

## Abstract

Water scarcity is a serious global challenge, affecting billions of people worldwide. Limited access to safe water poses health risks and exacerbates social disparities, requiring urgent actions from policymakers and scientific communities. In this thesis, we discuss two possible approaches to alleviate this problem: Atmospheric Water Harvesting -a technology which enables the production of fresh water potentially anywhere, starting from the vapor in humid air- and Water Desalination -a technology which allows treating existing sources of water to obtain a potable liquid-.

Specifically, we explore adsorption-based solutions, where a hydrophilic material is exploited to collect, transport and condense water molecules. Conventional plants use adsorbent materials such as silica-gels and zeolites; in contrast, we propose a novel bio-derived hydrogel, Calcium Alginate (CaAlg), providing evidence that it is a competitive and cost-effective alternative for heat driven atmospheric water harvesting and water desalination applications.

First, we produced and characterized six different compositions of CaAlg. Our results show that composition  $Alg_1Ca_{10}$  has the best equilibrium capacity, of up to 1.28 g/g at a relative humidity  $RH = 70\%$  and a temperature  $T = 30^\circ\text{C}$ , a fourfold increase compared to silica-gels. Starting from the experimental type-II isotherms, we estimated an adsorption enthalpy of 2600 kJ/kg at  $30^\circ\text{C}$ .

Second, we tested CaAlg dynamics over adsorption-desorption transients. We found that composition  $Alg_1Ca_5G_{0.1}$  has the best dynamics, and demonstrates a long-term stability over 300 cycles. We proposed an improved variation of the Linear Driving Force model (LDFDw) with which we were able to best-fit the experimental data, estimating a water vapor diffusivity of  $3 \cdot 10^{-12} \text{ m}^2/\text{s}$  at  $30^\circ\text{C}$ .

Third, we tested a surface coating of CaAlg in an atmospheric water harvesting unit. The experiments were performed in laboratory conditions as well as in arid climates, resulting in a Specific Daily Water Production of up to  $1.19 \text{ m}^3/\text{day}/\text{ton}$  and showing a stable cycle and water condensation over 2.5 days of consecutive testing, at medium-low desorption temperatures ( $65^\circ\text{C}$ ) and medium-low RH levels (45%).

Fourth, we tested a batch of CaAlg beads in an adsorption desalination unit. We achieved a desalination effect, reaching a Specific Daily Water Production of  $6.04 \text{ m}^3/\text{day}/\text{ton}$  at  $60^\circ\text{C}$  under optimized cycling times, and obtaining a salt rejection rate of over 99.2%. Most

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importantly, we achieved a sub-optimal water production of 2.2 m<sup>3</sup>/day/ton with a desorption temperature as low as 45°C.

Finally, we designed and tested a larger-scale adsorption device using a silica-gel composite and extrapolated the results to the use of CaAlg. Our analysis suggests that, by replacing the composite sorbent with our hydrogel, we should observe an increase in efficiency and a resulting reduction of material weight and cost of over 50%.

In general, we have proved that calcium alginate is indeed a suitable sorbent in adsorption-based atmospheric water harvesting and water desalination, outperforming existing alternatives especially at low driving temperatures. This opens a new set of opportunities: ultralow-grade heat sources can be integrated with adsorption-based solutions using CaAlg, providing water production as well as a cooling effect. Waste heat coming, for example, from power plants heat dissipation or data-centre cooling (45-60°C) is of no use for production of work, given the low exergetic content; nevertheless, it is already sufficient to drive an adsorption-based machine employing calcium alginate, providing fresh water in areas in need. These findings align with the global energy objectives established by the UN General Assembly in 2015, providing options for recycling waste heat, reducing impact on climate and increasing global access to drinkable water. Future research on CaAlg should assess experimentally its long-term stability, performance at short cycle times and bio-degradability.