Thermodynamics and kinetics on slag-steel-inclusion interactions

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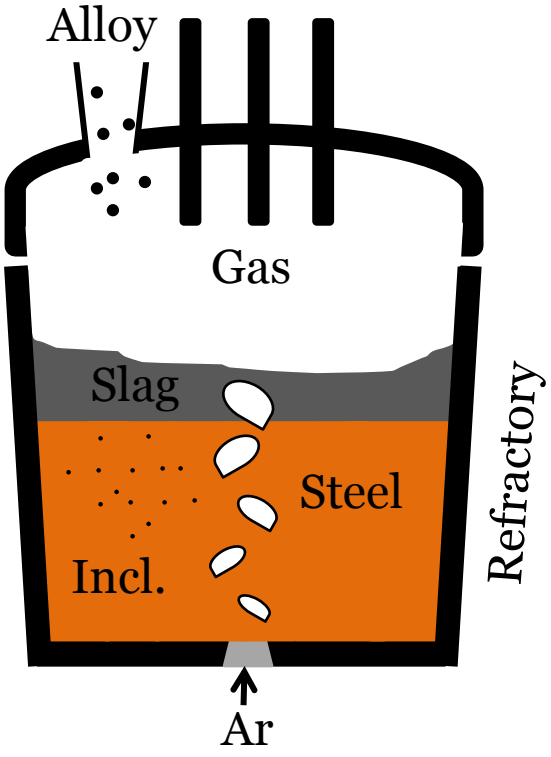
  - Slag-steel-inclusions
- Conclusions

Introduction

Ladle furnace refining



Purposes

- Impurities removal
- Temp. & comp. adjustment

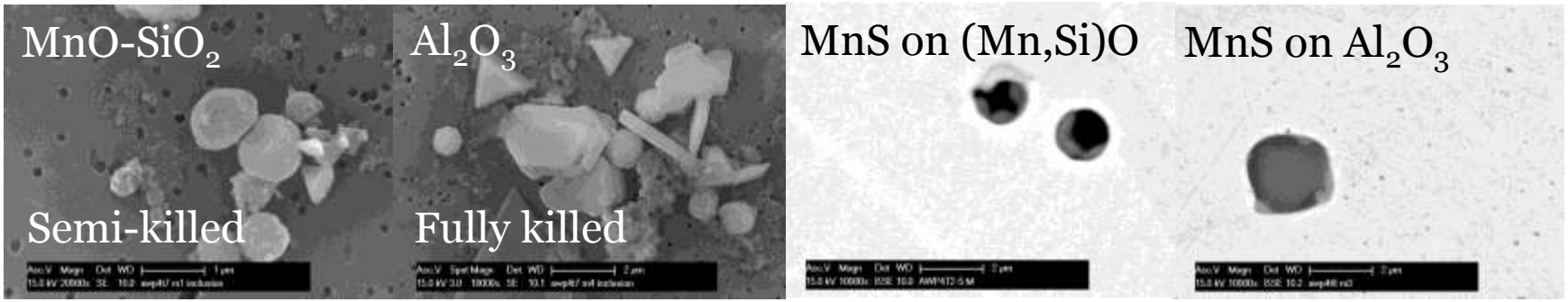
Interactions

- Gas-slag-refractory-steel-inclusions

Introduction

Non-metallic inclusions

- Oxides, sulphides & nitrides



Functions

- Harmful
- Positive

Challenge: to control the inclusions by playing with slag, alloy, operation etc.

Experimental

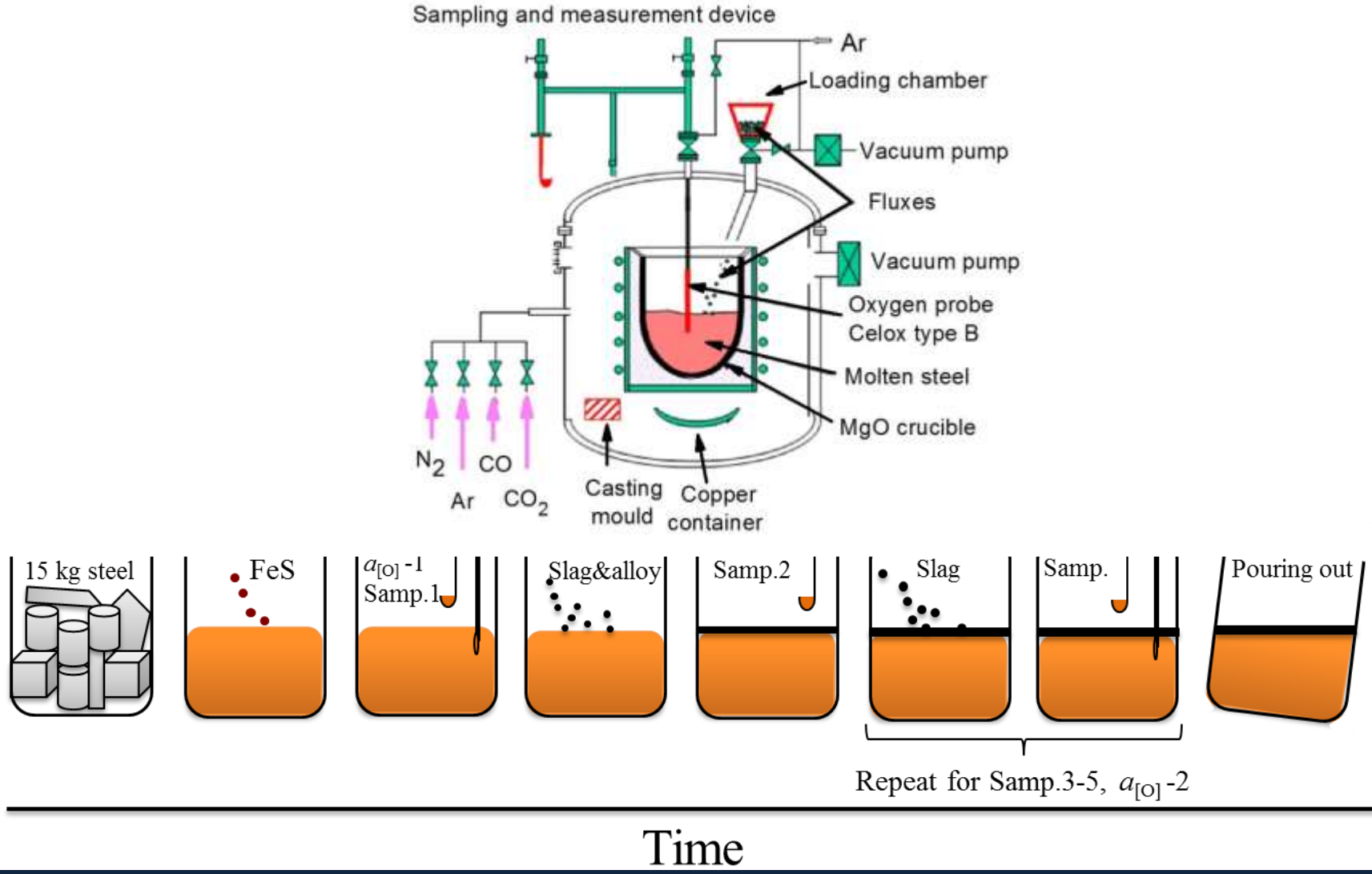
Steel composition

C	Mn	P	S	Si	Cr	Ni	Mo	Cu	Ti	Co	N	Al	B
0.03	1.2	0.03	0.0045	0.44	18.3	7.96	0.28	0.36	0.001	0.166	0.057	-	0.0006

Slag composition

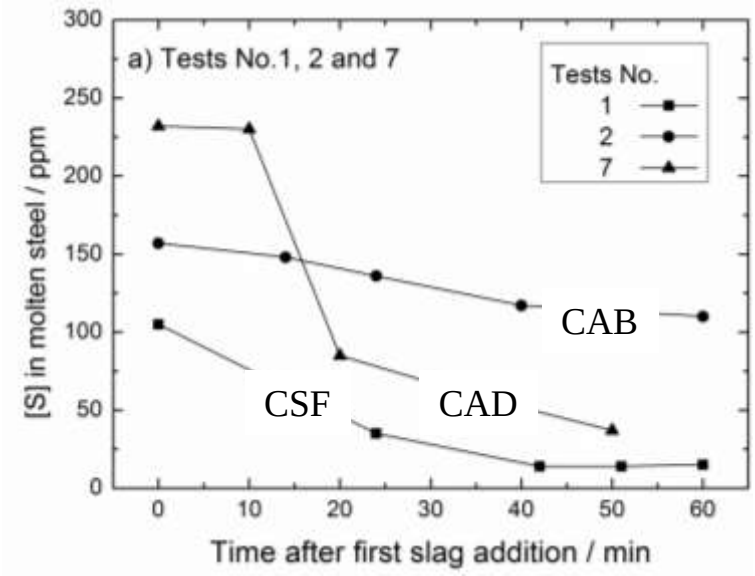
Test No.	Slag type	Remarks	Chemical composition (wt%)							Al addition (g)	Ar stirring (L/min)
			CaO	Al_2O_3	Fe_2O_3	SiO_2	MgO	TiO_2	CaF_2		
1	A	Oxides	81.8	-	-	2.13	1.26	-	14.81	0	0
2	B	Synthetic	40.0	45.5	2.5	6.0	1.0	4.0	-	0	0
3	C	Oxides	55.0	40.0	-	5.0	-	-	-	3	0
4	C	Oxides	55.0	40.0	-	5.0	-	-	-	0	0
5	C	Oxides	55.0	40.0	-	5.0	-	-	-	3	0
6	C	Oxides	55.0	40.0	-	5.0	-	-	-	3	0.5
7	D	Synthetic	50.0	40.4	2.1	4.3	0.6	1.7	-	3	0

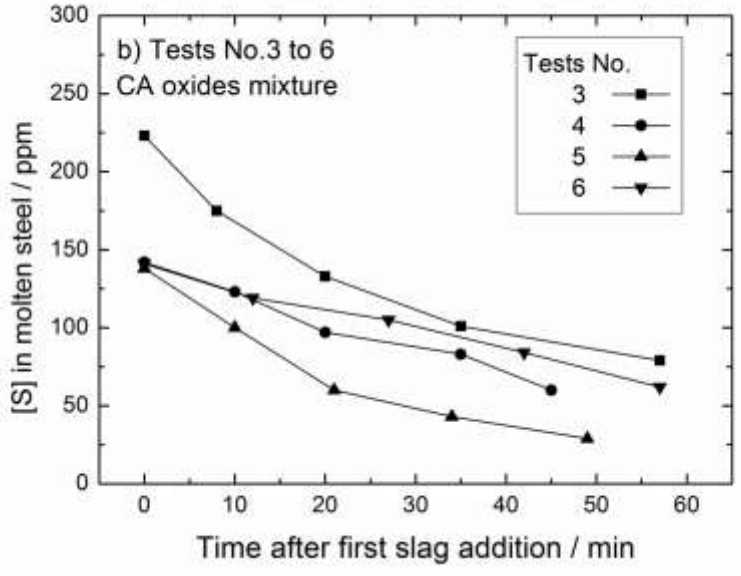
Experimental



Results

Impurity: sulphur

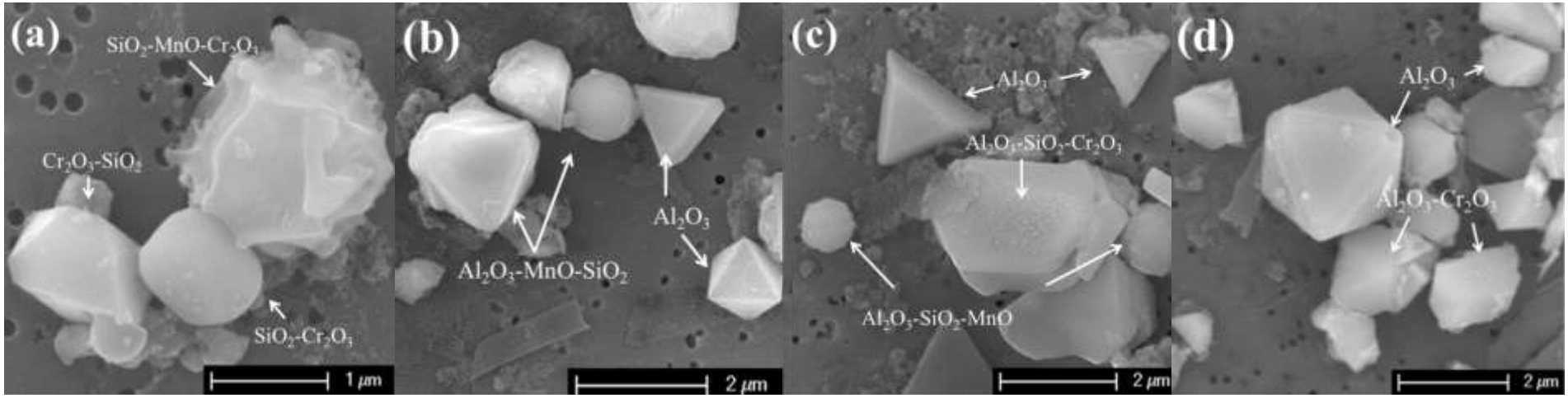




- ✓ All slags remove sulphur
- ✓ Deoxidation benefits sulphur removal
- ✓ Ar blowing worsens the desulphurization

Results

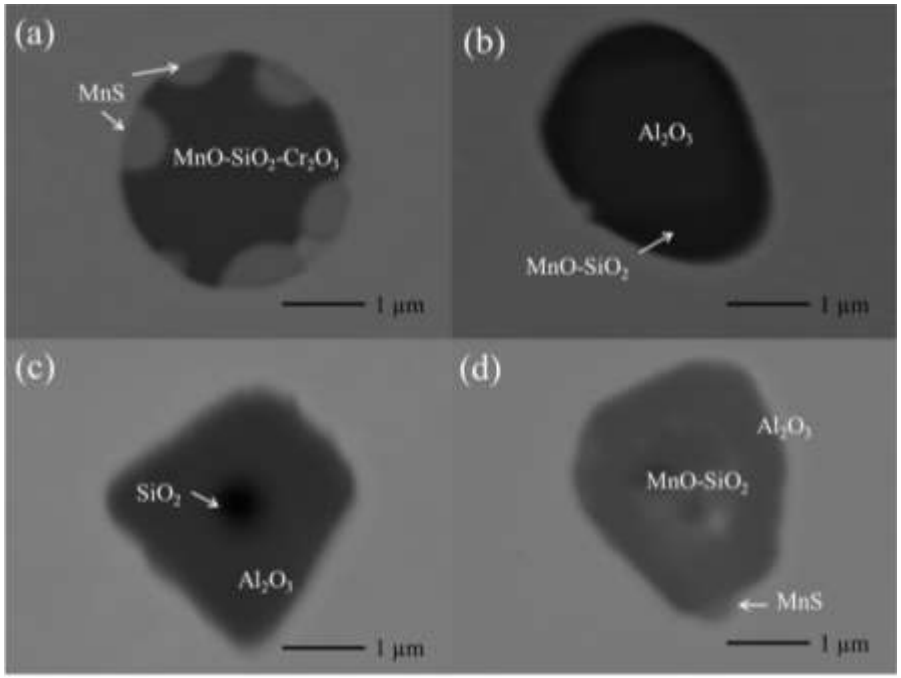
Impurity: inclusions

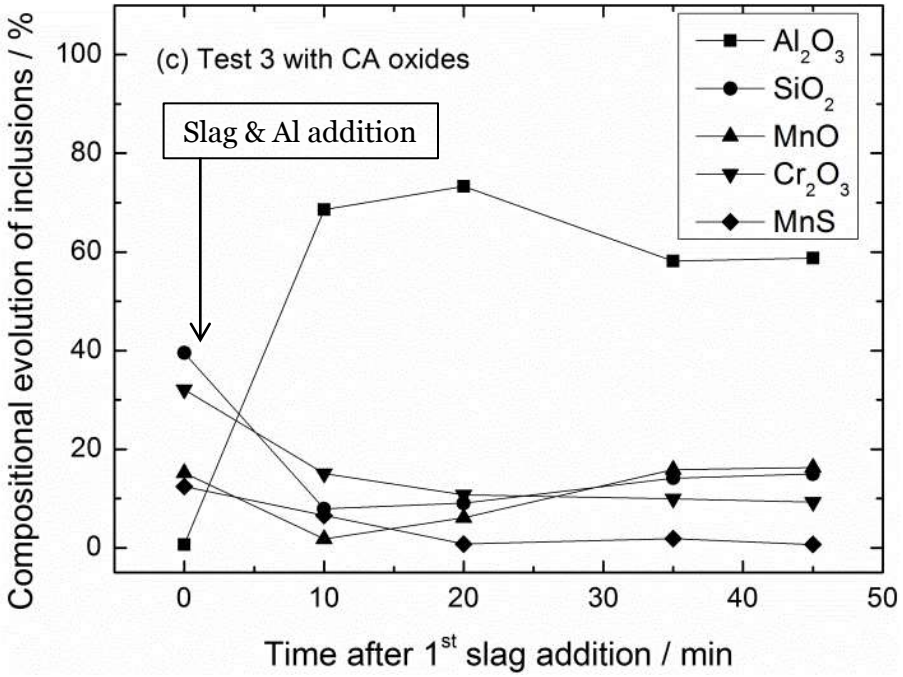


- ✓ Original inclusion with spherical and angular shape
- ✓ New formed octahedral or plate like Al2O3 containing inclusion

Results

Impurity: inclusions

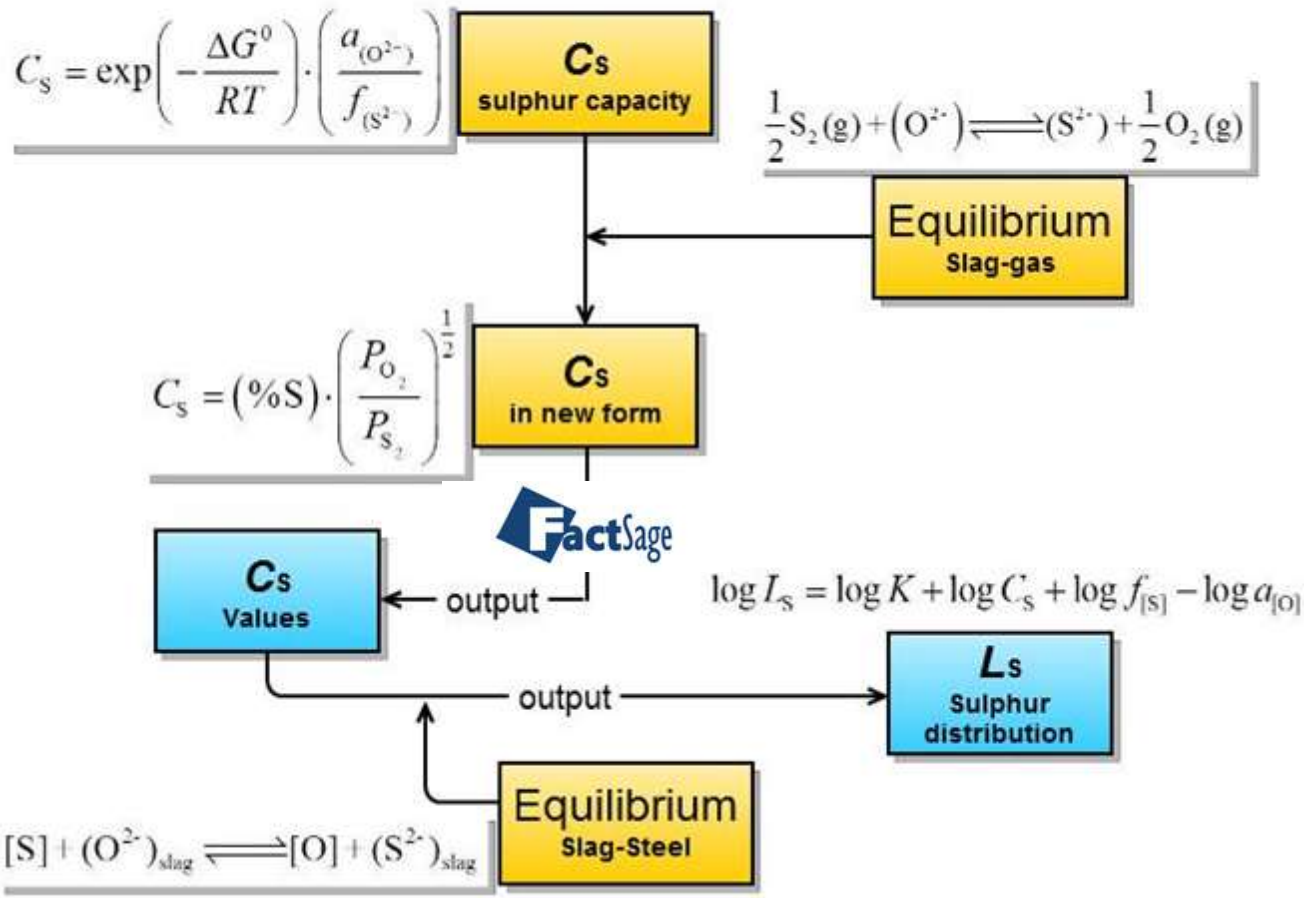




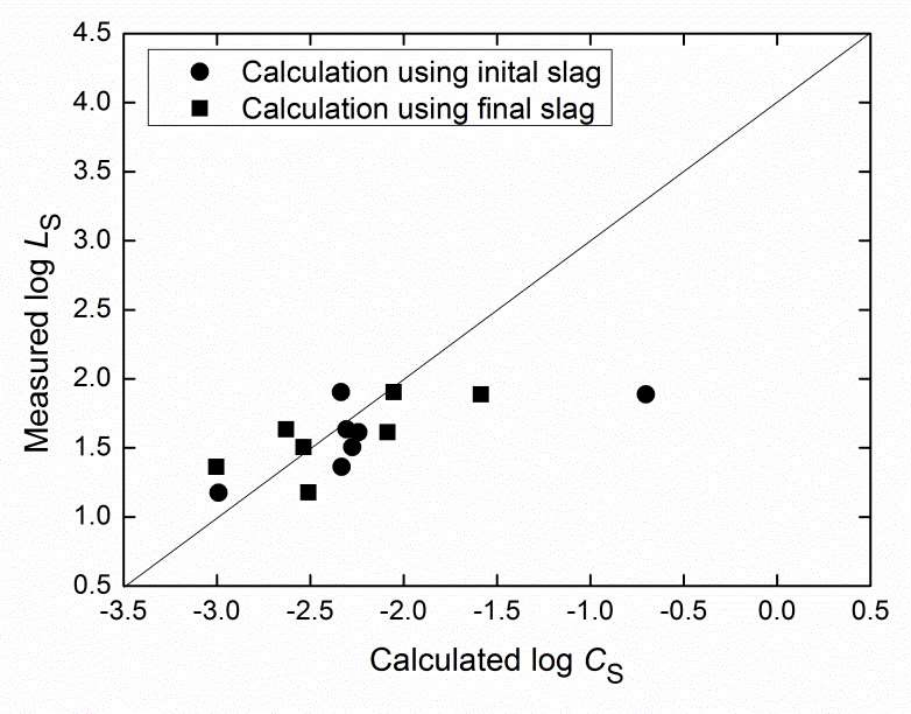
- ✓ Composition evolution after slag and alloy addition

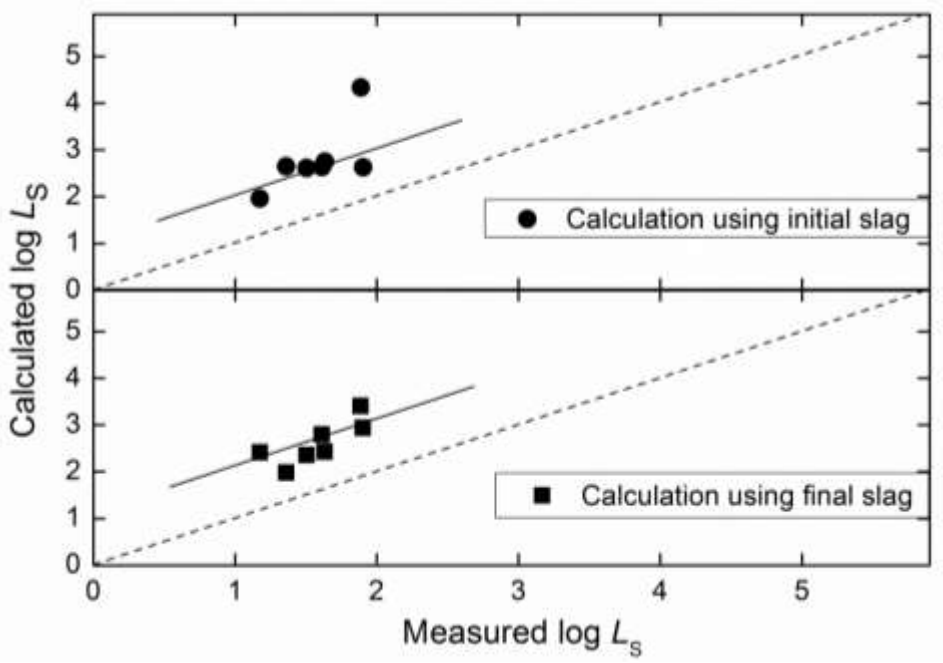
Thermodynamics on De-S

Sulphur capacity



Thermodynamics on De-S

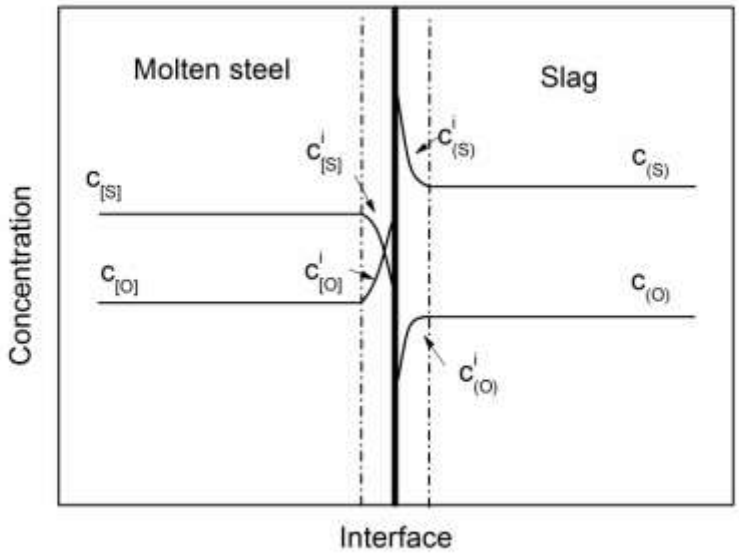




- ✓ Linear relation between L_S and C_S
- ✓ Linear relation cal. and mea. L_S
- ✓ Under equilibrium

Thermodynamics is not enough, Kinetics

Kinetics on De-S



$$J = k(c^{i}_{(S)} - c_{(S)})$$

Two film theory

Sulfur conservation

$$(S)^t = \frac{W_m([S]^o - [S]^t)}{\sum_I W_S^I}$$

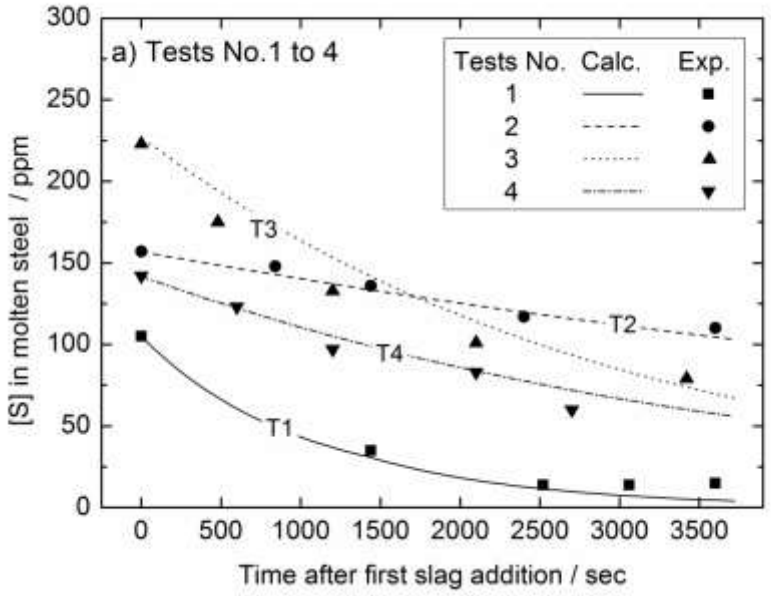
$$\frac{d[S]^t}{dt} = \frac{\sum_I W_s^I}{W_m} \times \frac{d(S)^t}{dt}$$

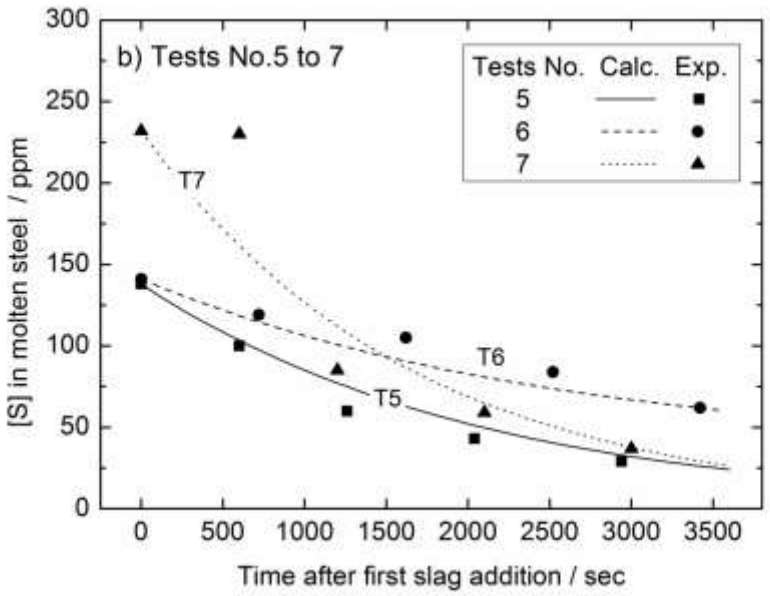
[S] removal rate

$$-\frac{d[\%S]}{dt} = \frac{A}{W_m} k \rho_s \left\{ [\%S] - \frac{(\%S)}{L_S} \right\}$$

- Assumptions
  - Permanent contact
  - Equilibrium at interface
  - No species accumulated at interface
  - ✓ Rate-limiting step: S transport in slag

Kinetics on De-S

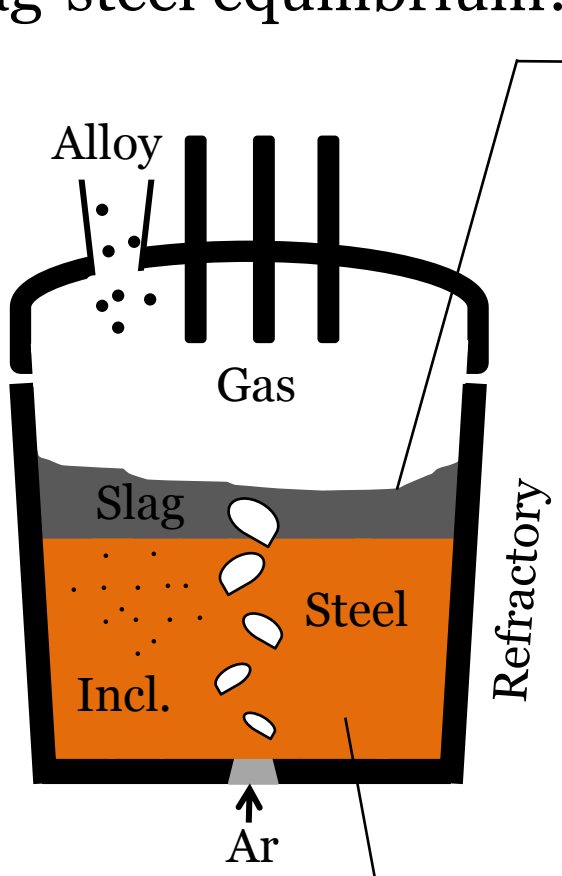




- ✓ Predictable of [S] evolution through thermodynamic and kinetic consideration

Thermodynamics and kinetics on inclusions

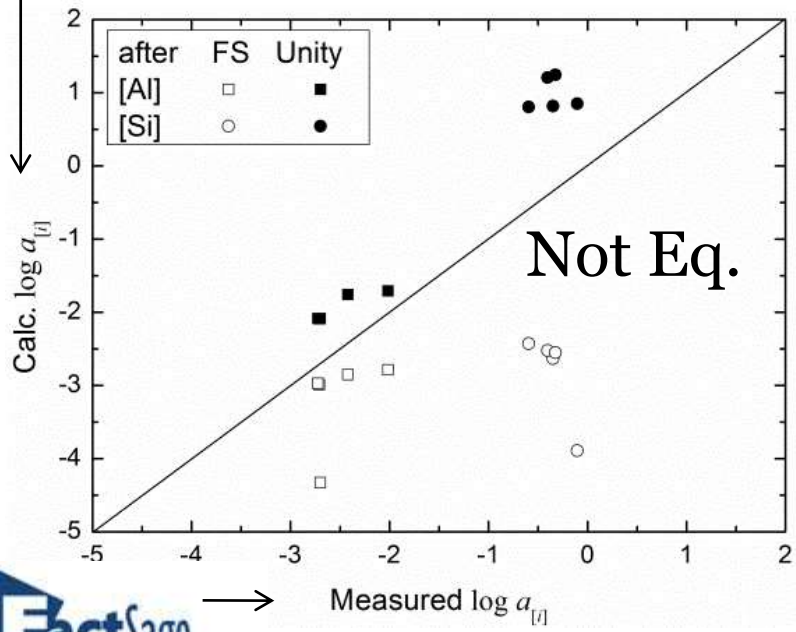
Slag-steel equilibrium?



Comp. + T → FactSage → $a_{(Al2O3,\ SiO2)}$

$$2[Al]+3[O]=(Al_2O_3),\log K_3=\frac{45300}{T}-11.62$$

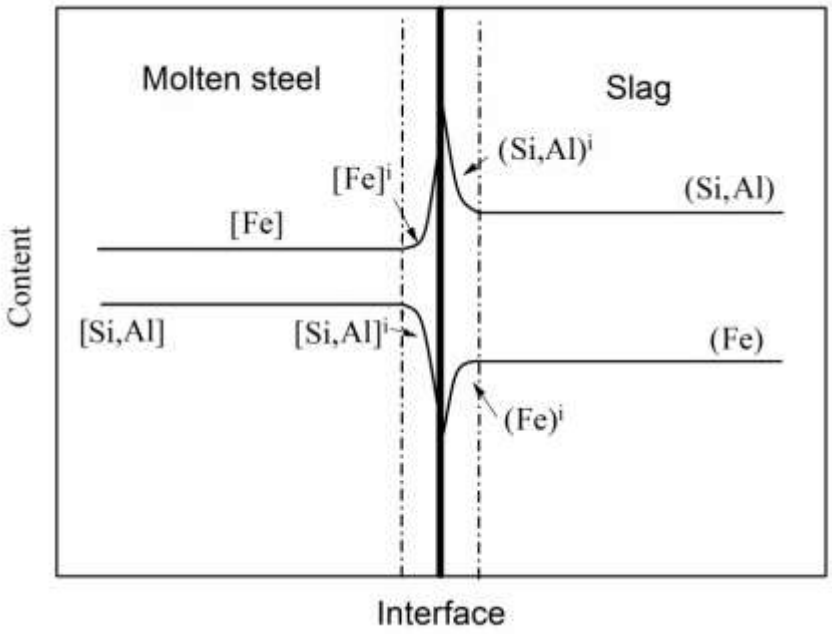
$$[Si]+2[O]=(SiO_2),\log K_4=\frac{24600}{T}-8.4$$

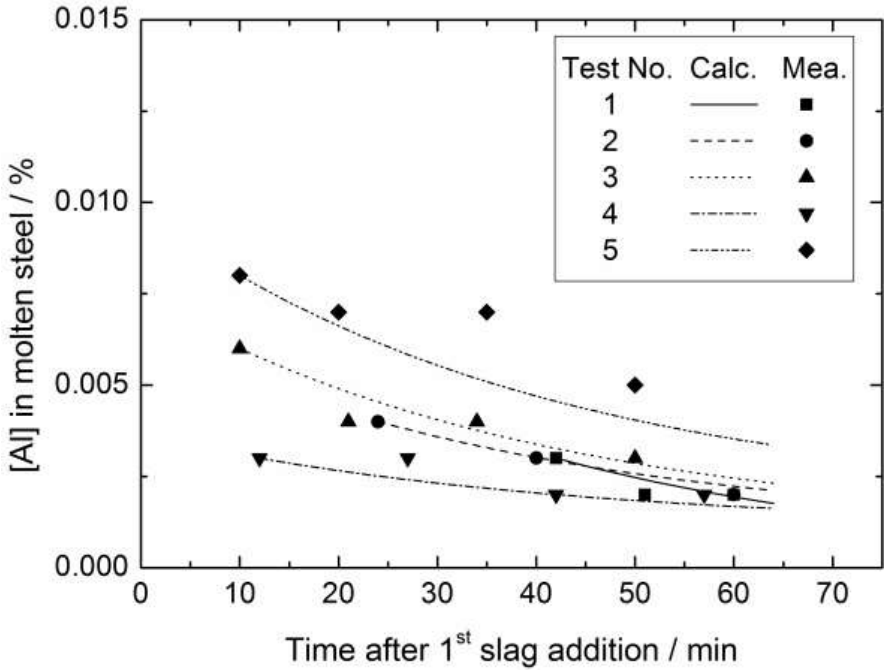


Comp. + T → FactSage → Measured log $a_{[i]}$

Thermodynamics and kinetics on inclusions

Slag-steel kinetics

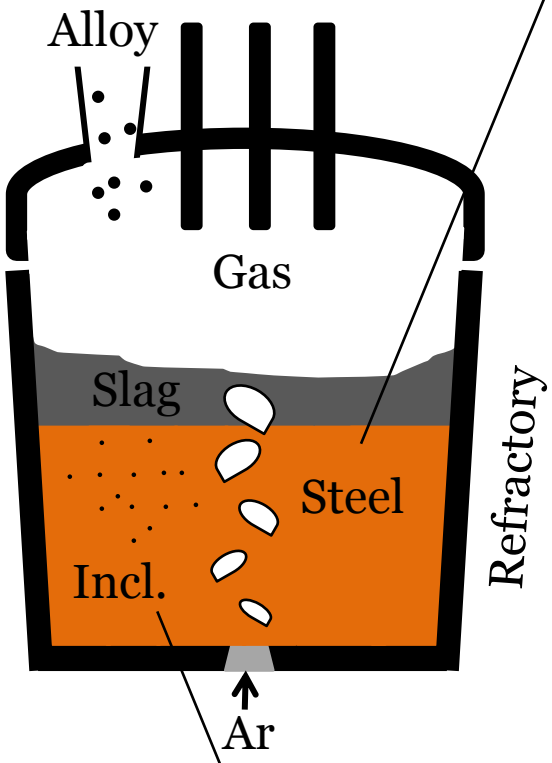




- ✓ [Al] is oxidized with slag at interface
- ✓ Consumption of [Al] by slag

Thermodynamics and kinetics on inclusions

Steel-incl. equilibrium? → Comp. + T → FactSage → $a_{[Al, Si, Mn, Cr]}$

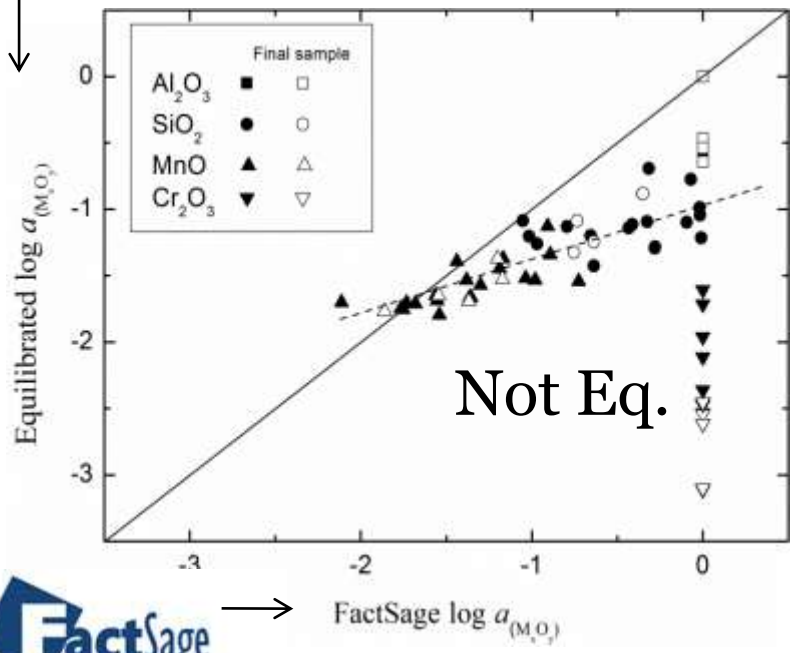


$$2[Al]+3[O]=(Al_2O_3)_{incl}, \log K_9 = \frac{45300}{T} - 11.62$$

$$[Si]+2[O]=(SiO_2)_{incl}, \log K_{10} = \frac{24600}{T} - 8.4$$

$$[Mn]+[O]=(MnO)_{incl}, \log K_{11} = \frac{11070}{T} - 4.53$$

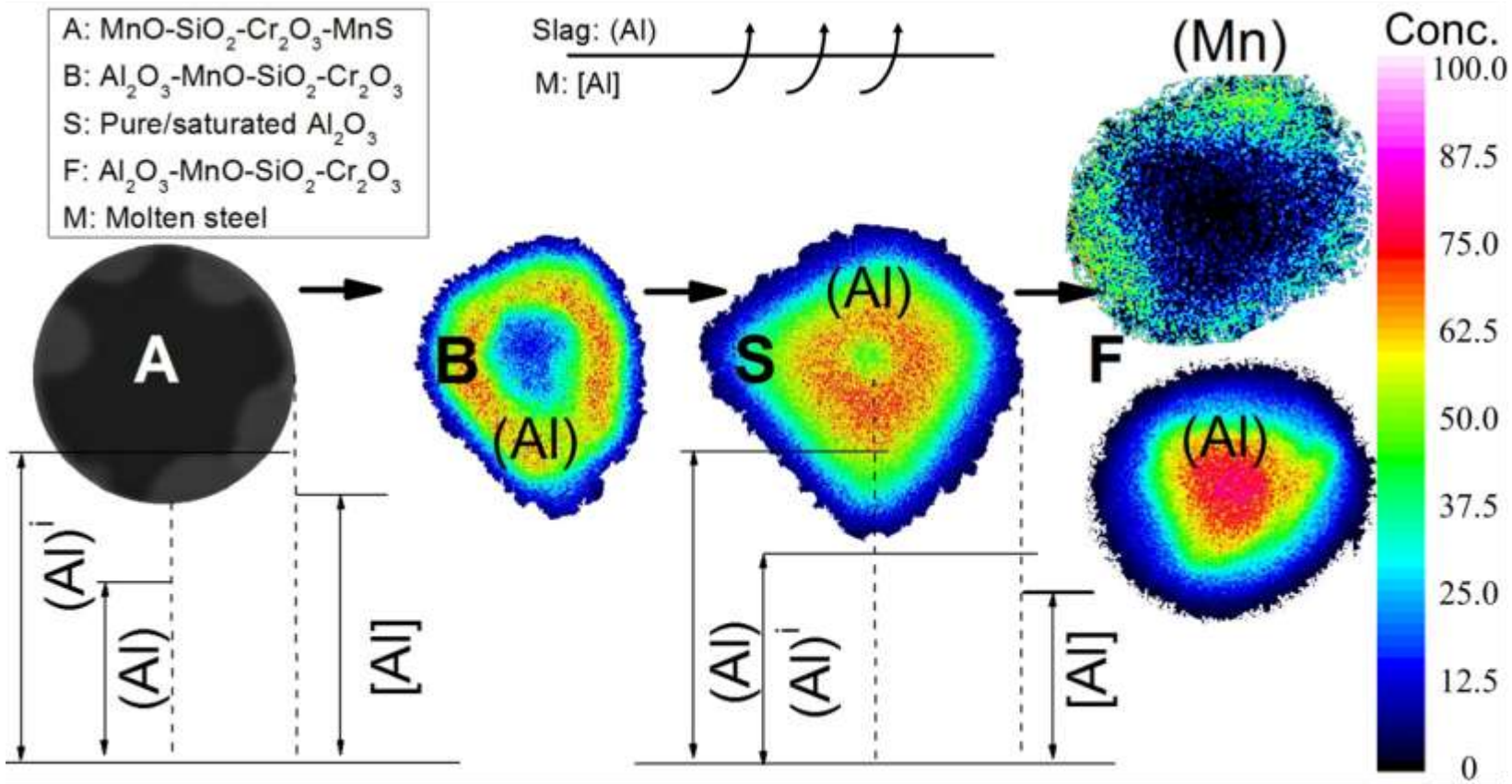
$$2[Cr]+3[O]=(Cr_2O_3)_{incl}, \log K_{12} = \frac{36200}{T} - 16.00$$



Comp. + T → FactSage → FactSage log $a_{(M_xO_y)}$

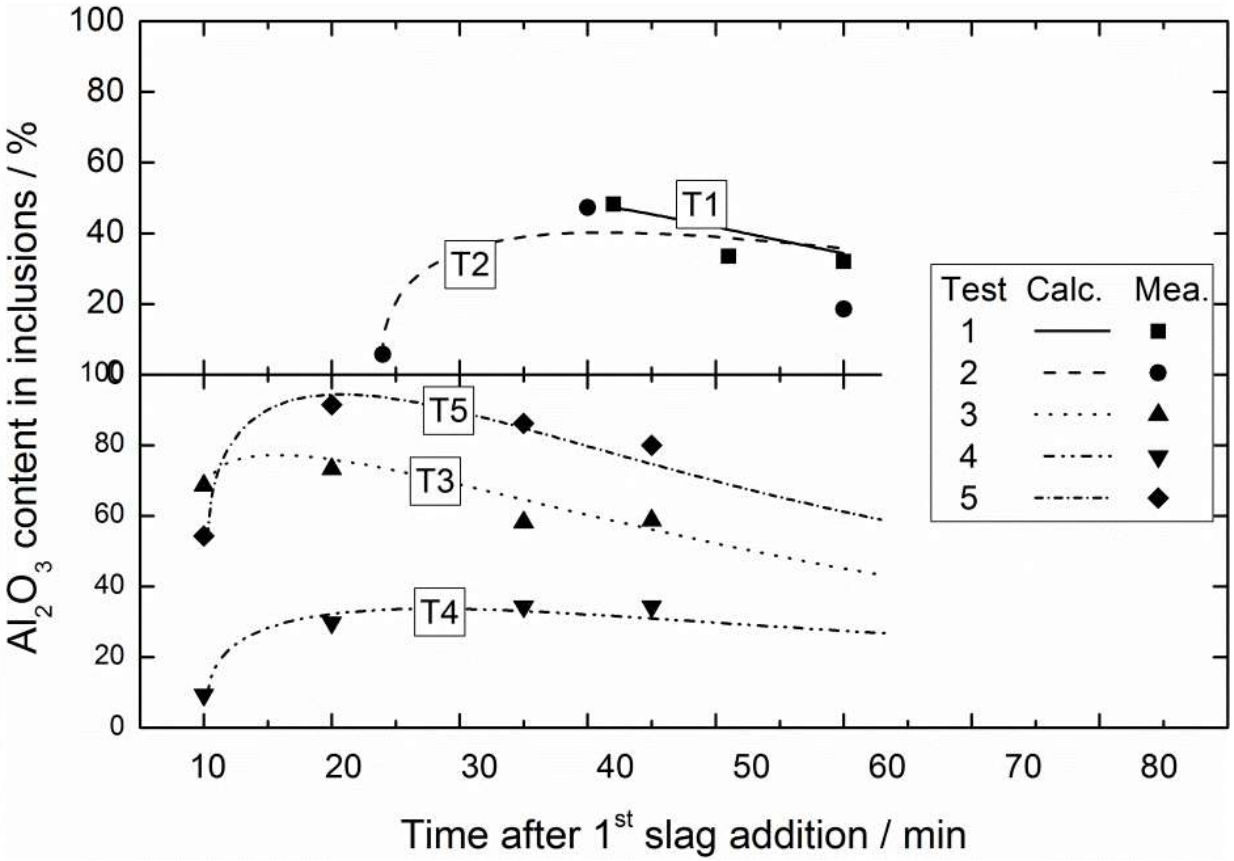
Thermodynamics and kinetics on inclusions

Steel-incl. kinetics



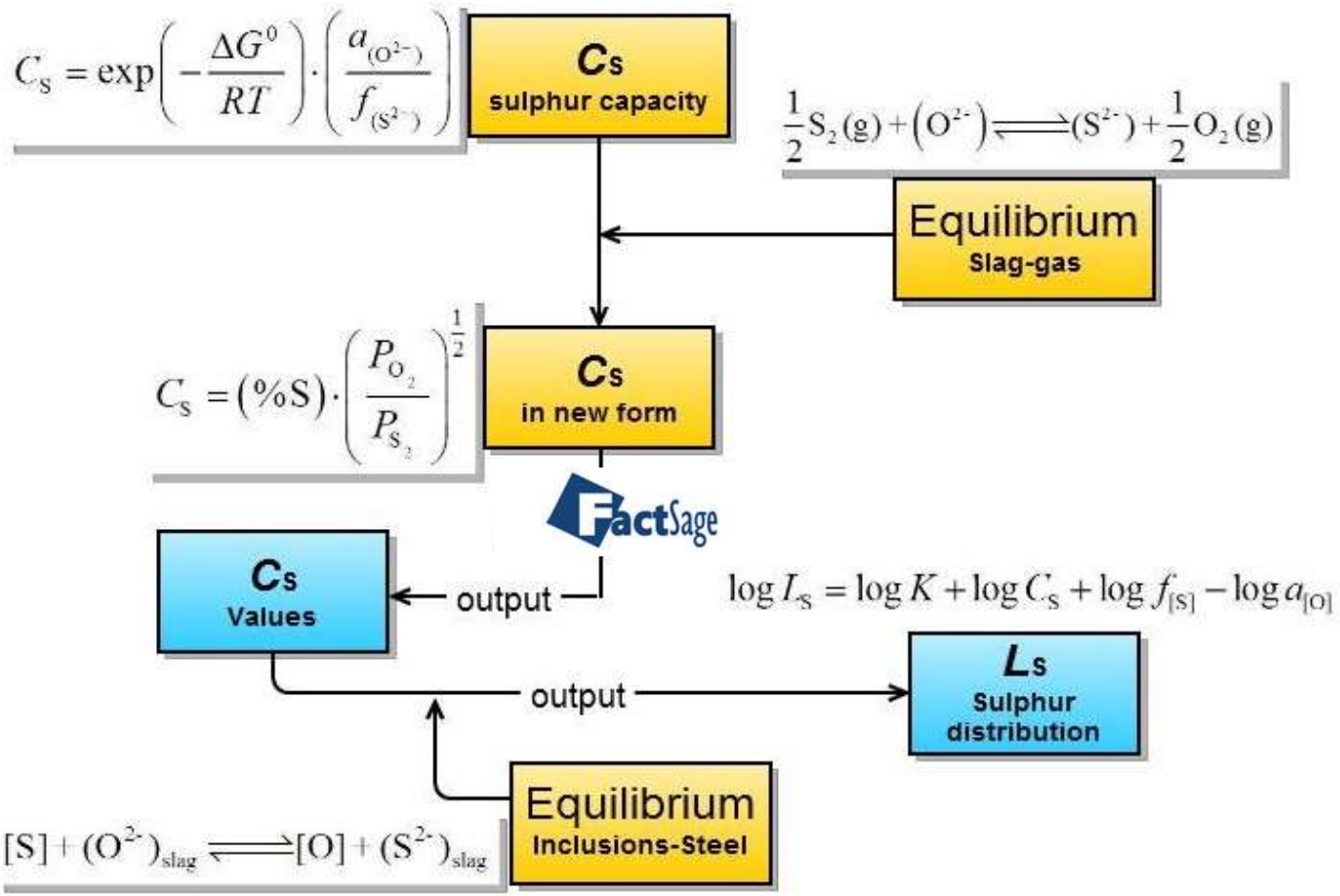
Thermodynamics and kinetics on inclusions

Slag-steel-incl. kinetics



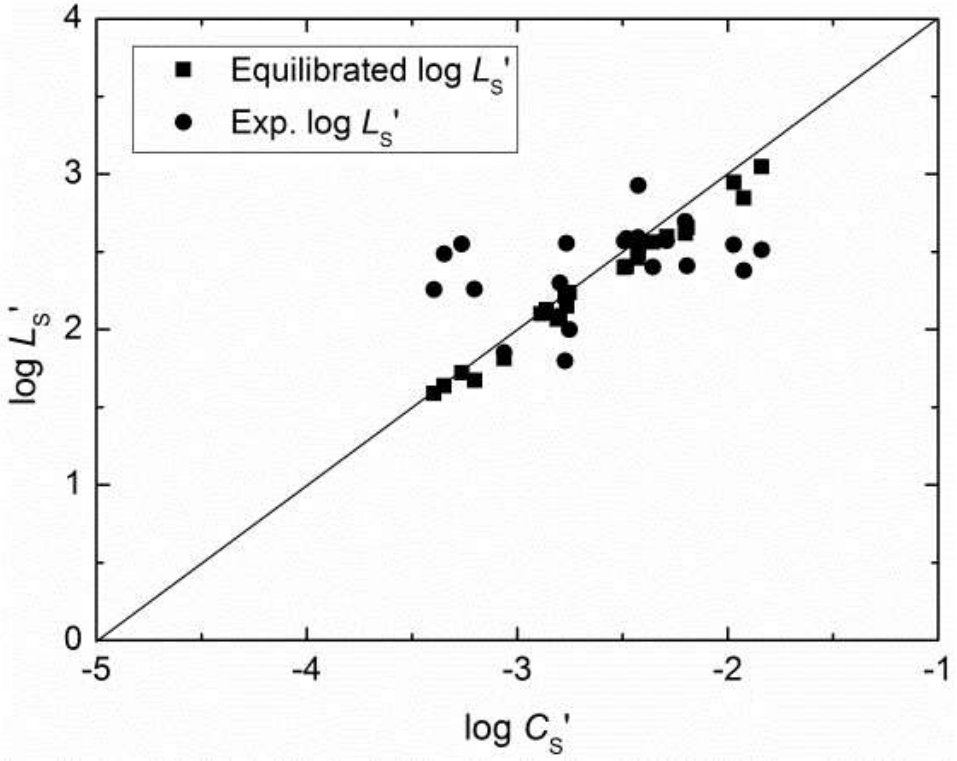
Thermodynamics and kinetics on inclusions

Sulphur capacity of incl.



Thermodynamics and kinetics on inclusions

Sulphur content



- ✓ Linear relation between L_S and C_S: predictable
- ✓ Extreme condition: discrepancy

Conclusions

- Thermodynamics
  - Sulphur capacity calculation
  - Partial Eq. at slag/steel interface
  - Steel/incl. close to Eq.

- Kinetics
  - Slag-steel model to predict steel: [S and Al]
  - Slag-steel-incl. to predict inclusion chemistry
  - Sulphur content calculation

Thanks for you attention