

SMELTING APPLICATIONS OF DC ARC FURNACES

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ABSTRACT

Sustainable smelting requires technology that can process metallurgically complex, low-grade, fine ores, and waste materials, as well as the more desirable ores. Electric smelting in an open-arc open-bath direct current (DC) furnace provides the required flexibility for this type of processing. DC arc furnace technology was first used for smelting applications in the mid 1980s, and has subsequently been applied industrially to the smelting of chromite for the production of ferrochromium, the smelting of ilmenite to produce titania slag and pig iron, and the recovery of cobalt from non-ferrous smelter slags. Newer applications of this technology involve the smelting of nickel laterites to produce ferronickel, and the smelting of oxidised concentrates containing platinum group metals (PGMs).

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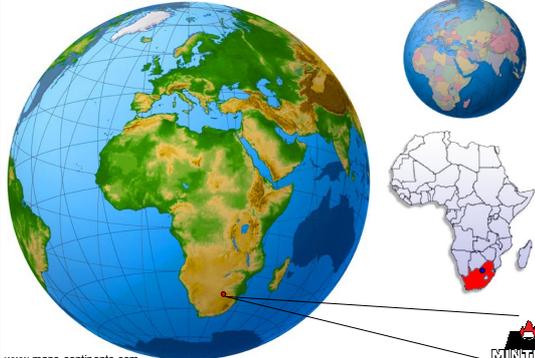
Smelting applications of DC arc furnaces



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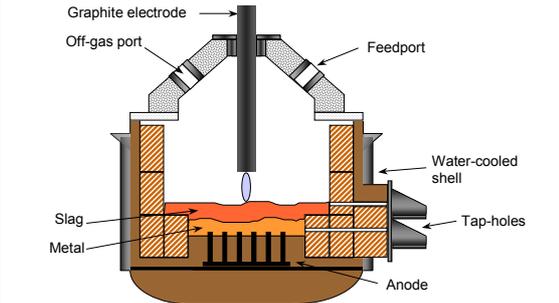
Mintek (Established 1934)

- Government-owned minerals research organization
- Employs ~775 people (300 professionals)
- Annual budget of ~R420m (US \$50m)
- State & corporate funding (30:70)





Schematic view of DC arc furnace



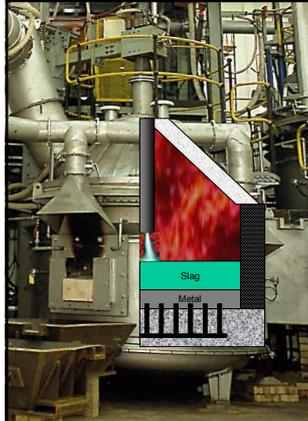

DC arc furnace

- 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



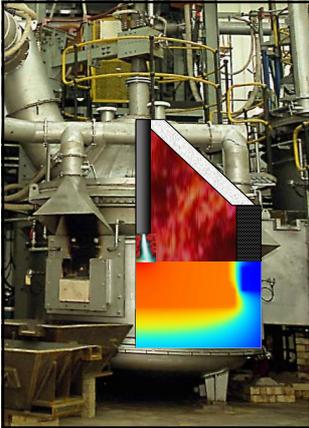

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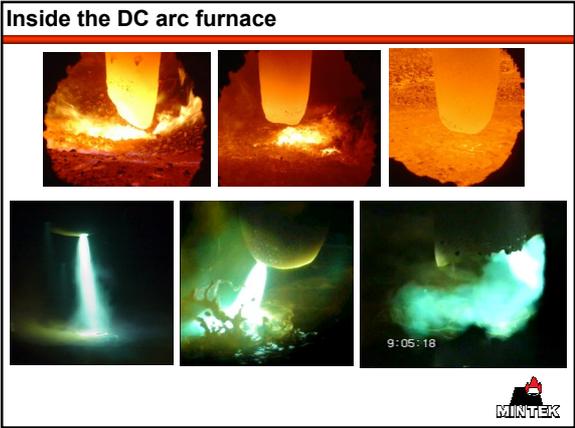



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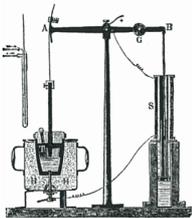



Inside the DC arc furnace




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





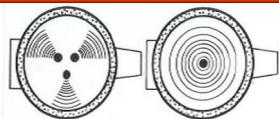
Simplified classification of smelting furnaces

T ↑ High >1500°C Low 1000-1500°C	Open arc (DC or AC)	Submerged arc
	Slag resistance Reverberatory Flash furnace	Blast furnace Cupola
	Fine 0.01 – 10mm	Coarse 10 – 200mm
	Ore size →	



Advantages of DC open-arc furnaces (vs AC)

- No arc repulsion and hot spots
- Lower electrode consumption
- Higher current per electrode (or smaller electrodes for the same current), because of AC 'skin effect'

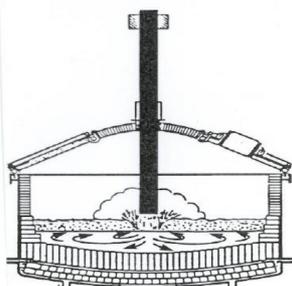


Mintek's initial work on 'plasma furnaces'

- Peter Jochens identified 'plasma furnaces' as a possible solution to the 'chromite fines' problem
- Mintek and Middleberg Steel & Alloys (now part of Samancor Chrome) conducted smelting trials on Tetronic's pilot transferred-arc plasma furnaces in 1979/80
- Successful metallurgy, 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
- 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



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



- However, another four 72MW furnaces are under construction in Kazakhstan



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. Ilmenite smelting (Namakwa Sands)

- 25MW DC furnace at Namakwa Sands in 1994
- 35MW DC furnace followed in 1998



2. Ilmenite smelting (Ticor and CYMG)

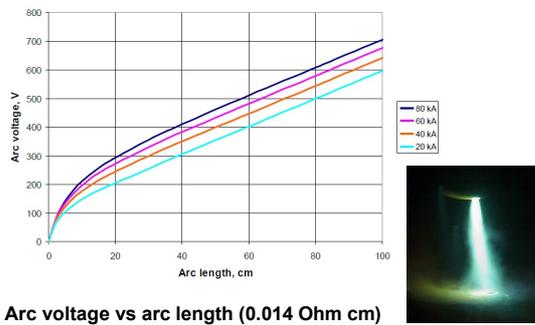
- Two further 36MW DC furnaces at Ticor near Empangeni were commissioned in 2003



- A 30MW furnace was commissioned for CYMG in China in 2009



2. Ilmenite smelting (arc fundamentals)

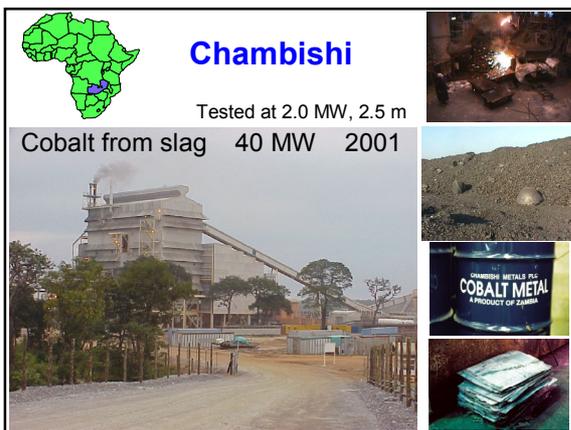


Arc voltage vs arc length (0.014 Ohm cm)



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)



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

- 12MW furnace in Southern Urals, Orsk, Russia commissioned in 2011



6. Nickel laterite smelting

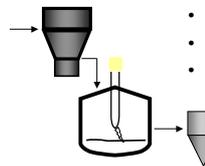
- Two 80MW twin-electrode DC furnaces constructed by Xstrata Nickel for the Koniambo FeNi smelter in New Caledonia, to be commissioned in 2012



7. ConRoast



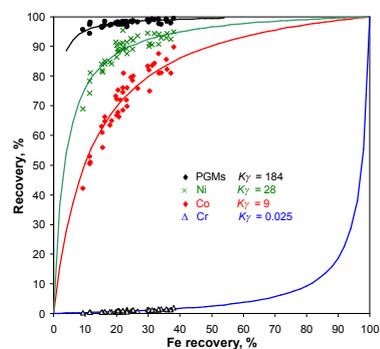
- The ConRoast process treats sulfide concentrates by roasting followed by reductive smelting in a DC arc furnace, where an iron-based alloy is used to collect the valuable metals
- This addresses the three big challenges in PGM smelting today:
 - The sulfur problem
 - The chromium problem
 - The containment problem
- A 5MW furnace has been announced, but not yet built



ConRoast demonstration smelting of 50 000 tons



K_γ Recovery model for PGM smelting



$$R_{Co} = \frac{K_{\gamma} \cdot R_{Fe}}{1 - (1 - K_{\gamma})R_{Fe}}$$

- K_γ recovery equation for NiO, CoO, and CrO
- PGM behaviour can be modelled this way too (empirically)



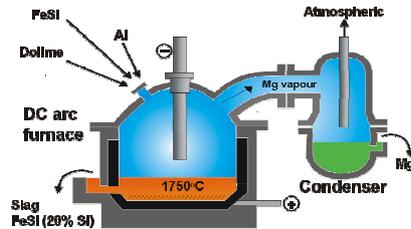
8. Lead blast furnace slag

- 2 t/h pilot plant, including a zinc condenser, was commissioned in 1994
- Piloted at Mintek from 1994 to 1998
- Recover 98% Zn metal via fuming & condensation
- Distillation to 99.5% Zn purity also developed

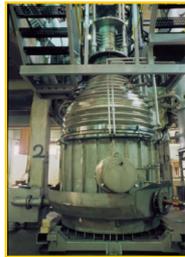


9. Mintek Thermal Magnesium Process

- Thermal production of magnesium vapour is done elsewhere under vacuum
- Problem to be solved:
 - Change slag composition to allow process to run under atmospheric pressure
 - Condensation of magnesium vapour



9. Mintek Thermal Magnesium Process



Conclusions

- DC arc furnaces have some wonderful features.
- Good at accommodating finely sized feed materials (because of the open bath)
- Do not require coke or char (no burden porosity required)
- Can treat feed materials with a wide range of composition (because of extra degree of freedom coming from power being supplied by an open arc); this allows choice of chemistry for metallurgical benefit
- Geometrically simple and elegant, reducing uneven wear on side-walls, and lower cost
- However, thermal efficiency is decreased by hot off-gas
- Absence of burden does not allow for capture of volatile species
- Well suited to reductive smelting (FeCr, TiO₂, FeNi), but less so in the case of processes involving a gaseous intermediate such as SiO, or those with a low-melting (super-heated) product



Conclusions ...

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.



DC furnace installations

- **Steel:** > 80 DC furnaces, up to 120 MW or more
- **FeCr (1985):** 10MW, 30MW, 44MW, 60MW, (4 x 72MW)
- **TiO₂ (1994):** 25MW, 30MW, 35MW, 36MW, 36MW
- **Co (2001):** 40MW
- **Batteries (2008):** 2.5MW
- **Stainless steel dust:** 32MW
- **FeNi (2011):** 12MW, (2 x 80MW)
- **PGM (2012):** (5MW)

