Supplementary Information

Conductive carbonaceous membranes: recent progress and future opportunities

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Variables for cost analysis

Performance Improvement Ratio (PIR): The rate at which fouling is delayed in membranes. This is practically the ratio between the operation time before the membrane needs cleaning with electrification, to the operation time before cleaning without electrification. A high PIR would result in reduction of fouling chemicals used, as well as higher membrane lifetime.

Percent higher energy requirement: The percent higher energy consumption due to electrical energy consumed by the membrane, assuming a total energy consumption of 10 kWh m^{-3} of water in the process without electrification. This does not consider the energy savings that may result from membrane electrification.

Percent higher cost for membrane: The increase in cost resulting from additional materials and processing complexity associated with making the membrane conductive. This is a percentage of the existing cost of the membrane.

Formulas for cost analysis

All formulas in this section solve for the change in annual costs from the costs calculated by Hafez and El-Manharawy based on the Investor Purchase model.[1] The formulas are categorized by OpEx (operational expenses) and CapEx (capital expenses). The electrolyzer cost[2] and estimated PIR[3] are based on previous reports. An example of a cost-savings calculation is shown in **Table S1.**

Increase in footprint (OpEx)

$$\Delta cost[\$] = (infrastructure)[\$] \cdot 10\%$$

Pre-treatment chemicals costs (OpEx)

$$\Delta cost[\$] = -(pretreatment)[\$] \cdot \left(1 - \frac{1}{PIR}\right)$$

RO Replacement membrane costs (OpEx)

$$\Delta cost[\$] = (membrane\ cost)[\$] \cdot \left((1 + material\ cost[\%]) \cdot \left(\frac{1}{PIR}\right) - 1\right)$$

Post-treatment chemicals costs (OpEx)

$$\Delta cost[\$] = -(posttreatment)[\$] \cdot \left(1 - \frac{1}{PIR}\right)$$

Electrical energy consumption cost (OpEx)

$$\Delta cost[\$] = (energy\ cost)[\$] \cdot (energy\ consumption[\%])$$

Electrolyzer depreciation (CapEx)

$$\Delta cost[\$] = \frac{capital\ cost[\$]}{electrolyzer\ lifetime}$$

Table S1. Analysis of cost change from a theoretical electrified membrane setup in a model reverse-osmosis desalination plant in Egypt. Costs are adjusted for inflation from previous reports. Red text (positive values) represent an increase in annual cost, while green text (negative values) represent a decrease in cost. The values in the table correspond to an example case where PIR = 3, % higher energy requirement = 5%, and % higher membrane cost = 7%.

Cost detail	Lifetime (years)	Cost for 250 m^3/day (2020 USD)	Cost for 4800 m^3/day (2020 USD)	Cost change for 250 m^3/day plant (2020 USD)	Cost change for 4800 m^3/day plant (2020 USD)
ANNUAL DEPRECIATION					
Intake system	10	26291	212677		
Pretreatment phase	10	6947	112558		
RO desal phase	10	17764	235608		
Post-treatment	10	395	954		
Brine disposal	10	3079	42881		
Infrastructure	40	5151	71780	515	7178
Professional and financing	10	3868	62001		
ANNUAL OPERATIONS / MAINTENANCE COST					
Pretreatment chemicals		5905	56852	-3937	-37901
RO replacement membranes		31595	304155	-20326	-195673
Post treatment chemicals		12113	116545	-8075	-77697
Brine disposal		4724	45481		
Cost of power		124901	1202407	6245	60120
Cost of repair and replacement		64753	447295		
Cost of labor		27502	189980		
Cost of insurance		23789	164328		
ADDITIONAL DEPRECIATION					
Electrolyzer	20	2337	39803	2337	39803
Total Annual Costs		**361115**	**3305306**		
Annual Cost Savings		23241	204170		
Annual % Savings		**6.4%**	**6.2%**		
Estimated Payback Time for Electrical Capital (years)		1.70	3.29		

References

1 A. Hafez and S. El-Manharawy, *Desalination*, 2003, 153, 335-347.

2 G. Saur, *Wind-To-Hydrogen Project: Electrolyzer Capital Cost Study*, National Renewable Energy Laboratory, Golden, Colorado, USA, 2008.

3 X. Zhu and D. Jassby, *Accounts of Chemical Research*, 2019, 52, 5, 1177–1186.