

# BOF process

# Case-6 Oxygen steel making

- Based on the following HM and flux chemistry chemistry , we would like to calculate the equilibrium composition of HM and Slag at 1600 deg C.
- We would also like to calculate the slag viscosity of the equilibrium slag at its liquidus temperature.
- We can assume excess oxygen in the system.

## HM Chemistry (wt%)

CARBON	4.6844
CHROMIUM	0.028
COPPER	0.0035
MANGANESE	0.6975
NICKEL	0.0075
PHOSPHORUS	0.0612
SILICON	0.4935
SULPHUR	0.0027
TITANIUM	0.0404
VANADIUM	0.0097

## Scrap Chemistry (wt%)

Si	0.02%
Mn	0.05%

## Flux Chemistry (Wt%)

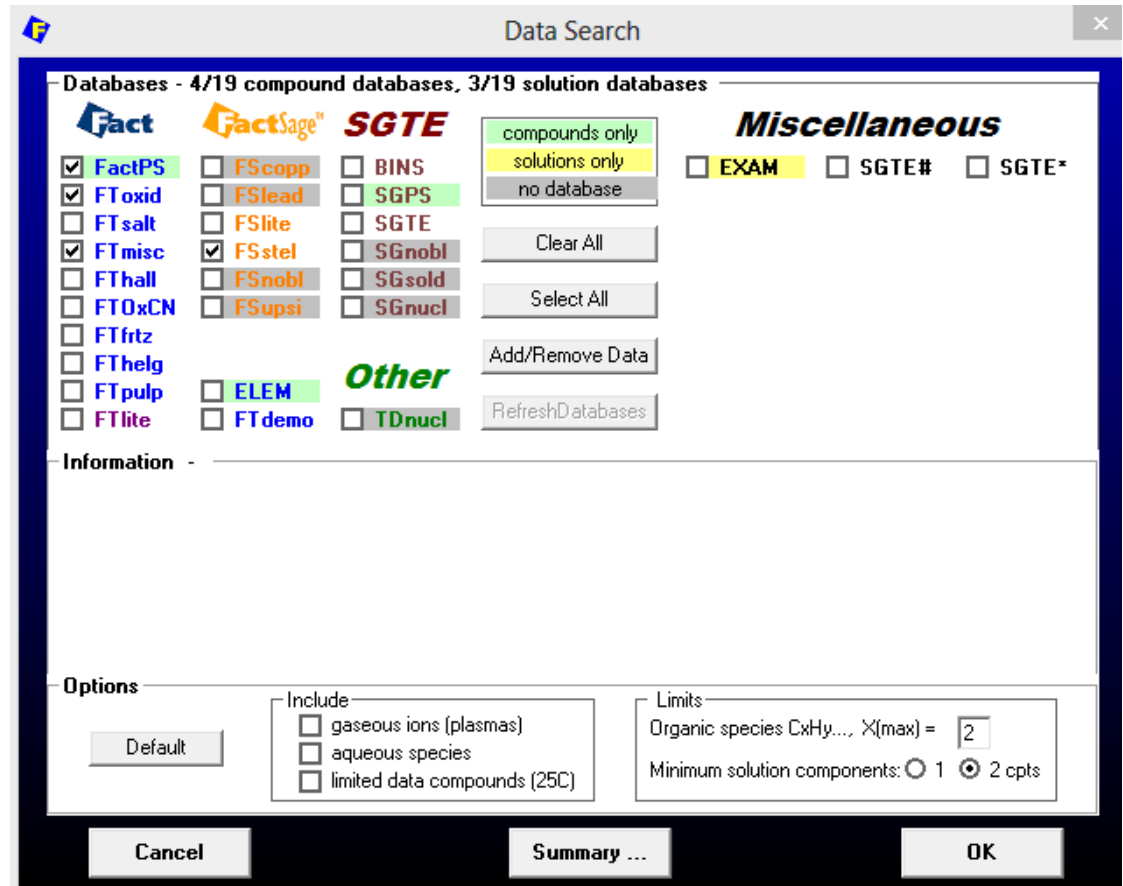
Burnt Lime	95% CaO
Dolo Lime	55% CaO

## Amounts charged (tons)

Type	Wt Charged
HM	213
Scrap	60
Dolo	5
Burnt	7

# Databases

- FToxid: slag
- FTmisc: molten steel
- FSstel: scrap



# Using Streams

Reactants - Equilib

File Edit Table Units Data Search Help

T(C) P(atm) Energy(J) Mass(g) Vol(litre)

1 - 7

Mass(g)	Species	Phase	T(C)	P(total)**	Stream#	Data
4.6844	C				0	
+ 0.028	Cr				1	
+ 0.6975	Mn				1	
+ 0.4935	Si				1	
+ 0.0027	S				1	
+ 0.0404	Ti				1	
+ 93.9716	Fe				1	

Initial Conditions

Next >>

FactSage 6.3 Compound: 2/20 databases Solution: 1/19 databases

# Selecting Solution and Temperature

Menu - Equilib: last system

File Units Parameters Help

T(C) P(atm) Energy(J) Mass(g) Vol(litre)

**Reactants (7)**

(gram) 4.6844 C + 0.028 Cr + 0.6975 Mn + 0.4935 Si + 0.0027 S + 0.0404 Ti + 93.9716 Fe

**Products**

Compound species

- gas  ideal  real 0
- aqueous 0
- pure liquids 0
- pure solids 0
- suppress duplicates

species: 0

Solution species

*	+	Base-Phase	Full Name
	+	FTmisc-FeLQ	Fe-liq
		FTmisc-MATT	Matte
		FTmisc-FeS_	FeS-liq
		FTmisc-MAT2A	ALiq(Matte/Metal)
		FTmisc-MAT2C	CLiq(Matte/Metal)
		FTmisc-MAT2?	?Liq(Matte/Metal)
		FTmisc-PYRRA	APyrrhotite
		FTmisc-PYRRC	CPyrrhotite

Legend  
+ - selected 1

Show  all  selected

species: 7

solutions: 1

Custom Solutions

- fixed activities
- ideal solutions
- activity coefficients

Pseudonyms

apply

include molar volumes

Total Species (max 1500) 7

Total Solutions (max 40) 1

**Final Conditions**

<A>	<B>	T(C)	P(atm)	Product H(J)
		1400	1	

10 steps  Table

**Equilibrium**

- normal  normal + transitions
- transitions only
- open

FactSage 6.3

# Check Results

Results - Equilib 1400 C

Output Edit Show Pages

T(C) P(atm) Energy(J) Mass(g) Vol(litre)

FactSage 6.3

```
(gram) 4.6844 C + 0.028 Cr + 0.6975 Mn + 0.4935 Si +
(gram) 0.0027 S + 0.0404 Ti + 93.9716 Fe =

99.918 gram Fe-liq
(99.918 gram, 2.1045 mol)
(1400 C, 1 atm, a=1.0000)
( 94.049 wt.% Fe FTmisc
+ 4.6882 wt.% C FTmisc
+ 2.8023E-02 wt.% Cr FTmisc
+ 0.69807 wt.% Mn FTmisc
+ 2.7022E-03 wt.% S FTmisc
+ 0.49390 wt.% Si FTmisc
+ 4.0433E-02 wt.% Ti FTmisc)
```

System component	Mole fraction	Mass fraction
Fe	0.79959	0.94049
Mn	6.0329E-03	6.9807E-03
Cr	2.5588E-04	2.8023E-04
Ti	4.0105E-04	4.0433E-04
S	4.0012E-05	2.7022E-05
Si	8.3495E-03	4.9390E-03
C	0.18533	4.6882E-02

The cutoff concentration has been specified to 1.0000E-75

```
*****
H          G          V          S          Cp
(J)       (J)       (litre)   (J/K)   (J/K)
```

# Save Stream

The screenshot shows the FactSage 6.3 interface with the 'Stream File' menu open. The 'Save stream file' option is selected, which has opened a sub-menu. In this sub-menu, 'Save solutions' is selected, which has opened another sub-menu. In this final sub-menu, 'FTmisc-FeLQ Fe-liq' is selected. The background shows the 'Results - Equilib 1400 C' window with a table of system components and their mole and mass fractions.

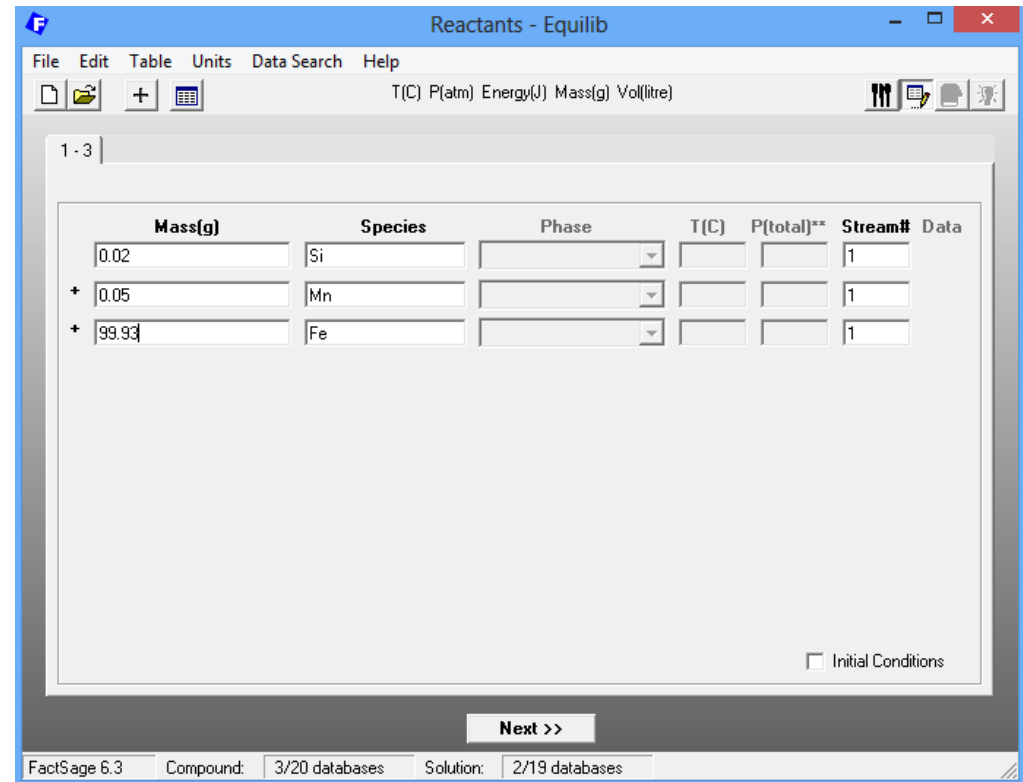
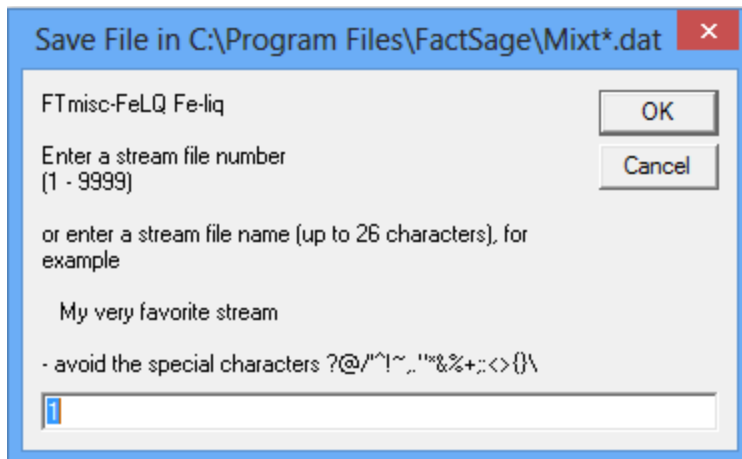
System component	Mole fraction	Mass fraction
Fe	0.79959	0.94049
Mn	6.0329E-03	6.9807E-03
Cr	2.5588E-04	2.8023E-04
Ti	4.0105E-04	4.0433E-04
S	4.0012E-05	2.7022E-05
Si	8.3495E-03	4.9390E-03
C	0.18533	4.6882E-02

The cutoff concentration has been specified to 1.0000E-75

H	G	V	S	Cp
(J)	(J)	(litre)	(J/K)	(J/K)

# Save Stream

- Save this as a stream (I named it HMChem)
- Perform similar actions for remaining streams





# Scrap

- This time 25C was chosen
- Along with BCC from FSstel

Menu - Equilib:

File Units Parameters Help

T(C) P(atm) Energy(J) Mass(g) Vol(litre)

Reactants (3)

(gram) 0.02 Si + 0.05 Mn + 99.93 Fe

Products

Compound species

gas  ideal  real 0

aqueous 0

pure liquids 0

pure solids 0

suppress duplicates apply

species: 0

Target

- none -

Estimate T(K): 1000

Mass(g): 0

Solution species

*	+	Base-Phase	Full Name
		FSstel-BCC1	BCC_A2

Legend

+ - selected 1

Show  all  selected

species: 3

solutions: 1

Custom Solutions

0 fixed activities

0 ideal solutions

0 activity coefficients

Details ...

Pseudonyms

apply  List ...

include molar volumes

Total Species (max 1500) 3

Total Solutions (max 40) 1

Default

Final Conditions

<A>	<B>	T(C)	P(atm)	Product H(J)
		25	1	

10 steps  Table

1 calculation

Equilibrium

normal  normal + transitions

transitions only

open

Calculate >>

FactSage 6.3

# Adding Lime

- You now have two streams (I've named them HMChem and Scrap)
- Now we need two more streams (1 for dolo lime and one for burnt lime)

Reactants - Equilib

File Edit Table Units Data Search Help

T(C) P(atm) Energy(J) Mass(g) Vol(litre)

Mass(g)	Species	Phase	T(C)	P(total)**	Stream#	Data
1	CaO					

Initial Conditions

Next >>

FactSage 6.3 Compound: 3/20 databases Solution: 2/19 databases

Reactants - Equilib

File Edit Table Units Data Search Help

T(C) P(atm) Energy(J) Mass(g) Vol(litre)

1-3

Mass(g)	Species	Phase	T(C)	P(total)**	Stream#	Data
55	CaO				1	
+ 40	MgO				1	
+ 5	SiO2				1	

Initial Conditions

Next >>

FactSage 6.3 Compound: 3/20 databases Solution: 2/19 databases

# Pure Solids

Menu - Equilib:

File Units Parameters Help

T(C) P(atm) Energy(J) Mass(g) Vol(litre)

Reactants (3)

(gram) 55 CaO + 40 MgO + 5 SiO2

Products

Compound species

- gas  ideal  real 0
- aqueous 0
- pure liquids 0
- pure solids 71
- suppress duplicates [apply](#)

species: 71

Solution species

*	+	Base-Phase	Full Name
---	---	------------	-----------

Legend

Show  all  selected

species: 0  
solutions: 0 [Select](#)

Custom Solutions

- fixed activities
- ideal solutions
- activity coefficients

[Details ...](#)

Pseudonyms

apply  [List ...](#)

include molar volumes

Total Species (max 1500) 71  
Total Solutions (max 40) 0

[Default](#)

Target

- none -

Estimate T(K):   
Mass(g):

Final Conditions

<A>	<B>	T(C)	P(atm)	Product H(J)
		25	1	

10 steps  Table [1 calculation](#)

Equilibrium

- normal  normal + transitions
- transitions only
- open

[Calculate >>](#)

FactSage 6.3

# Combine Mixtures with Weights

Reactants - Equilib

File Edit Table Units Data Search Help

T(C) P(atm) Energy(J) Mass(g) Vol(litre)

1 - 4

Mass(g)	Species	Phase	T(C)	P(total)**	Stream#	Data
5000000	[DoloLime]				1	
+ 213000000	[HMChem]				2	
+ 7000000	[Lime]				3	
+ 60000000	[Scrap]				4	

Initial Conditions

Next >>

FactSage 6.3 Compound: 3/20 databases Solution: 2/19 databases

# Add Variable Oxygen

Adding variable oxygen

Solutions chosen

-Iron liquid

-Liquid slag

-Calcium Silicate

-Monoxides

Amount of oxygen

-Educated guess

**Menu - Equilib: last system**

File Units Parameters Help

T(C) P(atm) Energy(J) Mass(mol) Vol(litre)

**Reactants (5)**

5000000 [DoloLime] + 213000000 [HMChem] + 7000000 [Lime] + 60000000 [Scrap] + <A> O2

**Products**

Compound species  
\* + gas  ideal  real 59  
aqueous 0  
pure liquids 0  
\* + pure solids 229  
 suppress duplicates   
\* - custom selection  
species: 288

Solution species

*	+	Base-Phase	Full Name
	+	FTmisc-FeLQ	Fe-liq
	I	FToxid-SLAGA	ASlag-liq all oxides + S
	I	FToxid-MeO_A	AMonoxide
	+	FToxid-bC2S	a-Ca2SiO4
	+	FToxid-aC2S	a-Ca2SiO4

Legend  
I - immiscible 2  
+ - selected 3

Show  all  selected  
species: 84  
solutions: 7

Custom Solutions  
 fixed activities  
 ideal solutions  
 activity coefficients

Pseudonyms  
 apply

include molar volumes  
Total Species (max 1500) 372  
Total Solutions (max 40) 7

**Final Conditions**

<A>	<B>	T(C)	P(atm)	Product V(litre)
15000000	1600000	1600	1	

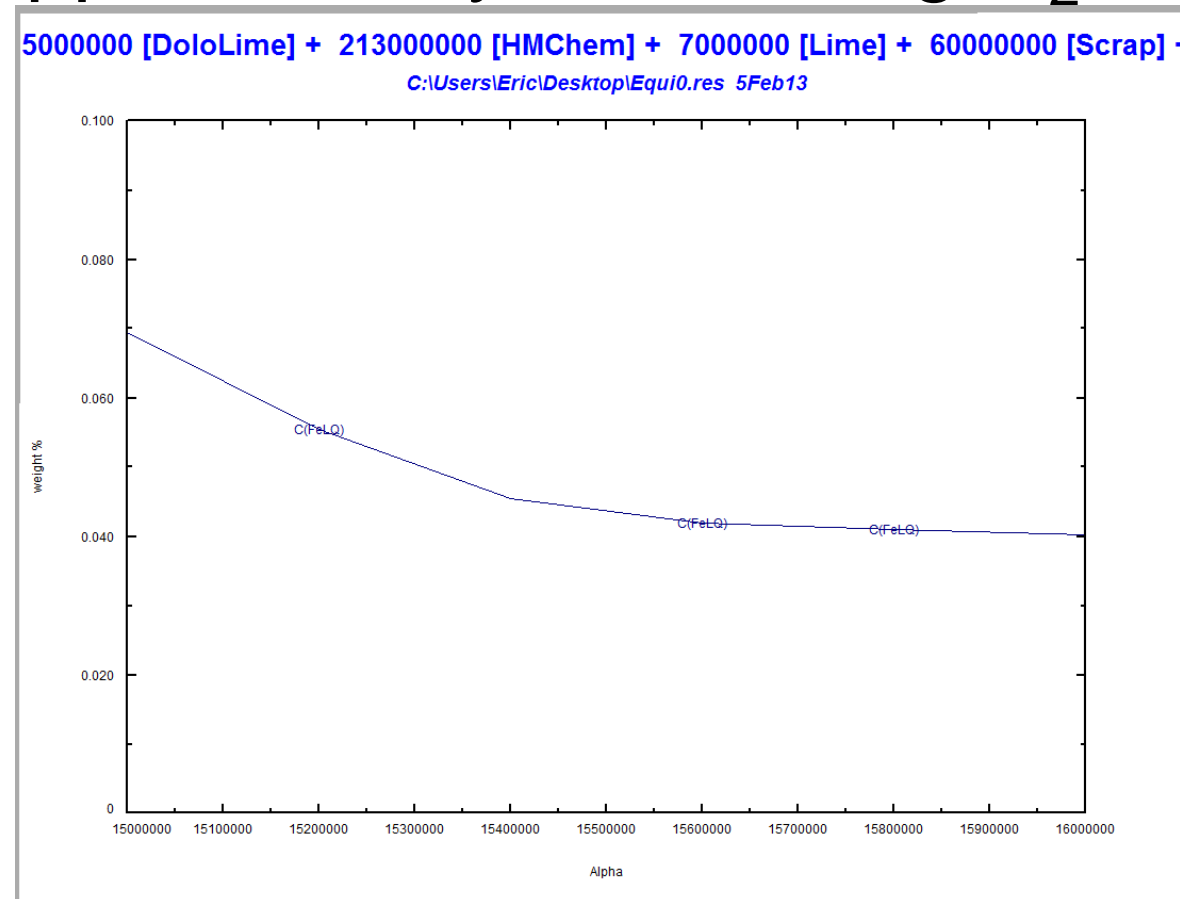
10 steps  Table 11 calculations

**Equilibrium**  
 normal  normal + transitions  
 transitions only  
 open

FactSage 6.3

# Limit of Oxygen Blowing

- Aiming for 500ppm (or 0.05 wt% C in FeLQ)
- Occurs at approximately 15300000g O<sub>2</sub>



# Products

- Gas
- Fe liquid
- **a-Ca<sub>2</sub>SiO<sub>4</sub>**
- **Amonoxide#1**
- **Amonoxide#2**

```
+ 2.6063E+08 gram Fe-liq
(2.6063E+08 gram, 4.6801E+06 mol)
(1600 C, 1 atm, a=1.0000)
( 99.675 wt.% Fe
+ 4.9950E-02 wt.% C
+ 2.5290E-09 wt.% Ca
+ 1.6186E-02 wt.% Cr
+ 0.21547 wt.% Mn
+ 3.7013E-02 wt.% O
+ 2.1753E-03 wt.% S
+ 1.2811E-06 wt.% Si
+ 6.7243E-08 wt.% Ti
+ 4.0606E-07 wt.% Mg
+ 1.0582E-03 wt.% MgO
+ 1.4818E-03 wt.% CaO
+ 5.0430E-08 wt.% TiO
+ 3.2375E-04 wt.% CrO
+ 2.6259E-09 wt.% SiO
+ 1.3664E-03 wt.% MnO
+ 4.5965E-07 wt.% Cr2O
+ 1.2129E-15 wt.% Ti2O
```

```
+ 9.0432E+05 gram ASlag-liq#1
(9.0432E+05 gram, 15123. mol)
(1600 C, 1 atm, a=1.0000)
( 17.638 wt.% SiO2
+ 54.355 wt.% CaO
+ 6.2383 wt.% FeO
+ 0.15936 wt.% Fe2O3
+ 4.0114 wt.% MgO
+ 1.6328 wt.% MnO
+ 2.2442E-02 wt.% CrO
+ 5.8106E-02 wt.% Cr2O3
+ 9.6847E-02 wt.% Ti2O3
+ 15.773 wt.% TiO2
+ 2.9364E-03 wt.% Mn2O3
+ 3.4781E-03 wt.% SiS2
+ 8.9846E-03 wt.% CaS
+ 9.8076E-04 wt.% FeS
+ 2.5652E-05 wt.% Fe2S3
+ 7.2084E-04 wt.% MgS
+ 2.5731E-04 wt.% MnS
+ 3.5647E-06 wt.% CrS
+ 9.8331E-06 wt.% Cr2S3
+ 1.6616E-05 wt.% Ti2S3
+ 2.8419E-03 wt.% TiS2
+ 4.9246E-07 wt.% Mn2S3
```

Solids are forming already (at 1600C)  
Slag in a BOF typically >100C hotter than melt

```
+ 2.3745E+06 gram AMonoxide#2
(2.3745E+06 gram, 50553. mol)
(1600 C, 1 atm, a=1.0000)
( 13.341 wt.% FeO
+ 0.11941 wt.% Fe2O3
+ 1.9438 wt.% CaO
+ 67.136 wt.% MgO
+ 16.927 wt.% MnO
+ 0.53103 wt.% Cr2O3
+ 9.7763E-04 wt.% TiO2
```

```
FToxid
FToxid
FToxid
FToxid
FToxid
FToxid
FToxid
FToxid)
```

```
+ 6.7623E+06 gram a-Ca2SiO4
(6.7623E+06 gram, 39391. mol)
(1600 C, 1 atm, a=1.0000)
( 1.7890 wt.% Mg2SiO4
+ 97.731 wt.% Ca2SiO4
+ 0.28042 wt.% Mn2SiO4
+ 0.19931 wt.% Fe2SiO4
```

```
FToxid
FToxid
FToxid
FToxid
FToxid
FToxid
FToxid)
```

```
+ 6.2565E+06 gram AMonoxide#1
(6.2565E+06 gram, 1.0951E+05 mol)
(1600 C, 1 atm, a=1.0000)
( 3.8730 wt.% FeO
+ 0.12320 wt.% Fe2O3
+ 78.398 wt.% CaO
+ 4.7469 wt.% MgO
+ 12.679 wt.% MnO
+ 0.18018 wt.% Cr2O3
+ 6.6229E-04 wt.% TiO2
```

# Heating Slag

- Save all oxide products as streams

Reactants - Equilib

File Edit Table Units Data Search Help

T(C) P(atm) Energy(J) Mass(g) Vol(litre)

1 - 4

Mass(g)	Species	Phase	T(C)	P(total)**	Stream#	Data
100%	[SlagA1600]				1	
+ 100%	[Ca2SiO41600]				2	
+ 100%	[AMonoxide11600]				3	
+ 100%	[AMonoxide21600]				4	

Initial Conditions

Next >>

FactSage 6.3 Compound: 4/19 databases Solution: 3/19 databases



# Calculate at 1750C

Menu - Equilib:

File Units Parameters Help

T(C) P(atm) Energy(J) Mass(g) Vol(litre)

**Reactants (4)**

(gram) 100% [AMonoxide11600] + 100% [AMonoxide21600] + 100% [Ca2SiO41600] + 100% [SlagA1600]

**Products**

Compound species

- gas  ideal  real 43
- aqueous 0
- pure liquids 0
- pure solids 201
- suppress duplicates **apply**
- \* - custom selection species: 244

Solution species

*	+	Base-Phase	Full Name
	+	FTmisc-FeLQ	Fe-liq
	l	FToxid-SLAGA	ASlag-liq all oxides + S
	l	FToxid-MeO_A	AMonoxide
	+	FToxid-bC2S	a'Ca2SiO4
	+	FToxid-aC2S	a-Ca2SiO4

Legend

- l - immiscible 2
- + - selected 3

Show  all  selected

species: 83 **Select**

solutions: 7

Custom Solutions

- fixed activities
- ideal solutions
- activity coefficients

**Details ...**

Pseudonyms

apply  **List ...**

include molar volumes

Total Species (max 1500) 327

Total Solutions (max 40) 7

**Default**

**Final Conditions**

<A>	<B>	T(C)	P(atm)	Product V(litre)
		1750	1	

10 steps  Table **1 calculation**

**Equilibrium**

- normal  normal + transitions
- transitions only
- open

**Calculate >>**

FactSage 6.3

# Examining Products

```

+ 5.9733E+06 gram AMonoxide#1
(5.9733E+06 gram, 1.0588E+05 mol)
(1750 C, 1 atm, a=1.0000)
( 2.1965 wt.% FeO FToxid
+ 4.5933E-02 wt.% Fe2O3 FToxid
+ 76.999 wt.% CaO FToxid
+ 7.1776 wt.% MgO FToxid
+ 13.455 wt.% MnO FToxid
+ 0.12513 wt.% Cr2O3 FToxid
+ 4.6990E-04 wt.% TiO2 FToxid)

+ 1.7833E+06 gram AMonoxide#2
(1.7833E+06 gram, 39352. mol)
(1750 C, 1 atm, a=1.0000)
( 6.7838 wt.% FeO FToxid
+ 4.2044E-02 wt.% Fe2O3 FToxid
+ 2.5646 wt.% CaO FToxid
+ 73.913 wt.% MgO FToxid
+ 16.301 wt.% MnO FToxid
+ 0.39407 wt.% Cr2O3 FToxid
+ 5.5205E-04 wt.% TiO2 FToxid)

+ 4.2816E+06 gram a-Ca2SiO4
(4.2816E+06 gram, 24958. mol)
(1750 C, 1 atm, a=1.0000)
( 2.0871 wt.% Mg2SiO4 FToxid
+ 97.460 wt.% Ca2SiO4 FToxid
+ 0.30432 wt.% Mn2SiO4 FToxid
+ 0.14828 wt.% Fe2SiO4 FToxid)

+ 4.2593E+06 gram ASlag-liq#1
(4.2593E+06 gram, 73209. mol)
(1750 C, 1 atm, a=1.0000)
( 24.104 wt.% SiO2
+ 55.966 wt.% CaO
+ 8.5096 wt.% FeO
+ 0.34639 wt.% Fe2O3
+ 4.6657 wt.% MgO
+ 2.7993 wt.% MnO
+ 6.5583E-02 wt.% CrO
+ 0.16459 wt.% Cr2O3
+ 8.9577E-02 wt.% Ti2O3
+ 3.2731 wt.% TiO2
+ 1.1991E-02 wt.% Mn2O3
+ 1.0084E-03 wt.% SiS2
+ 1.9626E-03 wt.% CaS
+ 2.8383E-04 wt.% FeS
+ 1.2292E-05 wt.% Fe2S3
+ 1.7788E-04 wt.% MgS
+ 9.3587E-05 wt.% MnS
+ 2.2101E-06 wt.% CrS
+ 5.9091E-06 wt.% Cr2S3
+ 3.2605E-06 wt.% Ti2S3
+ 1.2512E-04 wt.% TiS2
+ 4.2666E-07 wt.% Mn2S3

```

- Still a large amount of solid oxide
- Over-saturation of MgO and CaO

# Hypothetical Case

- Ignore the current solid products
  - Take SlagA as a stream and determine melting T

Reactants - Equilib

File Edit Table Units Data Search Help

T(C) P(atm) Energy(J) Mass(g) Vol(litre)

1-1

Mass(g)	Species	Phase	T(C)	P(total)**	Stream#	Data
100%	[SlagA1750]				1	

Initial Conditions

Next >>

FactSage 6.3 Compound: 4/19 databases Solution: 3/19 databases

# Multiple Temperatures

Menu - Equilib: last system

File Units Parameters Help

T(C) P(atm) Energy(J) Mass(g) Vol(litre)

Reactants (1)

(gram) 100% [SlagA1750]

Products

Compound species

- \* + gas  ideal  real 43
- aqueous 0
- pure liquids 0
- \* + pure solids 201
- suppress duplicates
- \* - custom selection species: 244

Solution species

*	+	Base-Phase	Full Name
	+	FTmisc-FeLQ	Fe-liq
		FToxid-SLAGA	ASlag-liq all oxides + S
		FToxid-MeO_A	AMonoxide
	+	FToxid-bC2S	a'Ca2SiO4
	+	FToxid-aC2S	a-Ca2SiO4

Legend

- | - immiscible 2
- + - selected 3

Custom Solutions

- 0 fixed activities
- 0 ideal solutions
- 0 activity coefficients
- 

Pseudonyms

apply

include molar volumes

Total Species (max 1500) 327

Total Solutions (max 40) 7

Target

- none -

Estimate T(K):

Mass(g):

Final Conditions

<A>	<B>	T(C)	P(atm)	Product V(litre)
		1750 1600 10	1	

10 steps  Table

Equilibrium

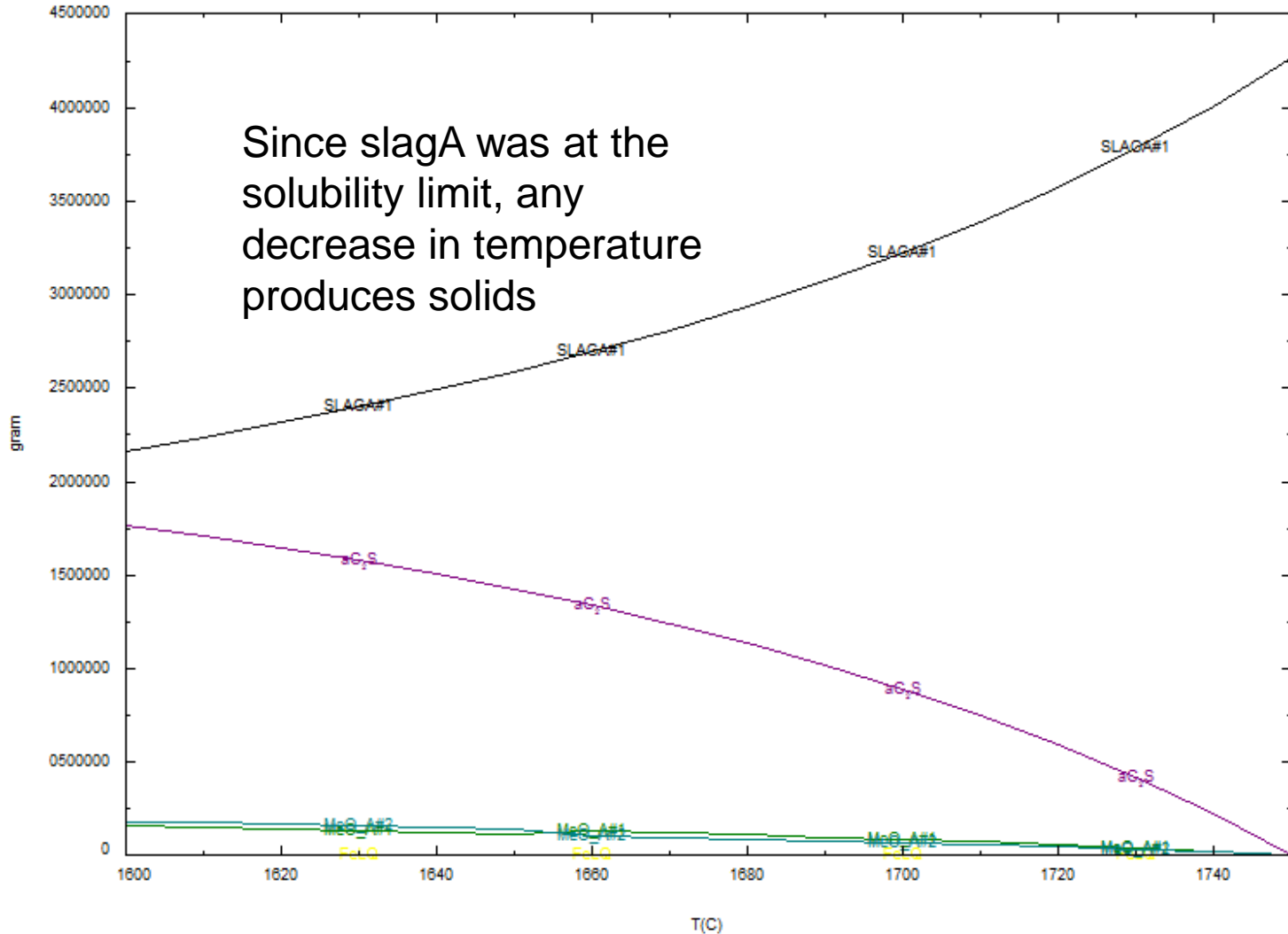
- normal  normal + transitions
- transitions only
- open
- 

FactSage 6.3

# Plot Results of Solids Formed

100% [SlagA1750]

C:\Users\Eric\Desktop\Equi0.res 7Feb13



# Based on Criteria Select Temperature

Calculate >> Database: Melts Glasses | Include/Remove Fluoride Components | Clear ALL

Enter the amounts of the constituents in the rows below. Then press on Calculate to show the viscosity.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	
1	SiO2 [g]	Al2O3 [g]	CaO [g]	MgO [g]	MnO [g]	ZnO [g]	FeO [g]	NiO [g]	PbO [g]	Na2O [g]	K2O [g]	TiO2 [g]	Ti2O3 [g]	B2O3 [g]	Fe2O3 [g]	CaF2 [g]	NaF [g]	KF [g]	MgF2 [g]	AlF3 [g]	FeF2 [g]	MnF2 [g]	PbF2 [g]	ZnF2 [g]	NiF2 [g]	FeF3 [g]	Temperature [°C]	
2																												

- Enter slag composition and temperature
  - Obtain viscosity