Supplementary Materials

Organic Acid-Assisted Hydrothermal Leaching of Silver from End-of-Life Photovoltaic Panels

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Section S1.

The acid dissociation constant (pKa) and the dissociation reactions of oxalic and citric acid are displayed below, where pK values refer to 25ºC (Golmohammadzadeh et al., 2018).

Oxalic acid

$H_2C_2O_4 \rightleftharpoons HC_2O_4^- + H^+$ $pK_{a1} = 1.23$

$HC_2O_4^- \rightleftharpoons C_2O_4^{2-} + H^+$ $pK_{a2} = 4.19$

Citric acid

$C_6H_8O_7 \rightleftharpoons C_6H_7O_7^- + H^+$ $pK_{a1} = 2.79$

$C_6H_7O_7^- \rightleftharpoons C_6H_6O_7^{-2} + H^+$ $pK_{a1} = 4.3$

$C_6H_6O_7^{-2} \rightleftharpoons C_6H_5O_7^{-3} + H^+$ $pK_{a1} = 5.65$

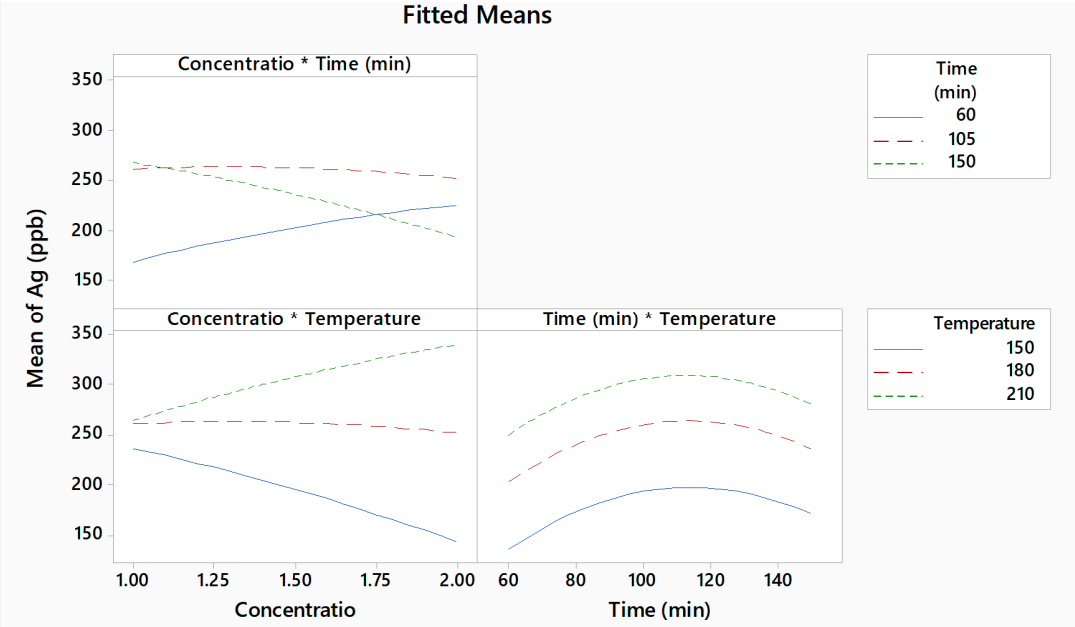


Fig. S1. Interaction plot for parameters during citric acid leaching.

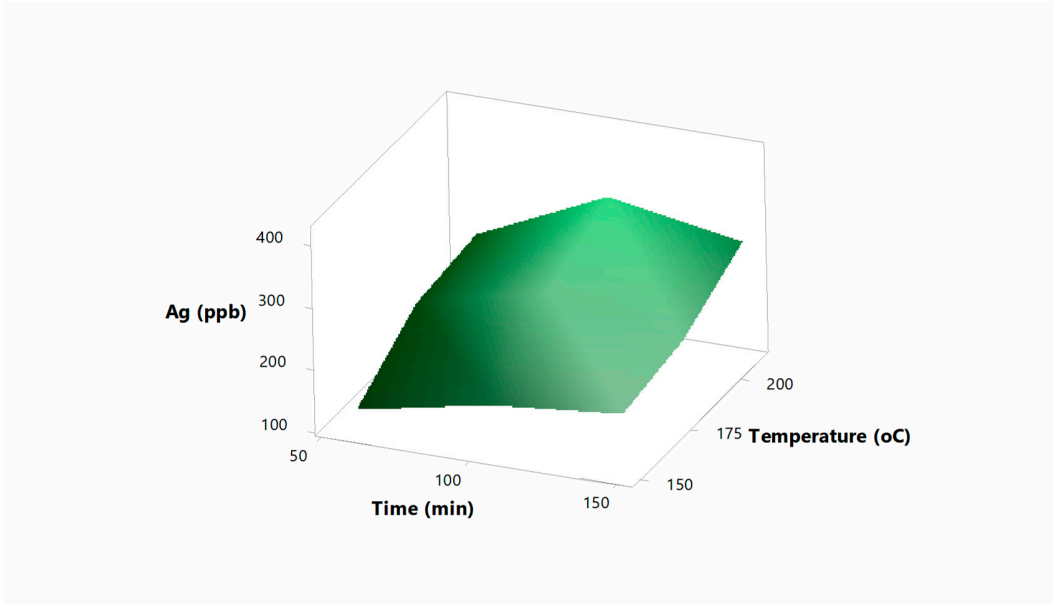


Fig. S2. Surface plot of Ag vs temperature (ºC) and time (min) during citric acid leaching.

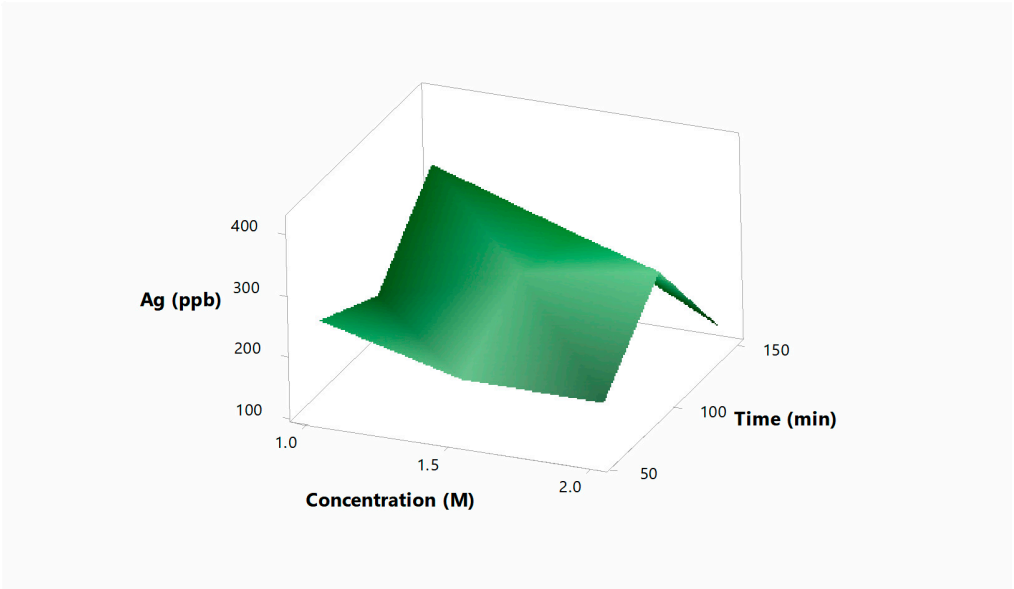


Fig. S3. Surface plot of Ag vs time (min) and citric acid concentration (M).

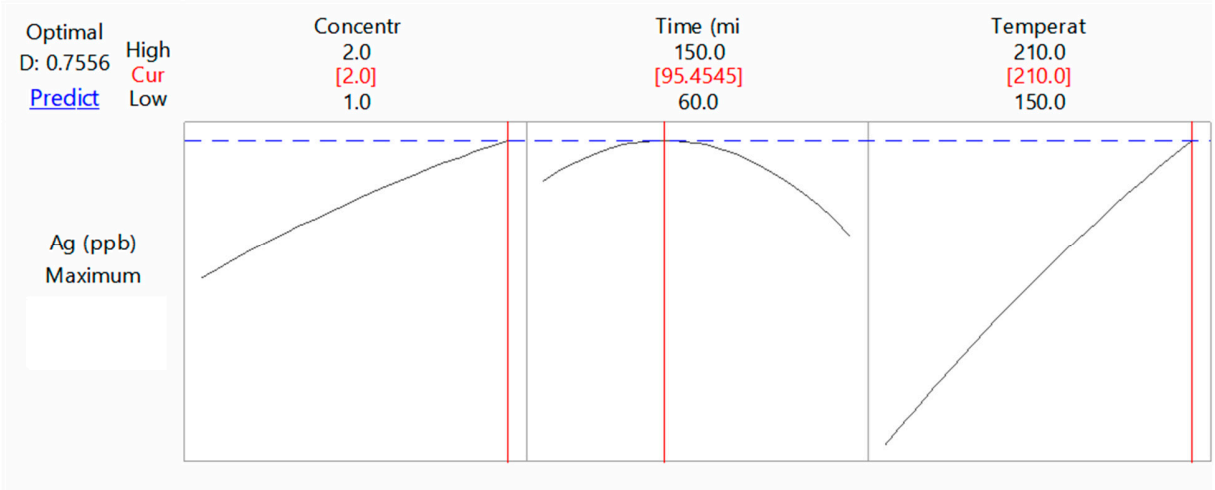


Fig. S4. Optimization for Ag leaching with CA

Table S1. Analysis of Variance for CA experiments

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	64762	7195.8	0.80	0.637
Linear	3	48972	16324.0	1.82	0.261
Concentration (M)	1	2563	2563.3	0.29	0.616
Time (min)	1	3337	3337.4	0.37	0.569
Temperature (oC)	1	43071	43071.1	4.79	0.080
Square	3	9857	3285.6	0.37	0.781
Concentration (M)*Concentration (M)	1	15	15.5	0.00	0.969
Time (min)*Time (min)	1	9455	9455.2	1.05	0.352
Temperature (oC)*Temperature (oC)	1	94	94.0	0.01	0.923
2-Way Interaction	3	5933	1977.8	0.22	0.879
Concentration (M)*Time (min)	1	4323	4323.1	0.48	0.519
Concentration (M)*Temperature (oC)	1	1448	1447.8	0.16	0.705
Time (min)*Temperature (oC)	1	163	162.6	0.02	0.898
Error	5	44930	8986.0		
Lack-of-Fit	3	23439	7813.0	0.73	0.623
Pure Error	2	21491	10745.6		
Total	14	109692			

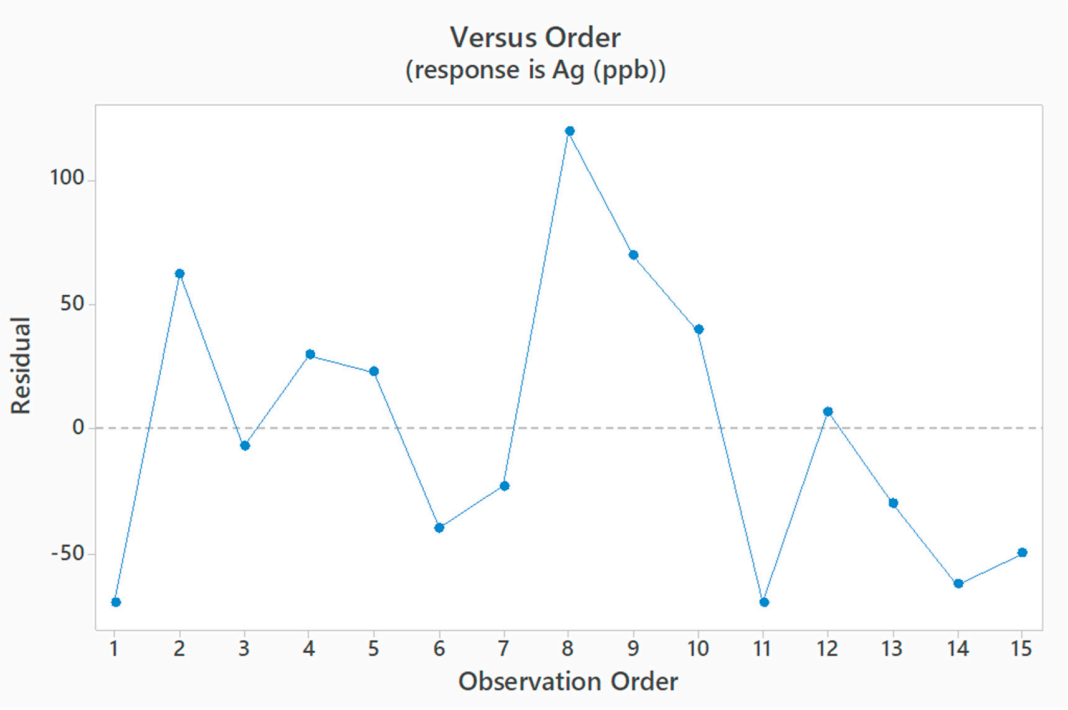


Fig. S5. Residuals versus order for CA leaching.

Table S2. Analysis of Variance for OA experiments

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	1782138	198015	3.03	0.117
Linear	3	1058966	352989	5.4	0.05
Concentration (M)	1	1039898	1039898	15.92	0.01
Time (min)	1	741	741	0.01	0.919
Temperature (oC)	1	18327	18327	0.28	0.619
Square	3	610112	203371	3.11	0.127
Concentration (M)*Concentration (M)	1	378289	378289	5.79	0.061
Time (min)*Time (min)	1	211011	211011	3.23	0.132
Temperature (oC)*Temperature (oC)	1	28539	28539	0.44	0.538
2-Way Interaction	3	113060	37687	0.58	0.655
Concentration (M)*Time (min)	1	4907	4907	0.08	0.795
Concentration (M)*Temperature (oC)	1	100679	100679	1.54	0.269
Time (min)*Temperature (oC)	1	7474	7474	0.11	0.749
Error	5	326564	65313		
Lack-of-Fit	3	308744	102915	11.55	0.081
Pure Error	2	17820	8910		
Total	14	2108702			

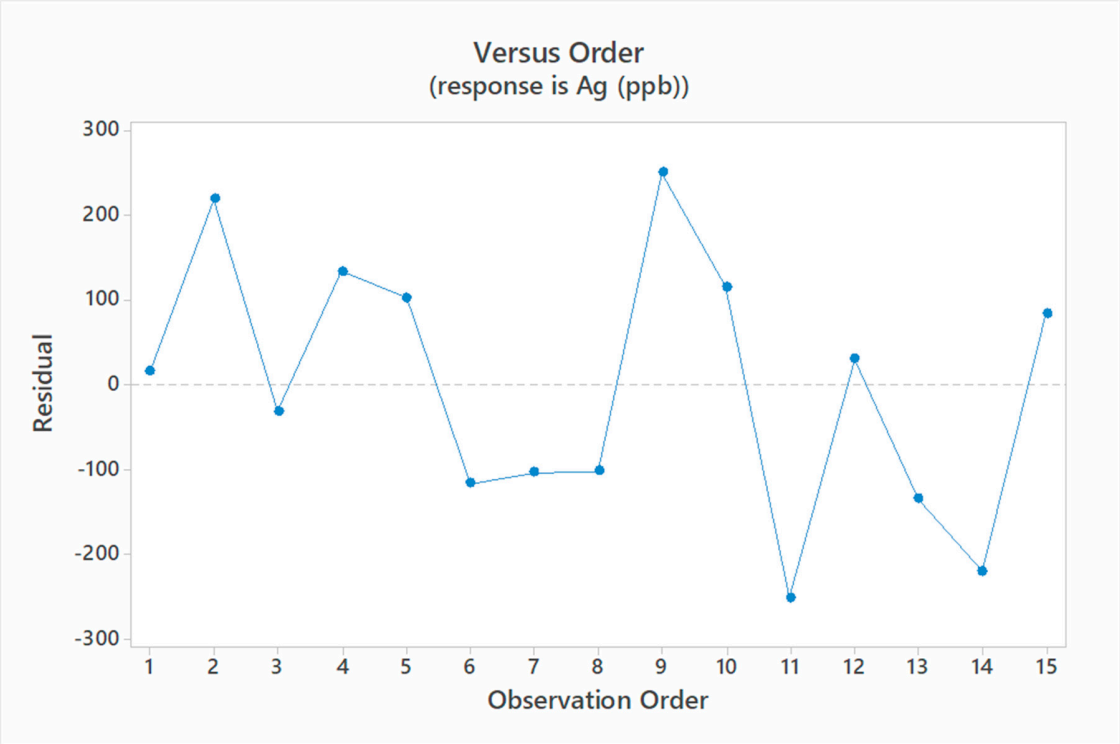


Fig. S6. Residuals versus order for OA leaching.

References

Golmohammadzadeh, R., Faraji, F., & Rashchi, F. (2018). Recovery of lithium and cobalt from spent lithium ion batteries (LIBs) using organic acids as leaching reagents: A review. *Resources, Conservation and Recycling*, *136*, 418–435. https://doi.org/10.1016/j.resconrec.2018.04.024