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# Recovering water from brine: Assessments of feasibility and applicability to irrigation processes

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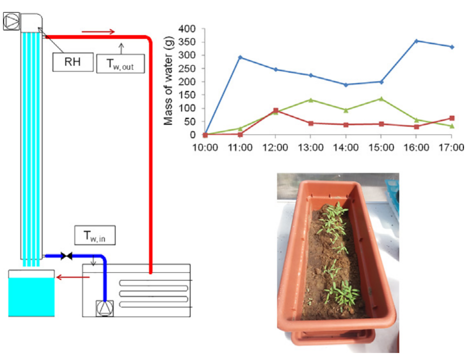
## GRAPHICAL ABSTRACT




## ARTICLE INFO

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## ABSTRACT

This study investigated the recovery of moisture from brine drying processes and evaluated the applicability of recovered water for irrigation purposes, while taking into consideration applicable Chilean regulations. For moisture recovery, a heat exchanger was installed on the outside of the solar dryer and connected to an air extractor that ejected the vapor produced during the process; the objective of this setup was to condense vapor produced while drying brine inside the solar dryer. Using refrigerated circulation (0.136 L/s flow), 312 g of freshwater was recovered. Overall condensation performance was 17.2%, with each kg of condensed water requiring 40,480 J/s of transferred condensation heat, a logarithmic mean temperature difference of 12.9 °C, and 7.9 kWh of specific energy consumption. The condensed water was subsequently assessed according to Chilean regulations for irrigation-water quality, as well as through phytotoxicity analyses using lettuce (*Lactuca sativa*) seeds. All evaluated quality parameters met legal requirements, and the condensed water was nontoxic for L. *sativa* seeds. The return-on-investment for the process was 5.4 years, and the produced freshwater costed 0.35 US $/L.

## 1. Introduction

Obtaining freshwater is critical for the survival of mankind, particularly in the current contexts of a growing global population and climate change [1]. One chronic problem arising from these contexts is water scarcity [2], thus underscoring the need to develop technological strategies for producing this important resource [3] and to ensure that agricultural processes can meet the increasing food-supply demanded by a growing human population [4].

Going beyond basic survival, freshwater is needed for numerous

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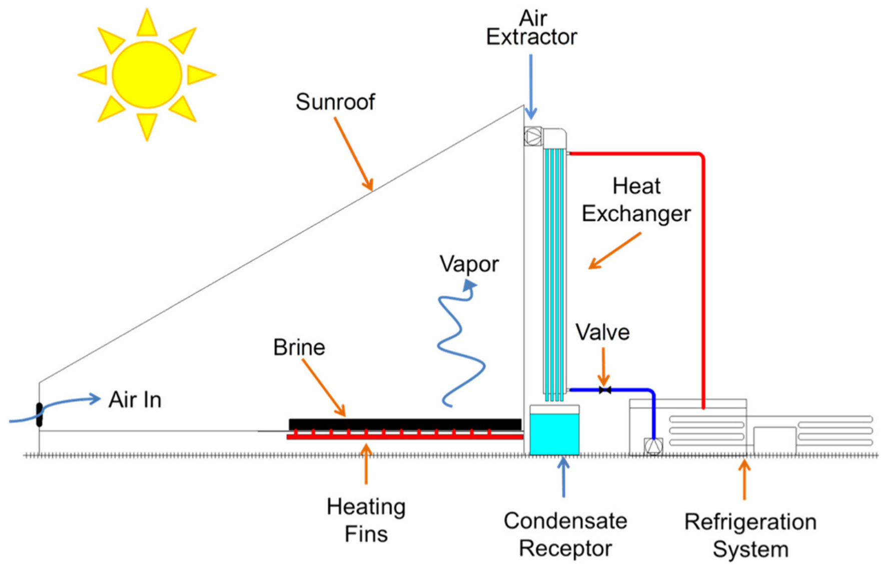


**Fig. 1.** Schematic diagram of the solar still setup used to recover water.

industrial/productive processes. The ongoing, and increasing, demand for freshwater access has contributed to growing interests in seawater desalination systems [5]. Indeed, several desalination plants are constructed daily worldwide. The most used technologies at these plants include multistage flash distillation and reverse osmosis distillation, which result in high water yields [6]. Although desalination ultimately provides freshwater, the wastewater discharges of desalination, such as brine, can cause environmental damage, principally in the ocean [7]. Brine derived from desalination processes can negatively impact marine environments as a result of being hypersaline and containing post-processing chemicals [8]. The adverse effects of brine waste on ocean ecosystems have already been documented [9]. Water degradation, for example, negatively affects marine life and ecosystems [10]. The environmental effects of shedding brine into soils are also concerning, particularly as related to ground-water quality, which affects livestock and agricultural activities [11].

The issue of brine waste can be addressed through drying processes, a promising alternative for adequately managing this refuse. Waste-drying processes can significantly decrease refuse volume by minimizing moisture content [12], thereby facilitating more and improved waste management and storage options [13]. Wastes can be dried using artificial or solar dryers. While both options offer improvements over open-air drying in terms of process quality and time investments, solar drying is a particularly attractive waste-management method for reducing waste mass and costs associated with waste transportation and landfilling [14]. Artificial dryers are comparatively quicker than solar dryers, but artificial approaches have high energy requirements and elevated operational costs [15]. Conversely, solar dryers use solar energy and, consequently, have significantly lower operational costs than artificial dryers.

Solar drying is a promising management solution for brine discharge produced as a byproduct of seawater desalination. The simple structure of solar stills translates into easy installation and maintenance [16]. Furthermore, recent research has shown that modifications to solar dryers, including a mirror and heated basin, are important factors that can impact the efficiency, performance, and time investment of solar stills [17]. However, further improvements can still be achieved. In most cases, for example, water vapor produced during the drying process is lost to the surrounding environment. This inefficiency means a loss of water resources, which is particularly important to consider in geographical areas with already limited freshwater access. Such is the case in the desert landscape of northern Chile, where seawater is desalinated for use in massive mining operations.

In addition to mining applications, solar drying processes also have potential uses in agricultural contexts. For example, common grapes (*Vitis vinifera*) and bitter melon (*Momordica charantia*) are more effectively dried, in terms of required time and rate of removed moisture, when dried in a solar tunnel dryer that uses thermal storage materials [18]. Other reports support that solar drying processes are improved by the use of thermal storage, phase-change materials [19]. Studies have even gone so far as to assessed the effects of wind-tunnel configuration and flow velocity through computational fluid dynamics, specifically assessing ammonia volatilization, which can have damaging environmental effects [20]. To this end, computational fluid dynamics simulations can calculate the air velocity within dryer tunnels, ultimately aiding in optimizing flow distribution to obtain a uniform distribution of velocity profiles [20].

Despite the importance of managing brine waste and optimizing waste management, research on these specific subjects is relatively scarce. Therefore, the aim of this study was to evaluate the feasibility of recovering water from brine-drying processes and, thereafter, of using the recovered water for crop irrigation purposes. Drying and water-recovery processes were optimized, and the recovered water was evaluated for phytotoxicity and according to Chilean quality standards for irrigation water. A preliminary economic analysis was also conducted for the developed process.

## 2. Methodology

### 2.1. Experimental procedure

The feasibility of recovering water from vapor produced when drying brine in a solar still was assessed. Experiments were conducted with brine (500 g) samples obtained from a solar thermal desalination plant [17]. This amount of waste mass was chosen for ease-of-handling. For assessments, three trays (7 cm height and 1000 $cm^2$ surface area) were halfway filled with brine. The solar still (Fig. 1) used in analyses had a heated base with fins, as previously described [17]. The trays with brine were placed on top of the fins in the solar still, and all experiments lasted 7 h (from 10:00 am to 5:00 pm).

To recover water present in vapor form, a heat exchanger was installed on the outside of the solar dryer. The exchanger was connected to an air extractor, resulting in a condensation of the vapor produced from the brine drying inside of the solar still (Fig. 1).

In simplified terms, water vapor was condensed inside of the solar still through the following process: (i) the air extractor (20 W) suctions