Full-Scale Seawater Reverse Osmosis Desalination Plant Simulator

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ABSTRACT: Reverse Osmosis (RO) is an efficient and clean membrane-based technology for water desalination. This work presents a full-scale Seawater Reverse Osmosis (SWRO) desalination plant simulator using MATLAB/Simulink that has been validated using the operational data from a local plant. It allows simulating the system behavior under different operating conditions with high flexibility and minimal cost.

1 Introduction

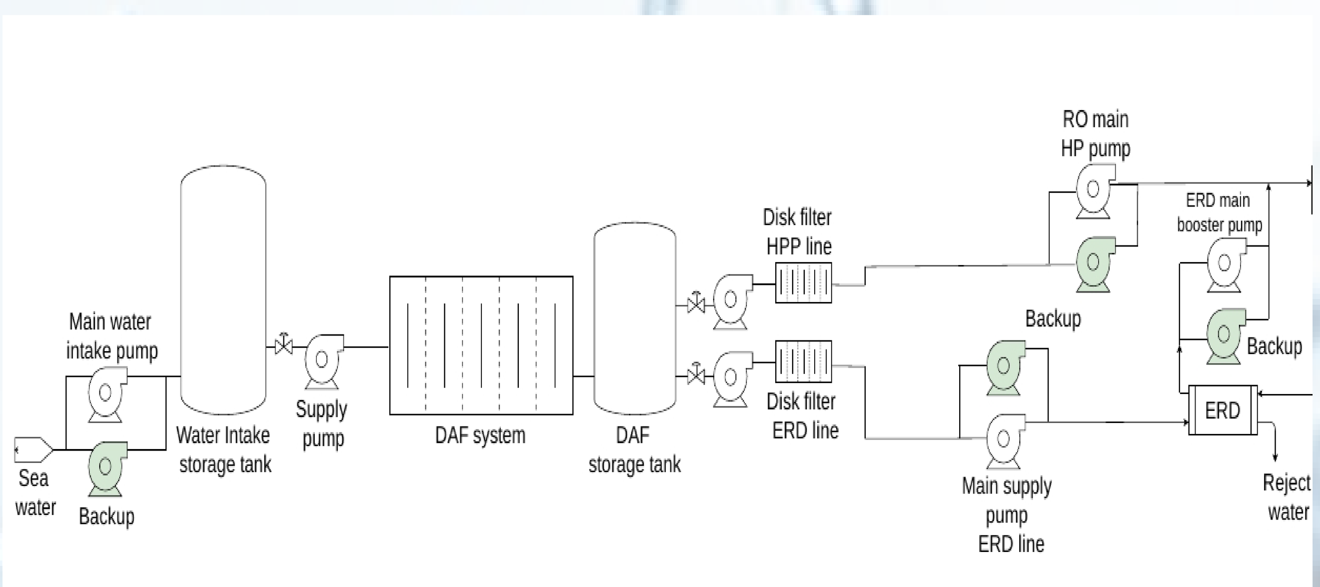
Given the increased demand on freshwater due to the worldwide population growth, technologies for seawater desalination have become essentially important. Among the existing technologies for seawater desalination, **Reverse Osmosis** (RO), which is a membrane-based separation technique, has been proven to be one of the most efficient methods due to its low carbon footprint and energy requirement.

2 Objective

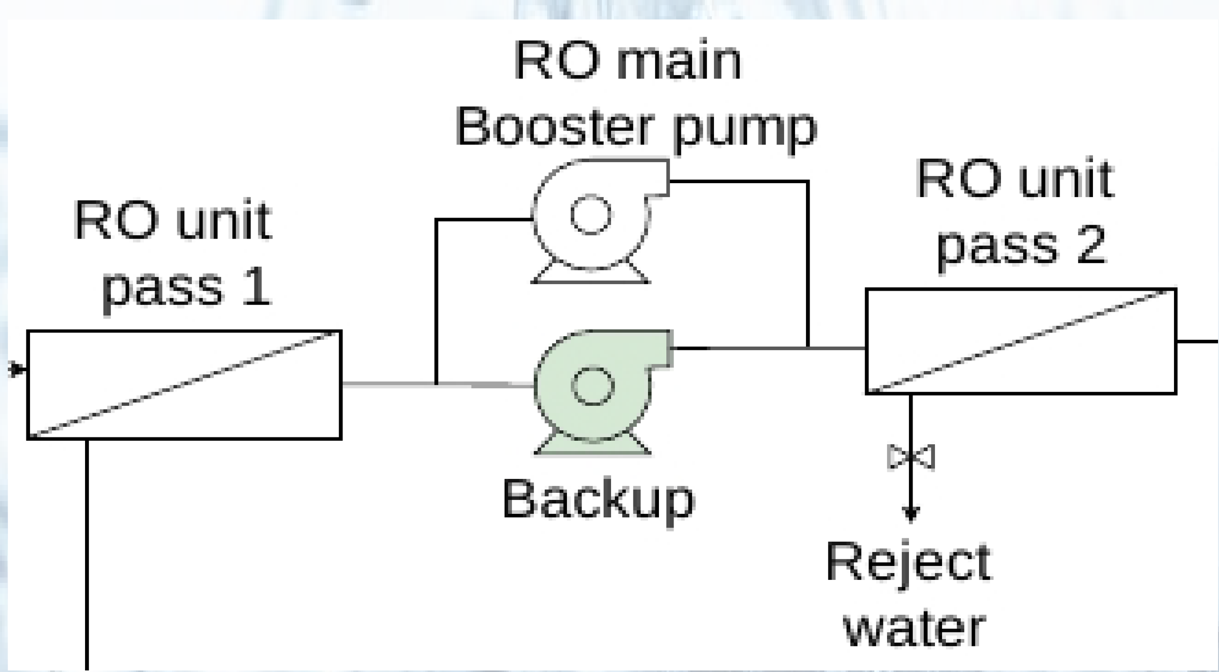
The objective is to develop a **simulator** capable of demonstrating the operation of the reverse osmosis plants, **1)** It simulates the actual full-scale plant operation and incorporates the full control system of the plant. **2)** It can be used for several research purposes such as performance analysis, health monitoring applications, and cybersecurity-related research with high flexibility.

3 Architecture of the Simulated Reverse Osmosis Plant

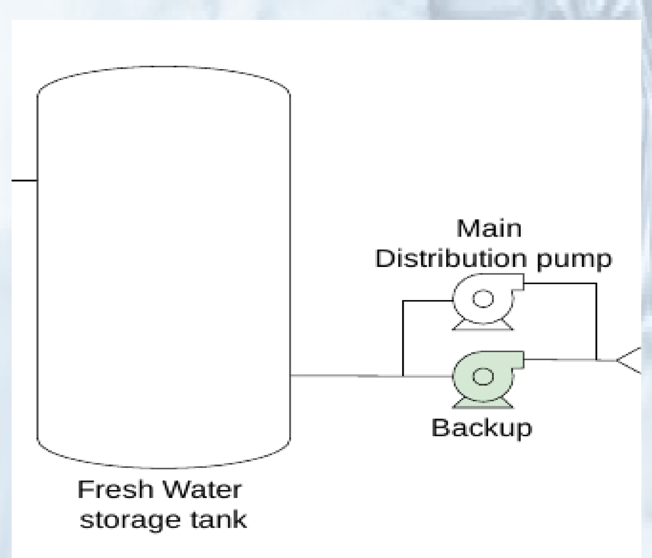
Pre-Treatment



Reverse Osmosis

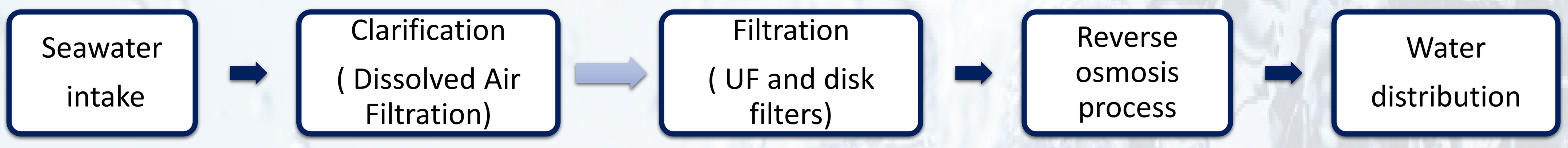


Water Distribution



4 Design of the RO Plant Simulator

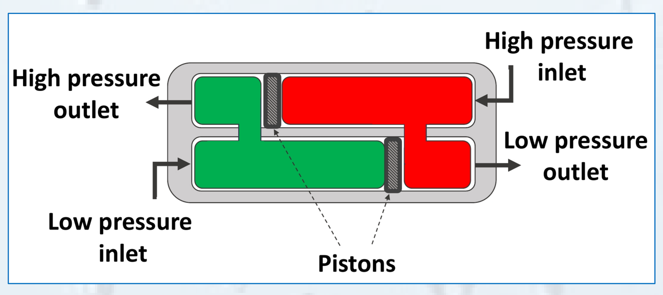
- It is a two- pass RO desalination plant operating with an overall salt rejection of 99.9% and a recovery rate of 40%.



- The RO membrane units are manufactured by **TORY** with models **TM820M-440** and **TM720D-440**.

Parameter		Value
Number of elements in a pressure vessel		7
Number of pressure vessels	RO 1 pass	141
	RO 2 pass	52

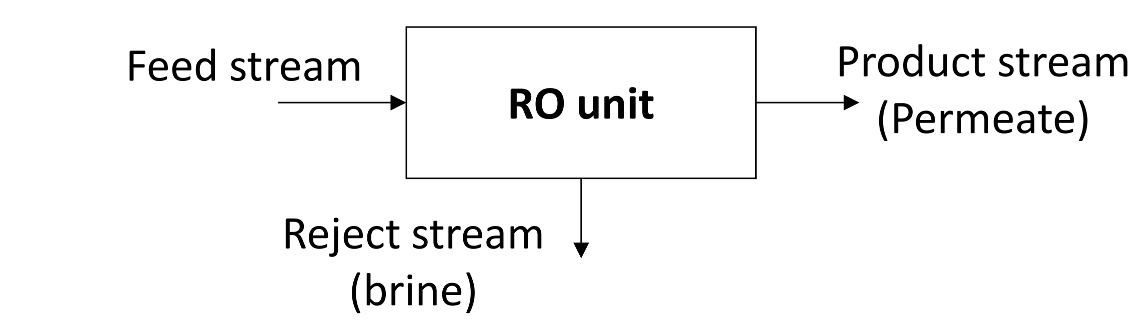
- A Pressure Exchanger - Energy Recovery Device (PX-ERD) is used o recover and transfer the pressure to a portion of the main feed water



- The pre-treatment stage's model is based on regression models from the practical data.
- The simulation model of the RO process is based on the mathematical models in [1].
- The control system is implemented using **Proportional Integral Derivative (PID)** controllers.

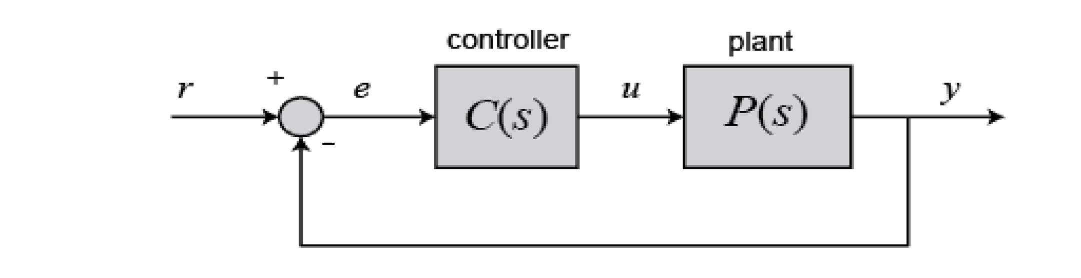
Stage	Number of controllers
Pre-treatment	6
Reverse Osmosis	2
Post-treatment	1

Diagram of RO unit



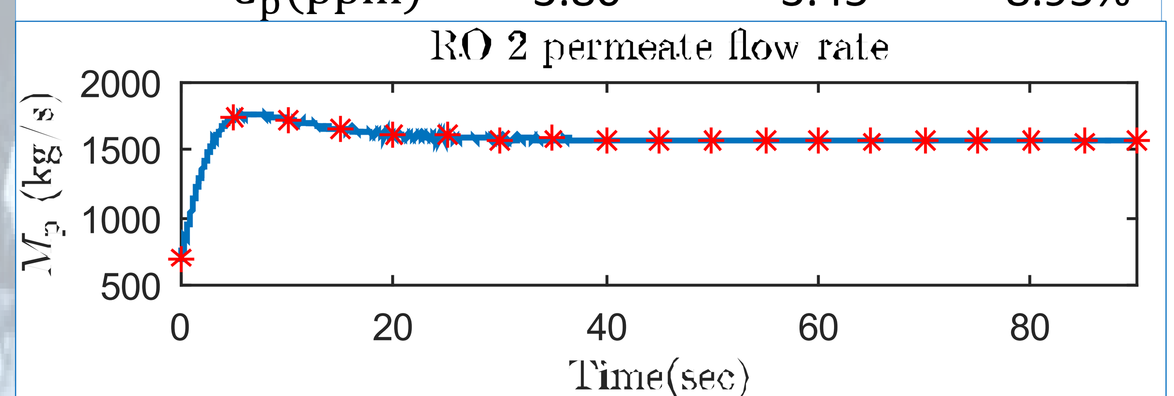
Variable	Mathematical Expression
Disk Filter	$M_{out} = M_{in}$ $P_{out} = P_{in} - \Delta P$ $\Delta P = \alpha_{f1} T^2 + \alpha_{f2} T + \alpha_{f3}$
Permeate flux	$J = \dfrac{\Delta P - \Delta\pi}{\eta(R_m + R_c)}$
Permeate concentration	$C_p = \dfrac{K_s C_b}{\dfrac{J}{\exp(J/k) + K_s}}$
Permeate flow rate	$M_p = K_w A_{em} T_m \rho_w (\Delta P - \beta\Delta\pi)$
Temperature dependency correction factor	$\exp\left(b_T \dfrac{T_f - T_{ref}}{T_f + 273.15}\right)$

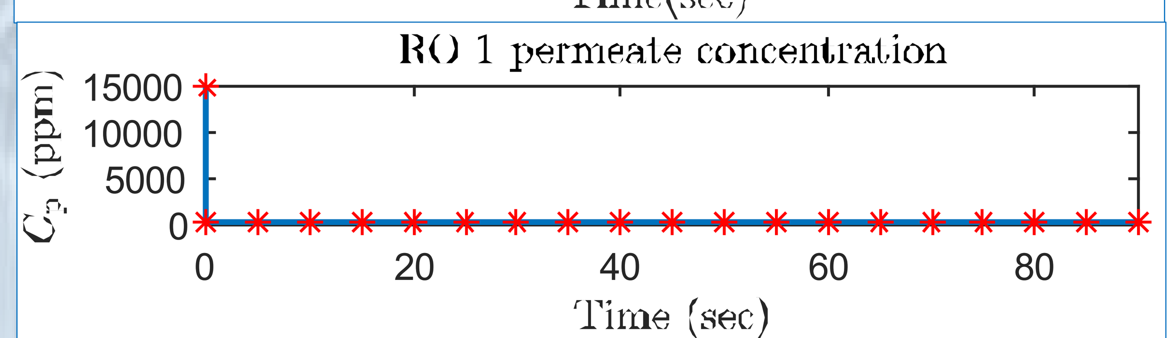
Feedback Control system

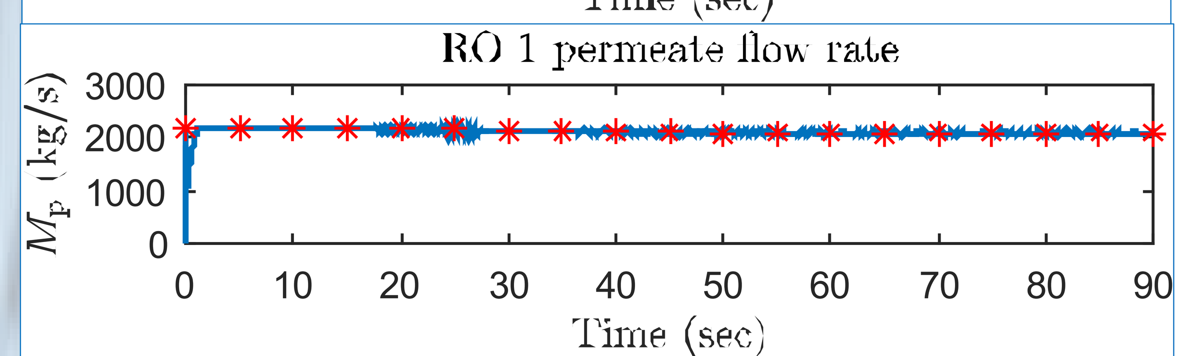


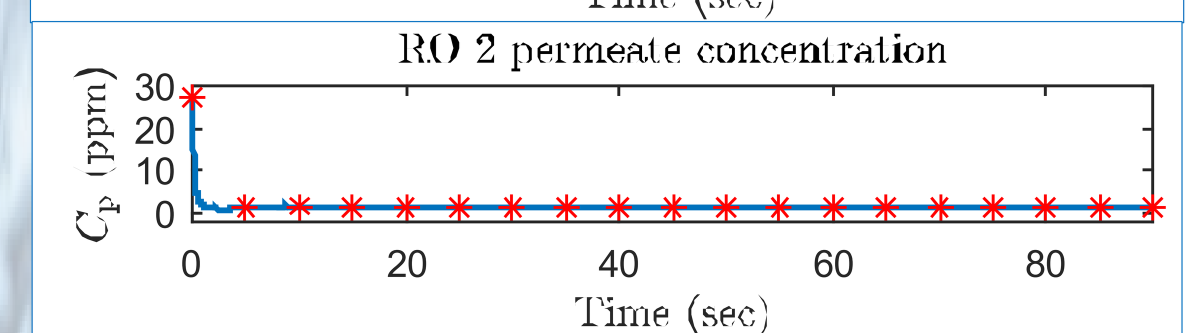
5 Simulation Results

Unit	Variable	Actual	Simulation	Error
RO 1	M_f (kg/s)	5010	5171	3.21%
	C_f (ppm)	45817	45900	0.18%
	P_f (kPa)	7210	7210	0.00%
	M_p (kg/s)	2178	2150	1.29%
	C_p (ppm)	252	242	3.97%
RO 2	M_p (kg/s)	1474	1570	6.51%
	C_p (ppm)	3.80	3.45	8.95%









6 Conclusion

- A full-scale seawater reverse osmosis desalination plant simulator has been developed and validated using MATLAB/Simulink
- It is capable of simulating the actual plant operation with an average error of less than 5% for most of the system variables.
- It provides a feasible, low-cost, and flexible solution for: **1)** analyzing the plant performance, and **2)** promoting research in the area of health monitoring and cybersecurity of industrial control systems.

7 Acknowledgement

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[1] Joseph, A. and Damodaran, V. (2019). Dynamic simulation of the reverse osmosis process for seawater using LabVIEW and an analysis of the process performance. Computers and Chemical Engineering , 121, 294 – 305