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ADVANCING WATER SECURITY: INTEGRATED DESIGN AND TECHNO-ECONOMIC ANALYSIS OF A SEAWATER REVERSE OSMOSIS PLANT

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INTEGRATED DESIGN AND TECHNO-ECONOMIC EVALUATION OF A LARGE-SCALE SWRO SYSTEM DELIVERING SUSTAINABLE, ENERGY-EFFICIENT, AND COST-EFFECTIVE POTABLE WATER FOR LONG-TERM WATER SECURITY

WATER SECURITY, ENVIRONMENTAL MANAGEMENT AND THE SDGS

INTRODUCTION

Seawater desalination plants are increasingly needed as growing populations, climate change, and over-extraction place pressure on limited freshwater resources. Reverse osmosis is now the dominant desalination technology due to its relatively low energy demand compared to thermal methods, and is widely applied in water-scarce coastal regions worldwide. In this project, the plant is situated in a coastal, water-stressed region, highlighting its relevance for both local supply and potential replication at national and global scales. By converting abundant seawater into potable water, it supports water security and contributes to UN Sustainable Development Goals such as clean water access and climate resilience, while reinforcing the water–food–energy nexus by stabilizing water supply for agriculture and energy production (World Health Organization, 2022).

OBJECTIVE

The objective of this project is to develop a technically feasible, economically viable, and environmentally responsible seawater reverse osmosis (SWRO) desalination system. The study also incorporates a summary of relevant desalination technologies to relate the design to current practice and specifies the project location to assess its potential for wider application at local, national, and global scales. A techno-economic evaluation is conducted to determine costs, energy use, and overall feasibility in support of sustainable water security.

METHODOLOGY

The methodology involved designing and evaluating an SWRO plant using a process engineering approach. Mass balances and operating conditions were defined from feed data and production targets, with key stages integrated and supported by PFD/P&ID development and equipment sizing. Safety and reliability were assessed through control design and HAZOP, followed by plant layout planning and a techno-economic evaluation of costs, energy use, and overall performance.

KEY FINDINGS

The proposed SWRO plant treats 15,490 m^3/day of seawater (30 $kg \cdot m^{-3}$ salinity) to produce 9,000 m^3/day of potable water meeting WHO standards, with ~58% recovery (World Nuclear Association, 2024). It integrates optimized pretreatment, efficient RO, and post-treatment to ensure reliable performance.

The estimated capital cost is $15.85M, with annual energy use of 10.17 GWh as a key operating driver. Over 20 years, the project is expected to generate $26.6M in net profit, demonstrating strong technical, operational, and economic viability as a sustainable water security solution.

RESULTS

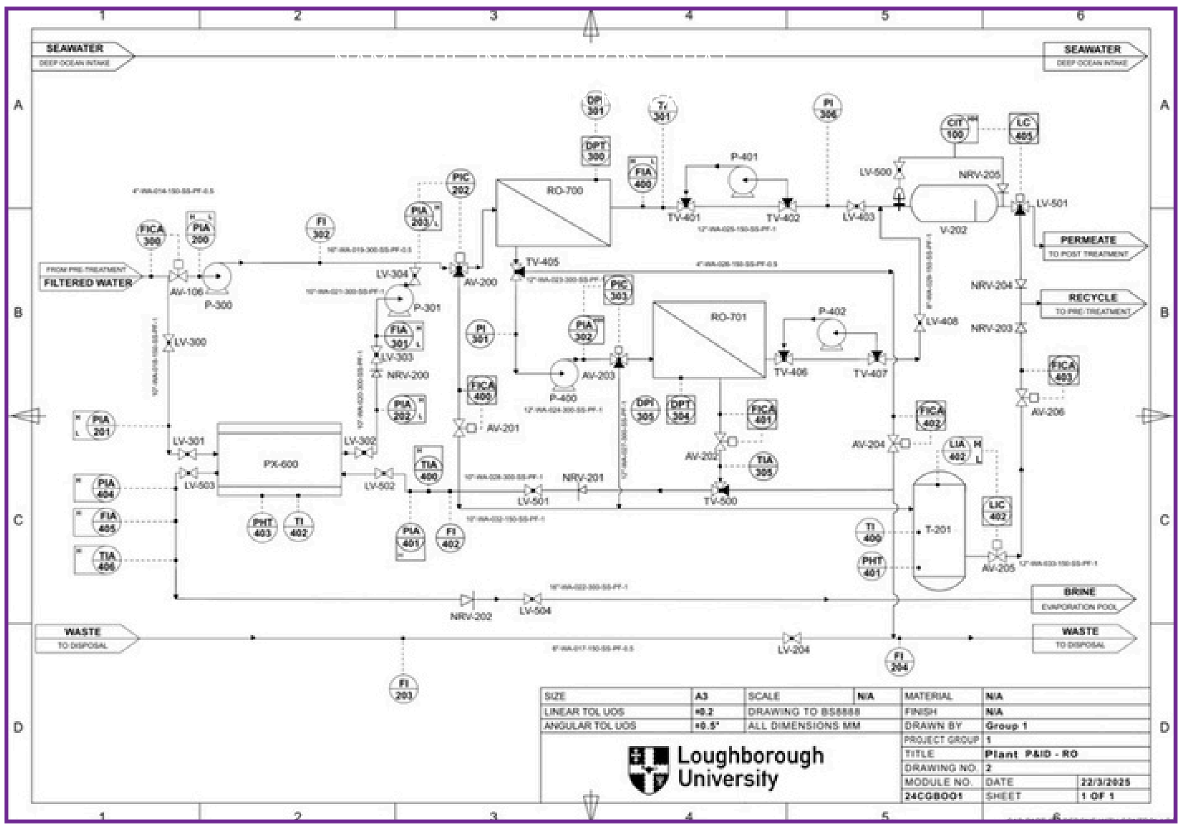

Figure1:*P&IDshowing Reverse Osmosis Membranes process and required control loops*

Figure 1 demonstrates strong technical performance, treating 15,490 m^3/day of seawater to produce 9,000 m^3/day of potable water meeting WHO standards at ~58% recovery. Reliable operation is achieved through optimized pretreatment, efficient RO separation, integrated energy recovery, and automated control systems to maintain stability and consistent water quality (Raphael Semiat, 2008).

The estimated capital cost is $15.85M, with annual energy consumption of 10.17 GWh identified as the primary operating cost driver, alongside membrane replacement. Over a 20-year lifespan, the plant is projected to generate $26.6M in net profit, demonstrating strong long-term economic viability. Environmental performance is enhanced through controlled brine disposal via evaporation ponds and reduced energy demand through recovery devices. Sensitivity analysis shows that energy prices, feedwater quality, and membrane lifespan have a significant impact on operating costs and overall performance. Overall, the SWRO plant represents a technically feasible, economically viable, and environmentally sustainable solution to regional water scarcity (Encyclopaedia Britannica, 2024).

CONCLUSION

The seawater reverse osmosis project is technically, economically, and environmentally viable. With proven RO technology, energy recovery, and automated controls, it ensures safe potable water and regulatory compliance, while key risks are effectively mitigated through design and brine management.
Beyond financial considerations, the project enhances water security and resilience, supporting the water–food–energy nexus and contributing to broader sustainability goals. It offers a sustainable and adaptable solution to regional water scarcity and is recommended to proceed to the EPC phase.

REFERENCES

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