ELECTRIC SLAG FURNACE DIMENSIONING

A.K. Kyllo, N.B. Gray, and A. Filzwieser,
Proceedings of EMC 2005

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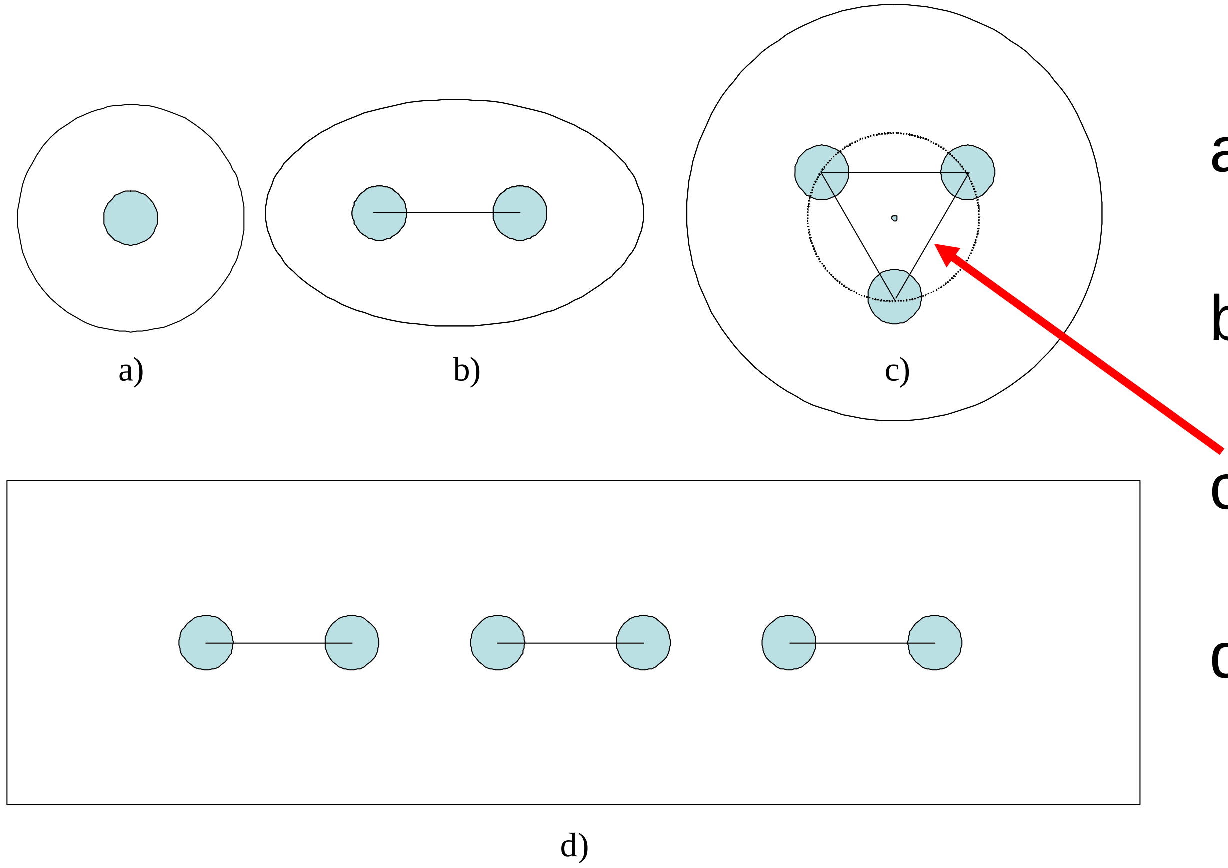
Outline

1. Introduction to modern slag furnace designs
2. ‘Work’ and ‘Losses’ in the furnace
3. Slag furnace dimensioning steps
4. Use of electrode ratio method
5. Types and sizing of electrodes
6. Slag ‘resistance’ furnaces – What is the nature of the resistance and how does this create uncertainty in our designs?

Typical Electric Furnace Electrode and Body Arrangements



- a) single top entering electrode (1-phase),
- b) two electrodes (1-phase),
- c) three electrodes (3-phase), and
- d) six-in-line electrodes (3-single phase).

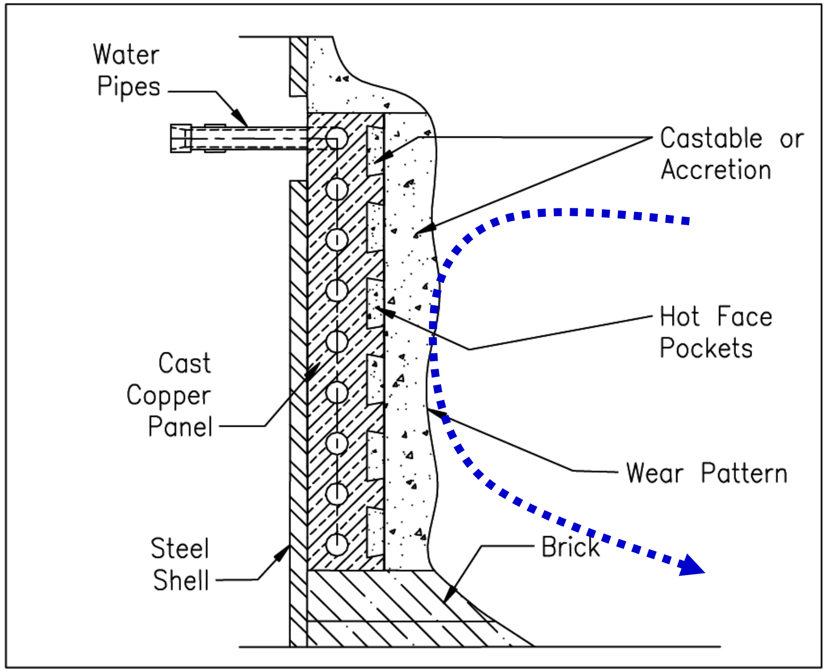
Furnace Generations and Indicative Intensity

Furnace Generation	Energy Intensity (kW/m^2 of hearth area)	Typical Side Wall Heat Flux (kW/m^2)
1	~100	<15
2	~200	<20
3	300-400	~30-60
4 (4) experimental	500-1000	>30

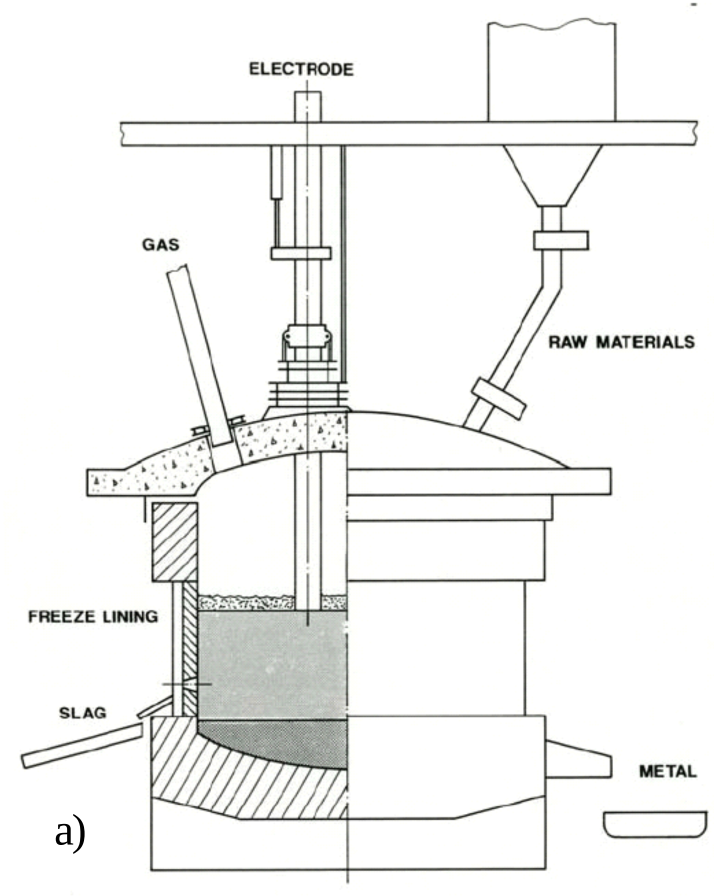
Energy intensity and total furnace power have been increasing in order to decrease furnace sizes and increase thermal efficiency.

Modern High Intensity Slag Furnaces

Side Wall Cooler EXAMPLE

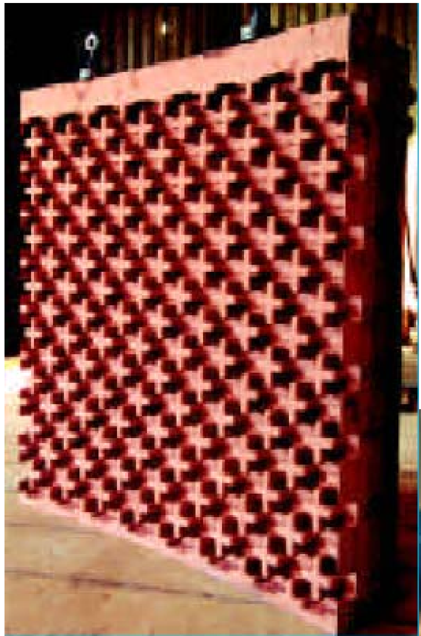


With Permission of MacRae Technologies



Elkem Multi-Purpose Furnace®

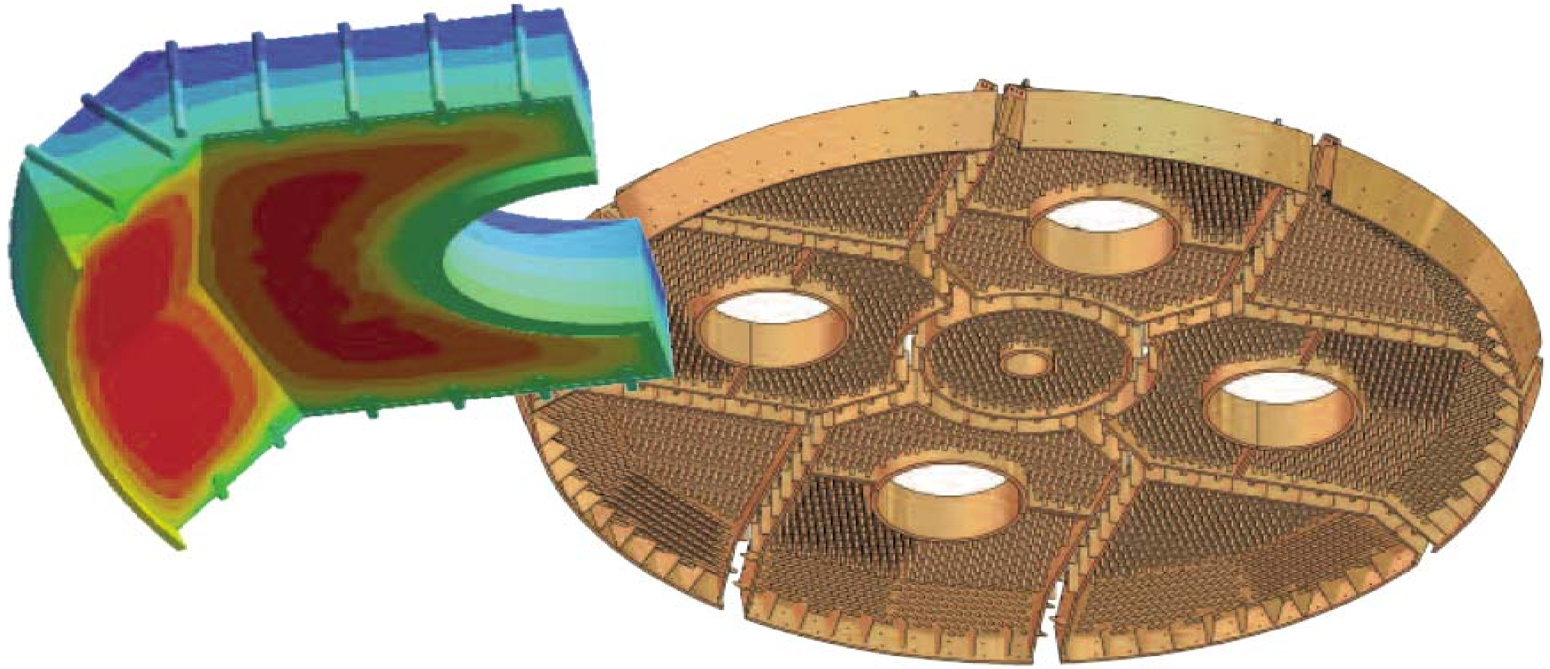
Textured Panels – Example by Tenova - Pyromet



Complete bathline for a 12 m diameter slag furnace

Maxicool ® cooling panels for a 12m dia. slag cleaning furnace

Composite Furnace Modules (CFM) with FEM modelling results by Bateman



Bateman Copper Cooler Technology, company brochure

Heat in the Furnace

Work:

1. Preheat charge,
2. Pre-reduce charge,
3. Melt charge,

} **Higher rates = more superheat**

4. Produce the superheat required to achieve tapping, and
5. **Drive reduction reactions in the slag phase.**

We can assume that the superheat is controlled by items (1)-(4).

Heat in the Furnace

Losses:

- Any heat that is not consumed productively must necessarily leave the furnace as heat losses.

Any 'mistake' in either design or operation, will increase losses!

- Cooled copper structures are the main 'sinks'.

Heat in the Furnace

Work (work for melting is shown):

$$Q_{slag-charge} = A_{slag-charge} h_{slag-charge} (T_{bulkslag} - T_{liquidus})$$

Increases with power input, gas bubbles and buoyant mixing effects.

Loss (assume hot face is @$T_{liquidus}$):

$$Q_{slag-wall} = A_{slag-wall} h_{slag-wall} (T_{bulkslag} - T_{liquidus})$$

Natural convection if properly designed and operated, magnitude independent of power input.

Slag Resistance Furnace Dimensioning steps

1. A target furnace production rate (PR) is chosen **[mt/h]**,
2. Specific energy requirement (SER) of the process is established (excluding heat losses) **[kWh/mt]**,
3. The smallest electrode diameter is selected **[m]**, along with the number and type,

Slag Resistance Furnace Dimensioning steps

4. Furnace dimensions are chosen based on an acceptable energy intensity **[kW/m^2]** or by standard ratios to the electrode dimensions,
5. Furnace heat losses are estimated **[MW]**, and
6. Total furnace power verified **[MW]**.

Furnace Power

$$P_{furnace} = NP_{electrode}$$

Where N is the Number of electrodes.

$$P_{electrode} = I^2_{electrode} R_{electrode}$$

'Wye' or E-heath

Andræ, 1933:

(immersed elec.)

$$R_{electrode} = \frac{k}{\pi D_e}$$

First and simplest

Electrode Resistance Varies Inversely to D_e

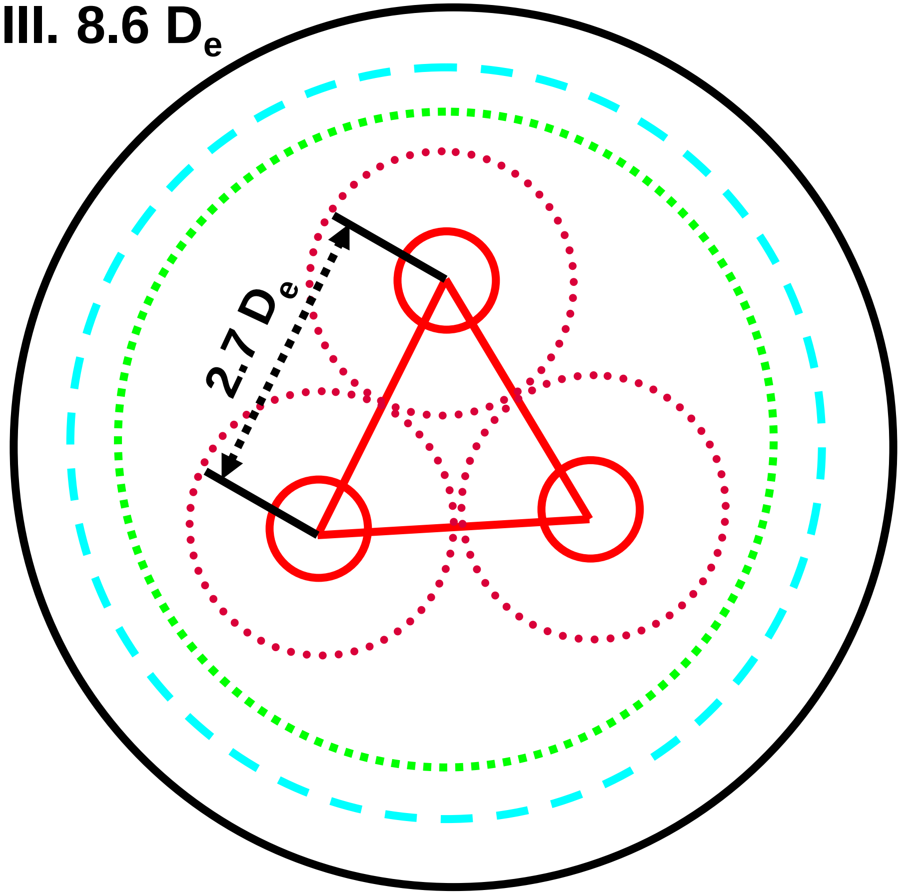
Furnace Dimensioning by Ratio's

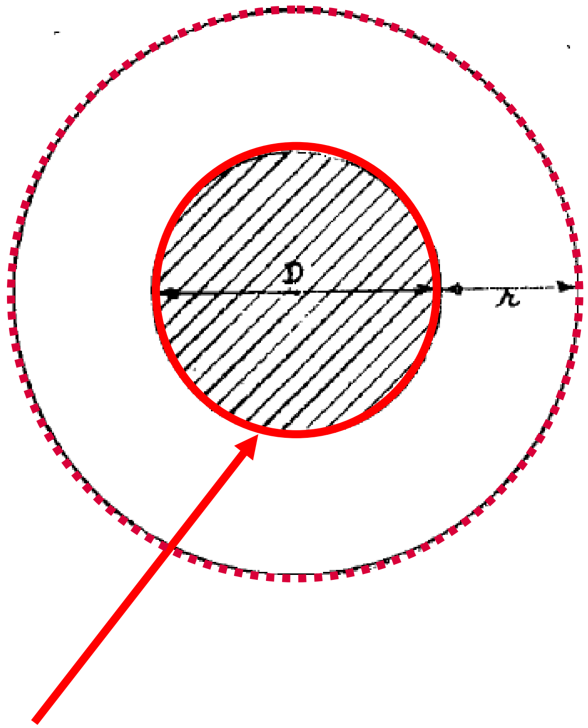
R.H. Eric and A.A. Heija, 1995:

I. 6 D_e

II. 7.7 D_e

III. 8.6 D_e



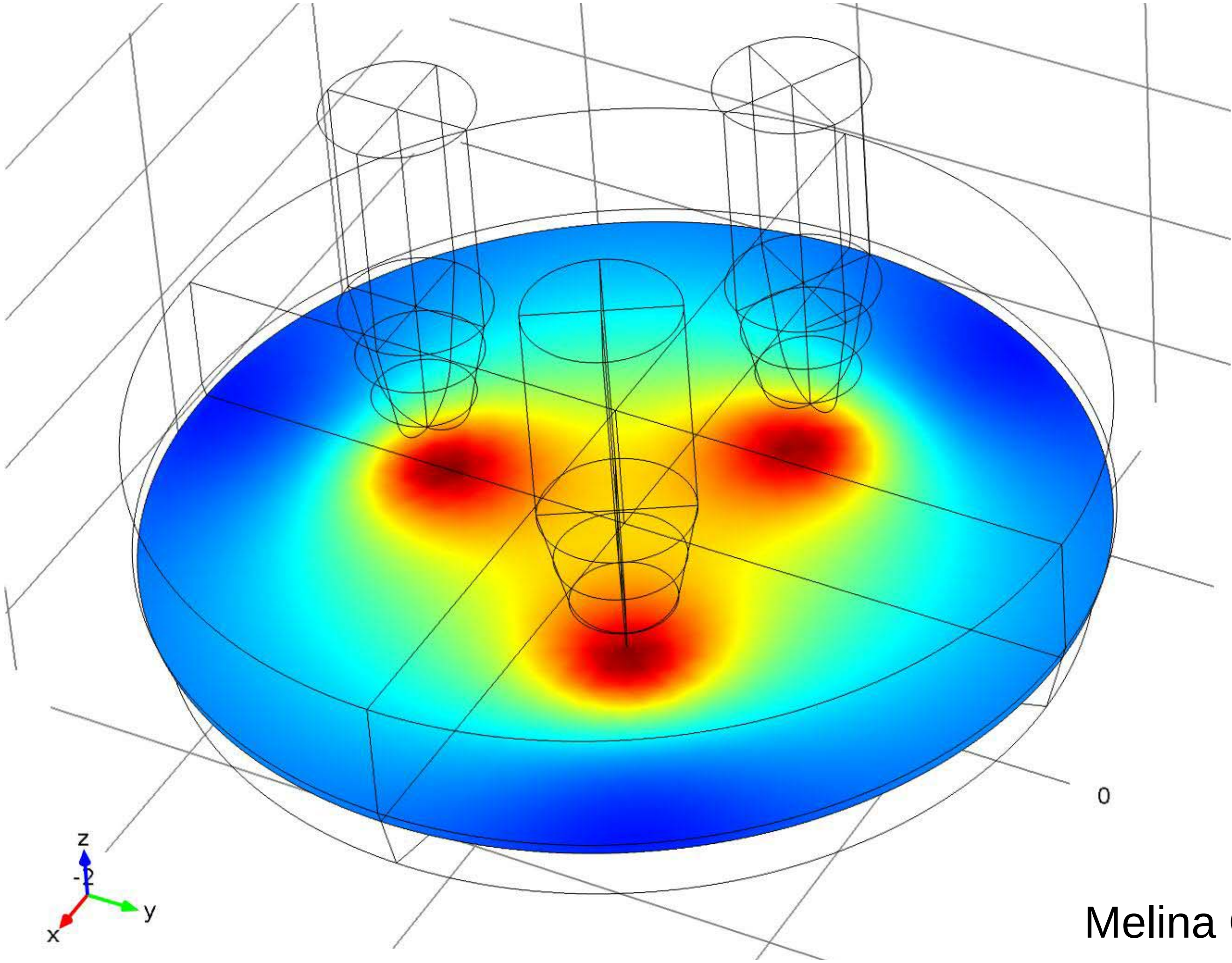


'Active' Electrode Area

Or 'Crater' concept: **2 D_e**

P. B. Wowk, 1964

3D FEM Model Current Density at the Slag-Metal Interface



Melina Garcia, Elkem

‘Ratio’ Rules of Thumb

- Active Electrode Area, **2-3 D_e**
- Electrode Spacing, **2.7 D_e (2.4-3.0)**
- Furnace Diameter, **6-8.6 D_e**

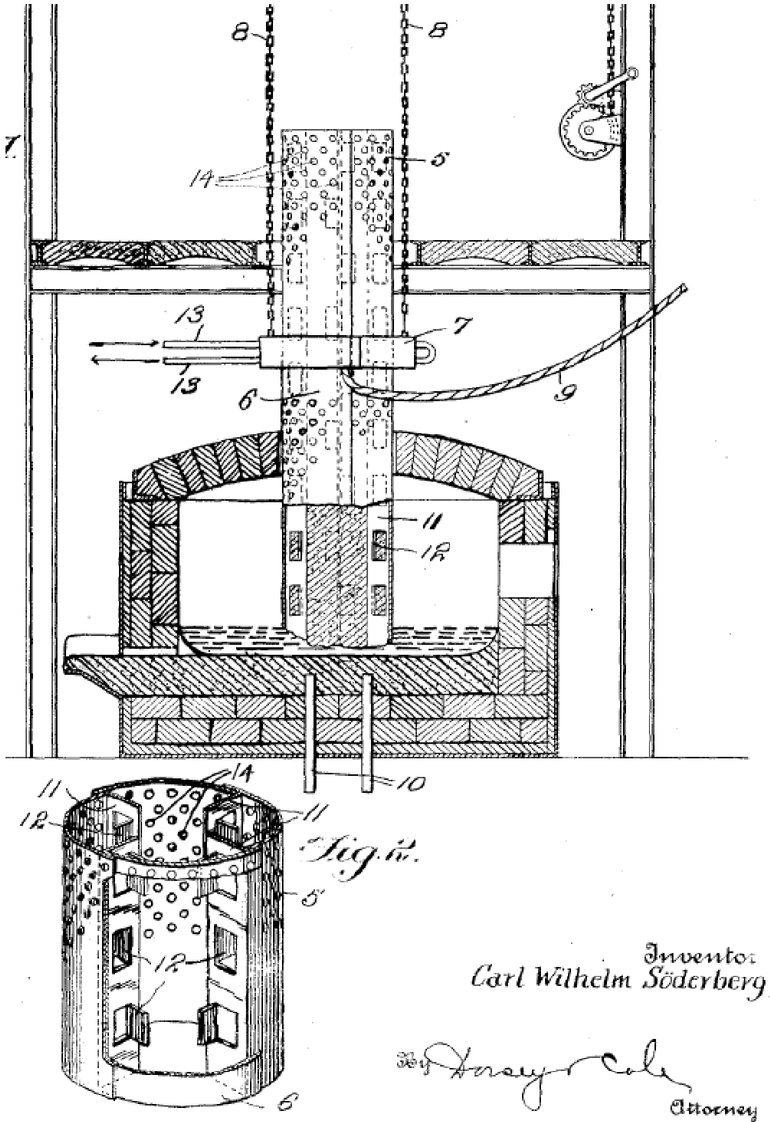
Using a system of ratios, everything depends on the electrode size. Electrode size is established by the possible power input per electrode, i.e. from the electrode current limitations, and furnace resistance.

Carbon Electrodes

Søderberg, **4 – 7** A/cm^2

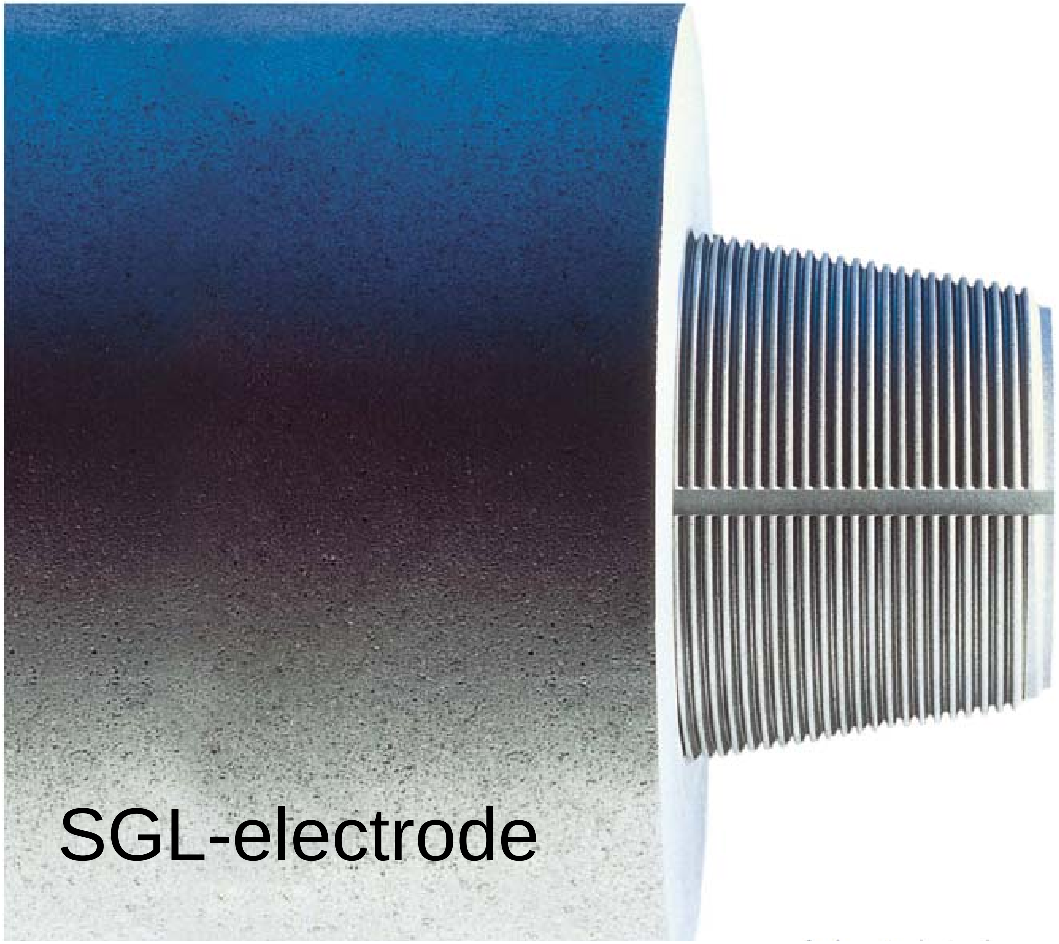
Pre-baked, ~**6** A/cm^2

Søderberg 1923



SGL carbon electrodes

Ultra-High-Power Graphite Electrodes



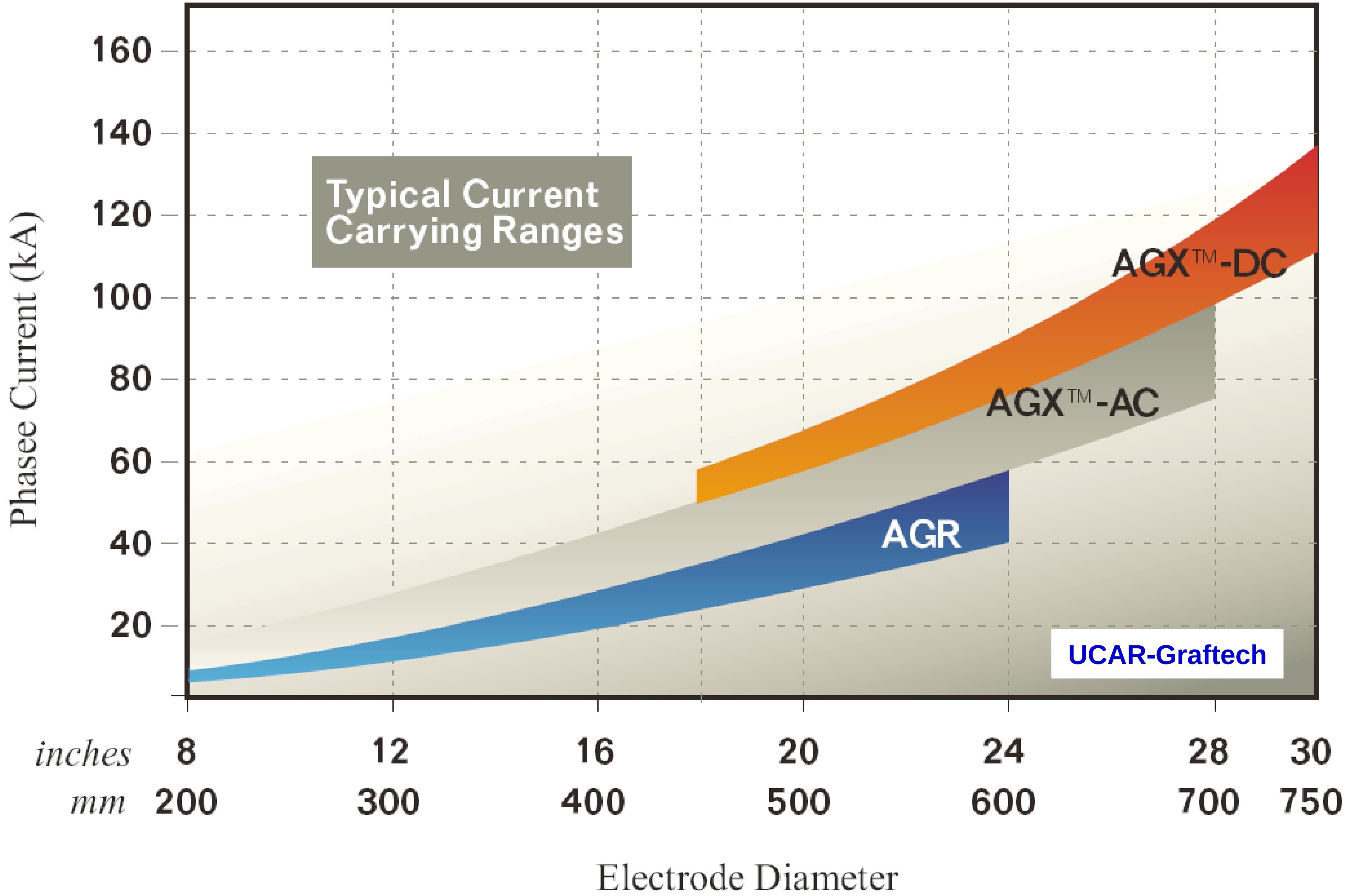
J_e (A/cm^2)

$= 22D_e(\text{m})^{-0.5}$

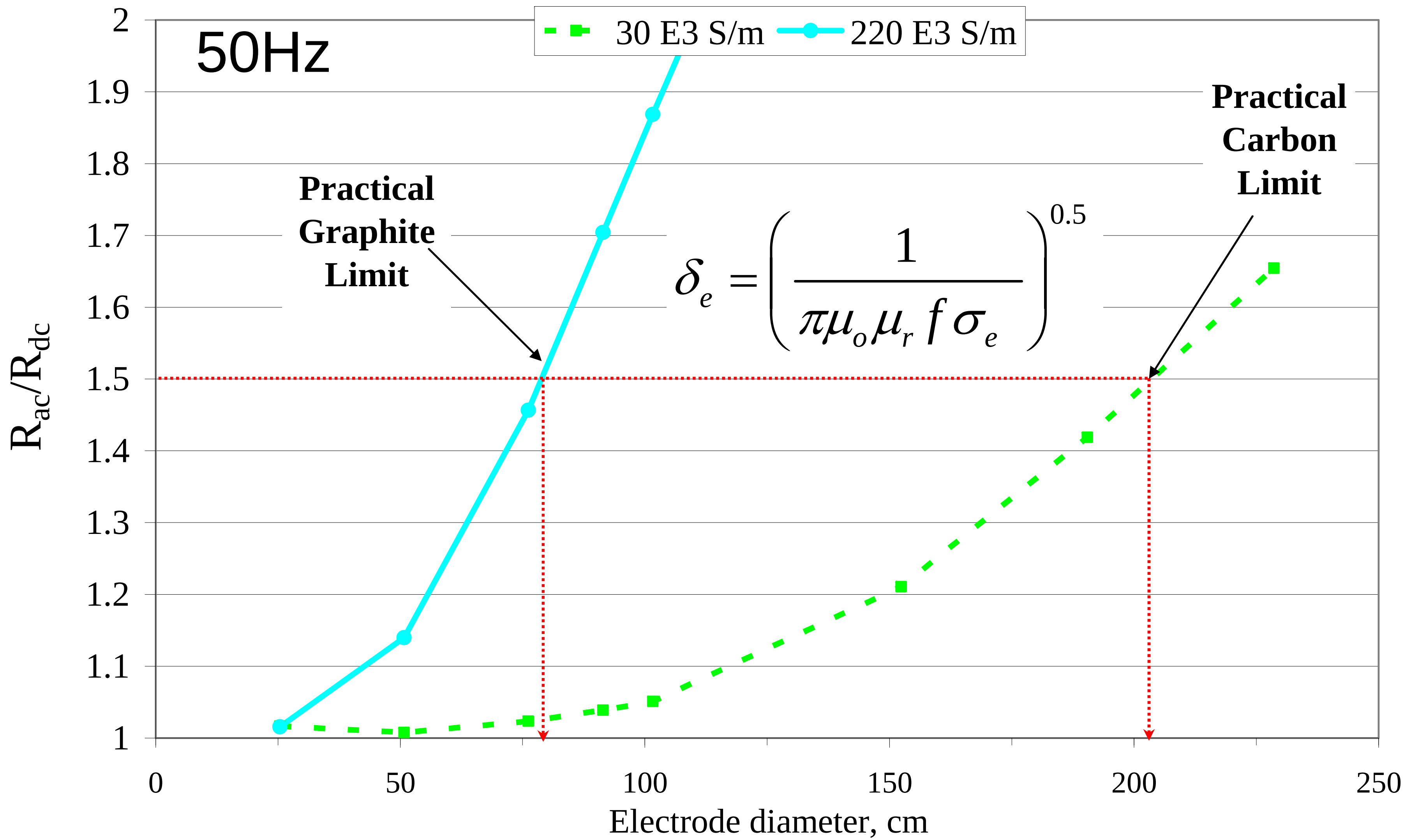
I_e (kA)

$= 170D_e(\text{m})^{1.5}$

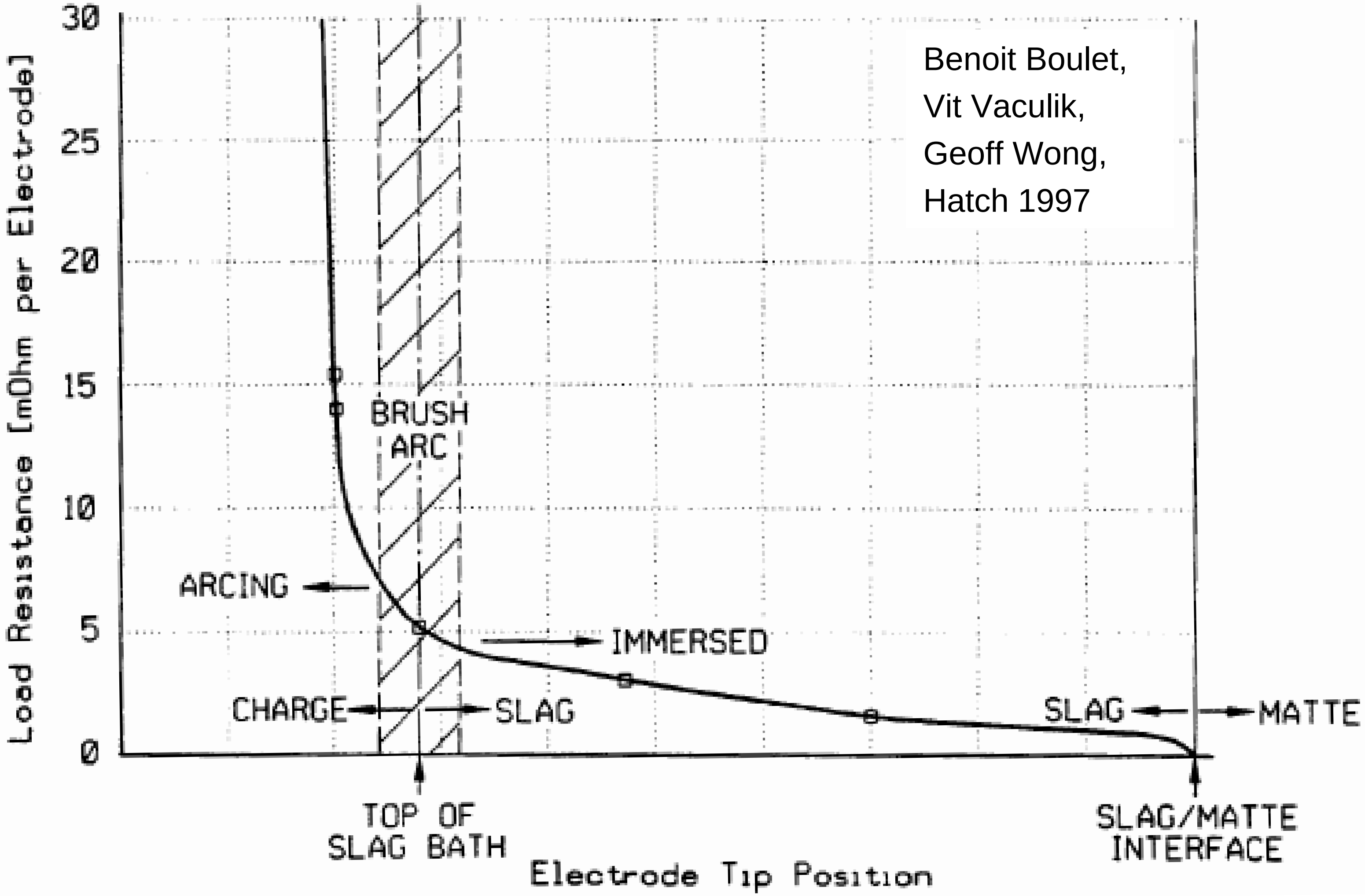
Graphite Electrodes Current Carrying Capacities



Impact of Skin Effect on Electrode Resistance

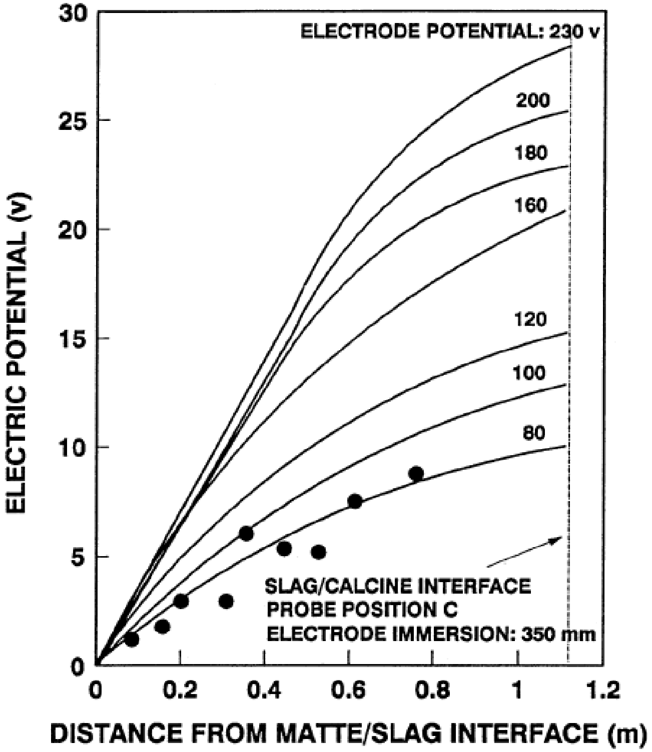


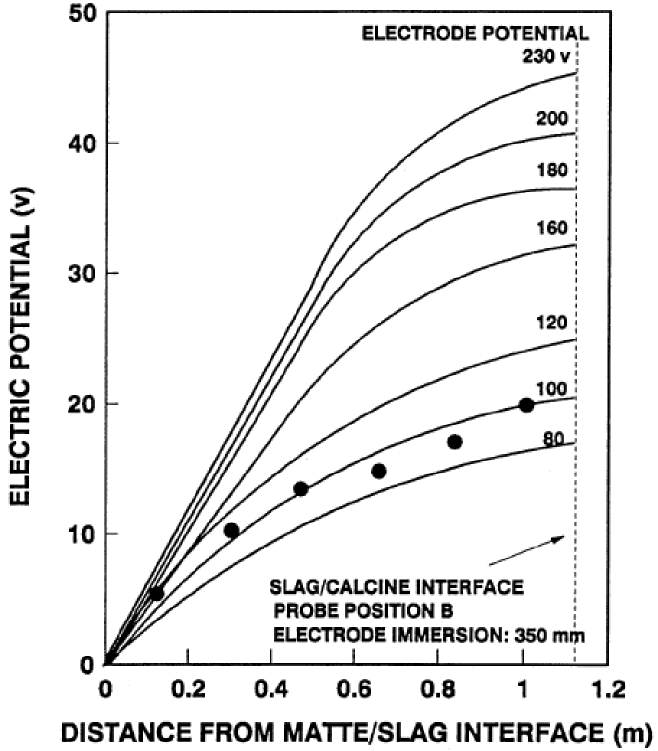
What Determines Furnace Resistance?



Benoit Boulet,
Vit Vaculik,
Geoff Wong,
Hatch 1997

Where are the Voltage Drops?





"It is indeed striking that the measured electric potentials only agree...if the potential applied to the slag is 100-120 V less than that applied to the electrodes."

Y.Y. SHENG, G.A. IRONS, and D.G. TISDALE, 1998

What Really is Slag 'Resistance'?

- Standard conduction losses? (joule heating)
- Gas bubbles at the electrode surface?
- Polarization, over-potential?
- Charge transfer losses?
- Capacitance?
- Complex permittivity?
- Etc.

Conclusions

- Methods for systematically designing slag furnaces are restricted by our lack of fundamental understanding of the true nature of electrical heat production and heat transfer in slag furnaces.

Simplistic models have been presented, which might be significantly improved by targeted temperature and electrical measurements in industrial slag furnaces.

Thank You!

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