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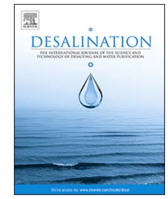

Mist harvesting using bioinspired polydopamine coating and microfabrication technology

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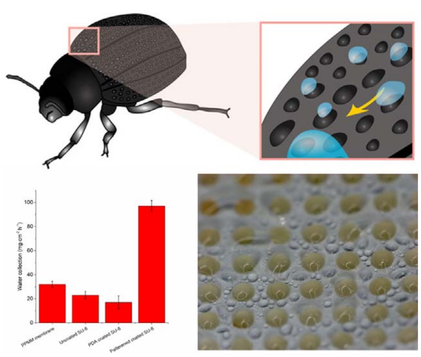
GRAPHICAL ABSTRACT



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ABSTRACT

The fascinating biopolymer of polydopamine (PDA) and negative photolithography method was utilized to produce porous membrane surfaces with contrast wettabilities via creating hydrophilic patterns (nanoscale PDA coated SU-8 bumps) on the hydrophobic background of polypropylene (PP) membranes. The high rate of water collection (97 mg cm^{-2} h^{-1}) highlighted the impact of hydrophilic patterns and wetting properties on mist-harvesting results. Modified samples exhibited droplet motion by coalescence rather than rolling which means created hydrophilic patterns also have a significant impact on the behavior of the droplets on these surfaces. Surface characterization including Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM) and contact angle as well as surface free energy measurement were performed to study the effect of topography and roughness on the system performance. This created structure has the great potential to be fabricated in large scale. Also, due to the porous nature of its hydrophobic background, water collection rate can be substantially increased by using vacuum pressure, makes it attractive for industry.

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1. Introduction

Clean water shortages affect approximately 900 million people in drought areas and desert regions worldwide. Although, water exists in the air, as water vapor form, it cannot be directly used for either drinking or agriculture; therefore, available fresh water is not equally distributed all around the world [1]. In fact, drinking water shortage has become one of a major growing and thorny global crises affecting all facets of human life, ecosystem, and industrial developments. Biodesalination has recently attracted researcher attention for fresh water production. Biodesalination is defined as “utilizing living organisms or biological elements directly or indirectly, mimicking their structures and mechanisms, and borrowing concepts or inspiration from their desalination mechanisms for the production of sustainable freshwater” [2]. Industrial multi-stage flash distillation and reverse osmosis are widely used as current commercially main water desalination methods. Both multi-stage flash distillation and reverse osmosis approaches have many side effects including a great deal of heating energy consumption and chemical cleaning of the membrane as well as significant capital cost. Unfortunately, hundreds of thousands of people are living in villages and remote areas in developing countries with no or very limited access to healthy fresh water across the world. Therefore, providing those poor areas with an affordable green sustained technology is a continuing quest [3–5].

Atmospheric water, especially ocean fog represents an invaluable untapped source of fresh water in inhabited deserts and arid regions [6]. Years of evolution in some species of desert plants and animals have offered ingenuousness ways of collecting water in nature [7]. For instance, Hipster herbs is an obscure herb with leaves covered by ultra-hydrophobic hairs that collect the water moisture and retain it over an extended period of time [8]. *Cotula fallax* is a South African plant with uncanny wetting properties that can collect moisture due to its super-hydrophobic and 3D hierarchical structure of leaves [9,10]. Green tree frogs, Nimb grass, and Australian desert lizards are other species that show outstanding and interesting fog harvesting ability [10–12]. For Namib beetles (family Tenebrionidae) millions of years of evolutions are the secret to success in harsh conditions of African deserts with annual rainfall less than 13 mm (0.5 in.) [7]. This beetle is able to absorb the environments' humidity thanks to their very special wetting properties of their body surface [13]. The beetle's backside surface consists of hydrophobic and hydrophilic regions that serve the purpose of droplet formation and absorption [14]. Namib beetles collect water through both smooth and grooves of their backside surfaces in which water droplets disposed on the upper wing [14,15]. Then, droplets gather size until they combine and are guided to the beetle's mouth. A unique three-dimensional surface in fog collection to stores small water droplets and prevents them from being lost or evaporating before they can be collected by the deserts species [7,16–18].

As shown in Fig. 1, the beetles of Namib Desert serves as a source of inspiration for a significant amount of future research which has been devoted to the development of fog harvesting devices to achieve a substantial water-collecting surface for fresh water collection in a novel and functional way [7,14–16,19–21]. Through the use of biomimicry, we have studied the beetles' skins to distill the principles and functions of their skins that have developed through recent decades and applied this knowledge to develop a novel and exciting measure to address water shortage crisis in the arid area [14].

Andrew R. Parker and Chris R. Lawrence [22] studied the Namib Desert beetles on a macroscopic scale. They observed that the elytra of the beetles are covered in a near-random array of bumps 0.5–1.5 mm apart, each about 0.5 mm in diameter. They also found at the microscopic level that bumps peaks are smooth and are not covered. But, the troughs, including their sloping sides, are covered by a microstructure coated in wax. They reported that the microstructure consists of flattened hemispheres, 10 μm in diameter and arranged in a regular hexagonal array, which creates a superhydrophobic system reminiscent of the lotus leaf.

Biomimetic water-collecting materials inspired by nature have been recently reviewed by Zhu et al. [23]. In their review, a great number of bioinspired materials with the water collection ability have been developed. In addition, they simultaneously detailed water collection mechanisms and their corresponding bioinspired materials of natural animals and plants such as cactus, spider, desert beetles butterfly, shorebirds, wheat awns, green bristlegrass, Cotula fallax plant, Namib grass, green tree frogs and Australian desert lizards. General attempt is to develop a porous surface consist of at least two portions with different wettability properties [24,25]. Superhydrophilic region is responsible for fog absorption and forming the droplets while superhydrophobic portion transport the water droplets [14,26]. Guo group introduced a water-harvesting device with water collection rate (WCR) of 1309.9 mg h^{-1} cm^{-2} by using TiO_2 and Cu as hydrophilic areas and hydrophobic areas, respectively [27]. The same group has also been able to demonstrate a WCR of 1316.9 mg h^{-1} cm^{-2} using a nanoneedle to create two superhydrophobic circular patterns on a copper $Cu(OH)_2$ super hydrophilic surface [28]. White et al. [29] tested other samples (e.g. PTFE, Al, Ti, and SS-CNT) to better understand of the wetting properties of materials as well as the effect of pattern structure on the desert beetles' capability of collecting water. They found that, although there were slight differences in the coalescence and motion of the drops on the differently patterned surfaces, no direct influence of the type of pattern on the sample was found on its water collection ability [29]. Although the Guo's group's approach can create a reasonable high WCR, their approach is costly and seems difficult for large-scale production.

Dopamine has many amine and catechol functional groups and received large attention due to its unique properties such as self-polymerization, anchoring capability, reactivity, reductive ability, powerful adhesive capability, carbonizable feature, and special recognition [30]. The surface properties of virtually any material can be easily altered by the tightly adhesive hydrophilic PDA coating. More importantly, the PDA layer comprises active secondary reaction functional entities which could form covalent bonds with species containing primary amine or thiol groups. In addition, various metals, metal oxides, and semiconductors nanoparticles can be readily grown on the PDA coating owing to its reductive ability. This virtually unlimited variety provided by PDA layer will provide an opportunity to design and produce highly

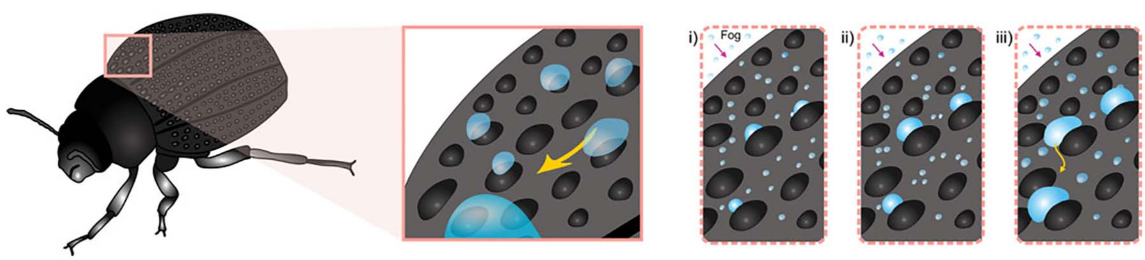

Fig. 1. Schematic of the fog-harvesting process in a desert beetle. Beetle' back side surface consists of a micro-sized bumpy super-hydrophilic structure that absorbs the fog and a hardened forewings which are superhydrophobic and helps collect and direct water droplets toward the beetle's awaiting mouth.