Integrating CO_2 Capture into Thermal Desalination Systems: A Dual-Purpose Approach to Climate-change Mitigation and Freshwater Production

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To meet future climate targets, it will be essential to generate negative emissions through technologies like Direct Air Capture (DAC) and durable carbon storage (DOC). Moreover, the escalating threat of water scarcity and ocean acidification underscores the urgent need for innovative and scalable water and carbon capture solutions. This study presents a novel approach that integrates CO_2 capture directly into thermal desalination processes, thus transforming desalination plants into dual-purpose facilities capable of producing freshwater and mitigating climate change at the same time. The proposed method investigates DOC integration into conventional and innovative desalination processes, starting from multi-stage flash (MSF) and multi-effect distillation (MED) systems in order to remove inorganic carbon efficiently. Detailed process modelling and simulation are employed to assess this integration. The paper includes thermodynamic evaluations and process flow diagrams as well as the investigation of key operational parameters, such as temperature profiles, system pressure and capture technologies to optimize the overall energy consumption. In addition, a comprehensive economic analysis assesses capital and operating costs, as well as economic indicators such as the levelized cost of water (LCOW) and CO_2 capture (LCOC) and the payback period. Results indicate that the integrated process achieves competitive CO_2 capture performance with modest additional energy demands, while improving the environmental footprint of desalination facilities. Preliminary data show that for a small MED plant of 20,000 m3/day it is possible to extract a CO2 flow rate of approximately 2 ton/day with a capture cost of less than 100 €/ton, leading to significant savings compared to DAC which currently has costs in the order of 500 €/ton. This dual-purpose can reduce atmospheric CO_2 levels, mitigate ocean acidification, and contribute to water security to address two major global challenges synergistically.

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