BOFdePhos II

Slag formation in the BOF converter process: Thermochemical and experimental Findings

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Introduction to the BOF Dephos project

Objective of the BOF Dephos project

- Enhancement of dynamic on-line models for an optimized BOF end-point control
  - with focus on dephosphorisation
  - by means of
    - comprehensive thermochemical data base
    - detailed multi-zone reaction models
    - laboratory experiments relevant to dephosphorisation reaction
    - CFD Model investigation of flow fields
  - Validation of the results based on BOF process data from
    - Port Talbot plant
    - IJmuiden plant

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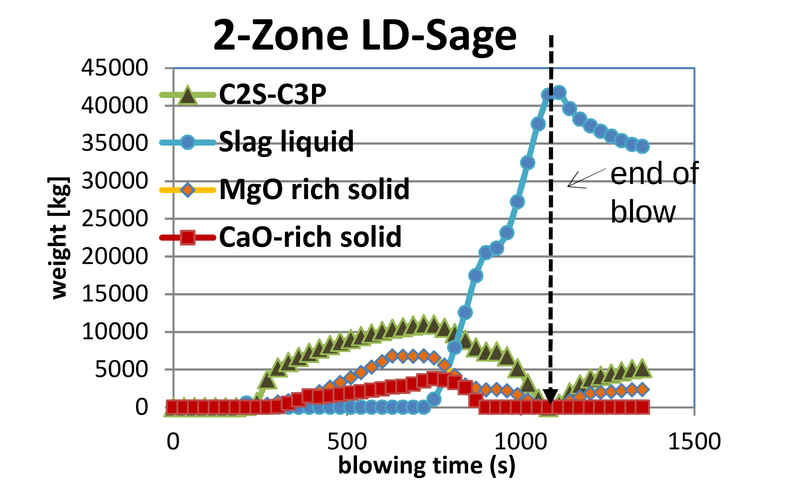
Introduction to the BOF Dephos project

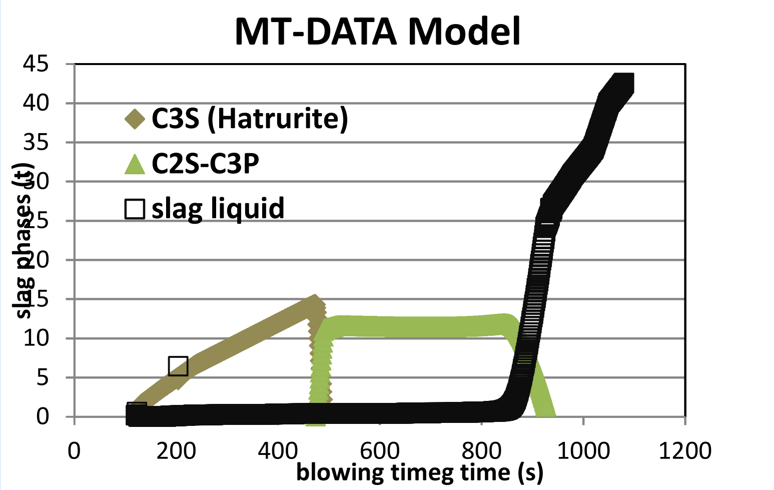
Multi-Zone-Models

- 2 Models based on interlinked local equilibria

Multi-Zone-Models	LD-Sage	MT-Data
Developer	GTT/SMS	Tata Steel
Therm. data base	FactSage (GTT)	MT-DATA (NPL)
Number of zones (Status 2016)	2-3: bath + slag-metal + (optional) hot spot	3: bath + slag-metal + hot spot

- Slag formation according to Models : absence of liquid slag until middle of the blow





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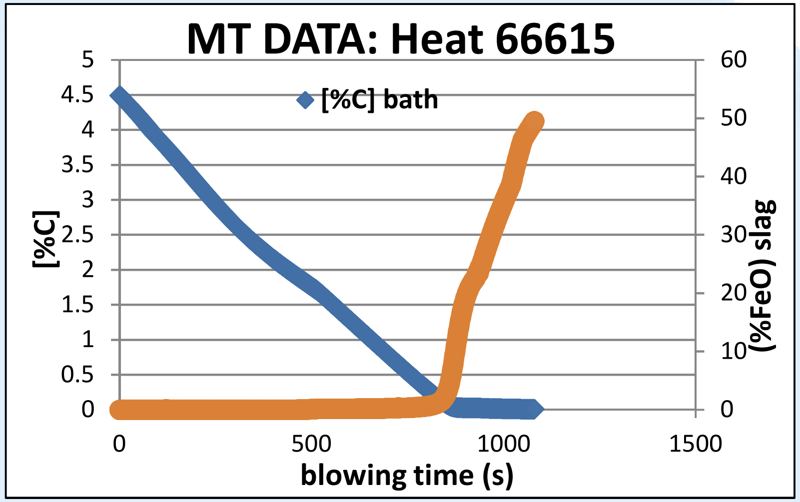
Multi-Zone Models

The liquid slag issue: slag-metal equilibrium

- (FeO) formation begins only when [%C] drops to a certain level
  - 1 % in case of LD-Sage
  - 0.2% in case of MT-Data
- intensive BOF DePHOS data base review (master thesis) → consistency of data base



Investigation of (%FeO)-[%C] equilibrium

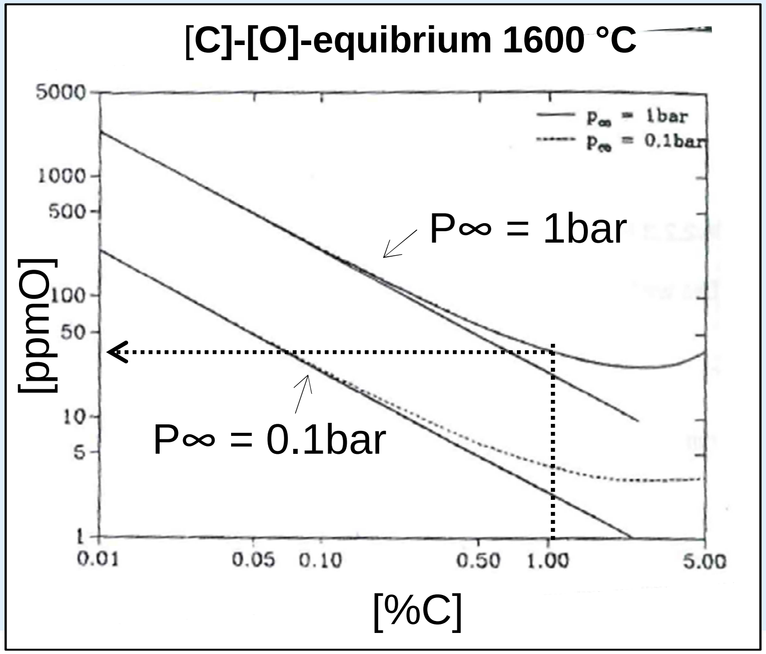
(%FeO)-[O] equilib:

$$a_{(FeO)} = \frac{[O]_{actual}}{[O]_{max}}$$

[C]-[O] equilib:

$$K_{CO} = \frac{P_{CO}}{[\%C]_{eob}[\%O]_{eob}}$$

- no to little dissolution of [%O] in bath possible in equilibrium with high [%C]
  - for [%C]=1% ↔ [ppmO]< 50 ppm!
  - no (%FeO) in slag → no liquid slag



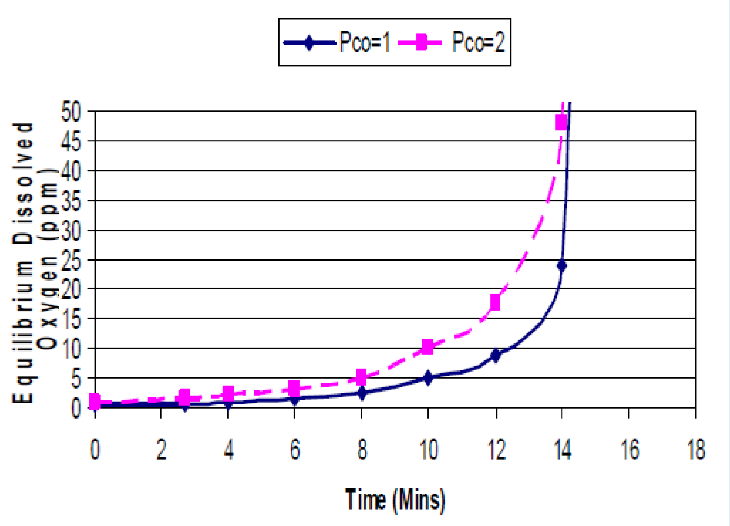
Multi-Zone Models

The liquid slag issue: literature overview

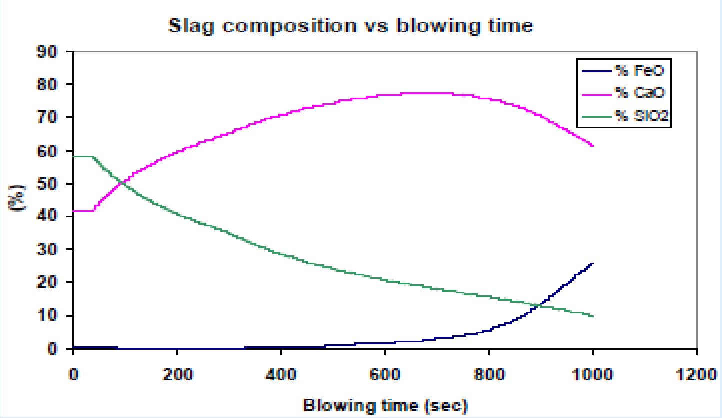
- IMPHOS[1] project: calculation with FactSage
  - no dissolution of oxygen possible in the bath until middle of the blow
  - no relevant improvement through ↑ P_{CO}
  - slag equilib. calculated without reference to liquid metal phase

  „although the slag has a direct association with hot metal/liquid steel, thermodynamic analysis will not allow a slag phase with such high proportions of FeO to be in equilib. with hot metal chemistry "

- DeO [2]: calculation with FactSage
  - slag phases during the blow for BOF converter
  - no (%FeO) in slag unti middle of blow



IMPHOS [1] : [O] equilib calc. by FACTSAGE



DeO [2] : slag phases calc.by FACTSAGE

(1) RFSR-CT-2006-00006; Improving Phosphorus Refining (IMPHOS); 12/2009
(2) DeO,B.; 5th International Congress on the Science and Technology of Steelmaking ; Dresden, 1. – 3. Oct. 2012

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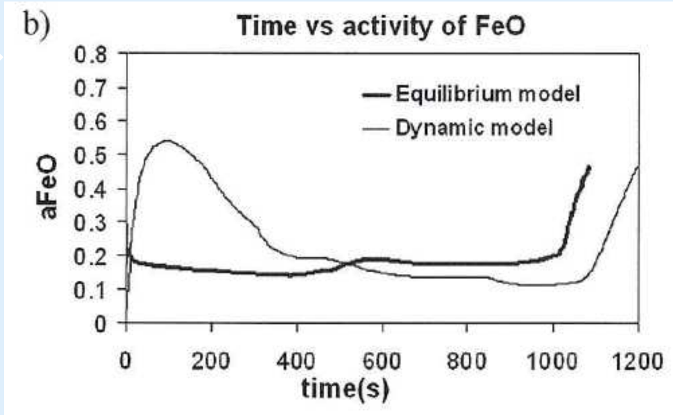
Multi-Zone Models

The liquid slag issue : literature overview

- ➢ calculated (%FeO) early in the blow lower than practice values

- Shukla [3] : deviation from equilibrium at the beginning due to increased loss of iron to dust
  - (FeO) increase from 20% (equilib) to 50% (dynamic)



- Brooks [4]: rapid FeO formation early in the blow hard to explain, possibilities:
  - $FeO-SiO_2$ slag supresses gas removal → provides a kinetic barrier
  - "*In the view of the authors, a rigorous experimental study is required to assess this issue*"

- ➢ Summary: FeO formation early in the blow
  - Significant deviations between thermodynamical and industrial findings
  - Laboratory experiments vs. Industrial findings?

(3) Shukla: Steel Research int.10 (2010) ,N°11, p 940-948
(4) Brooks, J; CAMP-ISIJ Vol.28 (2015)-509

Experimental set up

Initiation

- Master thesis at the University of Duisburg-Essen, Departement of Metals Technology
- Idea to experimentally investigate the slag formation during O_2-blow

Procedure

O_2-blow of a high and a low C melt

- Fe-C-Si-Mn melt
- initial composition (similar to Heat 66615)
- 1 kg melt at temp 1550 °C
- O_2-blowing rate 2.4 l/min + Blowing time 2 mins (lime input time)
- sampling: bath+ slag
- record experiments by a camera

Videos of the experiments

Low Carbon

V2_2016-11-03_SMS_Low Crabon.mp4 - Verknüpfung.lnk

High Carbon

V1_2016-11-03_SMS_High Carbon.mp4 - Verknüpfung.lnk

- **Observations**

- „Dimpling“ blow was observed
- braun gas/ dust generation in case of high C melt
- liquid + solid slag formation observed
- no emulsion or foamy slag formation

Results of the experiments

1. Experiment: Low C melt

- *Cruciable: Graphite*

2. Experiment: High C melt

- *Cruciable: Alumina*

Sample Analysis (1)

Bath analysis (wt.-%)	**C**	**Si**	**Mn**
initial	0,13	0,76	0,63
after 2 mins of blow	0,22	0,18	0,17
Δ% [element] after 2 mins	**-0.09**	**0.58**	**0.46**
Slag comp. (wt.%)	**$(FeO)_{tot}$**	**(SiO2)**	**(MnO)**
	24	**59**	**17**

- O_2 mass balance
  - Blown: 6.24 l (blowing time 2.6 mins)
  - consumed: 5.6 l → 90% efficiency
- ~ 0.1% C dissolved from cruciable
- ↑ Si- and ↑ Mn- oxidation (fast) at ↓C melt
- formed slag is SiO_2-saturated

Sample Analysis (2)

Bath Analysis (wt.%)	**C**	**Si**	**Mn**
initial	4,17	0,71	0,71
after 2 mins of blow	4,11	0,51	0,56
Δ% [element] after 2 mins	**0.05**	**0.16**	**0.12**
Slag comp. (wt.%)	**$(FeO)_{tot}$**	**(SiO2)**	**(MnO)**
Not available: too little to be analysed			

- no slag analysis

→ no mass balance verification possible

- no to little C-oxidation when ↑ Si present
- ↓ Si and ↓ Mn oxidation in high C melts
  - ~ 26% slower than 1.exp
- ↓ formed slag amount compared to 1.exp

Findings

1. Experiment: Low C melt

- very fast Si- and Mn- oxidation although
  - dimpling blow (low mixing energy through top lance) + no inert gas stirring :

    → high diffusion potential of those elements to the reaction site
  - absence of an emulsion: Mn and Si oxidation not necessarily occuring in the emulsion
  - Gibbs energy at 1550°C $\frac{\Delta G^o_{MnO}}{\Delta G^o_{SiO2}} = 0.82$ in accordance with $\frac{\Delta[\%Mn]}{\Delta[\%Si]} = 0.79$

- Conclusions for last blowing phase (after C critical point)
  - ↑Δ [%Mn] as high as 0.5% possible during the last 2 mins of blow

  → Mn-reversion during the middle of blow can be fully recovered
  - a high amount of reactive FeO-rich slag can be formed quickly

Findings

2. Experiment: High C melt

- Effect of ↑ [%C] in bath
  - blocking Fe-oxidation and liquid slag formation
  - ↓ Si- and ↓ Mn-oxidation rate: ~ 72% lower as in the 1.experiment
  - no to very little C-oxidation → what was the braun gas/dust?

➡ ↑ [%C] blocks [%O] dissolution in the bath

- in accordance with multi-zone models results (LD-Sage + MT-DATA)
  - no to little slag formation
  - no Mn-removal
  - Si-removal only due C_2S phase formation
- disagrees with the formation ↑ amounts of liquid slag in industrial process!!!
  - explanation?

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Conclusion/Outlook

- rapid FeO-formation early in the blow in converter process, possibilities:
  - forced [%O] dissolution due to high O2-jet impact velocity ?
  - O2-lance in converter: O_2-exit velocity supersonic→ expands at ambient furnace temperature
    - ↑ Flow rate 1000 Nm3/min → ↑ Impact velocity in the range of 250-400 m/s (5)
    - experiment carried out at ↓ flow rate of 2.4 l/min (scaled for 1 kg of melt)

- Next: Further experiments for a high C melt
  - O2 blow at increased oxygen flow rate: 4 * higher than in previous exp.
  - sampling at different blowing times, for example at 30 s

we will let you know about the results next year!

(5) internal calculations, SMS group