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Including

Refractory and Complex Gold Ores Forum

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ALTA 2018 GOLD-PM SESSIONS

Including

Refractory and Complex Gold Ores Forum

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CONTINUED DEVELOPMENT OF THE BIOX PROCESS FOR THE TREATMENT OF REFRACTORY GOLD ORES

By

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ABSTRACT

The BIOX Process, for the treatment of refractory gold concentrates, has been commercially available for over 30 years with a total of 13 commercial BIOX plants commissioned during that time. All rights to the BIOX process were acquired in 2015 by Outotec, and Outotec continued to develop the technology. This paper will give feedback on two important Outotec development initiatives, the development of the MesoTherm process to reduce cyanide consumption following biooxidation and the development of an OKTOP BIOX reactor and agitator for improved mixing efficiency in the BIOX reactors.

The MesoTherm process utilizes a combination of the traditional BIOX mesophile process for the primary biooxidation stage, followed by a thermophile biooxidation stage to complete the oxidation. The higher oxidation rates and more complete oxidation at the higher temperature results in lower cyanide consumption during subsequent leaching of the biooxidation product. Development of the process included several stages of batch and continuous pilot plant testing. The final stage in the development is the successful operation of a 21 m^3 demonstration tank, currently in operation at the Fairview BIOX plant. This paper will describe the most important results achieved during the development of the process.

The BIOX agitator performance is critical for the overall performance and efficiency of the BIOX process. The Outotec OKTOP® 3105 dual impeller was developed to give superior gas handling and oxygen mass transfer rates under typical BIOX operating conditions. The Outotec OKTOP® 3105 unit was tested in water and BIOX slurry using a 21 m^3 test reactor at the Fairview Mine in South Africa. This paper will detail the results achieved during the test program benchmarked against the standard single high solidity axial down pumping impeller used to date in most BIOX applications.

Keywords: Gold Recovery, BIOX, Biooxidation, Cyanide Consumption, Agitation, Oxygen Utilization, OKTOP® 3105

1. Introduction
2. MesoTherm Process
   - Introduction
   - Process Development
   - 21 m^3 Fairview Demonstration Plant
3. Agitator Design Development
   - Introduction
   - 21 m^3 Fairview Water Tests
   - 21 m^3 Fairview Slurry Tests
   - Commercial Implications

BIOX: Refining a World Class Technology

1986 - 2010	2011 & 2012	2013 & 2014
BIOX G1, G2	BIOX G3	BIOX G4
Current BIOX® Design	**Ease of Operation and Maintainability**	**10 % Reduction in Capex & Opex**
• BIOX® design is sound • Established testing, design and commissioning procedures	• Increase robustness of BIOX® design • Improve BIOX® service offering • Improve knowledge base & application	• Focussing on main capital and operating cost items

Factors affection BIOX® performance:
• Mechanical failures
• Maintenance issues
• Process control
	• Attend to major problem areas:
	  • BIOX® frothing
	  • Sparge ring design
	  • CCD#1 gold losses
	  • Agitator failures
		• Improved agitator system
		• Materials of construction
		• High temperature bugs

MesoTherm Process

Development & 21 m^3 Fairview Demonstration Trial

Introduction

- The BIOX process uses mesophilic microorganisms to break-down sulphide sulphur matrices, thus liberating gold
- The BIOX product residue is characterised by the presence of reactive polysulphides which react with CN^- and forms thiocyanate:

$$S_xS^{2-} + CN^- \rightarrow [S_{(x-1)}]^{2-} + SCN^-$$

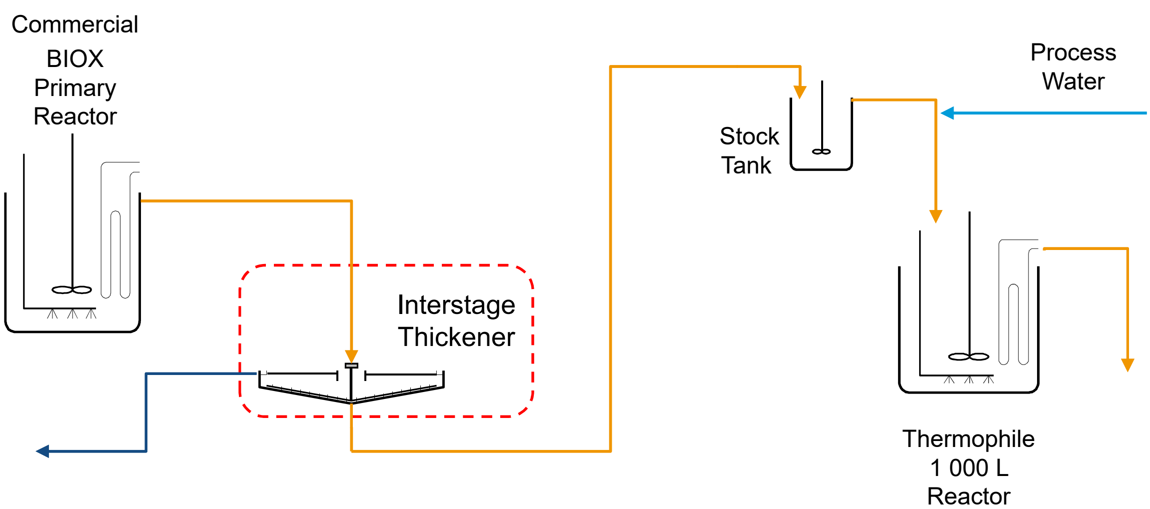
$$S_2O_3^{2-} + CN^- \rightarrow SO_3^{2-} + SCN^-$$

- This can increase cyanide consumption which can be one of the highest reagent costs

Introduction: the MesoTherm Process

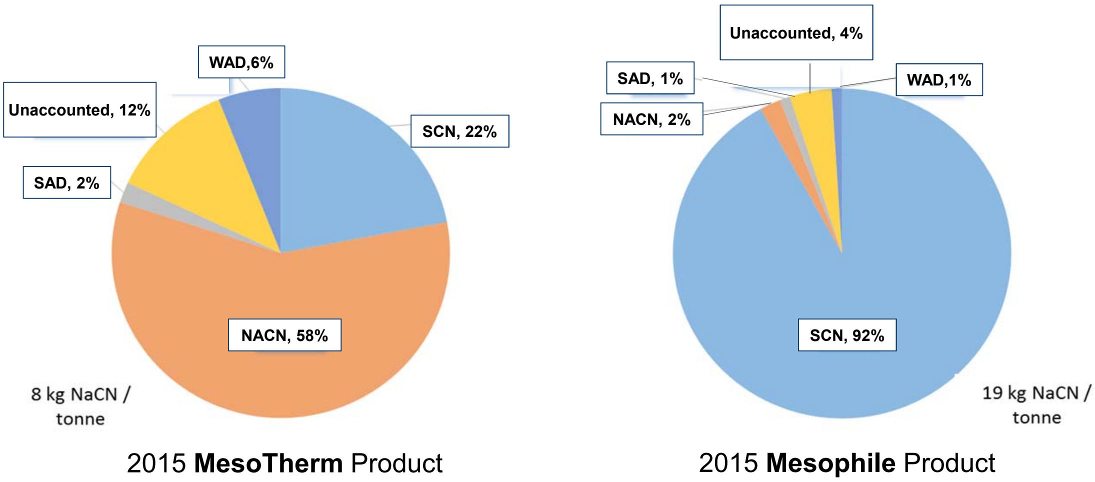
- MesoTherm = combination mesophile (40 °C) and thermophile (65 °C) biooxidation
- Standard BIOX process for the primary oxidation ~ 60 – 70 % Sox
- High Temperature to complete the oxidation
  - More complete oxidation of the intermediate sulphur species
  - Resulting in lower cyanide consumption during leaching
- Initial process development done in 2005/6
- Development resumed in 2012:
  - Lab culture development and process verification
  - 2015 - 2016: 1 m^3 continuous pilot reactor operated at the Fairview mine
  - 2017 – 2018: 21 m^3 continuous demonstration reactor operated at the Fairview mine

MesoTherm Process Flow Sheet



MesoTHERM Technology

Fairview Leach Residue Solution Cyanide Speciation:



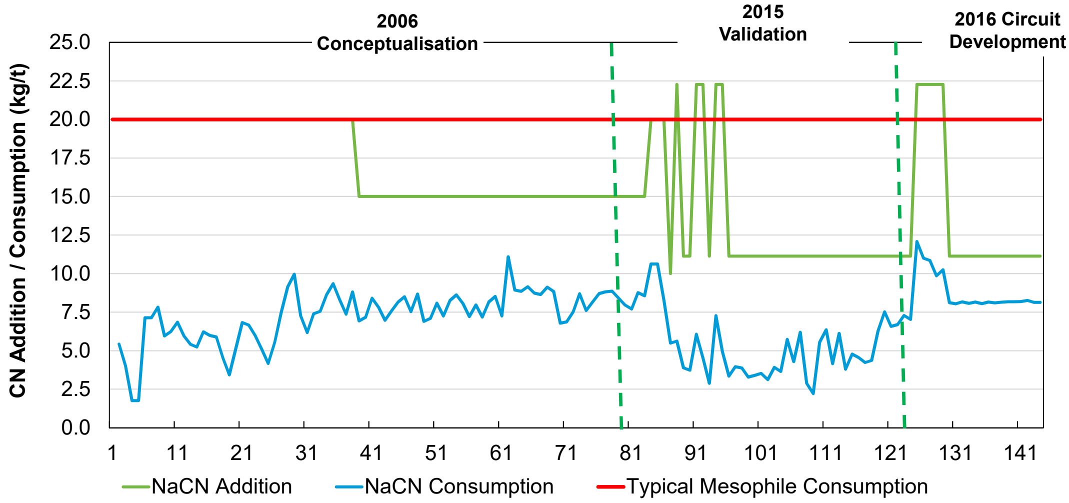
MesoTherm Process Development Stages

Description	Units	Opportunity Checking	Concept Development	Commercialisation
Reactor Size	m^3	0.24	1.0	21
Solids	%	15 – 20	15 – 17	17
Sulphate	g/L	50	105	100
NaCN	kg/t	8 - 10	7 - 11	< 10

1 m^3 Test Reactor Set-up and Objectives

- **Demonstrate a stable thermophile reactor operation & Culture robustness:**
  - Feeding diluted partially oxidised BIOX material
  - Target 2.5 day RT
  - Match or exceed plant sulphide oxidation
- **Demonstrate reduction in Cyanide**
  - More complete oxidation of the intermediate sulphur species
  - Resulting in lower cyanide consumption during leaching

1 m^3 Demonstration Trail – Summary of Results



NB – Comparable gold dissolution in batch leach tests

21 m^3 Reactor Set-up and Objectives

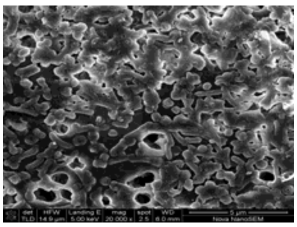
Reactor Operational Philosophy

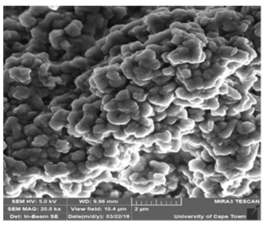
- Fully integrated with plant SCADA
- Ability to feed fresh and / or oxidised slurry
- Chimney for oxygen off-gas analyses
- Routine measurements:
  - DO_2, pH, Redox, Temperature
  - Fe^{2+}, mV, Sulphide, Fe, Au
- Daily cyanidations

21 m^3 Reactor Set-up and Objectives

- **Demonstrate a stable thermophile reactor operation & culture robustness**
  - Feeding various blends of fresh and partially oxidised slurry
  - Operate the reactor at impeller tip speeds expected in commercial operation
  - Determine extent of sulphide oxidation and compare with commercial plant oxidation
  - Show reactor operation using air only is feasible
- **Validate previous 240 litre and 1 000 litre performance results**
  - Achieve same cyanide consumptions to previous opportunity checking and concept development phases
  - Achieve same gold dissolutions to previous opportunity checking and concept development phases
  - Achieve improved cyanide consumption and similar gold dissolutions as commercial plant

Mesophiles



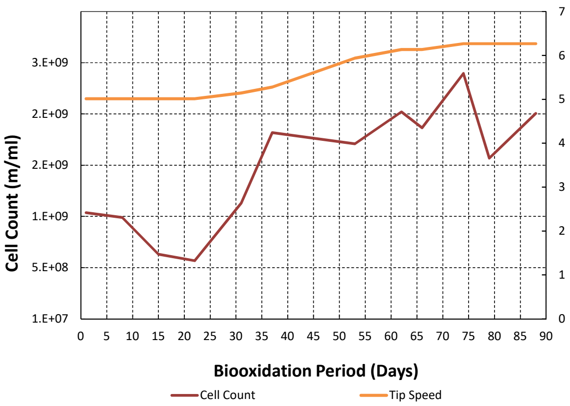


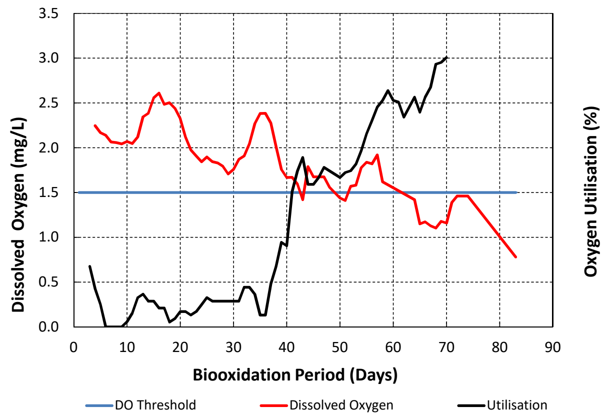
Thermophiles

21 m^3 Trial – Culture Robustness and Stability

No mechanical shear effects – culture operated well at commercial tip speeds

No challenges with maintaining DO at high slurry temperatures



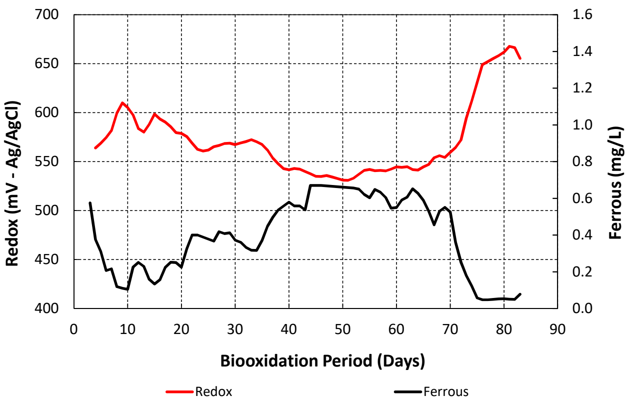


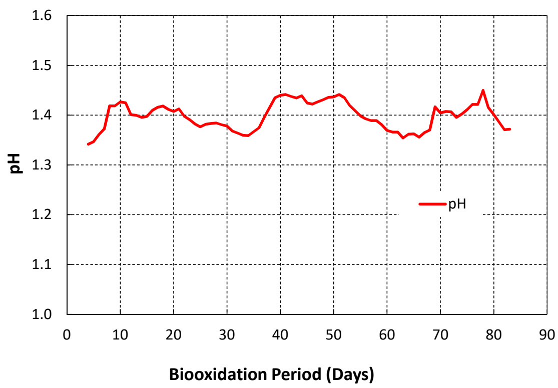
21 m^3 Trial – Culture Robustness and Stability

High rates of ferrous ion oxidation

Stable pH control

Standard microbial parameters measured / similar to mesophile BIOX®

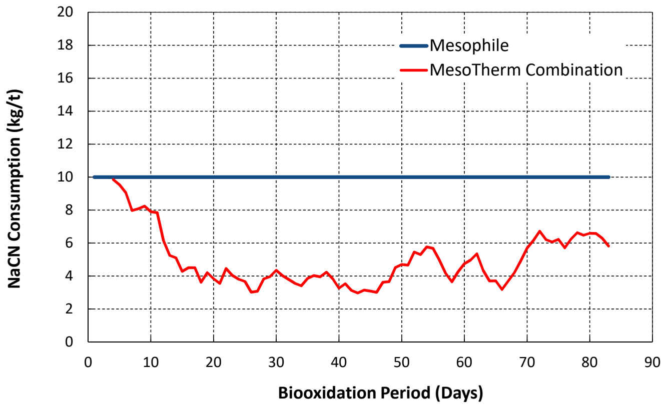




21 m³ Trial – NaCN Consumption Results

Excellent technology validation at the larger demonstration scale

Lower NaCN consumption than plant



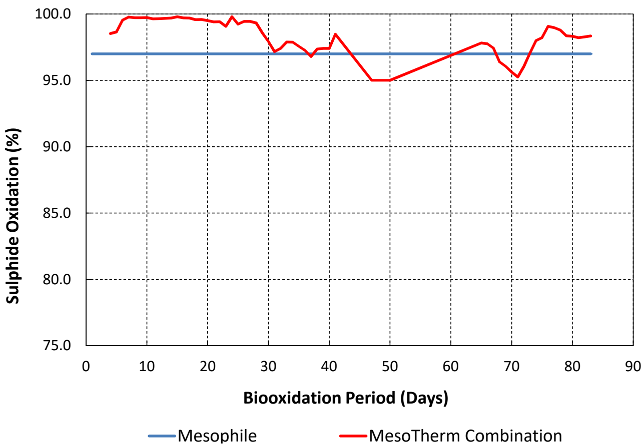
Description	Units	Opportunity Checking	Demonstration	Mesophile Comparison
Period		2006	2018	-
Reactor Size	m^3	0.24	21	Plant Sample
Solids	%	15 – 20	15 – 17	20
Sulphate	g/L	50	15 – 70	~120
Average NaCN	kg/t	7.5	5.0	10.0

Bottle roll test results

21 m³ Trial – Sulphide Oxidation Results

Excellent technology validation at the larger demonstration scale

Similar sulphide oxidation to commercial plant

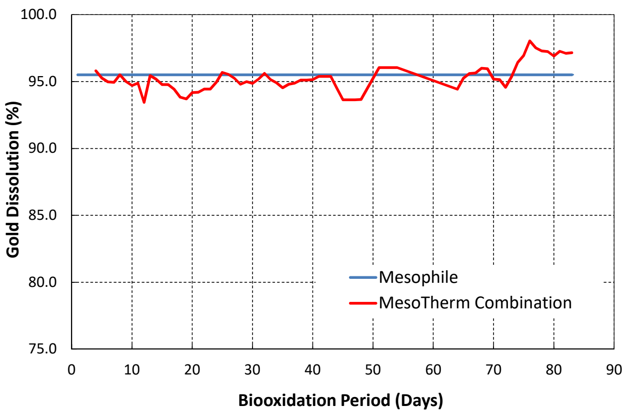


Description	Units	Opportunity Checking	Demonstration	Mesophile Comparison
Period		2006	2018	-
Reactor Size	m^3	0.24	21	Plant
S^{2-} Oxidation	%	96	97	97
Average NaCN	kg/t	7.5	5.0	10.0

21 m^3 Trail – Gold Dissolution Results

Excellent technology validation at the larger demonstration scale

Similar gold dissolutions obtained on mesophile only product



Description	Units	Opportunity Checking	Demonstration	Mesophile Comparison
Period		2006	2018	-
Reactor Size	m^3	0.24	21	Plant
Au Dissolution	%	96	96	96
Average NaCN	kg/t	7.5	5.0	10.0

21 m^3 Trail – Conclusions and next steps

Operation of the larger 21m^3 reactor allowed validation of the previous 0.24 m^3 and 1 m^3 trials

- This scale allowed some engineering scale up concepts to be investigated
  - No mechanical shear effects observed at commercial reactor tip speeds
  - Adequate mass transfer rates achieved at the higher slurry temperatures
- Operation of the larger 21m^3 reactor allowed validation of the previous 0.24 m^3 and 1 m^3 trials
  - MesoTherm combination trial achieved an average NaCN consumption of 4.9 kg NaCN / tonne concentrate
  - Sulphide oxidations with this combination matched plant performance (~ 97%)
  - Gold dissolutions yielded similar results to that of mesophile plant product batch leaches (96%)

Future work looking at:

- Inoculation of a commercial reactor for plant personnel to operate solely
- Plant personnel to evaluate robustness and operability with reactor in-situ (part of plant)
- Incorporate MesoTherm design protocols in standard BIOX circuit design model

Agitator Development Program

21 m^3 Test Reactor Results

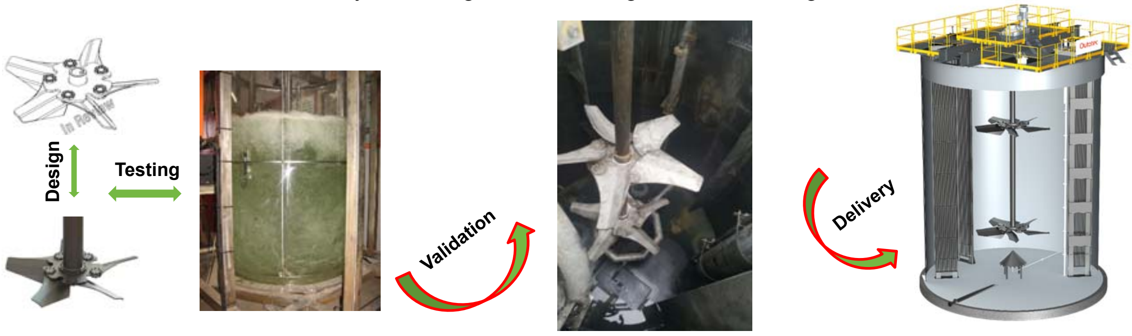
Background and Objectives:

- Agitation and aeration constitute significant portion of BIOX capital and operating cost:
- Long term R&D program to maximize oxygen delivery at lower specific power consumption, thereby reducing capital and operation expenditure
- Dual impeller configuration showed step change performance in slurry trials
- Very strict tollgates and rigour applied in our evaluation
- Commenced OKTOP 3105 trials in 1st Q 2016 with same protocols

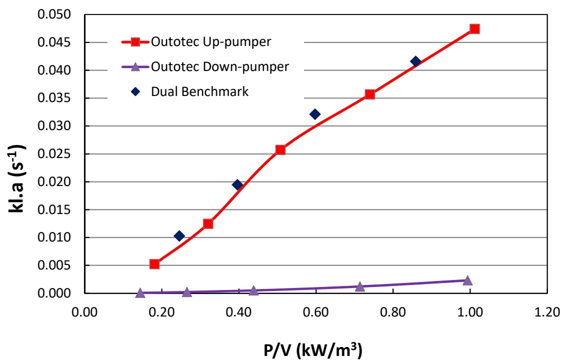
OKTOP 3105 – 21 m^3 Test Program

Two stage development program:

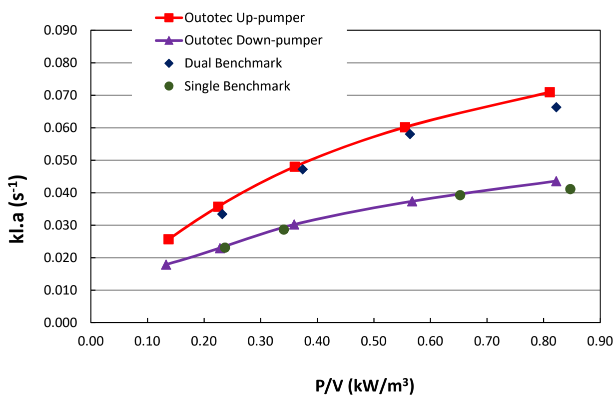
- Stage 1 – Water tests evaluating 2 different dual impeller configurations:
  - Up-pumping top impeller and Down-pumping bottom impeller
  - Down-pumping top and bottom impellers
- Stage 2 – Slurry tests:
  - Continuous BIOX slurry trail using the best configuration from stage 1



OKTOP 3105 Water Test Results – k_La Measurements



Water Tests – Ungassed Condition



Water Tests – Typical BIOX primary tank gas rate

OKTOP 3105 Water Tests - Conclusions

- Down-pumper yielded greater gas hold–up but lower k_La values across all superficial gas velocities tested
- Lower surface effect (turbulence) for dual down-pumping configuration
- Significant surface air induction using Up-pumping configuration
- OKTOP 3105 dual Up-pumping configuration yielded similar results to dual impeller benchmark
- OKTOP 3105 dual Down pumping configuration yielded similar results to single impeller benchmark
- OKTOP 3105 dual Up-pumping configuration selected for slurry trial

OKTOP 3105 BIOX Slurry Test – Objectives

- Operation of 21 m^3 reactor as Primary BIOX reactor
- Operating reactor in parallel to Fairview primary BIOX reactors
  - 2.8 day retention time
  - 25 % solids in the feed
  - Same control parameters

<u>Objectives of Slurry Tests</u>

- Determine the performance of the OT 3105 on a continuous basis:
  - Sox (%) achievable under specified conditions
  - Oxygen mass transfer coefficient
  - Agitator power & aeration rate required to maintain DO

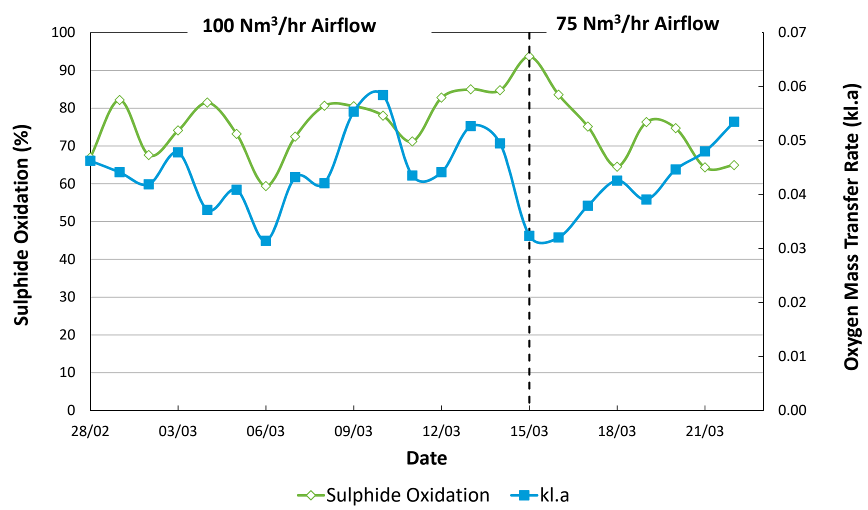
OKTOP 3105 BIOX Slurry Test – Sox Results

Retention Time (d)	Airflow (Nm³/h)	Days	S^{2-} Feed (%)	S^{2-} Prod (%)	Sox[(1)] (%)
2.8	100	15	8.94	2.49	77.1
2.8	75	6	9.04	2.59	71.9

(1) – taking mass change into consideration

- Sox in line with primary BIOX reactors recorded
- High bacterial activity maintained throughout test program

OKTOP 3105 BIOX Slurry Test – Sox & k_La Results



OKTOP 3105 BIOX Slurry Test – Results Comparison

Description	Units	Single Hydrofoil Benchmark	Dual Hydrofoil Benchmark	OKTOP 3105 @ 100 Nm^3/h	OKTOP 3105 @ 75 Nm^3/h
Retention Time	d	2.8	2.8	2.8	2.8
Feed Density	%	25	20	25	20
Average Feed S^{2-}	%	9.1	9.9	8.9	9.1
S^{2-} Oxidation	%	74	65	77	72
Aeration rate	Nm^3/h	102	100	100	75
k_L.a	**s^{-1}**	**-**	**-**	**0.044**	**0.043**
Motor power draw	kW	26	10	9.9	8.2
Power/unit volume	**kW/m^3**	**1.58**	**0.59**	**0.58**	**0.48**

Commercial Implications

Case Study – BIOX® Primary Reactor

Description	Units	Gen III	2018
Sulphide Design	(%)	15	15
Airflow	(Nm^3/hr)	7 667	7 667
Required Mixer Power	**(kW)**	**250**	**200**
Estimated Blower Power (1)	(kW)	810	754
Specific Reactor Power	**(W/m^3)**	**894**	**715**
Mass Transfer Coefficient	(s^{-1})	0.025	0.025

(1) – Improvements in blower design and efficiency

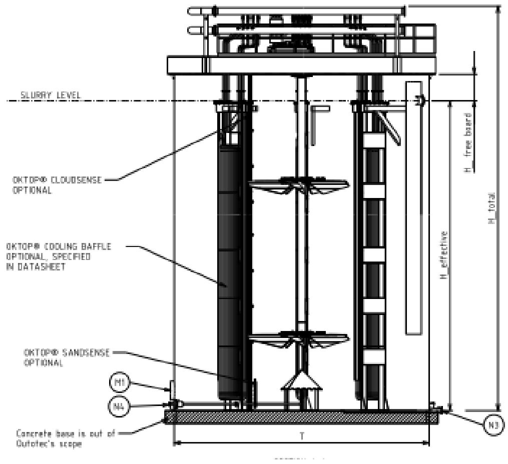
Commercial Implications

Capital Cost Saving:

- BIOX Agitator Capital Savings ~ 15%
- BIOX Blower Capital Savings ~ 10%
- Overall BIOX Capital Savings ~ 5%

Operating Cost Saving:

- BIOX Agitator Power Savings ~ 20%
- BIOX Blower Power Savings ~ 8%
- Overall BIOX Power Savings ~ 10%



Conclusions – OKTOP Agitator Development Program

- Successful operation of 21 m^3 reactor as Primary BIOX reactor
  - High bacterial activity maintained
  - Confirmed oxygen mass transfer capabilities
  - Confirmed design and scale-up calculations
- Produced similar to lower power utilised per unit volume than the benchmark dual hydrofoil
- Significant Capex and Opex saving compared to GEN III BIOX Design