MEMORANDUM
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SUBJECT:	**The Effect of Radio Frequency on Silver Leaching of Veladero Type 1 Ore**		
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EXECUTIVE SUMMARY

3 frequencies with 5-90 seconds RF exposure were studied on -32 mm Veladero Type 1 ore by Edward Melcarek. The silver recovery after 13 days' cyanide leaching at BTC was separately 7.8% at 92 kHz, 8.3% at 332 kHz and 6.6% at 3339 kHz compared to 2.9% of baseline. The leaching results suggest silver recovery would be higher if the bottle roll cyanide leaching is extended beyond 13 days. Gold recovery for RF treated samples was consistently 10-17% higher than baseline, suggesting RF treatment may significantly enhance gold leaching for Veladero Type 1 ore.

1. INTRODUCTION

Edward Melcarek from Sono-Dyne Inc., Canada applied radio frequency (RF) technology on Veladero Type 1 ore to enhance silver cyanide leaching recovery. More than 18 tests were separately performed by Edward Melcarek at frequencies of 92, 332 and 3339 kHz with exposure time from 5 to 90 seconds. The RF treated Veladero Type 1 samples were then shipped to Barrick Technology Centre (BTC) for the evaluation of silver recovery by bottle roll direct cyanidation during August 11 and 24, 2009. Edward Melcarek was invited to observe the cyanide leaching tests for the first 3 days at BTC.

Radio frequency has been widely studied in food, chemical, waste destruction and mining industries. In a radio frequency heating system, the RF generator creates an alternating electric field between two electrodes. The material to be heated is conveyed between the electrodes, where an alternating energy field causes polar molecules in the material to continuously reorient them to face opposite electrodes much like the way bar magnets move to face opposite poles in an alternating magnetic field. Friction resulting from this molecular movement causes the material to rapidly heat throughout its entire mass. The amount of heat generated in the product is determined by the frequency, the square of the applied voltage, dimensions of the material and its dielectric loss factor which are essentially measures of the ease with which the material can be heated by radio frequency waves [(1)].

The RF coil was employed to treat Veladero Type I ore in Edward Melcarek's study. The coil serves as the transformer primary, and the target metal becomes the secondary. When metal placed within the coil encounters the magnetic field, circulating eddy currents are induced within the metal. These currents flow against the electrical resistivity of the metal, generating precise and localized heat without any direct contact between the metal and the coil [(2)].

As we know, there is large difference of the thermal conductivity between silver and silica which is 430 and 1.3 $Wm^{-1}K^{-1}$ respectively. Their coefficient of expansion is also significantly different with 18.6 x 10^{-6} mm/^{0}C for silver and 0.55 x 10^{-6} mm/^{0}C for silica [(2)]. When the ore is inductive heated by RF, silver sulphide (acanthite) expands, while the silica does not. Any silica encapsulation is thereby stressed and micro fractures in silica are generated [(2)]. Those micro fractures may also help connecting numerous micro-pores which have already been present in silica [(3)] and thus the penetration of cyanide solution to the ore can be improved. As a result, silver leaching recovery can be increased.

Paul Meubus [(4)] applied RF to study the behavior of low nickel content (around 0.25%) serpentine. It was found that a magnetic phase (spinel) enriched in nickel can be separated from the products of reaction. Nickel concentrations up to 2.3% were found in this phase which also should contain up to 50% of the total nickel present in the original serpentine.

One US Patent [(5)] claimed a method of extracting metal from an underground ore body using electric induction heating. The ore body is heated to a temperature sufficient to break up the metallic ore compound and liquefy the metal. The metal flows into production wells where it is collected and transported to the surface. The electric induction is conveniently effected by passing alternating current through a conductor encompassing that portion of the ore body to be heated.

Mina Sakano and Takayuki Watanabe [(6)] investigated the recovery of useful metals and material from fly ash generating from melting furnace using RF thermal plasma system. The RF plasma torch constructed by the quartz tube and the induction coil has an injection tube along the centre axis for feeding fly ash into thermal plasma region and is operated with 50 kW plate power and at the oscillation frequency of 2 MHz.

Limited literature has been found citing the use of RF to enhance the extraction of metals from minerals.

2. METHOD

The sample of Veladero Type 1 ore was subjected to bottle roll direct cyanidation to leach silver and gold after being treated by RF. The methods of the treatment of RF and bottle roll cyanidation are described below.

2.1 RF Treatment

The method of RF treatment on Veladero Type 1 ore was designed and provided by Edward Melcarek [7] and the test work was carried out at Comdel Equipment, Ajax Tocco and Ambrell/Ameritherm in the United States respectively under the supervision of Edward Melcarek.

20 bags each with 1 kg of -32 mm Veladero Type 1 ore were shipped to Edward Melcarek. Each sample was prepared for RF treatment at above US labs and baseline cyanide leaching test at BTC as shown in Figure 1. The larger ore particles were not able to fit within the beaker and were therefore excluded from the test.

Figure 1: 500 cc 3.50" Diameter Pyrex Glass Beaker with a PET centre core insert.

The irradiated samples are thus less than 1 kg. The weight of the excluded rocks was not measured, but is estimated to be 200-400 g. The centre core provided a volumetric zone of exclusion by the ore. It constrained the ore to the inner walls of the glass beaker where there is maximum proximal RF energy coupling to the coil. The PET core material and the glass are essentially transparent to RF energy at the low frequencies and essentially are not thermally affected by the applied RF field. However, Edward Melcarek did observe some heating of the centre core at these higher frequencies with this set-up, but it did not affect ore temperature data.

The ambient average temperature of the ore was recorded utilizing a laser thermometer prior to exposure. The glass test cell beaker was then inserted into the centre of the RF coil. The RF coil was energized at constant exposure time and frequency at a preselected power input to the coil. The temperatures were recorded immediately after each exposure, at random vertical surface regions of the beaker and the top exposed ore surfaces. The contents of the beaker were then deposited into the sample cans, sealed and annotated with the applicable and observed data on the label fields, signed off as completed and shipped to BTC for cyanide leaching test.
Repeat of the procedure with the next sample at the next increased power level using the Bird wattmeter as the monitor to calibrate power.

2.2 Direct Bottle Roll Cyanide Leaching

The Veladero Type 1 ore was crushed to -32 mm. After thoroughly blending, the ore was split to 1 kg charges and delivered to Edward Melcarek for RF treatment. Ed Melcarek then shipped back the RF treated ore to BTC for direct bottle roll cyanide leaching tests to evaluate silver recovery. The pulp density in testing was adjusted to 35% solids with Vancouver tap water. 200 g/L lime slurry was used to maintain pH at 11.0. The level of cyanide was maintained at 1 g/L. All bottle roll leaching tests were performed at ambient temperature.
Leached solution samples were taken every 24 hours for the analysis of silver and gold after filtration. At the end of the test, the contents in the bottle were filtered, with the filtrate and washings collected and analyzed separately. The entire washed filter cake was dried, weighed and crushed to -2 mm, followed by pulverizing to 90% passing -75 µm. A representative split of the pulverized sample was analyzed for silver and gold in duplicate.

3. RESULTS AND DISCUSSION

Standard bottle roll direct cyanide leaching tests on RF treated samples were performed at BTC. The silver leaching kinetics and recovery were studied. Approximately 530 g of Veladero Type 1 ore prepared by the same method shown in Figure 1 was used in a baseline test.

3.1 Feed Chemical Properties

The chemical analysis results [8] on general -32 mm Veladero Type 1 ore are listed in Table 1.

Table 1: Veladero Type 1 ore chemical analysis

Sample		Ag	Au	S total	C total	Hg	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	LOI
		g/t	g/t	%	%	g/t	%	%	%	%	%	%	%	%	%
Veladero Type 1 ore -32 mm	UTV32-1	49	3.54	0.06	0.03	16.5	97.9	0.3	0.81	1.02	0.03	0.02	0.04	0.03	0.4
	UTV32-2	47	9.35	0.07	0.04										
	UTV32-3	49	5.34	0.07	0.04										
	Average	48.3	6.08	0.07	0.04	16.50									
	STDEV	1.15	2.97												
	Rel. SD	2.4%	48.9%												

The grade of silver and particularly gold may vary from sample to sample for the particle size of -32 mm when the sample mass was too small to be representative. It was therefore impossible to conduct head analysis for each of cyanide leaching tests.

3.2 Leaching Results

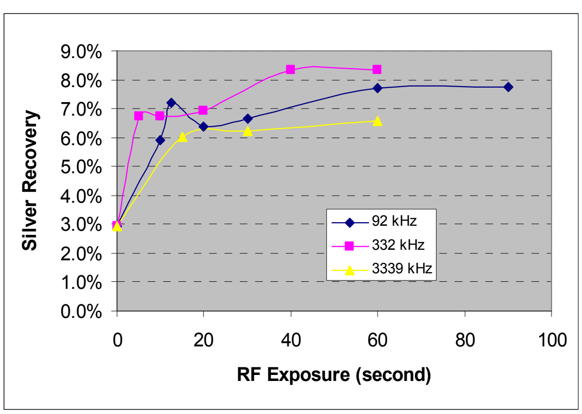
18 bottle roll cyanide leaching tests on Edward Melcarek's RF treated samples and 1 bottle roll of baseline test were carried out at BTC during August 11 and 24, 2009. The bottle roll results after 13 days leaching are summarized in Table 2.

Table 2: Summary results of RF treated samples and baseline

BTC Test No.	Sample Weight	Radio Frequency Treatment by Melcarek				Residence of Bottle Roll		Calculated Head Grade (g/t)		Residue Grade (g/t)		Calc. Recovery		Reagent Consumption (kg/t)	
	(g)	Sample No	Exposure (second)	RF (kHz)	RF (kW)	(Hour)	(Day)	Ag	Au	Ag	Au	Ag	Au	NaCN	lime
UTVBR0M	537.0					312	13	47.34	2.47	46.10	0.63	2.9%	69.6%	1.00	2.94
UTVBR29	537.9	A6	60	3339	3	312	13	51.86	2.43	48.10	0.46	6.6%	82.2%	1.84	5.13
UTVBR24	501.2	A1	30	3339	1	312	13	47.11	2.25	45.90	0.61	2.9%	70.3%	0.86	1.51
UTVBR25	591.1	A2	30	3339	1.5	312	13	48.56	2.71	45.80	0.57	5.9%	76.3%	0.79	1.93
UTVBR26	511.2	A3	30	3339	2	312	13	50.11	2.50	46.50	0.51	6.6%	78.8%	1.65	4.77
UTVBR27	512.1	A4	30	3339	3	312	13	48.94	2.75	45.60	0.55	6.2%	79.5%	1.04	3.13
UTVBR28	557.1	A5	15	3339	4	312	13	48.38	2.73	45.00	0.54	6.0%	78.3%	1.20	3.75
UTVBR35	572.9	C6	90	92	21.3	312	13	51.33	3.76	47.10	0.55	7.8%	82.0%	1.96	4.74
UTVBR30	638.0	C1	60	92	21.3	312	13	51.04	3.79	46.60	0.47	7.7%	84.2%	2.17	5.04
UTVBR31	469.9	C2	30	92	21.3	312	13	50.81	2.78	47.00	0.51	6.6%	76.9%	0.99	2.74
UTVBR32	496.4	C3	20	92	21.3	312	13	49.18	2.83	45.60	0.51	6.4%	79.9%	1.34	4.01
UTVBR33	491.4	C4	12.5	92	21.3	312	13	49.09	3.78	45.70	0.56	7.2%	82.8%	1.98	5.06
UTVBR34	407.8	C5	10	92	21.3	312	13	50.25	4.04	46.90	0.86	5.9%	75.2%	1.57	5.38
UTVBR40	431.2	B5	60	332	4	312	13	49.93	4.19	45.70	0.49	8.3%	86.7%	1.56	4.38
UTVBR37	563.1	B2	40	332	4	312	13	48.72	3.64	46.50	0.56	8.3%	83.2%	1.69	2.78
UTVBR38	466.6	B3	20	332	4	312	13	49.53	3.49	45.80	0.51	6.9%	81.9%	1.34	3.40
UTVBR39	538.0	B4	10	332	4	312	13	49.54	2.79	45.40	0.55	6.7%	81.1%	1.85	4.82
UTVBR41	529.6	B6	5	332	4	312	13	49.41	2.84	46.20	0.47	7.3%	83.3%	2.11	4.83
UTVBR36	494.0	B1	5	332	4	312	13	49.47	2.81	46.00	0.51	6.2%	81.3%	1.99	4.92

3.2.1 Effect of RF Exposure Time

Based on the results of Table 2, the effect of RF exposure time is shown in Figure 2.



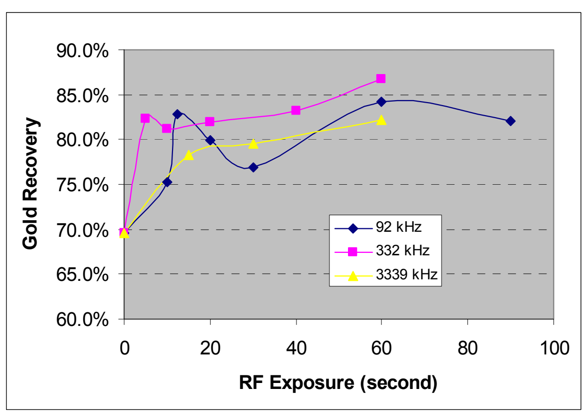


Figure 2: Leaching recovery of silver (left) and gold (right) with RF exposure time

The above results clearly reveal that both silver and gold recovery increased with the RF exposure time except 1 test (C4) at 12.5 seconds with 92 kHz frequency. The test record indicates that the ore surface temperature gain in test C4 was unusually much higher than that of C3 and C2 with RF exposure of 20 and 30 seconds respectively. This might be the reason why recovery at RF exposure of 12.5 seconds (C4) was higher than that at 20 seconds (C3) and 30 seconds (C2), which will be discussed in details in the following section of Relationship between RF Temperature Gain and Cyanide Leaching Recovery. Figure 2 also suggests that the silver recovery may not increase significantly after the RF exposure time is longer than 60 seconds.

3.2.2 Effect of Frequency

3 frequencies at 92, 332 and 3339 kHz were separately studied by Edward Melcarek with different RF exposure time from 5 to 90 seconds. The highest recovery for each frequency was demonstrated in Figure 3.

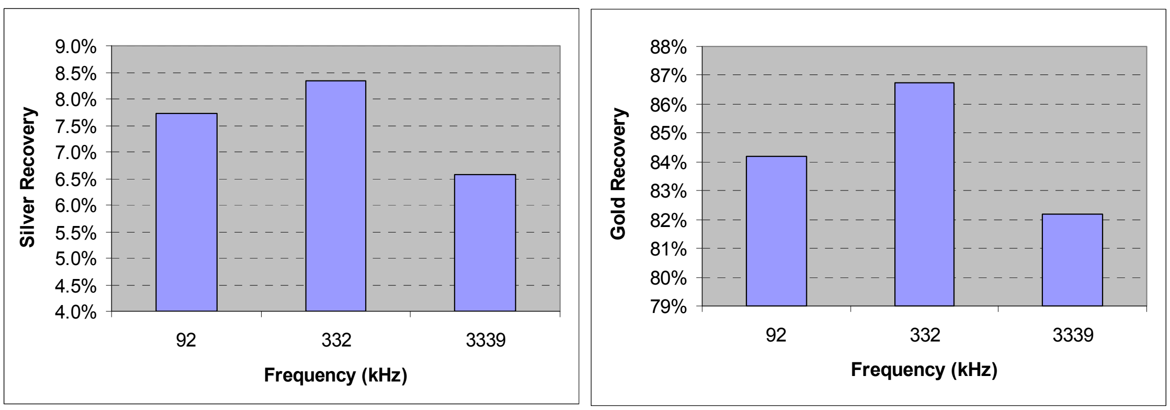


Figure 3: Leaching recovery vs. RF frequency

Figure 3 presents the silver recovery achieved was 7.8% at 92 kHz, 8.3% at 332 kHz and 6.6% at 3339 kHz. It appears the recovery of both silver and gold was the lowest at a high frequency of 3339 kHz, suggesting high frequency is not necessary in improving leaching recovery of Veladero Type 1 ore. The frequency needs to be further optimized in a future study.

3.2.3 Relationship between RF Temperature Gain and Cyanide Leaching Recovery

The ambient temperature of the ore was recorded prior to starting of each test. The temperature was then measured by a Fluke IR Laser thermometer immediately after RF exposure at random vertical surface regions of the beaker and the top exposed ore surfaces. The temperature difference between the start and end of the test is called RF temperature gain. The results are given in Table 3.

Table 3: RF temperature gain

Melcarek's Test No.	C1	C2	C3	C4	C5	C6	B1	B2	B3	B4	B5	B6	A1	A2	A3	A4	A5	A6
Temperature Gain by RF (^{0}C)	7.6	5.1	2.0	5.6	1.9	8.5	0	1.0	0	0	2.0	0	0.5	1.0	1.1	0.9	0.8	2.7
RF Exposure (second)	60	30	20	12.5	10	90	5	40	20	10	60	5	30	30	30	30	15	60

If the silver recovery data in Table 2 and the temperature gain data in Table 3 are compared, the trend of recovery and temperature gain with RF exposure time becomes readily apparent (see Figure 4).

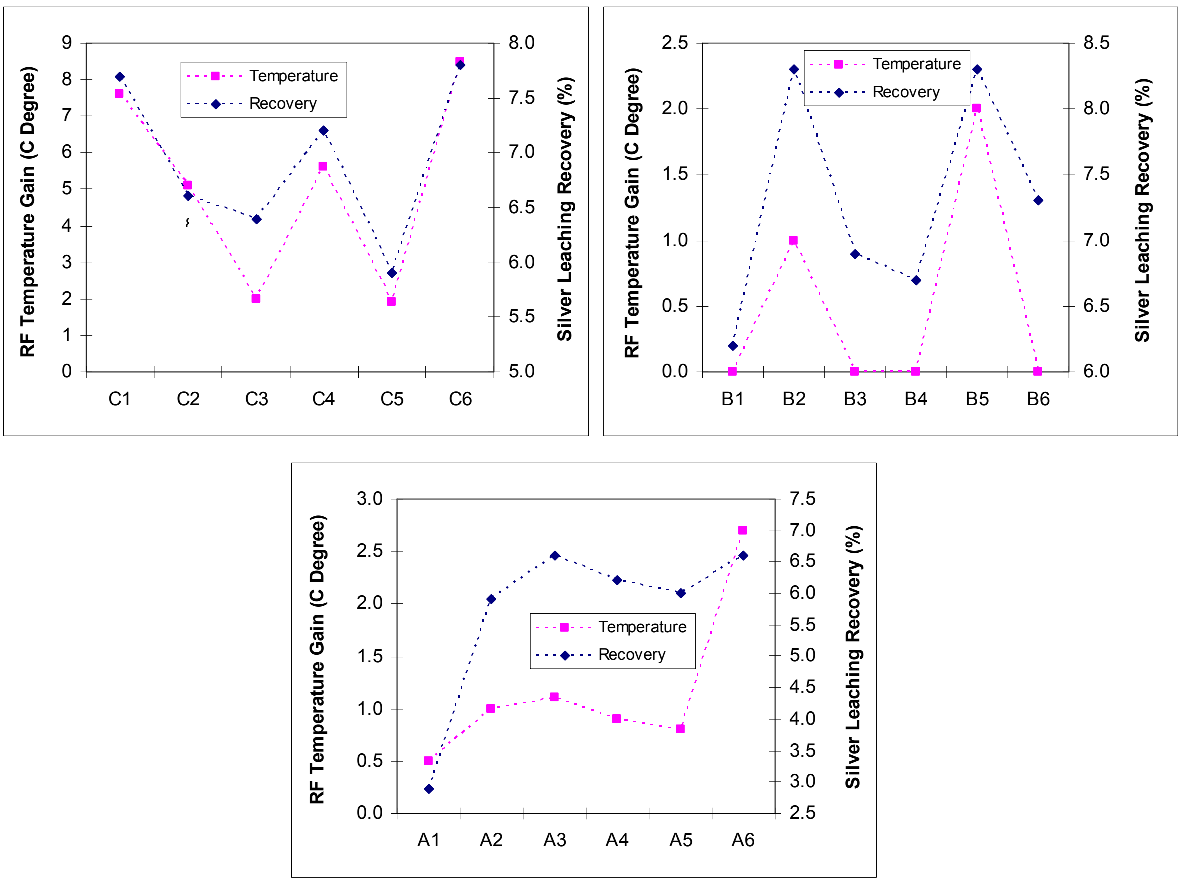


Figure 4: Relationship between leaching recovery and RF temperature gain

Apparently, there is a strong correlation between silver leaching recovery and ore surface temperature gain during RF for all 3 tested series of A, B and C. Higher temperature gain resulted in higher silver recovery. Particularly for test series C, the value of temperature gain was almost the same as the silver recovery. The results presented in Figure 4 suggest that the factors affecting the temperature gain, e.g., RF exposure time, coil power and temperature measuring method should be investigated.

3.2.4 Leaching Kinetics

The leaching kinetics shown in Figure 5 (left) reveal that silver leaching was very slow. There was little improvement in silver recovery for the base sample after 8 days leaching while the recoveries of 3 RF treated samples consistently increased with leaching time. It appears the silver recovery would be higher if the bottle roll cyanide leaching is extended beyond 13 days.

The gold recovery for both baseline and RF treated samples was fast (see Figure 5 right) and gold leaching was completed within 3 days. Gold recovery for RF treated samples was consistently 10-17% higher than baseline, suggesting RF treatment may significantly enhance gold leaching for Veladero Type 1 ore.

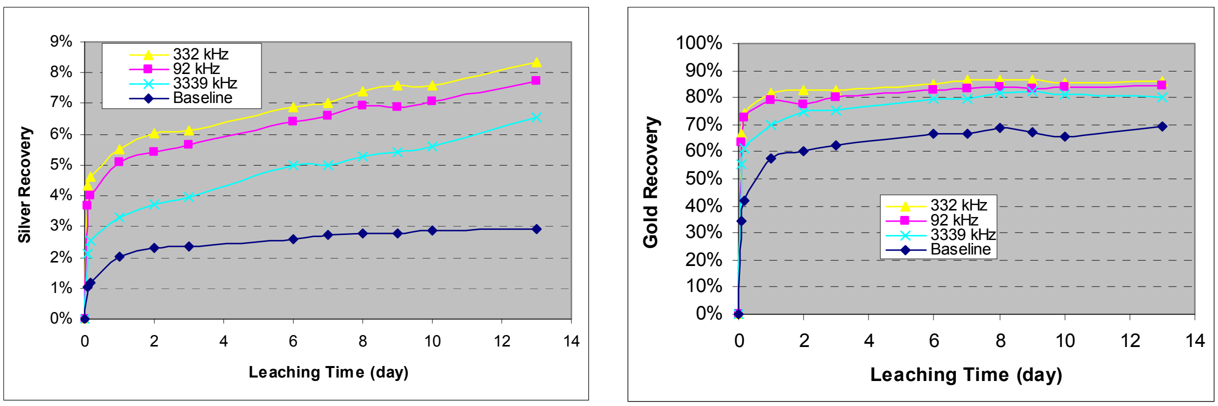


Figure 5: Silver (left) and gold (right) leaching kinetics

4. CONCLUSION

- 18 bottle roll cyanide leaching tests on Edward Melcarek's RF treated samples and 1 bottle roll of baseline test were carried out at BTC to evaluate the effect of RF treatment of Veladero Type 1 ore.
- Cyanide leaching results reveal that both silver and gold recovery increased with the RF exposure time from 5 to 60 seconds. The silver recovery may not increase significantly if the RF exposure time period was extended beyond 60 seconds.
- 3 frequencies were studied by Edward Melcarek and silver recovery after cyanide leaching was separately 7.8% at 92 kHz, 8.3% at 332 kHz and 6.6% at 3339 kHz. High frequency is not necessary to improve leaching recovery of Veladero Type 1 ore.
- There is a strong correlation between silver leaching recovery and ore surface temperature gain during RF for all 3 tested series of A, B and C. Higher temperature gains correlated with higher silver recoveries.
- Gold leaching kinetics for both base and RF treated samples was fast. It was completed within 3 days. Gold recovery for RF treated samples was consistently 10-17% higher than

baseline, suggesting RF treatment may significantly enhance gold leaching for Veladero Type 1 ore.

- Silver leaching kinetics was very slow. There was little improvement of silver recovery for base sample after 8 days leaching while the recoveries of 3 RF treated samples consistently increased with leaching time. The silver leaching is not completed after 13 day leaching period.

5. RECOMMENDATION

- To better evaluate the effect of RF technology and have relatively consistent feed, the mass of sample for each test should be increased from currently 0.5-0.8 kg to 2-3 kg.
- The frequency to be applied should be further optimized although the results show that an intermediate frequency works better.
- The factors of affecting the temperature gain such as RF exposure time, coil power and temperature measuring method should be investigated.
- The silver recovery would be higher if the bottle roll cyanide leaching period is extended beyond 13 days.
- The improving of gold leaching by RF should be further investigated.

6. REFERENCE

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