Supplementary Information

High water and metal recovery from acid mine drainage using hybrid membrane processes and selective metal precipitation

Elena León-Venegas, Luis F. Vilches-Arenas, Custodia Fernández-Baco, Fátima Arroyo-Torralvo

Combined process cost estimation

The water production cost (WPC) was calculated considering the capital cost and the operational cost. The first was calculated considering OARO, RO and FO membrane units (direct cost) and pumps, energy recovery devices, and additional equipment for the FO unit (indirect cost) (see Figure S1). Additionally, the operational cost was estimated using the energy consumed, membrane replacement, overhead and maintenance costs, and chemical reagents. The specific energy consumption (SEC) was calculated by the energy required by the pumps. Table S1 shows the fluxes and pressures for each line of the process required to estimate WPC and SEC.

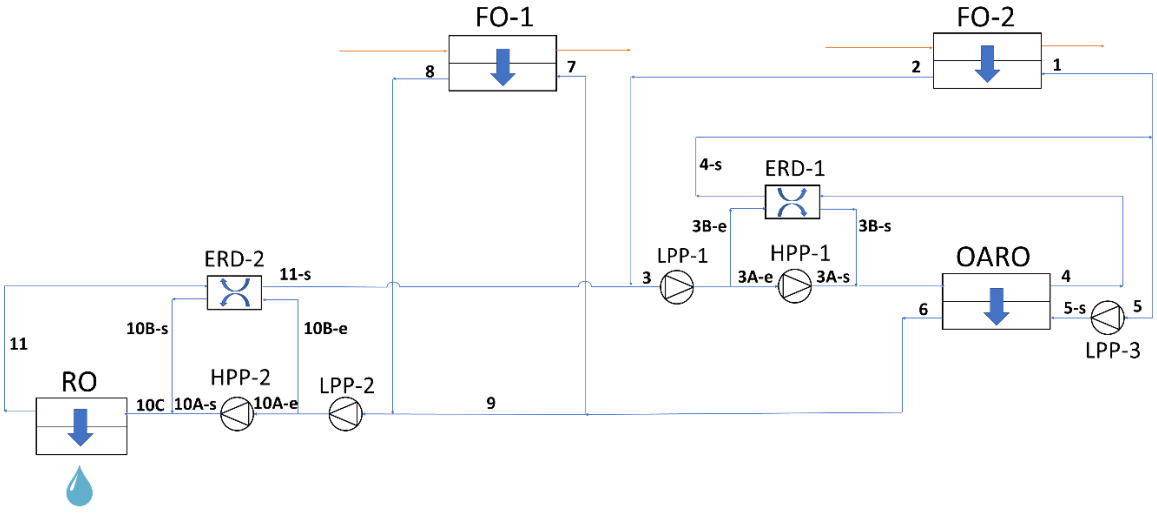

Figure S1. Equipment considered in the cost estimation. HPP: High-Pressure Pump; LPP: Low-Pressure Pump; ERD: Energy Recovery Device

Table S1. Fluxes and pressures of each line of the combined process

Q (m3/h)		P (bar)		Q (m3/h)		P (bar)	
Q_1	11.61	**P_1**	1	**Q_2**	17.99	**P_2**	1
Q_3	48.63	**P_3**	1	**Q_3-s**	48.63	**P_3-s**	2
Q_3A-e	25.53	**P_3A-e**	1.5	**Q_3A-s**	25.53	**P_3A-s**	65

Q_3B-e	23.09	**P_3B-e**	1.5	**Q_3B-s**	23.09	**P_3B-s**	65
Q_3C	48.63	**P_3C**	65	**Q_4**	23.65	**P_4**	63
Q_4-s	23.65	**P_4-s**	1	**Q_5**	12.04	**P_5**	1
Q_5-s	12.04	**P_5-s**	2	**Q_6**	37.04	**P_6**	1
Q_7	18.72	**P_7**	1	**Q_8**	25.14	**P_8**	1
Q_9	18.32	**P_9**	1	**Q_10**	43.44	**P_10**	1
Q_10-s	43.44	**P_10-s**	2	**Q_10A-e**	13.53	**P_10A-e**	1.5
Q_10A-s	13.53	**P_10A-s**	65	**Q_10B-e**	29.91	**P_10B-e**	1.5
Q_10B-s	29.91	**P_10B-s**	65	**Q_10C**	43.44	**P_10C**	65
Q_11	30.64	**P_11**	63	**Q_11-s**	30.64	**P_11-s**	1

- **Specific energy consumption**

The Danfoss manufacturer provided the data to estimate the pressures (Goh et al., 2019). Pumps were positive displacement pressure types for OARO and RO and centrifugal pumps for low-pressure lines. The power needed for the pumps and energy recovery devices was calculated using Equation S1 and Equation S2, respectively.

$$Power - pump\ (kW) = \left[\frac{Q(P_0 - P_i)}{\eta_{power} \cdot \eta_{pump}}\right] \cdot \left(\frac{100}{3600}\right) \qquad \text{(eq. S1)}$$

$$Power - ERD\ (kW) = \left[\frac{Q(P_0 - P_i)}{\eta_{power} \cdot \eta_{ERD}}\right] \cdot \left(\frac{100}{3600}\right) \quad \text{(eq. S2)}$$

where Q is the flux in the line (m^3/h), P_0 is the output pressure (bar); Pi is the inlet pressure (bar); η_{pump}: is the pump efficiency; η_{power}: is the power efficiency; η_{EDR}: is the exchange efficiency.

The specific energy consumption (SEC (kWh/m^3) was estimated as the sum of the power required by the pumps, EquationS 3.

$$SEC = \sum Power - pump \qquad \text{(eq. S3)}$$

- **Water production cost estimation**
    - **Capital costs**

The membrane capital costs (CC_{mem} ($)) were calculated with Equation S4. The capital cost of the FO membrane and additional equipment were estimated to be 29.4% and 22.5%, respectively, of the total capital cost for FO.

$$CC_{mem} = CP_{mem} \cdot A_{mem} \qquad \text{(eq. S4)}$$

where CP_{mem} is the capital cost per unit of area ($/m^2), and A_{mem} is the membrane area (m^2). High pressure pump capital costs (CC_{pump} ($)) were calculated with Equation S5 and the low-pressure pump capital cost was calculated as 15 % of the high pressure pump capital cost. In the case of FO, the pumping cost was considered 6.5% of the total capital cost for FO.

$$CC_{pump}\,(\$) = 2{,}103.5 \cdot [Q]^{0.831} \qquad \text{(eq. S5)}$$

The capital costs of the energy recovery device (CC_{ERD} ($)) were estimated using Equation S6.

$$CC_{ERD}\,(\$) = 18{,}99.2 \cdot [Q]^{0.8387} \qquad \text{(eq. S6)}$$

The total investment cost (TIC ($)) was calculated using Equation S7.

$$TIC = F_{CTI} \cdot (CC_{mem} + CC_{pump} + CC_{ERD} = CC_{auxFO} \quad \text{(eq. S7)}$$

where F_{CTI} is considered 1.6 and is a correction factor for installation and engineering costs.

- **Operation and maintenance costs**

The annual electric cost (EC ($/y)) was obtained using Equation S8 considering an electricity cost (CE) of 0.088 $/kWh being AWP the annual water production (m^3/y).

$$EC = CE \cdot SEC \cdot AWP \qquad \text{(eq. S8)}$$

The replacement membrane cost (RMC ($/y)) was estimated with the replacement cost (RF (%/y)), which is considered 15%/y, using Equation S9.

$$RMC = CC_{mem} \cdot RF \qquad \text{(eq. S9)}$$

Maintenance and labor costs (MLC ($/y)) was calculated using Equation S10 taking into account the maintenance factor for automatized chemical plants (F_{mant} (%)), 5%.

$$MCL = TIC \cdot F_{mant} \qquad \text{(eq. S10)}$$

The cost of the chemical reagents (CR ($/y)) used in the process was estimated using Equation S11 considering the chemical factor of additives (F_{chem} (%)) as 1% of TIC.

$$CR = TIC \cdot F_{chem} \qquad \text{(eq. S11)}$$

Finally, to calculate the WPC ($/m^3) using Equation S12 it is necessary to calculate the annual operating cost (AOC ($/y)), with the cost above shown with Equation S13, and the annual total cost (TC ($/y)), considering a capitalization factor (CF (%)) of 10%, using Equation S14.

$$WPC = TC/AWP \qquad \text{(eq. S12)}$$

$$AOC = EC + RMC + MLC + CR \qquad \text{(eq. S13)}$$

$$TC = AOC + (CF \cdot TIC) \qquad \text{(eq. S14)}$$

References

Goh, P. S., Ismail, A. F., Ng, B. C., & Abdullah, M. S. (2019). Recent progresses of forward osmosis membranes formulation and design for wastewater treatment. In *Water (Switzerland)* (Vol. 11, Issue 10). MDPI AG. https://doi.org/10.3390/w11102043