Application of Thermochemistry in BOF process modeling: What did it teach us about the dynamics of decarburisation reaction?

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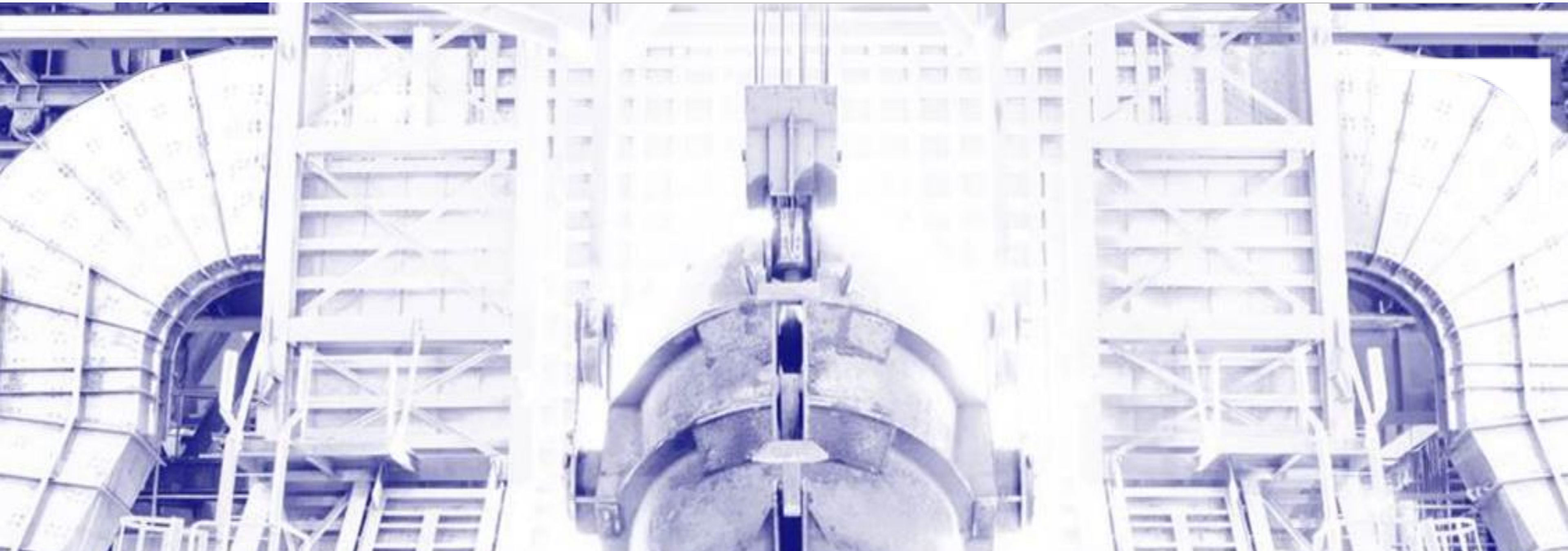

Application of thermochemistry in BOF process modeling: What did it teach us about the dynamics of decarburisation reaction?

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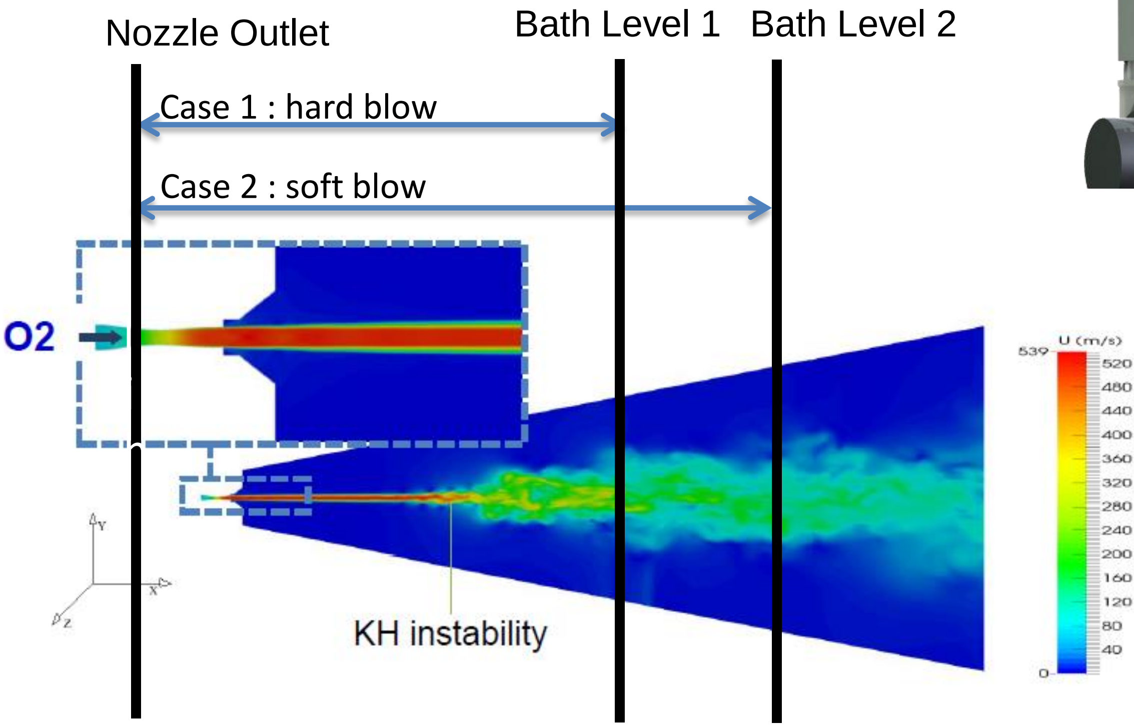
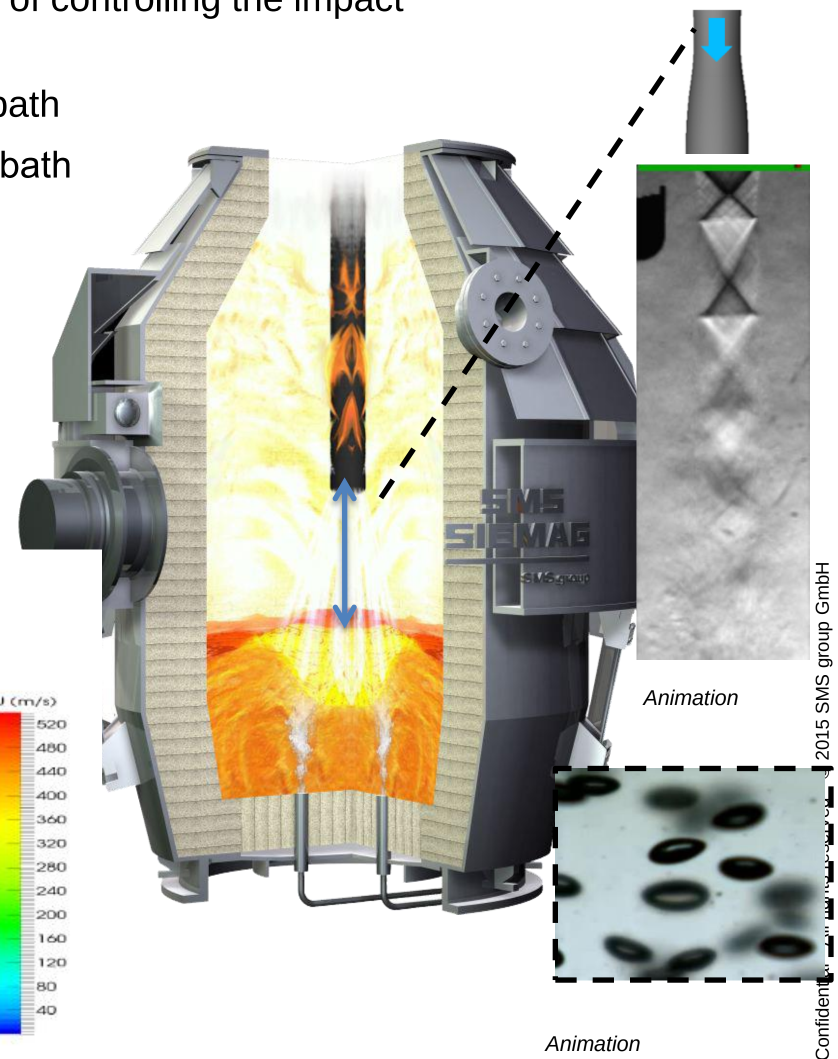
- LD-Sage: Which functions depend on process dynamics
- Simulation Results
- Conclusion

Application of Thermochemistry in BOF process modeling

BOF Process dynamics: What is a blowing profile and BAP profile

- A blowing profile: A profile defining variations in the oxygen lance distance from the bath over the total process time. This is done for the purpose of controlling the impact velocity of the jet at the time it hits the bath
  - ✓ ↓ lance height : increase the jet impact velocity on the bath
  - ✓ ↑ lance height : decrease the jet impact velocity on the bath
- BAP profile: change of inert gas flow rate over blowing time
  - Axial velocity decay of the O_2-jet

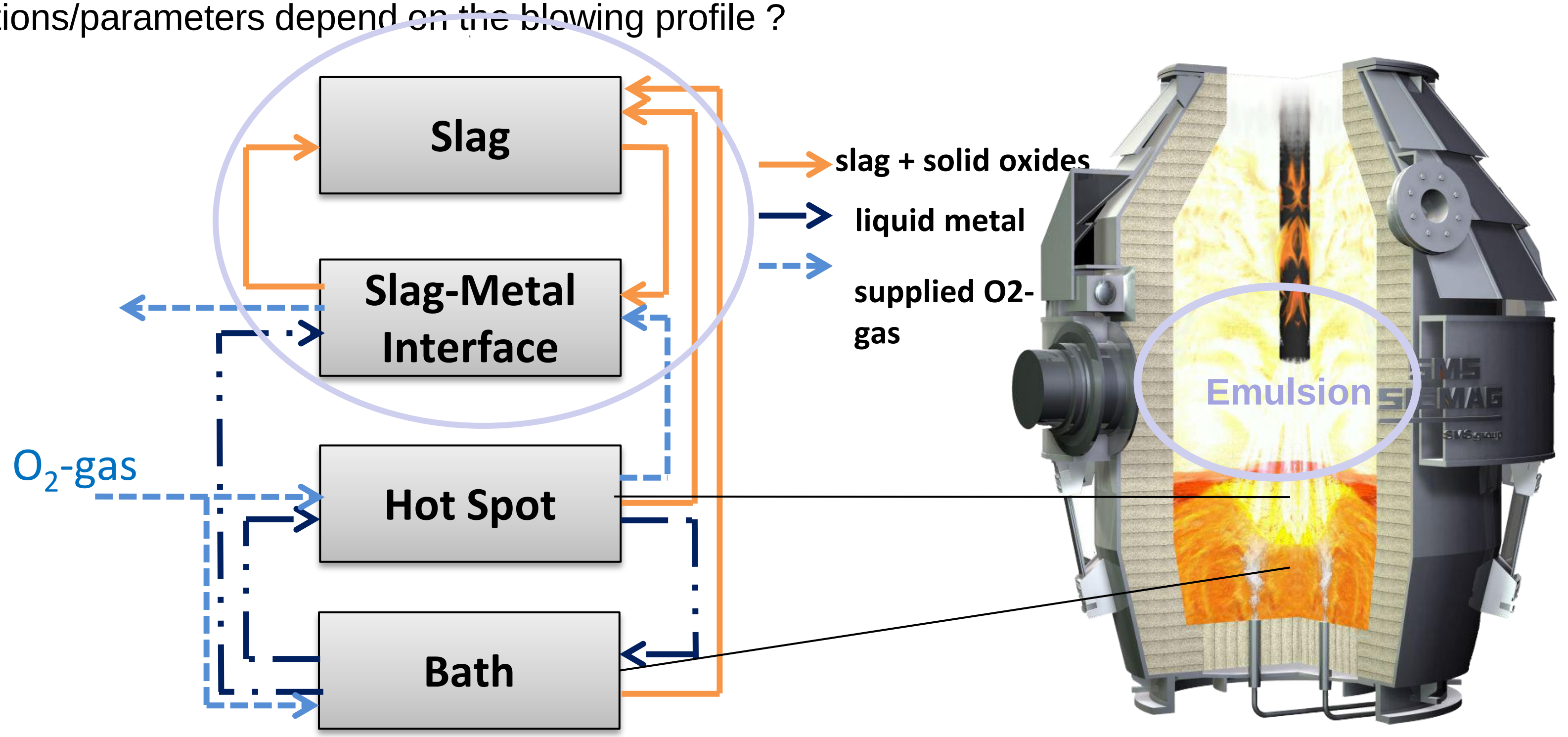




Application of Thermochemistry in BOF process modeling

Which functions/parameters depend on the process dynamics?

➢ Which functions/parameters depend on the blowing profile ?



I. The mixing intensity and the exchange between reaction zone

- Circulation rate between bath and emulsion zone as a function of
  - ✓ lance distance: Very strong effect
    - velocity decay determined based on a CFD approach
  - ✓ inert gas stirring intensity: effect on circulation is very small

Application of Thermochemistry in BOF process modeling

Which functions/parameters depend on the process dynamics?

II. It is necessary to set the total pressure in 2 reaction zones as a function of the dynamic process conditions (Blowing profile + BAP)→ setting a barrier for deC when it is „kinetically“ not possible!

1. Bath zone

- Decarburisation in the Bath zone: When is it possible?
  - the p(CO) threshold (above which C oxidation is possible) in case of a homogeneous CO-nucleation is very high ([C] + [O] →{CO})
  - at the same time, the hydrostatic pressure in the bath (at levels below the hot spot) is high, makes it difficult for {CO} to nucleate

  → Bath reactor: increasing the total pressure to block decarburisation

  - Fe, Mn, Si oxidation in the bath is not affected by the pressure increase
  - O_2 blow experiments of Fe-C-Si-Mn (reported in a previous presentation: GTT user meeting 2017) confirmed the CO-nuceation difficulties in the bath while Fe, Si and Mn oxidation occured
  - However: When inert gas is blown from the bottom (BAP profile) which is generally done at the later stage of the blow CO- nucleation becomes possible!

  → Increase of Pressure in the bath when no/little inert gas stirring is made

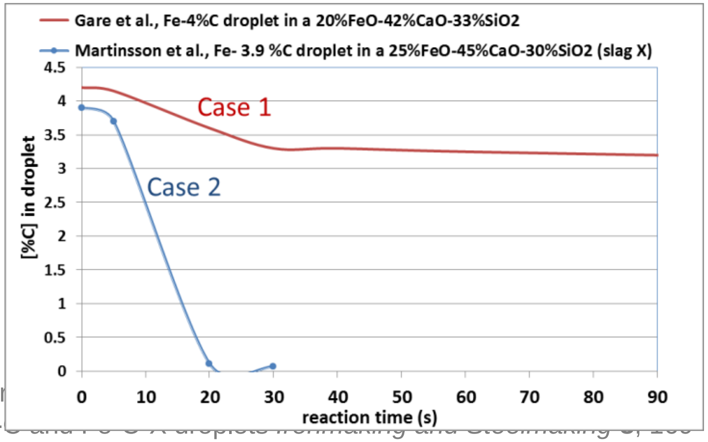
  → drops to 1 bar when high rate of inert gas flow is supplied

  → Barrier for {CO} nucleation is lifted!

⇨ Pressure in the bath is dynamic parameter as it depends on the BAP profile!

2. Metal-Slag interface zone

- Main idea: decarburisation in the metal slag interface zone is a strong function of the mixing intensity (when C in droplet is higher than 0.2 wt.%!)
  - There exists a nucleation barrier (of different nature than that in the bath!) which is
    - maintained by a low mixing state : high lance height (soft blow)-→ Pressure should be set high >10 bar
      - ✓ during such a state : the oxygen activity set in the metal is high against the C-O-equilibrium state → **„ oxygen overpotenial state“**
      - ✓ during such a state : Fe, Mn and P oxidation proceed with a high rate
    - lifted by a high mixing state→ pressure set back to 1 bar
- We derived this conclusion based on the assessment of a large number of experimental and industrial data
  - Details can be found in a recent publication: ESTAD conference, Düsseldorf, 2019
    - Example: Experiments at 1560°C-1600°C: 1. Gare (1981), 2. Martinsson (2019)
      1. Case 1: very little decarburisation
      2. Case 2: very fast decarburisation: a full deC within 20 seconds:
         - ✓ reference to application of external mechanical mixing in Case 2!



[1] J. Martinsson and D. Sichen (2019). "Decarburization of Pig Iron in Synthetic BOF Converter

[2] T. Gare and G. Hazeldean (1981). "Basic oxygen steelmaking: decarburization of binary Fe-

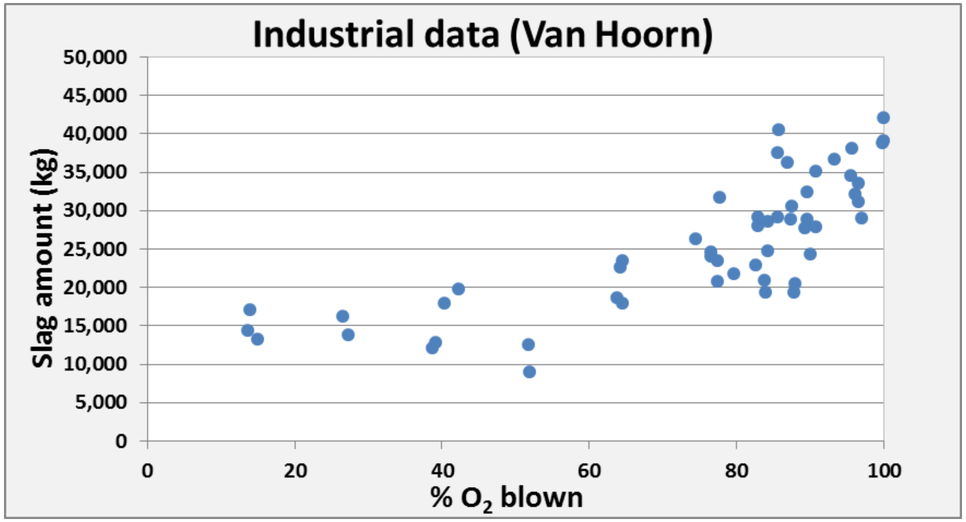
Content

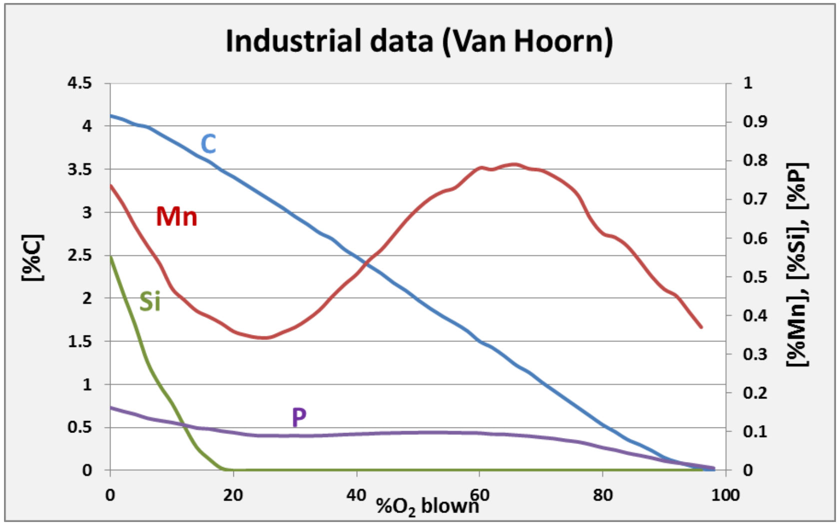
Application of Thermochemistry in BOF process modeling

Simulation results

based on industrial data of Van hoorn et al. [3]

- provided dynamic data : blowing profile, input time of materials
- focused on determining the slag evolution during the blow,
- the bath evolution curve were given for a different heat !





[1] A. Van Hoorn et al. (1976). Evolution of slag composition and weight during the blow. McMaster University Press.

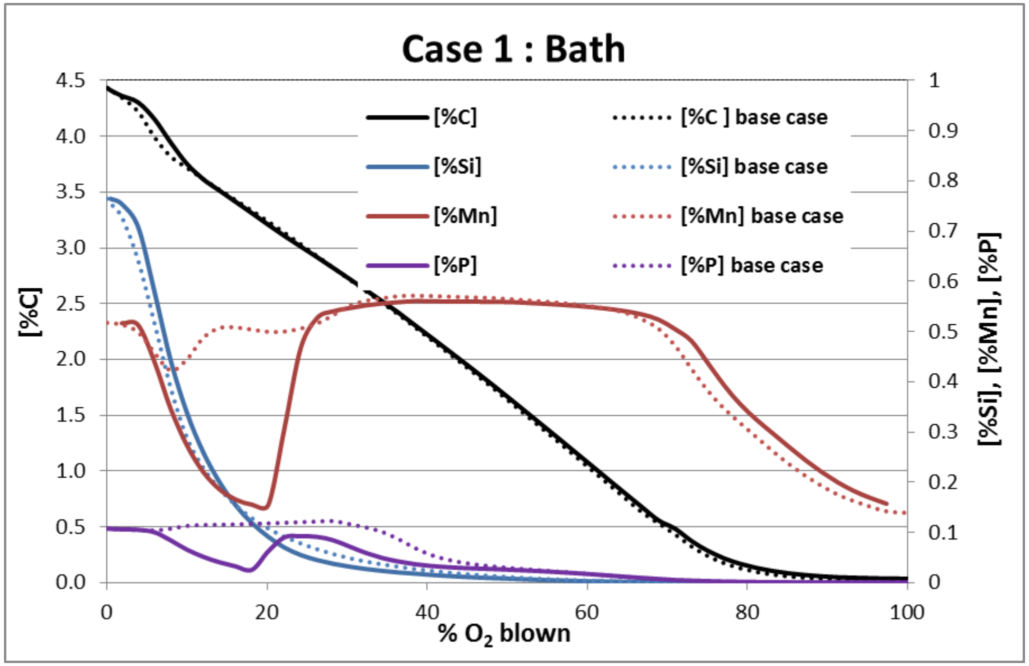
Application of Thermochemistry in BOF process modeling

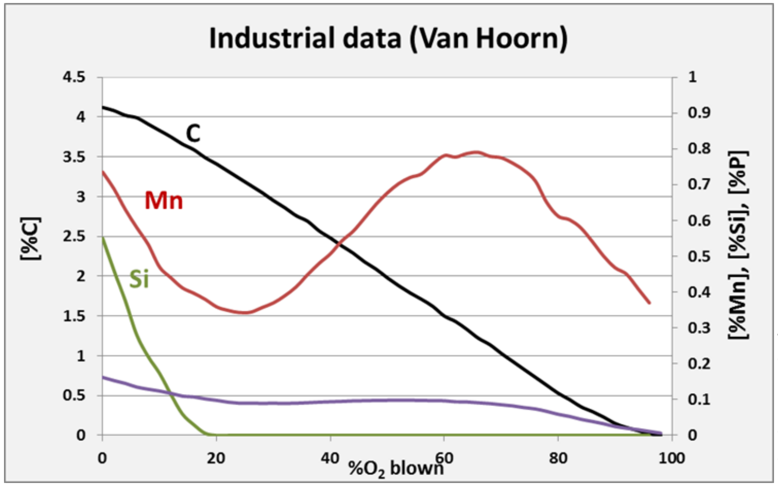
- ➢ Effect of varying the pressure on metal-slag-interface (1)

Base case : Pressure is 1 bar in all reactors

- **Case 1**: P_Interface = 100 bar for 20% of the blow (soft blow) and drops back to 1 bar for the rest (hard blow)

  - ➢ Bath evolution: case 1 (solid) Vs. Base case (dashed)





Case 1: onset of deP and deMn for the first 20% of the blow with a high rate as a result of:

- DeC slow down in the interface reactor → Oxygen overpotential state on the metal-slag interface (High oxygen activity)

→ onset of deP and deMn

→ immediate reversion in Mn and P is observed once the CO-nucleation barrier is lifted!

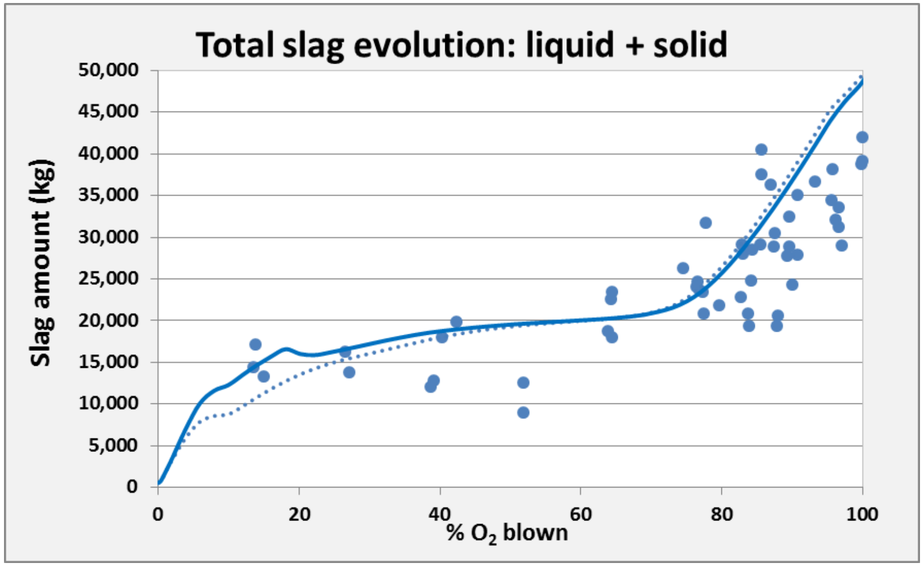
Application of Thermochemistry in BOF process modeling

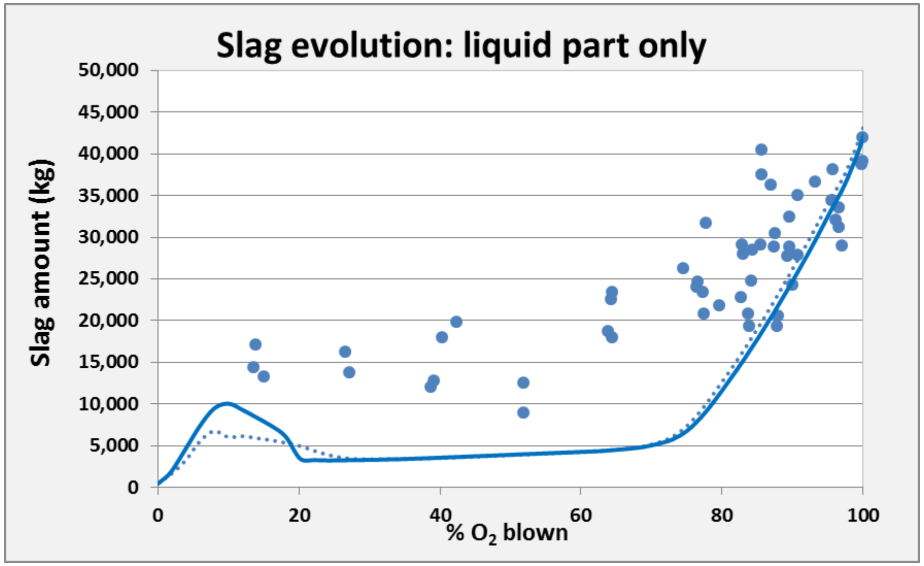
➢ Effect of varying the pressure on metal-slag-interface (2)

Base case : Pressure is 1 bar in all reactors

- **Case 1**: P_Interface = 100 bar for 20% of the blow (soft blow) and drops back to 1 bar for the rest (hard blow)

  ➢ Slag evolution: case 1 (solid) Vs. Base case (dashed)





Case 1: Significant increase in liquid slag amount and moderate increase in total slag amount for the first 20% of the blow

- as a result of favored Fe, Mn and P oxidation in the metal-slag-interface
- sharp decrease in liquid slag amount once the once the CO-nucleation barrier is lifted!

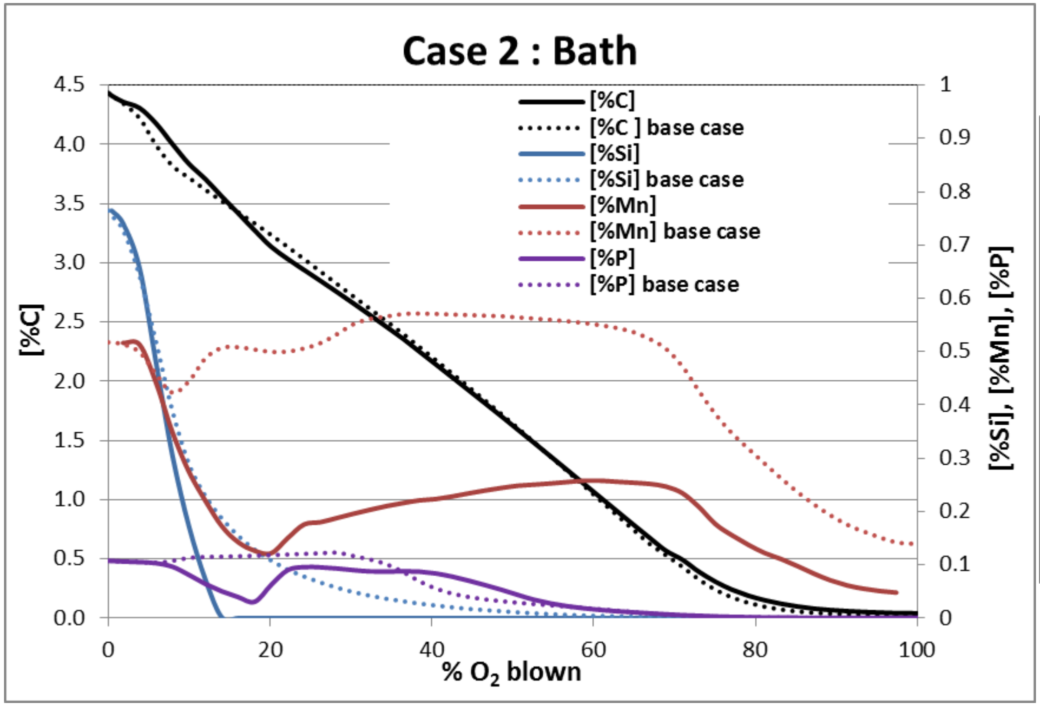
→ slopping risk: Excessive slag foaming and running out of the converter mouth at „Transition point“

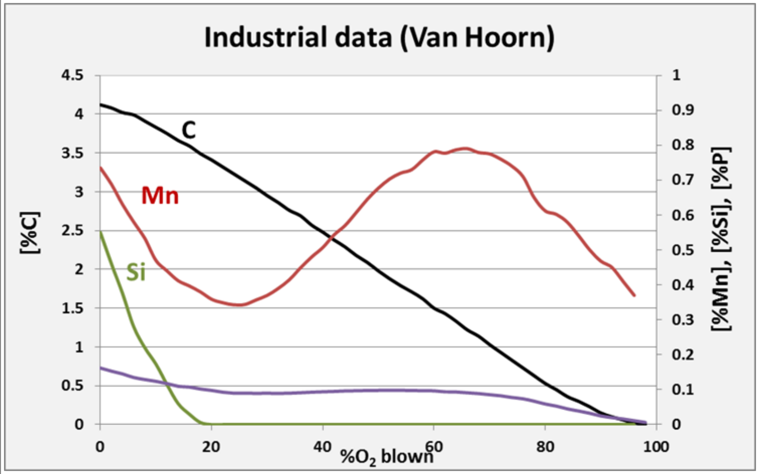
Application of Thermochemistry in BOF process modeling

- Effect of varying the pressure in the bath reactor (1)

Base case : Pressure is 1 bar in all reactors

- **Case 2**: P_Interface = 100 bar for 20% of the blow (soft blow) and drops back to 1 bar for the rest (hard blow)
  - Pressure in the bath is 100 bar all the time + 40% of O_2 is reacting in the bath
- Bath evolution: case 2 (solid) Vs. Base case (dashed)





Case 2: Mn reversion rate is not as high as in case 1

- Mn is now oxidized in the bath (reacting with O dissolved directly in the bath while deC is suppressed)
- Mn reversion occurs on the metal-slag interface and is limited by the circulation rate (mass transfer in the metal phase)

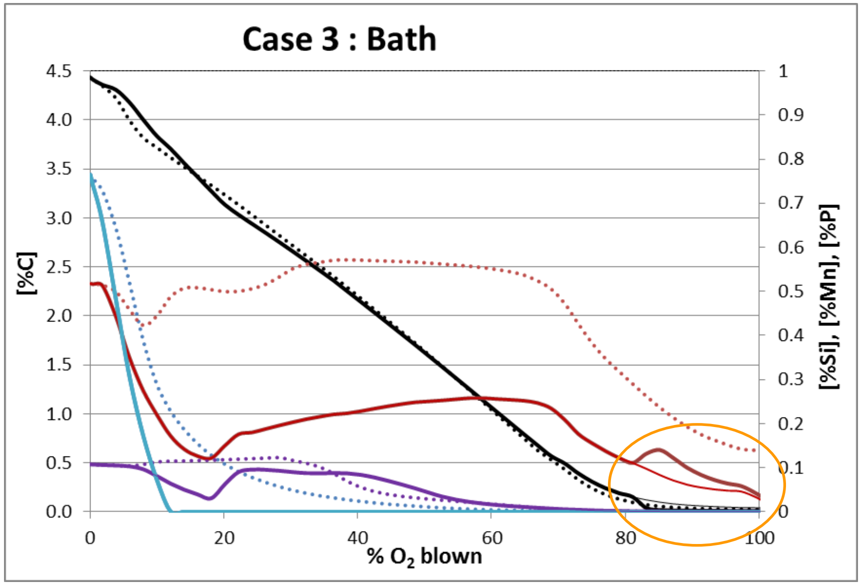
Application of Thermochemistry in BOF process modeling

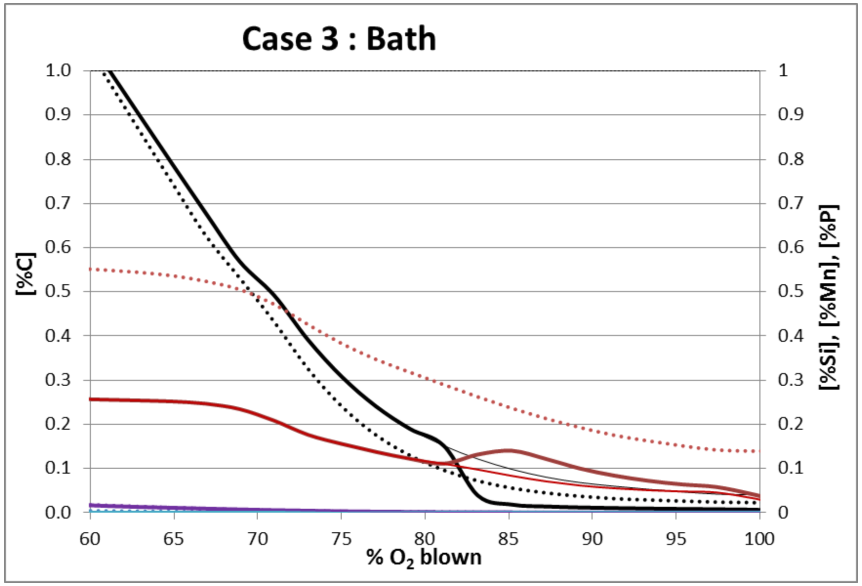
➢ Effect of varying the pressure in the bath reactor (2)

Base case : Pressure is 1 bar in all reactors

- **Case 3**: P_Interface = 100 bar for 20% of the blow (soft blow) and drops back to 1 bar for the rest (hard blow)
    - Pressure in the bath is 100 bar all the time + 40% of O_2 is reacting in the bath
    - Pressure in the bath is set back to 1 bar for the last 20% of the blow :

➢ Bath evolution: Case 3 (solid-thick) Vs Case 2 (solid-thin) Vs. base case (dashed)





Case 3: improved deC at the last stage of the blow

- CO-nucleation becomes possible in the bath when inert gas is supplied from the bottom
- general practice for steelworks at the last blowing stage to achieve low C contents while avoiding excessive Fe oxidation

Application of Thermochemistry in BOF process modeling

Conclusion: What did we learn about dynamics of deC in BOF converter?

The blowing conditions during BOF process operation are „dynamic“ (jet impact, inert gas stirring)

- mass exchange between the reaction zones must be „dynamic“
- The pressure in some zones where {CO} nucleation difficulties occur depending on the process operation should also be „dynamic“

The low DeC rate accompanied by high deMn, deP and Fe oxidation rates observed <u>early in the blow</u>

- is not due to a low thermodynamic driving force for C oxidation as generally believed
- is explained by the presence of a {CO} nucleation barrier
- In such a case it is necessary for comp. thermodynamics approaches to include such a barrier
- -→ In LD-Sage this was done by increasing the total pressure

this barrier is lifted once the blow type changes from „soft“ to a „hard“ blow

- There may be other aspects which contribute to triggering the CO-nucleation
- At this „Transition“ the pressure should be set back to „normal“
- usually a strong reversion in Fe, Mn and P removal is observed
- During this transition, an explosive behaviour of CO-nucleation may occur