DC arc furnaces –
The story of a successful
South African technology

Rodney Jones
Mintek (Established 1934)

- Government-owned minerals research organization
- Employs ~800 people (300 professionals)
- Annual budget of ~R420m (US $40m)
- State & corporate funding (50:50)
DC arc furnaces at Mintek

1.5 MW furnace

3 MW furnace
Early description of an arc by Humphry Davy

- Humphry Davy was first to describe a man-made electric arc in the early 1800s. His early experiments were only a few months after Volta’s introduction of the electric battery.

- Humphry Davy’s “Elements of Chemical Philosophy” in 1812 depicted a long horizontal arch of flame that gives the arc its name.
DC arc furnaces for melting metals date back to 1878

- Sir William Siemens used a DC arc furnace in 1878 with a vertical graphite cathode, with the arc transferred to the melt in contact with a water-cooled bottom anode.
AC furnaces are more recent than DC furnaces

- The AC electric furnace was patented in 1900 by Paul Héroult, and operated in La Praz, France in 1900.

First AC electric arc furnace in USA, 1906 (Philadelphia)
However, AC furnaces were widely used for a long time.

- AC power was widely used, for reasons of effective power transmission from large central power stations, following developments by Nikola Tesla and George Westinghouse in 1887 and 1888.
Features of DC arc furnaces

- Can achieve high temperatures (> 1500°C)
- Can accept fine feed materials (< 10 mm)
- Energy supplied by open plasma arc, so less sensitive to electrical properties of slag
- Lower electrode consumption
- No arc repulsion (and resulting hot spots)
- DC furnaces carry higher currents per electrode (no ‘skin effect’)
DC arc furnace

- Cylindrical steel shell
- Refractory lined
- Central graphite electrode
- Anode imbedded in hearth
- Metal layer in electrical contact with anode
- Energy supplied by open plasma arc
- Fairly uniform temperature distribution
DC arc furnace

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Inside the DC arc furnace

[Images of inside a DC arc furnace, showing intense heat and flames]
Mintek’s initial work on ‘plasma furnaces’

- Peter Jochens identified ‘plasma furnaces’ as a possible solution to the ‘chromite fines’ problem.
- Mintek and Middelburg Steel & Alloys (now part of Samancor Chrome) conducted smelting trials on Tetronics’ pilot transferred-arc plasma furnaces in the UK in 1979/80.
- Metallurgically successful, but difficult to scale up to very large furnaces.
ASEA’s DC arc furnace

- ASEA in Sweden developed high-power thyristor rectifiers in the 1970s
- 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’s early work with DC graphite electrodes

• Nic Barcza recognised the synergy between the metallurgy proven at Tetronics, and the scale-up potential of ASEA’s DC arc furnace

• Mintek built a 1.2MW DC arc furnace in 1983 to support this development

• MS&A converted an existing AC furnace at Palmiet Ferrochrome (now Mogale Alloys) in Krugersdorp to a 12MW DC arc furnace of ASEA design in 1984
1. Chromite smelting

• Chromite is smelted to produce ferrochromium
  \[
  \text{FeO} \cdot \text{Cr}_2\text{O}_3 + 4\text{C} \rightarrow \text{Fe} + 2\text{Cr} + 4\text{CO}
  \]

• Problem to be solved:
  Devise a process to treat fine chromite ore

• The DC arc furnace
  – Operates with open arc, open bath
  – Does not require coke
  – Power supplied to furnace is independent of slag composition, so slag can be changed to one that allows higher Cr recovery
  – Has lower electrode consumption
1. Chromite smelting (Mintek)

- DC arc furnace studies commenced in 1976 as a means of smelting chromite fines (< 6 mm)
- First ferrochromium was produced in a bench-scale DC furnace in 1979
- 1 t/h DC arc furnace pilot plant commissioned in 1984
- Patented process – jointly owned initially
1. Chromite smelting (Palmiet Ferrochrome)

- Tested at 0.3 - 0.5 MW, 1 – 2 m
- A 12MW (16MVA) furnace was built initially in 1984, then upgraded to 40 MVA (25 - 30 MW) in 1988
- An additional 10MW furnace was later built on the same site (for Mogale Alloys)
1. Chromite smelting (Samancor Cr, Middelburg)

- 44 MW (62 MVA) in 1997
1. Chromite smelting (largest furnaces)

- Samancor Chrome’s 60 MW furnace, built in Middelburg in 2009, is currently the largest DC arc furnace in South Africa.

- The 44 MW furnace was recently upgraded to 60 MW as well.
- Use of technology grew after patent expired.
1. Chromite smelting (Kazchrome)

- However, another four 72MW furnaces have recently been built in Kazakhstan.
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2. Ilmenite smelting

- Ilmenite is smelted to produce titania slag and pig iron
- Problem to be solved:
  Find alternative equipment in which to produce a very conductive slag (needs an open arc)
- Piloted at Mintek in 1990 (0.5 MW, 1.8 m)
2. DC arc furnace for ilmenite smelting

- Same DC arc furnace equipment can be used for very different reasons
- Titania slag is highly conductive, therefore an open arc is required
- Slag is a valuable product; contamination must be avoided
- Degree of reduction must be carefully controlled, therefore no electrode immersion
2. Ilmenite smelting (Namakwa Sands)

- 25MW DC furnace at Namakwa Sands in 1994
- 35MW DC furnace followed in 1998
2. Ilmenite smelting (Ticor and CYMG)

- Two further 36MW DC furnaces at Ticor near Empangeni were commissioned in 2003

- Many other enquiries from around the world
- Constrained by licence agreements
- A 30MW furnace was commissioned for CYMG in China in 2009
3. Cobalt recovery from non-ferrous slags

- The recovery of cobalt from copper discard slags was investigated from the 1980s
- Problem to be solved: Recover cobalt from its oxidized form in slag
- Piloted at Mintek at 2MW in 1999
- 40MW DC furnace in operation at Chambishi in Zambia in 2001
- First commercial DC smelting furnace to use solid electrodes with side-feeding
- (A number of furnaces have now changed away from hollow electrodes)
Chambishi

Tested at 2.0 MW, 2.5 m

Cobalt from slag  40 MW  2001
Chambishi Metals, Zambia
4. Battery recycling

• Batrec, Switzerland
• 2.5MW furnace in 2008 treats 5000 t/a and produces Zn and FeMn
5. Stainless steel dust smelting

- Steel-plant dusts contain hazardous heavy metals
- DC arc furnace recovers Cr and Ni and produces a slag that can be safely disposed of
- Process operated at Mogale Alloys on a 32MW furnace
6. Nickel laterite smelting

- Piloted at Mintek from 1998 to 2006
6. Nickel laterite smelting (Russia)

- 12MW furnace in Southern Urals, Orsk, Russia commissioned in 2011
6. Nickel laterite smelting (New Caledonia)

- Two 80MW twin-electrode DC furnaces constructed by Xstrata Nickel for the Koniambo FeNi smelter in New Caledonia, were started up in 2013 and 2014.
## Summary of DC arc furnace smelting installations

<table>
<thead>
<tr>
<th>Process</th>
<th>Year</th>
<th>Furnaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>&gt; 80 DC furnaces, up to 175 MW</td>
<td></td>
</tr>
<tr>
<td>FeCr</td>
<td>10MW, 30MW, 60MW, 60MW, (4 x 72MW)</td>
<td></td>
</tr>
<tr>
<td>TiO2</td>
<td>25MW, 30MW, 35MW, 36MW, 36MW</td>
<td></td>
</tr>
<tr>
<td>Co</td>
<td>40MW</td>
<td></td>
</tr>
<tr>
<td>Stainless steel dust</td>
<td>32MW</td>
<td></td>
</tr>
<tr>
<td>Battery recycling</td>
<td>2.5MW</td>
<td></td>
</tr>
<tr>
<td>FeNi</td>
<td>12MW, (2 x 80MW)</td>
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</tbody>
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Conclusions

- DC arc furnaces – an interesting past, a productive present, and a promising future
- DC arc furnaces are not a panacea for all metallurgical problems, but are very well suited to a number of reductive smelting processes where they have been applied successfully in a number of industrial contexts, and many further applications are expected
Mintek’s DC furnaces

http://www.mintek.co.za/Pyromet/