

TECHNOLOGICAL DEVELOPMENTS IN BIO-LEACH PROCESSING OF REFRACTORY GOLD ORES AND POTENTIAL APPLICATION IN ZIMBABWE

SAIMM – ZIMBABWE BRANCH CONFERENCE

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The logo for Manhize Mineral Consultants (MMC) features the letters 'MMC' in a large, white, sans-serif font. The background of the logo is a dark teal color with a subtle, textured pattern of small, dark, irregular shapes, possibly representing mineral grains or a rock surface.

Manhize Mineral Consultants
Mineral Process Specialists and Project Managers

OUTLINE OF PRESENTATION

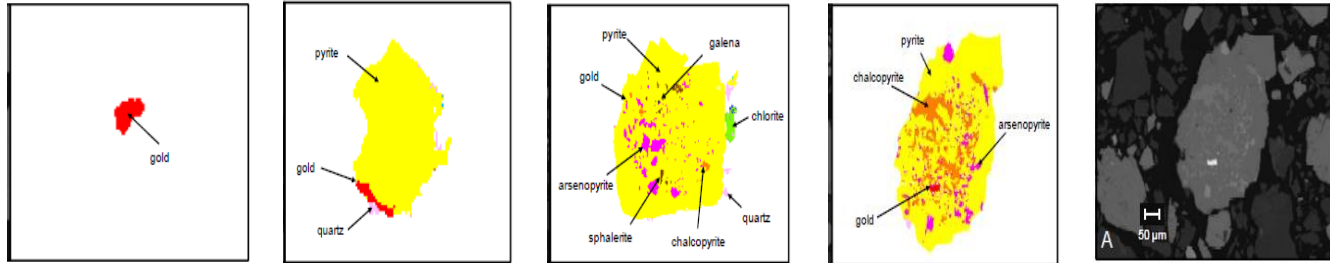
- Defining and understanding Refractoriness
- Why Refractory Ores?
- Significance of Bioleach in Refractory Gold processing
- Bioleach Economic Drivers
- Bioleach Technical Developments
- Bioleach potential for Zimbabwe

REFRACTORINESS OF GOLD ORES

Reasons for Refractoriness

- Invisible gold present as extremely fine particles (<5 microns) incorporated in the sulphide matrix- arsenopyrite and pyrite-solid solution gold atomically distributed in the crystal structure sulphide minerals
- Naturally occurring active carbon which results in preg-robbing . Gold may be exposed to cyanide solution for leaching but recovery is inhibited by the gold getting adsorbed onto carbon
- Double refractory are concentrates or ores in which gold is in solid solution and also there is active carbon

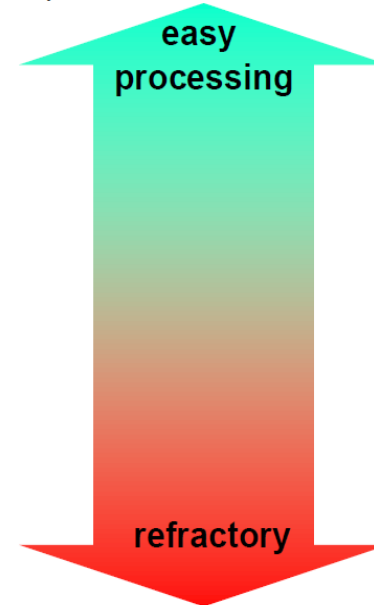
REFRACTORINESS OF GOLD ORES



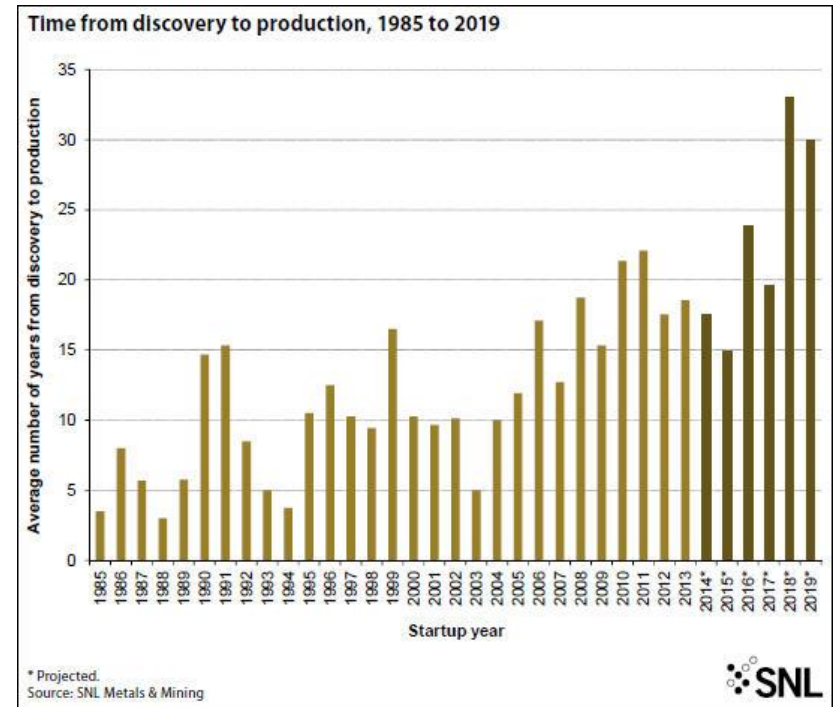
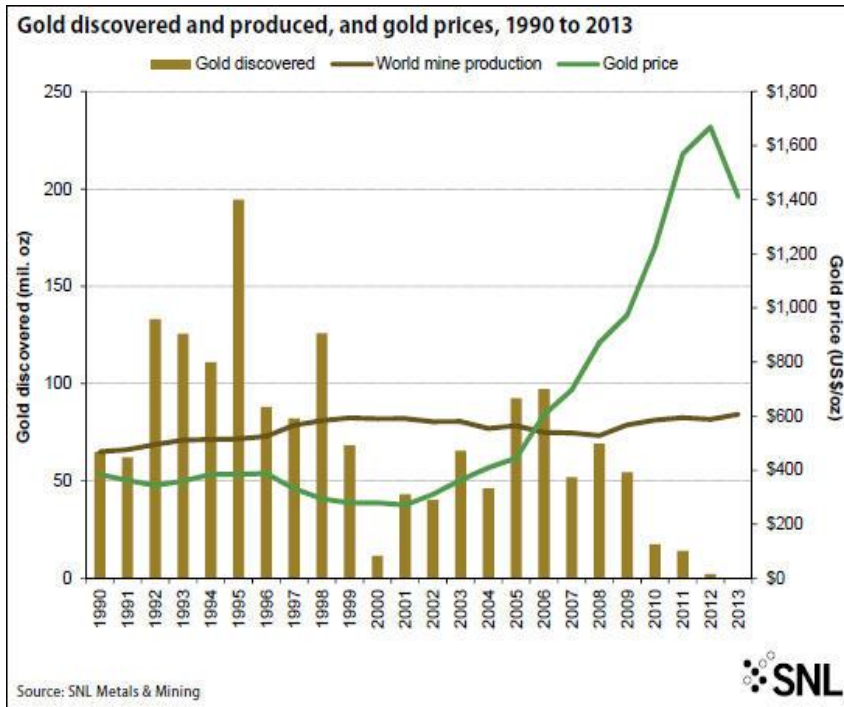
INCREASING DEGREE OF REFRACTORINESS

Main ore types (after Marsden)

- ✓ placers
- ✓ oxidized
- ✓ free milling
- ✓ silver rich
- ✓ iron sulphide bearing
- ✓ arsenic sulphide bearing
- ✓ carbonaceous
- ✓ copper bearing
- ✓ antimony bearing
- ✓ gold telluride bearing



WHERE WILL WE FIND THE GOLD?



- Major gold discoveries have been trending down significantly over time (**1.1 billion ounces in 124 deposits in the 1990s to only 605 million ounces in 93 deposits discovered since 2000**).
- Only **seven** gold deposits holding more than **2 million** ounces have been discovered this decade vs **22** in 1995 alone
- The time from discovery to production increased to **11 years for 57** new mines between 1996 and 2005, and to **18 years for 111** new mines between 2006 and 2013.

INDEPENDENCE IN PROCESS EVALUATION

PROCESS ROUTE DEVELOPERS

BIOX/POX/Albion/Kell

INDEPENDENT PROCESS EVALUATORS

Project Management/Owners' Representative

PROJECT AND OPERATION OWNERS

REFRACTORY GOLD PROCESSES BACKGROUND

- Economics of refractory gold treatment dictate a higher gold content (grade) in the feed or higher gold price-higher capex and opex
- Cost and availability of utilities (electricity and water) is much more demanding as refractory gold has a greater demand for these
- Higher reagent consumption and unit costs for acid neutralisation and cyanide consumption and maintenance compared to conventional process
- Prior to 1986 refractory gold processing was predominantly by Roasting
- Introduction of the use of Bacterial and Pressure Oxidation commenced in 1986 these have grown rapidly at the expense of Roasting due to more stringent air pollution regulations
- Number of refractory gold plants built since 1986:
 - **Roasting – 9**
 - **Pressure Oxidation – 9**
 - **Bacterial Oxidation - 22**

GOLD BIOLEACH TECHNOLOGY PROCESSES

BIOX® Process

Pioneered by Gencor in the early 80's

Later marketed by Goldfields Limited and then BIOMIN which is now part of the Outotec

First commercial plant was Fairview in 1986

BACOX Process

First commercialised at Youamni mine in Western Australia in 1994

Later incorporated at Beaconsfield Gold Mine in Tasmania in 1998 using the Mintek Bactec Technology

Currently marketed by REBgold Corp, a Canadian gold development company

Changchun Gold Research Institute (CCGRI) Process

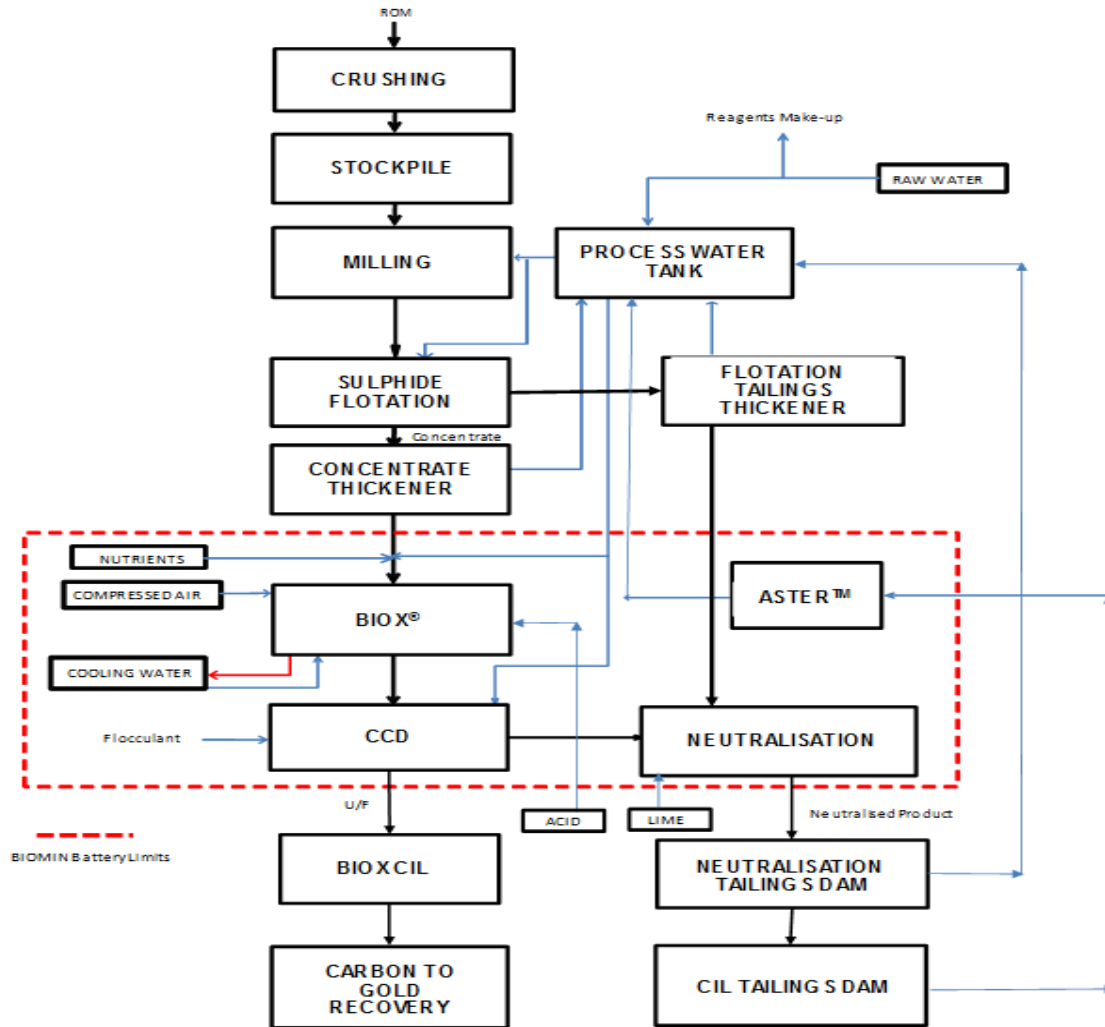
CCGRI provides process technology support for many bio-oxidation plants in China

Different cultures for different conc types

BIONORD®

Developed by Olympiada Mining Combine Russian Federation to accommodate the extremely cold climatic conditions at the Olympiada mine in the Krasnoyarsk Region of Russia

TYPICAL BIOLEACH CIRCUIT



BIOX® PROCESS PLANTS

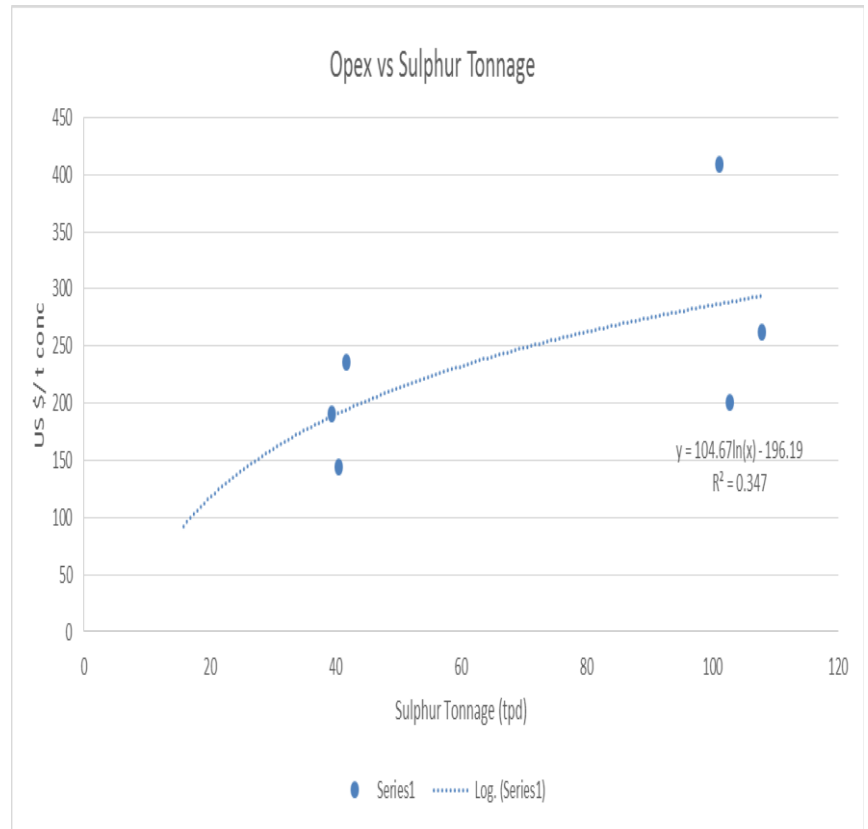
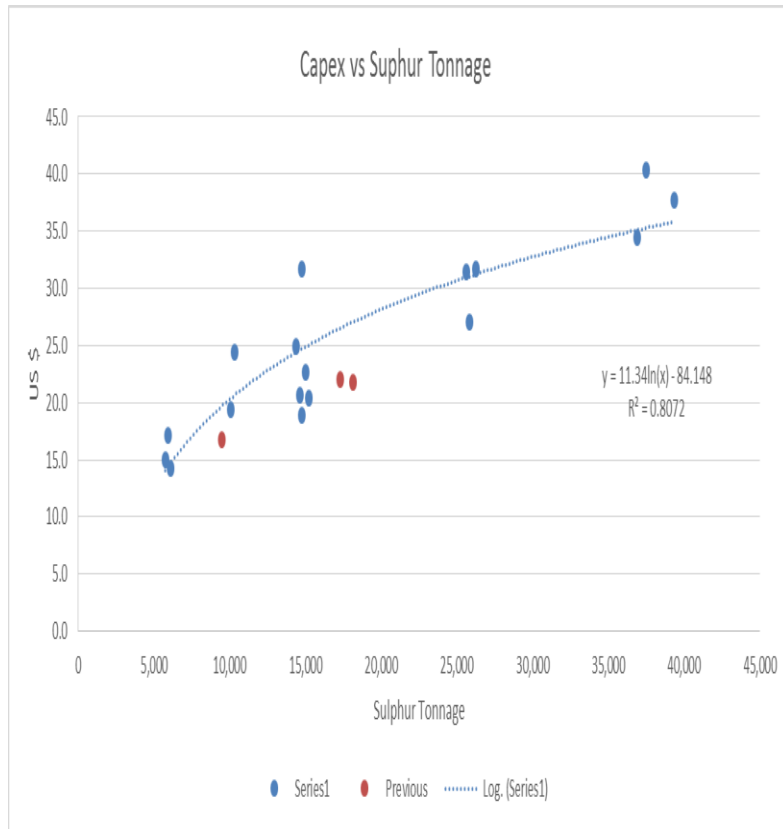
Mine	Year Commissioned	Capacity (tpd Conc)	Reactor Size (m ³)	Status
Fairview, South Africa	1986	62	340	Operating
Saõ Bento, Brazil	1990	150	550	Care and Maintenance
Harbour Lights, Australia	1991	40	160	Decommissioned
Wiluna, Australia	1993	158	480	Care and Maintenance
Ashanti, Ghana	1994	960	900	Care and Maintenance
Coricancha, Peru	1998	60	262	Care and Maintenance
Fosterville, Australia	2005	211	900	Operating
Suzdal, Kazakhstan	2005	520	650	Operating
Bogoso, Ghana	2007	820	1 500	Care and Maintenance
Jinfeng, China	2007	790	1 000	Operating
Kokpatas, Uzbekistan	2009	2138	900	Operating
Agnes, South Africa	2010	20	20	Care and Maintenance
Runruno. Philippines	2016	404	1400	Operating

OTHER BACTERIAL LEACH PLANTS

No.	Mine	Owner	Technology	Location	Capacity (t/d)	Start Up
1	Yantai Gold		CCGRI	Yantai, Shandong	50+80	2000
2	Beaconsfield	BCD Resource	BACOX	Australia	70	2000
3	Laizhou	Tarzan BioGold	BACOX	China	200	2001
4	Olympiada	Polyus	BIONORD®	Russia	1000	2001
5	Tianli		CCGRI	Fengcheng, Liaoning	100	2003
6	Axi		JLMRI	Yining, Xinjiang	50+80	2004
7	Sanhe		CCGRI	Dexing, Jiangxi	70	2006
8	Innovation		CCGRI	China	150	2007
9	Jinchilling		CCGRI	Zhaoyuan, Shandong	100	2007

BACTERIAL OXIDATION ECONOMICS DRIVER – Gold:Sulphur Ratio

A gold-to-sulphur ratio of **>0.7 g/t of Au per % of sulphur** is usually required in the concentrate for an economically-viable process



BACTERIAL OXIDATION ECONOMICS DRIVER

S²⁻:CO₃²⁻ Ratio

Typically, the S²⁻-to-CO₃²⁻ ratio in the feed concentrate should be between 5 and 6

- The CO₃²⁻ dissolves, evolving CO₂ to support the biological growth rate in the primary bacterial oxidation reactors
- Required ratio will vary, according to type of sulfides, sulfide oxidation levels in the primary reactors, and CO₃²⁻ solubility
- More CO₃²⁻ will result in H₂SO₄ addition to the primary bacterial oxidation reactors to maintain the pH at the required level
- Less CO₃²⁻ will require CaCO₃ or CO₂ gas to be added to the reactors to provide the carbon needed to support bacterial growth

BACTERIAL OXIDATION ENVIRONMENTAL DRIVER : Fe:As Ratio

- For the production of stable arsenic-bearing precipitates using a low-temperature lime precipitation process, a molar **iron-to-arsenic ratio of >3** is required in the leach liquor

BIOLEACH TECHNOLOGICAL DEVELOPMENTS

IMPROVING CONCENTRATE QUALITY THROUGH OPTIMISED MILLING AND FLOTATION

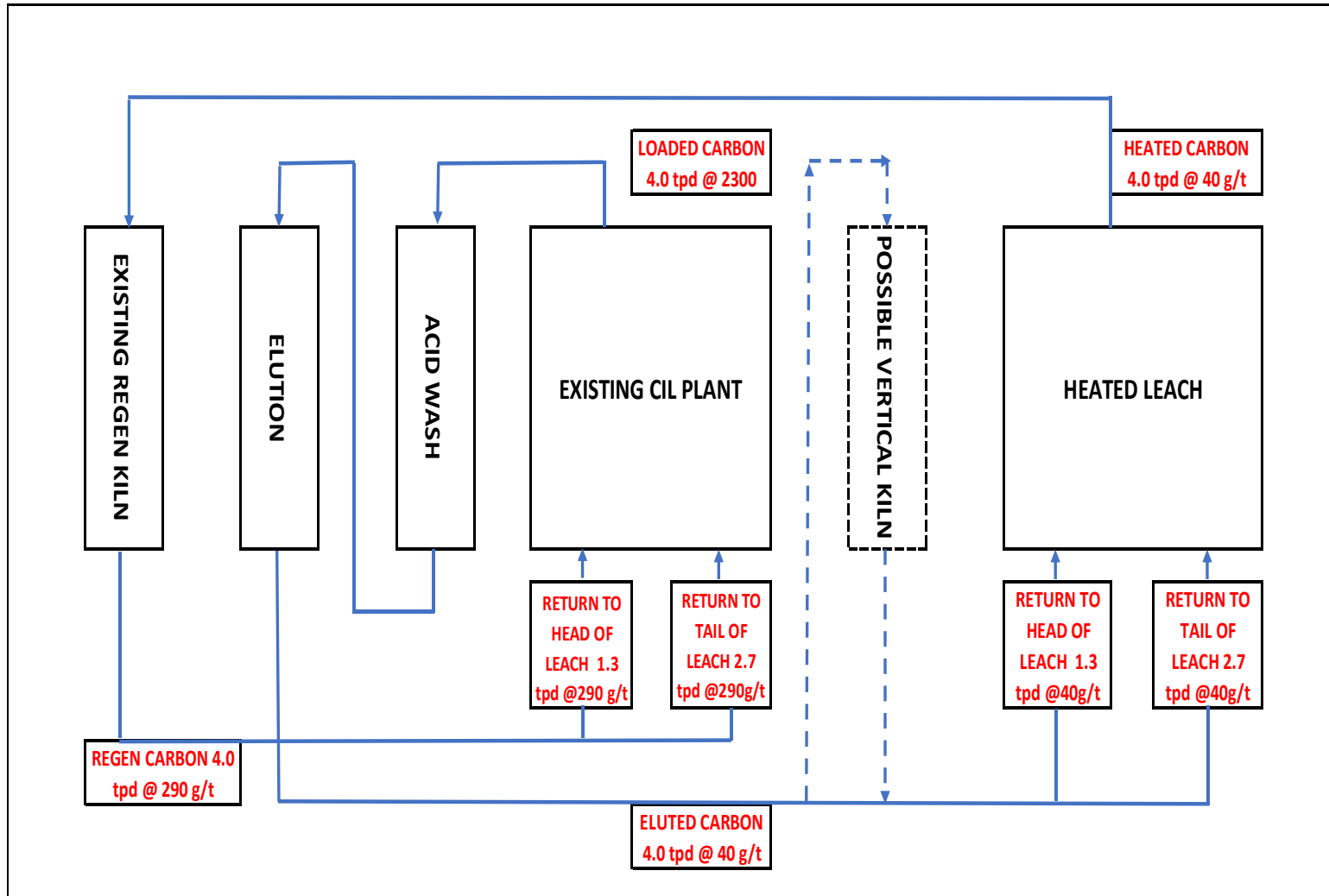
- **Gold:Sulphur Ratio >0,7**
- **$S^{2-}:CO_3^{2-}$ Ratio of 5-6**
- **Fe:As Ratio >3**

BIOLEACH TECHNOLOGICAL DEVELOPMENTS

FOSTERVILLE HEATED LEACH PROCESS FOR PREG-ROBBING

- Developed by Fosterville Gold Mine, Victoria, Australia (now owned by Crocodile Gold Company, Canada)
- To solve preg-robbing problem in CIL circuit caused by carbonaceous material(bituminous coal)
- After flotation, bio-oxidation, CCD washing and conventional CIL, the slurry is passed counter-currently to activated carbon through a 5 stage heated leach circuit.
- Gold is desorbed from the carbonaceous material in the first 3 stages at upto 70 C. then is adsorbed by the activated carbon in the final 3 stages after cooling in a heat exchanger and by cooling water addition
- Based on lab and pilot plant scale studies, a commercial circuit was installed and commissioned in 2009 – gains in gold recovery of 4-14 % are reported.

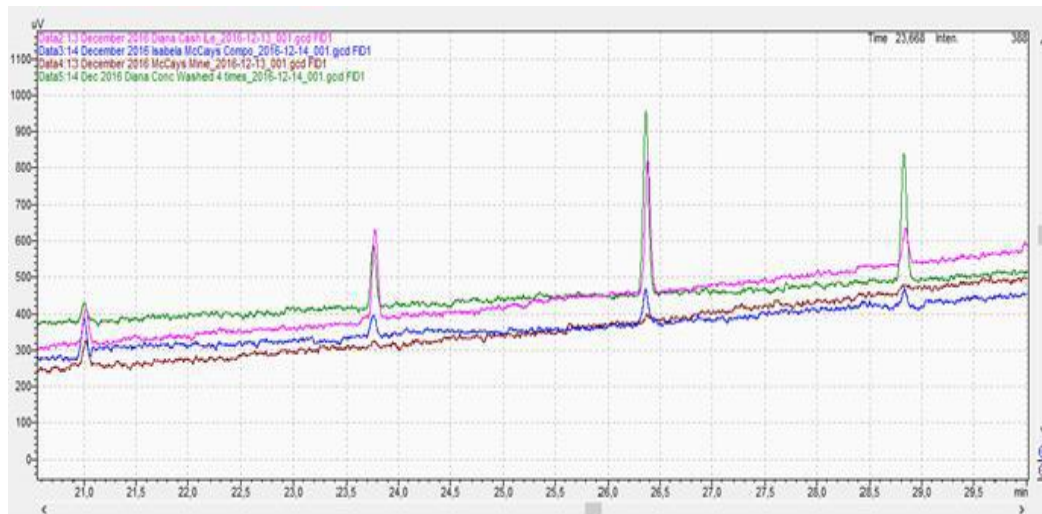
FOSTERVILLE HEATED LEACH PROCESS FOR PREG-ROBBING



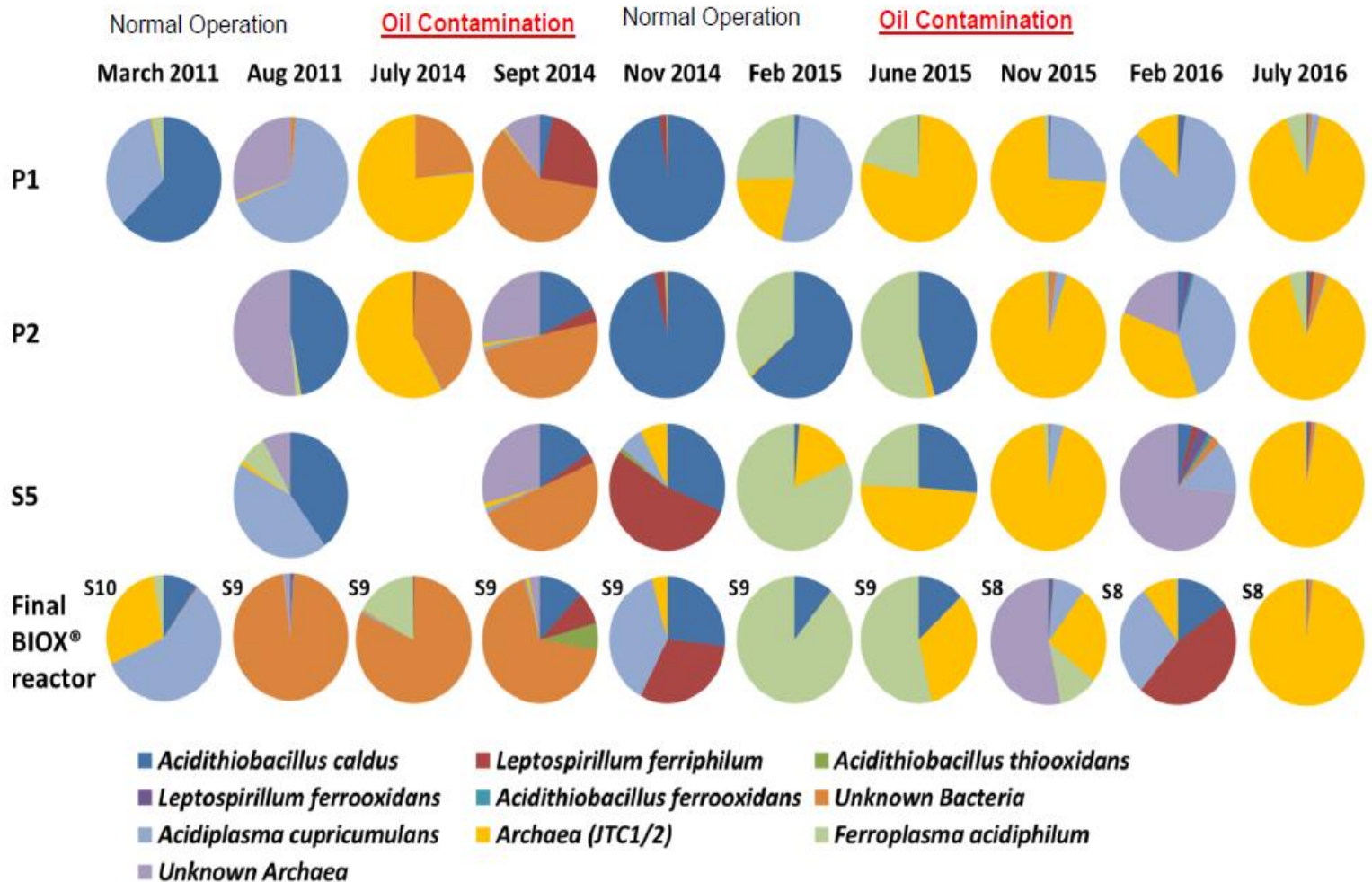
BIOLEACH TECHNOLOGICAL DEVELOPMENTS

MANAGEMENT OF HYDROCARBON CONTAMINATION

- Ingress of Hydrocarbons into the BIOX plant resulting in inhibition of bacterial activity
- Avoidance of ingress through robust design
- Use of Gas Chromatography for Plant Monitoring and Diagnostics
- Identifies Long and Short chain hydrocarbons that can be traced to source for identification of source of problem and possible solutions



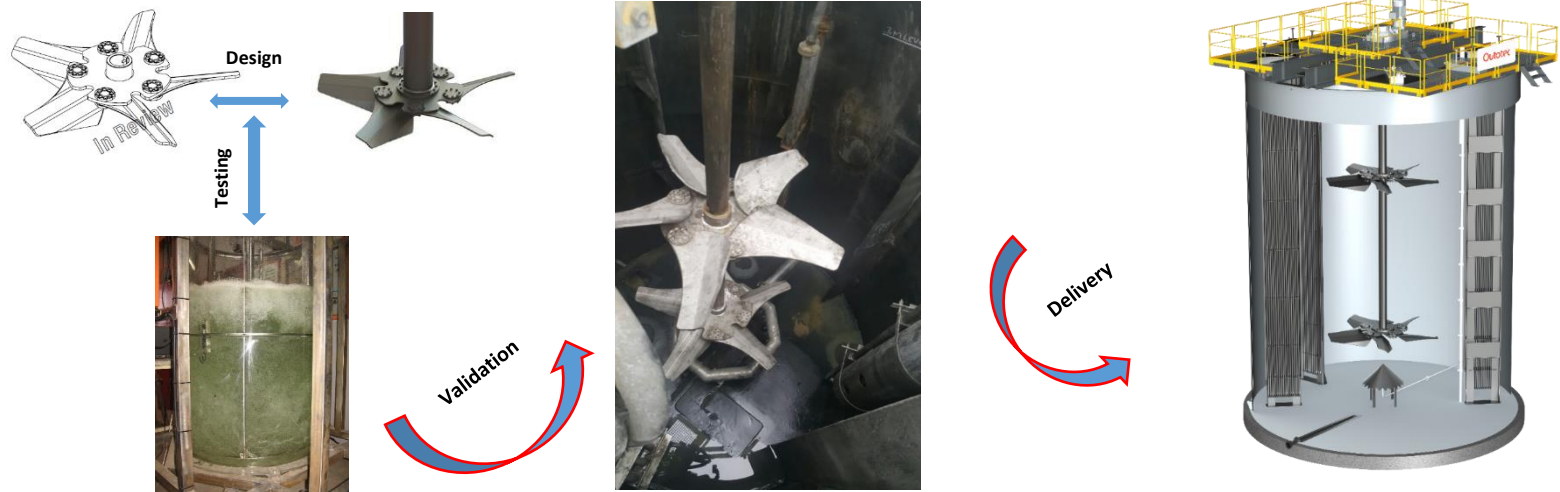
MONITORING OF MICROBIAL SPECIES (Changes due to Hydrocarbon Inhibition)



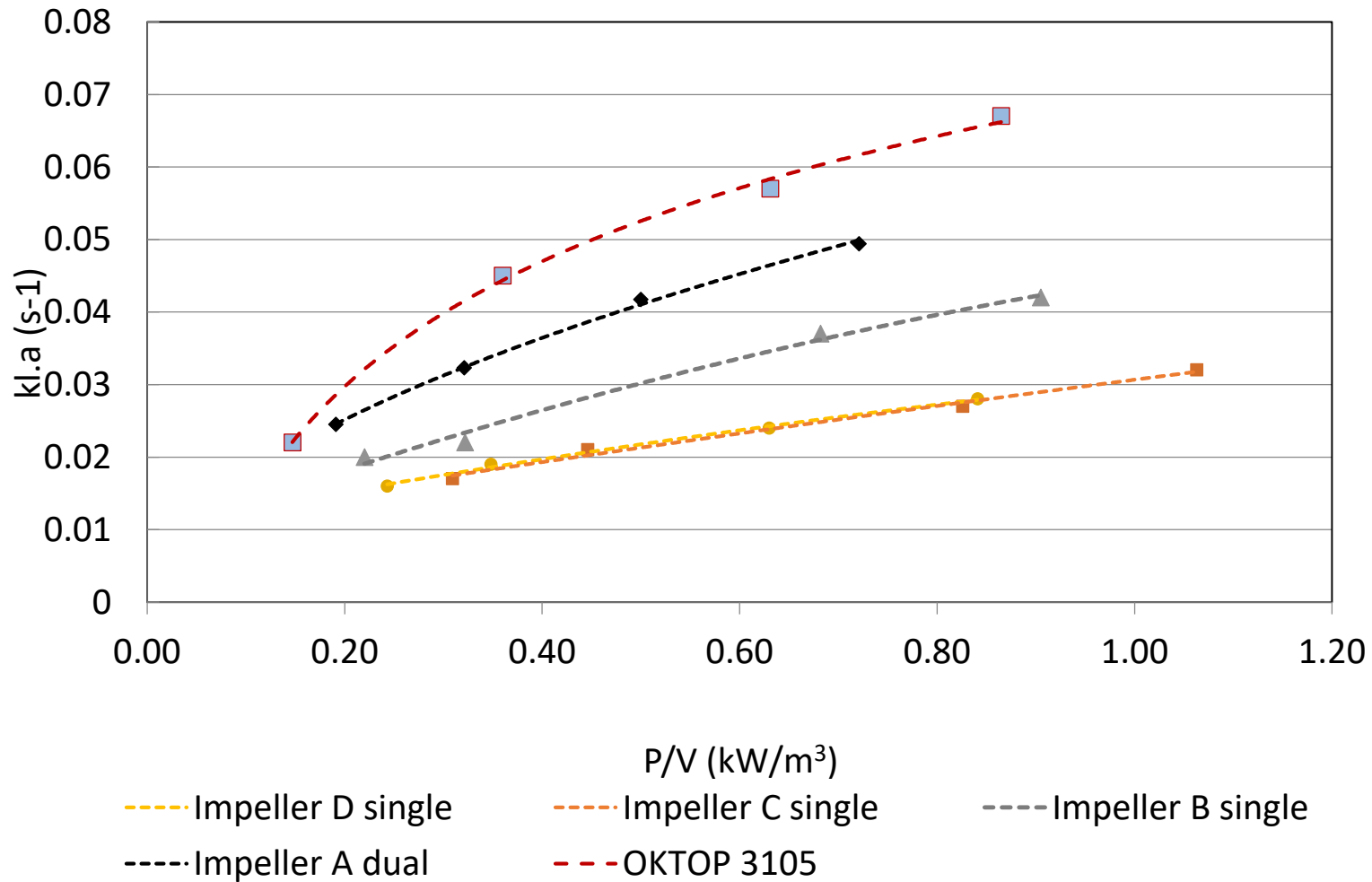
BIOLEACH TECHNOLOGICAL DEVELOPMENTS

REACTOR AGITATOR MECHANISM DESIGN

Generation IV BIOX[®] OKTOP 3105



REACTOR AGITATOR MECHANISM DESIGN

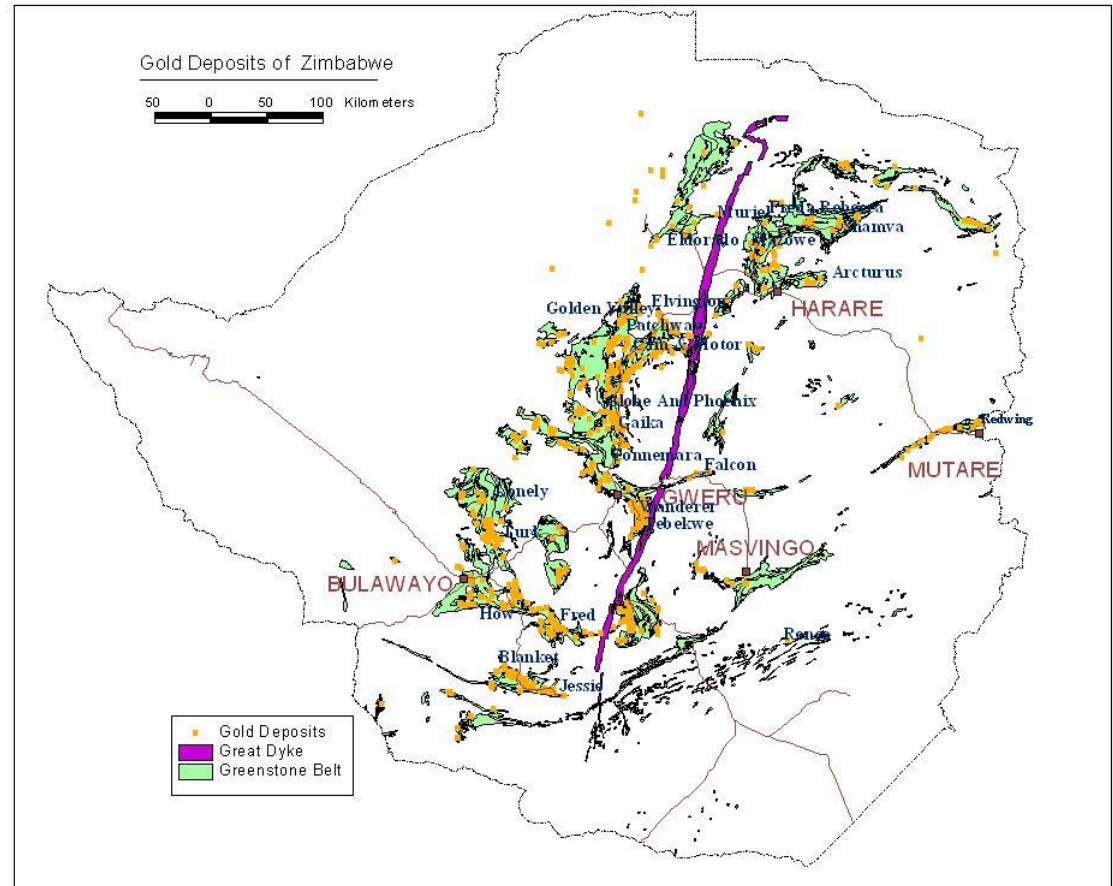


REFRACTORY GOLD OCCURENCES IN ZIMBABWE

- Study by THC Nutt for the Chamber of Mines in 1993 reported potential for **+/-2Moz** of refractory gold ore as “proven”.
- Based on the studies that we are currently involved we estimate resources are **>30Moz** (subject to confirmation by drilling)

Gold Mining Districts

- ✓ North
 - Harare-Shamva-Norton GB
 - Chinhoyi-Guruve GB
 - Beatrice GB
- ✓ Midlands
 - Kwekwe-Munyati GB
 - Kadoma—Chegutu GB
- ✓ South-Central
 - Gweru-Shurugwi GB
 - Mwanesi-Mvuma GB
 - Nkayi-Silobela GB
- ✓ South-West
 - Bulawayo-Bubi GB
 - Filabusi GB
 - Fort-Rixon-Shangani GB
 - Gwanda-Lower Gwanda GB
- ✓ South-East
 - Masvingo-Mashava GB
 - Mberengwa GB
 - Buhwa GB
 - Mutare GB



SNAPSHOT OF KWEKWE ROASTING PLANT

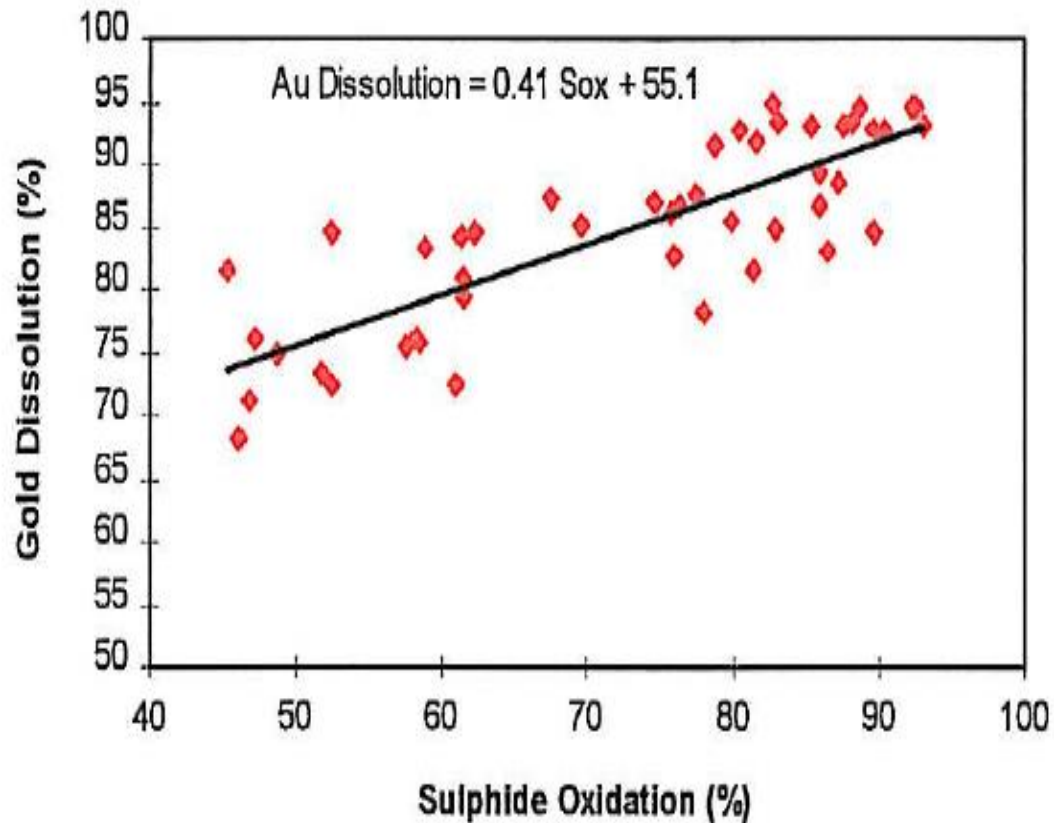
Mine	Approximate Tonnage	
	tpm	tpd
C-Mine	30	0.98
Sheba	6	0.20
Up-to-Date	3	0.10
Grandeur	5	0.16
Owl	3	0.10
Hamburg	7	0.23
Criterion	11	0.36
Joyce	29	0.95
Durban	5	0.16
Hannie	21	0.69
Commoner	43	1.41
Chaliesona	38	1.25
Venice	41	1.34
Anzac	117	3.84
Bar 20	145	4.75
Globe & Phoenix	149	4.89
Riverlea	184	6.03
Indarama	210	6.89
Cam and Motor	296	9.70

BIO-OXIDATION PILOT PLANT CAMPAIGN ON KWEKWE ROASTING PLANT FEED

Phase Of Operation	Period Of Operation		Retention (days)	Remarks
	Start	End		
1	27/01/96	31/01/96	9	Continuous Operation
2	31/01/96	10/02/96	8	
3	10/02/96	02/03/96	7	
4	02/03/96	20/03/96	6	
5A	20/03/96	22/05/96	5	
5B	22/05/96	30/06/96	5	Limestone pH control

Retention (Days)	Tank Number	Sulphide Oxidation (%)		Au Dissolution(%)	
		GENCOR	Roasting Plant	GENCOR	Roasting Plant
8	1	58.8	51.8	62.4	64.3
8	2	74.9	64.5	72.2	75.4
8	3	87.7	77.5	82.8	92.5
8	4	92.7	80.3	91.9	92.8
8	O/F	95.7	92.4	95.0	95.3
7	1	65.3	44.6	74.3	64.5
7	2	70.2	51.5	66.3	73.9
7	3	79.2	68.7	71.0	83.0
7	4	81.1	79.5	83.8	89.6
7	O/F	89.9	83.9	93.7	93.3
6	1	71.4	62.5	73.9	62.5
6	2	69.5	69.4	75.8	74.9
6	3	85.9	81.4	92.1	85.6
6	4	92.8	86.3	93.2	90.9
6	O/F	95.1	89.7	94.1	93.6
5A	1	50.8	48.6	72.0	70.7
5A	2	59.8	60.3	78.0	78.1
5A	3	72.1	73.1	87.1	85.6
5A	4	80.8	81.1	88.0	88.2
5A	O/F	86.8	86.2	93.0	92.9
5B	1	54.4	47.4	77.7	74.3
5B	2	65.5	63.2	83.1	80.8
5B	3	81.0	77.1	84.3	86.2
5B	4	85.9	83.8	88.8	88.4
5B	O/F	86.8	83.0	93.3	92.4

BIO-OXIDATION PILOT PLANT CAMPAIGN ON KWEKWE ROASTING PLANT FEED



END THANK YOU

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