Evaluation of a Hybrid CAES-Reverse Osmosis Plant Driven by Concentrated Solar Power

SolarPACES

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1. Introduction

Over 40% of the population faces water scarcity, with 700 million lacking safe drinking water. Reverse Osmosis (RO) is the most effective solution but it still relies on conventional energy, increasing CO_2 emissions. Solar energy is a sustainable alternative, though its intermittency challenges RO systems. The European project ASTERIx-CAESar [1] project integrates RO with Concentrated Solar Power (CSP) and PV-driven Compressed Air Energy Storage (CAES). PV powers RO and stores pressure in CAES by day, then drives RO at night via a Gas-Liquid Pressure Exchanger (GL-PX). This CAES+GL-PX-RO system will be tested at PSA by 2026. This study models the system to optimize operation and assess large-scale feasibility.

2. Modelling

3.1. RO unit

Figure 1 shows the integration between the RO unit and CAES through the GL-PX.

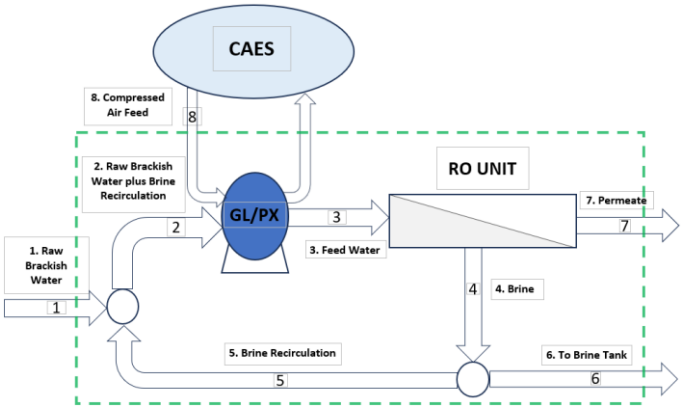

***Fig. 1*:** RO-CAES diagram.

The model is based on the one published in [2]. For the determination of the salinities, a quasi-dynamic model has been implemented taking into account the variation in salinity at the inlet to the RO module due to recirculation. The input variables and parameters for the model are shown in Table 1.

Table 1. Input variables for the CAES+GL-PX-RO model

X_1 (g/L)	T_1 (ºC)	N_e	N_v	SR (%)	A_e (m^2)	FF	RR (%)	P_1(bar)	P_7 (bar)	P_8 (bar)	$\dot{m}_1$ (m^3/h)	$\dot{m}_8$ (m^3/min)
2.139	25	4	2	99.5	7.43	0.86	70	1.01	1.01	4.2	1	0.7

TDS is the total Dissolved Solids, N_e is the number of elements, N_v is the number of vessels, SR is the salt rejection, FF the fouling factor, RR is the Resovery Ratio, $\dot{m}$ is flow rate, P is pressure, X is salt concentration

3.2. Gas Liquid pressure exchanger

A pneumatic pump, Almatec AHD 25 EEE [3], was chosen for the GL-PX to convert compressed air into hydraulic pressure for RO without electricity. Two functions were derived via multivariate regression from the pump's performance chart, relating air flow rate, pressure, and feed water flow rate.

$$\dot{m}_3 = 1.4604312 + 5.6122594\dot{m}_8 - 0.5982324P_8 \quad R^2=0.90 \qquad (ec.8)$$

$$P_3 = 33.7841411 - 68.05417\dot{m}_8 + 23.6573058P_8 \quad R^2=0.91 \qquad (ec.9)$$

where $\dot{m}_3$ is in m^3/h, $\dot{m}_8$ in m3/min, P_3 in m.w.c (meters of water column) and P_8 in bar

3.3. Results

Figure 2 shows the results of the permeate salinity model and Table 2 shows the comparison with the design values provided by the manufacturer (Apria Systems). It can be observed that the permeate salinity achieves the steady state after 30 iterations and that the maximum relative error (ε) is 6.38%, which means a good approximation of the predicted values of the model to the design data.

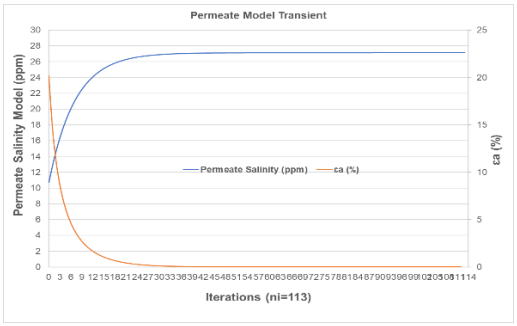

Fig. 2. Results from the permeate salinity model

Variable	Value	Model	ε (%)
$\dot{m}_2$ (m^3/h)	3.00	2.88	4.17
$\dot{m}_3$ (m^3/h)	3.00	2.88	4.17
$\dot{m}_4$(m^3/h)	2.30	2.18	5.55
$\dot{m}_5$ (m^3/h)	2.00	1.88	6.38
P_3 (bar)	8.98	8.61	4.29
X_2 (mg/L)	5356	5354	0.04
X_4 (mg/L)	6964	7068	1.47

Table 2. Validation of the model for the design case

References

[1] https://asterix-caesar.eu

[2] A.S. Nafey, M.A. Sharaf, "Combined solar organic Rankine cycle with reverse osmosis desalination process: Energy, exergy, and cost evaluations," Renewable Energy, 35, 2571-2580, 2010, doi:10.1016/j.renene.2010.03.034

[3] https://www.psgdover.com/almatec/products/specialty-pumps/ahd-ahs-high-pressure-chemical-pump

Acknowledgments

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