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PRESSURE OXIDATION OF REFRACTORY GOLD ORES: THE METATES GOLD PROJECT EXPERIENCE

By

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ABSTRACT

Chesapeake Gold Corp. is currently studying the development of its Metates Gold project in the state of Durango, about 175 km north of the city of Mazatlan, in Mexico. A preliminary feasibility study has been concluded to date.

The overall flow sheet that has been considered comprises of a concentrator to produce a pyritic concentrate which, on account of the gold and silver being locked within the sulfide minerals, requires a pressure oxidation step prior to cyanide leaching. Two sulfate based pressure oxidative leach flow sheet concepts were considered in order to identify the lower capital and operating cost option without negatively impacting precious metals recovery.

Pressure oxidation test work was conducted in North America and in Australia on concentrates containing 2.8 – 3.8 g/t gold, 100 – 117 g/t silver, 24 – 26% iron and 27 – 29% sulfur. The results of this work and a high level presentation of their impact on engineering outcomes are presented in this paper.

INTRODUCTION

Chesapeake Gold Corp. is currently studying the development of its Metates Gold project in the state of Durango, about 175 km north of the city of Mazatlan, in Mexico. At the time of publication of this paper, a preliminary feasibility study (PFS) has been concluded.

The overall flow sheet considered comprises of a concentrator located in the Metates project area and a processing plant facility located in the "Ranchito" site, 65 km southwest of the Metates Project site and 15 km northwest of the Municipality of Cosala.

Flotation concentrate will be pumped from the Metates Project site to the Ranchito hydrometallurgical facility where it will be leached in a POX facility, followed by cyanide leach and Merrill Crowe recovery of gold and silver. Zinc will be recovered from the overflow of the autoclave product counter-current decantation (CCD) stage. **Figure 1** provides a schematic representation of the PFS Metates hydrometallurgical flow sheet.

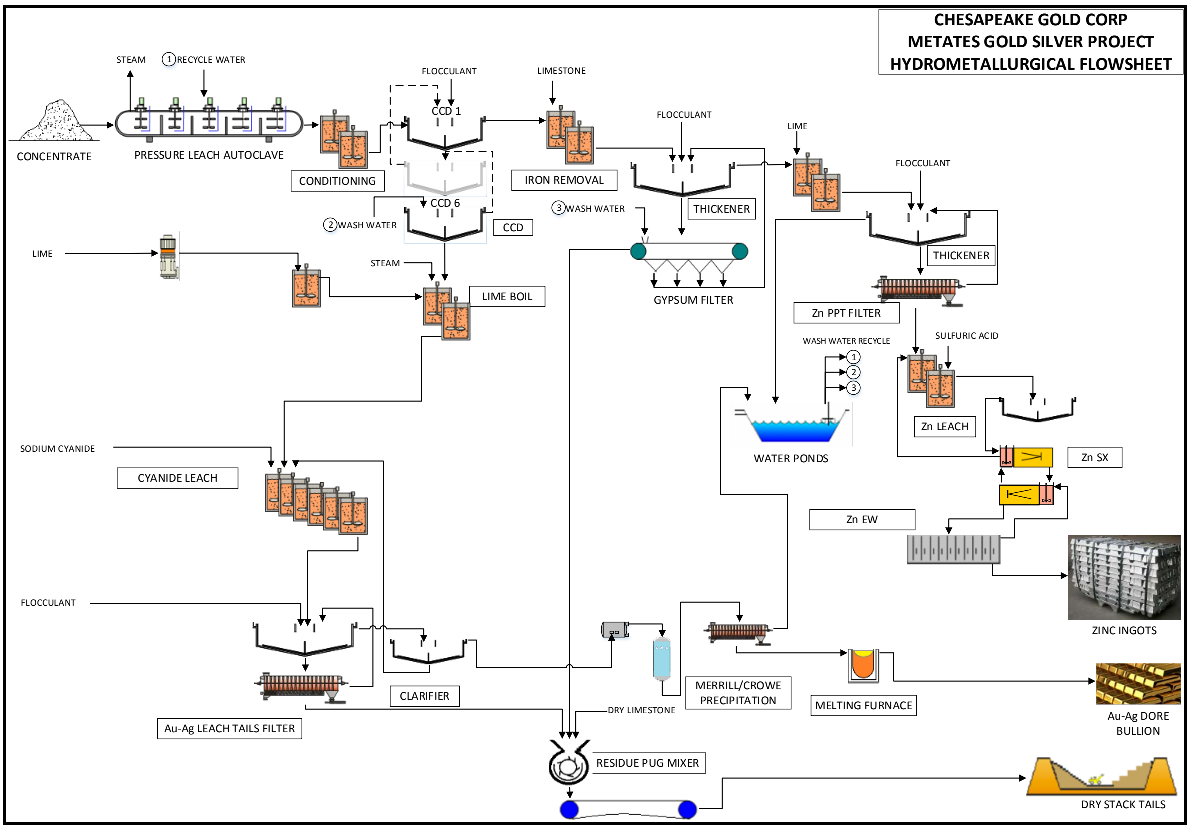

Figure 1: Metates Gold Silver Project Hydrometallurgical Flow Sheet

The metals of economic interest in the Metates Gold Project are gold, silver and zinc. Gold and silver in the concentrate are refractory. These two metals are contained within the matrix of the sulfide minerals, mainly pyrite and to a lesser extent pyrrhotite and arsenopyrite. Zinc is present as sphalerite. The refractory nature of the concentrate requires a pressure oxidation (POX) step to oxidise the sulfide minerals and unlock the value metals.

The oxidation of sulfides is a highly exothermic reaction. The energy generated by the reaction of the sulfide minerals is such that the autoclave temperature can exceed the 210 – 230°C operating range considered suitable for treating refractory sulfides. In the case of the high sulfide sulfur grades of the Metates concentrate, there is the need to cool the autoclaves in order to maintain temperature and the desired oxygen partial pressure in the vessel.

There are a variety of heat removal processes that can be employed to remove energy from pressure oxidation vessels (e.g. quenching, internal cooling coils, external coolers and flash recycle). Given the characteristics of the Metates project, only two concepts were considered, namely:

- Classical POX (quenching cooling) and
- Flash-Thickener-Recycle (FTR) POX system

The objective of investigating these two concepts was to identify the lower capital and operating cost option without negatively impacting on the precious metals recovery.

The Classical POX system employs a quench cooling system. This system has been employed in the leaching of gold and copper sulfides for many years, it is simple to configure and has relatively easy control features. In this system, cool quench liquor is fed to the autoclave compartments on temperature control. The use of quench liquor requires an increase in the autoclave active volume and can result in dilution of the pregnant leach solution (PLS) if water or some diluted liquor is employed.

The FTR POX system is an extension of the Flash-Recycle system introduced in South Africa in the mid 1980s[(1)] and later introduced in Zimbabwe[(2)], the USA[(3)] and Australia. In the FTR POX system a portion of the energy released in the first compartment is removed by withdrawing slurry from this compartment. The slurry is flashed and the underflow thickened. The partially leached solids are returned to the autoclave (to compartment 1 and in some cases compartment 2) and the thickener overflow forwarded to the Solution Neutralisation and Zinc Recovery steps. In so doing, the thickener overflow fluid plays no further part in the autoclave process dynamics. The thickener thus provides a means of increasing the solids retention time in the autoclave over that of the liquid phase[(4)].

Classical and FTR Pressure oxidation test work was conducted in North America and in Australia to determine the engineering requirements and metallurgical effects of the two methods of cooling the autoclave.

TEST WORK

Test work was conducted on concentrate from a flotation pilot plant campaign. The pressure oxidation test work was conducted employing the Classical POX and the FTR POX systems. The test work program comprised of three discrete phases:

- Classical pressure oxidation: Batch test work – Batch Classical POX
- Classical pressure oxidation: Pilot plant test work – Pilot Classical POX
- FTR pressure oxidation: Batch test work – Batch FTR POX

The test work flow sheet employed in the Classical (Batch and Pilot) and FTR POX tests included the following process unit operations:

- Pressure oxidation
- Conditioning
- Cyanide leach
- Solid liquid separation

Concentrate Sample Assay and Mineralogy

The head assay of the samples tested in the three phases of test work is provided in Table 1. While there was some variation in the assay values, the difference was not significant for the concentrates employed in the batch test work (Classical and FTR) and the pilot plant campaign.

Table 1: Feed Concentrate Assays

Phase	Sample	Analysis (g/t)		Analysis (%)		
		Au	Ag	Fe	S	Zn
1	Batch Classical POX	2.78	99.8	25.9	28.8	0.87
2	Pilot Classical POX	3.22	112.0	25.0	27.3	1.11
3	Batch FTR POX	3.75	114.0	24.8	27.5	1.14

Table 2 shows the mineralogical analysis of the samples employed in the Batch and Pilot Classical POX test work programs. The concentrate sample for the FTR POX test work program was drawn from the pilot plant feed. For the purposes of the Batch FTR and Pilot Classical POX test work the mineralogy of the feeds was similar if not identical, and their outcomes can be compared.

Table 2: Feed Concentrate Mineralogy

Mineral	Chemical Formula	Batch Classical POX (wt %)	Pilot Classical POX & Batch FTR POX[a] (wt %)
Pyrite	FeS_2	50.5	49.5
Pyrrhotite	FeS	3.3	2.7
Sphalerite	ZnS	1.3	1.7
Arsenopyrite	FeAsS	0.8	0.8
Chalcopyrite	$CuFeS_2$	0.2	0.2
Galena	PbS	0.1	0.3
Total Sulfides		**56.2**	**55.2**
Silica	SiO_2	28.2	28.7

[a] Batch FTR POX sample was drawn from this Pilot feed therefore it is assumed to have very similar mineralogy.

The iron and sulfide sulfur concentrations in the feed were very similar in the batch and pilot campaigns. A consequence of this is that the total specific energy release per tonne of concentrate was expected to be the same irrespective of whether a Classical or an FTR POX autoclave system was employed.

Chemistry

Pressure Oxidation

Pressure oxidation is often employed to liberate gold and silver in refractory sulfide concentrates and ores.

The main pressure oxidation products from iron sulfide minerals are sulfuric acid (and metal sulfates) and hematite. Depending on the conditions within the autoclave, acid containing iron compounds can be formed. Such compounds include basic iron sulfate (BFS) and jarosites.

The pressure oxidation reactions for pyrite, pyrrhotite, sphalerite and arsenopyrite can be written as follows:

Pyrite: $$4FeS_2 + 15O_2 + 8H_2O \rightarrow 2Fe_2O_3 + 8H_2SO_4$$

Pyrrhotite: $$4FeS + 9O_2 + 4H_2O \rightarrow 2Fe_2O_3 + 4H_2SO_4$$

Sphalerite: $$ZnS + 2O_2 \rightarrow ZnSO_4$$

Arsenopyrite: $$2FeAsS + 7O_2 + 6H_2O \rightarrow 2FeAsO_4.2H_2O + 2H_2SO_4$$

The hydrolytic precipitation of iron as BFS and jarosites under POX conditions can be represented by the following equations:

BFS: $$Fe_2(SO_4)_3 + 2H_2O \rightarrow 2FeOHSO_4 + H_2SO_4$$

Jarosites: $$3Fe_2(SO_4)_3 + K_2SO_4 + 12H_2O \rightarrow 2KFe_3(SO_4)_2(OH)_6 + 6H_2SO_4$$

$$3Fe_2(SO_4)_3 + Ag_2SO_4 + 12H_2O \rightarrow 2AgFe_3(SO_4)_2(OH)_6 + 6H_2SO_4$$

Conditioning

The conditioning process re-dissolves BFS. Reducing sulfate content of the POX discharge solids lowers lime consumption in the lime boil step and allows for the neutralisation of the acid (free or as ferric sulfate) using the cheaper limestone in the Solution Neutralisation step. Jarosites are not re-dissolved in the conditioning step. The re-dissolution of BFS in the conditioning stage can be represented by the following equation:

$$2FeOHSO_4 + H_2SO_4 \rightarrow Fe_2(SO_4)_3 + 2H_2O$$

Classical POX Leach Test Work

The flow sheet employed in the Batch and Pilot Classical POX test work is provided in Figure 2.

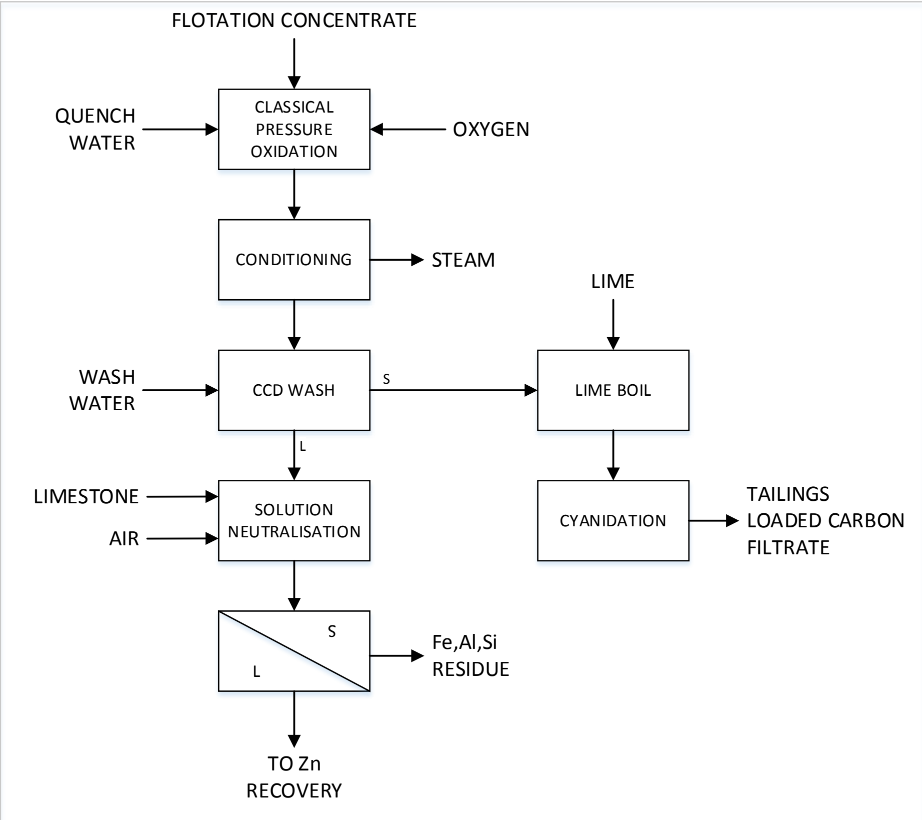

Figure 2: Classical POX Test Work Flow Sheet

Classical Pressure Oxidation

A very similar suite of conditions was adopted in all of the Batch and Pilot Classical POX tests (Table 3). In the Pilot Classical POX test (continuous test) a distinction was drawn between the conditions in the first compartment of the autoclave, referred to as Stage 1, and those in the balance of the autoclave (compartments 2 to 6) referred to as Stage 2.

Table 3: Classical POX Test Work Conditions

	Temperature (°C)	Pressure O_2 (kPa)	Solids Density (wt %)		Retention Time (min)		Dilution Water Added (Yes/No)	
			Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2
Batch	220	500 - 700	11 - 13	NA	40 - 80	NA	Yes	NA
Pilot	210 - 220	500 - 540	11.2 - 11.9	8 - 10	22 - 25	25 - 35	Yes	Yes

The pilot plant campaign totalled 96 hours and was divided into four periods based on variations in operating temperature:

- 220°C for Periods 1, 2 and 3
- 210°C for Period 4

The autoclave residence time was also varied across the pilot campaign:

- 60 minutes for Period 1
- 50 minutes for Periods 2 and 4
- 45 minutes for Period 3

The run times for the four pilot campaign periods were:

- Period 1: 36 hours
- Period 2: 24 hours
- Period 3: 22 hours
- Period 4: 14 hours

Table 4 provides the main outcomes from the Batch and Pilot Classical POX leach test work. The gold and silver recovery after lime boil from the cyanide leach step is provided in this table as an indicator of the success of the pressure oxidation step.

Table 4: Classical POX Autoclave Results

Test	Weight change (%)	Soluble Iron in Leachate (g/L)	Overall Fe Extraction (%)	Sulfuric Acid in Leachate (g/L)	Sulfide Sulfur in Solids (%)	Sulfate Sulfur in Solids (%)	Au Recovery[a]	Ag Recovery[a]
Batch	0 – 9	6 - 7	12 – 18	50 - 61	0.1 - 0.2	7 - 12	89 - 95	87 – 94
Pilot (all periods)	+2 to -2	5 - 7	~ 23	40 - 48	0.02 - 0.04	5 - 6	95 - 97	80 – 95

[a] Recovery from cyanide leach after lime boil.

Sulfide Oxidation

Sulfide sulfur was almost completely oxidised in the autoclave. Total sulfur was reduced from approximately 27% in the feed to 5 – 6% in the autoclave residue during the Pilot campaign and to 7 – 12% in the residue of the Batch test work. In both of these cases the sulfur remaining in the solids was present as sulfate.

The Pilot Classical POX test work achieved in excess of 99% sulfide oxidation under the conditions tested as shown in Figure 3. In this figure, C1/C2 represent the first, double sized, compartment and C3 to C6 the subsequent compartments.

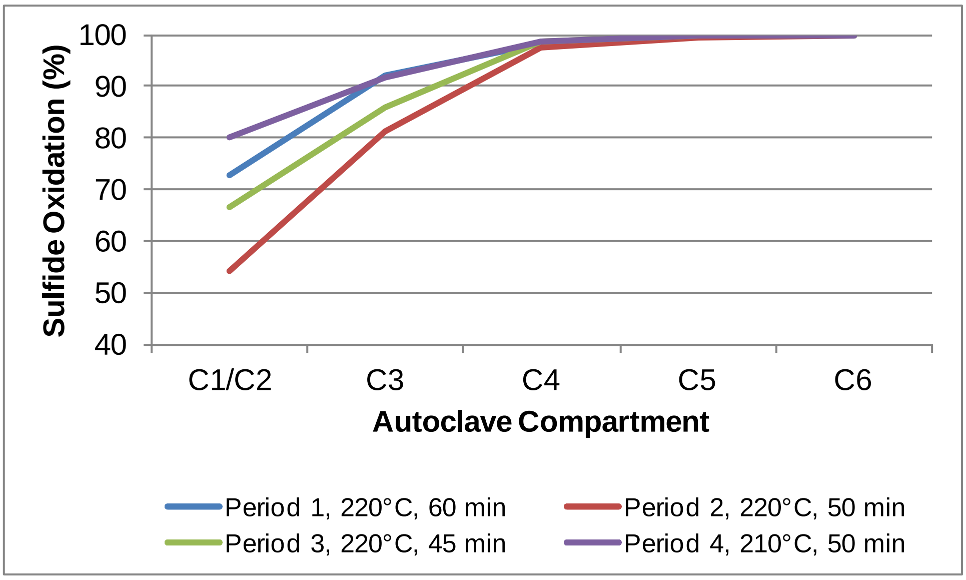

Figure 3: Pilot Classical POX Sulfide Oxidation Profile

Iron Extraction

Figure 4 shows the iron extraction, sulfide oxidation and total acid production of a batch sighter test conducted at 220°C and 700 kPa O_2 overpressure as a function of residence time. Above 45 minutes residence time, sulfide oxidation was in excess of 98% and iron extraction was approximately 33%. Figure 4 shows that, despite the sulfur oxidation levelling off, the acid production continued to increase at the expense of iron hydrolysis.

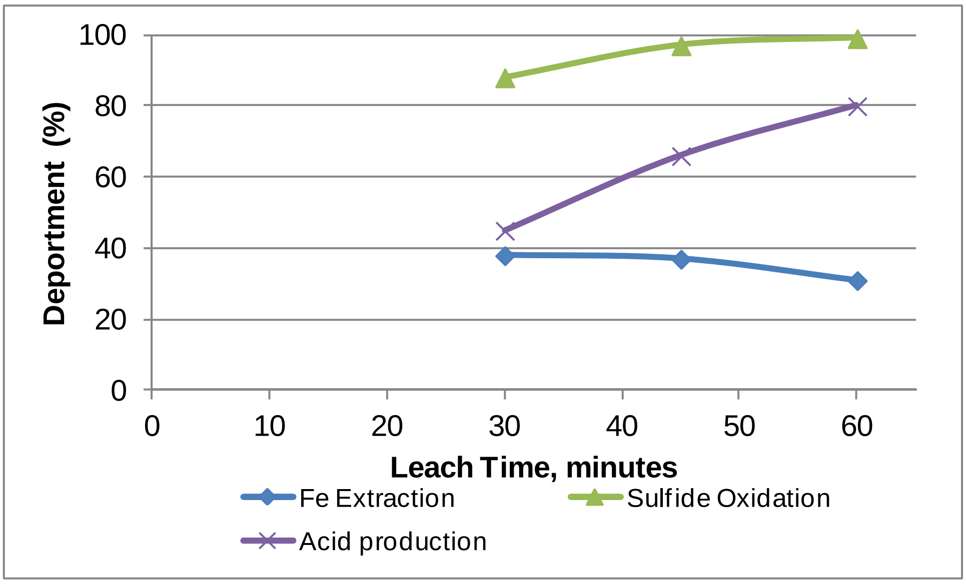

Figure 4: Batch Classical POX on Concentrate at 220 °C, 700 kPa O_2 Overpressure

The decrease in iron extraction (Figure 4) is supported by the presence of sulfate sulfur in the autoclave residue (Table 4).

The predominant iron speciation in the autoclave PLS was ferric iron as seen from Table 5.

Table 5: Pilot Classical POX Autoclave PLS Iron Speciation

	Fe^{2+} g/L	Fe^{3+} g/L	Fe^{2+}/Fe^{3+}
Period 1	0.25	5.01	0.05
Period 2	0.58	6.44	0.09
Period 3	0.59	5.98	0.10
Period 4	0.7	6.61	0.11

Zinc Extraction

In excess of 96% of the zinc in the feed was leached. Conditioning subsequent to the autoclave did not significantly affect the zinc extraction, as shown in Figure 5.

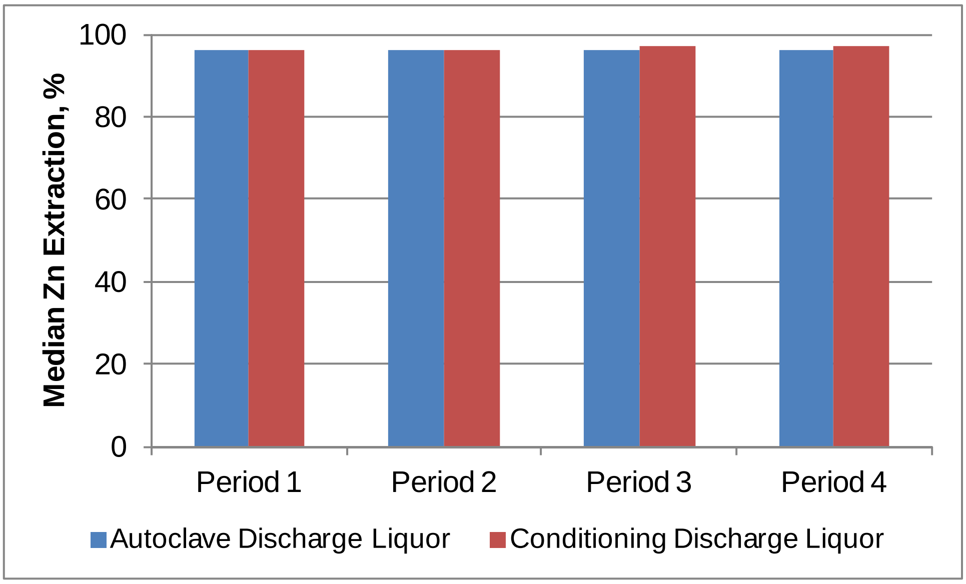

Figure 5: Pilot Classical POX Test Work Zinc Extraction

Conditioning

The pilot plant autoclave discharge slurry was discharged to a train of either 2 or 3 conditioning tanks with a total retention time of 5 to 7 hours. The temperature in the conditioning step was 95°C. Conditioned discharge slurry was washed with water in a 4 stage CCD circuit prior to Cyanide Amenability (CNA) test work. Table 6 shows the effect of conditioning on POX residue sulfate content.

Table 6: Effect of Conditioning on Classical POX Residue Sulfate Sulfur Content

Test	Sulfate Sulfur in residue (wt %)		
	Final POX Residue	Conditioning (1h) Residue	Conditioning (4h) Residue
Batch Classical POX	8.4 – 11.6	9.5 at 11% solids	2.8 at 9.4% solids
Pilot Classical POX	10.3 – 10.8	--	5.7 at 11.9% solids[1]

[1] After 6 hours.

Cyanide Leach

Gold and silver recovery from Pilot Classical POX leach residues was determined in subsequent CNA test work employing Carbon in Leach (CIL).

CNA test work was conducted on the following samples:

- Pilot plant autoclave residue (from compartment 6)
- Pilot plant conditioning product – with lime boil
- Pilot plant conditioning product – without lime boil

Gold extraction from the residues of compartment 6 of the autoclave (Autoclave residue) were approximately 95% during Period 1 (220°C, 60 minutes residence time) and then decreased to 90 – 93% for the duration of the campaign (210 – 220°C and 45 – 50 minutes residence time). The conditioned samples exhibited an increased gold extraction of up to 2% and the lime boil resulted in an additional 2 – 5% gold extraction. The trends for the pilot plant Periods 1, 2, 3 and 4 are shown in Figure 6.

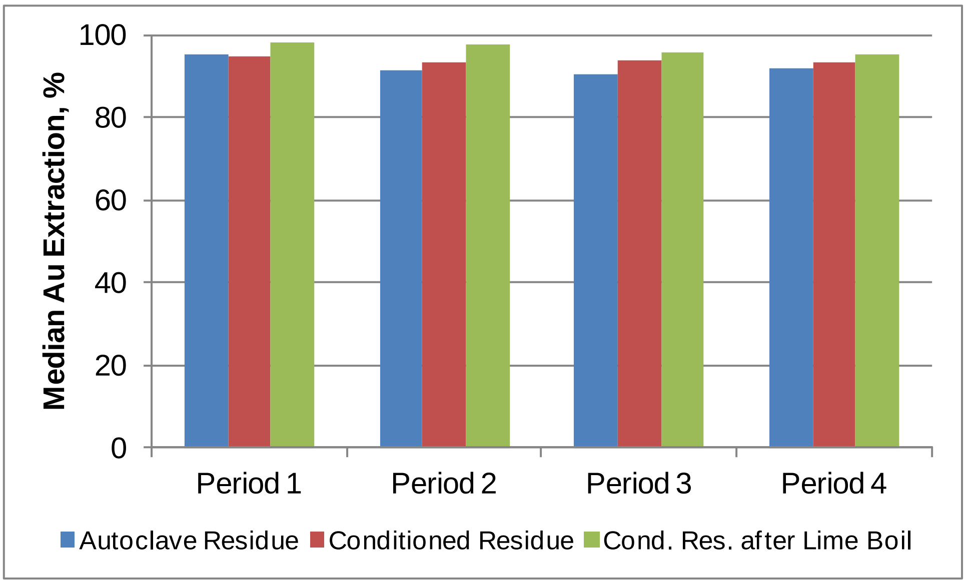

Figure 6: CNA Gold Extraction from Pilot Classical POX Test Work

Silver extraction from the autoclave residues (without conditioning) was insignificant. As expected, silver was occluded possibly in the form of argento-jarosite. The silver extraction of conditioned POX residue during Period 1 after lime boil was notably low, 40 – 50% due to insufficient lime addition (lower than the target addition of 200% of the stoichiometric amount). In Period 2, however, the silver extraction from the lime boil samples increased to 95% and averaged 90% for the duration of the remaining periods (refer to Figure 7).

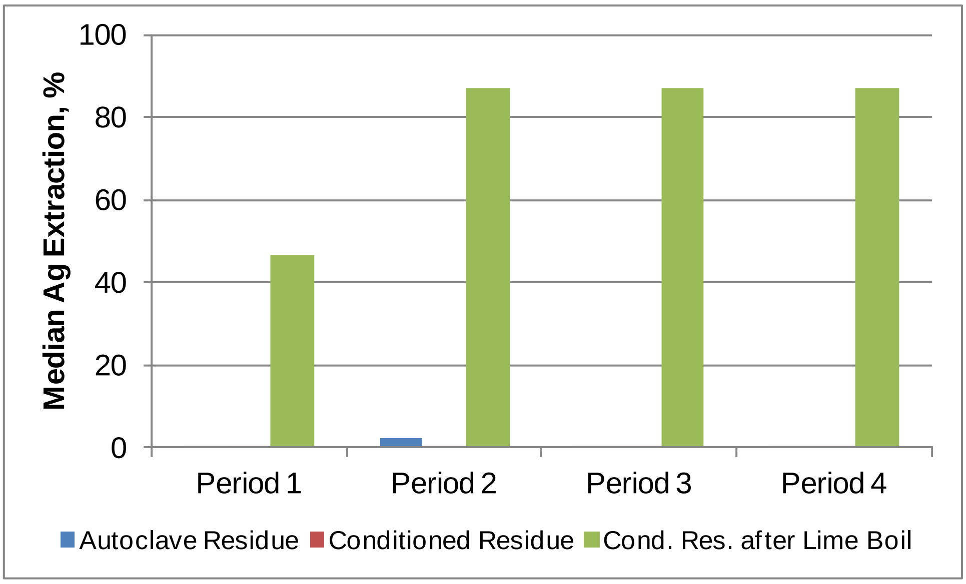

Figure 7: CNA Silver Extraction from Pilot Classical POX Test Work

FTR POX Leach Test Work

The test work flow sheet employed in the FTR POX leach test work is provided in Figure 8.

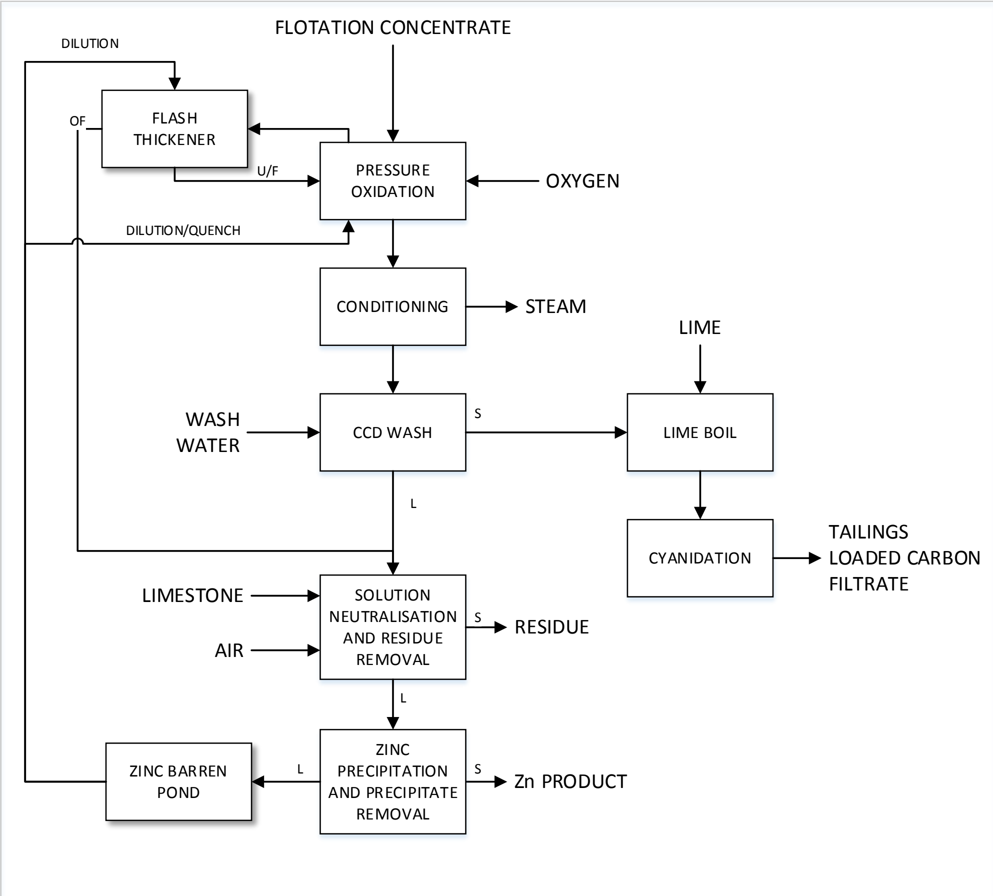

Figure 8: FTR POX Test Work Flow Sheet

The batch FTR POX test work was conducted on a concentrate sourced from the feed to the Classical POX pilot plant. The configuration employed was designed to mimic a continuous operation, both, in compartment 1 (Stage 1) and the following compartments 2 to 5 (Stage 2).

Stage 1 was a partial oxidation step. This was followed by autoclave depressurisation and solid-liquid separation of the product slurry.

Stage 2 involved returning the solids from Stage 1 to the autoclave together with a quantity of PLS and dilution fluid. The pressure leach was then concluded at the same temperature and oxygen partial pressure of Stage 1.

The final autoclave discharge solids were subjected to cyanidation tests to determine gold and silver recoveries. Cyanidation was conducted on residues with and without a lime boil step. The effect of a conditioning step was examined in some tests prior to the lime boil and cyanidation. The conditioning was done by depressurising the autoclave and leaving the slurry within the vessel under temperature control for 4 hours.

FTR Pressure Oxidation

The suite of conditions adopted in the FTR POX (Table 7) was very similar to those employed in the Classical POX test work (Table 3). In the FTR POX test work, a distinction was drawn between the conditions in Stage 1 (simulating the first compartment) and those of Stage 2 (subsequent compartments).

Tests numbers 1 and 2 were sighter tests to identify the optimal sulfide oxidation extent for Stage 1.

Table 7: FTR POX Test Work Conditions

Test #	Temp. (°C)	Pressure O_2 (kPa)	Solids Density (wt %)		Retention Time (min)		Dilution Water:PLS (g/g)		Condition-ing
			Stage 1	Stage 2	Stage 1	Stage 2	Stage 1	Stage 2	Yes/No
1	220	500	15.0	16.2	40	30	--	3.2:1	No
2	220	700	15.0	14.6	40	30	--	2.9:1	No
3	220	700	13.0	20.0	17	30	--	2.7:1	Yes
4[a]	220	700	13.0	20.0	16	30	--	2.3:1	Yes and No[b]

[a] Stage 1 for test 4 was conducted in duplicate to produce sufficient combined residue sample for Stage 2 requirements.
[b] After Stage 2, approximately 50% of the slurry was withdrawn from the autoclave to examine what the conditioning step impact was on the sulfate content of the FTR POX residue.

Table 8 provides the results from the FTR POX autoclave test work.

Table 8: FTR POX Autoclave Results

Test #	Stage 1 (Compartment 1)			Stage 2 (Autoclave Discharge)		
	Sulfuric Acid in Leachate (g/L)	Soluble Fe in Leachate (g/L)	Sulfide Oxidation (%)	Sulfuric Acid in Leachate (g/L)	Soluble Fe in Leachate (g/L)	Overall Sulfide Oxidation (%)
1	64.8	8.6	99.5	33.3	0.310	99.6
2	61.8	7.2	99.9	35.3	0.300	99.9
3	60.4	13.7	91.3	32.0	0.890	99.4
4.1[a]	59.3	16.5	81.3	49.5	0.630	99.1
4.2[a]	53.4	15.4	85.0			

[a] Stage 1 for test 4 was conducted in duplicate to produce sufficient combined residue sample for Stage 2 requirements.

Sulfide Oxidation

Sulfide oxidation in the FTR POX autoclave tests was in excess of 98% (Figure 9), similar to that obtained in the Classical POX test work (Figure 4).

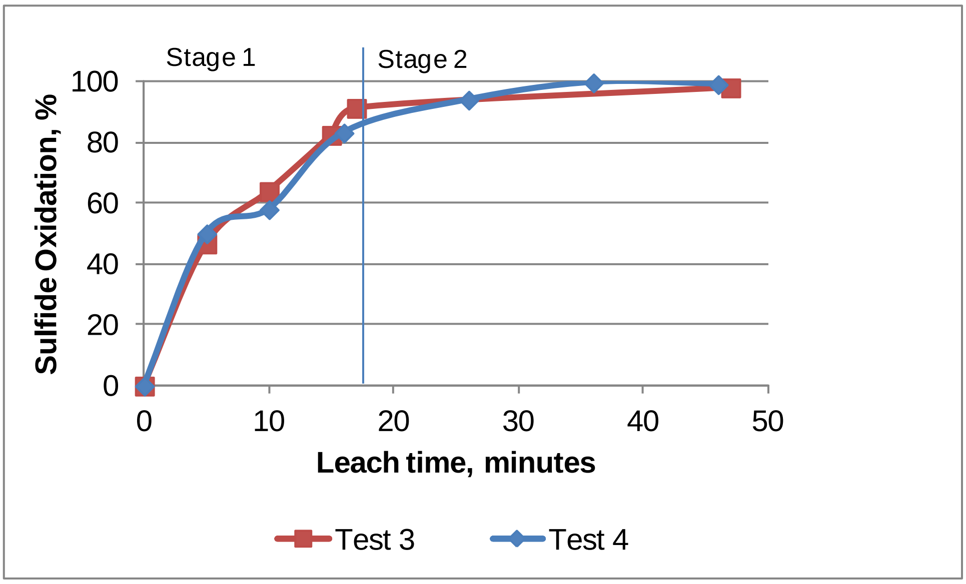

Figure 9: Batch FTR POX on Concentrate at 220°C, 700 kPa O_2 Overpressure

Iron Extraction

The iron extraction at 50% from the Batch FTR POX was higher than in the Classical POX process (33%). The iron displayed a progressive extraction from Stage 1 (at 40%) across the full autoclave retention time (Figure 10). Unlike in the Classical process, there was no evidence of any nett iron re-precipitation.

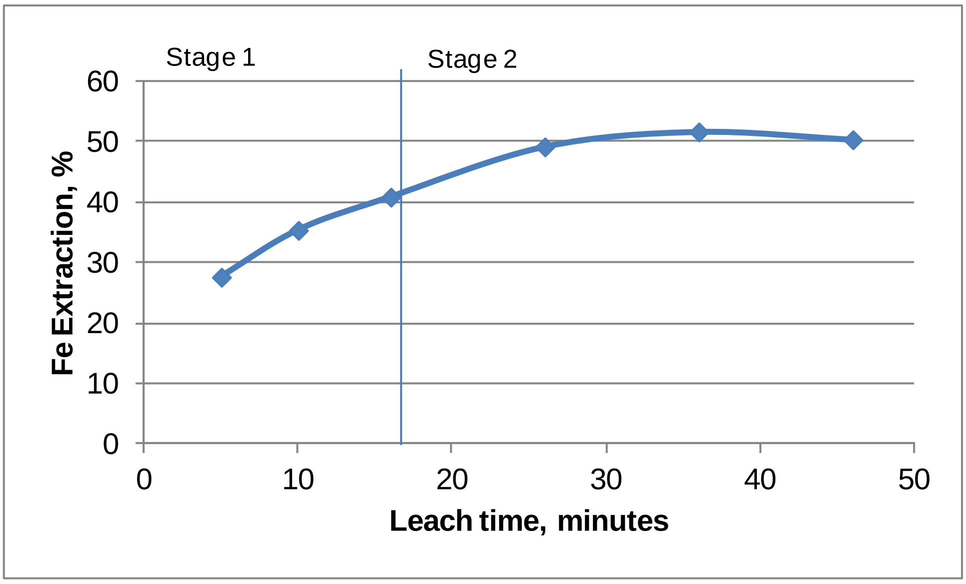

Figure 10: Batch FTR POX (Test 4) Iron Extraction

The contribution of ferrous and ferric in the Stage 1 and Stage 2 discharge is given in Table 9. Clearly, a majority of the iron extraction occurs in Stage 1 (or compartment 1) of a continuous autoclave.

Table 9: Batch FTR POX (Test 4) Iron Speciation

	Fe^{2+} g/L	Fe^{3+} g/L	Fe^{2+}/Fe^{3+}
Stage 1	5.0	11.5	0.43
Stage 2	0.63	1.13	0.56

Zinc Extraction

Figure 11 shows that the zinc extraction was approximately complete under the conditions of the Batch FTR POX test work.

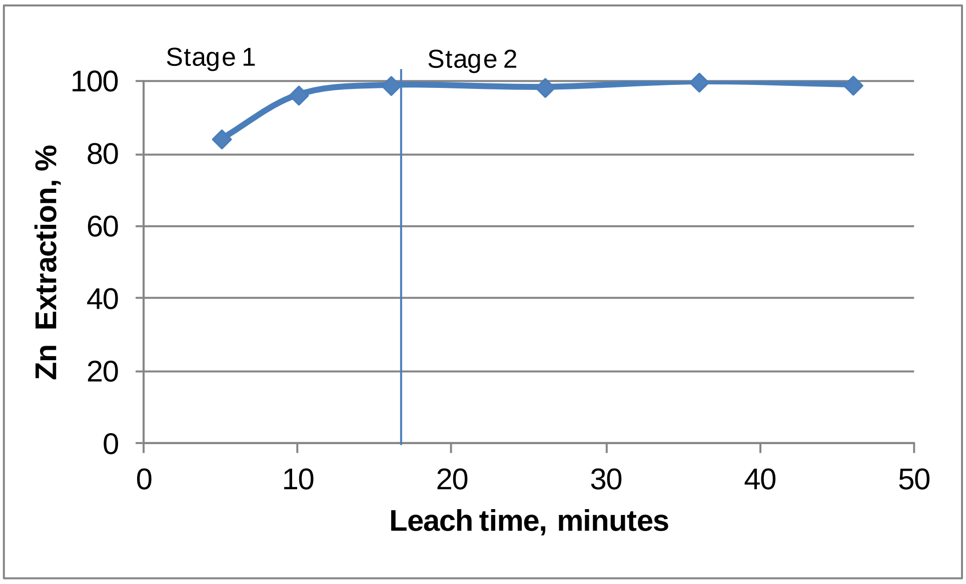

Figure 11: Batch FTR POX (Test 4) Zinc Extraction

Conditioning

The conditioning step as applied to FTR POX autoclave Stage 2 residue made very little impact on the sulfate levels, which were already low and largely comprising jarosites (refer to Table 10 and Table 11).

Table 10: Batch FTR POX Effect of Conditioning on Sulfate Sulfur

Test	Sulfate Sulfur in residue (wt %)		
	Final POX Residue	**Conditioning (1h)**	**Conditioning (4h)**
Batch FTR POX Tests 3 and 4	2.60 at 20% solids	2.68 at 20% solids	2.78 at 20% solids

The simulated FTR POX batch test work suggested that a conditioning step has little value in reducing the sulfate levels from any BFS contained in the Stage 2 discharge residue.

The mineralogical analysis (Table 11) showed that, while Stage 1 residue contained 18% w/w BFS, it was not present in Stage 2 residues.

Table 11: FTR POX Test Work Quantitative Mineralogical Analysis

Mineral	Stage 1 Residue (wt%)	Stage 2 Residue (wt %)	Conditioning Residue (wt%)
Clay Mineral	1	1	1
Illite	9	9	11
Muscovite	10	12	14
Alpha Quartz	26	30	29
Pyrite	8	0	0
Jarosite	14	18	18
Argento-jarosite	2	3	1
Basic Iron Sulfate	18	0	0
Hematite	12	27	26
TOTAL	**100**	**100**	**100**

Cyanide Leach

The FTR POX leach residues were subjected to batch cyanidation tests (CIL) to determine gold and silver extraction. The FTR POX residues were first subjected to a lime boil pre-treatment.

CIL gold and silver extraction from FTR POX leach residues without conditioning after lime boil reached in excess of 95 and 94% respectively (Table 12).

Table 12: FTR POX Test Work Gold and Silver Recovery

Residue from FTR POX Test No	Conditioning	Lime Consumption[a] (kg/tonne)	Extraction (%)	
			Ag	Au
1	No	269	93.9	97.1
2	No	306	96.7	98.5
3	Yes	130	86.8	96.6
4	No	135	87.5	96.9
4	Yes	137	79.5	95.7

[a] Lime consumption in lime boil (kg per tonne of FTR POX Stage 2 residue).

Classical and FTR POX Leach Test Work Comparison

Value Metals Extraction

The two pressure oxidative leach flow sheet concepts showed comparable extraction of gold, silver and zinc (Table 13).

Table 13: Classical and FTR POX Comparison – Value Metals Extraction

		Classical POX Batch Test Work	Classical POX Pilot Test Work	FTR POX Batch Test Work
Gold extraction[a]	%	89 – 95	95 – 97	95 – 97 [c]
Silver extraction[a]	%	87 – 94	80 – 95	80 – 97 [c]
Zinc extraction[b]	%	NA	>97	>97

[a] Recovery from cyanide leach after lime boil.
[b] Recovery from pressure oxidation to autoclave discharge liquor.
[c] CIL extraction.

Process Data

Table 14 summarises the important process data for the Classical and the FTR POX flow sheets. Again, Stage 1 simulates the autoclave first compartment and Stage 2 the remaining compartments 2 to 5.

Table 14: Classical and FTR POX Comparison – Process Data

Item			Classical POX Batch Test Work	Classical POX Pilot Test Work	FTR POX Batch Test Work[a]
1	Sulfur oxidation – Stage 1	%	--	55 – 80	81 – 85
	Sulfur oxidation – Overall (Stage 1 and 2)	%	> 96	>99	>99
2	Solids density – Stage 1	w/w%	--	11 – 12	13
	Solids density – Stage 2	w/w%	11 – 13	8 – 10	20
3	Iron extraction – Overall (Stage 1 and 2)	%	12 – 33	10 – 22	50
	Iron concentration (Stage 1)	g/L	--	15.5 – 18.2[e]	16.5
	Iron speciation (Fe^{2+}/Fe^{3+}) – Autoclave PLS (Stages 1&2)		0.03 – 0.07	0.05 – 0.10	0.43 – 0.56
4	Sulfate sulfur in solids – Pre-Conditioning residue	%	8.4 – 11.6	9.7 – 10.6	2.6 – 3.2
	Sulfate sulfur in solids – Post-Conditioning residue	%	2.8 – 3.0[b]	3.7 – 5.9[c]	2.8[b]
	Fe/S Molar ratio – Post-Conditioning residue		NA[d]	1.2 – 1.4	3.2 – 3.7

[a] Test 3 and 4.
[b] 4 hours conditioning.
[c] 6 hours conditioning.
[d] Not available.
[e] In compartment 1. This iron is carried over to the subsequent compartments in the autoclave.

Item 1:

Complete sulfur oxidation was achieved in both the Classical and the FTR POX flow sheets (Item 1 in Table 14). This is supported by the comparable gold and silver extractions. The similar sulfide oxidation suggests that the heat removal requirements for both circuits would be comparable.

Item 2:

In the Classical POX autoclave, the exothermic heat generated in the autoclave is quenched by the addition of a quench fluid with concomitant reduction in solids density.
In the FTR POX heat is abstracted from Stage 1 in both flash steam and the thickener overflow fluid and consequently the solids densities can be increased across the autoclave.

The thickener overflow liquor carries away BFS forming components of iron, sulfates and sulfuric acid.

Item 3:

Iron extraction and speciation: The iron extraction and the aqueous ferrous to ferric ratio in the FTR POX autoclave were higher than those of the Classical POX autoclave (Item 3 in Table 14). All iron extracted in the autoclave is neutralised and precipitated with limestone in the Solution Neutralisation step where the ferrous iron needs to be oxidised before it is precipitated.

Item 4:

The Fe/S mole ratio is an indicator of the residual sulfate in the final conditioned residue. A higher Fe/S mole ratio suggests that there is less residual BFS and jarosite and consequently should experience a lower specific lime consumption in the lime boil step. The conditioning step for the FTR POX was not required (Item 4 in Table 14).

Settling tests were conducted on Pilot Classical and Batch FTR POX autoclave residue slurries. In the case of the FTR POX residues, settling tests were conducted on slurries from Stage 1 and Stage 2. In the case of the Classical POX, settling tests were conducted on slurries from compartment 6 (autoclave discharge). Results of this test work are summarised in Table 15 and shows that the settling properties of slurries from both the Classical and FTR POX systems are comparable.

Table 15: Pilot Classical and Batch FTR POX Settling Test Work Results

Sample	Flocculant Dose (g/t Residue)	Well Density (wt% Solids)	Settling Rate (m/h)	Underflow Density (wt% Solids)
Pilot Classical Autoclave Residue	130 – 140	6	2.4 – 3.7	28
Batch FTR POX Stage 1 Residue	100 – 150	6	3.1	27 – 33
Batch FTR POX Stage 2 Residue	150	6	3.1	28.5

ENGINEERING

The Classical and FTR circuits deliver very similar gold, silver and zinc recoveries but the two processes are engineered differently.

Process Flow Sheet

Classical POX Autoclave

The Classical POX autoclave circuit flow sheet is provided in Figure 12.

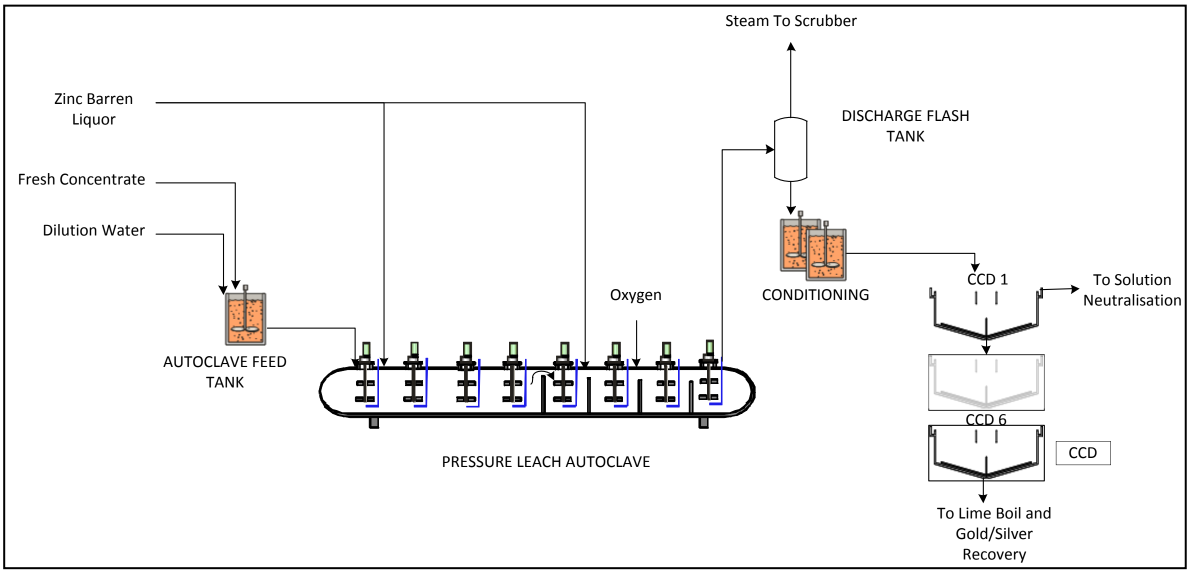

Figure 12: Classical POX Autoclave Flow Sheet

In the Classical POX autoclave circuit (refer to Figure 12), the feed to the autoclave is introduced into the first compartment and exits from the last compartment of the autoclave into a flash tank. In the autoclave, the sulfide minerals (including zinc and iron sulfides) in the feed are oxidised generating heat. A quench fluid is introduced into the autoclave for temperature control and this water occupies volume, thus reducing the autoclave capacity.

The discharge from the Classical POX autoclave flash tank reports to the Conditioning step where the slurry is kept at approximately 95˚C for 8 hours. In the conditioning step, most of the BFS is re-dissolved and removed from the leach residue (containing gold and silver) in the subsequent CCD step. The final CCD underflow slurry reports to the lime boil circuit where lime is added at near boiling point to destroy meta-stable iron hydroxy-sulfate compounds (BFS and jarosites) in the leach residue that survived the conditioning step. The lime boil discharge slurry reports to cyanidation for gold and silver recovery.

The CCD overflow liquor containing soluble zinc and impurities such as iron and aluminium reports to the Solution Neutralisation circuit where limestone is added and air is introduced to precipitate iron and aluminium. The precipitated impurities are removed by filtration and the liquor rich in soluble zinc reports to the Zinc Recovery circuit.

FTR POX Autoclave

The FTR POX autoclave circuit flow sheet is provided in Figure 13. The main features of the FTR POX process include the following:

- First compartment in which 70-85% of the sulfide sulfur is oxidised
- First compartment flash cooling step complete with flash underflow thickener to remove autoclave solute
- Recycle of first compartment flash underflow thickener to both compartment 1 and 2
- Higher slurry density within the autoclave
- No conditioning circuit

The discharge of the FTR POX autoclave reports to the CCD circuit and thereafter follows the classical circuit.

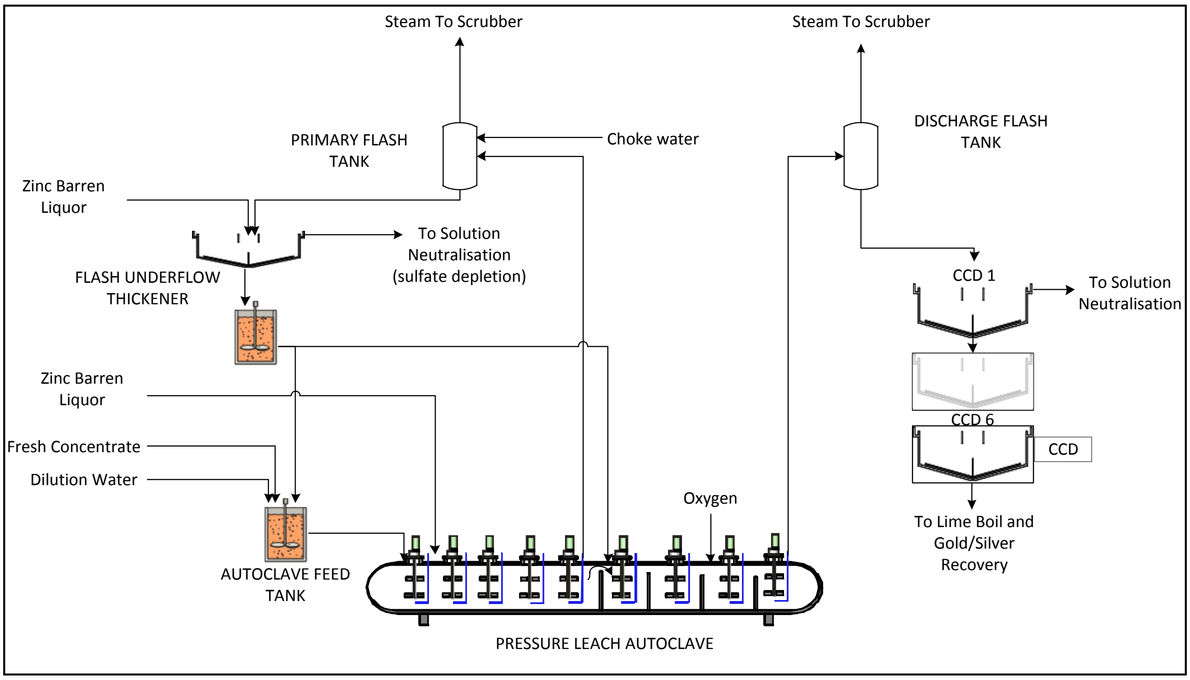

Figure 13: FTR POX Autoclave Flow Sheet

Comparison of Classical and FTR Flow Sheets

The main differences between the Classical (refer to Figure 12) and the FTR POX circuit (Figure 13) flow sheets for the Metates Gold Project are summarised below:

- **First compartment cooling**
    - The FTR circuit includes a flash tank for the first compartment FTR POX autoclave discharge. Zinc barren liquor is added to the first compartment of the autoclave to provide both dilution and cooling to the first compartment. A majority of the slurry from the first compartment is flashed to ambient boiling point releasing steam and thus cooling the slurry to the Flash Underflow Thickener. The balance of the first compartment slurry passes to the second and ensuing compartments.
    - The Classical POX option only relies on quench fluid for cooling throughout the autoclave

- **Flash underflow thickener**
    - The flash underflow slurry is diluted with the cool zinc barren liquor to provide the necessary dilution in the thickener well plus it further cools the slurry to between 60 to 70˚C. A majority of the zinc barren liquor added in the first compartment FTR POX autoclave and the Flash Underflow Thickener is removed in the thickener overflow. This allows higher density slurry to be returned to compartment 2 of the autoclave
    - The Classical POX option does not require the flash underflow thickener

- **High autoclave densities**
    - The increased slurry density of the FTR circuit reduces the overall autoclave volume, thus reducing the autoclave size for a fixed feed rate. The oxygen transfer rate (OTR) is therefore higher for FTR compared to Classical POX circuit
    - The Classical POX option will require an autoclave with a larger volume

- **Dissolution of basic iron sulfate**
    - The conditioning step is not normally required in the case of the FTR circuit. The Flash Underflow Thickener creates an equilibrium break as solutes such as sulfates, acid, ferric and ferrous are removed in the thickener overflow. This creates conditions suitable for the re-dissolution of any BFS made in the first compartment and thus removing the need of conditioning step
    - A conditioning step is required in the Classical POX option

Mass Balance

The key differences in the mass balance between the Classical and the FTR POX circuits are highlighted in Table 16. The Syscad mass balance outputs for the POX circuit for both options are shown in Figure 14.

Table 16: Mass Balance comparison between Classical and FTR POX Circuits

Description	Unit	Classical POX Circuit	FTR POX Circuit
Flash steam production	tonne/tonne of dry concentrate	1.7	1.7
Oxygen consumed	tonne/tonne of dry concentrate	0.52	0.52
Fresh concentrate feed throughput	Dry tonne/h	875	875
Sulfuric acid removal in compartment 1	kg/tonne of feed	0	116
Sulfur removal in compartment 1	kg/tonne of feed	0	89
Iron removal in compartment 1	kg/tonne of feed	0	55
Slurry density in compartment 2	% solids	10.7	17.3
Partial oxygen pressure	kPa	500	1000
Residue mass	tonne residue/tonne concentrate	0.90	0.83

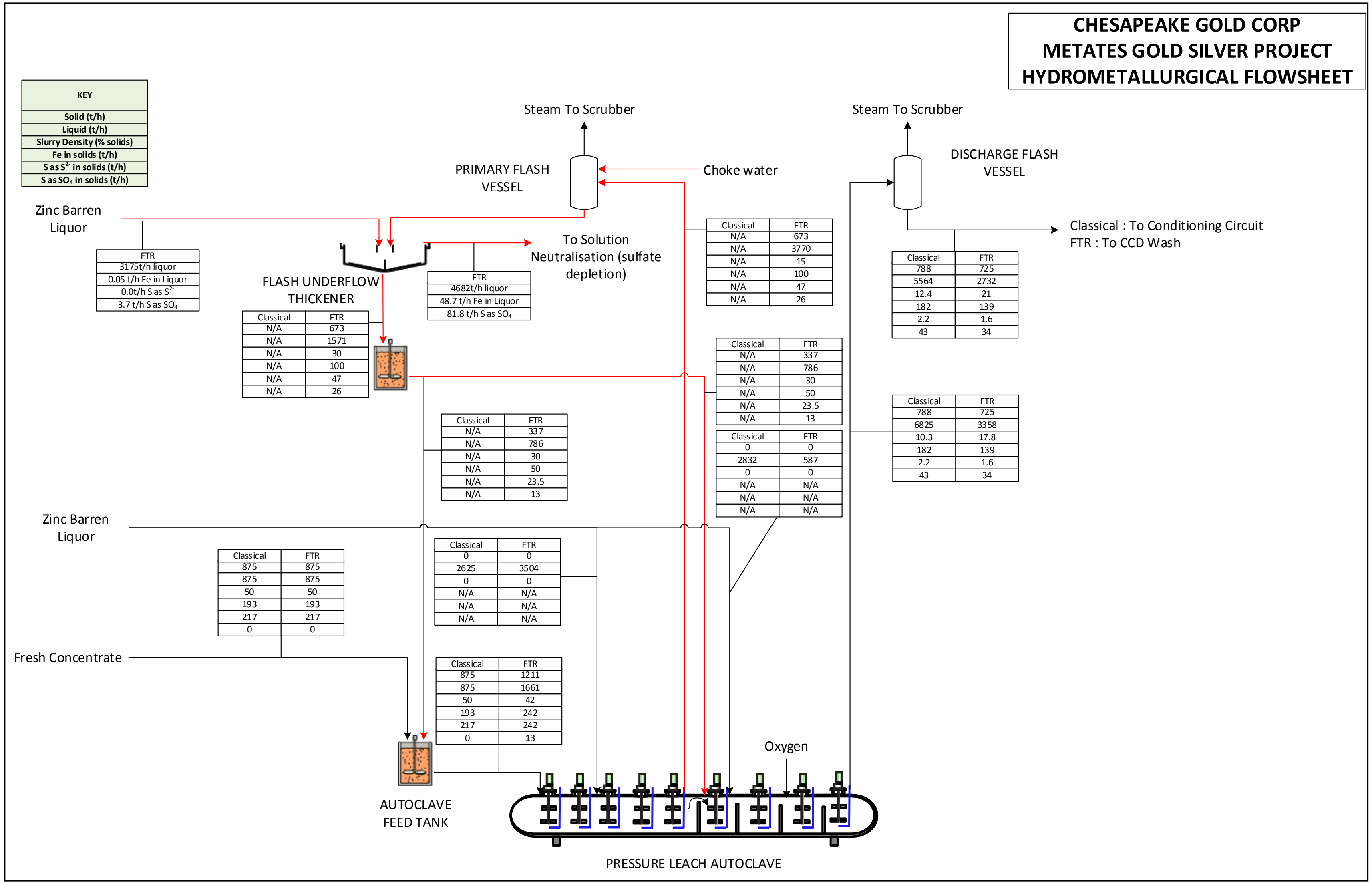

Figure 14: Mass Balance Comparison Between Classical and FTR POX Autoclave

Capital Costs

Major Equipment

The Classical and the FTR POX circuit flow sheets result in a number of differences in the equipment requirement. Table 17 provides a list of the major equipment required for both options.

Table 17: Major Equipment in the POX and Conditioning Circuits

Description	Classical POX Circuit		FTR POX Circuit	
	No.	Dimension	No.	Dimension
Total Number of Autoclaves	10	5.6 m (inside diameter) 44.5 m Length (tan to tan)	5	5.6 m (inside diameter) 44.5 m Length (tan to tan)
Agitators per autoclave	8	1900 kW (total installed power) (500 kPa Oxygen)	9	1980kW (total installed power) (1000 kPa Oxygen)
Flash tanks per Autoclave	1	5.77 m diameter	2	5.77 m diameter
Total Flash Underflow Thickeners	0	Not Applicable	5	40 m diameter
Total Conditioning Circuit Tanks	6	25 m diameter 20 m height	0	Not Applicable
Total Conditioning Circuit Agitators	6	4500 kW (total installed power)	0	Not Applicable
Total Number of Autoclave Feed Pumps	15	10 duty 5 standby	16	8 off Compartment 1 feed pumps (5 duty, 3 standby) 8 off Compartment 2 Feed Pumps (5 duty, 3 standby)
Autoclave Feed Pumps Installed Power	15	2250 kW (total installed power)	16	6400 kW (total installed power)

Major Equipment Costs

Table 18 provides the major mechanical equipment cost comparison between the Classical and FTR circuits.

Table 18: Major Equipment Supply Cost Estimate for the Classical and FTR POX Circuits (+/- 25% Accuracy, Q4 2013)

Description	Supply Equipment Cost Estimate (US$M)	
	Classical POX Circuit	FTR POX Circuit
Autoclaves	115.9	69.4
Autoclave agitators	30.2	18.5
Flash Underflow Thickeners	0	10.4
Flash Tanks	14.0	14.0
Autoclave Feed Pumps	22.8	35.8
Autoclave Fluid Tanks & Feed Pumps	7.2	4.7
Conditioning Circuits	29.6	0

The major supply equipment cost around the FTR POX circuit is approximately US$67 million less compared to what is required for a Classical POX option.

Operating Cost

The main operating cost differences for the Classical and FTR POX circuits are in the labour, power and maintenance material costs (refer to Table 19). The operating costs for both circuits are similar.

Table 19: Operating Cost Component Estimate for the Classical and FTR POX Circuits (+/- 25% Accuracy, Q4 2013)

Description	Operating Cost Estimate (US$M /annum)	
	Classical POX Circuit	FTR POX Circuit
Labour Costs	0.792	0.717
Power Costs	19.5	13.2
Maintenance Material Cost	15.3	13.9

CONCLUSIONS

The test work has shown that the Classical and the FTR POX circuits produce comparable extractions of gold, silver and zinc and the operating costs for both circuits are similar.

The main benefits of the FTR POX circuit over a Classical POX circuit are as follows:

- Reduced autoclave volume per tonne of concentrate feed in the FTR POX circuit compared to Classical POX circuit
- Depletion of sulfates, acid, ferric and ferrous from the liquor in the first compartment slurry discharge creates conditions suited for the re-dissolution of BFS and thus removing the need of a conditioning step
- FTR POX circuit is more capital efficient compared to a Classical POX circuit

These benefits have led to the Metates Gold Project adopting the FTR POX option in the Pre-Feasibility Study and pursuing further FTR POX test work.

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