Appendix L

Memo (30 January 2002) – WTP: Applicable WTP Feed Range

Memo (25 January 2002) – WTP: Proposed Use of Lime Softening Process for TDS Removal

amec

Memo

To	**Karl Hanneman**	File No.	**U419G**
From	**Tom Higgs**	cc	**Rick Zimmer, Bryan Nethery**
Tel	**1-604-664-4542**		
Fax	**1-604-664-3057**		
Date	**Jan 30, 2002**		

Subject **Pogo Mine Water Treatment Plant - Applicable WTP Feed Range**

As requested, I have reviewed the Predicted WTP Effluent Quality presented in Table 5.1 of the WMP and assessed the applicable water treatment plant feed concentrations over which the proposed treatment plant design would produce the predicted quality. The applicable feed concentrations, along with the predicted RWC values from the current water quality modelling work are presented below. The ability of the proposed WTP to meet the Predicted Effluent Quality values at the Applicable Feed Concentrations is based on the following assumptions:

- Ferric iron addition, subsequent co-precipitation and recycle will be used to enhance removal of As, Se and Cr to meet effluent quality targets.
- The feed will have a neutral to alkaline pH which will limit the concentration of most metals in solution to the ranges presented due to solubility limits.
- The treatment plant operating pH will be set to achieve optimum removal of designated target metals.
- The proposed WTP will include provisions for NaHS addition in the event that there was a demonstrated need to reduce Cd, Cu, Pb, Ni, Ag and Zn beyond what could be achieved with ferric co-precipitation and pH optimization. Experience however has demonstrated that the ferric co-precipitation process can likely meet the Predicted WTP Effluent Quality without the need for NaHS addition.
- The maximum feed concentrations listed below are not projections of expected feed, but instead are ranges over which the proposed process design is expected to be applicable. The intent in presenting this data is to demonstrate the capability of the technology being proposed.

The selection of applicable feed concentrations is based on a combination of experience at similar systems treating minewater, operating data from the existing WTP, as well as experience at other WTP's treating markedly higher feedwater concentrations.

Tom Higgs

AMEC E&C Services Limited
111 Dunsmuir Street, Suite 400
Vancouver, B.C. V6B 5W3
Tel (604) 664-4315
Fax (604) 669-9516
www.amec.com

Comparison of Average WTP Feed, RWC WTP Feed, Applicable Feed Concentrations and Effluent Quality Objectives

Metals (µg/L)	WTP Feed based on Average Values*	WTP Feed based on 95th Percentile RWC Values*	Applicable Feed Concentration (µg/L) (up to)	Predicted WTP Effluent Quality Objectives (µg/L)
As	1,700	3,800	6,000	30
Cd	0.3	0.5	50	0.3
Cr	6	10	100	30
Cu	15.1	23.4	500	5
Fe	1,800	3,300	10,000	300
Pb	21	49	500	1
Hg	0.1	0.2	2	0.1
Mn	500	900	10,000	200
Ni	13	24	500	30
Se	3.4	4.9	20	2
Ag	0.07	0.1	2	0.1
Zn	28	45	1,000	15

** - Rounded values*

amec

Memo

To	**Karl Hanneman**	File No.	**U419G**
From	**Tom Higgs**	cc	**Rick Zimmer, Bryan Nethery**
Tel	**1-604-664-4542**		
Fax	**1-604-664-3057**		
Date	**Jan 25, 2002**		

Subject **Pogo Mine Water Treatment Plant – Proposed Use of Lime Softening Process for TDS Removal**

Introduction

The new water treatment plant to be constructed for the Pogo Mine will incorporate a single stage lime softening/recarbonation process in order to reduce the total dissolved solids (TDS) of the treated effluent. A significant portion of the TDS in the expected water treatment plant feed is carbonate hardness, including dissolved Ca and Mg. A series of testwork has been completed, including bench tests, a full-scale site test with the existing water treatment plant, and an 11 month field trial. The purpose of this memo is to present the results of the lime softening testwork that has been completed to date and to predict the effectiveness of the full scale process.

Theory

Lime Softening

The lime softening process involves the addition of hydrated lime (Ca(OH)2) to increase pH through the addition of hydroxyl ion (OH-) and subsequently remove hardness through the precipitation of calcium and magnesium as CaCO3 and $Mg(OH)_2$. The increase in pH converts CO_2 and HCO_3^{-2} to CO_3^{-2} which in turn reacts with Ca^{+2} ion to precipitate $CaCO_3$. A reduction in TDS occurs primarily due to the removal of Ca^{+2}, Mg^{+2} and CO_3^{-2} ion from solution. The individual reactions associated with the lime softening process are illustrated below:

$$Ca(OH)_2 \Leftrightarrow Ca^{+2} + 2OH-$$

$$Ca^{2+} + 2OH^- + 2CO_2 \Leftrightarrow Ca(HCO_3)_2$$

$$Ca(OH)_2 + Ca(HCO3)2 \Leftrightarrow Ca\ CO_3\downarrow + H_2O$$

$$Mg^{+2} + Ca(OH)_2 \Leftrightarrow Mg(OH)_2\downarrow + Ca^{+2}$$

CO2 Neutralization (Recarbonation)

The lime softening process is conducted in the pH range of 9.8 to 11.2 depending on the degree of hardness removal required and the chemistry of the water. Therefore final pH adjustment is required prior to discharge. Neutralization after lime softening can be carried out using carbon dioxide (CO_2) gas to avoid the addition of TDS to the water. There are a number of potential mechanisms involved, depending on the chemistry of the water, but the primary mechanism responsible for pH adjustment is the reaction of carbon dioxide with hydroxyl ion to produce bicarbonate ion. Assuming the water contains some residual Ca and Mg the neutralization reaction using CO_2, can be summarized by the following mechanisms;

$$Ca^{2+} + 2OH^- + 2CO_2 \Leftrightarrow Ca^{2+} + 2HCO_3^-$$

$$Mg^{2+} + 2OH^- + 2CO_2 \Leftrightarrow Mg^{2+} + 2HCO_3^-.$$

The above combined lime softening and CO2 neutralization process is described as single stage lime softening since Ca remaining in solution after lime addition and solids separation is not subsequently removed but is re-dissolved and converted to soluble $CaHCO_3$ during CO_2 neutralization. Two stage lime softening requires a subsequent step where residual Ca is precipitated as $CaCO_3$ at pH between 10.2 to 10.6 using $NaCO_3$ however this second stage does not provide additional TDS removal since the addition of Na simply replaces the Ca that has been removed from solution.

Bench Test Results

As part of the process design testwork conducted for construction of the existing WTP, initial bench tests were conducted in 1998. Additional bench tests were conducted in early 2000 to evaluate the potential use of the lime softening process in the existing plant to remove TDS. This testwork utilized a sample of WTP feed collected on Feb 18/2000. The testwork procedure mimicked the WTP process and included ferric chloride addition to precipitate arsenic (As), followed by lime addition to increase pH to various levels to evaluate the precipitation of both Ca and Mg hardness to reduce TDS. The 2000 bench results demonstrated a reduction in TDS from 750 to 590 mg/L (approximately 20%) by increasing pH to 10.5 followed by solids separation and pH neutralization using CO_2 to pH 8.5.

Full-Scale Site Test Results- Lime Softening

Following successful demonstration of the lime softening TDS removal process at the bench test, a full scale trial was set-up and carried out at the Pogo WTP in March-April 2000. This program used the existing lime system and involved the addition of a recarbonation system (through CO_2 addition) to the filter feed tank to adjust pH prior to filtration and discharge to the injection wells. The pH set-point prior to the start of the test program was 7.8. The test program involved step-wise increase in pH set-point to 9.0, 9.8, 10.2, 10.8 and 11.2 in 24 hour intervals with concurrent sampling and analyses of feed and clarifier O/F to assess TDS removal. Each increase in the pH set-point resulted in an increase in the dry hydrated lime feeding rate. The results of the full-scale trial are summarized below.

Parameters	**Reactor pH**				
	9.0	9.8	10.2	10.8	11.2
Feed					
TDS (mg/L)	847	913	928	871	816

Ca (mg/L)	99	106	106	100	101
Mg (mg/L)	80	87	95	84	81
Hardness (mg/L as $CaCO_3$)	580	628	663	598	590
Clarifier O/F					
TDS (mg/L)	824	754	777	724	670
Ca (mg/L)	88	74	69	95	128
Mg (mg/L)	58	77	81	47	21
Hardness (mg/L as $CaCO_3$)	462	505	513	435	407
Performance					
Lime Dose (g/L as $Ca(OH)_2$)	0.24	0.29	0.41	0.47	0.51
TDS Removed (mg/L)	23	160	151	147	146
TDS Removed (%)	2.7%	17.5%	16.3%	17.0%	17.9%
Hardness Removed	119	123	150	163	183
Ca Removed (mg/L Ca)	11	33	37	5	-27
Ca Removed (mg/L as $CaCO_3$)	27	81	92	11	-67
Mg Removed (mg/L as Mg)	22	10	14	36	60
Mg Removed (mg/L as $CaCO_3$)	92	42	58	152	250

The full scale trial demonstrated that lime softening was able to reduce TDS by approximately 150 mg/L (equivalent to a 17% reduction) using a pH set-point range of 9.8-11.2. Most of the TDS removal was due to the precipitation of $CaCO_3$ with a lesser amount due to precipitation of $Mg(OH)_2$. The trial results demonstrated that further reductions in Mg could be achieved at higher operating pH's but there was no net benefit in terms of TDS removal from this approach since the concentration of residual Ca increased as the Mg concentration in solution decreased.

Evaluation of TDS Removal during 11 month lime softening field trial

Once the full scale test was complete, the lime softening system was operated for a period of 11 months to remove TDS from the minewater. During this period, feed and discharge samples were collected monthly to evaluate performance. The results of these analyses and the calculated percent removal based on field data are plotted in the attached figure.

The test period was broken down into 8 months when the pH set-point was 10 and 3 months when the pH set-point was reduced to 9.5. At pH 10, the amount of TDS removed varied from a low of 11% to a high of 21%,while at pH 9.5 TDS removal dropped to 4-10% Note that the actual Feed TDS concentration dropped from 906 mg/L to 533 mg/L during the period at pH 10 but remained relatively constant during the second period.

Conclusion

Based on the data collected on the use of the lime softening TDS removal process at Pogo, it is recommended that the lime-softening system be operated at pH 10.0 or higher. At these set points, it can be concluded that the proposed lime softening/recarbonation system with good automation and trained and experienced operators should remove approximately 15-20% of the TDS in the feed. For the purposes of system design we predict a 17% removal rate will be achieved over long term operation with a TDS feed in the range that expected from Pogo.

Teck-Pogo Inc.

TDS Removal
During Single Stage Lime Softening Period