Breakthrough application of moisture-trapping film to reduce heat stress in personal protective suits

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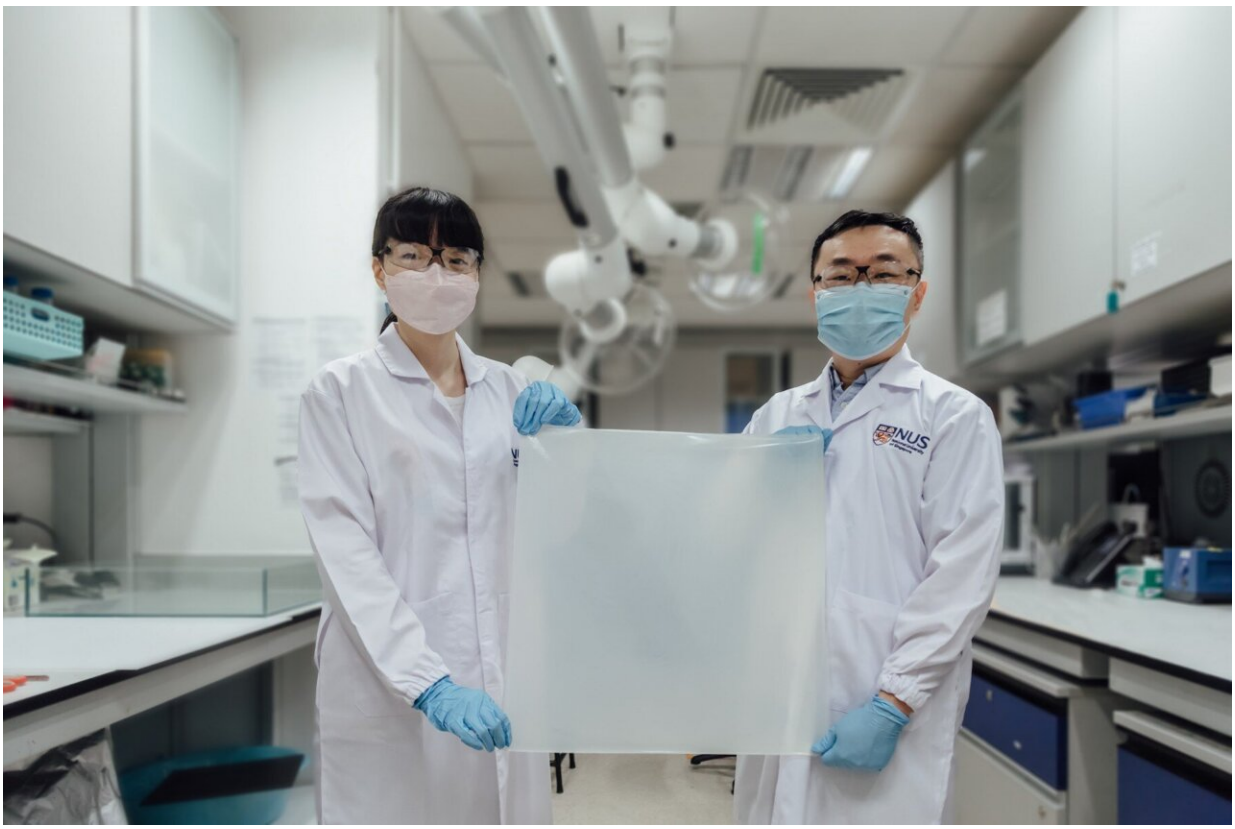

This novel moisture-trapping film has fast absorption rate, high absorption capacity and excellent mechanical properties. It is also affordable, light-weight, easy to fabricate, reusable, biocompatible and non-toxic. Credit: National University of Singapore

A team of researchers from the National University of Singapore (NUS) has developed a novel super-hygroscopic material that enhances sweat evaporation within a personal protective suit, to create a cooling effect for better thermal comfort for users such as healthcare workers and other frontline officers. This invention was validated through laboratory tests conducted in collaboration with researchers from HTX (Home Team Science & Technology Agency) in Singapore.

The new desiccant film, which is biocompatible and non-toxic, has fast absorption rate, high absorption capacity and excellent mechanical properties. This means that the material is very robust and durable for practical applications such as for protective suits worn by healthcare workers. It is also affordable, light-weight, easy to fabricate and reusable.

"Under room temperature of about 35º C, a healthcare worker who dons a protective suit for one hour typically experiences a heat index of about 64º C. This causes discomfort and prolong thermal strain can result in heat stroke and even death. Our novel composite moisture-trapping film achieves a cooling effect within the protective suit via evaporative cooling—by increasing sweat evaporation from the skin," explained research team leader Assistant Professor Tan Swee Ching, who is from the Department of Materials Science and Engineering under the NUS College of Design and Engineering.

Attaching a piece of novel composite film in a protective suit—for example at the back of the suit—could bring down the heat index by about 40%, remarkably lowering the likelihood of heat stroke.

The report was published in *Small* on 20 February 2022.

This research breakthrough demonstrates the positive outcome of leveraging the complementary strengths of NUS and HTX to create

tangible benefits for the Home Team and the wider community. By combining the NUS team's scientific knowledge of advanced hydrogel materials and HTX's deep understanding of the Home Team's needs and engineering capabilities, the joint research team was able to customize and optimize the novel moisture-trapping material for practical applications to enhance the performance and productivity of frontline officers.

Cooling down by increasing sweat evaporation

Medical protective suits have excellent anti-bacterial and water-proof properties. However, this high level of protection stops the venting of water vapor produced by evaporated sweat and impedes heat loss from the body. This is why users such as healthcare workers who need to don protective suits for long hours, especially in tropical environments, often report of occupational heat strain.

Thermal management solutions such as air-cooling garments with electrical fans or ingestion of ice slurry are impractical due to limitations such as bulkiness, heavy weight, and limited effectiveness. While advanced textiles and coatings are promising solutions, they are difficult to fabricate and production costs are high.

The NUS team came up with a practical strategy to overcome the current challenges by leveraging the principle of evaporative cooling. Their solution involves using a super-hygroscopic composite film to control the humidity level in the micro-environment in the protective suit. When the moisture-trapping composite film absorbs water vapor within the protective suit, the humidity level drops. This in turn speeds up sweat evaporation from the skin. As a result, more heat is dissipated from the human body through sweating, providing thermal comfort for users such as healthcare workers.

To examine the effectiveness of their solution, the NUS team conducted tests in collaboration with researchers from HTX, using a 20-zone "Newton" manikin within a climatic chamber. This is an important experimental milestone in assessing the feasibility of applying the composite film to the scale of full body clothing.

With the composite film, relative humidity (RH) under moderate sweating condition dropped by about 40%—from 91% to 48.2% after one hour of sweating and to 53.2% after two hours of sweating. The team also found that within the first hour of sweating, the heat index or "felt air temperature" dropped significantly from 64.6º C to 40º C at air temperature of 35º C. At this level, while users still feel hot, the likelihood of getting heat stroke, heat cramps and heat exhaustion is remarkably reduced.

"These experiments show that our moisture-trapping film effectively reduces the RH inside the protective suit, hence bringing the heat index down significantly and improving the thermal comfort for users," Asst. Prof. Tan explained.

In another laboratory experiment, the research team also showed that body temperature (or skin temperature) could be significantly reduced by 1.5º C through evaporative cooling. This further proves that the composite film can potentially help users—such as healthcare workers, soldiers or firefighters—relieve thermal stress, especially during strenuous activities.

Regeneration of the NUS team's composite film is also more energy efficient, as it requires a lower temperature to release the trapped moisture. At 50º C, the composite film releases 80% of its water contents after 10 minutes and this reaches 95% after 40 minutes. Most hygroscopic materials regenerate at a temperature of more than 100º C, over a duration of more than an hour.

"From the findings of various studies in this project, we are hopeful that the moisture-trapping film can be embedded to Personal Protective Equipment (PPE) and/or Personal Protective Clothing (PPC) of the Home Team officers, to enhance thermal comfort and improve performance of the frontline officers," said Ying Meng Fai, Director, Human Factors & Simulation Centre of Expertise, at HTX.

Encouraged by the results of their latest study, the NUS team is now working to improve their hygroscopic material so that it can absorb more and faster. The team is also planning to apply their cooling strategy to other types of protective apparel such as those for firefighters.

In addition, Asst. Prof. Tan and his team are looking for opportunities to commercialize this technology.

More information: Jiachen Yang et al, Reversible Hydration Composite Films for Evaporative Perspiration Control and Heat Stress Management, *Small* (2022). DOI: 10.1002/smll.202107636

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