Extraction of Gold Then, Now and the Future

Prof Sehliselo Ndlovu
DST/NRF SARChI: Hydrometallurgy and Sustainable Development
University of the Witwatersrand, Johannesburg

Building a Robust Minerals Industry
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- Founded Oct. 1896: School of Mines
- Approx. 37,000 Students
- 5 Faculties, 33 Schools, 3,610 Courses
- >160,000 Degrees Conferred since 1922
- 55% Female Students
- 10 National Centres of Excellence
- Home to the Bidvest Football Club (current PSL league Champions)

Nobel Prize Winners:
- Nelson Mandela
- Aaron Klug
- Sydney Brenner
- Nadine Gordimer

Over 85 Rhodes and 15 Mandela-Rhodes Scholars

A-rated researchers at Wits
Evolution in Gold Processing

Past Technologies
• Amalgamation
• Panning

Current Technologies
• Cyanide leaching
• Processing of refractory ores
• Bio-oxidation
• Alternative leaching reagents

Emerging and Future Technologies
• Ionic liquids
• Ultrasonic leaching
• Corn starch??
History of gold extends back at least 6,000 years.
Egypt and Mesopotamia around 4000 BC.

Gravity Separation: Gold Panning
- Gold concentrated by washing lighter river sands with water
  - Leaves dense gold particles
- Alternative - wash gold-bearing sand and gravel over a woollen fleece
  - Traps heavier gold dust that would sink into the wool fibres.

Advantages
- Simplicity

Disadvantages
- Labour intensive
Gravity Separation: Sluicing

- Water is channelled to flow through a sluice-box.
- Sluice-box is essentially a man-made channel with riffles (barriers) at the bottom.
- Riffles create dead-zones in the water current which allows gold to drop out of suspension.

Sluicing and panning results in the direct recovery of small gold nuggets and flakes.
Invented to remove Ag from Au-Ag mixtures around 6th century BC.

- Mix: argentiferous gold foil, common salt, brick dust or burnt clay and urine in a sealed container.
- Heated NaCl decomposes in the presence of silica and alumina to produce HCl and also some Cl.
- This reacts with Ag to produce AgCl.
- The urine is acidic and aids decomposition. AgCl is volatile and would be removed from the metal.

**Advantages**
- Ability to remove Ag which the cupellation process was unable to do

**Disadvantages**
- Labour Intensive
- Limited gold recovery
• Similar to salt cementation process but creates sulphides instead of chlorides.
• Finely divided impure gold and elemental sulphur are reacted together under moderate heat in a sealed crucible.
• The impurities form metal sulphides and the gold is left unreacted.
• The antimony process is the same but uses stibnite ($\text{Sb}_2\text{S}_3$) instead of sulphur.

**Advantages**
- Quicker than the salt process
- Gives a better gold purity than the salt process

**Disadvantages**
- Dissolves some of the gold as well hence, lowering recovery
Amalgamation

- Relies upon contact of ore with mercury to form a gold-mercury amalgam/alloy.
- Used ideally for coarse gold ores.
- The gold is separated from the mercury by distillation in retorts.
- The process is still used by artesian miners.

**Advantages**
- Simplicity

**Disadvantages**
- Highly toxic; mercury poisoning
- Inferior performance when compared to alternatives
INDUSTRIAL ERA
Extraction of Gold in Modern Times

CYANIDE AND less CYANIDE?
Gold Ore Mineralogy

Know what you have so you can know how to process it

Used as a predictive tool in feasibility studies and during the process development stage, and as a troubleshooting tool for mineral processing and hydrometallurgical operations.

However: Ore mineralogy not always given full consideration.
Identification and location of all gold minerals, their size distributions, compositions, liberation characteristics, and associations with other minerals

- Predicts the fineness of grind and possible response to conventional gold recovery techniques

Quantifies the fractions of liberated gold, gold associated with sulfides, gold associated with oxides/silicate, and gold associated with carbonaceous material (if present)

- Estimates the maximum amount of gold that can be recovered by gravity, flotation, and direct cyanidation or a combination of these processes
Gold Ore Mineralogy

- Quantifies the submicroscopic gold in sulfide and other minerals
  - gives amount of gold that can be recovered by employing pre-oxidation or biooxidation
- Determines the reasons(s) for high gold losses to tailings and opportunities to improve gold recovery
- Determines any other valuable metals (such as silver and copper) and deleterious minerals (e.g., talc, serpentine, graphite, cyanicides, oxygen consumers, and water-soluble minerals)
- Evaluates the preg-robbing potential of carbonaceous matter and gangue minerals
Refractory Ores: Oxidative Pretreatment

Applied when direct treatment by cyanidation gives unacceptable low gold recovery or is uneconomic due to:

- Gold is locked in relative gangue minerals often sulfides and cannot be adequately liberated even by fine grinding
- Gold occurs with minerals that consume unacceptable quantities of reagents for example pyrrhotite, marcasite and arsenopyrite
- Gold occurs with carbonaceous material that adsorb gold during leaching
- Any combination of the above
# Summary of Oxidative Pretreatment Processes

<table>
<thead>
<tr>
<th>Process type</th>
<th>Oxidative method</th>
<th>State of development of technology</th>
<th>Ore types treated</th>
<th>Application examples</th>
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</thead>
<tbody>
<tr>
<td>hydrometallurgical</td>
<td>Low pressure oxidation</td>
<td>Proven commercially</td>
<td>Mildly refractory-containing small quantities of reactive sulfides e.g. marcasite and pyrrhotite</td>
<td>East Driefontein (RSA)</td>
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<td></td>
<td></td>
<td></td>
<td>Lupin (Canada)</td>
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<td></td>
<td>High-pressure oxygen-acidic media</td>
<td>Proven commercially</td>
<td>Refractory sulphidic and arsenical ores - low carbonate, high sulfur</td>
<td>Sao Bento (Brazil)</td>
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<td></td>
<td></td>
<td>Goldstrike, Lonetree and Twin Creek (Nevada, USA)</td>
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<tr>
<td></td>
<td>High-pressure oxygen-nonacidic media</td>
<td>Proven commercially</td>
<td>Refractory sulphidic and arsenical ores - high carbonate, low sulfur</td>
<td>Mercur (Utah, USA)</td>
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<td></td>
<td>Nitric acid</td>
<td>Proven commercially for silver concentrates, unproven for gold</td>
<td>Refractory concentrates containing silver, copper and antimony</td>
<td>Sunshine (Idaho, USA)</td>
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<tr>
<td></td>
<td>Chlorine/chlorination</td>
<td>Proven commercially</td>
<td>Carbonaceous ores, low sulfur telluride ores</td>
<td>Carlin and Jerritt Canyon (Nevada)</td>
</tr>
<tr>
<td></td>
<td>Biological</td>
<td>Proven commercially for flotation concentrates</td>
<td>Refractory arsenical and sulphidic ores, gold preferably associated with arsenopyrite, marcasite</td>
<td>Fairview (RSA) Sao Bento (Brazil) Ashanti Sansu Ghana</td>
</tr>
<tr>
<td></td>
<td>Roasting</td>
<td>Proven commercially</td>
<td>Refractory sulphidic, arsenical, carbonaceous and telluride ores</td>
<td>Big Springs, Carlin, Cortez and Jerritt Canyon (Nevada)</td>
</tr>
</tbody>
</table>
Cyanide is universally used for gold leaching because of its:

- Relatively low cost
- Great effectiveness for gold dissolution
- High selectivity for gold and silver over other minerals
- However, it is highly toxic
Gold Processing

Concentrate

Pre-treatment

leaching

carbon adsorption

Loaded carbon

leachate

Spent carbon – reactivation

carbon stripping

Stripping solution

Electrowinning

Refined Gold
CIP and CIL Processes

- **Carbon-in-pulp (CIP):** Leaching takes place in tanks dedicated for leaching followed by adsorption onto carbon in tanks dedicated for adsorption.

- **Carbon-in-leach (CIL):** Carbon is added to the leach tanks so that leaching and adsorption take place in the same tanks, simultaneously.

- **CIL** process was developed for processing gold ores that contain preg-robbing materials.
  - These reduce the gold yield by attracting gold meant for the activated carbon.
  - Simultaneous leaching and adsorption helps minimize the problem [6].
CIP Process

HIGH RATE THICKENER

1. Preparation tank
2. Cyanide Addition as Required

3. Cyanide Addition as Required

4. Cyanide Addition as Required

5. Cyanide Addition as Required

6. Cyanide Addition as Required

7. Cyanide Addition as Required

8. Cyanide Addition as Required

Flocculant's and Lime Addition

CARBON DEWATERING SCREEN

- Regenerated Carbon
- Fine Carbon to be pressed & Water to be recovered

ADSORPTION SECTION

- 4Au + 8NACN + O₂ + 2H₂O = 4NaAu(CN)₂ + 4NaOH

ADSORPTION SAFETY SCREEN

SLIMES DAM

To Backfill plant

Loaded Carbon to Recovery Circuit
The use of cyanide in mining operations is facing increasing public opposition due to its toxicity with some countries banning it completely.

- **America**: Cyanide utilisation in gold processing has been banned in some states.
  - The US state of Montana in 1998

- **Argentina**: A number of Argentine provinces banned cyanide mining, but there is no ban at the federal level.

- **Czech Republic**: In 2002, the Czech Parliament decided to ban gold cyanide leaching
### Alternatives To Cyanide Leaching

<table>
<thead>
<tr>
<th>Process</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Thiourea</td>
<td>• Low environmental impact</td>
<td>• Expensive ferric ion oxidants</td>
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<td></td>
<td>• Fast kinetics of gold dissolution</td>
<td>• Higher reagent consumption compared to the cyanidation process</td>
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<td>• Greater selectivity towards gold and silver</td>
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<td></td>
<td>• Requires no neutralization step in case of bio-oxidative pre-treatment for refractory ores</td>
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<tr>
<td>Thiosulphate Process</td>
<td>• Reduced impact on environment compared to cyanide</td>
<td>• Chemistry more complex and less robust than the cyanide leaching</td>
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<td></td>
<td>• Yields similar gold recovery as cyanide and</td>
<td>• More difficult to optimize and more sensitive to operate</td>
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<td></td>
<td>• Greater efficiency with gold deposits associated with preg-robbing ores.</td>
<td></td>
</tr>
<tr>
<td>Haber Gold Process</td>
<td>• Extraction efficiencies with complex ores in the high 90%</td>
<td>• Only used on oxide ores</td>
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<td></td>
<td>• Range with gold purity in the +99% range</td>
<td>• Can Use electronic waste</td>
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<td>• extraction times of about 1 to 3 hrs and gold</td>
<td></td>
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<td>Recovery in minutes.</td>
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The Future
Extraction of Gold in Coming Years

Focus will be more on use of environmental friendly reagents and gold recovery from secondary resources.
Ionic Liquids

Considered alternatives to leaching and solvent extraction processes.

Potential applications involve extraction of gold from ores and electronic scrap
  • considered the future of recycling

Advantages

• Good selectivity for gold and silver in leaching.
• Potential “green solvent” leaching agent

Disadvantages

• Availability of quantitative solubility data of metal salts in ionic liquids is lacking.
• Chemicals are expensive
Jet Leach Reactor is a device designed to create and propagate micro-cavitation by impacting two pulp streams against one another at a high velocity.

Results in enhancement of mass transfer kinetics.

The cavitation process produces bubbles which, once collapsing, propagate stress at the inter-phase bubbles-particles, and increase the local pressure and temperature.

Changes such as cracks propagation, internal stress or mechanical activation may happen under emission of such extreme energy, and increase the leaching kinetics.
Jet Leach Reactor

Au Recovery Ore A

Recovery (%) vs Time (min.)

- Jetleach
- Pachucca
Alpha-cyclodextrin, a cyclic starch fragment composed of six glucose units, noted to be best at isolating gold. Process a lot less toxic than cyanide leaching and appears to be more efficient at isolating gold.

Could also be used to recover gold from electronic waste. Still at research level.
Key drivers of Tailings Retreatment

- Tailings generally considered to require fewer resources when compared to conventional mining.
  - This reduces costs related to capital equipment, labor, fuel and maintenance.

- Advances in processing technologies
  - Cost effective and efficient processes makes it more economical beneficial to recover value metals from discarded materials which were previously regarded as untreatable.

- Processing of tailing allows for additional production without increasing a mine’s footprint and without requiring additional land permits.

DRD Gold is one of the first South African companies who have abandoned traditional mining to focus on extracting gold from tailings.
Success in Tailings Processing

- Will depend on extraction technologies that
  - Give high recoveries
  - have high selectivity towards gold
  - are non toxic
  - have low conversion and energy costs
  - and have low environmental and ecological impact.
Conclusion

- Cyanide leaching still the dominant method used in gold processing
- Gravity separation techniques and highly toxic amalgamation method still used by artisanal miners
- Reprocessing of gold tailings a growing trend
- Research and development in the use of green solvents and recycling of gold bearing scrap material for the future some of the current focus


8. 2001 Assembly BILL 95, Wisconsin State Assembly.


