IXOS® Technology – Case Study Details Excellent Results for Hydrometallurgical Precious Metals and Base Metals Recovery

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Abstract

Today's mining companies must focus on technologies that provide improved recovery, low cost of operation, and environmental benefits that have the potential to enhance the overall rating of the company's environmental, social and governance (ESG) posture. This paper provides an overview of the projected benefits of using IXOS® Technology for gold and silver recovery from heap leaching with a throughput of 7.2M tons per annum @ 0.49g Au/t of ore. Based on recent test work at a client's site, data analysis confirmed higher adsorption recoveries compared to activated carbon in the laboratory for single pass, estimated reduction of 1,164.5 tons of CO_2/year to carbon emission (potential positive ESG impact), an operational cost expenditure cost savings of US$0.61M/year due to no thermal regeneration requirement, and operational cost expenditure savings due to reduced fuel usage, an improved energy cost savings of US$0.05M / year due to faster stripping kinetics and efficiency, and cost savings of US$0.22M /year due to lack of carbon fine losses. Thus, an estimated annual savings of $0.88M/year or US$0.122/ton of ore heaped.

IXOS® Technology uses a unique application of a branch of nanotechnology called "MIPS" – Molecularly Imprinted Polymers. IXOS® attributes include preferential adsorption of gold and silver cyanide complexes from mixed metal cyanide solution, mercury remediation. And gold recovery is not impacted by high silver or copper. IXOS® beads can be used for the recovery of copper cyanide after all the gold and silver have been recovered from the mixed metal cyanide complex solution. IXOS® beads are non-reactive with kerosine when used in gold and silver recovery, where kerosine is used to blind the carbonaceous ore during gold leach. Stripping of the adsorbed precious metals is conducted under ambient pressure and low temperatures (60 degrees C) at a significantly reduced strip time of three hours per batch. There is also an opportunity for additional cost savings without the thermal regeneration required with activated carbon. This yields another potential ESG benefit.

Introduction

This paper presents information regarding metal recovery, lower cost of operation and potential overall environmental, social and governance value enhancement following laboratory test work, field test work, and a detailed review of the monetary and environmental savings utilizing IXOS® beads instead of activated carbon for the field trial at a mine in Copiapo, Chile in the Atacama Desert.

Sixth Wave Innovation Inc.'s Molecularly Imprinted Polymer IXOS® beads have a profound use case in the mining sector for metal recovery. The metal selectivity coupled with the demonstrated high-loadings and recovery of gold compared to activated carbon advances IXOS® as the technology of choice when dealing with recovery of gold from a complex metal cyanide solution typical of complex ore types.

This paper provides brief details of laboratory test-work results for a single column 24-hour run for IXOS® beads and activated carbon C-60 respectively. Further, a predicted model for a five-column adsorption circuit effectively demonstrates the superior performance of IXOS® beads compared to activated carbon.

The paper provides data from a field trial to further evaluate the efficacy of IXOS® technology and to simulate real-time operation using solution from ore-heap-leach columns and a multi-column bench-scale setup for IXOS® adsorption that mimics a gravity fed counter current adsorption train and a single column strip circuit. The IXOS® adsorption performance is highlighted with a model of the adsorption performance during the first twelve hours as well as the last eight hours to confirm that the field cumulative adsorption recoveries agreed with the predicted laboratory cumulative adsorption recoveries by +/– 0.5%.

The strip performance data is also presented, and indicates that >95% of the Au on the loaded IXOS® beads will strip within two hours at 60 degrees C and ambient pressure as opposed to the high temperature and pressure stripping process for gold elution.

The overall OPEX cost savings associated with using IXOS® was calculated based solely on direct energy savings, since there is no thermal regeneration of the IXOS® beads after strip as required for activated carbon. The paper also demonstrates additional benefits of using the IXOS® technology (based on a throughput of 7.2M tons per annum @ 0.49g Au/t of ore) to include carbon emission reduction of 1164.5 tons CO_2/year; OPEX cost savings of US$0.61M/year without thermal regeneration. There are additional OPEX savings due to reduced fuel usage and improved stripping kinetics of US$0.05M/year, US$0.22M/year savings due to elimination of fine carbon losses and an estimated annual savings of $0.88M/year or US$0.122/ton of ore heaped.

Laboratory test work

Ore leach and single-pass cumulative percentage adsorption recovery

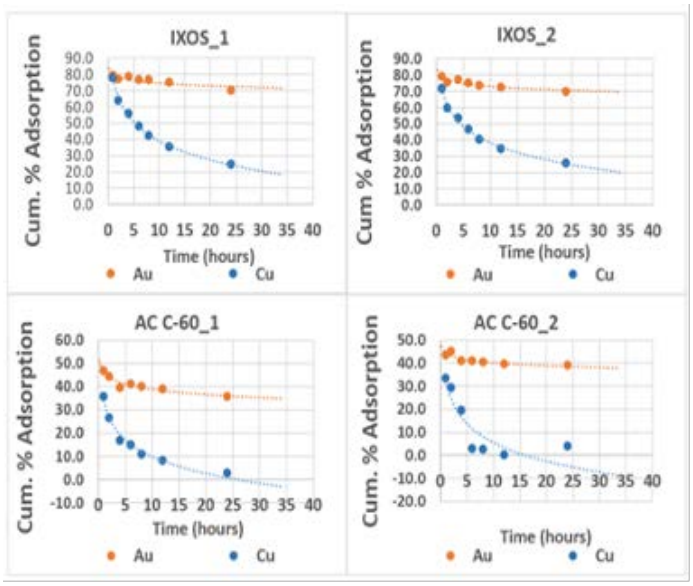
Column adsorption was conducted in the laboratory using pregnant leach solution (PLS) obtained from

bottle-roll leaching of client ore sample for 48 hours and collecting the filtered pregnant leach solution (PLS) with the metal cyanide complexes in solution. The ore sample leached was of average grade 0.426 g Au/t of ore, and 170.28 Cu/t of ore. The pregnant leach solution (PLS) passed through the adsorption columns was of grade 0.147 ppm Au and 1.361 ppm Cu.

The primary focus of the laboratory adsorption test was to evaluate the efficacy of IXOS® beads as a replacement for activated carbon in a proposed adsorption, desorption, and recovery (ADR) plant, with the following challenges:

- High copper concentration in the ore leached, meaning high copper in discharge which could influence adsorption kinetics.
- Low overall Au grade (~0.444 g Au/t of ore) leached.
- Process water used for all aspects of the ADR have a high salt concentration of ~207ppm of NaCl.

Test summary
Throughput 1bv/min
Parallel flow through two column beds of IXOS® beads and activated carbon AC-60
Solution samples taken 2, 4, 6, 8, 12 and 24 hours.
Cumulative % adsorbed gold on IXOS® and AC-60 were 69.9% and 37.3% respectively
Cumulative % adsorbed copper on IXOS® and AC-60 were 25.0% and 3.4% respectively



IXOS® Beads vs. AC-60

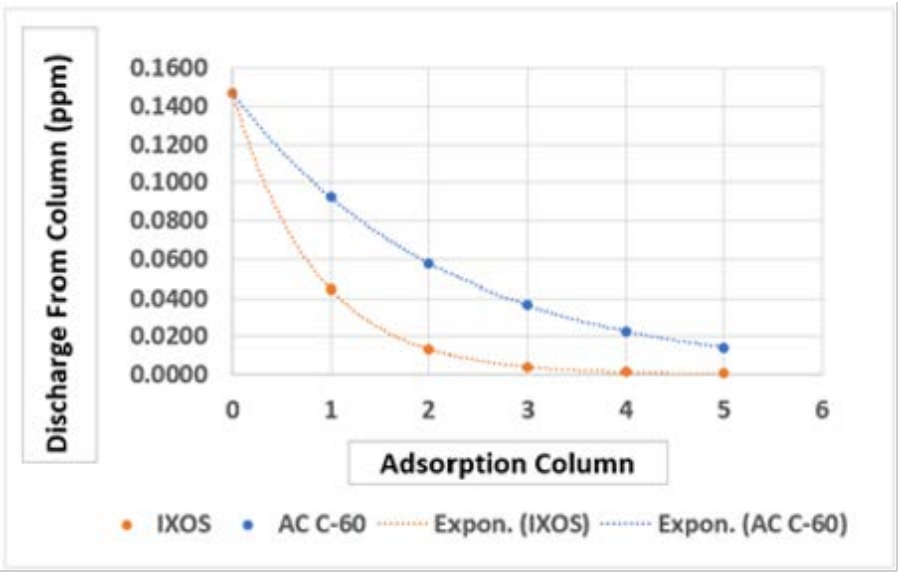
Figure 1: IXOS® beads vs. AC-60

Five-column adsorption circuit cumulative percentage adsorption recovery predictions

Using the single-pass cumulative gold adsorption recoveries for IXOS® and activated carbon AC-60 of 69.9% and 37.3%, extrapolation curves for cumulative circuit adsorption recovery were predicted for five columns in series for each train of IXOS® beads and activated carbon C-60. Figure 2 shows data and curves for predicted cumulative percentage gold adsorption for both IXOS® beads and activated carbon C-60 of 99.75% and 90.34% respectively.

Adsorption Column	Au					
	IXOS			AC C-60		
	Feed ppm	Barren ppm	Recovery %	Feed ppm	Barren ppm	Recovery %
0	0.1472	0.1472	-	0.1472	0.1472	-
1	0.1472	0.0443	69.9	0.1472	0.0922	37.3
2	0.0443	0.0133	69.9	0.0922	0.0578	37.3
3	0.0133	0.0040	69.9	0.0578	0.0362	37.3
4	0.0040	0.0012	69.9	0.0362	0.0227	37.3
5	0.0012	0.0004	69.9	0.0227	0.0142	37.3
Overall Adsorption Efficiency			99.75%			90.34%

24-hr 1bv/min extrapolation data



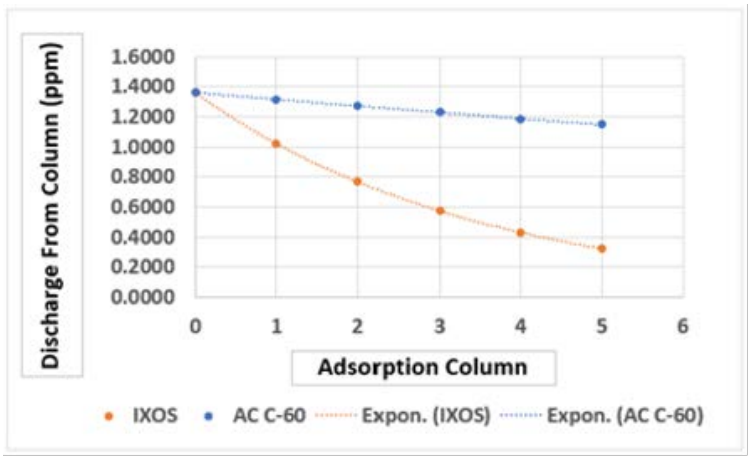
Projected recovery for 5 columns in series

Figure 2: Predicted cumulative circuit gold adsorption percentage recovery

Figure 3 shows data and curves for predicted cumulative percentage copper adsorption for both IXOS® beads and activated carbon C-60 of 76.21% and 15.69% respectively.

Adsorption Column	Cu					
	IXOS			AC C-60		
	Feed ppm	Barren ppm	Recovery %	Feed ppm	Barren ppm	Recovery %
0	1.3615	1.3615	-	1.3615	1.3615	-
1	1.3615	1.0216	25.0	1.3615	1.3158	3.4
2	1.0216	0.7666	25.0	1.3158	1.2717	3.4
3	0.7666	0.5752	25.0	1.2717	1.2290	3.4
4	0.5752	0.4317	25.0	1.2290	1.1878	3.4
5	0.4317	0.3239	25.0	1.1878	1.1479	3.4
Overall Adsorption Efficiency			76.21%			15.69%

24-hr 1bv/min extrapolation data



Projected recovery for 5 columns in series

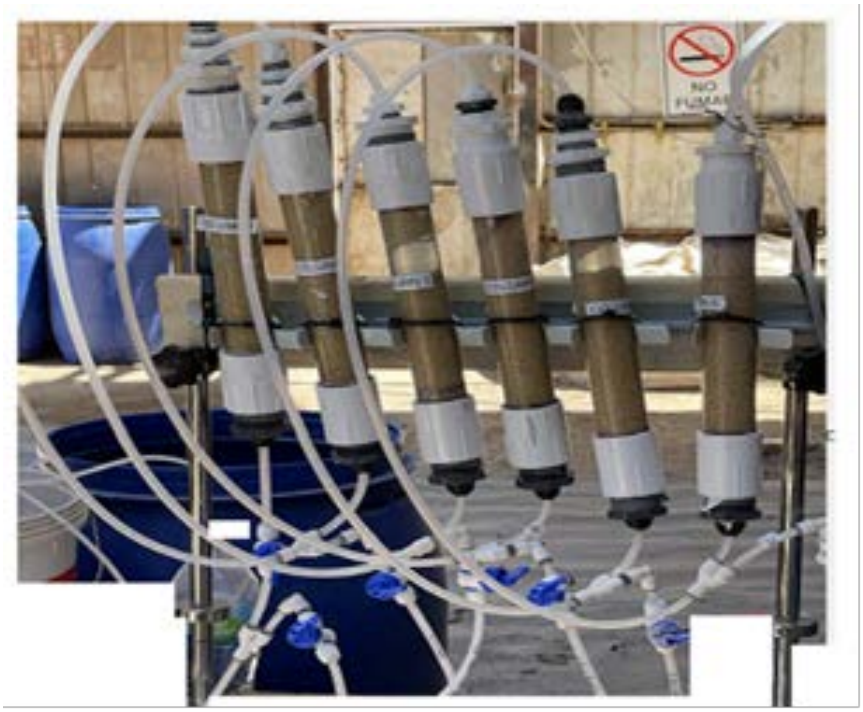
Figure 3: Predicted cumulative circuit copper adsorption percentage recovery

Field test work

Following compelling results obtained in the laboratory, the client contracted field testing using the same ore sample on a larger scale and at the mine site. Figure 4 contains pictures of the heap-leach columns and IXOS® adsorption column setup used. The IXOS® adsorption columns are scaled up from the laboratory configuration and representative of a typical carbon or resin train, and the scale-up parameters can be used for a full-scale operation with higher throughput.

A strip circuit setup with solution made up of 0.5% sulfuric acid and 1% thiourea was employed for stripping. Figure 5 shows the IXOS® Strip (Desorption/Elution) schematic process used.

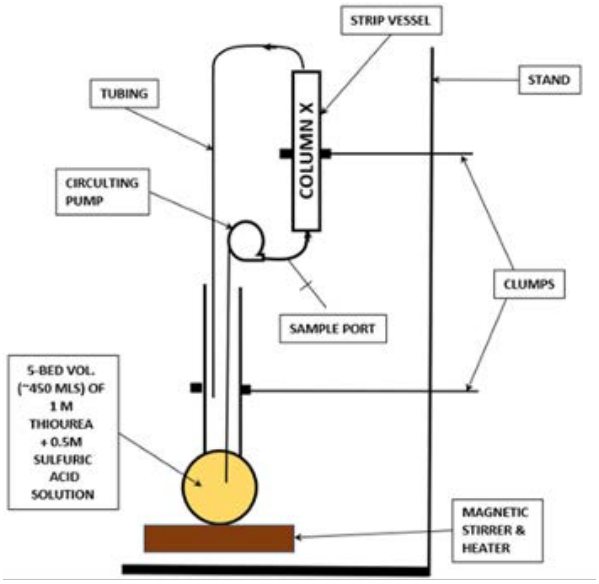
Heap leach column set-up



IXOS® adsorption column set-up

Figure 4: Field setup for heap-leach columns and IXOS® adsorption columns

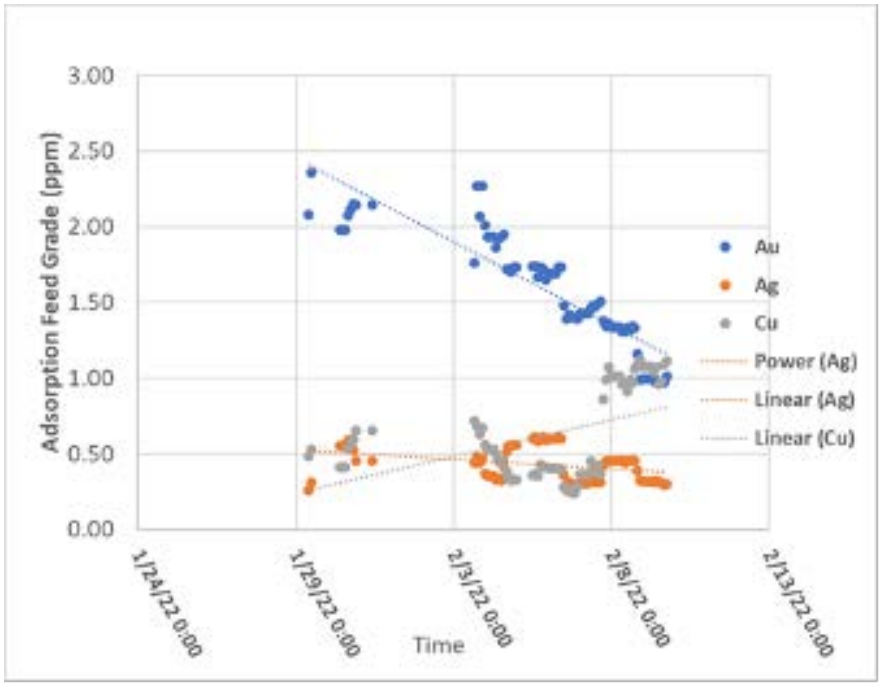
Site (strip/desorption/elution) circuit



Schematic strip (desorption/elution) circuit

Figure 5: Strip circuit – site and schematic strip (desorption/elution)

Run hours for the entire test program were 145.92 hours. During this time, 693.20 L of PLS was processed through the adsorption circuit. IXOS® bed volume per column was average 90 ml, and average solution flowrate was 90 ml/min (i.e., 1 bv/min). A metallurgical accounting sheet detailing results of solution samples was generated based on field data and solution samples submitted to the client's independent laboratory for analysis. Figure 6 provides PLS grades to adsorption and cumulative metal adsorbed.

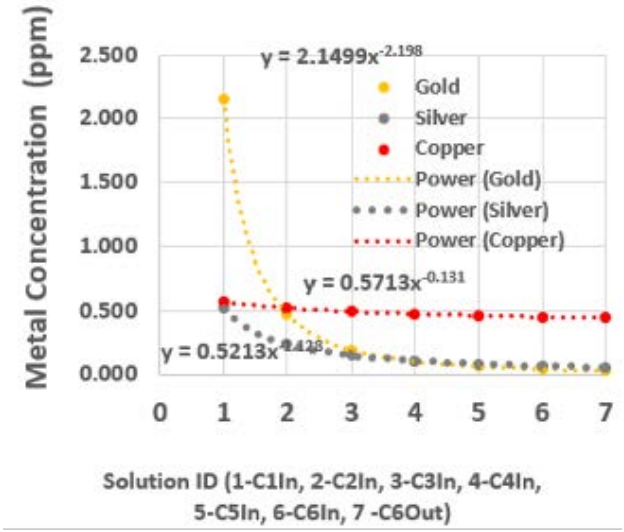


PLS grades to adsorption circuit

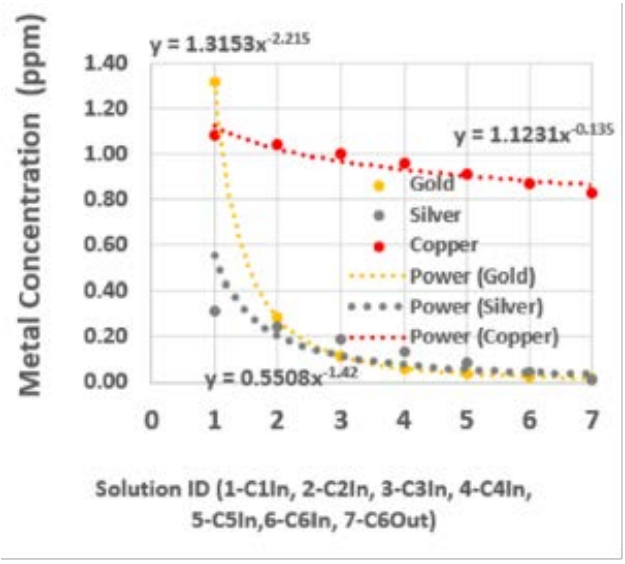
Cumulative metal adsorbed

Figure 6: Pregnant leach solution (PLS) and cumulative metal adsorbed during test run

Column rotation was established to remove batches of loaded IXOS® beads from the lead column, advance succeeding columns, and replace the last columns in each rotation with freshly stripped IXOS® beads consistent with a counter-current flow. With the data obtained, model derivatives were established for the first 12 hours at the start of testing and the last 8 hours before the test program came to an end.



First twelve hours of field test run



Last eight hours of field test run

Figure 7: Cum. ads models – first twelve hours and last eight hours

Figure 8 shows most of the gold being stripped within the first 3-4 hours. The low temperature strip and shorter strip time invariably will lead to energy savings which may reflect in the company's ESG performance.

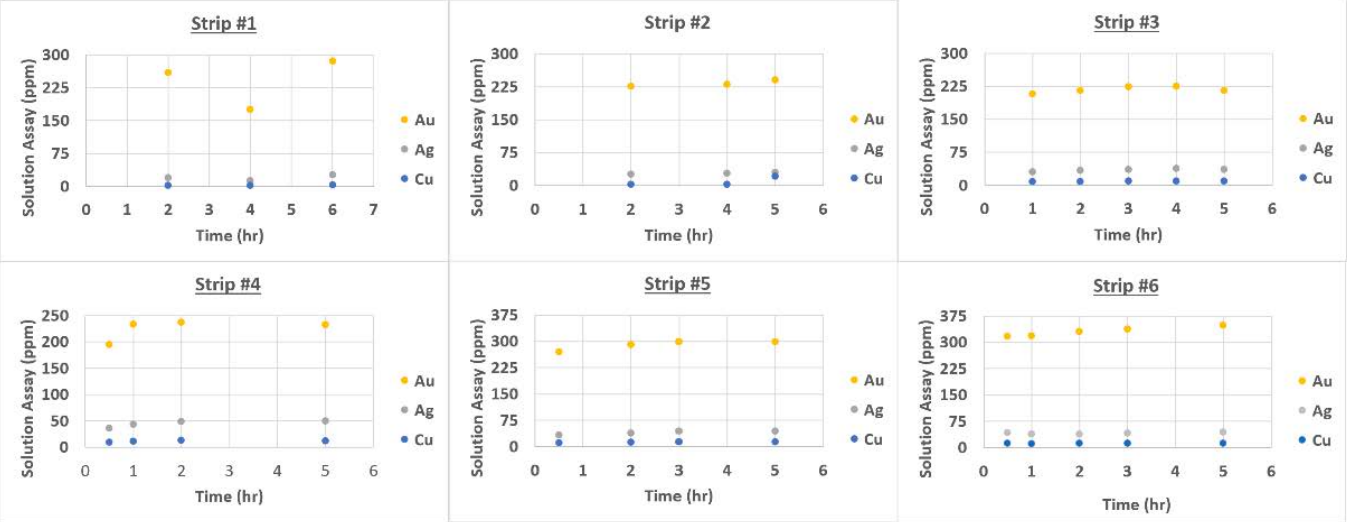


Figure 8: Strip solution curves for each batch of loaded IXOS® beads

Low cost of operation

AREA	Carbon-In-Solution Circuit			IXOS® -In-Solution Circuit		
	Installed Power (kw)	Maximum Demand (kw)	Energy Consumption (kwh/month)	Installed Power (kw)	Maximum Demand (kw)	Energy Consumption (kwh/month)
Facilities	37.3	22.4	14502.2	37.3	22.4	14502.2
Handling of Ragents	106.8	25.8	8651.0	106.8	25.8	6440.5
Adsorption	64.3	26.0	15971.1	65.1	26.4	17131.3
Desorption and Electrodeposition	579.4	303.1	130942.4	579.4	303.1	130942.4
Acid Wash	11.2	4.0	2175.3	11.2	4.0	2175.3
Thermal Regeneration	685.2	411.1	222001.6	0.0	0.0	0.0
Carbon Handling	34.5	8.1	3054.8	34.5	8.1	3054.8
Foundry	360.8	178.7	57886.9	360.8	178.7	32159.4
Complimentary Services	153.0	85.8	55604.2	153.0	85.8	55604.2
Total ADR Plant	2032.4	1065.0	510789.6	1347.9	654.3	262010.1
Cost $US/ kWh	0.24			0.24		
US cost			122,589			62,882
Mineral tonnage/month	600,000			600,000		
Cost US/t			0.20			0.10

Cost Savings US/t			0.10
Annual throughput	7,200,000		
Cost Savings in millions US			0.72

Figure 9: Energy requirement carbon-in-solution vs. IXOS®-in-solution

With the excellent field data obtained, a review of the comparative operating cost was undertaken. This was conducted with the full vetting/approval of the client's subject matter expert. IXOS® beads do not require thermal regeneration after strip. This is because IXOS® beads are not organic and therefore are not

subject to organic fouling. Inorganic materials like scaling are primarily removed during the IXOS® strip or desorption process. As can be seen in Figure 9, savings of $0.72M/ annum is expected in energy savings simply by eliminating the thermal regeneration equipment.

Per the Vertical Minfurn vendor manual, and depending on throughput, Figure 10 provides a summary of the Kw.h/ year requirement for a carbon batch of 10.375 tons per column going to strip. Equipment selection provided for a throughput of 432 kg carbon/hour, which will allow 10,375 kg of carbon to be regenerated in 24 hours. Thus, the Vertical Minfurn of 470 kw capacity is selected from the vendor specification as per Figure 10.

	Power								
	Power Kw	Kwh /Year	Kwh /day	Kg Carbon /hr	Kg Carbon /day	Kwh/ Kg	Kw.h /day	Kw.h /month	Kw.h / year
Vertical Minfurn	136	1191360	3264	125	3000	1.09	3264	97920	1175040
Vertical Minfurn	470	4120120	11288	432	10375	1.09	11288	338640	4063680
Carbon in Circuit	83	tons							
Carbon per tank	10.375	tons							

Figure10: Heat energy requirement – vertical Minfurn carbon regeneration

Description	Unit	Thermal Regeneration	Stripping (50% of combustible fuel for stripping loaded carbon)	Total Savings
	kwh/ month saved	338640.0	-	-
	months	12.0	-	-
	kwh/year	4063680.0		4,063,680.0
wt. of 1 liter of diesel	g	835.0	835.0	835.0
%C for 1 liter of diesel		0.9	0.9	0.9
C per liter of diesel	g	719.8	719.8	719.8
Oxygen required	g	1919.4	1919.4	1,919.4
CO2 from diesel	g/liter	2639.2	2639.2	2,639.2
1 liter of diesel produces approx.	MJ	38.0	38.0	38.0
1 liter of diesel produces approx.	kwh	10.0	10.0	10.0
Energy required for Vertical Minfurn	MkWh /year	4.1	0.0	4.1
Fuel required	liters / year	406368.0	34856.0	441,224.0
cost of diesel	US $/liter	1.5	1.5	1.5
Cost savings	US $M/ year	0.61	0.05	0.66
Reduced CO_2 emission	tons/year	1072.5	92.0	1,164.5
Tonnes of ore stacked	tons/year	7200000.0	7200000.0	7,200,000.0
Cost Savings per tonne of ore	US $/ton	0.08	0.01	0.09
Cost savings	US$/month	50796.0	4357.0	55,153.0
Carbon losses	kg/yr			72,000.0
Price of carbon	US $/kg			3.0
Carbon losses	US$/yr			216,000.0
Total Savings	US$/yr			877,836.0
Total Savings	US$/month			73,153.0
Cost Savings per tonne of ore	US $/ton			0.1

Figure 11: Savings due to using IXOS® beads

Figure 11 shows the combined energy savings using IXOS®-In-Solution for gold recovery for eliminating thermal regeneration, (US$0.61M / year). Reduction in the use of the combustible fuel (~50% of typical loaded carbon strip circuit) during strip due to shorter strip times and no heating above 60 degrees provides energy savings of (US$0.05M per year). Combined total savings of (US$0.66M per year) is expected. Savings from carbon losses of US$ 0.22 M per year with no carbon usage. Total of US$ 0.88 M per year with the use of the IXOS®-In-Solution Technology.

Potential enhancement of ESG values

The client case study budget figures were confirmed by an independent consultant familiar with similar mining properties in South America, indicating an ADR plant for handling gold recovery with ore throughput of 7.2M tons/year will require an average 69,712 L per annum for maintaining heat energy combustion. Using IXOS® it is anticipated that only 50% of fuel will be required to keep the strip at 60 degrees C since there is no need for stripping eight hours, as is the case with loaded activated carbon. Subsequently, the amount of fuel saved will be 34,856 L per year. With 2,639.2 g, CO_2 generated per litre of diesel used, the reduced emission resulting from stripping IXOS® beads is on the order of 91.99 tons reduction per year.

Similarly, without thermal regeneration of activated carbon, the client's consultant determined the fuel reduction is 406,368 L per year (Figure 11). Thus, reduced CO_2 emission per year is estimated to be 1072.47 tons per year per as also calculated in Figure 11.

The total reduction in CO_2 emission for using IXOS® compared to activated carbon is 1164.46 tons per year just from these usage sources. Additional indirect CO_2 savings can be quantified for fuel deliveries without the use of IXOS® for a functional activated carbon ADR plant at the mine site at high elevation in the Atacama Desert but are not presented for this analysis.

Results and discussion

The laboratory test work from Figure 1 and Figure 2 details:

- Better gold adsorption performance of IXOS® compared to activated carbon. The predicted 99.75% cumulative gold recovered using IXOS® beads for a 5-column adsorption circuit suggested that a 6-column adsorption circuit was optimum for a field test in combination with the strip.
- Removal of copper from solution using the predicting model suggests 4 times higher for IXOS® compared to activated carbon. However, it is well known from lab work that gold is preferentially adsorbed to copper in succeeding adsorption columns in a circuit. It should be noted that the laboratory test was data derived from a 24-hour single pass and therefore the field test was

warranted to investigate and ascertain the adsorption kinetics over a longer period at more operationally relevant conditions.

Furthermore, the field test results found:

- Per the model, derivatives in Figure 7, show 98.61% Au, 88.86% Ag and 22.46% Cu adsorption efficiencies respectively within the first twelve hours of the bench-scale adsorption testing.
- Per the model, derivatives in Figure 7, show98.7%Au, 96.6% Ag and 23.7% Cu adsorption efficiencies in the last 8-hours. Note: Gold values in PLS to adsorption circuit were low, copper values high and five column adsorption rotations, and two batches of stripped IXOS® beads transferred to two adsorption columns in the adsorption circuit.
- Achieved excellent performance, >98% gold adsorption recovery, at a nominal flowrate of >80% of design capacity. In addition, lower copper adsorption makes IXOS® beads a compelling adsorbent.
- Per Figure 8, strip times of ~2 hours are achievable without compromising complete metal removal. The benefits of 100% efficiency cannot be over-emphasized, as it allowed stripped IXOS® beads to return to the adsorption circuit without loss of adsorption recovery capacity, thereby mitigating gold losses in circuit performance. Moreover, it allows for a comparatively smaller strip circuit with lower energy and reagent usage

Conclusion

Use of IXOS® technology at heap leach mines can result in:

- Improved gold adsorption compared to activated carbon (lower Au/Ag in tailings).
- No losses to carbon fines.
- Reduced carbon dioxide emission or carbon footprint worth ~ $.116M annually in tradable carbon credits.
- Potential enhancement of ESG position.
- Reduced energy consumption resulting in US$ 0.88M per annum for the proposed 7.2 M tons of ore to heap per annum.

References

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Southard, G., J. Gluckman and B. Maull. Molecularly imprinted polymer applications for the gold mining industry. Proceedings of Heap Leach Solutions, 2015 September 14–16, 2015, Reno, Nevada, USA.

Vertical minfurn operation manual (provided by client).