MODELLING THE KIVCET FLASH SMELTING FURNACE

The Fact Sage Modelling Learning experience!

PROJECT OBJECTIVES

1. Build model of process using real plant input

2. Validate model by comparing with real output

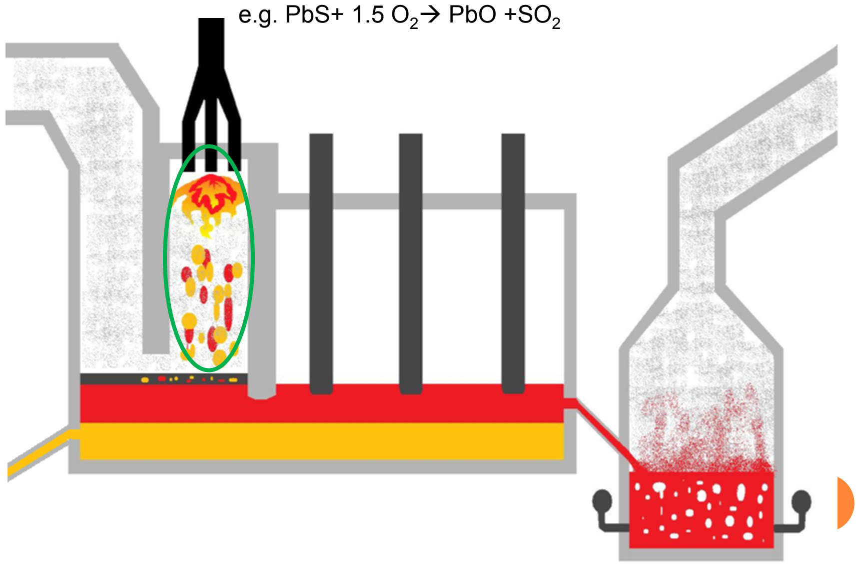
OUTLINE

- Intro to the Teck's Kivcet Smelter
- Fact Sage
  - Part 1: Reaction Shaft
    - Production Targets
    - What do I want to achieve with a Fact Sage to Model
    - Sample Calculations and graphs
    - Effect of main operational parameters
    - Ideal operating conditions
    - Fit with reality?
  - Part 2: Coke Checker
  - Part 3: Settling Furnace
  - Part 4: Slag Fuming Furnace

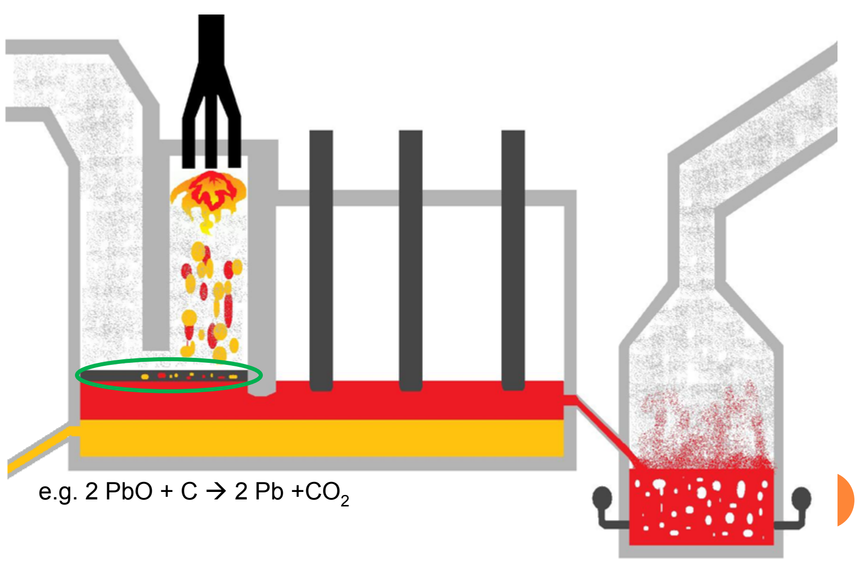
KIVCET SMELTER

- Crushed feed arrives by train or truck
  - Concentrates:
    - PbS/ZnS cons from AK, WA and Australia
    - Many trace elements: Ag, Au, Cu, Bi, Sn, etc
  - Fluxes:
    - Coke, Lime and Silica (C, CaO and SiO2)
  - In-plant recycle dust
  - Old Lead-Acid batteries (car batteries)
- Sent to dryer to blend and remove moisture
- Fine feed is sent into hopper above Rxn Shaft

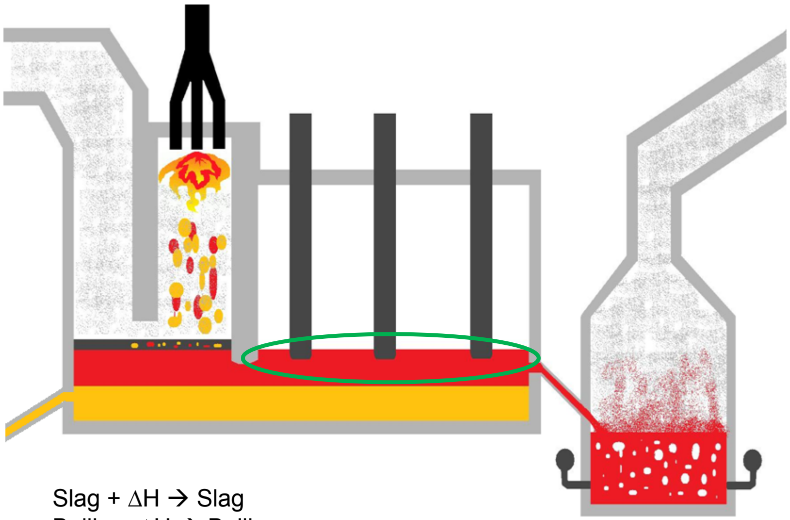
RXN SHAFT: FLASH SMELTING (1-3 SECONDS)



COKE CHECKER: OXIDE REDUCTION

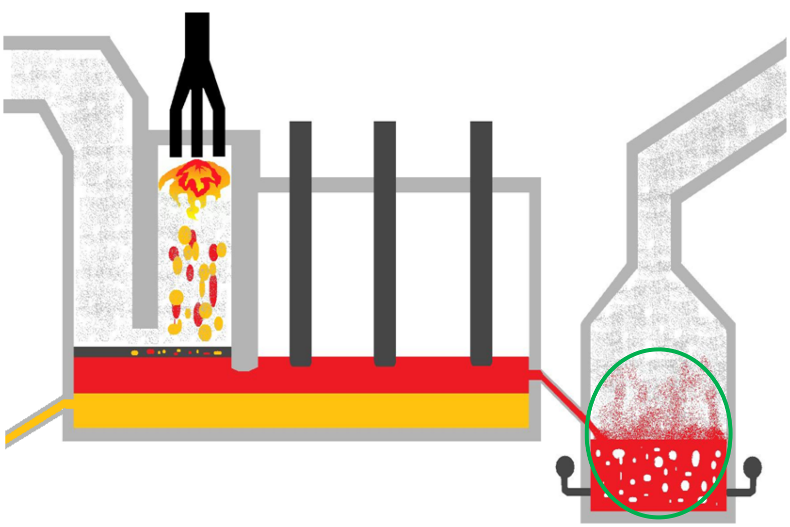


SETTLING FURNACE: SLAG HEATING



Slag + ΔH → Slag
Bullion- ΔH → Bullion

FUMING: #3 SLAG FUMING FURNACE



ZnO_{slag} + CO → Zn +CO2

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STARTING POINT: TECK'S FEED

- Feed data provided by Teck:
  - Actual feed rate is ~1400 tpd
  - Not every element is assayed or perhaps it was not provided…
- What I'm I going to do about it:
  - 1) non-reactive gangue
  - 2) Oxy from Oxy-bearing minerals?
  - **3) Ignore it!**
- Assume
  - Pb, Zn, and Cu → PbS, ZnS, $CuFeS_2$
  - What about the rest?

Element	Mass (tpd)	wt%
Pb	318.277	22.93%
Fe	148.126	10.67%
SiO2	136.523	9.84%
S	129.658	9.34%
Zn	125.796	9.06%
C	<A>	<A>%
CaO	77.365	5.57%
Cu	10.979	0.79%
Sb	5.218	0.38%
As	4.715	0.34%
Sn	3.383	0.24%
Cd	1.661	0.12%
Ag	1.307	0.12%
Bi	0.753	0.05%
Au	0.007	0.00%
Total	**963**	**69.74%**

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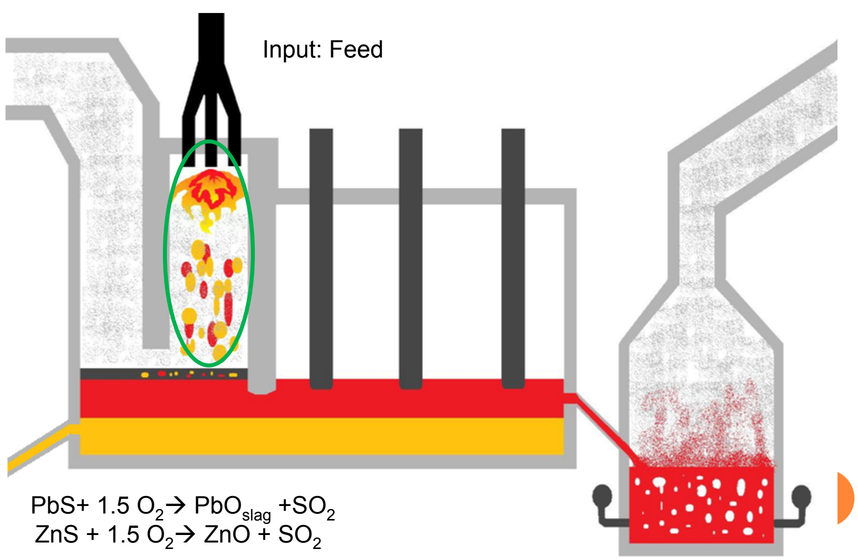
RECALL



$PbS + 1.5\ O_2 \rightarrow PbO_{slag} + SO_2$

$ZnS + 1.5\ O_2 \rightarrow ZnO + SO_2$

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REACTION SHAFT TARGETS:

- Maximize PbO and ZnO (slag) production
- Minimize unreacted PbS and ZnS
- Minimize PbO_g and ZnO_g production

Fact Sage Goal:

Find optimal O_2, T° and Coke addition to satisfy these targets

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FACT SAGE CONSIDERATIONS

- I can modify T, O_2 and C addition rates
  - O_2 is run full blast to favour oxidizing environment (375tpd O2)
  - Coke is added from 0 to 100tpd
  - Unknown reaction T°
    - Adiabatic Flame T° > 2400°C! (way too high!)
- Reaction occurs 1-3secs …
  - Are we really at equilibrium? Unlikely… But we'll assume we are
- Over 1500 species to choose from – FS Max of 732

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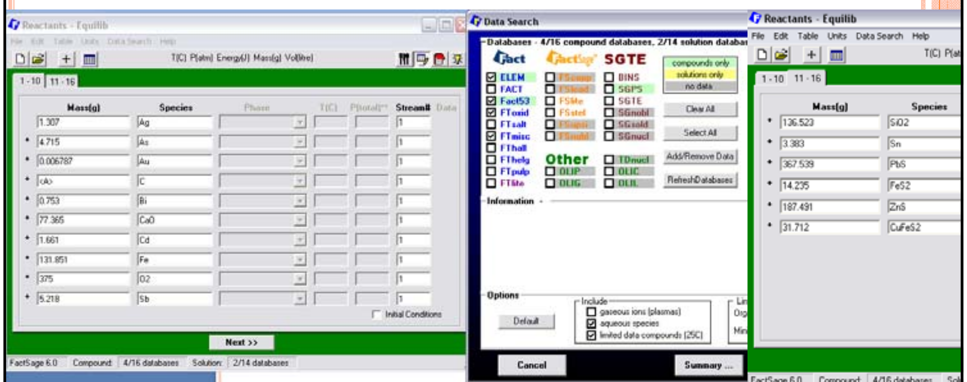
FACT SAGE SETUP



- 16 species: No initial conditions since mineralogy is unknown…
- 4 databases: FToxid, Ftmisc, Fact53, ELEM

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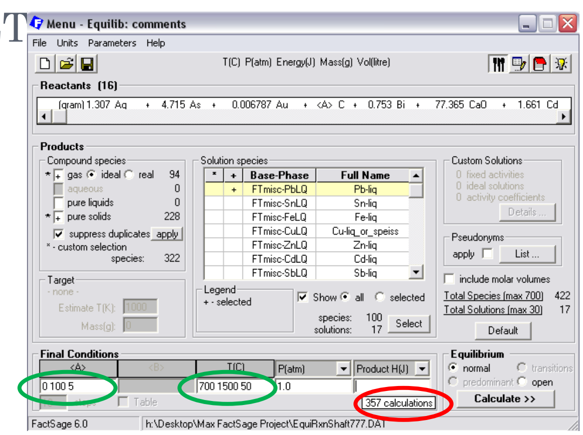
FACT SAGE SETUP

+	FTmisc-PbLQ	Pb-liq
+	FTmisc-MATT	Matte
+	FTmisc-SPHA	Sphalerite
+	FTmisc-WURT	Wurtzite
+	FTmisc-Cu2SA	ACu2S-s.s.
+	FToxid-SLAGA	ASlag-liq
+	FToxid-SPINA	ASpinel
+	FToxid-MeO_A	AMonoxide
+	FToxid-bC2S	a'Ca2SiO4
+	FToxid-aC2S	a-Ca2SiO4
+	FToxid-Mel_	Melilite
+	FToxid-OlivA	AOlivine
+	FToxid-ZNIT	Zincite
+	FToxid-WILL	Willemite
+	FToxid-PbO_	PbO-ZnO
+	FToxid-PCSi	Pb3M2Si3O11



- Normal equilibrium since "steady state" reaction
- Duplicates priority: FToxid, Ftmisc, Fact53, ELEM
- Vary <A> and T to find optimal conditions
- <A> = Coke addition
- O2 Fixed at 375tpd

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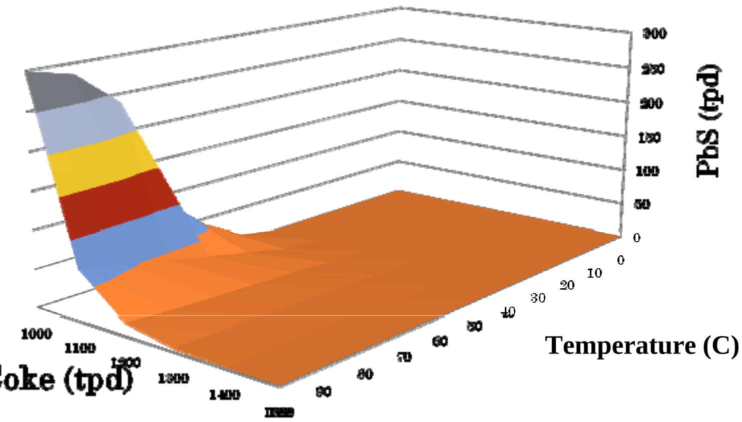
LOW)

- Why would they want to add 100tpd Coke?
- Due to maxed out O2 supply C competes with PbS and ZnS for O2



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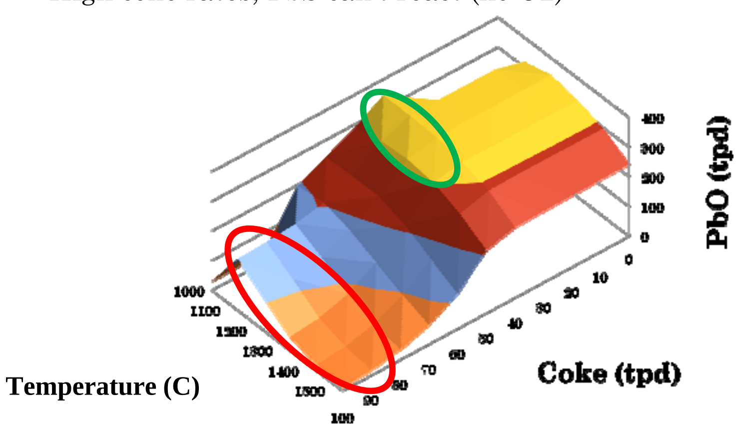
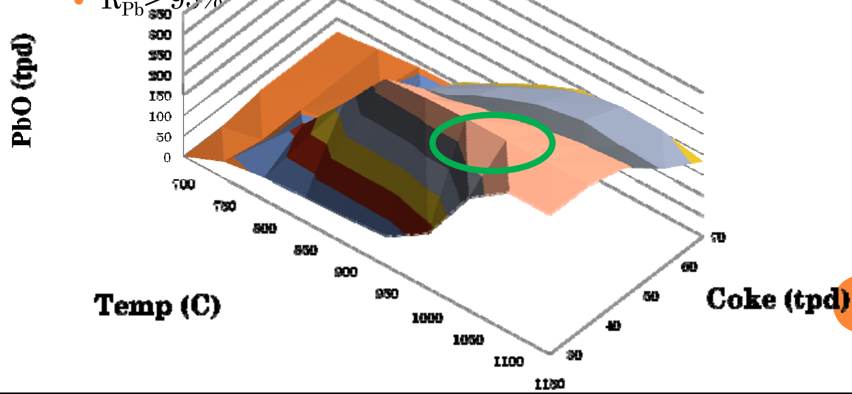
PBO FORMATION (WANT IT HIGH)

- Maximum PbO formation appears to occur @ 40tpd of Coke
  - High coke rates, PbS can't react (no O2)



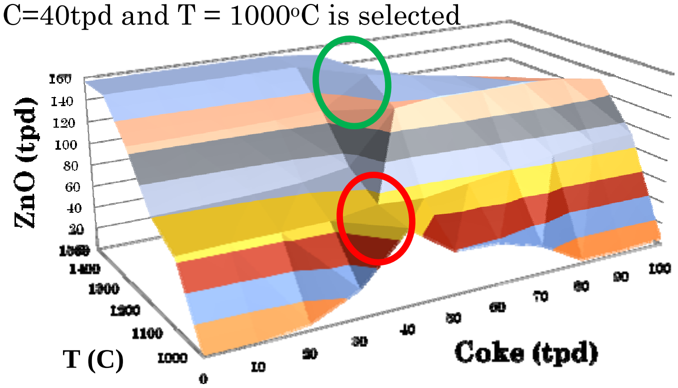
PBO FORMATION (CNTD)

- Further investigation at lower Temperature Range
  - Ideal conditions for PbO formation ~ @1000°C, 40 tpd C
  - $R_{Pb} > 95\%$



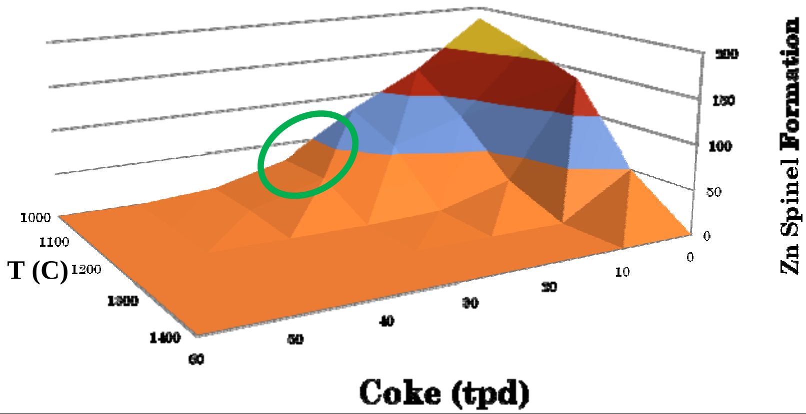
ZNO FORMATION (WANT IT HIGH)

- For ZnO
  - Best conditions at 40 tpd of coke are above 1200°C
  - However, at those T's Pb Recovery drops due to PbO_g formation
  - C=40tpd and T = 1000°C is selected



40TPD C?

- Formation of Zn Fe Spinels at Low Temperatures
- Ultimately Doesn't matter that if we have ZnO or $ZnFe_2O_4$



SUMMARY OF OBSERVATIONS

- High T
  - Formation of PbO_g and Zn_g significantly lowers metal recovery
- Low T
  - PbS and ZnS do not oxidize.
  - Remain as sulphide slags

- High C
  - C competes with sulphides for O2
  - Not enough O2 to oxidize sulphides
- Low C
  - In practice, low C means that the feed doesn't heat up fast enough on way down to Coke Checker

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OPTIMAL OPERATING CONDITIONS: 1000 ^{O}C, 40 TPD COKE

- 3 resulting streams
  1. Gas – 350 tpd
     - 52% CO2
     - 47% SO2
     - <1% Cd, Sb_4O_6, PbO, and other gases
  2. Slag – 605 tpd
     - Simple M-Oxides: 99% Pb as PbO, 44% Zn as ZnO
  3. Solids – 420 tpd
     - Complex oxides : 55% Zn as Spinels
- Heat
  - $-3.55*10^{12}$ J/day

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REACTION SHAFT TARGETS:

For 1000^{o}C, 40 tpd Coke

- Maximize PbO and ZnO (slag) production
  - 95% PbS → PbO
  - 45% ZnS → ZnO
  - 50% ZnS → Crazy/Zn Fe Spinels
- Minimize unreacted PbS and ZnS
  - <2%
- Minimize PbO_g and ZnO_g production
  - <2%

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DOES MODEL FIT REALITY?

- Hard to tell…

- No papers on this part of the Kivcet Smelter
  - Patented Technology
  - No public information

- From TMS website:
  - "[…] 1200ºC gas from the smelting shaft […] "
  - Difference is likely caused by the Coke Checker which operates at 1200ºC

- Remember this all happens in a few seconds…

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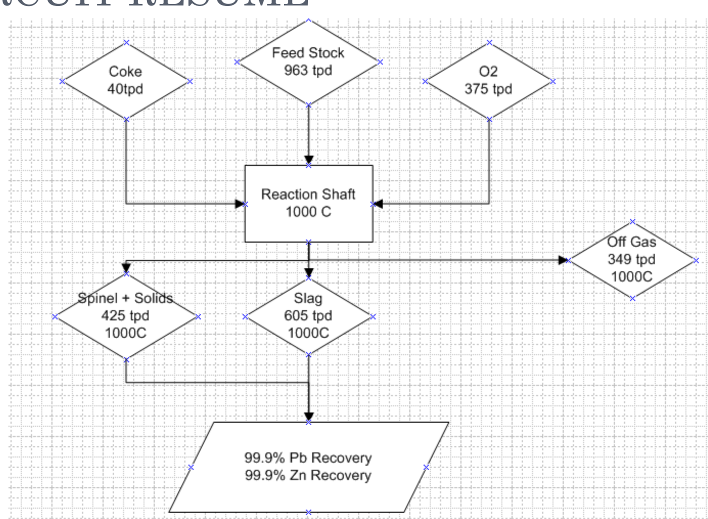
CIRCUIT RESUME



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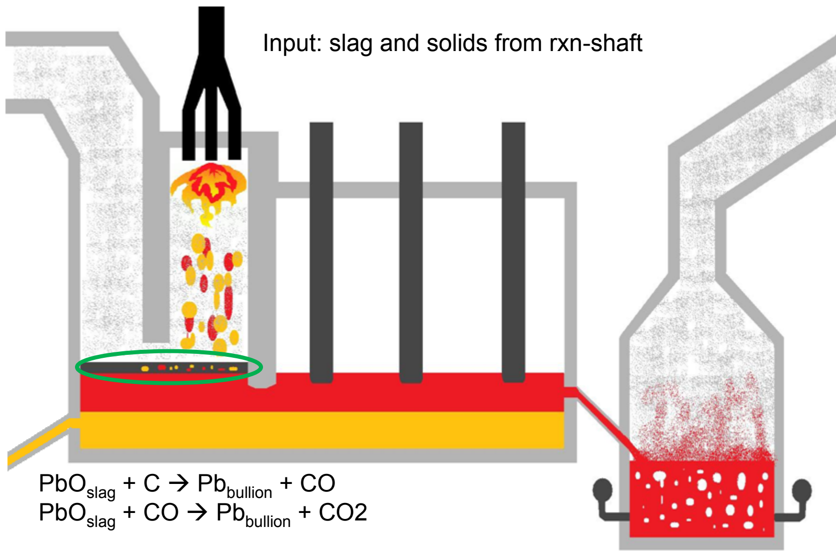
RECALL



$PbO_{slag} + C \rightarrow Pb_{bullion} + CO$
$PbO_{slag} + CO \rightarrow Pb_{bullion} + CO2$

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COKE CHECKER TARGETS

- Maximize reduction of PbO to Pb_l
- Reduce Zn Fe Spinel to ZnO (last chance)
- Maximize Production of ZnO
- Minimize Pb_g and Zn_g losses

FACT SAGE CONSIDERATIONS

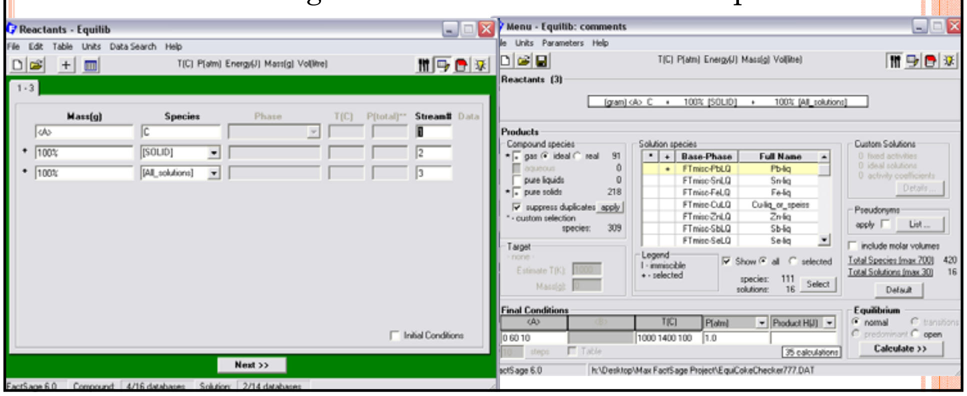
- Unknown reaction T°
- Similar calculations as in Rxn shaft.
  - No O2 added
  - Can modify C and T° for best performance
- Reaction has more time to occur
  - Are we really at equilibrium?
  - Perhaps…

Fact Sage Goal:

Find optimal T° and Coke addition to satisfy targets

FACT SAGE SETUP

- Same Species and Database as for Rxn Shaft
- <A> = C = 0 100 10
- T = 1000 1600 100
- All solids + slags from Rxn Shaft become Input



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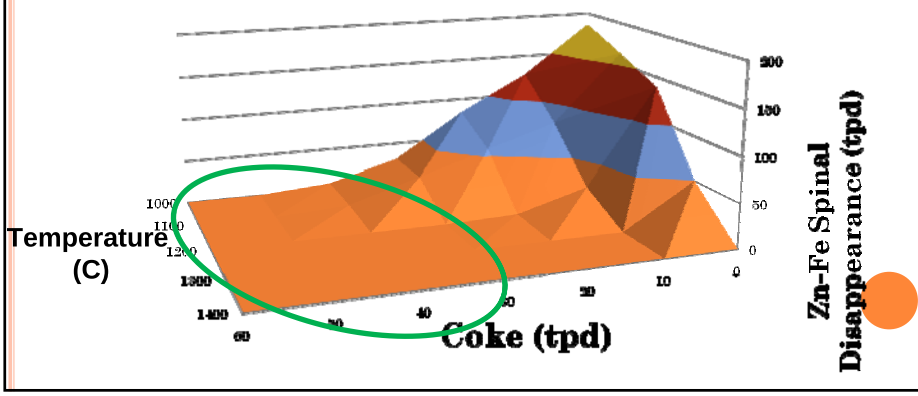
ZN-FE SPINEL TO ZNO_{SLAG}

- Recall ~50% ZnS formed Zn Fe Spinels?
- Coke checker continues to reduce these into simple oxides.
- Wide range of T and C to accomplish reduction



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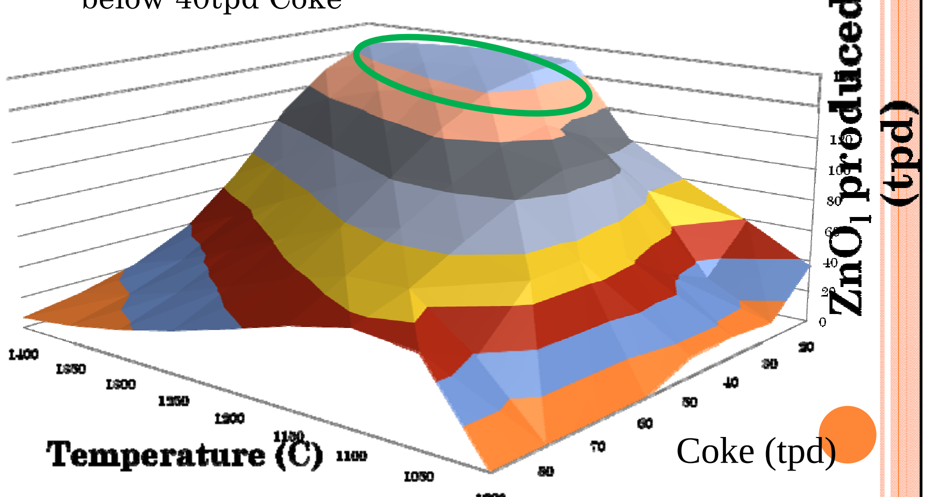
ZNO_{SLAG} PRODUCTION

- Optimal conditions appears to be above 1250 and below 40tpd Coke



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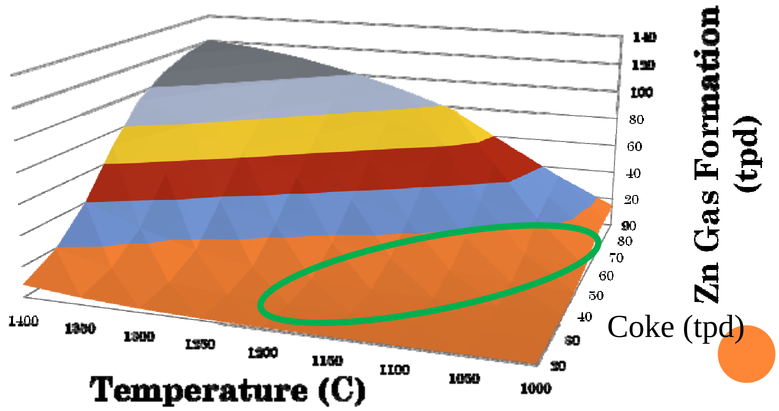
$ZNO_{SLAG} + CO \rightarrow ZN_L + CO_2 \rightarrow ZN_G$

- At high T and C, ZnO continue to reduce to Zn_l
- Unfortunately due to High T, Zn_g forms



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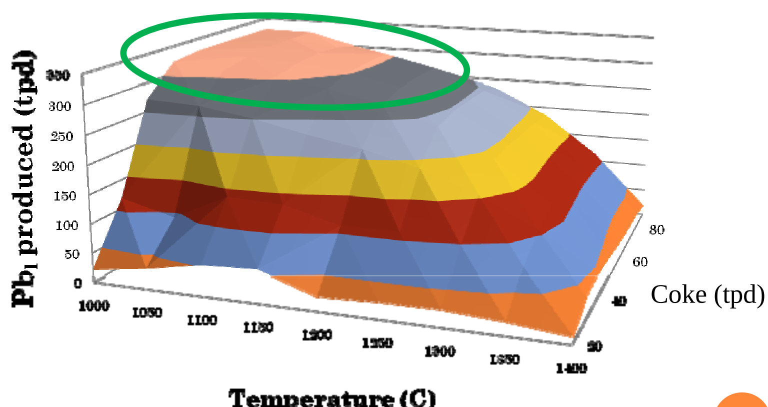
FORMATION OF PB_L (BULLION)

- Low T and High C favours reduction to Pb_l



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SUMMARY OF OBSERVATIONS

- Effect of High T
  - Formation of Zn and Pb Gas lowers recovey of both
- Effect of Low T
  - Incomplete reduction of Zn-Fe Spinels
  - High Bullion formation
- Effect of Low C
  - Incomplete reduction of Zn Fe Spinels
  - Medium ZnO formation
  - Low Pb bullion formation
- Effect of high C
  - High formation of Pb bullion

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OPTIMAL OPERATING CONDITIONS: 1200 ^{O}C, 60 TPD COKE

- 3 resulting streams
  1. Gas – 250 tpd
     - 45% CO
     - 42% CO_2
     - 9% Zn
     - <4% Pb
  2. Slag – 550 tpd
     - ZnO and other M-Oxides
     - ~3.5% Pb as PbO
  3. Bullion – 285 tpd
     - 97.7% Pb
     - 3.3 % Ag, Au, Sn, Cu, Bi

COKE CHECKER TARGETS

1200 °C, 60 tpd Coke

- Maximize reduction of PbO to Pb_l
  - 95% PbO→ Pb_l
  - 3.5% remained as PbO in slag
  - R_{Pb} ~ 86% so far
- Further Oxidize ZnFeO4 to ZnO
  - <<1% Zn as spinel
- Maximize formation of ZnO
  - 78% Zn is present as ZnO
  - R_{Zn} ~ 72% so far
- Minimize Pb_g and Zn_g losses
  - 3% Pb is lost to gas
  - 21% Zn is lost to gas

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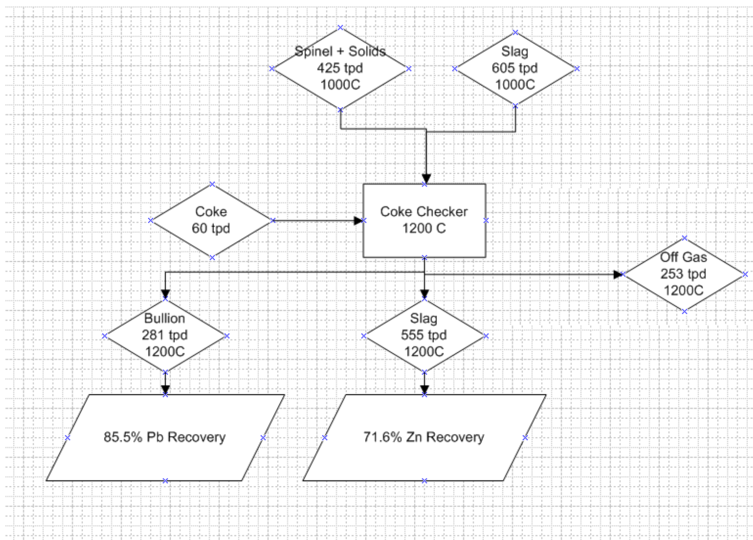
DOES THIS FIT REALITY?

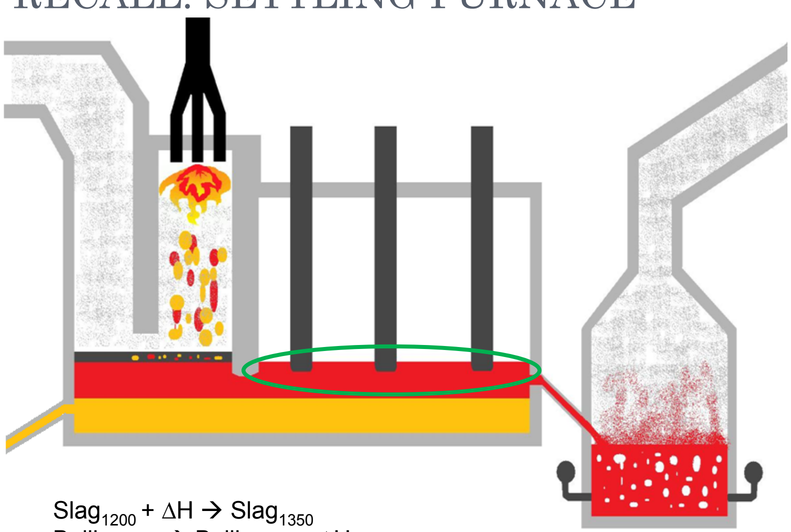
1200 °C, 60 tpd Coke

- From “Metal Recovery From Kivcet Slag” by Y. Zhang (Colleague from Teck)
  - ”In the second stage, the oxides of lead and zinc are reduced by carbon and carbon monoxide at about 1200 °C.”
- From TMS website:
  - “[...] 1200ºC gas from the smelting shaft [...] “
- From Teck:
  - 39 tpd Coke is added directly to the Coke Checker. Some of the Coke from the feed (100 tpd) contributes as well.

COKE CHECKER RESUME



RECALL: SETTLING FURNACE



$Slag_{1200} + \Delta H \rightarrow Slag_{1350}$

$Bullion_{1200} \rightarrow Bullion_{950} + \Delta H$

SETTLING FURNACE TARGETS

- Mass transfer:
  - Allow time for Slag and Bullion phases separate
  - No chemical reactions
    - For purpose of this analysis we assume electrodes are inert
- Energy Transfer:
  - Preheat Slag for Slag Fuming Furnace
  - Keep bullion and slag temperatures above solid
  - Prevent formation of accretions
  - Prevent formation of Matte interface between Slag and Bullion

SETUP

- Want to know total energy losses of this section of the furnace.
- I know slag is preheated to ~1350^{o}C
- I know bullion cools to ~950^{o}C due to heat losses in the system
- Unfortunately critical Information was lacking to perform calculations for this part of the system:
  - Can't recall Power of electrodes
  - Cooling water flow rate and ΔT

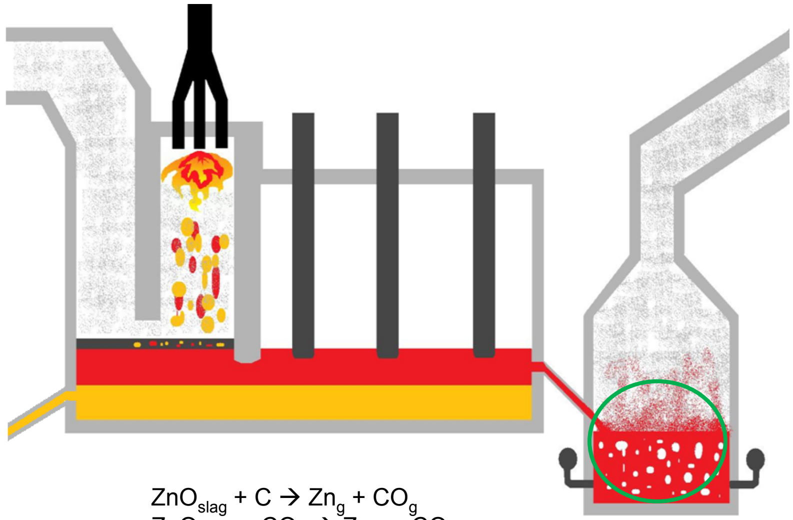
HERE'S WHAT I WOULD HAVE DONE

- Setup would have been trivial:

$$\begin{array}{l} \Delta H_{electrodes} \\ \Delta H_{slag1200\ to\ 1350} \\ \Delta H_{loss(water)} \\ +\ \Delta H_{bullion\ 1200\ to\ 950} \\ \hline \Delta H_{total} = 0 \ \text{(due steady State)} \end{array}$$

- Used Fact Sage to Obtain:
  - $\Delta H_{slag1200\ to\ 1350} = -1.40*10^{11}$ J/day
  - $\Delta H_{bullion\ 1200\ to\ 950} = 9.25*10^{9}$ J/day

RECALL: SLAG FUMING



$ZnO_{slag} + C \rightarrow Zn_g + CO_g$

$ZnO_{slag} + CO_g \rightarrow Zn_g + CO_{2g}$

PRODUCTION TARGETS

- Achieve 90% or greater Zn Recovery from incoming slag
- Final Zn assay ~2%
- 8 slag batches of ~70t (560tpd)

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FACT SAGE CONSIDERATIONS

- Batch Process ~ 8cycles/day
  - We will assume that an entire day's production can be processed in 1 cycle.
- 1 reference on similar Fuming Furnace
  - 1985 G. Richards (my old boss!)
  - Fuming occurs at 1300C
  - 1-2t coke / t of Zn (select 100tpd Coke)
  - 300-400Nm3/min of air (select 140tpd O2)

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FACT SAGE CONSIDERATIONS

- Any amount of N2 in the system inhibited the reaction to work in Fact Sage… Unknown to me why.
  - Instead $\Delta H_{50\text{-}1300}$ of N2 was removed from the fuming process
  - Overall reaction was still largely exothermic
    - 0 heat losses
    - Clearly, an excess of C and O2 was added
  - $\Delta H_{\text{Process}} - \Delta H_{N2\ 50\text{-}1300} = \Delta H_{\text{total}}$
  - -2.611×10^{12} J $+7.555 \times 10^{11}$ J $= -1.856 \times 10^{12}$ J

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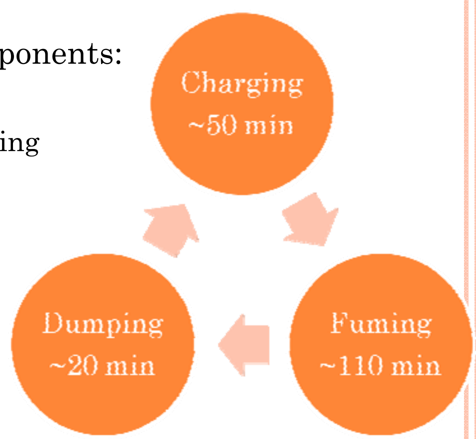
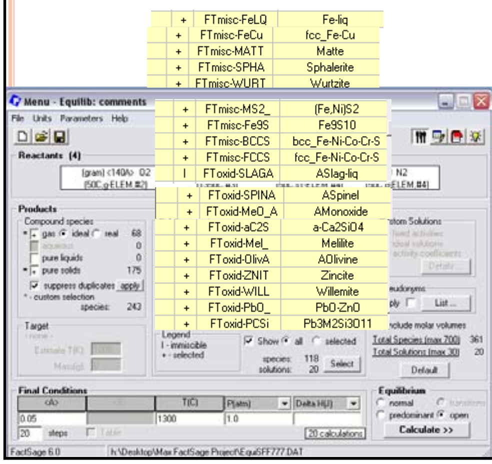
FUMING CYCLE: 180MINUTES

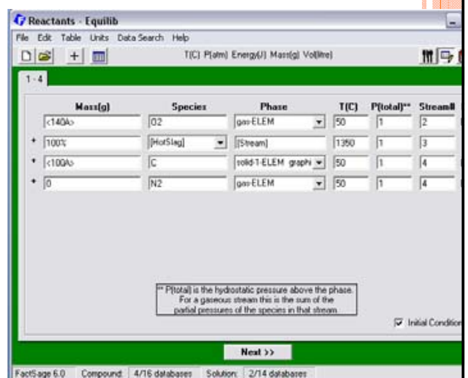
- A fuming cycle has 3 components:
- Charging
  - Slag is charged from Settling Furnace.
- Fuming
- Dumping
  - Slag is dumped out of the Slag Fuming furnace
- We will ignore charging and dumping for this analysis



FACT SAGE SETUP

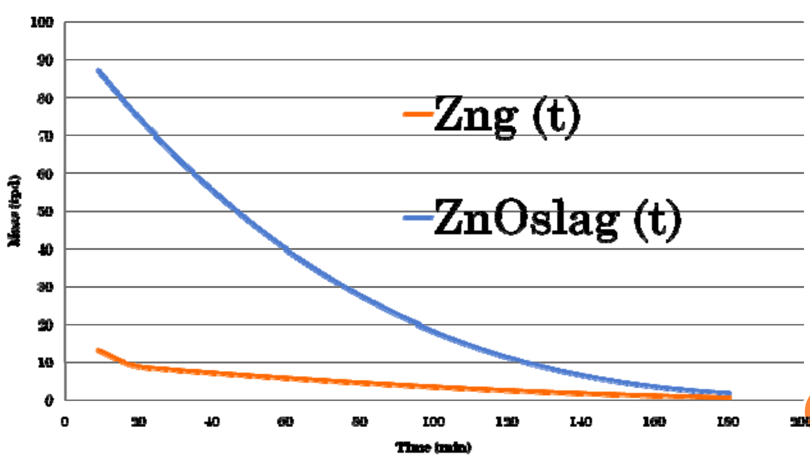
- This is a batch Process:
  - Requires open calculations





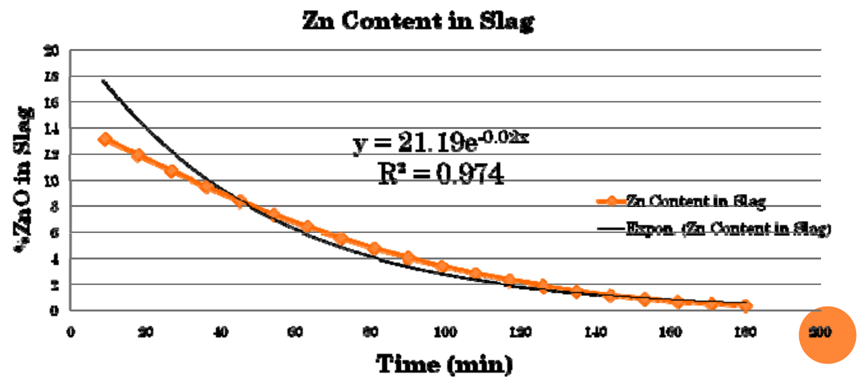
CALCULATION

- Theoretical Fuming rates and remaining ZnO in slag.



CALCULATION

- ZnO Fuming Kinetics were estimated
- 1st Order Kinetics



ZN FUMING

- In 180 minutes of “ideal” fuming:
  - 98.5% Recovery of Zn from slag
  - 0.37% final Zn Assay in slag

- Due to excessive C + O2
  - After 30 minutes Off gas > 50% CO
  - After 180 minutes Off gas > 91% CO
- Due to absence of Charging and Dumping phases
  - This adds 50-60 minutes of fuming time
  - Removing this time yields 90.5% recovery and 1.9% final Zn Assay

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EFFECT OF PARAMETERS

- Low C
  - Not enough energy in system
- High C
  - Good fuming rates
- Low O2
  - Not enough energy in system
- Higher O2
  - Fuming rates are too fast… (unrealistic)

- O2 and Coke addition should be tweaked to minimize wasted Coke near end of cycle.

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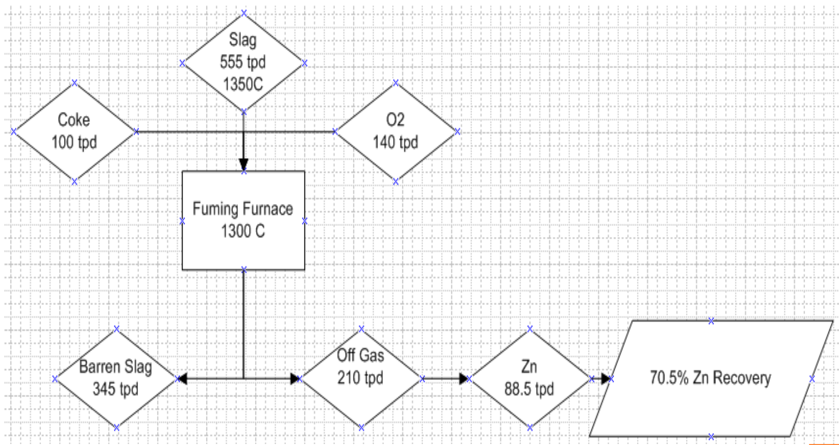
TARGETS ACHIEVED

- Achieve 90% or greater Zn Recovery
  - R_{Zn} = 98.5%

- Final Zn assay ~2%
  - Final assay was 0.37%

- 8 batches of ~ 70t (560tpd)
  - 1 large batch of 560tpd was processed
  - Did not include Charging and Dumping effects

RESUME



PROJECT CLOSING STATEMENTS

- Reaction Shaft:
  - Ideal operating conditions were found (1000C 40tpd Coke).
  - Require real data to validate
  - Identified formation of Zn Spinels instead of ZnO
- Coke Checker
  - Ideal operating conditions were found (1200C 60tpd Coke)..
  - The results were fairly close to the literature
  - Require real data to validate
- Settling Furnace:
  - Require more information to do a complete Heat balance.

PROJECT CLOSING STATEMENTS

- Slag Fuming:
  - First order Kinetics can be assumed for ZnO disappearance from Slag
  - Experimental results (from 1985) contradict this, however other models apparently agree
  - Require real data to validate model
  - Effect of charging and dumping on the fuming cycle must be taken into account to validate model
- General
  - Factsage is a powerful tool for thermodynamics modelling. However without real world validation, the model is useless!