A Sustainable Future: Zero Liquid Discharge System Improves Larnaca's WWTP Recycled Water in the Context of Environmental Protection and Energy Efficiency

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Introduction

The climate crisis and the increase in global population have a significant impact on the availability of water on a global scale. Agriculture currently accounts for 70% of global water consumption. Furthermore, it is projected that food demand will increase by 60% by 20501. This will necessitate increased water usage and potentially worsen the water availability. Desalination, rainwater harvesting, and wastewater reuse are some of the approaches needed to address existing and future water challenges. Cyprus is experiencing severe water stress, which has led to the urgent need for implementing processes, which have been proven to be effective in the production of irrigation water. After adoption of the other two possible sources of water such as seawater desalination and dumps, Cyprus also utilizes the reclaimed water for the wastewater treatment plant. The closing of the water mass balance with the reclaimed water from WWTPs seems a sustainable solution, but the high salinity of this stream can cause significant issues for sensitive crops and soil health 2,3. This study aims to present a customized Zero Liquid Discharge (ZLD) system, which will meet the specific needs and challenges of high-quality water for irrigation, sourced from the effluent of one of the largest WWTPs of Cyprus.

Materials and methods

In the case study of Larnaca's recycled water for crop irrigation, a customized ZLD system was designed as shown below in Figure 1, incorporating NF and RO membranes, a Multiple Effect Distillation (MED) Evaporator, and a Vacuum Crystallizer (VC). The NF90-4040 and BW30-4040 membranes were selected for the Larnaca case study for the NF and RO units, respectively. These membranes have a polyamide thin film composition and operate at low pressure. This results in low energy consumption while maintaining high salt rejection rates.4 The membrane system is controlled through a Programmable Logic Controller (PLC) interface, which connects numerous pressures, flow, water level, conductivity, redox, pH, and energy transmitters at various locations within the system to receive essential data for process control. The role of NF is to protect RO membranes as well as enhance the purity of recovered salts by separating divalent ions from the NF concentrate stream. The permeate of NF is led to RO which produces two streams. One of pure water and one concentrated stream, rich in NaCl. The concentrated stream from the RO is treated by a MED Evaporator and a VC. The MED evaporator consists of two consecutive effects and is monitored by Supervisory Control and Data Acquisition (SCADA) system.

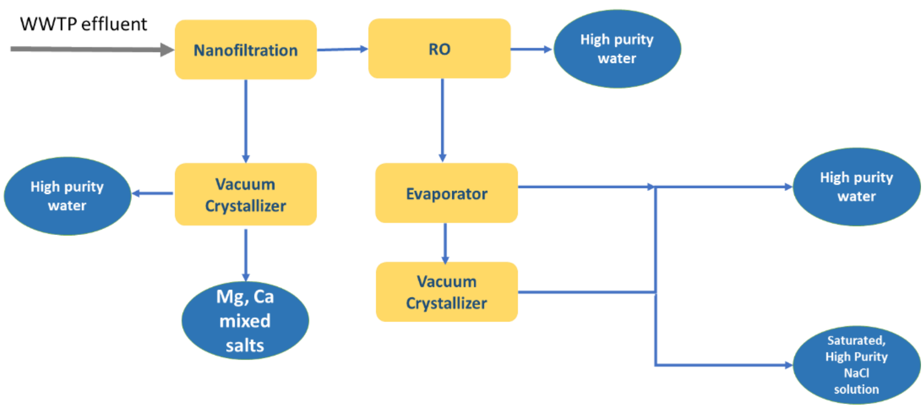

Figure 1. Flow diagram of the ZLD system

The brine in the feed boils at a low temperature and pressure, resulting in energy recovery. The MED evaporator concentrates the inlet stream and recovers high-purity water. The VC unit is an evaporator/concentrator that achieves the distillation of liquids at low temperatures through the combined effect of vacuum technology and the heat pump. In this specific case study, CV treats the NF retentate stream (recovering Mg and Ca mixed salt and high-purity water) and the MED concentrate (recovering high-purity NaCl salt and high-purity water), promoting the principles of circular economy. The design process involved the use of the Water Application Value Engine (WAVE) software for simulations and bench-scale tests conducted at the National Technical University of Athens (NTUA). Also, in terms of laboratory analyses of the ZLD system's samples, they were conducted at Brine Excellence Center (BEC) of the NTUA.

Results and discussion

The efficiency of the ZLD system was evaluated based on the following criteria: water recovery, energy consumption, permeate quality, ion rejection, operating pressure, and hours of operation. The maximum capacity of the system is 2 m3/h of feed water. Regarding the NF membrane, it was observed that its optimal performance is at 82% recovery rate, followed by 85% recovery rate due to better ion rejection and lower energy consumption. Regarding RO membrane, it can be concluded that it performs optimally at a recovery rate of 91%, with a rejection rate of over 95% for all ions. With regard to the RO membrane during the second pass, it is challenging to ascertain the optimal operating efficiency, given that it consistently demonstrates an ion rejection rate of over 99% across all studied recoveries. Consequently, we identify the optimal operating condition at 83% recovery rate.

The efficacy of the MED evaporator and VC was evaluated based only on their energy consumption and water recovery rates because it was determined that there are no significant differences in the average ion removal performance. To achieve higher concentration factors (CF), experiments varied the duration of brine feeding and operation while maintaining other parameters constant. It was observed that increasing operational hours generally resulted in improved water recovery, although this also led to an increase in energy consumption regarding the MED evaporator and less energy consumption regarding VC. Thus, the objective of the study was to identify an optimal balance between maximizing water recovery and managing energy consumption. Furthermore, the experimental observation regarding VC revealed that residual salt is deposited on the internal surface of the VC for both VC feeds after 10 hours of continuous operation. To avoid the process of cleaning and salt loss on the internal surface of the crystallizer, it is recommended that the process be operated continuously for a maximum of 8 hours.

The feed water of the ZLD system has conductivity in the range of 3.6 to 4 mS/cm and the produced permeate from the membrane system (NF and RO) has conductivity lower than 0.4 mS/cm. Regarding the MED Evaporator and VC, it should be noted that they operate by providing high water recovery, high ion rejection, and permeate conductivity around 0.05 mS/cm.

Conclusion

In conclusion, the proposed ZLD system achieves the initial goal of providing low salinity water for irrigation. However, special attention should be given to possible alternative configurations of the system to lower energy consumption and increase of water recovery efficiency

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