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Sustainable Evaporative Cooling Using Antifungal-Coated Water Hyacinth Pads

Nat Thuchayapong* and Nattawut Tharawadee*, [1]

Abstract – *This study presents the development of evaporative cooling pads made from water hyacinth fibers coated with Rocima 243, a broad-spectrum antifungal agent, aiming to create a sustainable and cost-effective alternative to commercial cooling media for tropical climates. Unlike conventional materials such as engineered cellulose, our approach valorizes an abundant invasive aquatic plant—Eichhornia crassipes—by transforming its fibrous stems into functional cooling media. The fibers were chemically treated to resist biodegradation and microbial colonization, addressing a key limitation of natural pads.*

Water hyacinth stems were collected, dried, and woven into 15 × 20 cm fiber pads, then coated with Rocima 243 to inhibit fungal degradation. Laboratory tests evaluated fungal inhibition using five isolates (including Aspergillus spp. and Rhizopus spp.), showing colony suppression to 0.5–2 cm. The pads were installed in a small evaporative cooling rig with an airflow of 3 m/s and water recirculation, operated for 7 days under simulated tropical conditions (~33 °C, 60–80% RH). The treated pads consistently achieved a temperature drop of ~3.5°C and a saturation efficiency of ~70% while maintaining their structural integrity.

Compared to untreated hyacinth pads, which rapidly degraded under the same conditions, the treated pads-maintained shape, color, and airflow integrity. These results confirm that Rocima-coated hyacinth fiber pads can match or exceed the thermal performance of synthetic commercial media while offering ecological co-benefits such as waste valorization and invasive species management.

Keywords – antifungal coating, biodegradation resistance, evaporative cooling, Rocima 243, water hyacinth fiber.

1. INTRODUCTION

The global demand for cooling is rising rapidly due to higher ambient temperatures, urban heat islands, and growing populations—especially in tropical regions—placing an unprecedented strain on energy systems and the environment [1]. Air conditioning (vapor-compression refrigeration) is the dominant method for space cooling, but it is energy-intensive and a major source of greenhouse gas emissions [2]. Building cooling loads have increased dramatically in recent years, and conventional HVAC systems consume a large amount of electricity [1]. In many hot countries, the penetration of air conditioners remains low (often <15%), yet studies project billions of new cooling units by mid-century, implying massive increases in electricity demand and CO_2 emissions [6]. These trends create a critical need for alternative cooling technologies that are both energy-efficient and low-cost in order to provide thermal comfort without exacerbating climate change or energy poverty. Evaporative cooling has long been recognized as an energy-efficient and environmentally friendly alternative to conventional air conditioning [1]. In a direct evaporative cooler, warm air is drawn through a wetted porous medium (cooling pad) where water evaporates into the air stream, lowering the air's dry-bulb temperature and increasing its humidity [2], [5]. This process utilizes only the latent heat of vaporization of water, thereby avoiding the high-pressure refrigerants commonly used in vapor-compression systems. State-of-the-art evaporative coolers can achieve high "saturation efficiencies" (often 60–90% of the theoretical cooling potential) and extremely high coefficients of performance (COPs above 20–30) under suitable conditions [1]. As a result, evaporative systems consume only a fraction (roughly 20–35%) of the electrical power of typical air conditioners for the same cooling output. The environmental benefits are also significant: evaporative coolers emit no ozone-depleting or high-global-warming refrigerants, and their only "working fluid" is water, a benign substance. These advantages make evaporative cooling especially attractive for sustainable climate control in hot climates. Despite these advantages, evaporative cooling has traditionally been limited to arid climates because its performance diminishes as ambient humidity rises. In humid tropical climates, simple direct evaporation yields smaller temperature drops (approaching the wet-bulb temperature of the outside air) and can raise indoor humidity significantly. Nevertheless, various strategies (such as hybrid indirect-direct systems, multi-stage cooling, or enhanced airflow) are being developed to extend evaporative cooling into hot-humid environments [5]. Crucially, the key component determining a cooler's performance is the wetted media, also known as the cooling pad [2], [5]. Traditional pads are often rigid honeycomb structures made of corrugated cellulose paper

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or treated aspen wood wool, providing a large wetted surface area and achieving very high saturation effectiveness (often 70–90% of the theoretical limit). Such engineered cellulose pads are effective but relatively expensive to produce and require specialized manufacturing. Other common materials include synthetic fiber mats and plastic media, which similarly have high performance but involve non-renewable materials and embodied energy. Given these costs and material constraints, there is growing interest in natural, low-cost cooling media derived from agricultural and forestry wastes. Many studies have explored alternative pad materials, ranging from coconut coir and jute fibers to agricultural by-products (*e.g.*, bagasse, dried reeds, or fruit peels), with promising results. Some waste-based media have achieved cooling efficiencies comparable to conventional cellulose pads. For example, Obando Vega et al. tested three alternative pad materials under tropical conditions and found that, while commercial cellulose still performed best, the low-cost alternatives provided substantial cooling (temperature drops and humidity reduction) and could significantly improve thermal comfort in agricultural buildings. In general, pad materials are selected based on local availability, low cost, and ease of disposal or recycling to minimize both economic and environmental costs. However, many natural fiber pads introduce new challenges. Being organic, they are prone to microbial and mold growth when kept wet under warm conditions, which can degrade the material and reduce cooling performance over time. Protecting such pads often requires biocidal or preservative treatment. For instance, copper-based or isothiazolinone biocides are commonly used in wood and paper products to inhibit the growth of fungi and algae. Rocima 243 (Lanxess) is one such broad-spectrum biocide widely used in wood coatings and paints for mold protection. Coating natural fiber pads with an antifungal agent can dramatically extend their service life by preventing the rapid decay that would otherwise occur in humid usage. In effect, coupling a renewable pad material with a safe preservative holds the promise of a high-performance, durable cooling media suited to tropical conditions. In parallel to these cooling-system considerations, the environmental management of invasive species has become a global concern. Eichhornia crassipes (water hyacinth) is one of the world's most notorious invasive aquatic plants; it proliferates explosively in warm, nutrient-rich waters, forming dense floating mats that block sunlight, deplete dissolved oxygen, and disrupt native ecosystems [3]-[4]. The ecological impacts include reduced biodiversity, altered water chemistry, and impaired fisheries, irrigation, and hydroelectric operations. The social and economic consequences are also severe: water hyacinth growth imposes significant management costs on communities while impairing agriculture and navigation in rural regions. Many conventional control methods (mechanical harvesting, herbicides, biocontrol insects) have limited success unless combined in integrated programs, and the volume of harvested biomass often remains a waste disposal problem. Notably, scholars have pointed out that water hyacinth also represents an untapped resource stream. Although a pest, its rapid growth translates into abundant biomass that can be repurposed. Recent reviews highlight various valorization strategies, including biogas production, composting, and biochar, as well as the use of dried fibers in construction boards, paper, or animal feed. By turning waste into products, these strategies can generate income for local communities and incentivize the removal of weeds. Aji Abba et al. emphasize that innovative uses of hyacinth biomass (for energy, crafts, and water treatment, among others) can convert an ecological problem into an economic opportunity, thereby supporting sustainable development and the circular economy.

The present work connects these two themes—sustainable cooling and the reuse of invasive species—by evaluating dried water hyacinth fiber as a material for evaporative cooling pads. Using water hyacinth for this purpose offers a double benefit: it exploits a free, rapidly renewable resource that is locally available in many tropical waters, and it helps manage an invasive plant by upcycling it into a value-added product. Importantly, the fibrous stem material of hyacinth possesses intrinsic properties (porosity, water absorption) that are potentially well-suited for use as an evaporative cooling medium. To address the biodegradation issue, the fibers are treated with a biocidal coating (specifically a Rocima 243-based preservative) to inhibit fungal growth during operation. The treated and untreated hyacinth pads are then tested under simulated tropical climate conditions to assess their thermal performance and durability. This paper builds on preliminary findings that water hyacinth pads can achieve cooling comparable to conventional pads while requiring low-cost processing. We significantly extend prior work by rigorously quantifying the cooling capacity, saturation efficiency, pressure drop, and water retention of the hyacinth media and by documenting the effectiveness of the antifungal treatment. The aim is to demonstrate that an eco-friendly, high-performance evaporative pad can be made from invasive plant waste, thus aligning energy-saving cooling technology with environmental remediation. In the following sections, we review the relevant literature on evaporative cooling media and hyacinth valorization, detail our experimental methods and results, and discuss the implications for sustainable cooling in tropical communities.

Beyond its cooling functionality, this work positions water hyacinth as a case study in biomass valorization, transforming invasive aquatic weeds into engineered materials for various applications. Such an approach addresses two parallel challenges: the environmental harm caused by unchecked hyacinth proliferation and the need for renewable, low-cost thermal control technologies in the Global South.

2. EXPERIMENTAL SETUP

2.1 Materials

Water hyacinth (Eichhornia crassipes) was collected from local freshwater sources in Nakhon Pathom, Thailand. The fibrous stem segments were selected due to their porosity and water retention capacity. Initial preparation involved thoroughly washing the stems with tap water to remove surface dirt and microorganisms, followed by slicing them into strips of two different widths (approximately 5 mm and 10 mm) to investigate their influence on pad structure. The sliced fibers were air-dried for 24 hours and then oven-dried at 105 °C for 1 day to completely remove moisture, following methods commonly used in biomass preparation. To enhance fungal resistance, the dried fibers were treated with an antifungal coating using Rocima™ 243, a commercial biocide containing isothiazolinones widely used in the wood and paint industries for mold protection [7]. The solution was prepared at a concentration of approximately 1% (v/v) in water based on recommendations from previous efficacy studies [8]. The fibers were fully immersed in the solution for 30 minutes to allow adequate absorption and then removed and air-dried for 48 hours at room temperature in a shaded, ventilated area.

2.2 Fungal Inhibition Tests

To evaluate the antifungal effectiveness of the treatment, in vitro fungal inhibition tests were conducted. Samples of both treated and untreated water hyacinth fibers were placed on nutrient agar plates inoculated with Aspergillus sp. and Syncephalastrum sp., common fungi isolated from decaying aquatic plants. The Petri dishes were incubated at 28 °C for 5 days, and the diameter of the fungal colonies (in cm) was measured and compared.

Fig. 1. The prepared wet pad.

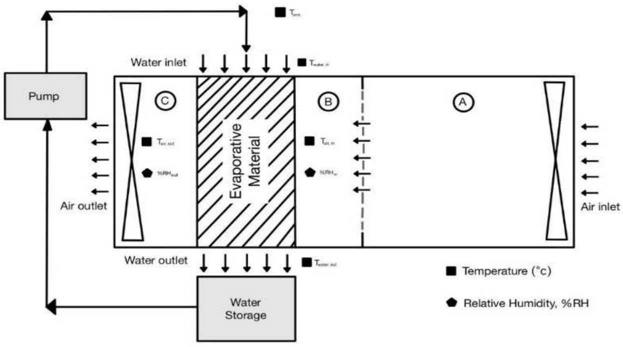
2.3 Cooling Performance Tests

For performance testing, the dried fibers were woven into square pads of 15 × 20 cm using a standard lattice method. These pads were installed in a small-scale evaporative cooling test rig equipped with a centrifugal fan providing a constant airflow of 3 m/s and a recirculating water system. Environmental conditions during the test reflected a typical tropical climate (ambient temperatures of 30–35 °C and relative humidity of 60–80%). The experiment was conducted continuously for 7 days, operating 8 hours per day. Temperature and relative humidity were measured at the inlet and outlet of the pad using digital thermo-hygrometers placed at strategic points. In this study, Type K thermocouples were used to measure the temperature at all designated points. A midi LOGGER GL820 data logger was employed to record the temperature data obtained from the thermocouples. The GL820 model allows data acquisition at a frequency as high as 10 ms, with a measurement accuracy of ± 0.05%.

The cooling performance of each pad was determined by measuring the air temperature and relative humidity at the inlet and outlet of the test chamber, as shown in Figure 2. Temperature drop (ΔT) and humidity increase (ΔRH) were indicators of evaporative efficiency. Each test was repeated in triplicate to ensure data reliability.

The experiment aimed to evaluate cooling performance (in terms of temperature drop and humidity gain), resistance to microbial degradation, and physical durability over repeated wetting cycles. Data were collected and analyzed statistically to determine the effect of antifungal treatment on overall pad efficiency.

(a)Experimental setup



(b) Diagram of Experimental setup

Fig. 2. Experimental setup for evaporative cooling test.

3. RESULTS AND DISCUSSION

3.1 Fungal Inhibition

Fungal growth tests were performed using fungal isolates cultured on PDA media with and without Rocima 243. Observations across three replicate plates for each isolate revealed that fungal colonies on untreated PDA exhibited active growth, with visible expansion across the plate surface. In contrast, plates containing Rocima 243 showed minimal fungal growth, confined to small circular zones with diameters ranging from 0.5 to 2 centimeters. These results demonstrate that Rocima 243 effectively inhibits fungal development across all isolates (Figure 3).

The fungal isolates were cultured and observed under a microscope after staining with Lactophenol Cotton Blue. Isolates 1 to 3 exhibited no distinguishable hyphal or spore structures, appearing translucent and morphologically ambiguous. These may be yeast or thin-structured fungi that did not stain effectively. Isolates 4 and 5, however, displayed clear characteristics of filamentous fungi. Specifically, Aspergillus spp. was identified by its septate hyphae, conidiophores, and vesicles with phialides, while Rhizopus spp. was recognized by its non-septate hyphae and prominent sporangia (Figure 4).

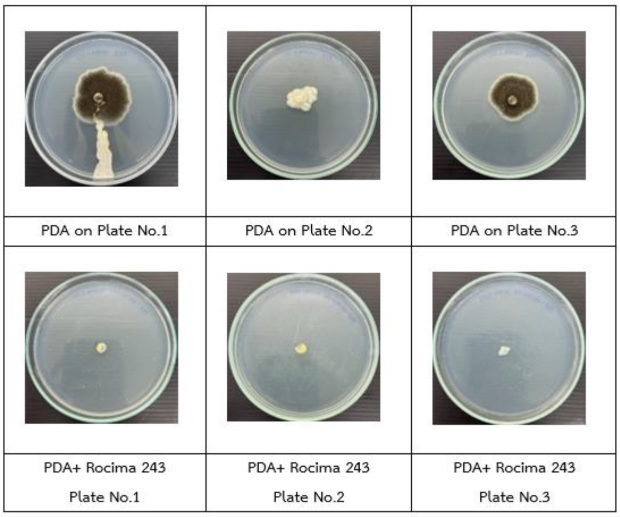


Fig. 3. Fungal growth in PDA and PDA+ Rocima 243.

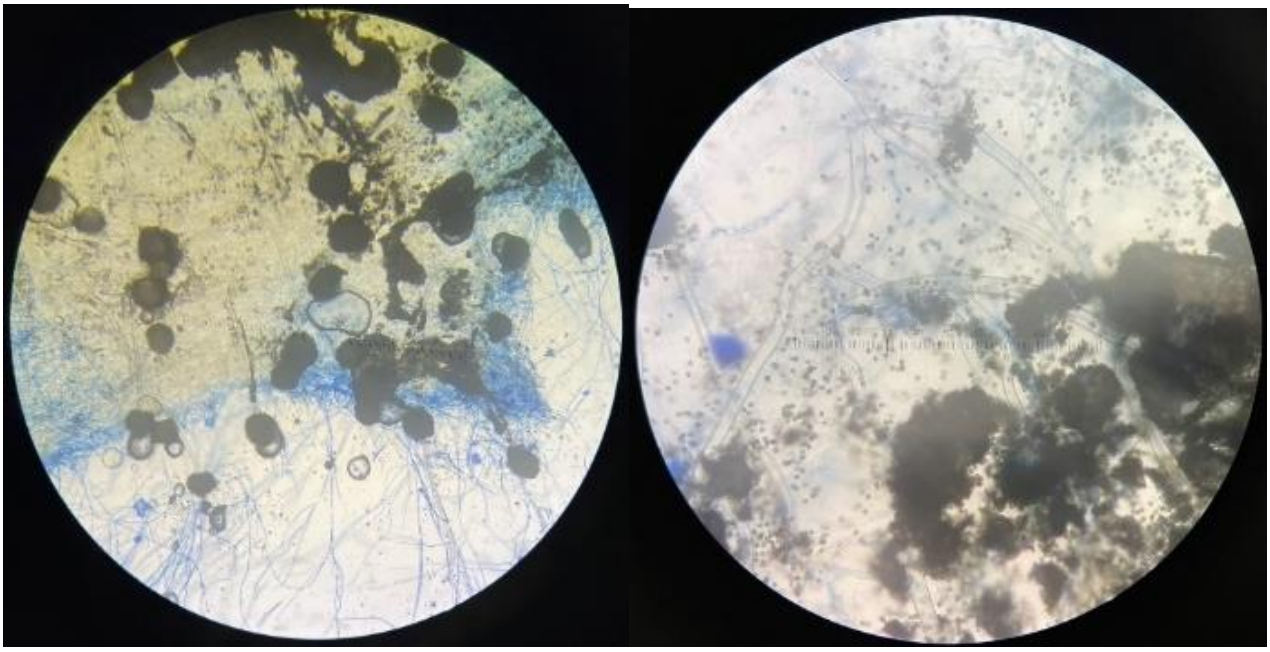


Fig. 4. Fungal growth was found in isolates 4 and 5 (Aspergillus spp and Rhizopus spp).

a. Pad without coating **b. Pad coated with Rocima 243**

Fig. 5. Biodegradation comparison between the uncoated pad and the Rocima 243-coated pad.

3.2 Biodegradation

Twenty pads measuring 15 × 20 cm were fabricated by weaving dried water hyacinth fibers. These were dried and placed in acrylic containers (20 × 20 × 15 cm) for use in evaporative cooling tests. Testing was conducted over 7 consecutive days, with each day involving 10 hours of continuous operation. Three full cycles were repeated under controlled conditions: airflow of 3 m/s and water flow rate of 150 L/h.

Daily physical inspections recorded changes in pad size, surface collapse, color alterations in both the pads and the circulated water, and the development of odors or fungal spots. Pads treated with Rocima 243 exhibited less physical deterioration and fewer signs of fungal colonization, indicating the preservative's role in maintaining structural integrity (Figure 5).

3.3 Cooling Performance

During a 7-day test under simulated hot-humid conditions (inlet ~33.5°C/56.9 °C/56.9% RH), the Rocima-coated pad consistently reduced air temperature by ~-3.5 °C, reaching ~30°C/69.4 °C/69.4% RH at the outlet. On Day 1, the saturation efficiency approached 70% of the theoretical limit based on wet-bulb temperature (~30°C), indicating good saturation efficiency for a 10 mm thick natural pad. This performance remained stable over the week, with outlet air temperature and velocity showing minimal variation (2.8–3.0 m/s), suggesting reliable performance and resistance to clogging or degradation (Figures 6 and 7).

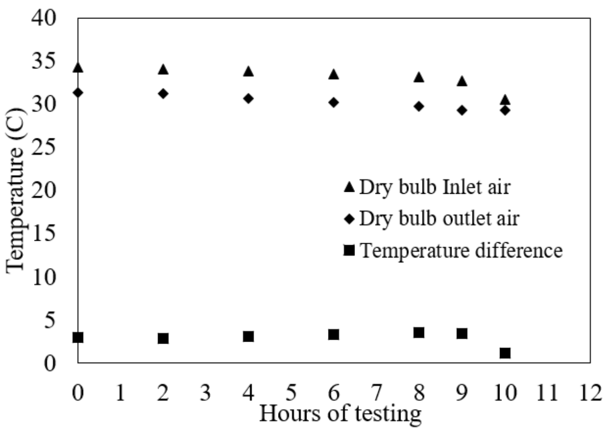


Fig. 6. Variation in dry-bulb temperature between inlet and outlet air during testing of the antifungal-coated pad.

A parallel test with an uncoated hyacinth pad revealed clear contrasts. While Day 1 cooling was comparable (~3.5°C drop, ~65% efficiency), fungal growth became apparent by Day 2. Mold colonization reduced airflow by ~10% and caused visible sagging of the pad structure by Day 4. A musty odor was detected, and the test was terminated on Day 5 due to heavy degradation. In contrast, the treated pad showed no visible mold or structural damage, retaining its shape and function throughout the 7 days.

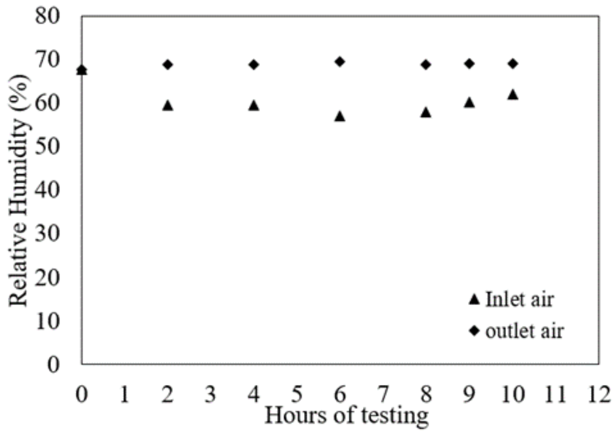


Fig. 7. Variation in relative humidity between the inlet and outlet air during testing of the antifungal-coated pad.

4. CONCLUSION

This study successfully demonstrated the potential of using water hyacinth fibers as a natural and sustainable material for evaporative cooling pads. The application of Rocima 243 as an antifungal coating significantly enhanced the biological stability of the material by effectively suppressing fungal growth, as confirmed through culture tests and microscopic observation. Among the five fungal isolates examined, two (Isolates 4 and 5) were identified as common contaminants—Aspergillus spp. and Rhizopus spp.—that were effectively inhibited by the Rocima treatment. The fabricated water hyacinth pads, woven into structured panels, maintained physical integrity and showed minimal degradation during a 7-day operation under controlled airflow and water flow conditions. In terms of cooling performance, the treated pads delivered a consistent temperature drop and an increase in relative humidity, demonstrating functionality comparable to that of commercial cellulose-based media.

In summary, the findings confirm that dried water hyacinth treated with Rocima 243 offers a promising, low-cost, and environmentally friendly alternative to synthetic evaporative cooling materials. Future research should focus on scaling the application, exploring eco-friendly biocides, and evaluating long-term performance in real-world environments.

The dual benefit of mitigating water hyacinth overgrowth and generating functional cooling media suggests that such systems may form part of an integrated environmental remediation strategy. Leveraging invasive biomass aligns well with circular economy principles and offers replicable benefits for other tropical regions facing similar ecological burdens.

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