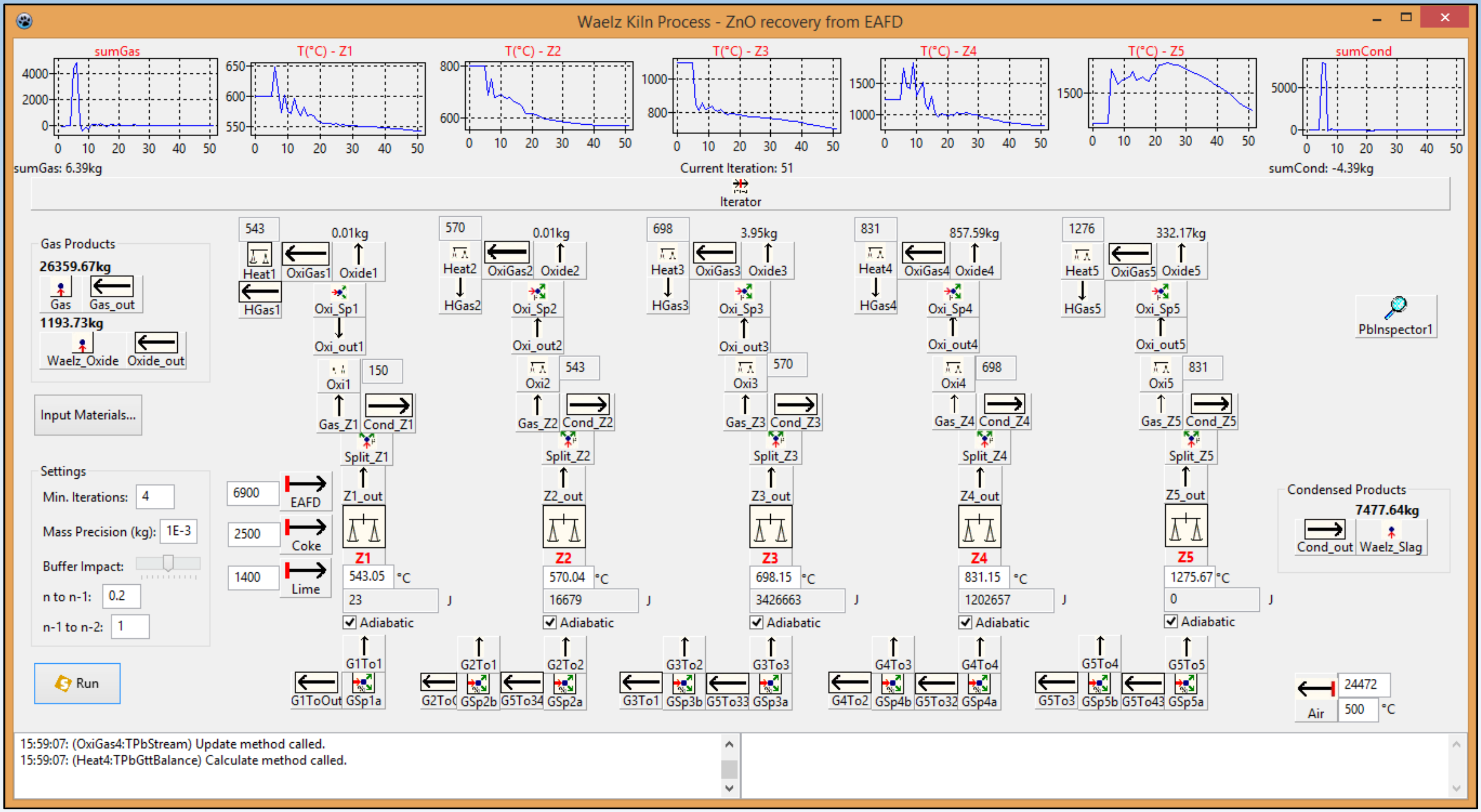
2. Despite the temperature deviations, the model was able to generate results close to the reference
   - Not possible to use the same air volume as reference
   - High sensitivity for the adiabatic mode
   - Further work should consider yet other factors, such as incomplete reactions
3. Computational thermodynamics has proven its great utility on the modelling of a counter-current reactor such as the Waelz Kiln

Further Work





Further Work



Acknowledgements

GTT - TECHNOLOGIES

STE Science Technology & Engineering

CNPq Conselho Nacional de Desenvolvimento Científico e Tecnológico

UFRGS

Thank you!

Eng. Bruno Reis

bruno.reis@ste-pdi.com.br

+55 51 8178 5760