Supplementary Information

S.1 Statistical significance and adequacy of the models

The results from the CCD design based on RSM methodology were analyzed to find the optimal operational parameter combination. GF_{PM} and EF_{PM} were significantly linearly and quadratically related to electrolyte temperature and current density of the cathode, respectively. Both CE_{Zn} and PC linearly responded to electrolyte temperature and H_2SO_4 concentration. The fitting model expressions were as follows:

$$\mathrm{GF_{PM}} = -3.25499 + 0.010932X_1 + 0.000178X_3 \quad , \tag{S1}$$

$$\mathrm{EF_{PM}} = -226.46840 + 0.843424\,X_1 + 0.162863\,X_3 + 0.000845X_1X_3 + 0.000085\,X_3^2 \quad , \tag{S2}$$

$$\mathrm{CE_{Zn}} = 0.712035 + 0.000863X_1 - 0.000455X_3 \quad , \tag{S3}$$

$$\mathrm{PC} = 2795.09 - 119.78\,X_1 + 55.25\,X_2 + 127.07\,X_3 \quad , \tag{S4}$$

where X_1, X_2, and X_3 are electrolyte temperature, H_2SO_4 concentration, and current density of cathode, respectively. The probability values (*p*-Value) of Fisher's F-test are tabulated in Table S5. The probability value (*p*-Value) of Fisher's F-test for the GF_{PM}, EF_{PM}, and PC models < 0.0001, and CE_{Zn} = 0.0003, indicating the models held high significance. A significant interaction between electrolyte temperature and the current density of the cathode in EF_{PM} ($p = 0.0005$) indicates significant combined effects on GF_{PM}.

Table S1 Chemical composition of primary zinc in the International Organization for Standardization, %. (ISO, 2006).

Designation	Pb	Fe	Cd	Al	Cu	Sn	Permitted total	Minimum zinc content
Zn-1	0.003	0.002	0.003	0.001	0.001	0.001	0.005	99.995
Zn-2	0.003	0.003	0.003	0.002	0.002	0.001	0.010	99.990
Zn-3	0.03	0.02	0.01	0.01	0.002	0.001	0.05	99.95
Zn-4	0.45	0.05	0.01	—	—	—	0.5	99.5
Zn-5	1.4	0.05	0.01	—	—	—	1.5	98.5

Notes: 1) All composition values are expressed in percentages (mass fraction). They are values indicated otherwise. 2) The specified elements are analyzed, and the zinc minimum is calculated by the difference between the sum of the specified elements listed and 100%.

Table S2 Three methods by adjusting operational parameters based on single-factor design.

Methods	Proposal	Electrolyte temperature (K)	H_2SO_4 concentration (g/L)	Current density (A/m^2)
Method I Adjusting electrolyte temperature	No. 1	298	160	500
	No. 2	313	160	500
	No. 3	328	160	500
Method II Adjusting H_2SO_4 concentration	No. 1	313	110	500
	No. 2	313	160	500
	No. 3	313	210	500
Method III Adjusting current density	No. 1	313	160	300
	No. 2	313	160	500
	No. 3	313	160	700

Table S3 The response surface methodology (RSM) based on central composite design (CCD) was used to optimize the particulate matter reduction and zinc production. The experiment matrix was designed by Design-Expert® Software Version 12.

Run	Factor 1	Factor 2	Factor 3
	Electrolyte temperature (K)	H_2SO_4 concentration (g/L)	Current density (A/m^2)
1	333	210	500
2	293	210	500
3	313	110	300
4	313	110	700
5	313	160	500
6	333	110	500
7	293	110	500
8	333	160	700
9	293	160	300
10	313	210	700
11	293	160	700
12	313	210	300
13	333	160	300
14	313	160	500
15	313	160	500

Table S4 Chemical composition of zinc produced under different operating parameter conditions, %.

Parameters	Levels	Cu	Fe	Pb	Cd	Total
Electrolyte temperature (K)	298	0.00011	0.0005	0.0036	<0.0003	<0.00451
	313	0.00012	0.0006	0.0046	<0.0003	<0.00562
	323	0.00015	0.0007	0.0053	<0.0003	<0.00645
Current density (A/m^2)	300	0.00022	0.0002	0.00305	<0.0003	<0.00377
	500	0.00029	0.0002	0.00375	<0.0003	<0.00454
	700	0.00028	0.0002	0.00385	<0.0003	<0.00463
H_2SO_4 concentration (g/L)	110	0.00013	0.0008	0.0044	<0.0003	<0.00563
	160	0.00012	<0.0006	0.0046	<0.0003	<0.00502
	210	0.00012	0.0009	0.0083	<0.0003	<0.00962

Table S5 The response surface models of PM generation flux (GF_{PM}), PM emission factor (EF_{PM}), the current efficiency of Zn deposition (CE_{Zn}), and power consumption (PC) based on RSM.

Response	Source	Sum of squares	Degree of freedom	Mean square	*F*-value	*p*-Value
GF_{PM}	Model	0.3926	2	0.1963	59.3	<0.0001
	X_1-Electrolyte temperature	0.3824	1	0.3824	115.53	<0.0001
	X_3-Current density	0.0101	1	0.0101	3.07	0.1054
	Residual	0.0397	12	0.0033		
	Lack of Fit	0.0322	10	0.0032	0.8591	0.6488
	Pure Error	0.0075	2	0.0038		
	Cor Total	0.4323	14			
EF_{PM}	Model	749.45	4	187.36	44.67	<0.0001
	X_1-Electrolyte temperature	566.76	1	566.76	135.11	<0.0001
	X_3-Current density	94.33	1	94.33	22.49	0.0008
	X_1X_3	45.71	1	45.71	10.9	0.008
	X_3^2	42.65	1	42.65	10.17	0.0097
	Residual	41.95	10	4.19		
	Lack of Fit	33.61	8	4.2	1.01	0.5877
	Pure Error	8.33	2	4.17		
	Cor Total	791.4	14			
	Model	749.45	4	187.36	44.67	< 0.0001
CE_{Zn}	Model	0.006	2	0.003	19.28	0.0003
	X_1-Electrolyte temperature	0.0024	1	0.0024	15.39	0.0024
	X_3-Current density	0.0036	1	0.0036	23.17	0.0005
	Residual	0.0017	11	0.0002		
	Lack of Fit	0.0017	9	0.0002	10.13	0.093
	Pure Error	0	2	0		
	Cor Total	0.0077	13			
PC	Model	2.63E+05	3	87615.32	24.58	<0.0001
	X_1-Electrolyte temperature	1.15E+05	1	1.15E+05	32.2	0.0002
	X_2-H_2SO_4 concentration	20647.23	1	20647.23	5.79	0.0369
	X_3-Current density	1.09E+05	1	1.09E+05	30.64	0.0002
	Residual	35642.98	10	3564.3		

Lack of Fit	35642.79	8	4455.35	46966.62	<0.0001
Pure Error	0.1897	2	0.0949		
Cor Total	2.99E+05	13			

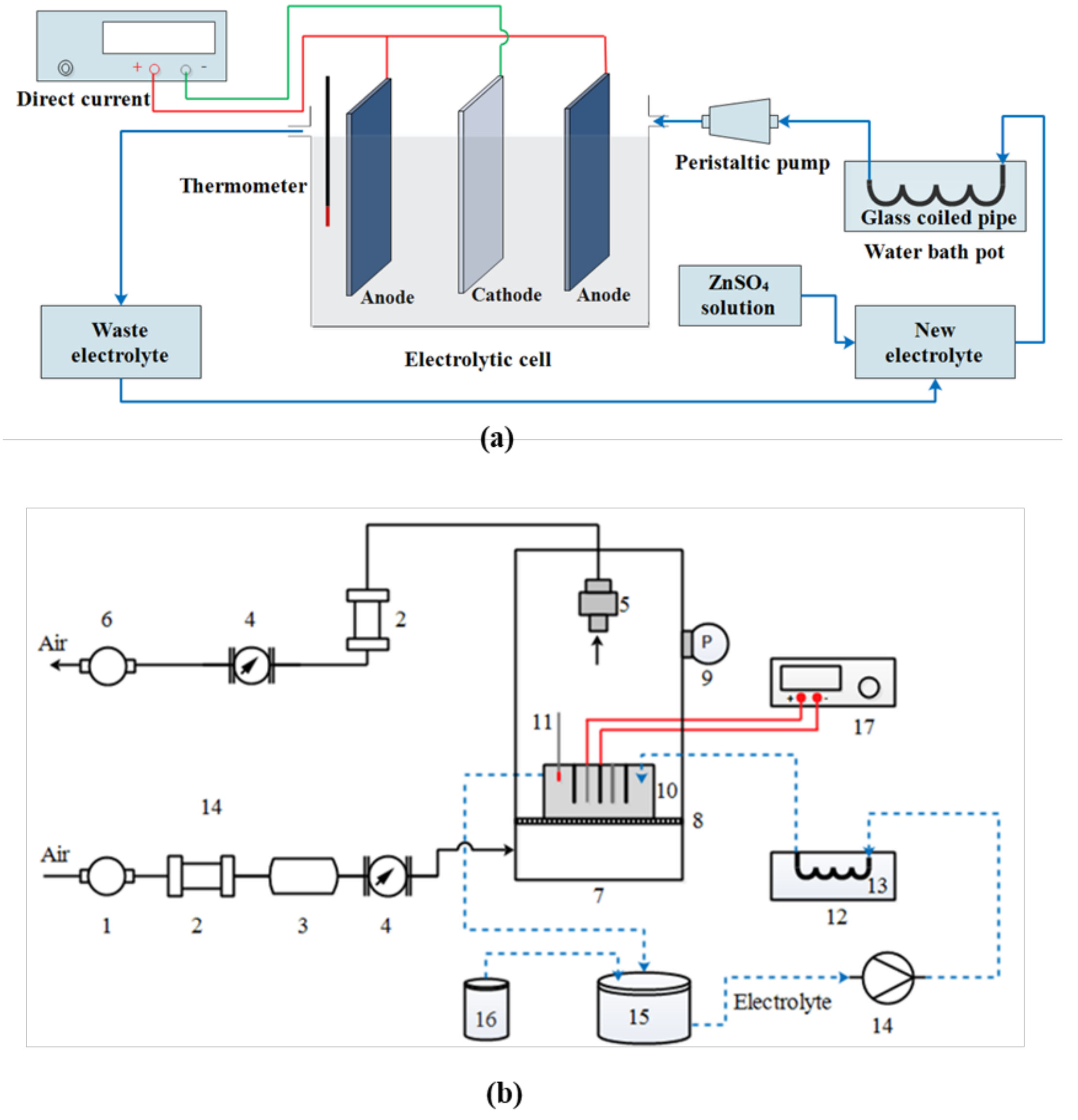

Fig. S1 (a) schematic of the zinc electrolysis system (Three anodes of a quaternary alloy of Pb-0.3% Ag-0.03% Ca-0.03% Sr (90 mm × 60 mm) and two cathodes made of aluminum (90 mm × 60 mm) were used. The distance between adjacent anodes was 60 mm, consistent with practical conditions in most industrial plants); (b) electrolysis and sampling system. (1-Air compressor; 2-Drying tube; 3-Particulate filter; 4-Mass flow meter; 5-Filter pack; 6-Vacuum pump; 7-Sampling box; 8-Air distributor; 9-Differential manometer; 10-Electrolysis cell; 11-Thermometer; 12-Water bath; 13-Glass coiled pipe; 14-Peristaltic pump; 15-Electrolyte; 16-$ZnSO_4$; 17-Direct current power).

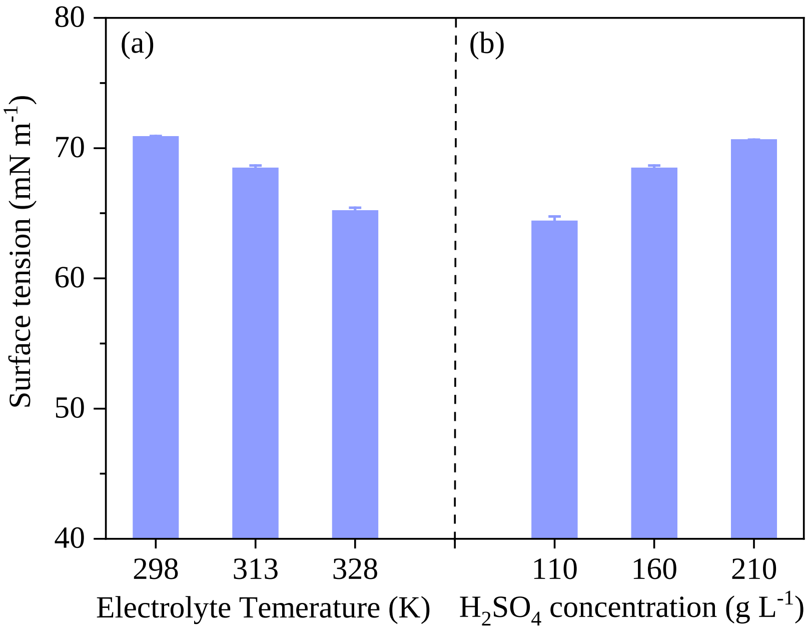

Fig. S2 Surface tension under different operating parameter conditions: (a) electrolyte temperature; (b) H_2SO_4 concentration.

References

ISO (2006). International Organization for Standardization, Zinc ingots, ISO 752:2004. Geneva, Switzerland: International Organization for Standardization