Electric Smelting in Southern Africa

Rodney Jones

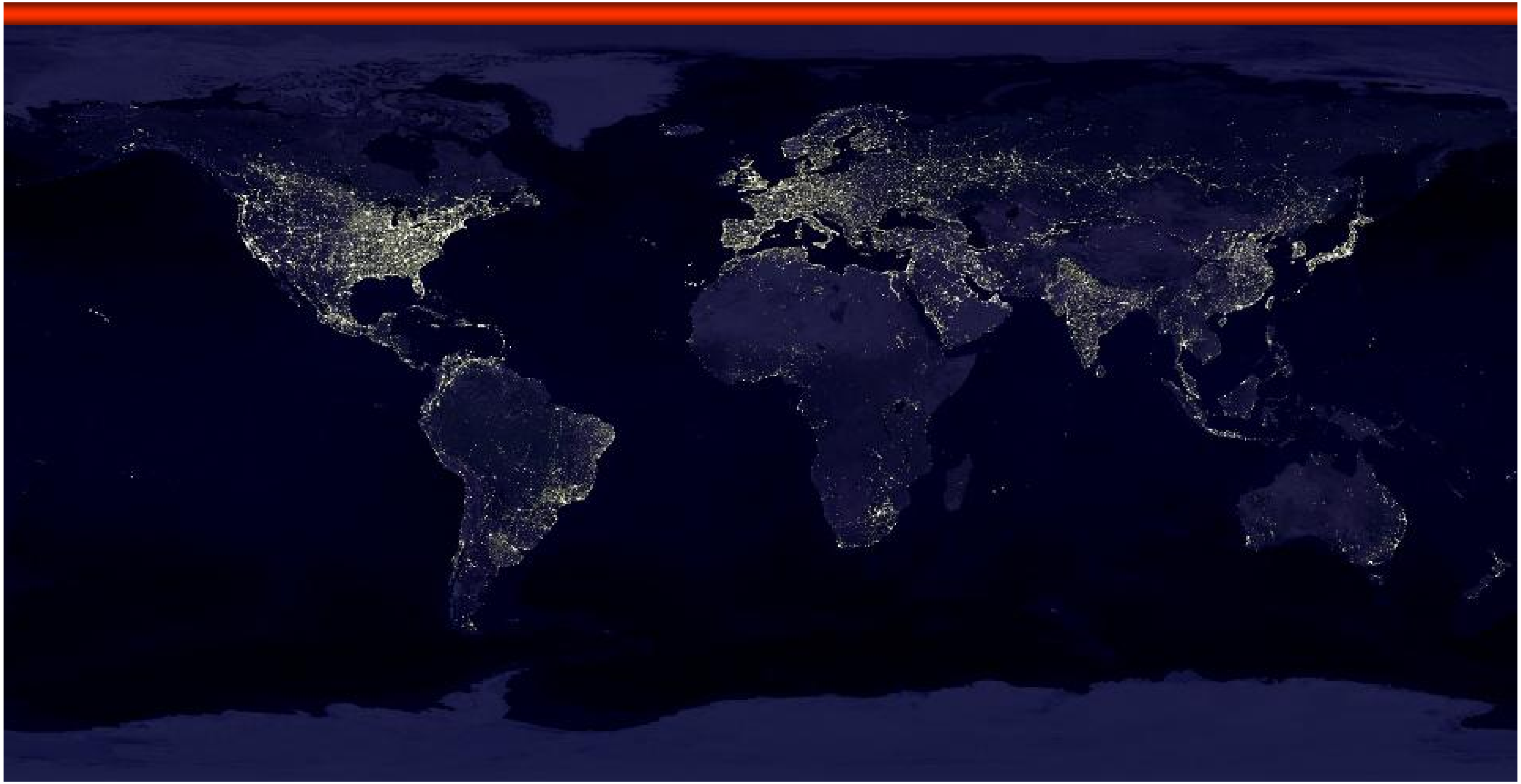
MINTEK

Mintek, Randburg, Johannesburg, South Africa

www.maps-continents.com

MINTEK

Some light on a dark continent



NASA’s composite image of the earth at night

1.6 billion people, 25% of humanity, remain in the dark

MINTEK

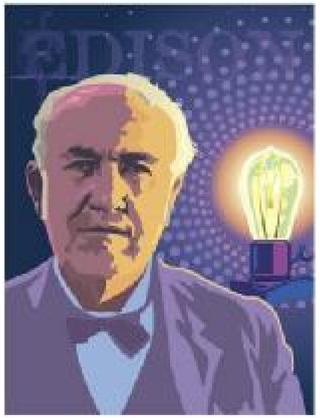
Smelting

- Smelting is the metallurgical process of extracting metals from their ores by heating to extreme temperatures
- Chemical reactions are often accompanied by melting or fusion of the products
- Smelting implies chemical reactions, not just ‘melting the metal out of its ore’
- Smelting is very old. Copper has been produced this way since 6000 – 5000 BC.
- Electric smelting is much newer: just over 100 years old

MINTEK

Electricity

- “Electricity is really just organized lightning” – George Carlin
- “We will make electricity so cheap that only the rich will burn candles” – Thomas Alva Edison



- “If it weren't for electricity we'd all be watching television by candlelight” – George Gobal

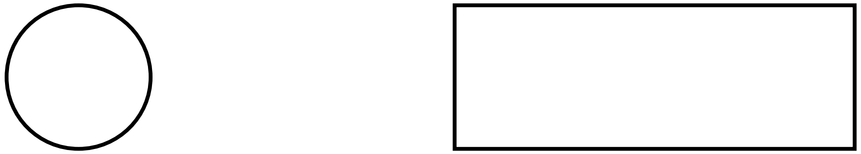
Why electric smelting?

- High temperatures > 1400 or 1500°C
- Low volumes of gas
- Does not contaminate slag with ash

Taxonomy of electric furnaces

- Shape
- Type of power
- Number of electrodes
- Type of electrodes
- Arc and bath
- Open or closed
- Feeding arrangement

Taxonomy 1: Furnace shape

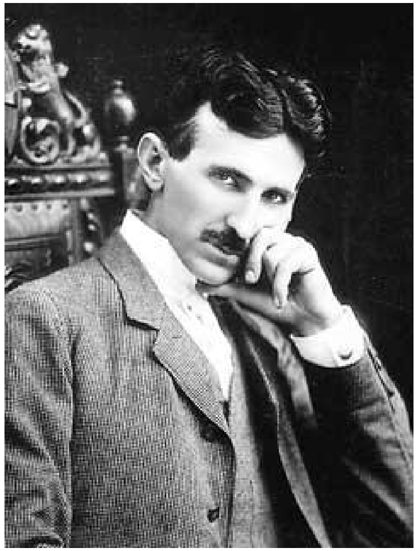


- Circular or rectangular cross-section
- Circular shape minimizes surface area per volume
- Rectangular shape has ‘dead zones’ in corners, but binding systems easier to make

Taxonomy 2: Type of power – DC or AC

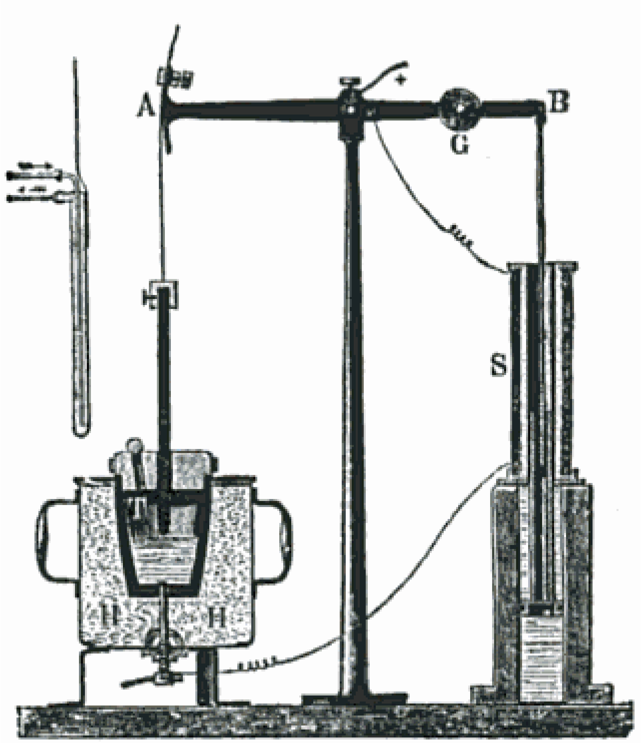
DC AC

- DC arc furnaces were developed in 1878, and AC furnaces in 1906
- AC power became more popular because of greater efficiency of AC distribution networks
- 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



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

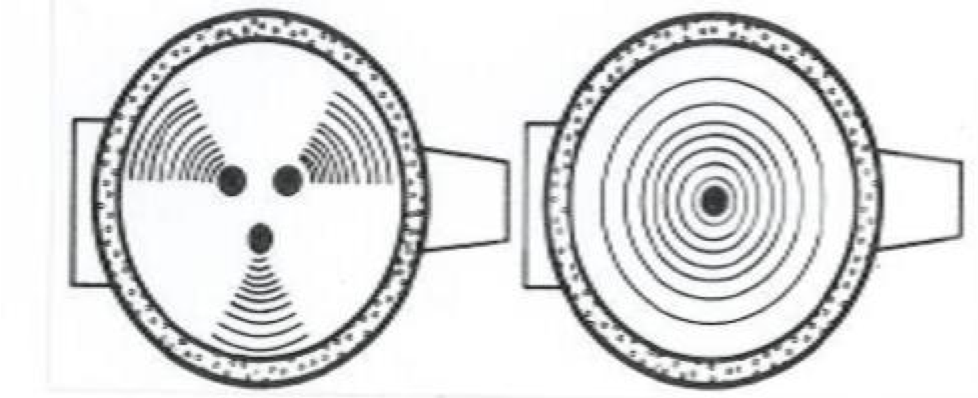


AC furnaces date back to 1900

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

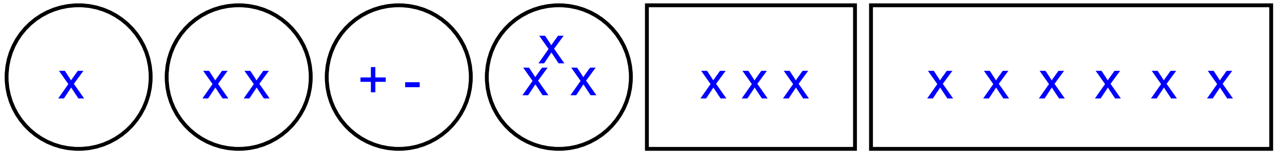
First AC electric arc furnace in USA, 1906 (Philadelphia)

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’

Taxonomy 3: Number of electrodes



- AC power has three phases, therefore requires 3 or 6 electrodes (3 pairs)
- DC furnaces use 1 electrode usually (easy to maintain and control), and 2 for very high power
- ‘Twin electrodes’ implies 2 cathode electrodes
- ‘Dual electrodes’ implies 1 cathode and 1 anode
- DC furnaces could conceivably use three electrodes for extremely high power

Taxonomy 4: Type of electrodes

Graphite Søderberg

- Søderberg self-baking electrodes use inexpensive electrode paste, but can be difficult to bake
- Graphite electrodes are simple to manage

Taxonomy 5: Arc and bath

Matyas *et al.*

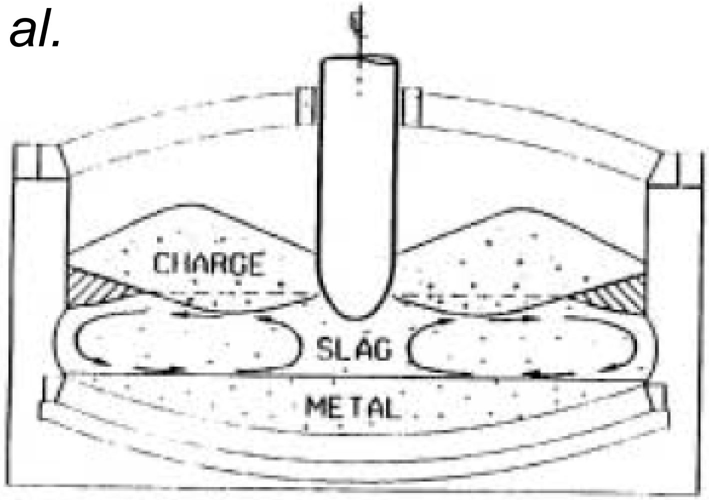


FIG. 1(a) IMMERSED ELECTRODE SMELTING

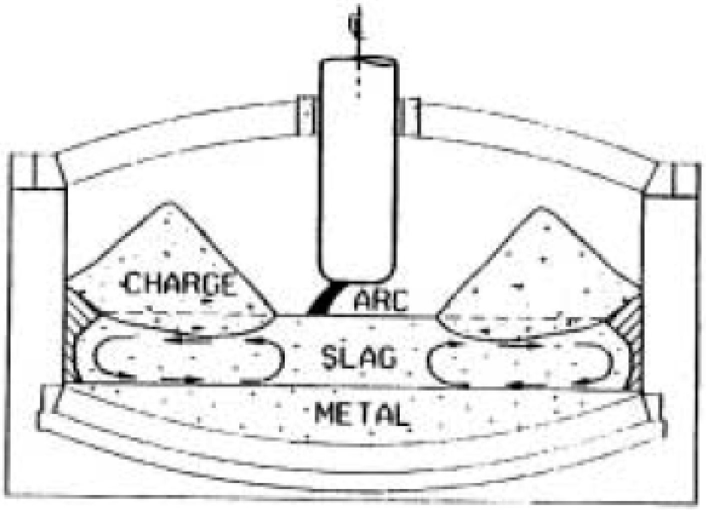


FIG. 1(b) OPEN-ARC SMELTING

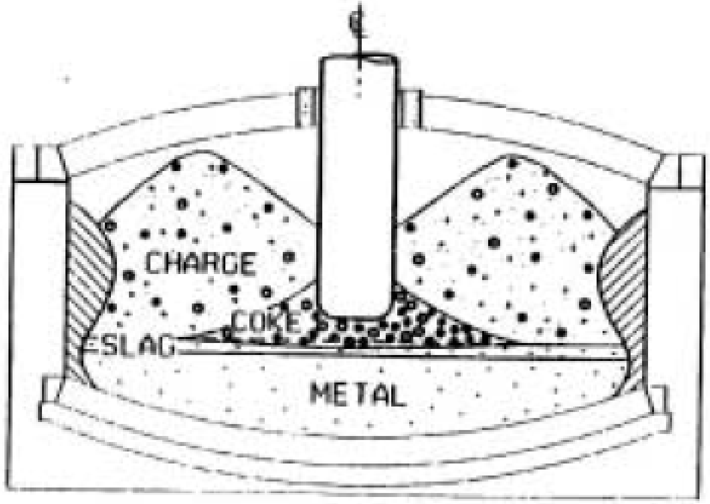


FIG. 1(c) SUBMERGED ARC SMELTING

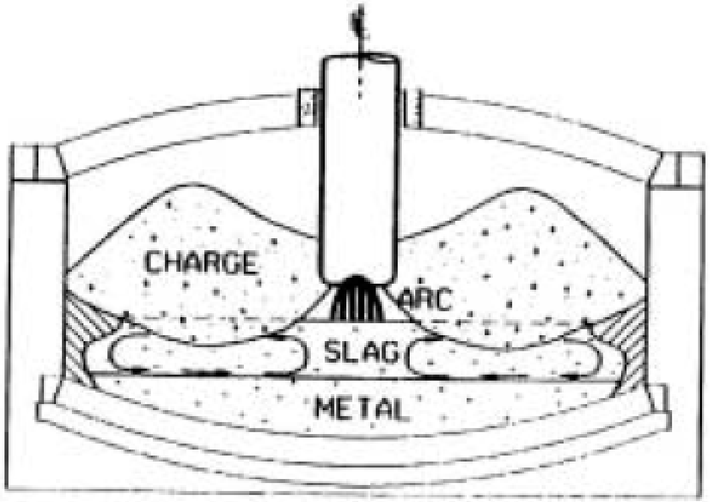
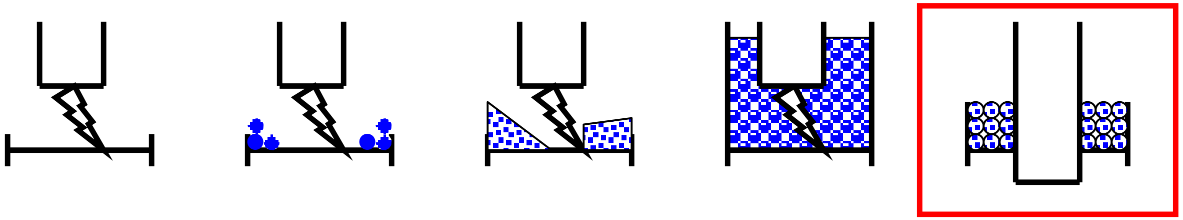
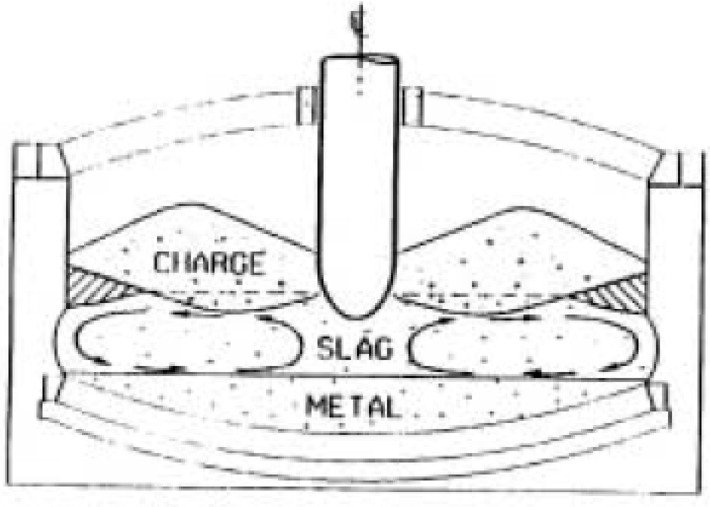


FIG. 1(d) SHIELDED-ARC SMELTING

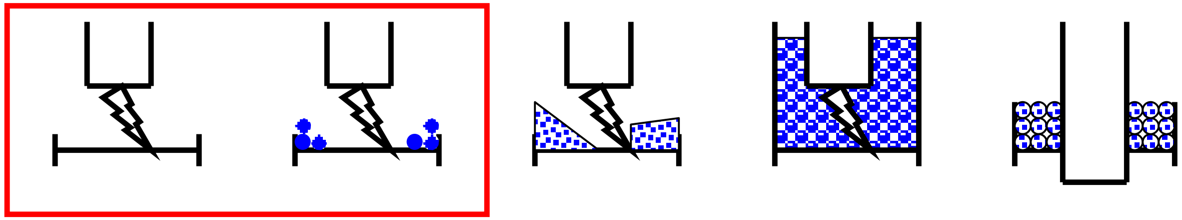
Immersed-electrode smelting



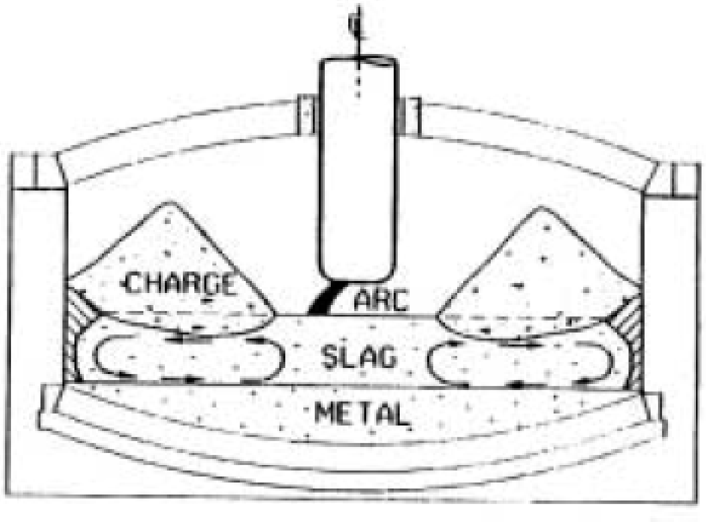
- Electrode tips are dipped in the molten slag
- Used in matte smelting and nickel laterite smelting
- Requires an electrically resistive slag to generate enough energy by resistive (joule) heating
- Superheated slag near electrode tips is convected outward under the floating banks of feed material



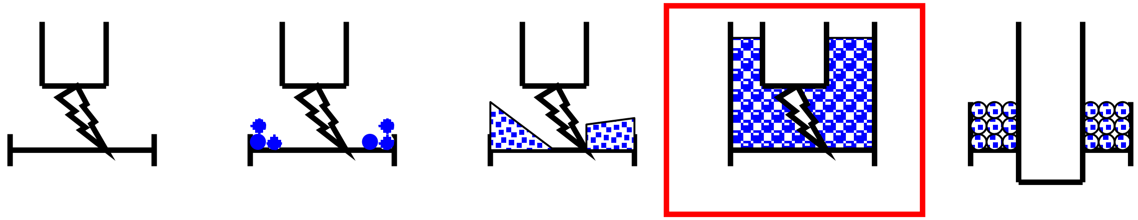
Open-arc open-bath smelting



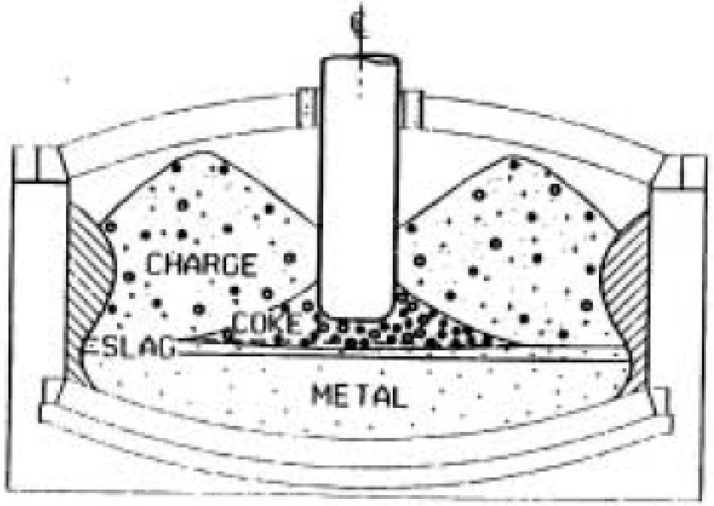
- A large fraction of energy is dissipated in the arc
- Extra degree of freedom in power control
- Able to accommodate fine feed
- Useful for highly conductive slags (and others)
- Open molten slag bath radiates significant energy to the roof and side-walls
- The open bath can be partially covered by feed material



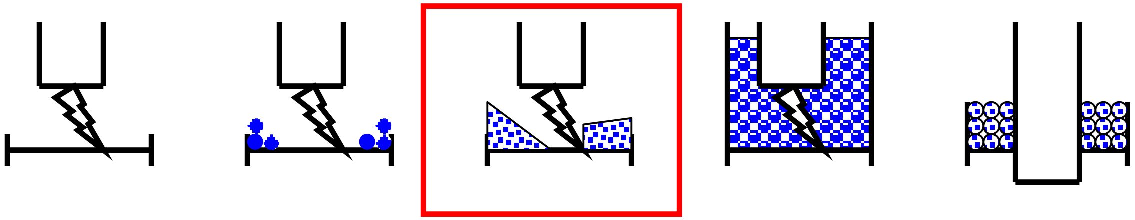
Submerged-arc smelting



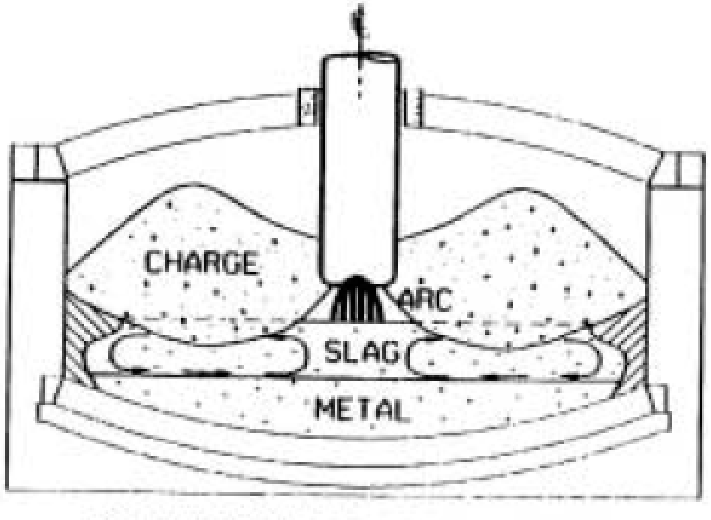
- Gas percolates through charge
  - Charge is heated
  - Gas is cooled
- Requires lumpy feed for gas permeability, and coke for structural strength



Shielded-arc smelting



- Developed by Falconbridge (now Xstrata Nickel) in the 1960s
- Longer arcs have higher voltage, and require lower current
- Surrounding feed material absorbs energy from arc

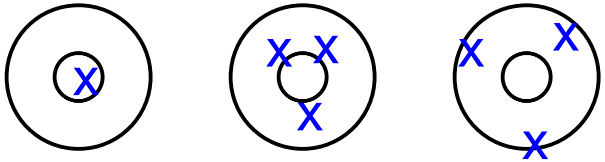


Taxonomy 6: Open or closed

Closed Open

- Some older furnaces are open at the top
  - Easy to construct
  - Easy to feed
- Newer furnaces are closed
  - Environmentally cleaner
  - More energy efficient

Taxonomy 7: Feeding arrangement



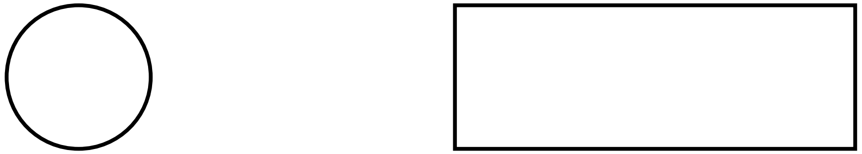
- Early DC arc furnaces were fed through a hollow electrode
- Feeding can be done close to the arc-attachment zone
- Formation of banks can be promoted by feeding near to the furnace walls

Taxonomy 8: Other

- Roof design
- Hearth design
- Tap-hole design
- Cooling systems (fingers, plates, waffles)
- Off-gas handling
- *etc.*

Taxonomy of electric furnaces

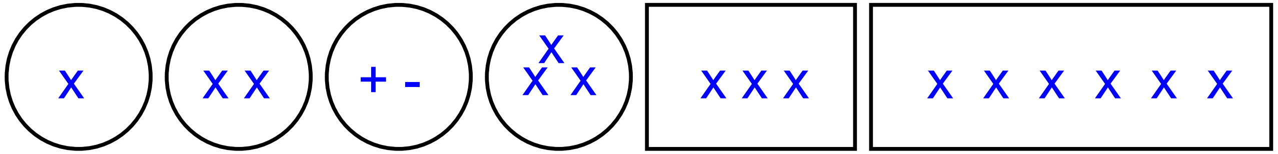
- Shape



- Type of power

DC AC

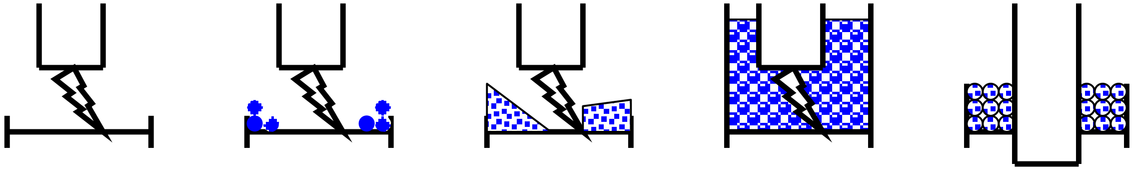
- No. of electrodes



- Type of electrodes

Graphite Søderberg

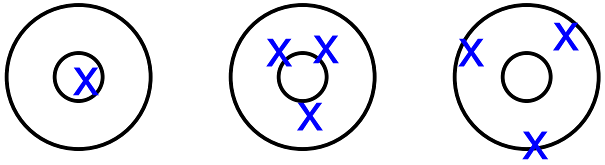
- Arc and bath



- Open or closed

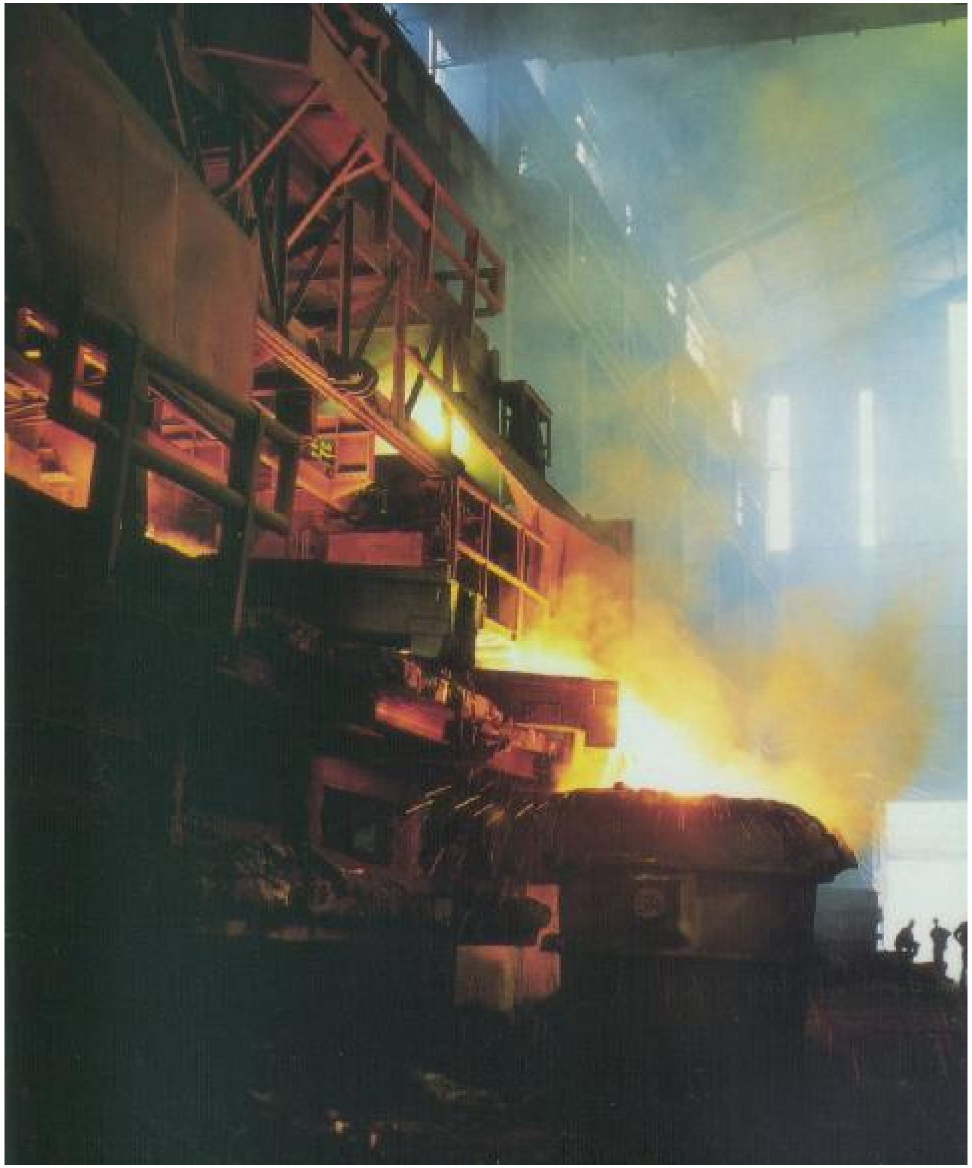
Closed Open

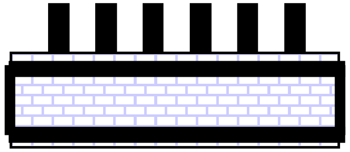
- Feeding arrangement



MINTEK

Example 1: Six-in-line furnace for PGM smelting

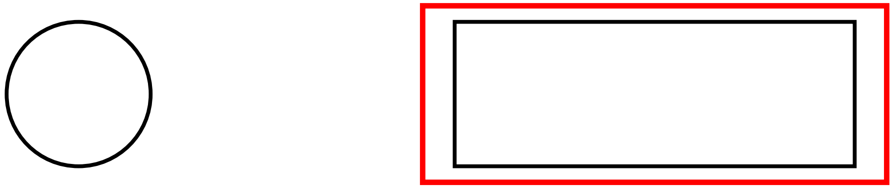




- Six-in-line furnace used for PGM smelting since 1969
- First furnace was 19.5 MVA, and was 27m long, 8m wide, and 6m high

Example 1: Six-in-line furnace for PGM smelting

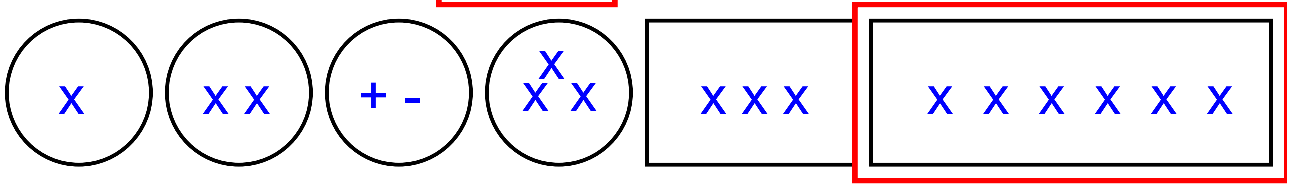
- Shape



- Type of power

DC AC

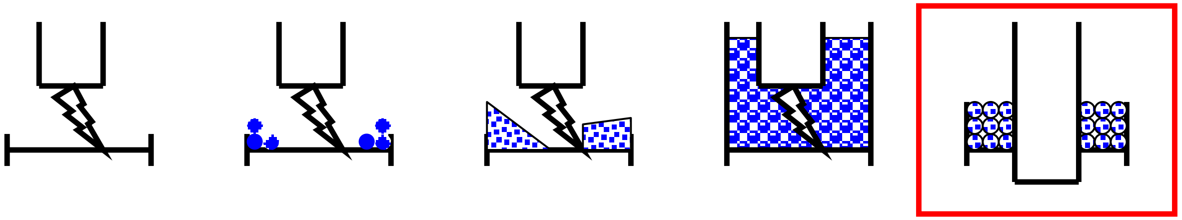
- No. of electrodes



- Type of electrodes

Graphite Søderberg

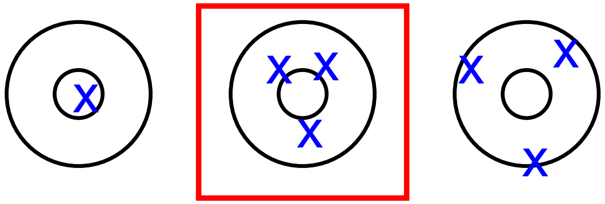
- Arc and bath



- Open or closed

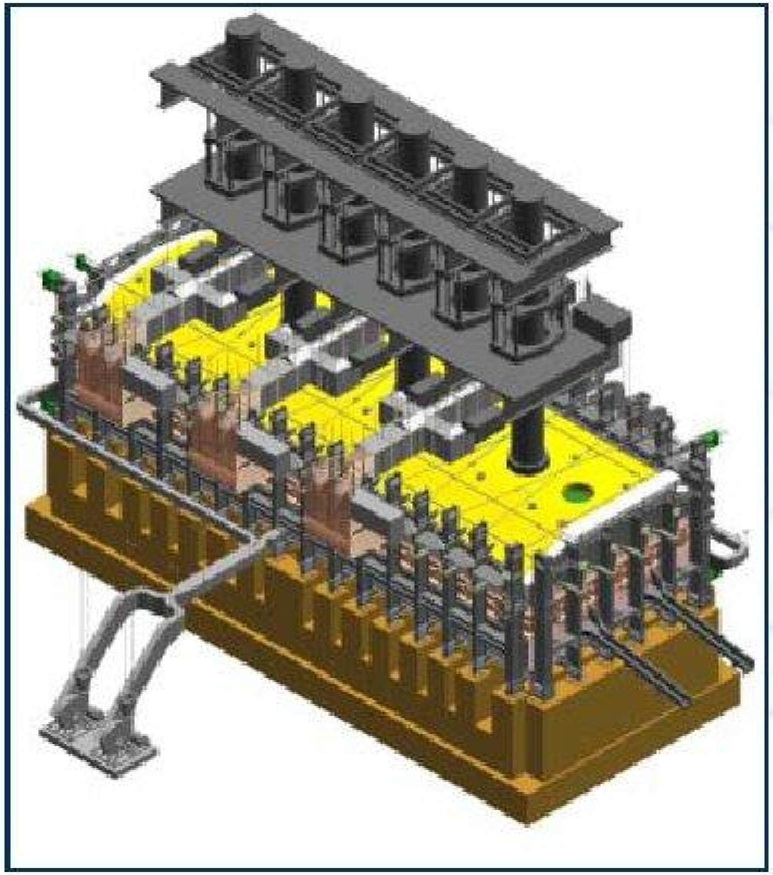
Closed Open

- Feeding arrangement



MINTEK

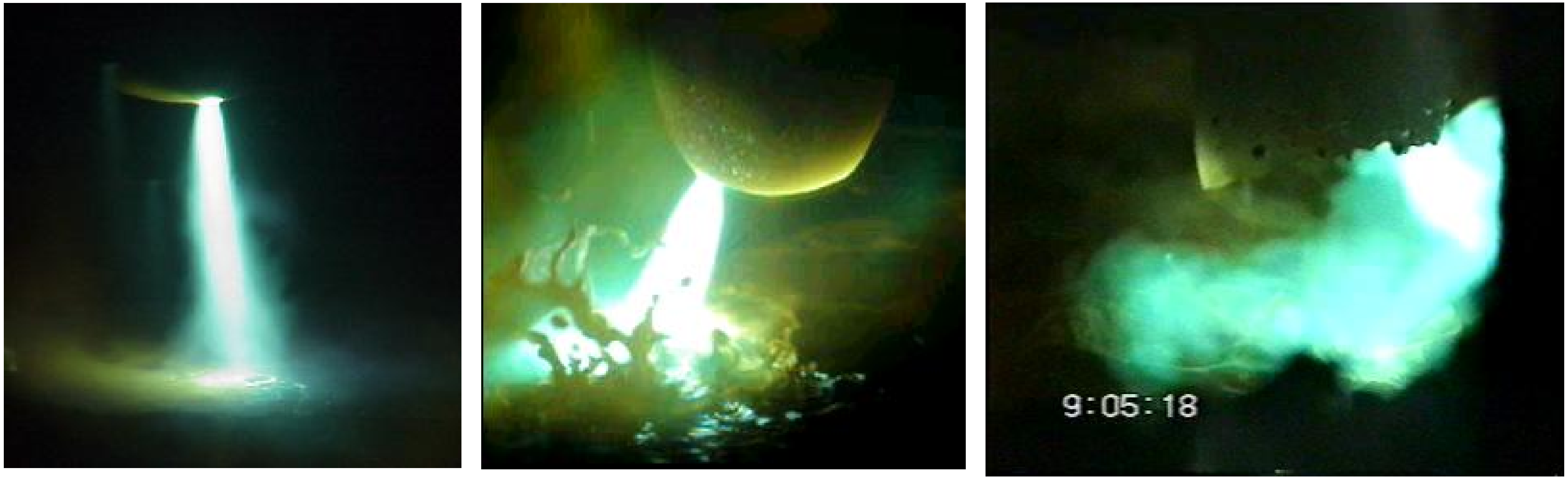
Anglo American Platinum – Polokwane furnace



- Capacity :
  - 650,000 t/a (87 tph)
- Power :
  - 68 MW (168MVA)
- Power density :
  - 250 kW/m^2
- Matte temperature :
  - 1,550^{O}C
- Slag temperature :
  - 1,600^{O}C

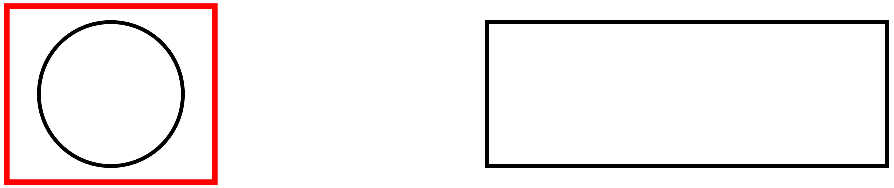
Example 2: DC arc furnace for chromite fines

- Circular DC furnace with one graphite electrode, running in open-arc open-bath mode in a closed vessel with feed distributed around the electrode



Example 2: DC arc furnace for chromite fines

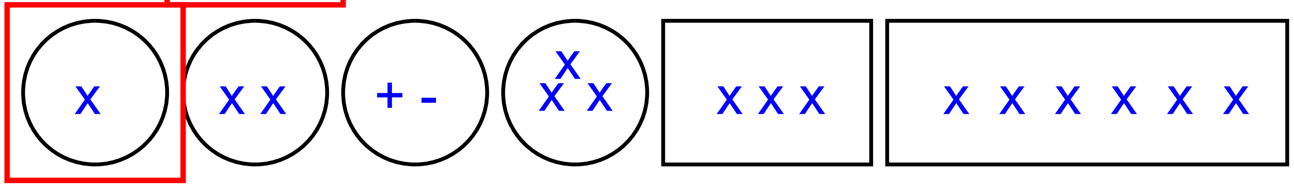
- Shape



- Type of power

DC AC

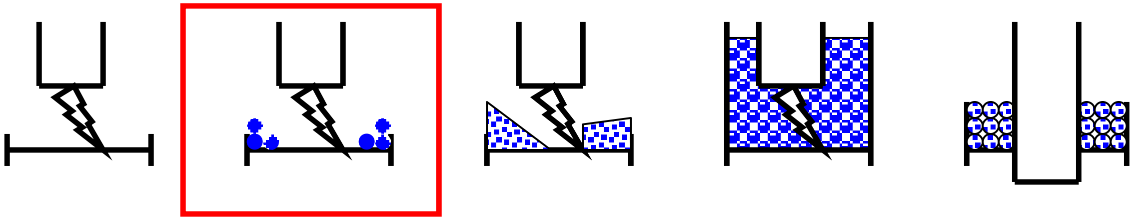
- No. of electrodes



- Type of electrodes

Graphite Søderberg

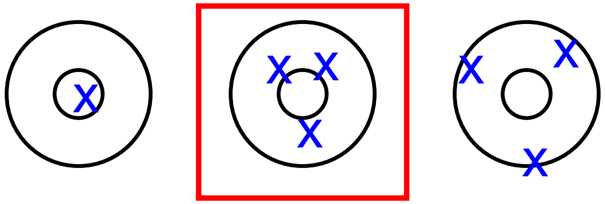
- Arc and bath



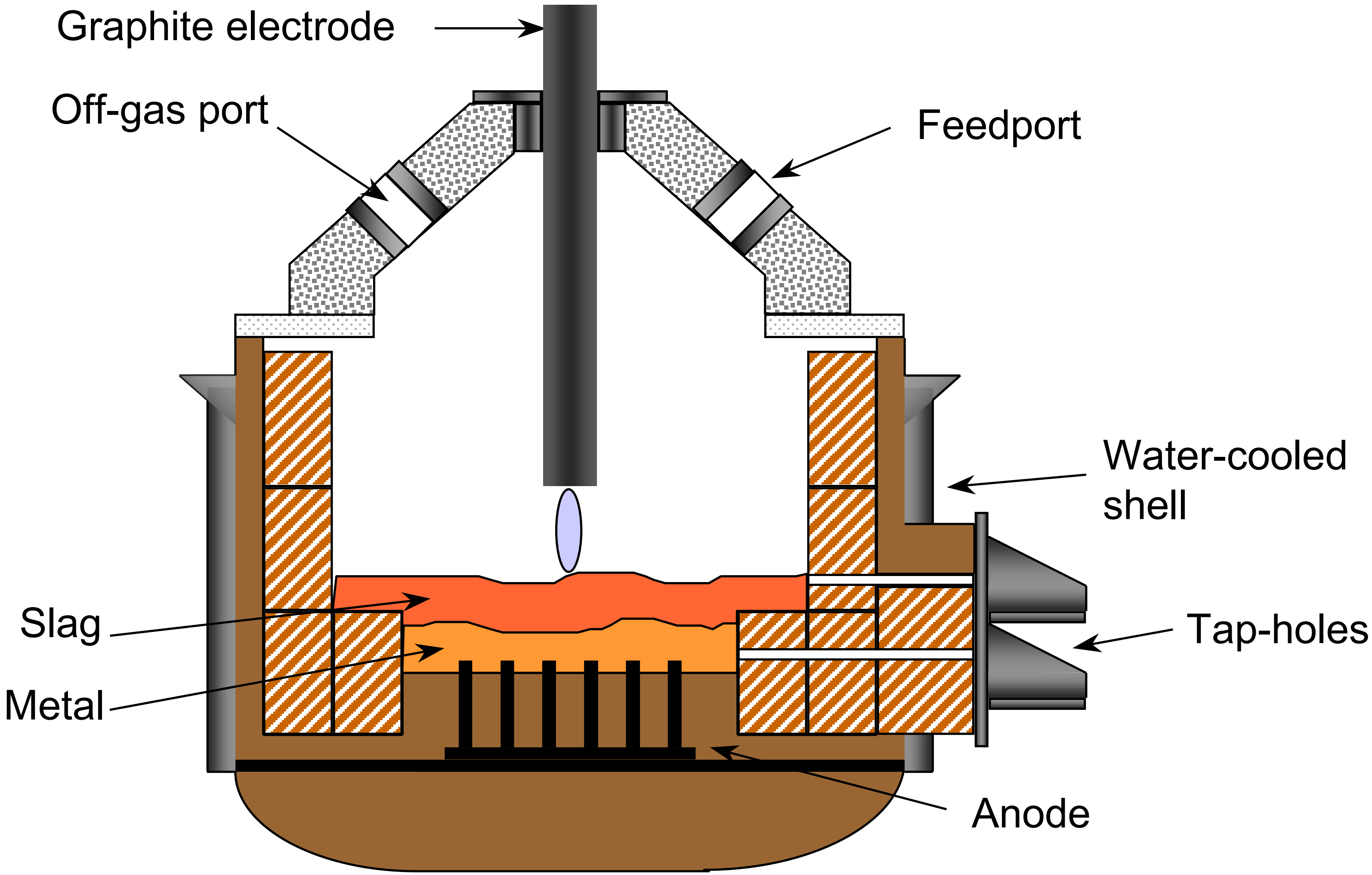
- Open or closed

Closed Open

- Feeding arrangement



Schematic view of DC arc furnace



Example 2: DC arc furnace for chromite fines

- 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
  - 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

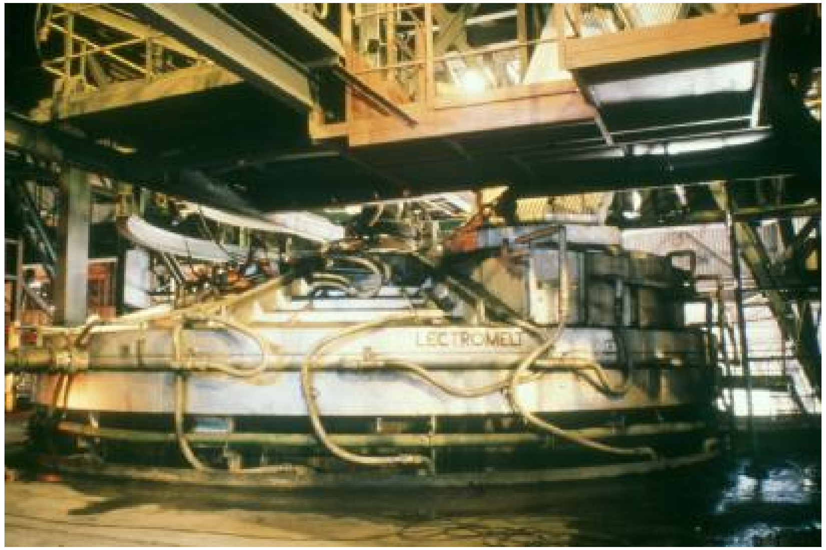
MINTEK

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

MINTEK

Chromite smelting (Palmiet Ferrochrome)

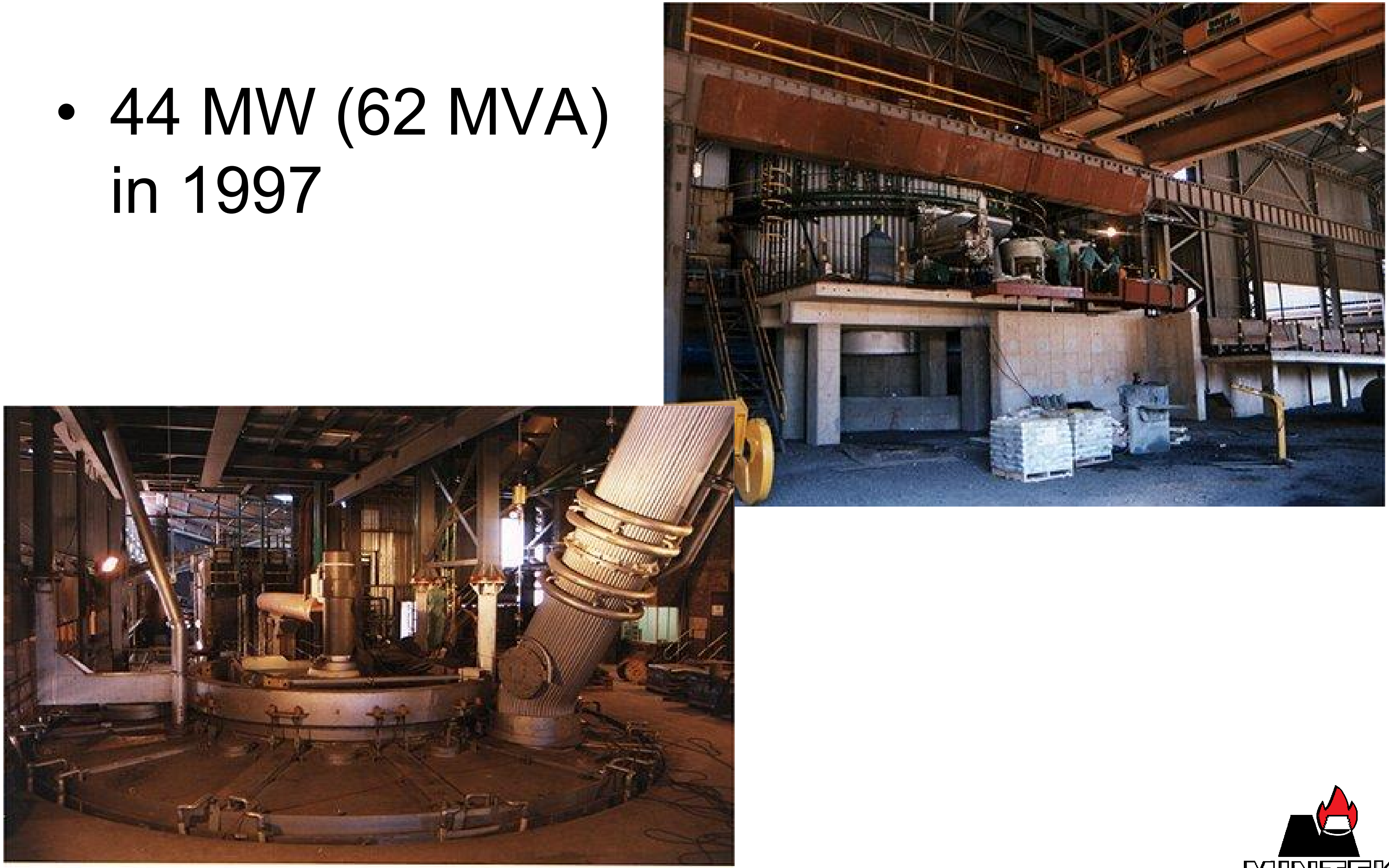


- Tested at 0.3 - 0.5 MW, 1 – 2 m
- A 12MW (16MVA) furnace was built initially in 1984, then upgraded to 40 MVA (25 - 30 MW) in 1988

- An additional 10MW furnace was later built on the same site (for Mogale Alloys)

Chromite smelting (Samancor Cr, Middelburg)

- 44 MW (62 MVA) in 1997



Chromite smelting (largest furnaces)

- Samancor Chrome's 60 MW furnace, built in Middelburg in 2009, is currently the largest DC arc furnace for FeCr production

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

Example 3: DC arc furnace for ilmenite smelting

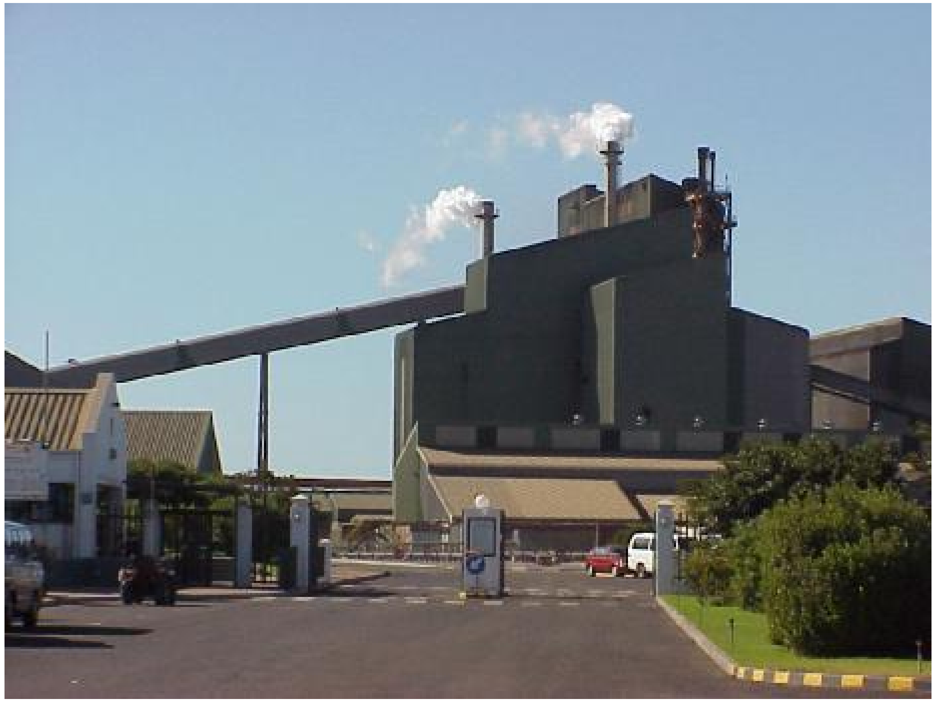
- Same DC arc furnace equipment can be used for very different reasons
- Titania slag is highly conductive, therefore an open arc is required
- Slag is a valuable product; contamination must be avoided
- Degree of reduction must be carefully controlled, therefore no electrode immersion

Ilmenite smelting (Mintek)

- 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)

Ilmenite smelting (Namakwa Sands)

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



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

MINTEK

South Africa & Electric smelting

South Africa & Electric smelting

- South Africa has a plentiful coal supply
- Many large coal-fired power stations built from 1960s to 1980s. Reserve margin of 55%. Power was cheap.
- Need to beneficiate minerals
- South Africa has ~40 GW of power generating capacity
- Mining industry uses ~15% of the country's electricity (~6 GW), with over 4 GW smelting capacity
  - 2 GW Ferro-alloys furnaces
  - 0.4 GW TiO_2 furnaces
  - 0.3 GW PGM furnaces
  - 1.5 GW Aluminium 'smelters'

Power to the people – a major success

- Democratic government came into power in 1994
- In 1994, only 36% of SA households had access to electricity
- By 2011, 83% of SA households had access to electricity

Power shortage in South Africa – a major failure

- Government wanted regional electricity distribution in addition to Eskom
- Electricity price was too low so no incentive to invest in power stations (which take a long time to build)
- Insufficient capital investment
- Electricity demand grew faster than supply
- Load-shedding crisis in 2008
- Electricity price has tripled in past six years (25% increase each year)

MINTEK

New power stations

- New power stations are now being built by Eskom
- The new Medupi and Kusile coal-fired power stations will total 9.6 GW – first base-load power plant to be built in SA in twenty years
- New Medupi power station (4.8 GW) should be operational in ~2014, ramping up to full power by 2016, at a cost of R100 billion (about € 7.5 billion)
- Kusile should follow about a year later

Medupi power station (4.8 GW)

FeCr industry constrained by lack of power

- Lack of power capacity is a major factor that prevented South Africa from benefiting from the minerals boom of the past decade (driven primarily by the urbanization of China)
- Many ferro-alloy smelters are currently shut, and some are paid by Eskom to not use electricity to make it available to others
- Much South African chromite ore is now being sold to China (to make FeCr for stainless steel)
- News reports said that China overtook South Africa as the world’s leading FeCr producer in 2012

Conclusions

- Electric smelting continues to have a large part to play in the South African economy
- Challenges remain with regard to the supply of electricity over the next few years
- Electricity prices are increasing rapidly, and smelting processes will have to increase their energy efficiencies

Mintek's DC furnaces

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