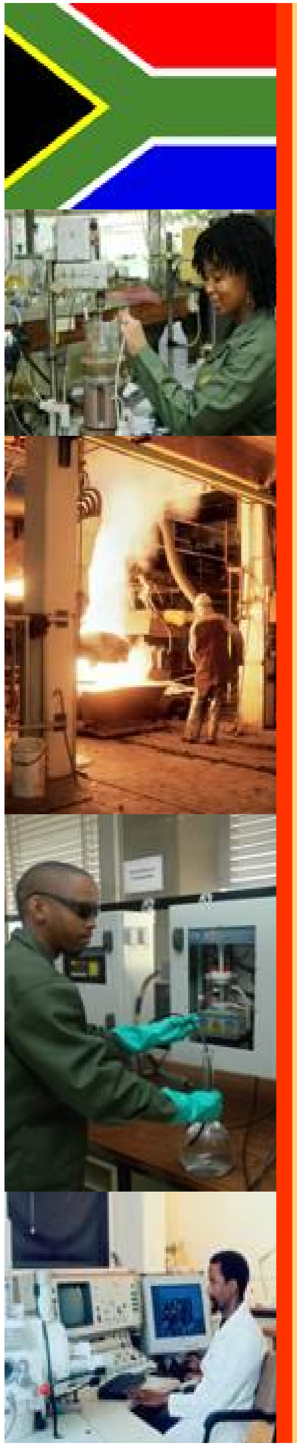


Council for Mineral Technology

A global leader in mineral and metallurgical innovation

The History of DC Arc Furnace Process Development

June 2009

TR Curr

Manager, Pyrometallurgy, Mintek

ELECTRIC FURNACES

- Evolved from late 1880's
- By early 1970's there were three basic types
  - Slag resistance
  - Open-arc
  - Submerged-arc
- All using graphite electrodes
- Note: induction and muffle furnaces excluded

SLAG RESISTANCE FURNACE

- Usually six-in-line electrodes, rectangular shell
- Non-ferrous industry Cu, Ni, PGM's
- Self-baking electrodes dipped into molten slag
- Ohmic heating from 3 single phase AC transformers

OPEN ARC FURNACE

- 3 AC-electrodes in a circular shell
- Steel scrap melting
- Pre-baked electrode sections
- Open-arc into solid scrap or molten slag

MINTEK

SUBMERGED – ARC FURNACE

- 3 AC-electrodes in circular shell
- Ferroalloy industry (FeCr, FeMn, FeSi)
- Self-baking electrodes, choke-fed lumpy feed
- Arcs submerged, typically >3m deep in feed

A SMELTING FURNACE CLASSIFICATION

Operating Temperature	Fine 0,01 – 10mm	Coarse 10mm – 200mm
High > 1500°C	Open-Arc	Submerged-Arc
Low 1000°C - 1500°C	Slag resistance Reverbatory Flash furnace	Blast furnace Cupola

Ore size

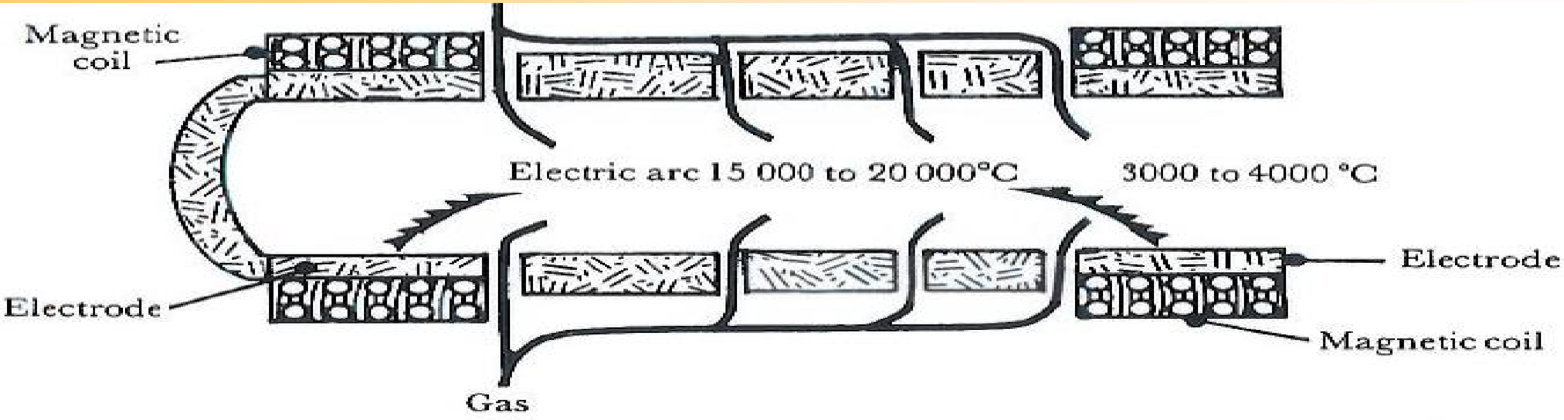
MINTEK

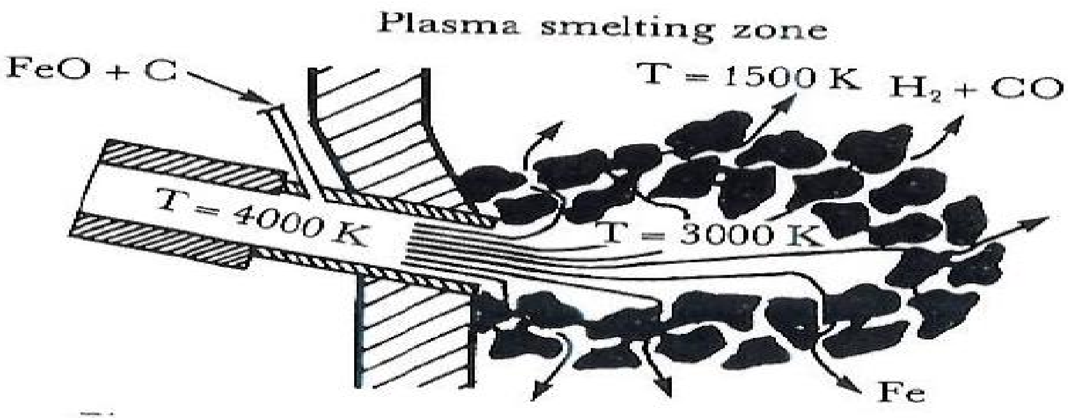
THE ADVENT OF PLASMA FURNACES

- Origins in the 1960’s space race
- Need to test re-entry materials at >4000°C
- Concept is to pass gas through an electric arc
- Precedent in a 1900’s process to produce NO_x
- Two plasma torch types were developed
- Characterized by using water-cooled metallic electrodes

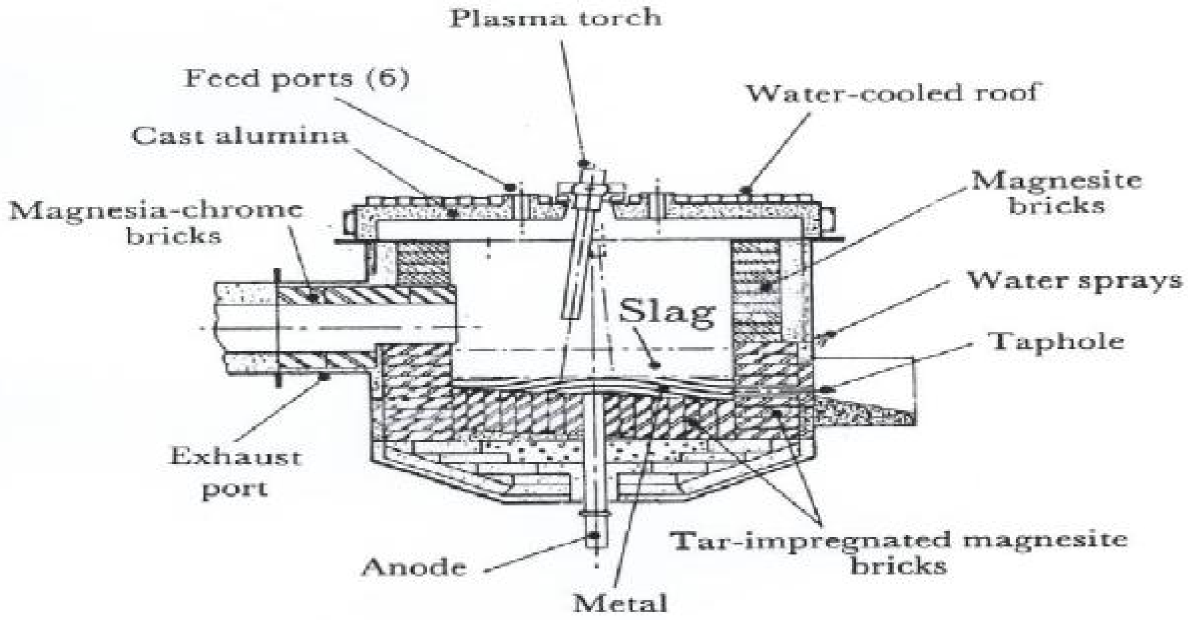
MINTEK

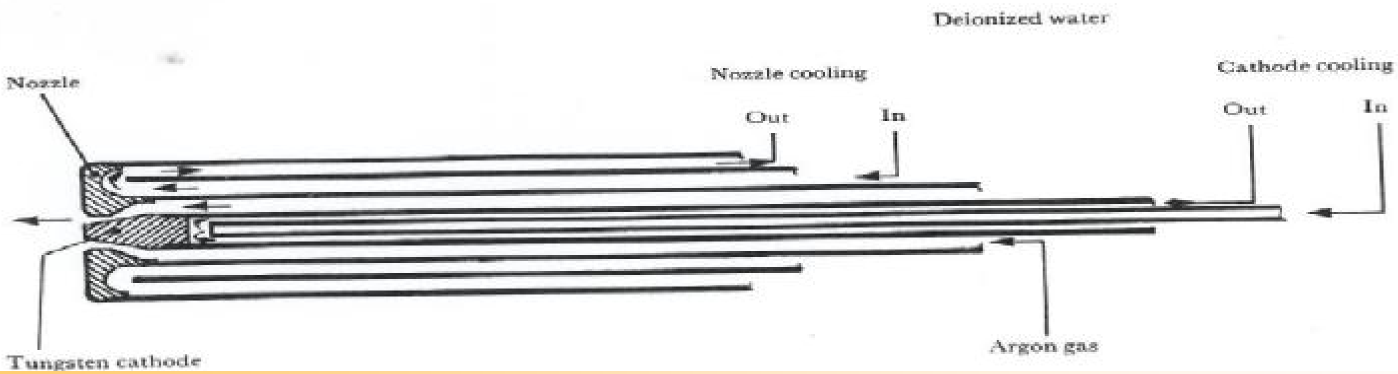
NON-TRANSFERRED ARC





TRANSFERRED ARC





MINTEK

MINTEK'S INVOLVEMENT IN PLASMA FURNACES

- Peter Jochens identified plasma furnaces as a possible solution to the " Chromite fines" problem.
- Chromite mining usually results in > 50% of < 6mm ore fines – not suitable for submerged-arc furnaces
- Mintek and Middleberg Steel & Alloys (now part of Samancor Chrome) conducted smelting trials on Tetronic's pilot transferred-arc plasma furnaces in 1979/80

MINTEK

MINTEK’S INVOLVEMENT IN PLASMA FURNACES (Continued)

- Although metallurgically successful there were problems of scale-up
- Plasma torches could not be scaled up to > 5 MW, due to excessive electrode wear

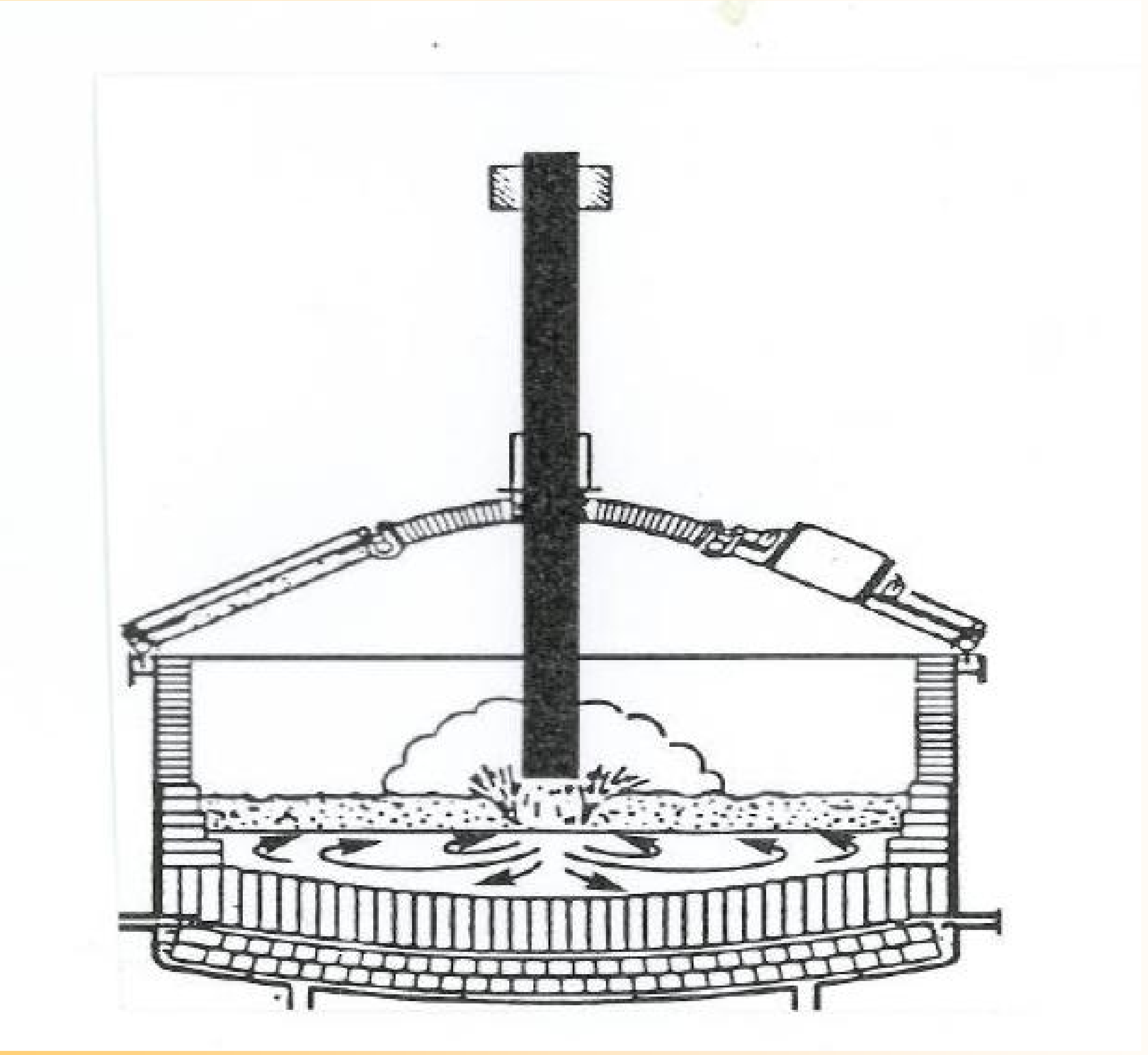
MINTEK

THE ADVENT OF DC ARC FURNACES

- In the 70's ASEA in Sweden developed high power thyrsistor rectifiers
- Sven-Einar Stenkvist investigated the conversion of AC open arc furnaces to DC, principally for steelmaking
- Identified a graphite cathode electrode arcing onto a slag/metal bath as the anode
- Devised an electrically conductive hearth and a hollow graphite electrode for finely sized iron ore smelting

MINTEK

ASEA's DC ARC FURNACE



DC ARC SMELTING OF CHROMITE

- The metallurgy proven at Tetronics, plus
- The scale-up potential of ASEA's DC arc furnace.
- This synergy was recognized by Nic Barcza
- It resulted in MS & A converting an existing

  AC furnace at Palmiet Ferrochrome (now Mogale Alloys) to a 12MW DC arc furnace of ASEA design in 1984
- It also resulted in Mintek building a 1,2MW DC arc furnace in 1983, to support this development and extend it to other applications

MINTEK

DC ARC SMELTING OF CHROMITE (continued)

- The 12 MW furnace was upgraded to a 28 MW furnace in 1988
- A 42 MW DC arc furnace was built at Middleberg Ferrochrome in 1997 and was followed by a 60 MW DC arc furnace in 2009

MINTEK

A SMELTING FURNACE CLASSIFICATION

Operating Temperature	Fine 0,01 – 10mm	Coarse 10mm – 200mm
High > 1500°C	Open-Arc	Submerged-Arc
Low 1000°C - 1500°C	Slag resistance Reverbatory Flash furnace	Blast furnace Cupola

Ore size

MINTEK

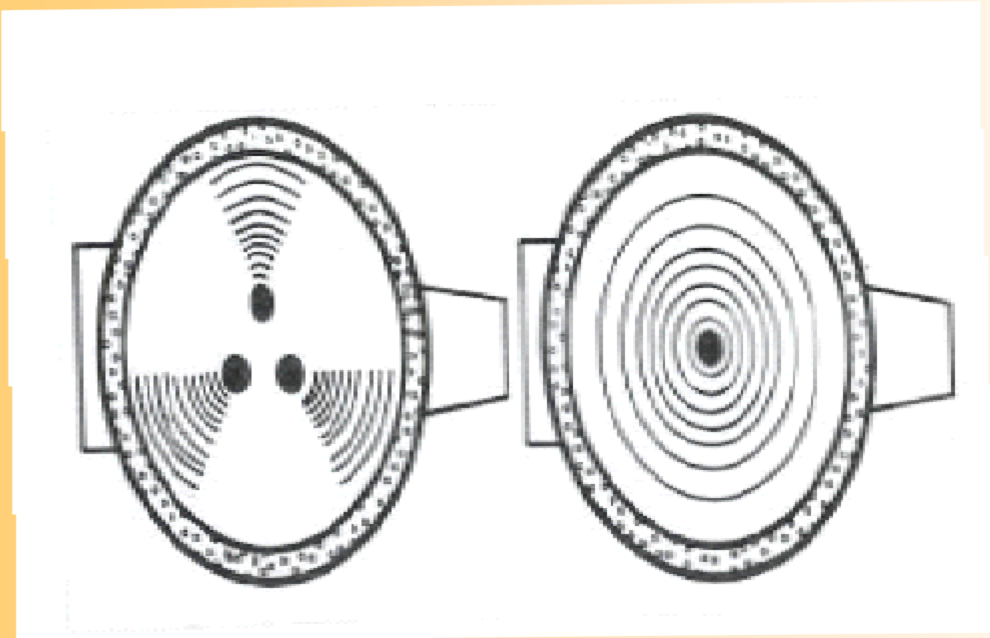
WHY USE A DC ARC FURNACE

- In principle could use DC or AC for smelting ore fines in an open arc furnace
- In fact RBM operate 4 x 60 MW AC open-arc six-in-line furnaces to smelt ilmenite ore fines

MINTEK

ADVANTAGES OF DC OPEN ARC FURNACES VS AC

- No arc repulsion and hot spots



- Lower electrode consumption
- Higher current per electrode, “ skin effect”

SUBSEQUENT DC OPEN-ARC FURNACE APPLICATION

- Ilmenite smelting
  - Piloted at Mintek in 1990
  - 25 MW DC furnace at Namakwa Sands 1995
  - 35 MW furnace followed in 1998
  - Two further DC furnaces in Empangeni

SUBSEQUENT DC OPEN-ARC FURNACE APPLICATION (continued)

- Cobalt recovery from copper discard slags
  - Investigated since 1980's
  - Piloted at Mintek in 1999 at 1,5 MW
  - 40 MW DC furnace in operation in Zambia, 2002
  - First commercial side-feeding DC smelter

MINTEK

PILOTED BUT NOT YET COMMERCIALIZED

- Nickel Laterite
  - Piloted at Mintek from 1998 to 2006
  - 2 x 80 MW DC arc furnaces planned for Xstrata's Koniambo FeNi smelter in New Caledonia

- Lead blast furnace slag
  - Piloted at Mintek from 1994 to 1998
  - Recover 98% Zn metal via fuming & condensation
  - Distillation to 99.5% purity also developed

MINTEK

PILOTED BUT NOT YET COMMERCIALIZED (continued)

- Magnesium metal
  - Fuming & Condensation
- PGM smelting (Conroast process)
  - Smelting roasted concentrates

FUTURE DEVELOPMENTS

- Improved arc stability
- DC self-baking electrode
- DC submerged-arc furnace

CONCLUSION

- Technology development is not linear, it may have many roots and unexpected outcomes.

Thank you

MINTEK