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# Optimal operating conditions and configurations for humidification–dehumidification desalination cycles

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ABSTRACT

This article applies nonlinear programming techniques to optimize humidification–dehumidification (HD) desalination cycles for operating conditions that result in maximum gained output ratio (GOR). Closed air open water as well as open air open water cycles, each with either an air or a water heater, were considered in this analysis. Numerical optimization resulted in a substantial increase in GOR for all four cycle types compared to previous best-case conditions found using heuristic studies. The GOR of the cycles was found to decrease with increasing component terminal temperature difference (TTD). In addition, different cycles perform best at different temperature differences. Optimization also revealed that some counterintuitive design configurations can result in superior performance under the appropriate operating conditions.



## 1. Introduction

Several excellent methods of desalination are available, including reverse osmosis (RO), multi-stage flash (MSF), and multi-effect distillation (MED), but these technologies are often unsuitable for developing regions because they require substantial infrastructure, typically use fossil fuels as the energy source, and may only be cost-effective at very large scales. Conversely, many areas that suffer from water scarcity have high solar insolation, which suggests that solar powered desalination could be very beneficial to the developing world since the sun provides an abundance of "free" energy.

Humidification–dehumidification (HD) desalination is a fairly simple technology that mimics nature's water cycle and has the potential to operate with solar heating. Solar stills are the most basic form of HD but prove to be inefficient since the enthalpy of vaporization is lost in the condensation process [1]. The basis of HD desalination cycles is to improve system efficiency by recapturing this energy, by separating the evaporation and condensation processes, and by incorporating regenerative heating of the feedwater stream in the condenser. Due to the straightforward design and the potential for production of potable water in remote areas without the need for electricity, HD has received considerable attention over the past few years [1–3].

Previous studies by Narayan et al. [4] and by Mistry et al. [5] investigated the thermodynamic behavior of HD cycles using the First and Second Laws of Thermodynamics, respectively. Both articles discussed methods for improvement and optimization of the cycles based on thermodynamic arguments and single parameter optimization. However, the cycles are functions of several parameters and therefore, more systematic optimization methods are required to find the true optimal conditions for each of the cycles. The goal of this paper is to determine operating conditions that maximize the gained output ratio (GOR), or performance ratio, of a variety of promising HD cycles. Three numeric codes (SNOPT [6,7], Interior Point Optimizer (IPOPT) [8], and an in-house genetic algorithm) were used to perform the optimization. A multi-start method was also used for heuristic global optimization, implemented in parallel computers in order to reduce computation time.

## 2. HD desalination cycles

HD cycles must consist of at least three components: a humidifier, a dehumidifier, and a heater. Depending on how these three components are arranged, various classes of cycles can be formed. The cycles are classified based on the nature of the flow pattern of each of the streams. Two primary cycle classes are considered here: closed air, open water (CAOW) cycles and open air, open water (OAOW) cycles.

The characteristics of these basic cycles are discussed below.

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