

Extraction of Gold Then, Now and the Future

Take *the lead* with *WITS*

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Building a Robust Minerals Industry

3 – 4 July 2017,

Cresta Lodge, Harare



University of the Witwatersrand Johannesburg



Founded Oct. 1896: School of Mines

Approx. 37 000 Students

5 Faculties, 33 Schools, 3610 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)



Nelson Mandela

Aaron Klug

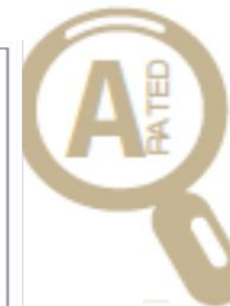
Sydney Brenner

Nadine Gordimer

4

NOBEL PRIZE WINNERS

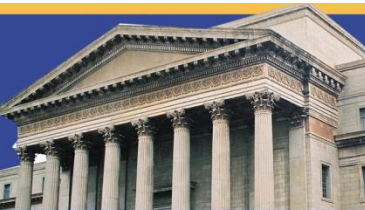
over **85**
RHODES &
15 MANDELA-
RHODES
SCHOLARS



26

A-rated
researchers
at Wits

Recognised by peers
internationally as global
leaders in their field



Evolution in Gold Processing

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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??

Past Technologies Used in Ancient Times

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- ❖ 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

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- 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.



Gold Parting: Salt Cementation Process

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- 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



Sulphur and Antimony Process

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- 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 (Sb_2S_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

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- 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 artisan miners

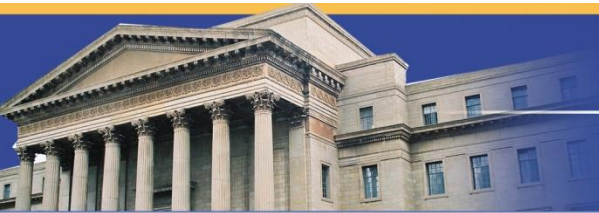
Advantages

- Simplicity

Disadvantages

- highly toxic; mercury poisoning
- inferior performance when compared to alternatives





INDUSTRIAL ERA

Extraction of Gold in Modern Times

CYANIDE AND less CYANIDE?

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

Gold Ore Mineralogy: Benefits

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- 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 process

Gold Ore Mineralogy

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- 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

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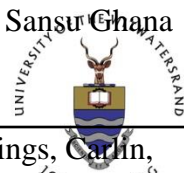
Applied when direct treatment by cyanidation gives unacceptable low gold recovery or is uneconomic due to:

- ✓ 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

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

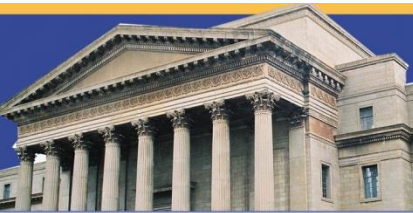


Cyanide Leaching Process

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Cyanide is universally used for gold leaching because of its;

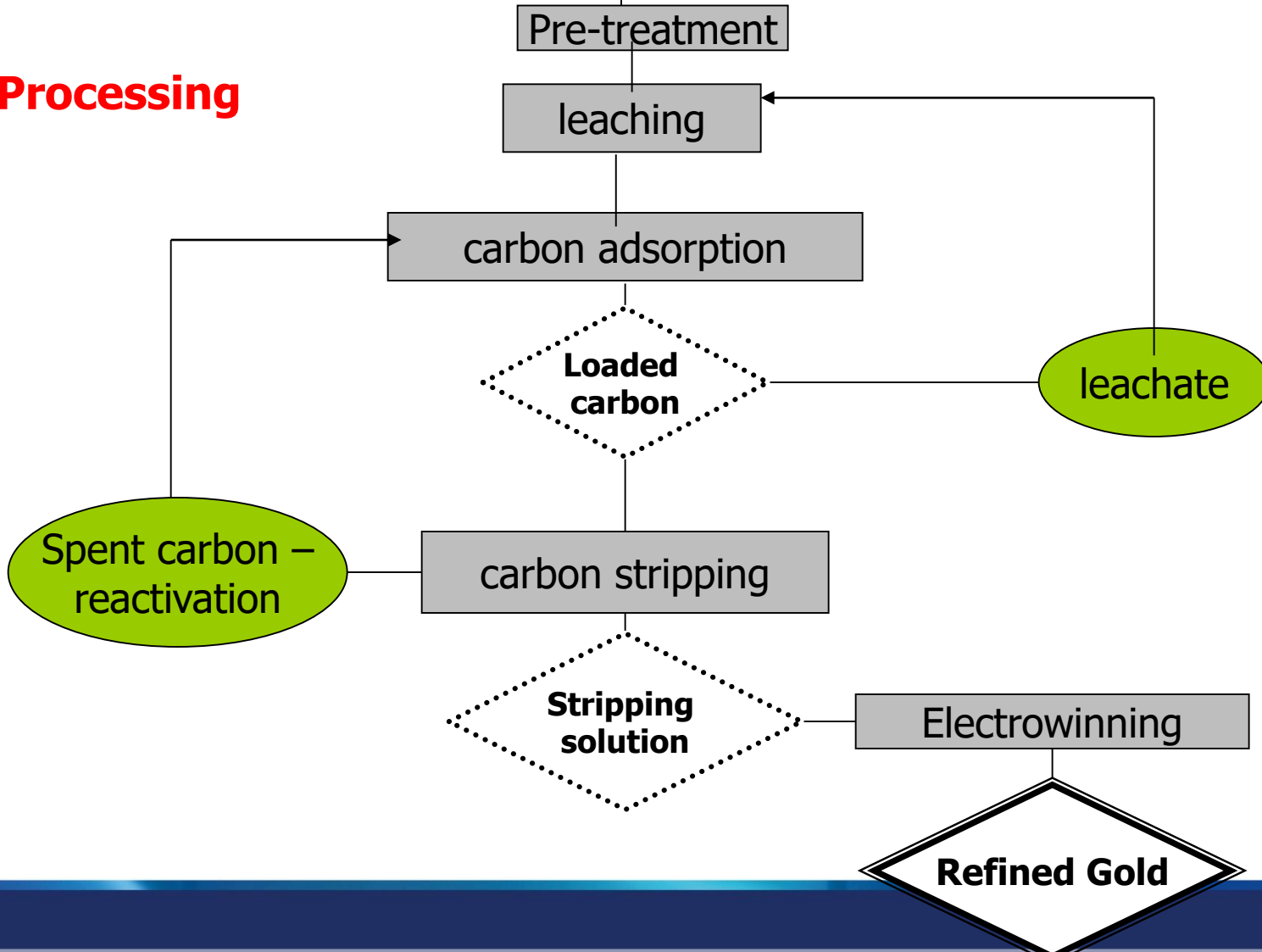
- Relatively low cost
- Great effectiveness for gold dissolution
- High selectivity for gold and silver over other minerals
- However, it is highly toxic



Concentrate

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Gold Processing



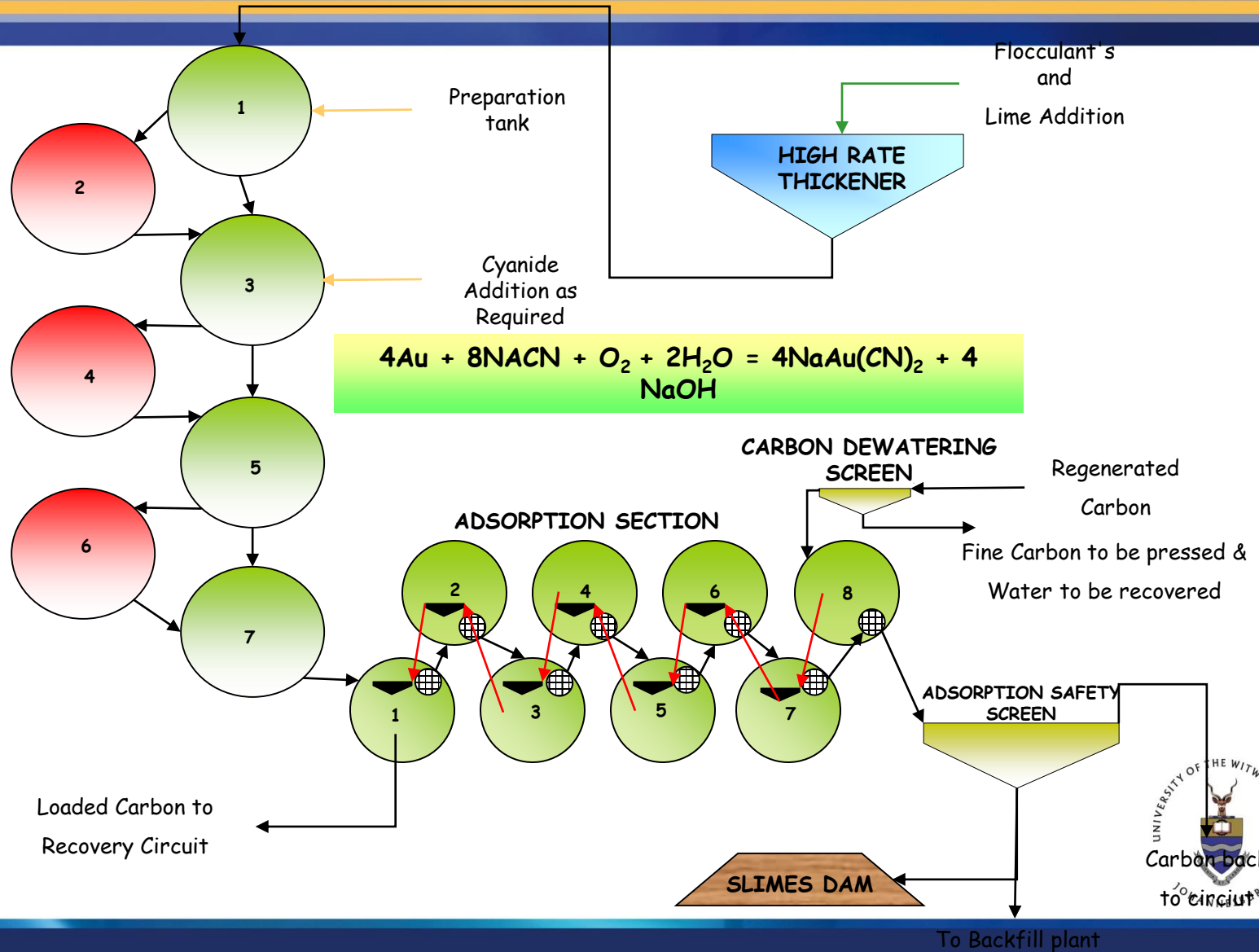
CIP and CIL Processes

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- **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

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Gold Cyanidation Ban

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- 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
 - The US state of Wisconsin banned the in 2001.
- **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

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Advantages

Disadvantages

Thiourea

- Low environmental impact
- Fast kinetics of gold dissolution
- Greater selectivity towards gold and silver
- Requires no neutralization step in case of bio-oxidative pre-treatment for refractory ores

- Expensive ferric ion oxidants
- Higher reagent consumption compared to the cyanidation process

Thiosulphate Process

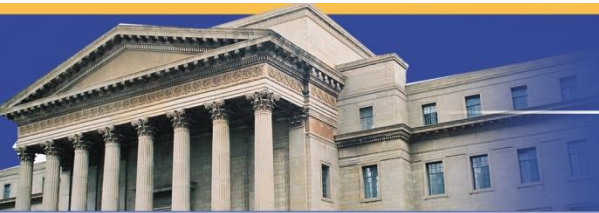
- Reduced impact on environment compared to cyanide
- Yields similar gold recovery as cyanide and
- Greater efficiency with gold deposits associated with preg-robbing ores.

- Chemistry more complex and less robust than the cyanide leaching
- More difficult to optimize and more sensitive to operate

Haber Gold Process

- Extraction efficiencies with complex ores in the high 90%
- Range with gold purity in the +99% range
- extraction times of about 1 to 3 hrs and gold Recovery in minutes.

- Only used on oxide ores
- Can Use electronic waste



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

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- 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



Cavitation Leaching: Jet Leach Reactor

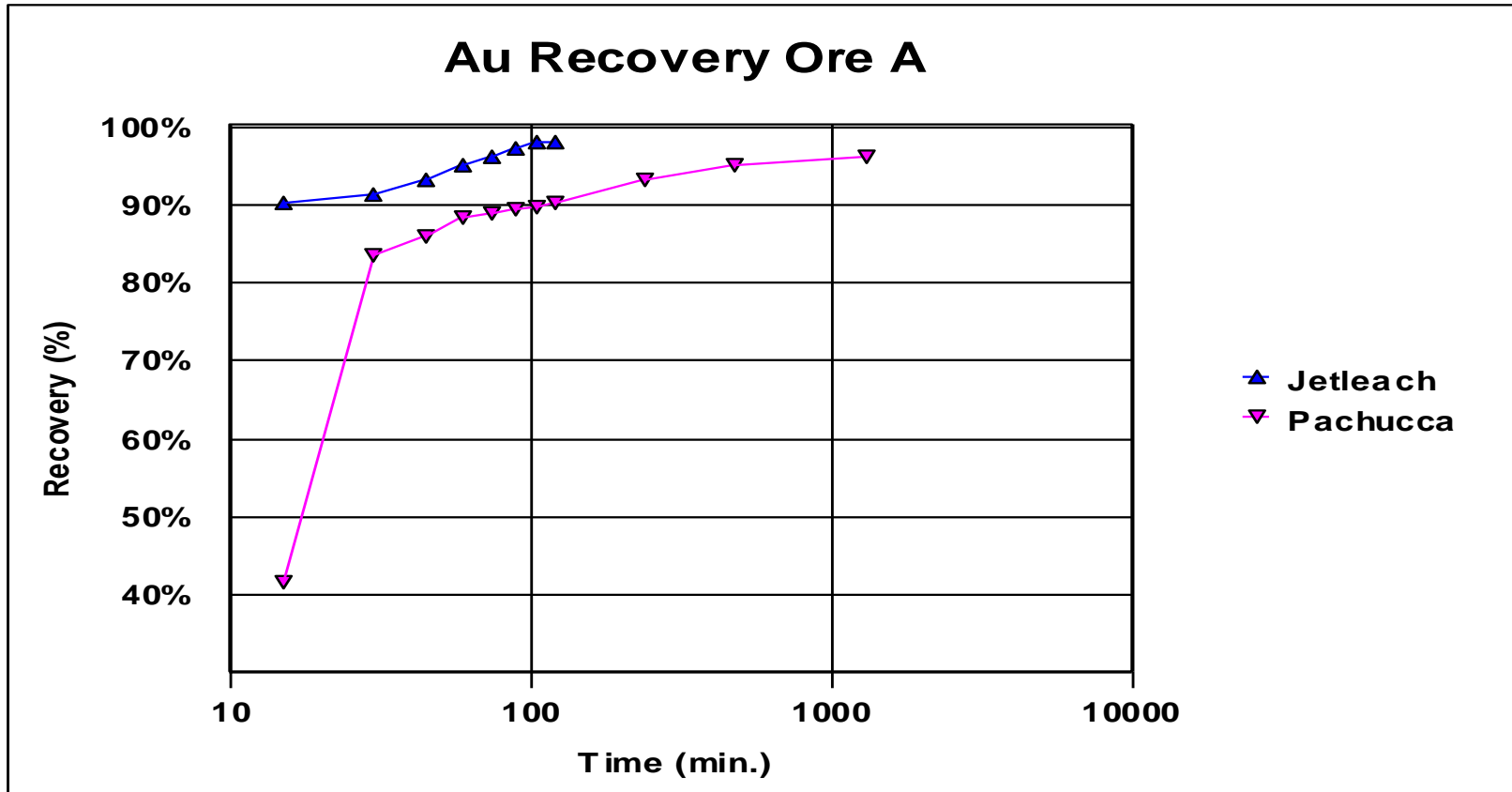
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- ❖ Jet Leach Reactor is a device designed to create and propagate micro-cavitation by impacting two pulp streams against one another at a high velocity
- ❖ Results in enhancement of mass transfer kinetics
- ❖ The cavitation process produces bubbles 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.



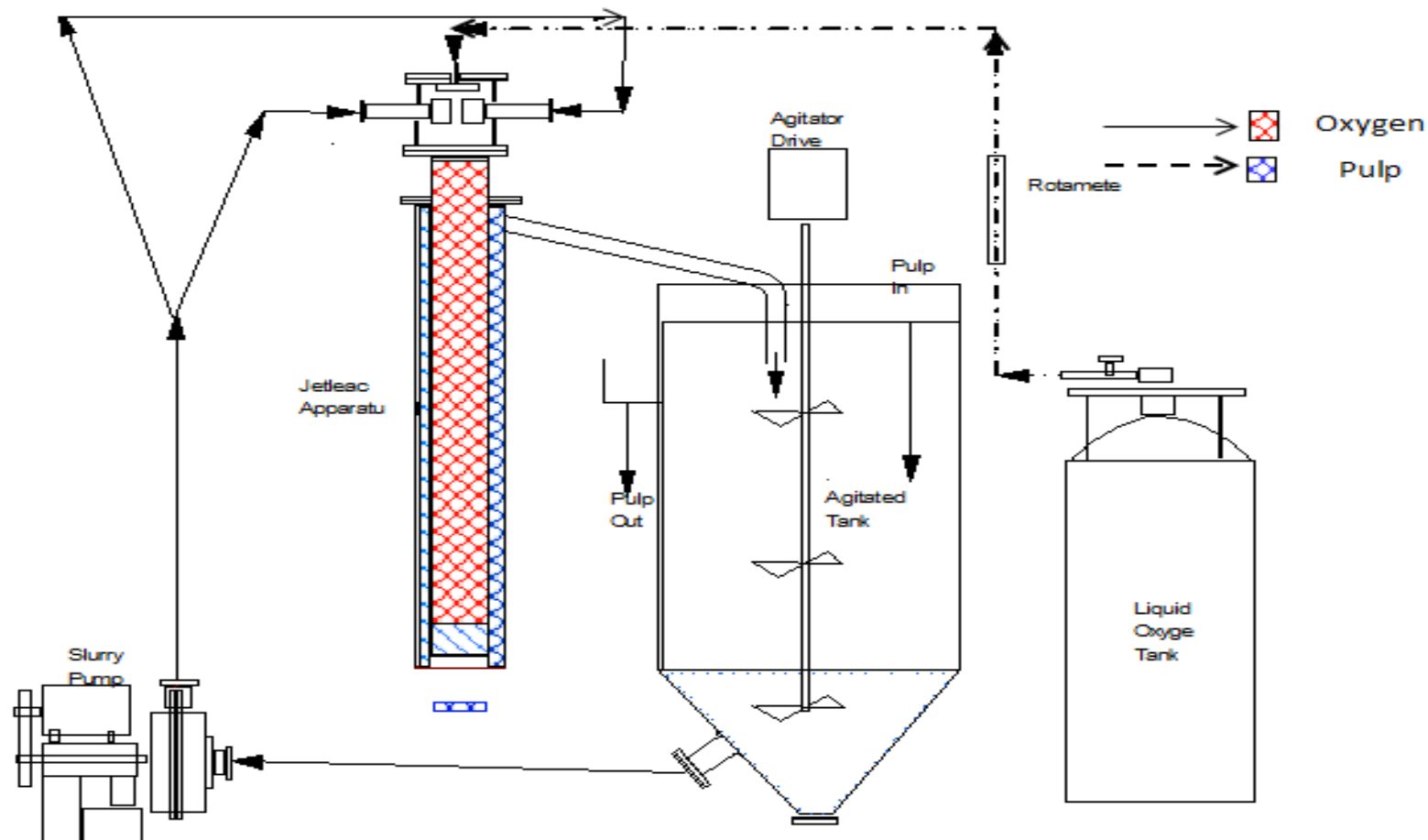
Jet Leach Reactor

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Typical In-line Installation

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Cornstarch Replaces Cyanide Leaching

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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

Processing of Tailings For The Future

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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

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- 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

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- 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

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