ELECTRICAL BEHAVIOR OF COPPER MINE TAILINGS DURING EKR WITH SINUSOIDAL ELECTRIC FIELDS

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ABSTRACT

The Electro-Kinetic Remediation (EKR) with a sinusoidal electric field obtained by simultaneously applying a DC/AC voltage produces conditions that reduce the polarization of the conventional EKR with DC voltage. In this case, the DC voltage value defines both: the electrical charge for electro-kinetic transport and the presence of a periodic reversal of the polarity of the working electrodes of the cell. For this proposed electric field, the frequency of the AC voltage is the main variable that favors the breaking of quasi-static polarization conditions promoting the conventional EKR with DC voltage. However, when voltage signals with different frequencies are used, a negative effect occurs where the tailings may behave as a filter circuit, discriminating a frequency or frequency range of an electric signal passing through.

The main goal of this work is to analyze the electrical behavior of tailings in sinusoidal EKR from 7 days of remediation experiments. The conditions selected were as follows: voltage DC/AC, 10/15 and 20/25 [V], and voltage AC frequency 50, 500, 1000 and 2000 Hz. When the frequency of the AC voltage reaches 2000 Hz, the copper removals using EKR tend to zero, because the tailings sample behaves as a filter circuit, specifically as a high-pass filter because the DC voltage was removed. For this reason, the electrical charge for electro-kinetic transport was negligible.

Keywords: Electro-remediation; Sinusoidal electric field; Filter circuit; Copper mine tailings.

1. Introduction

Electro-Kinetic Remediation (EKR) is an in-situ treatment technology for restoring contaminated hazardous waste sites (Acar *et al.*, 1993). The conventional practice of this alternative treatment uses a DC electric field that generates a current through electrodes placed in a humid solid waste, thereby causing the mobilization and removal of contaminants (Probstein *et al.*, 1993). Using this method, the applied electric field promotes transport of pollutants mainly by electro-migration and electro-osmosis in the solution contained in the pores of the contaminated waste.

In the case of mine tailings, previous work (Rojo and Hansen, 2006) has shown that the conventional DC system was limited with regard to metal removal efficiency and high electrical energy consumption. In this context, the chemical nature of the tailings is the main difficulty, because they are partially oxidized sulfides as a consequence of physical-chemical changes due to weathering and bacterial action during disposal. The dissolution and the subsequent transport of contaminants are therefore restricted to the oxidized species of the tailings. With a limited amount of the species available for the electro-kinetic transport, low removals and high energy consumption resulting from significant increases in polarization over time can be expected. However, despite the limitations of EKR for treating tailings from copper mining, due to the large amounts of the material accumulated in mining operations, it is a valuable tool for stabilizing this residue, removing pollutants from the oxidized species to mitigate the risks of contamination by leaching into nearby water aquifers.

Under this scenario, sinusoidal EKR applying an electric field with the simultaneous application of DC/AC voltages (Rojo and Hansen, 2010, 2011, 2012 and 2014) was investigated. In this case, the resulting electric field is sinusoidally displaced from the origin according to the DC voltage value (see Figure 1), and the electro-kinetic transport is the result of the positive electrical charge obtained when DC/AC voltages are applied simultaneously. The application of a DC/AC electric field as a power source for electro-remediation of organic contaminants in soils and removal of nitrate complexes has recently been investigated (Lageman *et al.*, 2005, Ha *et al.*, 2009). In some cases, the combination DC/AC voltages can produce a periodic reversal of polarity of the system electrodes, as observed in Figure 1. For the latter, a cyclic process with two stages is obtained, one stage with direct polarity of the electrodes followed by a reverse polarity stage. In this case the electro-kinetic transport corresponds to the positive net charge obtained during this cyclic process.

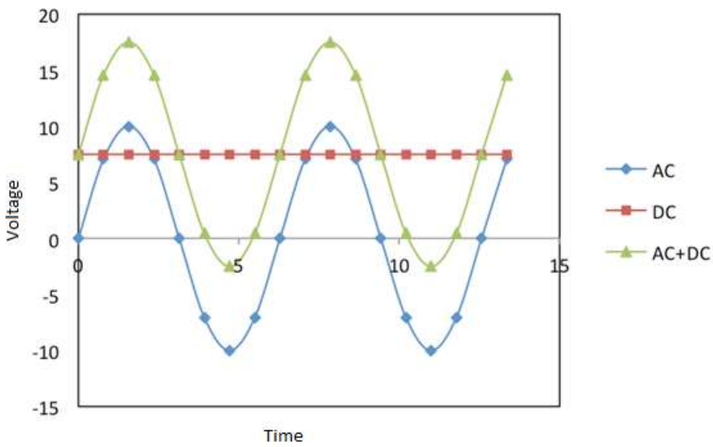

Figure 1: AC+DC electric field as power source for EKR.

Briefly, in the application of EKR with this type of electric field produces conditions that reduce polarization, because is ever-changing over time, especially when the polarity of the working electrodes is reversed. When such an electric field is applied, the frequency of the AC voltage is the variable that favors the breakdown of the quasi-static polarization conditions promoting the conventional DC EKR. However, by applying an electric field that combines DC/AC voltages for the EKR of the tailings, this residue may behave as a filter circuit, an element that discriminates a frequency or frequency range of an electric signal passing through it. This frequency selection may be a desirable capability in certain high-performance electronic systems, but may be a limitation to the performance of a sinusoidal EKR with a DC voltage (frequency zero) and AC voltage (frequency $>$ 50 Hz).

The main goal of this work is to determine the electrical behavior of mine tailing with the sinusoidal EKR. This investigation is part of the search for a remediation technique to environmentally stabilize the large amount of solid waste generated by the Chilean copper industry (Government of Chile, 2011, Minería Chilena Magazine, 2010).

2. Experimental

The electrical behavior of tailings using sinusoidal EKR was analysed by remediation experiments previously performed over a period of 7 days [7]. In these experiments, a synthetic mine tailings were prepared with dry sand (< 200 μm), copper concentrate (chalcopyrite) and copper sulfate pentahydrate. Based on data from Minera Los Pelambres (Antofagasta Minerals, 2012), the synthetic sample was adjusted to 820 mg/kg of total copper in the tailings with 45% soluble copper.

In all experiments a periodic reversal of polarity of the system electrodes was observed, because the conditions of voltage for DC/AC were 10/15 V (effective voltage 14.6 V) and 20/25 V (effective voltage 26.7 V). The six experimental conditions selected to determine the filter effect are shown in Table 1. A conventional reference EKR with 20 V DC was included.

Table 1: Summary of the experimental conditions.

Exp.	Applied potential ΔV (V)					Frequency f_{VAC} (Hz)
	DC	AC	$V_{effective}$	$V_{maximun}$	$V_{minimun}$	
0	20	--	20	--	--	--
1	10	15	14.6	25	-5	50
2	10	15	14.6	25	-5	500
3	10	15	14.6	25	-5	1000
4	10	15	14.6	25	-5	2000
5	20	25	26.7	45	-5	1000
6	20	25	26.7	45	-5	2000

3. Results and discussion

Table 2 shows total and soluble copper overall removal from the cell as percentages, obtained from a material balance before and after the EKR experiments.

For the experimental conditions tested, copper removal with a sinusoidal EKR with 14.6 V effective voltage DC/AC is twice as effective as the conventional EKR 20 V voltage DC, when the frequency of the AC voltage reaches 500 Hz. This example shows the important role played by the frequency of the AC voltage for the sinusoidal EKR proposed here, because with a lower electric field intensity the copper removal of a sinusoidal EKR (14.6 V DC/AC) can overcome the copper removal of a conventional EKR (20 V DC), only increasing the frequency of the AC voltage.

Table 2: Overall removals of total and soluble copper, frequency AC Voltage effect, for $V_{effective}$ 14.6 and 26.4 (V).

Exp.	Frequency f_{VAC} (Hz)	$V_{effective}$ (V)	Overall removal (%)	
			Total copper	Soluble copper
0	--	20	8.8	19.9
1	50	14.6	3.1	5.8
2	500		18.0	31.9
3	1000		24.5	47.9
4	2000		0.4	1.0
5	1000	26.4	21.5	55.3
6	2000		-0.5	-1.3

In this context, because the filter effect is the ability to selectively filter different frequencies in a circuit, this effect may be a limitation to the performance of a sinusoidal EKR of this type. In this case where only two voltage signals are mixed in the tailings (the “circuit”), DC (frequency zero) and AC (50 to 2000 Hz), two EKR conditions encountering the undesirable filter effect can be obtained: EKR with just a DC voltage signal (AC out) or an AC voltage signal (DC out). The filters related to the two preceding EKR conditions are known as the low-pass filter and the high-pass filter, respectively.

By definition, a low-pass filter is a circuit offering easy passage to low-frequency signals and difficult passage to high frequency signals, and the task of a high-pass filter is the opposite of a low-pass filter (Kuphaldt, 2007). Accordingly, in sinusoidal EKR with an electric field through the simultaneous application of DC/AC voltages, copper removal would be similar to a conventional DC EKR in the presence of a low-pass filter. With a high-pass filter, the removal would be as expected with an AC EKR.

According to the results of Table 2, special phenomena have been observed to be associated with the higher frequency of the AC voltage, which require a better understanding of the electrical behavior of the tailings when a sinusoidal EKR is applied.

Sinusoidal EKR with voltages of DC/AC = 10/15 V, producing an effective voltage of 14.6 V, show a steady increase in the removal of copper (total and soluble) if the frequency of the AC voltage increases from 50 to 1000 Hz. However, when the frequency of the AC voltage is increased to 2000 Hz removal is negligible. The same effect was observed for the experiments with DC/AC = 20/25 V, $V_{effective}$ = 26.4 V, obtaining a negligible removal going from 1000 to 2000 Hz. The above removals show that EKR experiments were carried out with only the AC voltage signal (DC out) with the presence of a high-pass filter that occurs when the AC frequency reaches 2000 Hz.

Finally, the presence of a low-pass filter could not be as well detected as the high pass filter, based on the results shown in Table 2. Comparing copper removals between conventional EKR with 20 V and the sinusoidal EKR with an effective voltage of 14.6 V, approximately equivalent removals are obtained between 50 and 500 Hz. However, to check whether the low-pass filter is established, it would be necessary to compare the results of the sinusoidal EKR of 14.6 V with a conventional EKR of 10 V as a reference. In summary, as in the sinusoidal EKR of 14.6 V, the copper removal always increases in the frequency range 50 to 1000 Hz. The low-pass filter does not seem to be a problem because the low-pass filter is disabled easily with increasing frequency, without risking the importance of the process.

4. Conclusions

For the conditions selected in this discussion, in sinusoidal EKR experiments with simultaneous application of DC/AC voltages, the conclusions are:

- Better copper removal and lower energy consumption results can be obtained by only increasing the AC voltage frequency.
- When the frequency of the AC voltage reaches 2000 Hz, the tailings sample behaves as a filter circuit, specifically as a high-pass filter.
- In this case, the high-pass filter removes or attenuates all frequency components bellow a specific frequency threshold. In the experiments 4 and 6, the removed DC voltage signal (frequency zero) does not produce the net charge to promote electro-kinetic phenomena for remediation.
- In sinusoidal EKR, the activation of a high-pass filter can be considered a limitation, as it interrupts the increase in copper removal by increasing the frequency of the AC voltage over 1000 Hz.
- In a large-scale operation, a filter effect can be detected automatically with instruments that measure the net electric charge passing through the tailings.
- The low-pass filter is not a limitation, because the low pass filter is disabled by increasing the AC voltage frequency.
- In summary, the frequency range where both filters (low-pass and high-pass) are disabled or enabled respectively should first be defined.

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