Modeling of Oxygen Steelmaking

Mid term Report

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Commenced PhD in February 2007

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Content Outline

1. Introduction
2. Overview of Progress

- ✓ Literature Review on fundamentals of basic oxygen steelmaking process (Draft submitted Feb 29 2008)
- ✓ Development of models for overall decarburization reaction kinetics (commenced)
- ✓ Implementation of the algorithm to computer program (commenced)
- ✓ Validation of developed model against industrial data (commenced)
- ✓ Papers and Presentations

3. Next Stage

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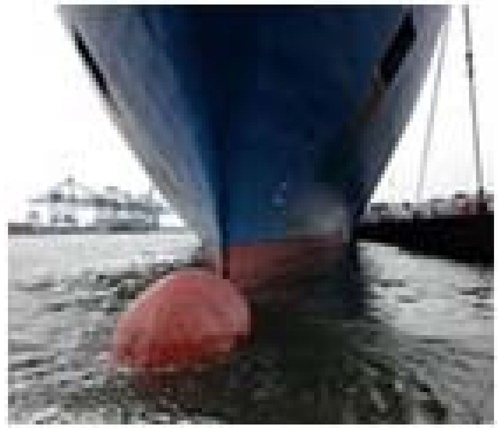
1. Introduction

Nothing is manufactured, processed or transported without steel.



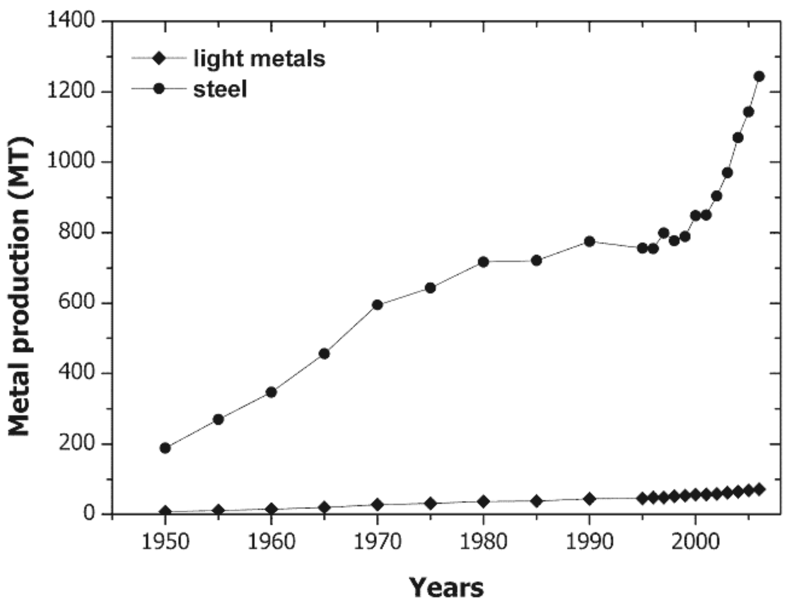


Image from www.steeluniversity.org

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Basic Oxygen Steelmaking Process

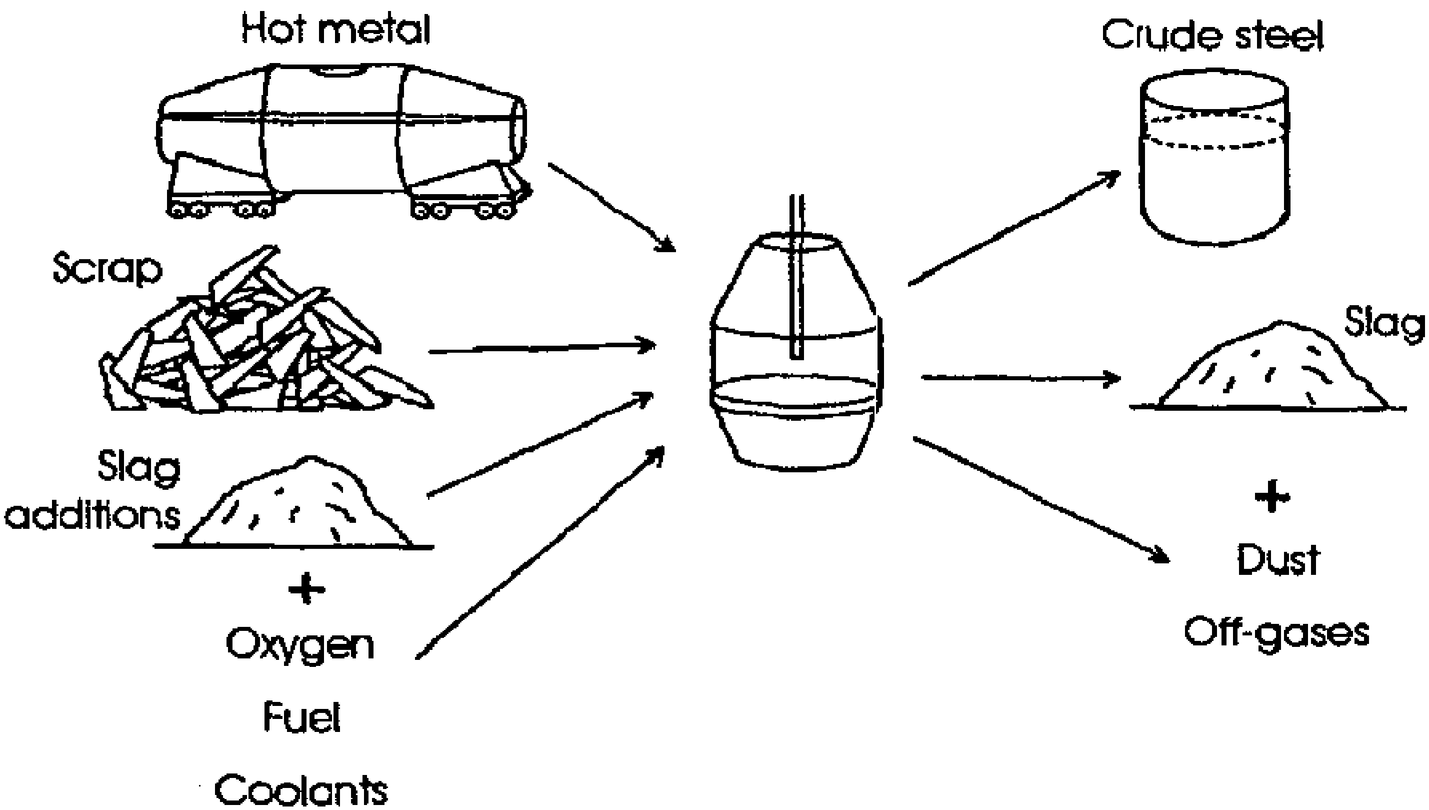

Image from http://ieeexplore.ieee.org/iel5/7073/19103/00883186.pdf?tp=&isnumber=&arnumber=883186

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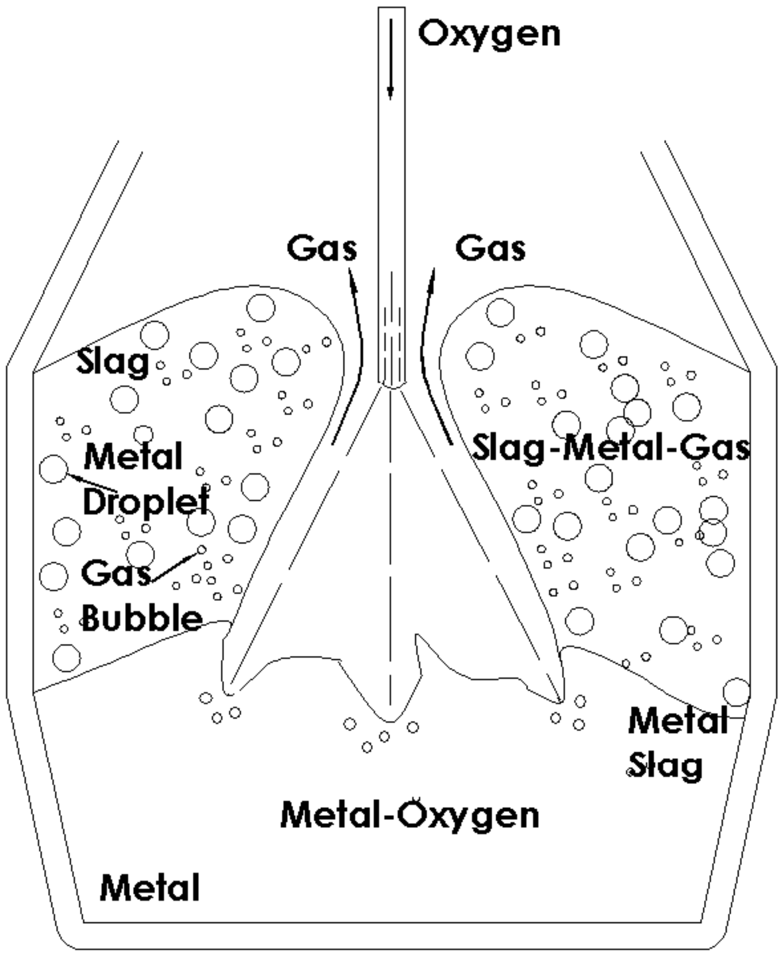
Modelling of Oxygen Steelmaking



Hot Zone

$O_2(g) = 2\underline{O}$

$\underline{O} + \underline{C} = CO(g)$

Emulsion

$(FeO) + \underline{C} = Fe + CO(g)$

Why modelling??

- Difficult to conduct experiments
- Hard to understand and optimize

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Previous Models

- Static models

  H. W. Meyer and J.A. Glasgow, 1966

  L. Pigjaner and A. Espuna, 1991

- Dynamic models

  Asai and Muchi, 1970

  J.R. Middleton and R. Rolls, 1973

  Knoop et al., 1992

  Modigell et al., 2007

  E. Graveland-Gisolf et al., 2007

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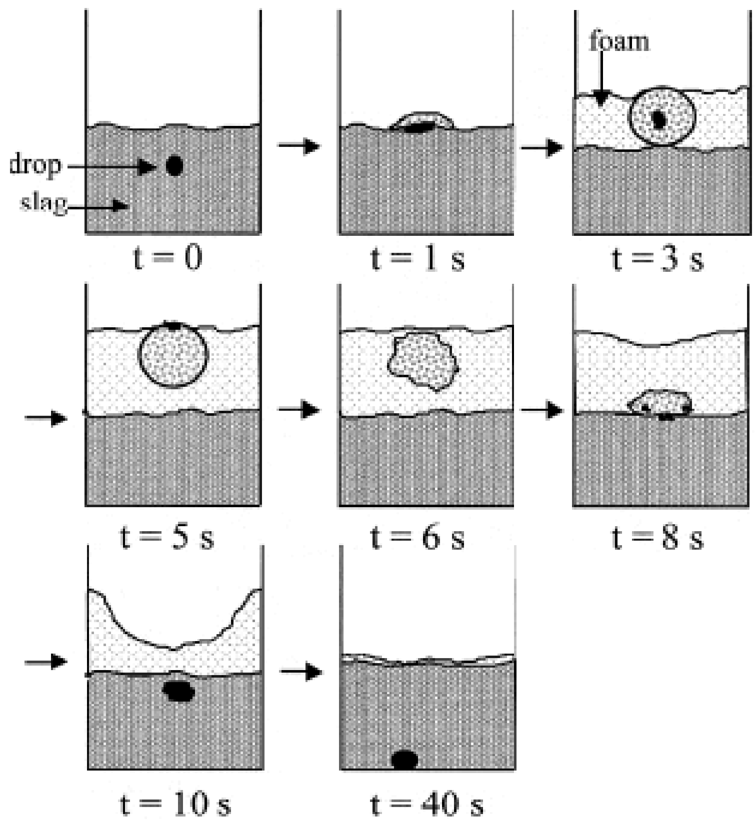
“Bloated” Droplet Theory



$$(FeO) + \underline{C} = Fe + CO(g)$$

X-ray fluoroscopy of an Fe-C drop in a slag

Molloseau and Fruehan, Met. Matl. Trans. B, 2002

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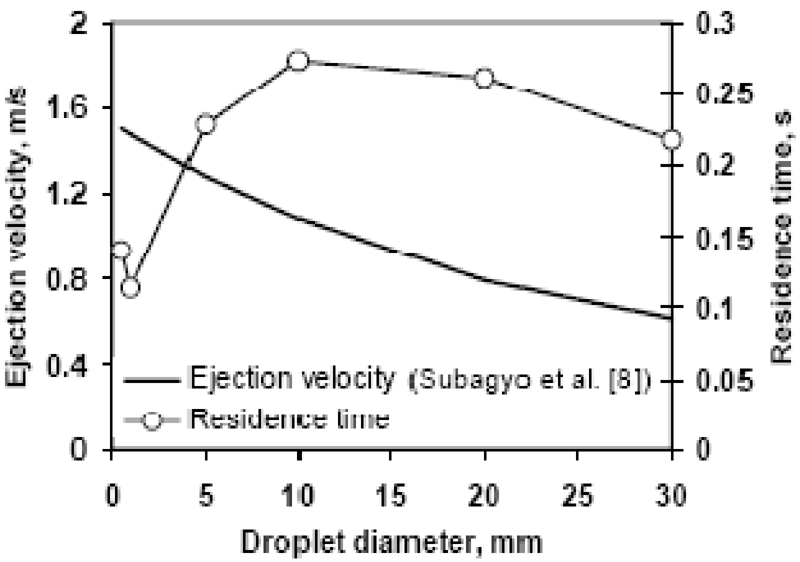
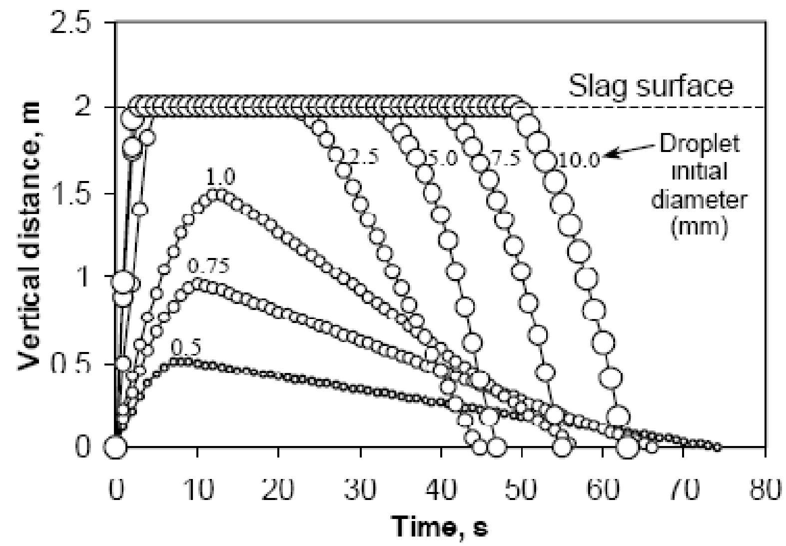
Residence time of droplets



(i) dense droplets



(ii) bloated droplets

Brooks, Pan, Subagyo and Coley, Met. Matl. Trans. B, 2005

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Aims of the Project

1. Analysis of previous oxygen steelmaking models
2. Development of mathematical models of oxygen steelmaking coupled with bloated droplet theory
3. Validation of the results of the model against data from industrial systems
4. Evaluation of the repercussions of the model on the operation of oxygen steelmaking

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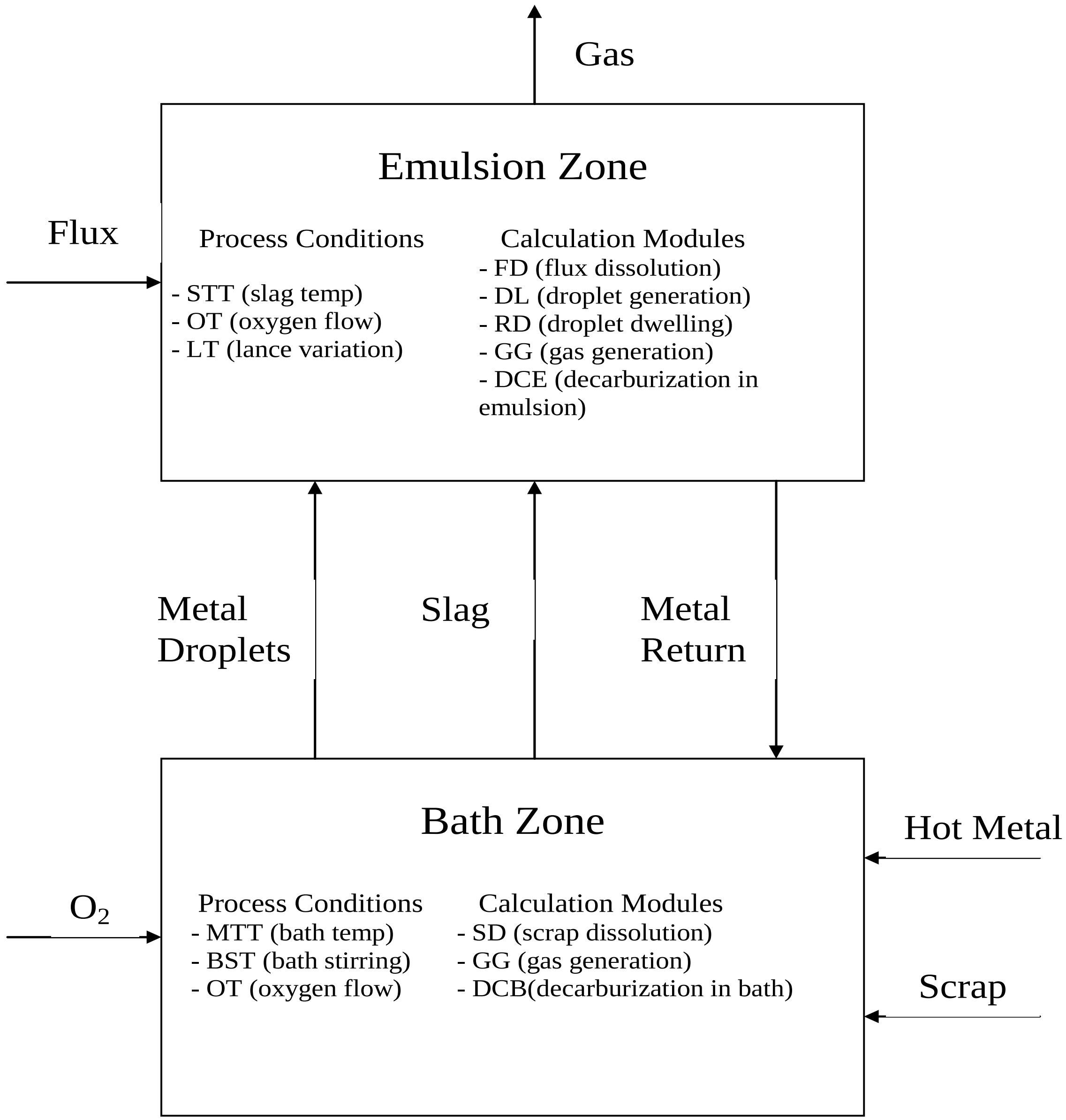
Conceptual Model



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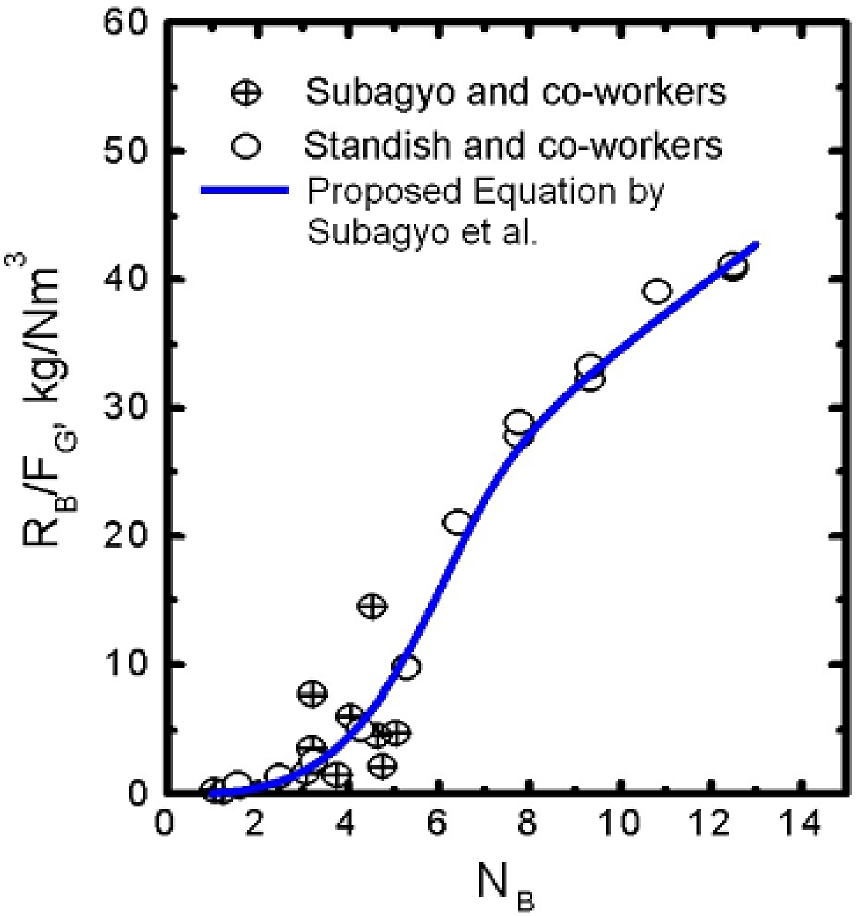
Droplet Generation Model

Designed to calculate the amount of metal droplets generated for a given time step

Kelvin-Helmholtz Instability Criteria

$$N_B = \frac{\rho_g U_G^2}{2\sqrt{\gamma g \rho_m}}$$

R_B=droplet generation rate (kg/s)
F_G=gas flow at lance exit (Nm^3/s)



Subagyo, Brooks, Coley and Irons, ISIJ, 2003

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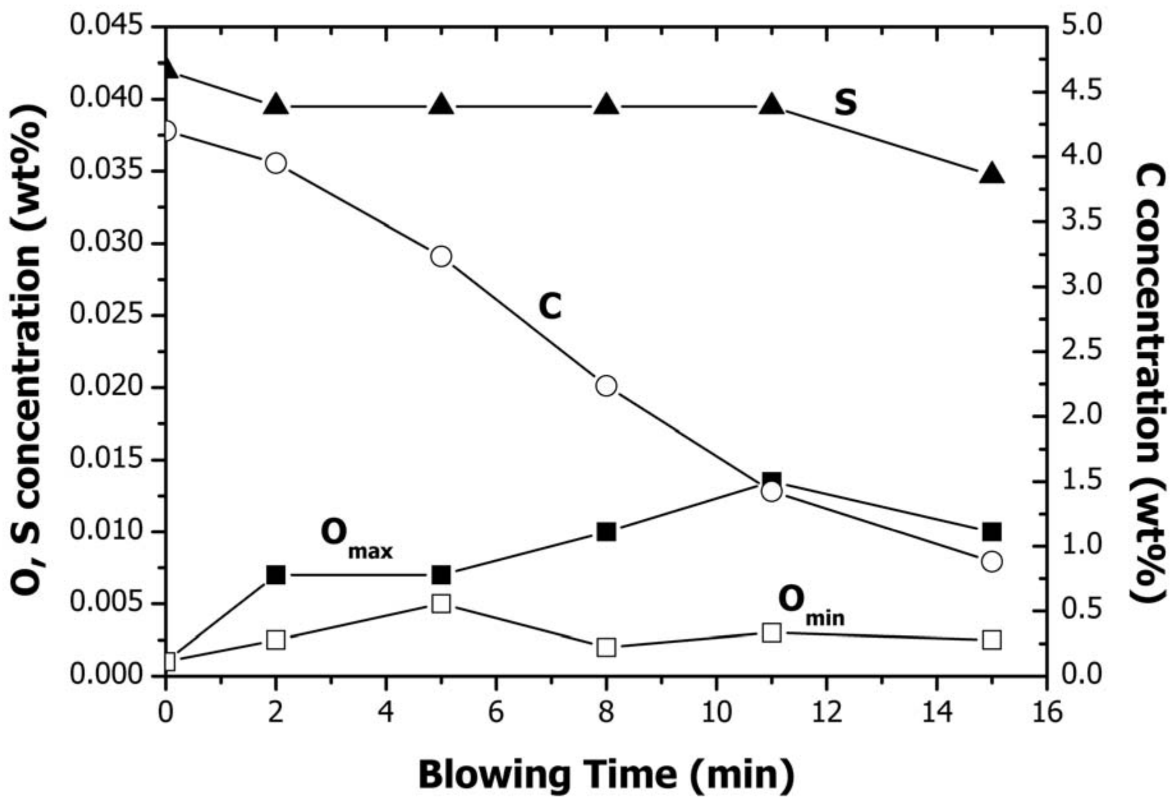
Evaluation of metal composition during the blow



Jalkanen and Holappa, VII International Conference on Molten Slags Fluxes and Salts, 2004

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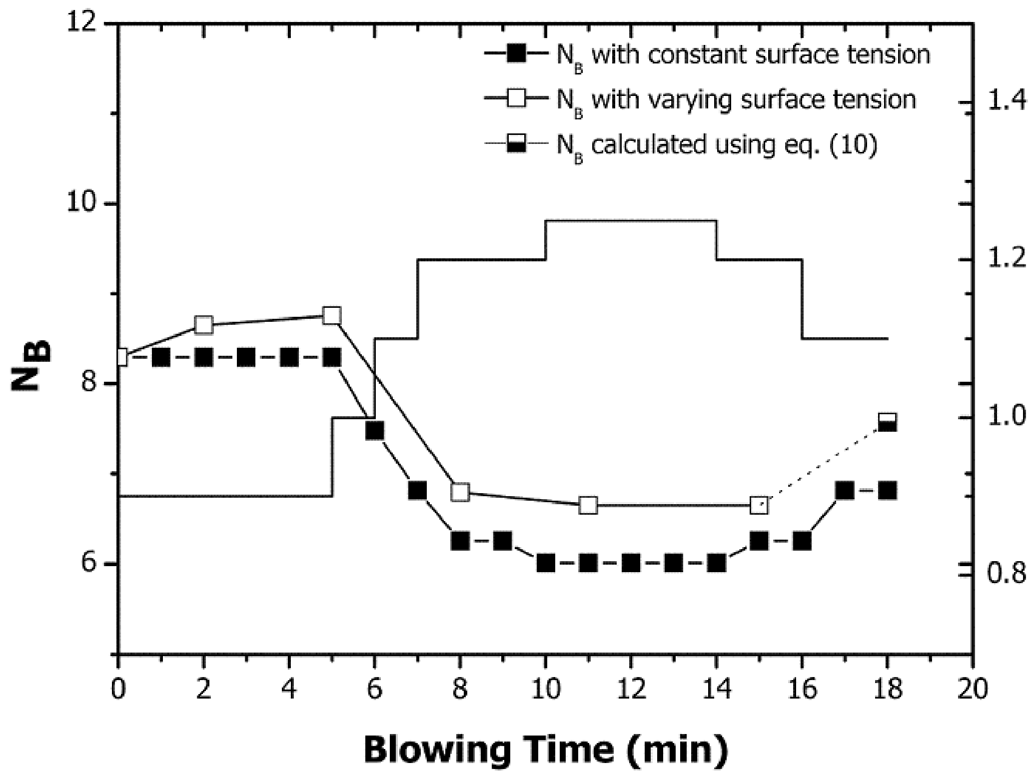
Results

Comparison of the blowing number as a function of surface tension



for [C]<0.05 wt pct

$$[ppmO][\%C] = 30$$

for [C]>0.05 wt pct

$$[ppmO]\sqrt{\%C} = 135 \pm 5$$

(After Turkdogan, 1996)

Dogan, Brooks and Rhamdhani, Chemeca Conference, 2008

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Summary of Droplet Generation Model

- Droplet generation in top blown oxygen steelmaking is dominated by the blowing conditions, not by the physical properties of liquid metal.

- Chemistry of the steel does strongly effect the generation of droplets for low carbon steels towards the end of the blow

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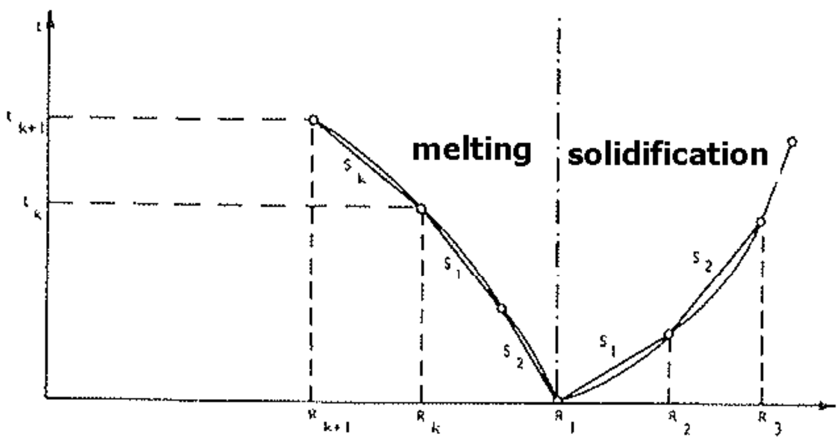
Scrap Melting and Dissolution Model

Includes melting and dissolution of scrap in the melt

Influences the carbon concentration in the melt and end point temperature



Includes three stages

1. Solidification stage
2. Solidified shell melting stage
3. Normal melting stage

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Mathematical modelling of kinetics of scrap melting

Modelling based on

- ❖heat transfer control
- ❖heat transfer from melt to scrap
- ❖unsteady state heat conduction within the scrap

The amount of scrap melted can be found by

$$\frac{\partial W}{\partial t} = \rho A v$$

Melting rate of scrap can be obtained using

$$v = \frac{1}{\rho(-\Delta H_{Fe})}\left\{ h(T_b - T') + \lambda \left.\frac{\partial T_{Sc}(x,t)}{\partial x}\right|_{x=0} \right\}$$

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One dimensional heat equation

$$\alpha \frac{\partial^2 T_{Sc}(x,t)}{\partial x^2} = \frac{\partial T_{Sc}(x,t)}{\partial t}$$

Equation can be solved using error function

$$\frac{T_{Sc} - T_b}{T_{Sc,i} - T_b} = 1 - \left[erfc\frac{(1-x/L)}{2\sqrt{Fo}} + erfc\frac{(1+x/L)}{2\sqrt{Fo}} \right] + exp\left[Bi(1-x/L) + Bi^2 Fo\right] \cdot erfc\left[Bi\sqrt{Fo} + \frac{1-x/L}{2\sqrt{Fo}} \right]$$
$$+ exp\left[Bi(1+x/L) + Bi^2 Fo\right] \cdot erfc\left[Bi\sqrt{Fo} + \frac{1+x/L}{2\sqrt{Fo}} \right]$$

Poirier and Geiger, "Transport Phenomena in Material Processing", 1994

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Model Structure and Assumptions

- Consists of stepforward calculation procedure
- Time interval is 1 second.
- Carbon content of interface = carbon content in the liquid bath.
- Carbon content of solid surface is related to the temperature at equilibrium (binary-phase diagram of Fe-C).
- ΔHFe is the enthalpy change for scrap melting and raising the temperature.
- Convective heat transfer
- Specific heat capacity of scrap is the function of temperature, which is the average value of interface temperature and centreline temperature of scrap
- x is distance from the centreline thickness of scrap

Boundary conditions

- Solidification occurs until the thickness of the scrap reaches the maximum thickness.
- Solidified shell melting occurs until the thickness of the scrap reaches the initial thickness.
- Normal melting stage occurs until all the scrap is melted.

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Data used for calculations

Amount of scrap charged, kg	8000
Initial hot metal temperature, K	1573
Initial scrap temperature, K	303
Bulk carbon concentration, wt%	4.26
Area of scrap/liquid interface, m^2	5.4
δ, scrap thickness, m	0.2
h, heat transfer coefficient in liquid metal, W/m^2K	3630
ρ, density of scrap, kg/m^3	7200
ΔH_{Fe}, Entalphy change in scrap melting and raising the temperature of liquid metal to interface temperature, kJ/kg Fe	277.2
α, thermal diffusivity of scrap, m^2/s	0.000062

Sethi, Shukla, Das, Chandra and Deo, AISTech 2004 Proceedings, 2004

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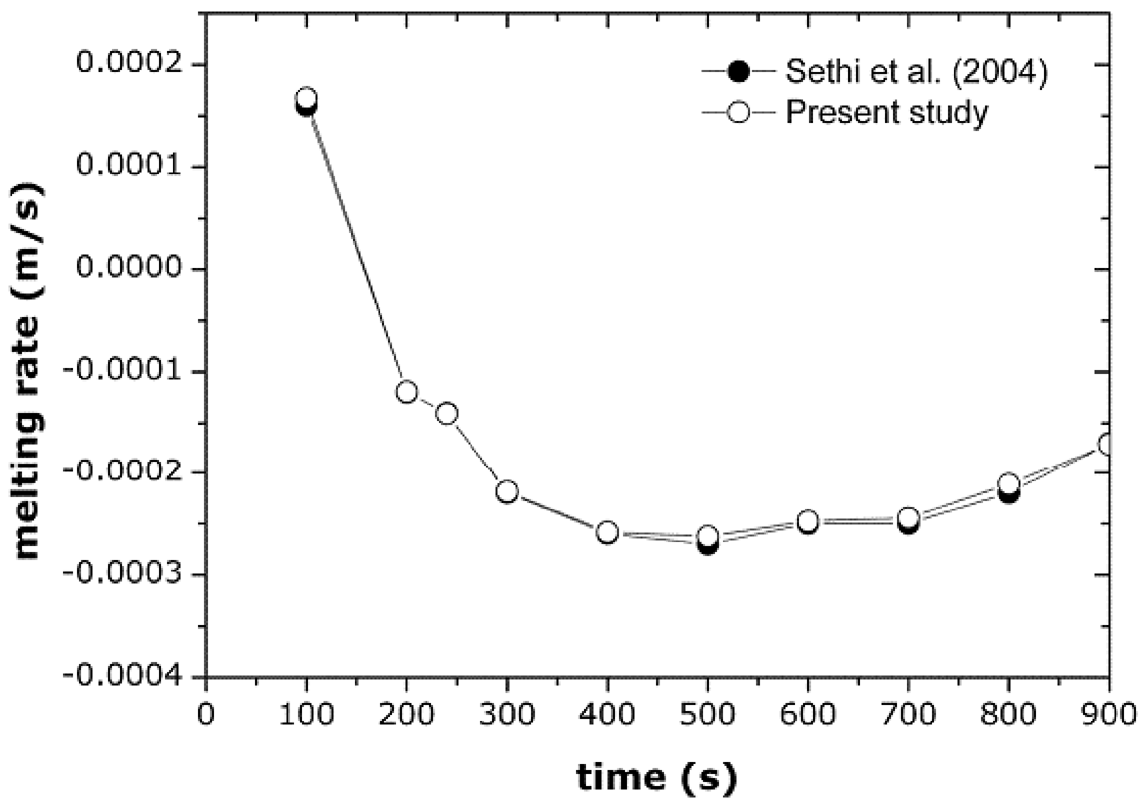
Results

Comparison of melting rate with the study of Sethi et al.



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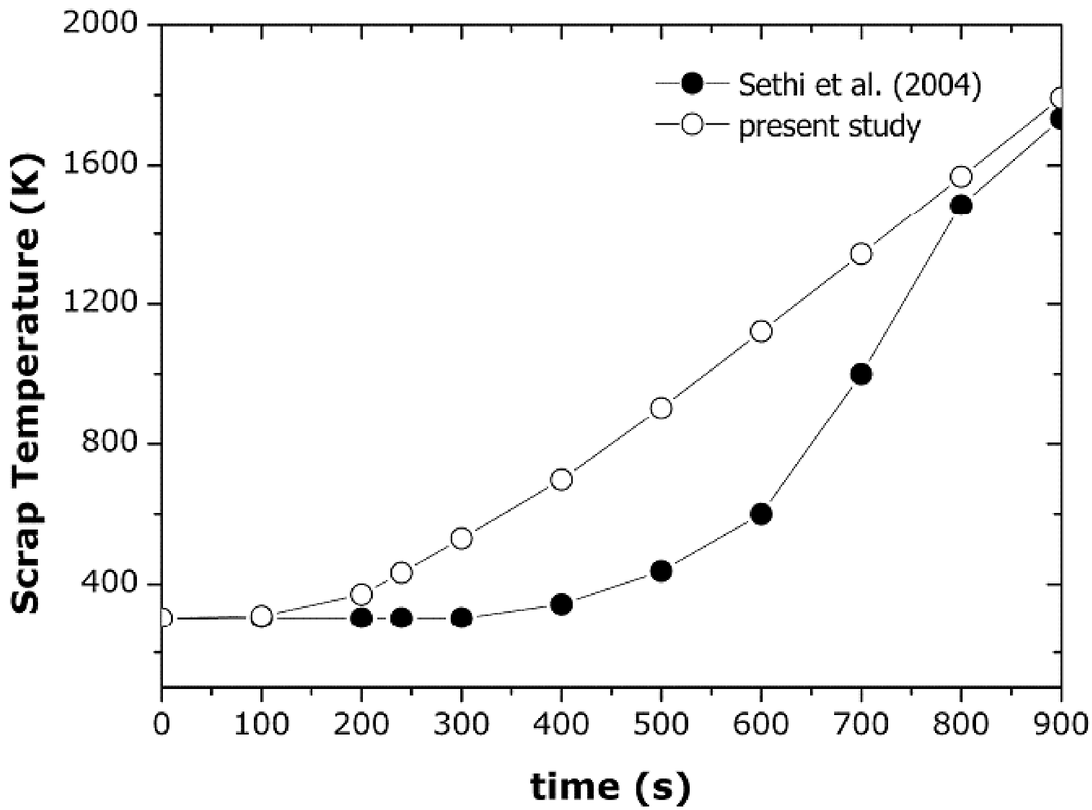
Results

Temperature profile of scrap as a function of time



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Presentations and Papers

(1) “Modelling of Oxygen Steelmaking”, University of Wollongong, (Jul 19, 2007)

(2) “Decarburization Reaction at the impact zone”, High Temperature Processing (HTP) Group meeting, (Feb 27, 2008)

“Analysis of Droplet Generation in Oxygen Steelmaking” journal paper submitted for ISIJ Journal (May 26, 2008)

“The bloated droplet model of oxygen steelmaking” Abstract submitted for European Oxygen Steelmaking Conference (May 30, 2008)

“Modelling of Metal Droplet Generation in Oxygen Steelmaking” conference paper accepted for Chemeca 2008 Conference (Jun 30, 2008)

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3. Plan for Next Stage

- developing mathematical models for the sub-models (Aug-Feb 2009)
- verification and validation of these models against the previous models based on industrial trials (Feb-July 2009)
- In the next 12 months, I am aiming to write 2 journal publications.
- completion of thesis (July-Feb 2010)

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Thank you

Any Questions??

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