Recent Advances in the BIOX® Technology

Jan van Niekerk
ALTA Conference
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Introduction
BIOX® vs Biooxidation

- **Biooxidation** is a bio-hydrometallurgical process for the pre-cyanidation treatment of refractory gold concentrates. This includes:
  - Tank Bioleaching
  - Heap Bioleaching
  - Vat Bioleaching

- **BIOX®** is the patented process using stirred tanks reactors. The patent and all rights to the process is owned by Gold Fields Ltd through its wholly owned subsidiary Biomin Technologies SA
BIOX®: 25 Years Since Commercialisation

- 1986  Fairview 10 tpd pilot plant
- 1990  Harbour Lights: First BIOX® licence sold
- 1994  Ashanti: 720 tpd BIOX® plant
- 2005  2nd generation BIOX® plants
- 2007  Bogoso: 1,500 m³ BIOX® tanks
- 2010  Kokpatas: 2,136 tpd BIOX® plant
- 2012  3rd generation BIOX® plants
Current Status of Operating Plants
Map of current BIOX® and ASTER Operations
## Current & Historical BIOX® Operations

<table>
<thead>
<tr>
<th>Mine</th>
<th>Year Commissioned</th>
<th>Capacity (tpd Conc)</th>
<th>Reactor Size (m³)</th>
<th>Status</th>
</tr>
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<tbody>
<tr>
<td>Fairview, South Africa</td>
<td>1986</td>
<td>62</td>
<td>340</td>
<td>Operating</td>
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<tr>
<td>Saô Bento, Brazil</td>
<td>1990</td>
<td>150</td>
<td>550</td>
<td>Care and Maintenance</td>
</tr>
<tr>
<td>Harbour Lights, Australia</td>
<td>1991</td>
<td>40</td>
<td>160</td>
<td>Decommissioned</td>
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<tr>
<td>Wiluna, Australia</td>
<td>1993</td>
<td>158</td>
<td>480</td>
<td>Operating</td>
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<tr>
<td>Ashanti, Ghana</td>
<td>1994</td>
<td>960</td>
<td>900</td>
<td>Operating</td>
</tr>
<tr>
<td>Coricancha, Peru</td>
<td>1998</td>
<td>60</td>
<td>262</td>
<td>Operating</td>
</tr>
<tr>
<td>Fosterville, Australia</td>
<td>2005</td>
<td>211</td>
<td>900</td>
<td>Operating</td>
</tr>
<tr>
<td>Suzdal, Kazakhstan</td>
<td>2005</td>
<td>520</td>
<td>650</td>
<td>Operating</td>
</tr>
<tr>
<td>Bogoso, Ghana</td>
<td>2007</td>
<td>820</td>
<td>1500</td>
<td>Operating</td>
</tr>
<tr>
<td>Jinfeng, China</td>
<td>2007</td>
<td>790</td>
<td>1000</td>
<td>Operating</td>
</tr>
<tr>
<td>Kokpatas, Uzbekistan</td>
<td>2009</td>
<td>2138</td>
<td>900</td>
<td>Operating</td>
</tr>
<tr>
<td>Agnes, South Africa</td>
<td>2010</td>
<td>20</td>
<td>20</td>
<td>Operating</td>
</tr>
</tbody>
</table>
Operating Statistics

- **Gold Production:**
  - 2011 Estimated Gold Production: 1.5 mOz
  - Cumulative BIOX® Gold Production: 16.7 mOz

- **Installed BIOX® Treatment Capacity:**
  - 5,740 tpd concentrate
  - $S^{2-}$ range: 4.5% to 30%
  - Average: 16.7%

- **Installed ASTER Capacity:**
  - 320 m³/d @ 111 ppm SCN⁻ and 20 ppm CN⁻
BIOX® & ASTER: Development Path

First Biooxidation tests on Au

0.75 tpd Fairview

10 tpd Fairview

Sao Bento Reactor

35 m³ Fairview

40 tpd Harbour Lights

900 m³ tanks, Ashanti

960 m³ Ashanti

3000 mAMSL, 20% As Coricancha

2138 tpd Kokpatas

Gen II BIOX® Design

1,500 m³ tanks, Bogoso

Gen III BIOX® Design

Laboratory Tests

First Experiments For SCN-Degradation

80 l, Fairview

80 l, Greece

6 m³, Fairview

Pilot Plant

200 m³, Consort

Future Gen I ASTER plants

Demo Plant

25 m³, Mpumalanga

Generation I Design

20 m³, Greece

Generation II Design
The Kokpatas BIOX® Plant

Project Overview
- NMMC is a major gold producer central Asia.
- Project located central Kyzyl-Kum desert, Uzbekistan
- Oxides processed since 1995
- Gold locked in pyrite and arsenopyrite
- Project split into 2 Phases

Key Project Dates
- BIOX® license agreement: March 2000
- Phase 1 BIOX® detailed design: July 2004
- Phase 1 BIOX® commissioning: July 2008
- Phase 1 fully commissioned: February 2009
- BIOX® phase II commissioned: May 2011
The Kokpatas BIOX® Plant

Key Design Statistics

- Phase I capacity: 1,069 tpd @ 20% S²
- Phase II capacity: 2,138 tpd @ 20% S²
- BIOX® circuit: 8 modules x 6 reactors (900 m³)
- CCD circuit: 3 x 28m Delkor high rate thickeners
- BIOX® Blowers: 10 x 40,000 Nm³/hour
- BIOX® Cooling tower: 6-cell cooling tower of 9,000 m³/hour capacity
The Kokpatas BIOX® Plant

BIOX® Plant Performance Parameters

MAJOR CHALLENGES
- Sulphide sulphur grade exceeded design
- High variability in sulphide sulphur feed grade and tonnage
- Plant not operated according to design
Current Project Drivers & Business Environent
Current Business Environment

As seen from the point of view of the Technology Supplier

- Gold Price vs Production Cost
- Deposit types
- Environmental drivers
  - Cyanide & Water Management
- Geographical drivers
- Availability of skills
Gold Price vs Cost

Dramatic change in project economics

- Total Opex cost for 4 operating mines
- Total Opex cost for 4 new projects
- Line shows calculated Opex equivalent cost for average BIOX® project
- Fundamental change in economics for new projects
- Post Nov ’08 Au price > Opex for average BIOX® project
- At current Au price: ~ 50 to 33 % margin above Opex
- NB: 3 to 5 year development period from first contact to construction decision
Deposit Types – Current and Future

Hydrothermal Gold Resources

<table>
<thead>
<tr>
<th>Deposit Type</th>
<th>Average Size</th>
<th>Known Resource</th>
<th>Estimated resource depth (%)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>moz</td>
<td>%</td>
<td>&lt; 1 km</td>
</tr>
<tr>
<td>Epithermal</td>
<td>1.1</td>
<td>18.2</td>
<td>31.8</td>
</tr>
<tr>
<td>Orogenic</td>
<td>4.9</td>
<td>34.1</td>
<td>5.8</td>
</tr>
<tr>
<td>Cu-Porphyry</td>
<td>5.2</td>
<td>29.8</td>
<td>42.8</td>
</tr>
<tr>
<td>Skarn</td>
<td>1.1</td>
<td>3.1</td>
<td>8.7</td>
</tr>
<tr>
<td>VMS</td>
<td>0.7</td>
<td>7.7</td>
<td>7.9</td>
</tr>
<tr>
<td>Carlin Type</td>
<td>1.8</td>
<td>4.2</td>
<td>2.7</td>
</tr>
<tr>
<td>IOCG</td>
<td>3.1</td>
<td>2.8</td>
<td>0.2</td>
</tr>
</tbody>
</table>

- Important factors
  - Probability of discovery
  - Vertical height of deposit
  - Depth of deposit
  - Geology @ surface

- Increased focus on:
  - Cu-Au deposits
  - Polymetalic deposits
  - Double refractory deposits

Environmental Factors

Cyanide & Water Management

- Management of tailings streams containing cyanide
  - CN⁻ & SCN⁻ contaminated water cannot be recycled to the BIOX® Process
  - Toxicity levels ~ 5 ppm for all CN⁻ species

- Adherence to ICMC & other legislation
  - Mainly still for free and WAD CN⁻
  - Cannot discharge high CN⁻ levels onto tailing dam and allow natural degradation
  - Strict regulations for discharge of water to the environment – cost of processing
  - Availability & cost of fresh make-up water

- Need: efficient and cost effective CN⁻ & SCN⁻ destruction process
  - Enable discharge of CIL tailings to TSF
  - Recycle maximum volume of water to process

- Reduce the CN⁻ consumption by process improvements
Geographical Factors

- Remote locations:
  - Availability of skills & labour
  - Access to infrastructure
    - Power, water, road access
  - Ease of access and travel time required
  - Delivery of equipment and reagents
  - Altitude & availability of sites for locating plant

- Environmental legislation
  - Environmentally sensitive areas
  - Minimising impact of process on environment

- Political factors
  - Stability of country
  - Access to site or presence on site
Availability of Resources & Skills

- **Testing, Design and Construction Phase**
  - Availability and scheduling of drilling and testwork
  - Availability of skills during design & construction phases:
    - Quality of design / engineering team
    - Staff turn-over during design and construction phase
  - Lead time for major equipment

- **Operation**
  - Availability of skilled and unskilled operators
  - Availability of local technical skills & the availability of expat skills
  - Availability & reliability of delivery of reagents
  - Availability & lead time of delivery of spares
Future Trends and Developments
Future Trends & Developments

Technical Focus: Continuous Improvement of Products and Service

- Development of existing technologies
  - Understanding of the process
  - BIOX® Generation III design
    - Improving the operability / stability of the process
    - Improve the execution strategy / implementation of technology
  - BIOX® Generation IV design
    - Reducing capex and opex cost

- Development of new technology and applications
  - Expanding application of existing technologies
  - Development of new technologies
Understanding of the process

Understanding the Bacterial Culture in a BIOX® tank

- **1980s Culture:**
  - Dominated by *At. Ferrooxidans*, *At. thiooxidans* and *L. Ferrooxidans*
  - Work in late 1990s identified new species *L. Ferriphilum* and *At. Caldus* as dominant
  - GFGS stock culture characteristic of these species

- **Current Work**
  - Using qPCR shows *L. Ferriphilum* absent from operations
  - *Acidiplasma* and *Ferroplasma* dominant iron oxidisers
  - Reasons and consequences of shift being investigated under controlled conditions

Photo’s supplied by the Centre for Bioprocess Engineering Research, University of Cape Town
Understanding of the process

Maintaining Industry Leading Position

- Potential to improve performance by understanding dominant species
- Characterise Fe and S oxidation rates (Ratkowsky plots)
- Vary parameters (T°C, Solids Loading, pH) individually to assess effect on performance and species
- Another diagnostic tool to assist operating plants to improve performance

![Ratkowsky plots showing the relationship of temperature to the oxidation of elemental sulfur for a range of common biotransforming organisms: Acidithiobacillus ferrooxidans (X), Acidithiobacillus thiooxidans (O), Acidithiobacillus caldus (O), Sulfobacillus metallicus (O), Acidium brierleyi (●)].

![Ratkowsky plots showing the relationship of temperature to the oxidation of iron for a range of common biotransforming organisms: Leptospirillum ferrooxidans (●), Leptospirillum ferrilphilum (●), Acidimicrobium ferrooxidans (X), Sulfobacillus thermosulfidooxidans (O), Acidimicrobium brierleyi (●)].
BIOX® Generation III Design Package

Process Stability and Ease of Operation

**Increase Robustness**
- Review, standardise and improve BIOX® design program
- Improve mechanical reliability of BIOX® agitators
- Design for variability
- Third party review system

**Improved BIOX® Service Offering**
- Broaden guidance
- Best practice documentation
- Value adding products

**BIOX® Gen III Design**

**Process Improvement**
- Reduce BIOX® frothing problems
- Improved sparge ring design
- Reduce colloidal gold losses

**Improve Knowledge Transfer**
- Target decision makers
- Correct information in the correct format at the appropriate time
- Encourage feedback
BIOX® Generation IV Design Package

Major BIOX® Capital Equipment

- **Tanks:** 25% to 35%
- **Agitators:** 22% to 30%
- **CCD Thickeners:** 10% to 20%
- **Blowers:** 6% to 12%
- **Cooling towers, and Pumps:** 8% to 10%

Shown as % of total equipment cost
BIOX® Generation IV Design Package

BIOX® Operating Cost Breakdown

- **Power**: 49%
- **Reagents**: 40%
- **Labour**: 3%
- **Maintenance**: 8%
- **Limestone**: 8%
- **BIOX® Agitators**: 8%
- **BIOX® Blowers**: 8%
- **Pumps**: 8%

Lime
BIOX® Generation IV Design Package

Capital and Operating cost reduction of > 10 %

Improved Agitation System:
- Step change in process results with reduced mechanical stresses
- Use of vendors as partners in developing program
- Bogoso BIOX® plant: immediate implementation of dual impeller system
- Equipment on-site, awaiting installation for full scale validation of test results

2010:
- Development of process basics

2011:
- Determine scale-up factors

- 1,500 m³ Bogoso installation
- Prove commercial application
Exciting Pipeline of Opportunities to Expand Product Range

**MesoTherm**
- Combination Mesophile & Thermophile BIOX®
- Reduction in CN consumption
- Immediate and future applications

**Cu-Porphyry**
- Most important gold resource for the future
- Technology proven, further optimisation required
- Legislation in many countries will require beneficiation to final product

**Hot Caustic Conditioning**
- Treatment of highly preg-robbing ores
- Developed & proven commercially by Fosterville
- Immediate and future applications

**ASTER**
- Fully proven commercial process
- Continued development to increase operating window and reduce cost
MesoTherm (CN Reduction & Cu Recovery)

- **Mesotherm Design Criteria**
  - Complete S\(^2-\) oxidation for Mesophile/Thermophile BIOX®
  - Base case assessment 2011
    - ~ 50% lower NaCN consumption
    - Implies 17% - 40% overall reagent cost reduction
  - 2011 User interested partner
  - UCT thermophile culture ready
  - 2012 testwork & PFS evaluation to be completed
Hot Caustic Conditioning (HCC)

- **Double Refractory Ores**
  - Dissolved gold adsorbs onto finely disseminated carbon
  - Activated carbon reverses adsorption if preg robbing weak
  - In severe cases, large metal losses occur
  - Use of blinding agents partially successful – immiscible and difficult to control

- **HCC Allows**
  - Effective desorption of preg robbed gold from NCC
  - Adsorption dissolved gold onto fresh carbon
  - Process trialled, implemented successfully

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<table>
<thead>
<tr>
<th>2008</th>
<th>March 2012</th>
<th>April 2012</th>
<th>May 2012</th>
<th>June 2012</th>
</tr>
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<tbody>
<tr>
<td>FOSTERVILLE DEVELOPMENT AUSTRALIA</td>
<td>GFGS PROCESS VALIDATION JHB</td>
<td>GFGS PROCESS DUPLICATION JHB</td>
<td>GFGS PROCESS REPRODUCIBILITY JHB</td>
<td>GFGS PROCESS PACKAGE DESIGN</td>
</tr>
</tbody>
</table>
ASTER

Biological Process For Cyanide and Thiocyanate Destruction

- Alternative Process To Inco/\(\text{SO}_2\), Caro’s Acid and Alkaline Chlorination (Chemical)
  - Exotic, expensive reagents (Sodium meta-bisulphate, \(\text{H}_2\text{SO}_3\), hypochlorite (OCl / Cl\(_2\))

- ASTER Allows
  - Effective water management by treating CIL/CIP residual solutions and recycling upstream
  - Environmentally compliant tailings disposal

- ASTER Advantages
  - Low capital and operating cost
  - Safe, fertilizer type nutrients - no exotic additives
  - Degradation of SCN, CN, WAD CN to ICMC, IFC and Equator Principles Guidelines (< 0.1 ppm CN)
  - Commercially available


- DEVELOPMENT
- VALIDATION
- 1\(^{\text{ST}}\) INDUSTRY DELIVERY (SOUTH AFRICA)
- 2\(^{\text{ND}}\) & 3\(^{\text{RD}}\) INDUSTRY DELIVERY
- 4\(^{\text{TH}}\) & 5\(^{\text{TH}}\) INDUSTRY DELIVERY

*Ultimate Delivery: Cyanide detoxification of any tailings stream
Conclusions
Conclusions

- **The BIOX® process:**
  - Has been in operation for > 25 years
  - Proven process performance
  - Robust process, ideal for remote locations
  - Serviced by experienced team
  - Backed by the 4th largest gold mining company in the world

- **Changing business environment**
  - Improve both process and service offered to clients
  - Expand into new commodities
  - Develop or commercialise new processes
  - Ensure product can deliver:
    - Robust and dependable process
    - Backed by technical assistance
    - Cradle to Grave approach to client service