

Integration of Hygroscopic Salts into Natural Fibers for Enhanced Dew Condensation

Dr. Gunasekara U.S.W.

*Department of Textile & Apparel
Engineering*
University of Moratuwa, Sri Lanka
ujithe@uom.lk

Sethusan S.

*Department of Textile & Apparel
Engineering*
University of Moratuwa, Sri Lanka
sethusans.20@uom.lk

Liyanage H.V.C.

*Department of Textile & Apparel
Engineering*
University of Moratuwa, Sri Lanka
liyanagehvc.20@uom.lk

Madagoda M.R.H.S

*Department of Textile & Apparel
Engineering*
University of Moratuwa, Sri Lanka
madagodamrhs.20@uom.lk

Keywords—Dew Harvesting, Radiative Cooling, Hygroscopic Material, Atmospheric water harvesting

I. INTRODUCTION

Water scarcity affects ~4 billion people globally, with Sri Lanka's dry zone particularly impacted due to prolonged dry seasons, groundwater depletion, and saltwater intrusion. Traditional solutions such as dams, desalination, and groundwater extraction are often costly, energy-intensive, and unsuitable for decentralized communities. Atmospheric water harvesting (AWH), especially dew harvesting, offers a low-energy, scalable alternative that produces high-purity water by exploiting night-time radiative cooling. [1]

Two main AWH types exist: passive systems, which rely on natural cooling, and active systems, which use external energy for higher yields [2]. Hybrid systems combining radiative cooling and solar regeneration are emerging for enhanced efficiency.

This project develops a sustainable, locally adapted dew harvesting system by integrating hygroscopic calcium chloride (CaCl_2) into water hyacinth fibers—an abundant, invasive plant in Sri Lanka. The combination leverages CaCl_2 's strong moisture absorption and the fibers' high porosity, hydrophilicity, and radiative cooling capability. The system addresses gaps in existing research, aiming to boost yields in humid tropical climates while creating value from invasive biomass. It offers a cost-effective, deployable solution for rural and urban water-stressed communities using locally available materials and renewable energy.

The primary aim of this project is to develop an efficient and sustainable atmospheric dew harvesting system using radiative cooling textile material.

Objectives:

1. Conduct a comprehensive literature review to identify current advancements, challenges, and innovations in atmospheric dew harvesting systems.
2. Develop a dew harvesting medium by integrating water hyacinth fibers with Calcium chloride (CaCl_2) focused on

increasing moisture regain efficiency while maintaining material stability and environmental sustainability

3. Design and construct a passive dew harvesting system using the developed medium and evaluate its performance under real-world environmental conditions through field testing and analytical methods

II. LITERATURE REVIEW

Dew formation occurs when a surface radiates heat to the clear sky and cools below the ambient dew point, resulting in the condensation of water vapor. In arid climates, one square meter of a passive condenser can typically yield between 0.3 and 0.6 liters per night. For instance, a large-scale 850 m² dew array in Corsica collected approximately 10,710 liters of water over 192 nights, corresponding to about 0.56 liters per square meter per night [3]. These findings demonstrate the potential of passive systems, although yields vary significantly depending on surface material and environmental conditions.

Natural fibers have recently gained attention as alternative dew harvesting media due to their renewability, abundance, and hydrophilic properties. Studies on cotton, flax, and jute fabrics have reported their ability to absorb and retain moisture, while bamboo and coir fibers have been tested for their water sorption and wicking properties [6,7]. These natural materials act as both condensation substrates and absorptive media, owing to their porous microstructures. However, such systems generally achieve modest yields in the range of 0.1–0.2 liters per square meter per night, indicating the need for performance enhancement through material modification.

Water hyacinth (*Eichhornia crassipes*) presents an attractive candidate for such applications. This invasive aquatic plant, which poses major ecological challenges in Sri Lanka, produces fibers rich in cellulose (around 70%), making them highly emissive in the 8–13 μm atmospheric window crucial for radiative cooling. The fibers also possess high porosity and strong capillary action, enabling rapid vapor uptake and liquid wicking. They can naturally regain about 13–18% of their weight in moisture under ambient conditions

and absorb much more when submerged. Additionally, their abundance makes them sustainable and low-cost material that can be harvested as part of weed management. These properties suggest that water hyacinth fibers can serve a dual role in dew harvesting: they provide a radiative cooling surface while also acting as a porous carrier to immobilize hygroscopic salts such as calcium chloride.

Hygroscopic salts, particularly calcium chloride (CaCl_2), have been shown to significantly improve dew collection under humid conditions [1,5]. CaCl_2 has a strong deliquescent nature, low toxicity, and affordability, and can absorb multiple times its weight in water vapor before releasing it upon heating. However, conventional CaCl_2 beds are prone to leakage and require containment. Integrating the salt within natural fibers overcomes this challenge by binding it to a porous matrix, preventing contamination while enhancing moisture sorption.

Although prior research has explored natural fibers for dew harvesting and separately studied hygroscopic salts, little work has combined the two approaches. Furthermore, the potential of using invasive biomass such as water hyacinth remains underutilized. This study aims to bridge these gaps by developing a fiber-salt composite system and evaluating its performance under real-world tropical conditions in Sri Lanka.

III. MATERIALS AND METHODS

Fiber preparation: Water hyacinth stems were harvested and decorticated to isolate fibers. The fibers were retted and treated with 10% NaOH (at 90 °C for 30 min) to dissolve lignin and pectin, yielding purified cellulose fibers with improved hydrophilicity. The cleaned fibers were air-dried to constant weight.

CaCl_2 impregnation: Oven-dried fibers were soaked in aqueous CaCl_2 solutions of varying molarity. ASTM D2654 moisture-regain tests identified 5 M as the optimal concentration (higher concentrations yielded brittle fibers with no significant gain). Accordingly, 1 kg of fiber was submerged in 5 M CaCl_2 for ~6–8 hours, then gently squeezed and oven-dried (70–80 °C, 2 h) to crystallize the salt within the fiber matrix. The resulting CaCl_2 -treated fiber was stored sealed until testing.

System construction: A passive two-stage collector was built (Fig. 1, Fig. 2). The primary frame was a 1.44 m² wooden board set at a 30° angle. High-density transparent polyethylene covered the frame as insulation. A 1 m² galvanized-mesh mat was placed on the frame, into which the CaCl_2 -treated fibers were hand-entangled and secured; a gutter lined with polyethylene was attached at the lower edge to collect condensed water.



Fig. 1. Schematic diagram & Apparatus of primary frame



Fig. 2. Schematic diagram & Apparatus of primary frame

Field testing: The apparatus was deployed outdoors (Moratuwa, Sri Lanka) in a North–South orientation. Each night, the fiber mat on the primary frame (Fig. 1) was exposed to sky cooling (secondary cover removed). Before sunrise, the secondary wooden frame (Fig. 2) was placed over the primary frame, sealing the fibers in a transparent chamber. Solar heating during the day evaporated absorbed moisture, which condensed on the cover and dripped into the gutter. Environmental data (T, RH) were logged each minute to correlate weather with performance. Testing cycles were conducted under clear, calm conditions, with rain or strong winds excluded.

IV. RESULTS AND DISCUSSION

Moisture-regain tests confirmed that CaCl_2 impregnation dramatically increased hygroscopic uptake. Fibers treated with 5 M CaCl_2 exhibited roughly double the moisture regain of untreated fibers. Increasing concentration beyond 5 M produced no further gain and made fibers brittle, so 5 M was used for all prototypes. In field trials over 27 nights, the CaCl_2 -treated mats vastly outperformed untreated mats.

Fiber Type	No. of Cycles	Total Absorbed Water (ml)	Actual Extracted Yield (ml)
<i>CaCl₂-treated fibers</i>	18	8621	6590
<i>Untreated fibers</i>	9	1143	940

Table 1. Schematic diagram & Apparatus of primary frame

Table 1 shows that during the first 18 cycles (treated fibers), the total absorbed moisture was 8621 ml, whereas in 9 cycles with untreated fiber it was only 1143 ml. Equivalently, treated mats yielded ≈ 479 ml/m²-night versus 127 mL/m²-night for untreated mats (a ~377% increase). During the daytime release, 6590 ml of water was recovered from treated mats compared to only 940 ml from untreated ones. This superior performance reflects the salt’s hygroscopic action: CaCl_2 absorbs vapor via deliquescence throughout the night and then releases it under solar heating. Importantly, water quality analysis showed no detectable CaCl_2 contamination in the condensate, indicating the salt remained bound in the fibers and the collected water was safe.

V. CONCLUSION

The project successfully demonstrated a novel dew-harvesting textile system. All objectives were met, resulting in a functional prototype that exploits both radiative cooling and hygroscopic sorption. In field tests, the CaCl_2 -treated fiber mats averaged ~ 0.39 L/m² of water per night (with peaks of ~ 0.45 L/m²), versus only 0.09 L/m² for untreated mats. Water samples passed quality tests with no significant salt contamination. These results validate a low-cost, scalable approach to producing potable water using locally available biomass and solar energy. In summary, integrating CaCl_2 with water hyacinth fibers yielded a high-performance passive dew

condenser, offering a sustainable solution for decentralized water access in Sri Lanka and similar climates.

VI. REFERENCES

- [1] W. Zhu, Y. Zhang, C. Zhang, X. Shan, A. K. Rao, S. L. Pitts, T. J. Woodbury, T. S. Masnyk, D. Derome, D. M. Warsinger, X. Ruan, L. J. Mauer, J. Carmeliet, and T. Li, "Radiative cooling sorbent towards all weather ambient water harvesting," *Commun Eng*, vol. 2, no. 1, p. 35, Jun. 2023, doi: 10.1038/s44172-023-00082-3.
- [2] J. Xu, X. Huo, T. Yan, P. Wang, Z. Bai, J. Chao, R. Yang, R. Wang, and T. Li, "All-in-one hybrid atmospheric water harvesting for all-day water production by natural sunlight and radiative cooling," *Energy Environ. Sci.*, vol. 17, no. 14, pp. 4988–5001, 2024, doi: 10.1039/D3EE04363K.
- [3] D. Beysens, M. Muselli, I. Milimouk, and V. S. Nikolayev, "Measurement and modelling of dew in the Island of Corsica," *Atmospheric Research*, vol. 73, no. 1–2, pp. 1–22, 2005, doi: 10.1016/j.atmosres.2004.05.003.
- [4] S. Chonsakorn, S. Srivorradatpaisan, and R. Mongkholrattanasit, "Effects of different extraction methods on some properties of water hyacinth fiber," *J. Nat. Fibers*, vol. 16, no. 7, pp. 1015–1025, Oct. 2019, doi: 10.1080/15440478.2018.1448316.
- [5] I. Haechler, H. Park, G. Schnoering, T. Gulich, M. Rohner, A. Tripathy, A. Milionis, T. M. Schutzius, and D. Poulidakos, "Exploiting radiative cooling for uninterrupted 24-hour water harvesting from the atmosphere," *Sci. Adv.*, vol. 7, no. 26, p. eabf3978, Jun. 2021, doi: 10.1126/sciadv.abf3978.
- [6] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interface," *IEEE Transl. J. Magn. Japan*, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetism Japan, p. 301, 1982].
- [7] M. Young, *The Technical Writer's Handbook*. Mill Valley, CA: University of Science, 1989.