# **BOF** process



**Ferrous Processing 1** 

**McGill CRCT** 

# **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 Chemist	ry (wt%)			Amour	ts charged
CARBON	4.6844			(	tons)
CHROMIUM	0.028	Scrap Ch	emistry	Туре	Wt Charged
COPPER	0.0035	(wt <sup>o</sup>	%)		040
MANGANESE	0.6975	Si	0.02%	HIM	213
NICKEL	0.0075	Mn	0.05%	Scrap	60
PHOSPHORUS	0.0612	Elux Ch	omictry		_
SILICON	0.4935	Flux CI	emistry	Dolo	5
SULPHUR	0.0027	(W	t%)	Burnt	7
TITANIUM	0.0404	Burnt Lime	95% CaO	Berne	
VANADIUM	0.0097	Dolo Lime	55% CaO		



**Ferrous Processing 2** 

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

Databases - 4/19 compound databases, 3/19 solution databases         Miscellaneous         FactPS       SGTE       Compounds only       SGTE       Miscellaneous         Froxid       FSited       SGPS       no database       EXAM       SGTE#       SGTE         Froxid       FSited       SGnobi       Clear All       EXAM       SGTE#       SGTE*         FTmalc       FSstel       SGnobi       Select All       Add/Remove Data       FTfriz       Add/Remove Data         FThelg       Other       TDnucl       RefreshDatabases       Imite       Grganic species CxHy, X(max) = [2]         Information       -       gaseous ions (plasmas)       aqueous species       Organic species CxHy, X(max) = [2]         Minimum solution components: O 1 ③ 2 cpts       Imited data components: O 1 ③ 2 cpts       Imited data components: O 1 ③ 2 cpts	<b>(</b> 7		Data Search		
Options       Include         □ gaseous ions (plasmas)       □ aqueous species         □ limited data compounds (25C)       Minimum solution components: ○ 1 ⊙ 2 cpts	- Databases - 4/19 Cact FactPS F FactPS F FToxid F FTsalt F FThall F FThall F FTOxCN F FTfrtz FThelg FTpulp F FTpulp F FTlite F Information F	compound databases, : actSage" SGTE Scopp BINS Slead SGPS Slite SGTE Sstel SGnobl Snobl SGsold Supsi SGnucl Cther Tdemo TDnucl	3/19 solution databation databations only solutions only no database Clear All Select All Add/Remove Data RefreshDatabases	ASES <b>Miscellan</b> EXAM SGTI	E <b>#</b> □ SGTE*
Cancel Summary OK	- Options Default Cancel	Include gaseous ions (pla aqueous species limited data comp	ssmas) pounds (25C) Mi	imits ganic species CxHy, X(ma inimum solution components: (	x) = 2 O 1 ⊙ 2 cpts OK

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**Ferrous Processing 3** 

## **Using Streams**

4	React	ants - Equilib	- 🗆 🗙
File Edit Table Units Data	Search Help T(C) P(atm) I	Energy(J) Mass(g) Vol(litre)	M 📑 🛃
Mass(g)         4.6844         +         0.028         +         0.6975         +         0.4935         +         0.0027         +         0.0404         +         93.9716	Species	Phase       T(C)         I       I	P(total)**       Stream#       Data         I       I
FactSage 6.3 Compound: 2/	/20 databases Solution:	Next >> 1/19 databases	



Ferrous Processing 4

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## **Selecting Solution and Temperature**

🗘 Menu - Equilib: last system – 🗆 🗙
File       Units       Parameters       Help         Image: Comparison of the state of the
Reactants         (7)           (gram)         4.6844         C         +         0.6975         Mn         +         0.4935         Si         +         0.0404         Ti         +         93.9716         Fe
Products Compound species Custom Solution species Custom Solutions
gas © ideal © real       0         aqueous       0         pure liquids       0         pure solids       0         suppress duplicates apply       FTmisc-MAT2         species:       0         FTmisc-PYRRA       APyrrhotite         FTmisc-PYRRA       APyrrhotite         Image: Details       Image: Details         Image: Details       Image: Detai
Target       Legend       ✓ Show ● all ● selected       Total Species (max 1500)       7         Estimate T(K):       1000       +- selected 1       ✓ Show ● all ● selected       1         Mass(g):       0       0       0       0       0
Final Conditions       Conditions <a> <b>       T(C)       P(atm)       Product H(J)</b></a>
FactSage 6.3



**Ferrous Processing 5** 

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## **Check Results**

(y	Results -	Equilib	1400 C			x
Output Edit Show Pages	T(C) P(atm) E	nergy(J)	Mass(g) Vol(litre)		<u>III 📑 🗗</u>	<u>7</u>
(gram) 4.6844 C + 0.028 C (gram) 0.0027 S + 0.0404 99.918 gram Fe-liq (99.918 gram, 2.1045 mol (1400 C, 1 atm, ( 94.049 wt. + 4.6882 wt.	r + 0.6975 Mn + Ti + 93.9716 Fe ) a=1.0000) % Fe % C	0.493	5 Si +	FTmisc FTmisc	FactSage 6.3	~
+ 2.8023E-02 wt. + 0.69807 wt. + 2.7022E-03 wt. + 0.49390 wt. + 4.0433E-02 wt. System component	<pre>% Cr % Mn % S % Si % Ti Mole fract </pre>	ion M	lass fraction	FTmisc FTmisc FTmisc FTmisc)		
Fe Mn Cr Ti S Si C	0.79959 6.0329E 2.5588E 4.0105E 4.0012E 8.3495E 0.18533	-03 -04 -04 -05 -03	0.94049 6.9807E-03 2.8023E-04 4.0433E-04 2.7022E-05 4.9390E-03 4.6882E-02			
The cutoff concentration h	as been specified	i to 1.	0000E-75			
H G (J) (J)	V (litre)	S (J/K)	Cp (J/K)			~



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## Save Stream

Q		Results - Equilib 1400 C 🛛 🗕 🗖 🗙	
Out	put Edit Show Pages Save or Print Plot	T(C) P(atm) Energy(J) Mass(g) Vol(litre)	
	Equilib Results file	FactSage 6.3 A	
	Stream File	Recycle all streams	
	Fact-XML	Stream file properties     Save gas phase       Stream file properties     Save pure liquids	
	Fact-Optimal	Summary of streams Save aqueous Save pure solids	
	Fact-Function-Builder	Directory (C:\Program Files\FactSage\) Save solutions	ALL solutions
	Refresh	Mn FTmisc	FTmisc-FeLQ Fe-liq
Т	+ 0.49390 w + 4.0433E-02 w	% Si     FTmisc       % Ti     FTmisc)	
Ţ	System componen Fe Mn Cr Ti S Si C	Mole fraction Mass fraction 0.79959 0.94049 6.0329E-03 6.9807E-03 2.5588E-04 2.8023E-04 4.0105E-04 4.0433E-04 4.0012E-05 2.7022E-05 8.3495E-03 4.9390E-03 0.18533 4.6882E-02 as been specified to 1.0000E-75	
	ne cutorr concentration	as been specified to 1.00008-75	
	H G (J) (J)	V S Cp (litre) (J/K) (J/K)	



Ferrous Processing 7

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

Save File in C:\Program Files\FactSage\Mix	kt*.dat 🛛 🗙
FTmisc-FeLQ Fe-liq	OK
Enter a stream file number (1 - 9999)	Cancel
or enter a stream file name (up to 26 characters), for example	
My very favorite stream	
- avoid the special characters ?@/"^!~,.''*&%+;:<> $0$	
]0	

47		Reactants - Equilib	- 🗆 🗙
File Edit Table	Units Data Search Help	) P(atm) Energy(J) Mass(g) Vol(litre	
Mas [0.02 + [0.05 + [93.93]	s(g) Specie Si Mn Fe	s Phase	T(C) P(total)** Stream# Data
			Initial Conditions
		Next >>	
FactSage 6.3 Cor	mpound: 3/20 databases	Solution: 2/19 databases	

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**Ferrous Processing 8** 

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

4	Menu - Equilib:	_ 🗆 🛛
File Units Parameters Help	T(C) P(atm) Energy(J) Mass(g) Vol(litre)	11 🖳 🕞 😿
	(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	Image: Solution species       Full Name         Image: Figure 1       FSstel-BCC1       BCC_A2         Image: Figure 1       Image: Figure 1       Image: Figure 1         Legend - + · selected 1       Image: Figure 1       Image: Figure 1         Image: Figure 1       Image: Figure 1       Image: Figure 1         Image: Figure 1       Image: Figure 1       Image: Figure 1         Image: Figure 1       Image: Figure 1       Image: Figure 1         Image: Figure 1       Image: Figure 1       Image: Figure 1         Image: Figure 1       Image: Figure 1       Image: Figure 1         Image: Figure 1       Image: Figure 1       Image: Figure 1         Image: Figure 1       Image: Figure 1       Image: Figure 1         Image: Figure 1       Image: Figure 1       Image: Figure 1         Image: Figure 1       Image: Figure 1       Image: Figure 1         Image: Figure 1       Image: Figure 1       Image: Figure 1         Image: Figure 1       Image: Figure 1       Image: Figure 1         Image: Figure 1       Image: Figure 1       Image: Figure 1         Image: Figure 1       Image: Figure 1       Image: Figure 1         Image: Figure 1       Image: Figure 1       Image: Figure 1         Image: Figure 1       I	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
Final Conditions <a>       ID       steps       Table</a>	T(C)     P(atm)     Product H(J)     €q       25     1     C     C       1     calculation     C	uilibrium normal C normal + transitions transitions only open Calculate >>
FactSage 6.3		



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- 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)

🗘 Rea	actants - Equilib	X	I	Reactants - Equilib	- 🗆 🗙
File Edit Table Units Data Search Help		File Edit	Table Units Data Search Help		
□ 🖆 🕂 🔟 T(C) P(at	tm) Energy(J) Mass(g) Vol(litre)		+ 🔟 T(C) F	P(atm) Energy(J) Mass(g) Vol(litre)	III 📑 🕒 😿
 		1.3			
Mass(g) Species	Phase T(C) P(total)** St	tream# Data	Mass(g) Species	Phase T(C)	P(total)** Stream# Data
[I [LaU]		55	CaO		
		+ 40	MgO	<b>_</b>	1
		+ 5	Si02	▼	1
	🗖 Initi	ial Conditions			Initial Conditions
	_				
	Next >>			Next >>	
FactSage 6.3 Compound: 3/20 databases Solut	tion: 2/19 databases	FactSage 6.3	Compound: 3/20 databases S	iolution: 2/19 databases	



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## **Pure Solids**

4	Menu - Equilib:	- 🗆 ×
File Units Parameters Help	T(C) P(atm) Energy(J) Mass(g) Vol(litre)	M 📑 🔁
Products Compound species gas ⓒ ideal O real O aqueous O pure liquids O + pure solids 71 ✓ suppress duplicates apply species: 71	Solution species	Custom Solutions 0 fixed activities 0 ideal solutions 0 activity coefficients Details Pseudonyms apply List include molar volumes Total Species (may 1500) 71
- none - Estimate T(K): 1000 Mass(g): 0	Legend ✓ Show O all ⊙ selected species: 0 solutions: 0 Select	Total Solutions (max 40) 0
Final Conditions <a>       ID       steps       Table</a>	T(C)     P(atm)     Product H(J)       25     1       1 calculation	quilibrium normal C normal + transitions transitions only open Calculate >>
FactSage 6.3		11



Ferrous Processing 11

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## **Combine Mixtures with Weights**

47	React	ants - Equilib	- 🗆 🗙
File Edit Table Units I	Data Search Help T(C) P(atm) I	Energy(J) Mass(g) Vol(litre)	M 🕞 🖷 🚿
Mass(g) 5000000 + 213000000 + 7000000 + 60000000	Species [DoloLime]  [HMChem]  [Lime]  [Scrap]  [Scrap]	Phase T(C)	P(total)**       Stream#       Data         1       1         2       3         3       4
			Initial Conditions
		Next >>	
FactSage 6.3 Compound:	3/20 databases Solution:	2/19 databases	/



Ferrous Processing 12

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Amount of oxygen -Educated guess

4	Menu - Equilib	o: last system	- 🗆 ×
File Units Parameters Help	T(C) P(atm) Energy(	(J) Mass(mol) Vol(litre)	
Products     Compound species     * + gas O ideal • real 59     aqueous 0     pure liquids 0     * + pure solids 229     v suppress duplicates apply     * - custom selection         species: 288	Solution species Solution species + Base-Phase + FTmisc-FeLQ I FToxid-SLAGA I FToxid-SLAGA + FToxid-bC2S + FToxid-aC2S	Full Name Fe-liq ASlag-liq all oxides + S AMonoxide a'Ca2SiO4 a-Ca2SiO4	Custom Solutions 0 fixed activities 0 ideal solutions 0 activity coefficients Details Pseudonyms apply List include molar volumes <u>Total Species (max 1500)</u> 372
- none - Estimate T(K): 1000 Mass(mol): 0 Final Conditions <a> <a> <a> <a> <a> <a> <a> <a> <a> <a></a></a></a></a></a></a></a></a></a></a>	T(C)     P(atm)       1600     1	Show C all C selected species: 84 solutions: 7 Select Product V(litre 11 calculations	Total Solutions (max 40)       7         Default          Equilibrium          • normal       O normal + transitions         transitions only          open       Calculate >>
FactSage 6.3			///

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Limit of Oxygen Blowing

- Aiming for 500ppm (or 0.05 wt% C in FeLQ)
- Occurs at approximately 1530000g O<sub>2</sub>



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Ferrous Processing 14

### **Products**



(1600 C, 1	aum,	a-1.0
( 13.341	wt.%	FeO
+ 0.11941	wt.%	Fe203
+ 1.9438	wt.%	CaO
+ 67.136	wt.%	MgO
+ 16.927	wt.8	MnO
+ 0.53103	wt.%	Cr203
+ 9.7763E-0	)4 wt.%	TiO2

+ 6.2565E+06 gram AMonoxide#1 (6.2565E+06 gram 1 0951E+05

(Sestive gram, 1.09515tus mol)			
(1600 C, 1 a	tm, 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.% Cr203		
+ 6.6229E-04	wt.% TiO2		

- -

6063E+0	8 gram Fe-1	liq	
.6063E+	08 gram, 4.0	5801E-	+06 mol)
(	1600 C, 1 at	sm,	a=1.0000)
(	99.675	wt.%	Fe
+	4.9950E-02	wt.%	С
+	2.5290E-09	wt.%	Ca
+	1.6186E-02	wt.%	Cr
+	0.21547	wt.%	Mn
+	3.7013E-02	wt.%	0
+	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.%	Cr20

+ 1.2129E-15 wt.% Ti20

FToxid FToxid FToxid FToxid FToxid FToxid

FToxid FToxid FToxid FToxid FToxid FToxid

+ 2.

+ 9.0432E+05 gram ASlag-lig#1 (9.0432E+05 gram, 15123. mol) (1600 C, 1 atm, a=1.0000) ( 17.638 wt.% SiO2 + 54.355 wt.% CaO wt.% FeO + 6.2383 + 0.15336 wt.% Fe203 + 4.0114 wt.% MgO + 1.6328 wt.% MnO + 2.2442E-02 wt.% CrO + 5.8106E-02 wt.% Cr203 + 9.6847E-02 wt.% Ti203 + 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

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

+ 6.7623E+06 gram a-Ca2SiO	4
(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



Ferrous Processing 15

• Save all oxide products as streams

(7	Reactar	nts - Equilib	-	
File Edit Table Units Data	Search Help T(C) P(atm) En	erau(1) Mass(a) Vol(litre)		
		eigy(o) Mass(g) Vollade)	_ <u>m</u> _	
1 - 4				1
Mass(g) 100% 100% 100% 100% 100% 100% 100%	Species [SlagA1600] [Ca2Si041600] [AMonoxide11600] [AMonoxide21600] [AMonoxide21600] [Amon	Phase T	P(total)***         Stream           1         1           2         3           4         4	# Data
			🔲 Initial Con	ditions
		Next >>		
FactSage 6.3 Compound: 4/	19 databases Solution:	3/19 databases		1.



Ferrous Processing 16

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## Calculate at 1750C

4	Menu - Equilib:	- 🗆 🗙		
File       Units       Parameters       Help         Image: Strategy of the strategy of th				
Products         Compound species         * + gas ○ ideal ● real 43         aqueous       0         pure liquids       0         * + pure solids       201         ✓ suppress duplicates apply         * - custom selection         species:       244         Target         - none -         Estimate T(K):       1000         Mass(g):       0	Solution species       Full Name         +       FTmisc-FeLQ       Fe-liq         I       FToxid-SLAGA       ASlag-liq all oxides + S         I       FToxid-MeO_A       AMonoxide         +       FToxid-bC2S       a'Ca2Si04         +       FToxid-aC2S       a-Ca2Si04         Legend       I       Show C all ● selected         I - immiscible 2       + selected 3       Select	Custom Solutions 0 fixed activities 0 ideal solutions 0 activity coefficients Details 2 2 2 2 2 2 2 2 2 2 2 2 2		
Final Conditions <a>       ID     steps       Table   FactSage 6.3</a>	T(C)       P(atm)       Product V(litre ▼         1750       1       C trai         1 calculation       1 calculation	ibrium mal © normal + transitions nsitions only en Calculate >>		



Ferrous Processing 17

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+ 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	+ 4.2593E+06 gram ASlag-liq#1
+ 76.999 wt.% CaO	FToxid	(4.2593E+06 gram, 73209. mol)
+ 7.1776 wt.% MgO	FToxid	(1750 C, 1 atm, a=1.0000)
+ 13.455 wt.% MnO	FToxid	( 24.104 wt.% SiO2
+ 0.12513 wt.% Cr203	FToxid	+ 55.966 wt.% CaO
+ 4.6990E-04 wt.% TiO2	FToxid)	+ 8.5096 wt.% FeO
		+ 0.34639 wt.% Fe203
		+ 4.6657 wt.% MgO
+ 1.7833E+06 gram AMonoxide#2		+ 2.7993 wt.% MnO
(1.7833E+06 gram, 39352. mol)		+ 6.5583E-02 wt.% CrO
(1750 C, 1 atm, a=1.0000)		+ 0.16459 wt.% Cr203
( 6.7838 wt.% FeO	FToxid	+ 8.9577E-02 wt.% Ti203
+ 4.2044E-02 wt.% Fe2O3	FToxid	+ 3.2731 wt.% TiO2
+ 2.5646 wt.% CaO	FToxid	+ 1.1991E-02 wt.% Mn2O3
+ 73.913 wt.% MgO	FToxid	+ 1.0084E-03 wt.% SiS2
+ 16.301 wt.% MnO	FToxid	+ 1.9626E-03 wt.% CaS
+ 0.39407 wt.% Cr203	FToxid	+ 2.8383E-04 wt.% FeS
+ 5.5205E-04 wt.% TiO2	FToxid)	+ 1.2292E-05 wt.% Fe2S3
		+ 1.7788E-04 wt.% MgS
+ 4.2816E+06 gram a-Ca2SiO4		+ 9.3587E-05 wt.% MnS
(4.2816E+06 gram, 24958. mol)		+ 2.2101E-06 wt.% CrS
(1750 C, 1 atm, a=1.0000)		+ 5.9091E-06 wt.% Cr2S3
( 2.0871 wt.% Mg2SiO4	FToxid	+ 3.2605E-06 wt.% Ti2S3
+ 97.460 wt.% Ca2SiO4	FToxid	+ 1.2512E-04 wt.% TiS2
+ 0.30432 wt.% Mn2SiO4	FToxid	+ 4.2666E-07 wt.% Mn2S3
+ 0.14828 wt.% Fe2SiO4	FToxid)	

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



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





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## **Multiple Temperatures**

47	Menu - Equilib: last system	- 🗆 🗙
File Units Parameters Help	T(C) P(atm) Energy(J) Mass(g) Vol(litre)	III 📑 🕒 🕱
	(gram) 100% [SlagA1750]	
Products	- Colution appoint	Custom Solutions
Compound species *	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         -       +       FToxid-aC2S         Legend       I       Show O all I selected         -       -       species: 83         -       solutions: 7       Select	O fixed activities     O fixed activities     O ideal solutions     O activity coefficients     Details      Pseudonyms     apply     List      include molar volumes <u>Total Species (max 1500)</u> 327 <u>Total Solutions (max 40)</u> 7      Default
Final Conditions <a> <b> 10 steps □ Table</b></a>	T(C)       P(atm)       Product V(litre ▼         1750 1600 10       1         16 calculations	uilibrium normal C normal + transitions ransitions only open Calculate >>



Ferrous Processing 20

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## Plot Results of Solids Formed

#### 100% [SlagA1750]







**Ferrous Processing 21** 

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## **Based on Criteria Select Temperature**



- Enter slag composition and temperature
  - Obtain viscosity



Ferrous Processing 22

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