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Commentary

Hygroscopic all-polymer composite for moisture management and evaporative cooling

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Adsorption-based water management and evaporative cooling personal thermal management (PTM) technologies offer great potential to achieve adaptive temperature regulation, wide applicability, and low energy consumption. However, designing high-performance and durable hygroscopic composites that combine efficient heat dissipation with wear comfort is a challenge. More recently, Xu et al. used two hygroscopic polymers and crosslinking strategies to develop moisture-absorbent fabrics with excellent hygroscopicity, durability, ductility, air permeability, washable resistance, and antibacterial properties. This work paved an intriguing PTM application prospect of an all-polymer hygroscopic composite to achieve energy-efficient moisture sorption and evaporative cooling.

Environmental heat exposure poses a significant hazard to occupational safety and health, imposing limitations on athletic performance, physical work capacity, working hours, and labor productivity. The simultaneous heat and humidity can cause unexpected health problems, while conventional cooling strategies often drive rising global electricity use, fuel consumption, and greenhouse gas emissions, requiring more advanced technologies to address these issues [1–4]. In addition, conventional space cooling is not suitable for outdoor recreational activities and work environments, so it is difficult to fully satisfy individual preferences for thermal comfort [5–7]. Given this health-energy dilemma, innovative point-of-use technologies are pressingly needed to promote efficiency and sustainability [8,9].

Considering the drawbacks of space cooling technologies, PTM technology based on moisture management and evaporative cooling has received growing attention [10,11]. PTM technology emphasizes adaptive thermal management of the human body, skin, clothing, and microenvironments using smart wearables/textiles, offering great potential for achieving adaptive thermoregulation, broad applicability, and zero emission. Therefore, PTM plays a significant role in future heating/cooling technologies from the perspectives of energy saving, enhanced thermal comfort, and broad applicability. In this regard, PTM can improve the health of people who are at risk of heat stroke or burns when exposed to high temperatures. However, few hygroscopic fibers and fabrics are manufactured as adsorbent cooled textiles for PTM applications due to the following challenges: 1) the deliquescence and hygroscopic salt leakage issues, 2) the compatibility between high water uptake and hygroscopic kinetics, and 3) the difficulty of continuous wet spinning of hygroscopic and stable fibers in humid environments [12–14].

To effectively solve the above challenges, Li et al. [15] prepared a hygroscopic all-polymer composite based on hygroscopic polymers sodium alginate (SA) and polyethyleneimine (PEI) to realize moisture management and evaporative cooling using the air-assisted electrospinning method (**Figure 1(a)**). The multiple crosslinking reactions overcome the solubility of the hygroscopic polymer in a high-humidity environment and ensure the stability of the fabric structure. Furthermore, porous fiber not only ensures breathability but also significantly promotes the rapid hygroscopic and desorption kinetics of hygroscopic fabrics. The abundant protonated amino group on the surface of PEI also gave the fabric an excellent bacteriostatic property.

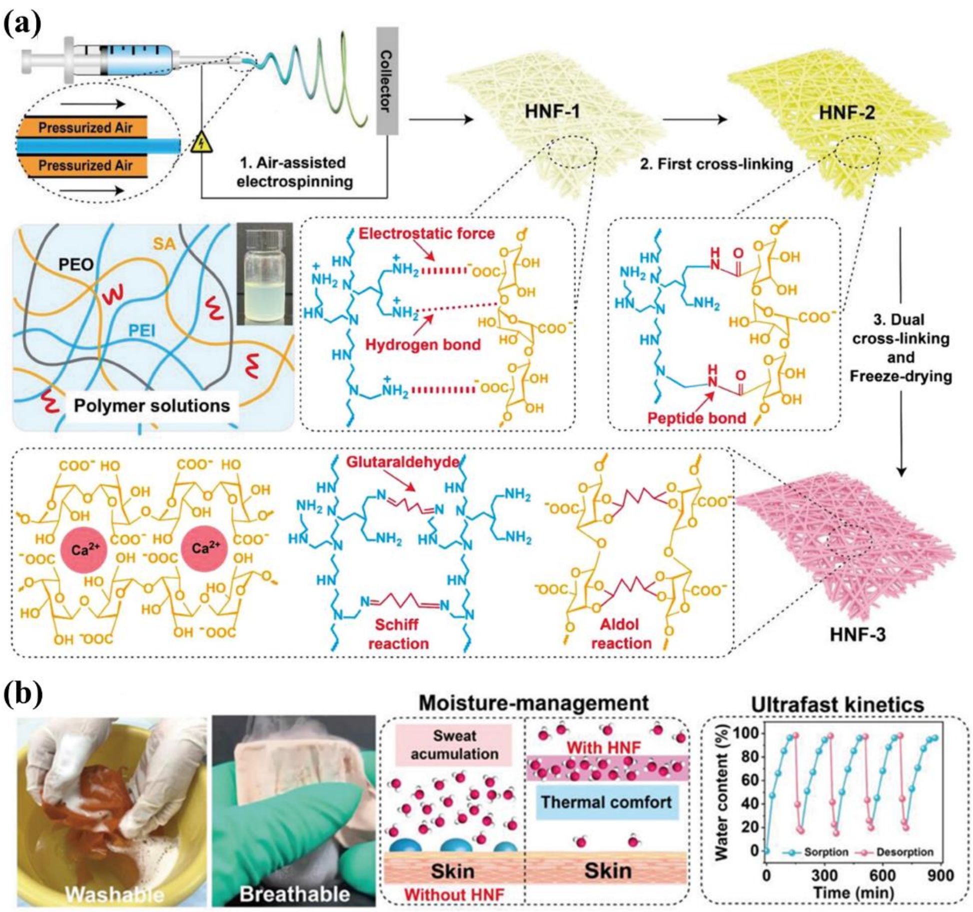

Figure 1. **(a)** Schematic illustration of air-assisted electrospinning of all-polymer hygroscopic fabrics. **(b)** Schematic illustration and digital photographs of all-polymer hygroscopic fabrics with breathability, durability, stretchability, and washability for rapid and reliable evaporation cooling and thermal management developed in the study [15]. Copyright 2023, Wiley-VCH.

Due to its stable nanofiber structure in high-humidity environments, the prepared fabric can achieve a much higher desorption rate than most other reported desiccants over a wide range of solar light intensity and temperature. Under real-world outdoor test conditions, the hygroscopic fabric was able to achieve five hygroscopic/desorption cycles a day. Moreover, the hygroscopic fabric can absorb water vapor in the air to reduce the relative humidity of the microenvironment between the skin and the fabric, thus reducing the skin surface temperature. The hygro-absorbent fabric with a size of

200 cm^2 can rapidly reduce the relative humidity (RH) of the airtight and transparent chamber (20 cm × 20 cm ×20 cm) from 92% to 51.5% in 30 min. The authors also performed a practical sweating experiment to understand heat stress management based on the fabric. As sweat evaporation took away heat, the palm temperature dropped from 34.5 ℃ to 32.6 ℃. The moisture-absorbent fabric also reduced the heat index from 71.0 ℃ to 37.2 ℃, which greatly improved the thermal comfort of the human body (**Figure 1(b)**). Furthermore, a piece of fabric can reduce the apparent temperature, relieve heat stress, and prevent sweat stains on clothing. Considering the excellent technical controllability and material preparation accuracy of the 3D printing technology, the authors used this technology to prepare a 3D hygroscopic aerogel matrix (HAM) by mixing hygroscopic materials of SA and PEI with nanocellulose to achieve cross-latitude applications of hygroscopic polymers from 1D nanofibers and 2D fabrics to 3D matrices. The HAM exhibited excellent moisture absorption and almost the same flexibility as commercial insoles. Humidity management of the plantar microenvironment can be achieved while ensuring comfort by integrating the HAM with the insole, preventing sweat accumulation and bacterial growth.

In summary, this study proposed two kinds of hygroscopic polymers and their multi-network crosslinking strategy to prepare 1D nanofibers and 2D porous fabrics with hygroscopic, durability, ductility, breathability, washability, and antibacterial properties by air-assisted electrospinning technology, which realized efficient atmospheric water adsorption, humidity management, evaporative cooling, and body-sensing temperature regulation. In addition, 3D printing technology was used to prepare hygroscopic 3D gels with multi-scale pore structures to obtain efficient hygroscopic properties with the least amount of hygroscopic material. This work highlighted the promising application prospect of active-adsorption all-polymer materials in atmospheric water collection and personal thermal management.

Conflict of interest: The authors declare no competing interests.

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