Overview of pyrometallurgical research on PGMs at Mintek: from conceptualisation to demonstration

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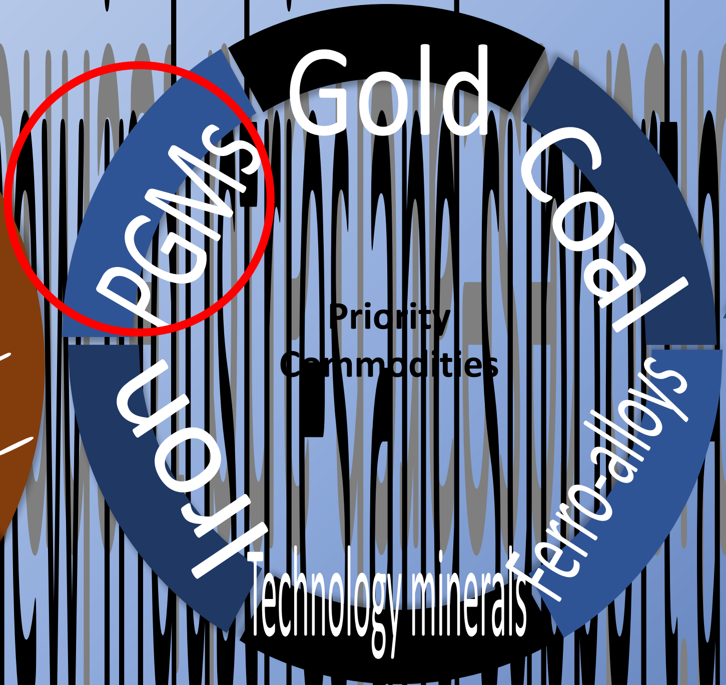

Gold
Coal
Ferro-alloys
Technology minerals
Iron
PGMs
Priority Commodities


Industry 4.0

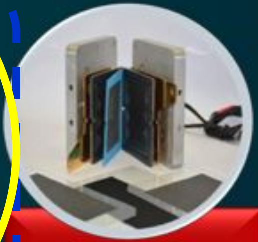
Introduction | About Mintek

Mineralogical & Analytical Testing

Small Scale Mining & Urban Mining

Mineral Processing (Concentration)

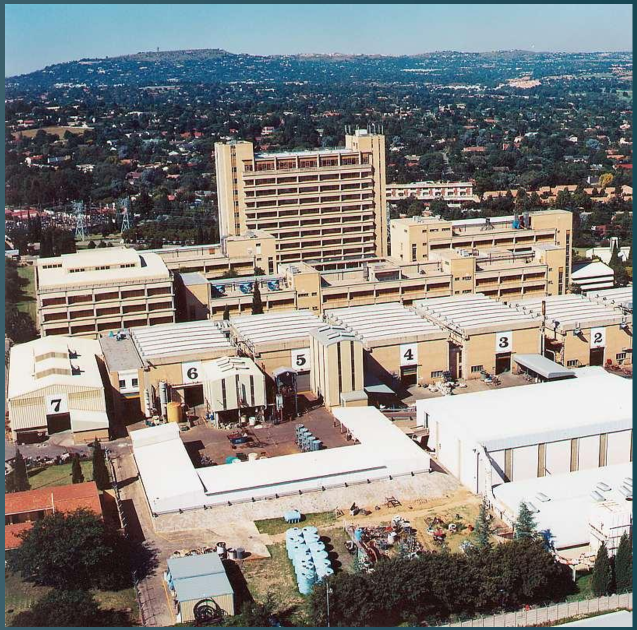
Pyrometallurgy



Digital Platform

Value Addition / Manufacturing

Post Mining Landscape



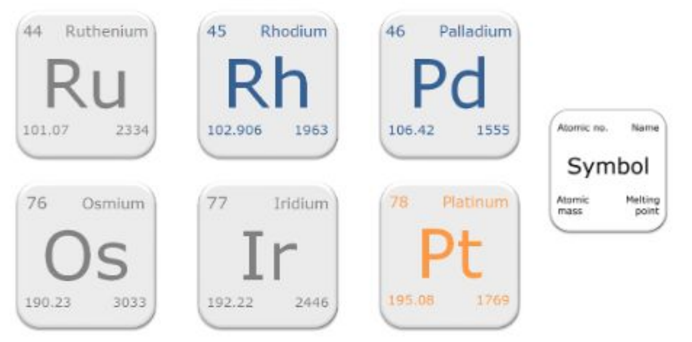
Hydrometallurgy

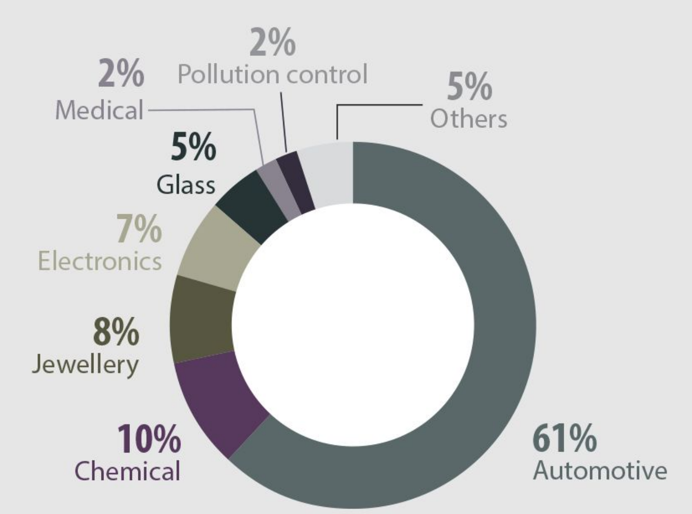
Biometallurgy

Introduction

- **Platinum Group Metals (PGMs) – critical metals in SA Critical Minerals strategy**

  - PGMs = group of six elements: Platinum (Pt), Palladium (Pd), Rhodium (Rh), Ruthenium (Ru), Iridium (Ir), and Osmium (Os)
  - Good physical and chemical properties: high resistance to corrosion, high melting point and excellent catalytic properties
  - Critical application (automotive): autocatalysis and pollution control in the automotive sector
  - The demand for PGMs is projected to be sustained, and even increase steadily, long into the future

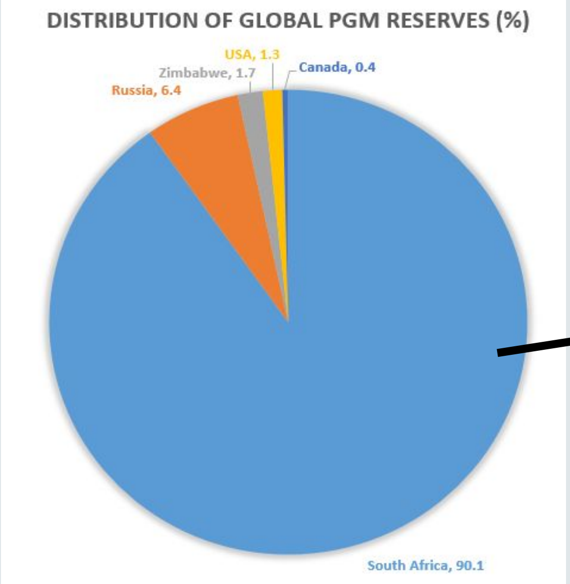




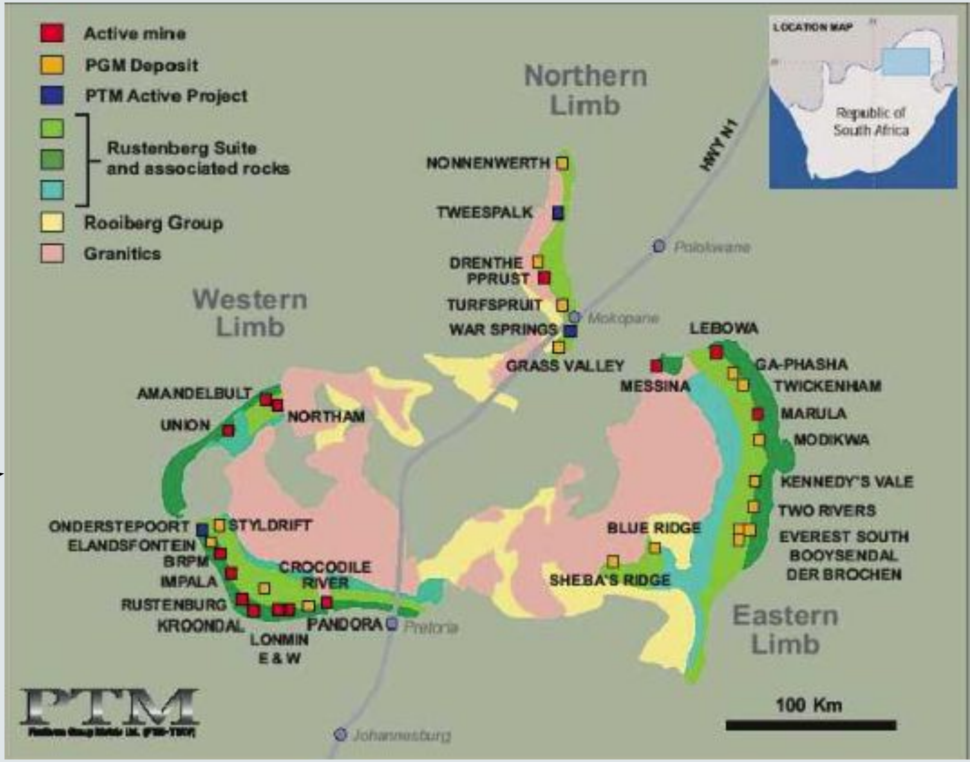
- **Global PGM reserves**

- Global reserves of PGMs are estimated to be about 70 000 – 81 000 tonnes (2023)

- Major reserves:



- In SA, PGMs are found in the Bushveld Complex (BC):



Geology of PGMs in South Africa

- PGMs mainly are found in the western, eastern and northern limbs of the BC

- PGMs occur in sulfides, tellurides, arsenides and metalloids: $PtAs_2$, PtS, $Pt(AsS)_2$, (Pt, Pd)S, (Pt, Pd, Ni)S, RuS_2 and Pd_3Sb and elemental ruthenium – valuable minerals

- PGMs, Au and base metals (BMs) typically occur in the same mineral deposits in the BC

- Mainly mined from three reefs:
  1. Merensky reef – historical and current source, high contenst PGMs, base metals (BMs), and S
  2. Platreef – lower PGM content, but high BM and S contents
  3. Upper Group 2 (UG2) reef – chromite-rich reef, higher PGMs' contents, lower BMs and S contents

Valuable minerals	
Chalcopyrite	$CuFeS_2$
Pentlandite	$(Fe, Ni, Co)_9S_8$
Pyrite	FeS_2
Pyrrhotite	$Fe_{1-x}S_x$
Gangue minerals	
Chromite spinel	$FeCr_2O_4$
Pyroxenes	$(Mg, Fe)SiO_3$ – $Ca(Mg, Fe)Si_2O_6$
Olivine	$(Mg, Fe)_2SiO_4$
Plagioclase/feldspar	$NaAlSi_3O_8$ – $CaAl_2Si_2O_8$
Quartz	SiO_2
Haematite	Fe_2O_3

- **Major SA operators and conventional process flowsheet**

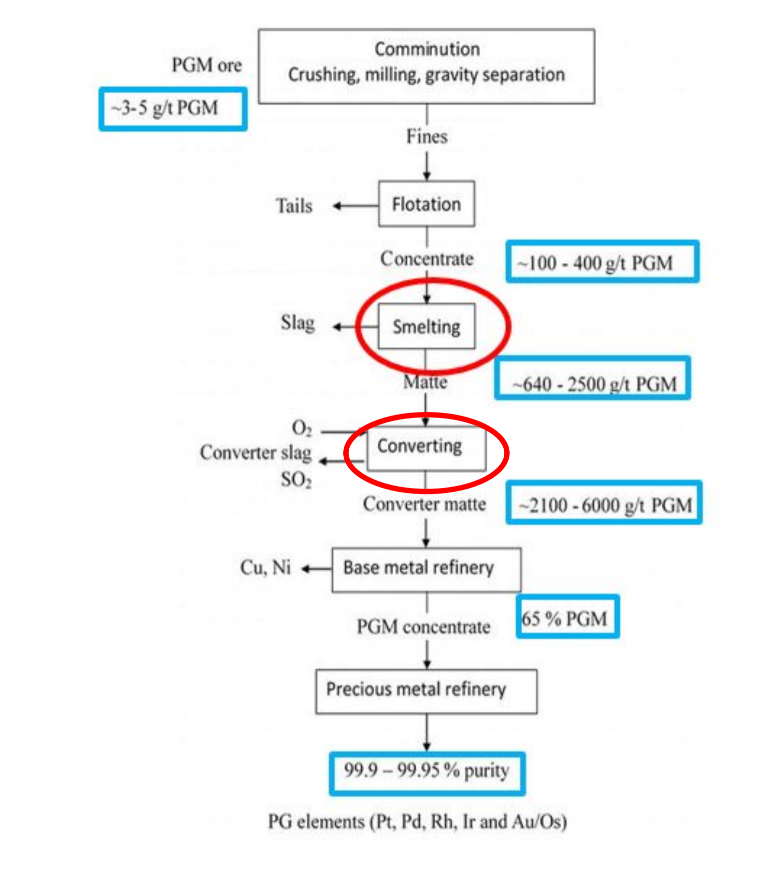
 Four integrated primary PGM producers in SA:

1. Valterra Platinum
(formerly AngloAmerican Platinum)

2. Sibanye-Stillwater
(formerly Lonmin/ Western Platinum)

3. Impala Platinum, and

4. Northam Platinum



Typical process flowsheet used in SA

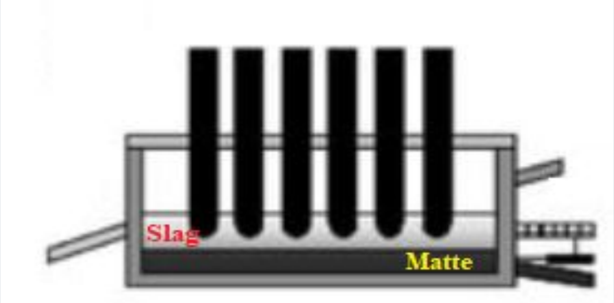
Introduction

- **Smelting**

Typical compositions of concentrates: Feed Mer or Mer: UG2

	Al_2O_3	CaO	Cr_2O_3	Cu	FeO	MgO	Ni	S	SiO_2	PGM (g/t)
Merensky	1.6	2.2	**0.3**	2.1	22.3	18.2	3.2	**9.0**	41.4	**100 – 600**
UG2	5.0	2.4	**2.9**	0.8	12.6	21.0	1.7	**3.6**	44.0	**100 – 600**

- Conventionally, PGM concentrate smelting in rectangular six-in-line submerged arc electric furnaces
- Circular three-electrode submerged arc electric furnaces have also been commissioned
- Furnace is typically operated with a 'black top', i.e. layer of un-smelted concentrate on top of the molten bath – limits radiation from molten bath to walls and roof of furnace



Introduction

- **Converting**

  - Controlled oxidation process by blowing air/oxygen for oxidising iron sulfide to FeO that is fluxed with silica to form low-liquidus temperature fayalitic slag, and SO_2 that is typically converted to sulfuric acid
  - S oxidation reaction is exothermic, providing most of the energy required for converting
  - Conventionally, converting is conducted in Pierre-Smith converters
  - Alternative Ausmelt process for converting is operated by Valterra Platinum – Anglo American Converting Process (APC)
  - Due to turbulence during converting, slag can have >10 ppm PGM content, therefore recycled to the primary smelting furnace or processed in a separate slag cleaning furnace
  - Converter Matte – slow cooled and crushed or granulated in water, and subsequently sent to the refineries (BMR and later PMR)

Introduction

- **Some challenges facing the PGM industry in SA**

 Smelting PGM concentrate with high contents of Cr_2O_3 – UG2 concentrate
 - Forms a spinel that accumulates at the slag-matte interface and prevents the clean separation of slag and matte – lower PGM recoveries
 - Spinel freezes onto the sidewall and hearth of the furnace, decreasing furnace volume – shorter campaign life of the furnace
 - Cr contaminates the matte. It gets into the converter slag, inhibiting the recycling of the slag

 Failure of furnace refractory lining
 - Refractory wear is typically severe at the matte-slag tidal zone. Matte temperature > the liquidus temperature of slag freeze lining, it destroys the lining and erodes the refractory

 Intermittent nature of the converting process makes the operation of the sulfuring acid plant challenging – SO_2 must not be released into the atmosphere.

Introduction

- **PGM recycling from end-of-life and secondary resources - spent autocats, e-waste, etc.**

    - Account for about 60% of new PGM products every year
    - Advantages of using secondary resources:
      - Reduction of carbon emissions by 97%
      - Curbing the need for extensive ore mining
      - Superior PGM recovery yields
    - Challenges facing the industry:
      - Secondary resource collection inefficiencies
      - Underdevelopment of processes for effective recycling of PGMs

Introduction

- Primary and secondary production of PGMs is required to meet the current and projected demand for PGMs

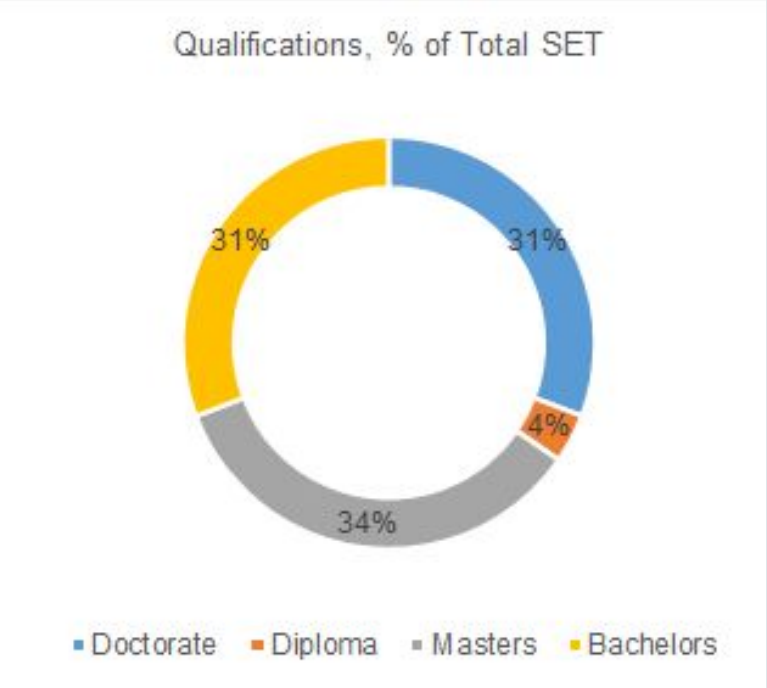
- Research, development and innovation (RDI) is key for addressing the technical challenges – primary and secondary PGM production industries
  Especially the RDI of pyrometallurgy-based processes

- Mintek has been providing high-impact and cutting-edge pyrometallurgical RDI to support the South African and global PGM industry since the early 1970s

- An overview of Mintek’s world-class RDI infrastructure and capabilities, and flagship technologies on the pyrometallurgical processing of PGMs

RDI infrastructure and capabilities – Pyrometallurgical RDI on PGMs

- Scientists, Engineers, Technologists (SET) = 27



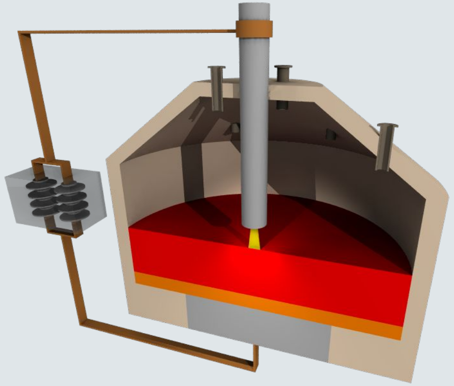
Functional groups according to TRLs

Research & Development	Technology Development	Technology Demonstration
Basic research, conceptualising applications, basic feasibility, proof of concept **Basic Technology Research** **TRL 1 to 3**	Viability and validation of process in relevant environment (demonstrated concept) **Applied Research** **TRL 4 to 5**	Integrated demonstration of prototype, demonstrated piloting in operational environment; design **TRL 6-8 (9)**

- Pyrometallurgical PGM RDI is supported by extensive Mineralogy and Analytical Chemistry analysis expertise – using speciality equipment and ISO accreditation (ISO 17025)

RDI infrastructure and capabilities – Pyrometallurgical RDI on PGMs

- **New technology and concept development through modelling and simulation –** to support laboratory and pilot scale tests
  - Thermochemical and process simulations: FactSage, HSC Chemistry, and Pyrosim
  - Mathematical modelling and computer simulations of different flow regimes in PGMs processing
  - Arc modelling work to support the electric arc furnace work



$$\frac{\partial(\rho h)}{\partial t} + \nabla\cdot(\rho \mathbf{u} h) = \nabla\cdot\left(\frac{k}{C_P}\nabla h + \frac{5k_B\mathbf{j}}{2eC_P}h\right) + \frac{\mathbf{j}\cdot\mathbf{j}}{\sigma} - Q_R$$

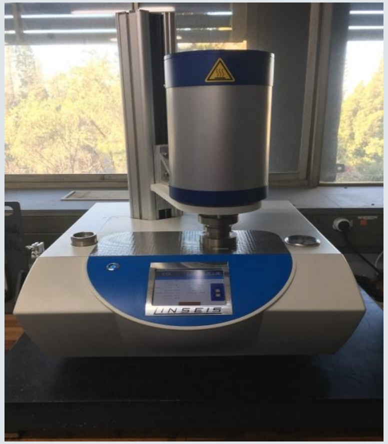
Momentum (Navier-Stokes continuity)

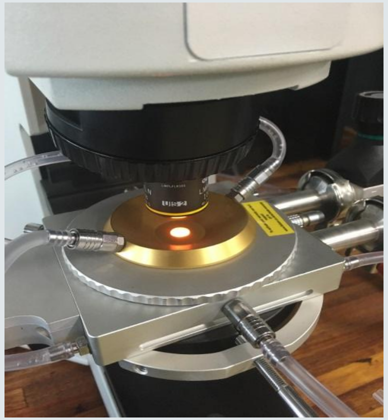
$$\mathbf{j} = -\sigma\left(\nabla\phi + \frac{\partial \mathbf{A}}{\partial t} - \mathbf{u}\times\nabla\times\mathbf{A}\right)$$

Electromagnetism (Maxwell equation)

RDI infrastructure and capabilities – Pyrometallurgical RDI on PGMs

- **Technology development through laboratory testwork**
  - Material property measurements
    - Conventional equilibration-quench tube furnace coupled with mineralogical analysis using EPMA, SEM-EDS, and/ or AutoSEM techniques – phase relations in multi-component and multi-phase systems, 1600°C, controlled pO_2
    - Differential Scanning Calorimetry coupled with Thermogravimetric Analysis (DSC-TGA) – liquidus temperatures and thermochemical properties - 1600°C, air/ inert atm
    - Hot-Stage Microscopy (HSM) – liquidus temperatures and video and optical images showing phase transformations - 1500°C, air/ inert atm
    - Furnace Rheometer System (FRS) – **viscosity and electrical conductivity** (capability under development) – NRF-Mintek funded equipment (Q1 of 2026 calendar year) - 1700°C, controlled pO_2





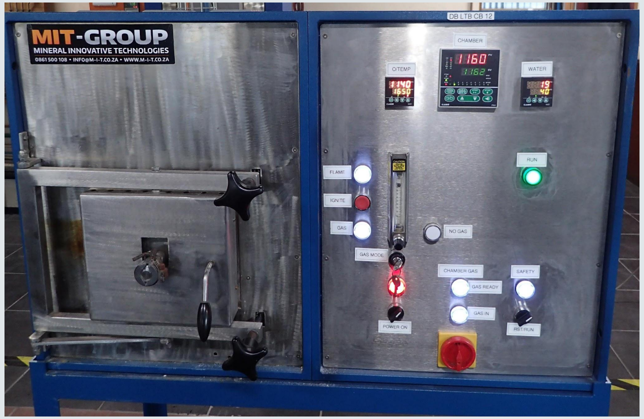
RDI infrastructure and capabilities – Pyrometallurgical RDI on PGMs

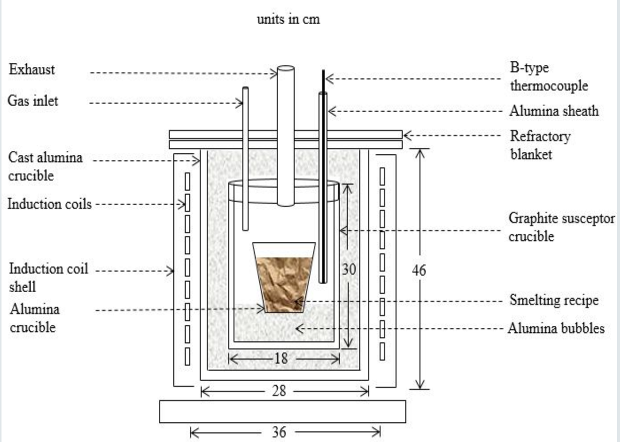
- **Technology development through laboratory testwork**

  - PGM smelting and converting process development
    - Gas-tight chamber furnace for completing smelting tests at temperatures of up to 1700°C, controlled air/ inert atm
    - Rotary kiln and fluidised bed setups, for roasting up to 1000°C, up to 5 kg (FB)
    - Induction furnaces for smelting and converting, up to 1700°C, 0.2 to 30 kg

  - Outcomes of laboratory scale testwork:
    - Results indicative of the feasibility or otherwise of a process
    - Allow for mitigation of risks at lower costs

  - Pilot-scale demonstration is essential for mimicking the targeted industrial furnace conditions





RDI infrastructure and capabilities – Pyrometallurgical RDI on PGMs

• Technology demonstration utilising pilot furnaces

- Available furnace capacity – from 30 kW to 2 MW
  - Smelting of PGM concentrates: AC furnace for matte smelting and DC furnaces for alloy smelting (ConRoast)
- Systematic approach to mitigate against technical and commercial risks
- Outcomes of pilot demonstration
  - A large pilot furnace used to generate design parameters for industrial operation – in collaboration with EPC company


(a)


(b)


(c)


(d)

Image	-	(a)	(b)	-	(c)	-	(d)
Current type	DC	DC	DC	AC	AC	DC	DC
Power, kW	30	50	200	200	250	1500	2000
Current, kA	0.4	0.5	≤1.3	≤1.3	≤1.4	≤5	≤6.6
Voltage, V	≤80	≤100	≤150	≤150	≤180	≤300	≤300
Shell diameter, m	0.35	0.45	1	1	1.5	2.5	2.5
Shell cooling	Forced	None	Film	Forced	Forced	Forced	Forced
Total batch size, kg	30	50	150	150	250	1500	1500
Throughput (t/day)	≤0.2	≤0.4	≤1	≤1	≤1.7	≤10	≤15

RDI infrastructure and capabilities – Pyrometallurgical RDI on PGMs

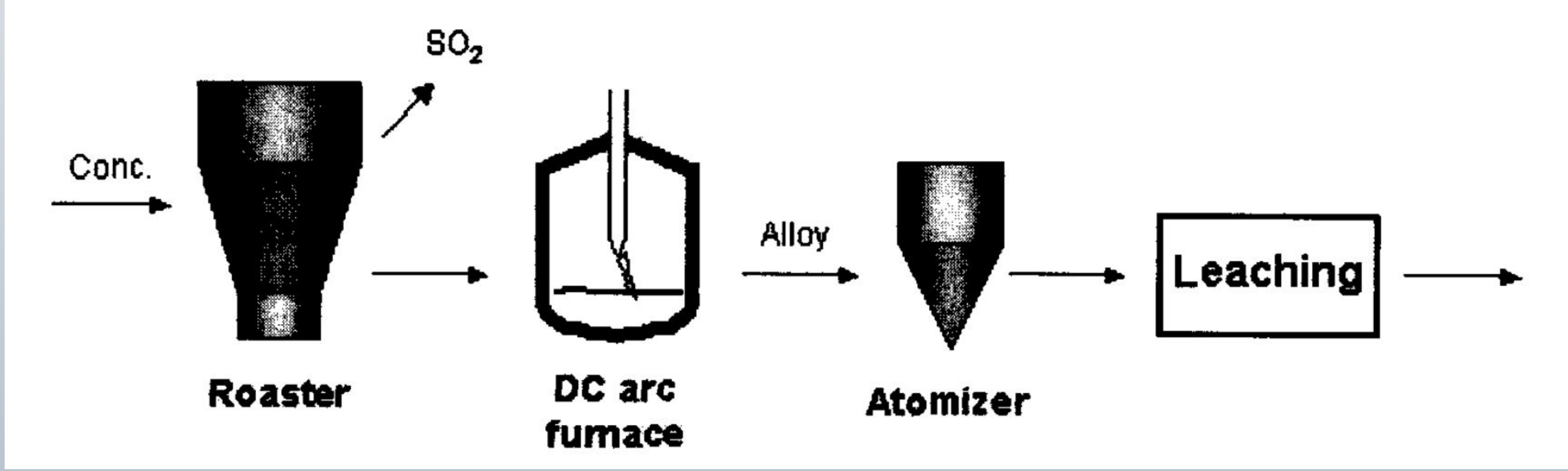
- **Technology demonstration utilising pilot furnaces**
  - Available furnace capacity – 120 and 600 kW oxy-propane burner TBRC
    - Converting PGM-bearing matte and alloy

(a) (b)

Image	(a)	(b)
Power source	Gas burner	Gas burner
Power, kW	120	600
Oxidant gas	Oxygen	Oxygen
Fuel gas	Propane	Natual gas
Shell diameter, m	0.6	1.5
Total batch size, kg	50	650
Throughput (t/day)	≤0.4	≤4

Flagship PGM RDI capabilities and technologies

- ConRoast Process
  - Innovative process for dealing with high Cr_2O_3 PGM concentrates
  - Dead roasting of sulfidic concentrate in a fluidised bed roaster – 1000°C
  - Alloy smelting of the roast to collect PGMs in Fe-rich alloy using DC arc furnace technology
  - Adopted by smelters in SA – e.g. Braemore Platinum, Jubilee Platinum



Summarised ConRoast process flowsheet

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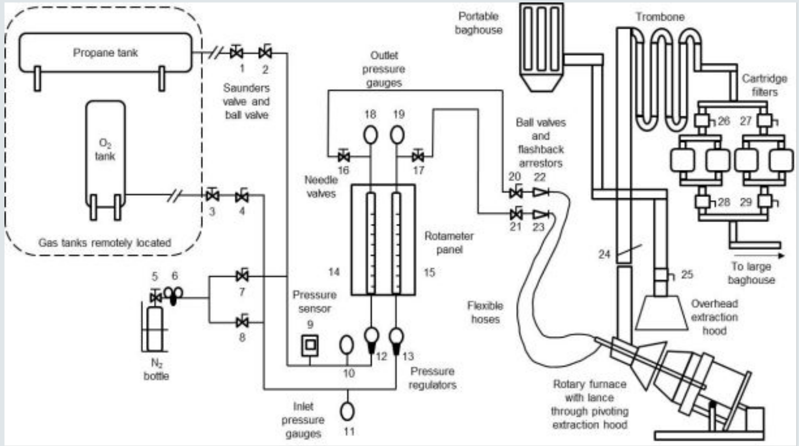
Converting of PGM-bearing alloy to concentrate PGMs (and BMs)

- Using a top-blown rotary converter (TBRC)
  development work from simulation studies to laboratory tests using an induction furnace

- Processed material:
  Fe-rich alloy from the ConRoast process (prior refining)
  Fe/Pb/Cu/ etc.-rich alloys from oxidic PGM ores, secondary materials (electronic waste, autocats)



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Flagship PGM RDI capabilities and technologies

- **Refractory-material (PGM matte/alloy/ slag studies)**
  - Developing towards ISO and ASTM standards
  - Developing own testing procedures:

Static ‘cup’ test (chemical wear)

Dynamic refractory testing – TBRC (Chemical and physical wear)

Conclusions

- Processing of PGMs in South Africa is well understood, especially the critical matte smelting process

- Deteriorating/ depleting ore bodies necessitate substantial use of marginal resources, like UG2, which present operational challenges

- Mintek is partnering with South African PGM operations for the intensification of the current process flowsheets and investigations of innovative and step-change process flowsheets
  e.g. ConRoast process, Converting work, and refractory studies are just a few examples

- Already collaborating with some international companies on the development of PGM projects

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