Researchers draw inspiration from pig snouts to design novel air filter technologies

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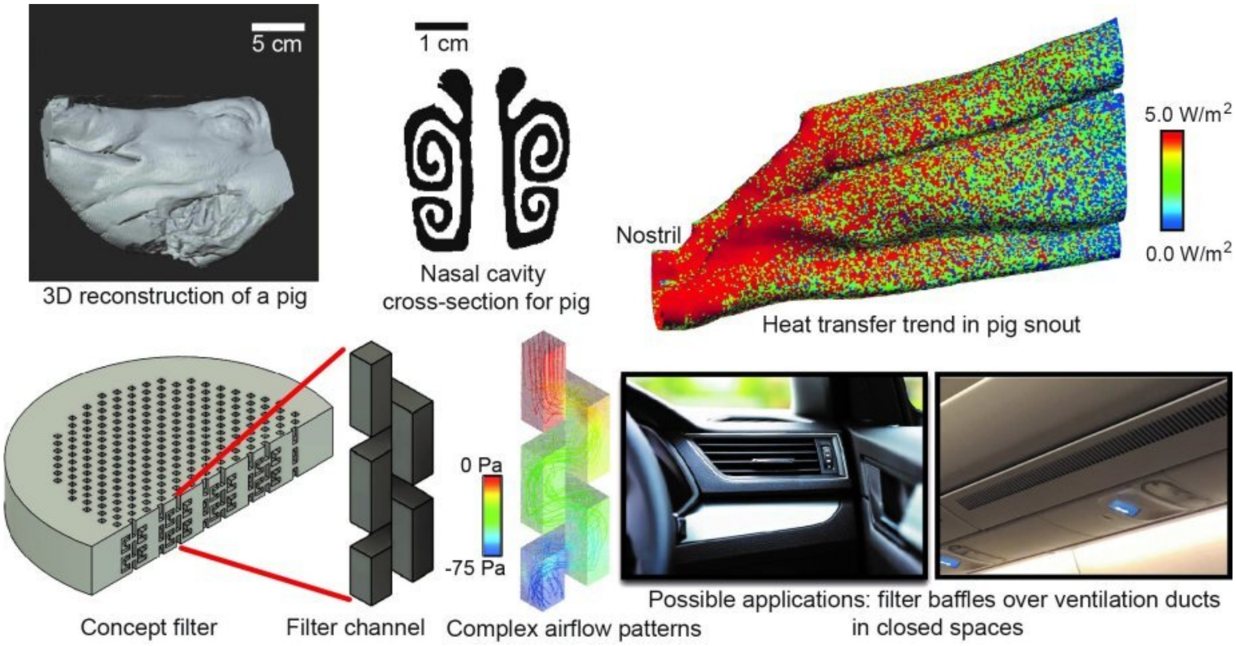

Concept filter deriving its inspiration from the complex morphology of a pig's nose. Credit: South Dakota State University

Since the beginning of human creative activity, nature has served as a source of inspiration. That continues to be true for Saikat Basu, an assistant professor in South Dakota State University's Department of Mechanical Engineering, who took inspiration from a pig's snout to investigate ways to improve air filtration.

"Researchers have not yet tried to design engineering filtration and thermal conditioning devices based on expressions, more specifically the particle capturing trends from the inhaled air and the heat transfer phenomena from the nasal tissues to the air, that are seen in this kind of animal's nose," Basu explained. "This was a novel idea."

Pigs (Sus domesticus) were among the earliest animals to become domesticated. Archeological evidence suggests that pigs were domesticated in China, from wild boar, 8,000 years ago, and more than 11,400 years ago in the region that is now Egypt. Since then, the animal—particularly the pig's snout—has evolved to adapt to a variety of climates.

The nose (snout for pigs) plays a highly important role in both humans and animals. The nose is a key component in any organisms' environmental interactions. When air is inhaled, the nose warms the air through the nasal cavity and air passages to protect key internal organs. This is true for both humans and pigs. Further, the nasal cavity acts as the first line of defense against airborne pathogens, disease, bacteria and other external particles. The winding nasal passages and the resulting complex airflow patterns help capture particles and filtering air.

Because pigs tend to eat from areas where there is a lot of dust, the snout must be particularly adept at filtering out harmful particles. Pigs have also had to adapt to a variety of climates, creating morphologically complex nasal structures. For pigs living in South Dakota, the snout has become highly efficient in heating up cold, inhaled air.

"Even as human beings, we need to warm up the air before we can breathe it into our lungs," Basu said. "Animals living in colder climates are much more efficient in warming air due to their airways."

If you compare the pig's snout to the human nose—particularly the crosssections near the sinus cavities—the pig's is much more prominent and tortuous.

"This was one of the reasons why we wanted to look at this animal," Basu said. "We wanted to see if the complex morphology of the area is helping in some way or if they are influencing the fluid mechanics. We also wanted to see if that can be correlated back to No. 1, air particle filtration, and No. 2, heat transfer."

The research was published recently in *Integrative and Comparative Biology*.

Air filters

In recent years, improving air filtration has been a point of focus for researchers. Due to the COVID-19 pandemic, understanding how filtration can better capture harmful particles has seen an increased level of research emphasis. In previous research related to this project, Basu investigated ways to improve filtration inside masks.

"Previously, we were working to design filters in a mask that would be as complex as airways in animals," Basu added.

For this project, Basu collaborated with a faculty member at Cornell University—Sunghwan Jung—as well as a faculty member from the University of Illinois at Urbana-Champaign– Leonardo Chamorro. Previously, the team had collaborated on the NSF-supported project that designed filters inspired by animal noses, including pigs, possums and dogs. This project was an offshoot of their previous work.

In terms of air filters, high-efficiency particulate air (HEPA) filters are currently the gold standard. According to the United State Environmental Protection Agency, these filters theoretically remove at least 99.97% of dust, pollen, mold, bacteria and any airborne particles with a size of .3 microns. The challenge with HEPA filters, according to Basu, is that they are not as energy efficient as they could be. Thus, there is a need to design an air filter that is both competent at removing harmful particles and be energy efficient.

Collaborative research

The researchers at Cornell conducted CT scans on pigs and characterized the geometry of their noses, which provided Basu and his research team with the blueprint to design filter models that could simulate the airflow and the heat transfer simulations. The team at UIUC performed follow-up experimental validations of Basu's numerical modeling research.

One of the key findings from the simulations were the differences in heat transfer between the areas in the anatomic structures. When air enters the nose, there is a high heat transfer, but that trails off as the air moves through the nasal passages.

"As the air travels further into the nasal cavity, the heat transfer goes down," Basu said. "Implying that the air is sort of attaining the temperature of the surrounding warmer tissues."

Basu found that the model based off the pig's nose provided a good amount of heat transfer—a crucial element to an air-conditioning filter—and was able to capture almost all particles beyond 10 microns. However, as the particles got smaller (under 10 microns), the efficiency of capturing the particles decreased, Basu explained.

"The downside is that if we look at particle sizes, two microns, four microns, even maybe five and six microns, the efficiency is quite low in terms of how many of those particles will be filtered," Basu said. "If you look at HEPA filters, those particles are going to be trapped as well, but if you look at our bio-inspired model design, they are not going to be."

This is an area where a key question—in terms of air particle research—remains. Do microns, under 10, need to be trapped by air filters in order to stay safe from viral infections, for example?

According to Basu's and other's previous research, smaller microns—under five microns—are not dominant in terms of how much viral load they can carry. If further research on harmful air particles concurs that "smaller" microns (under 10 microns) are not harmful in terms of their viral load that can trigger respiratory infections in an exposed human subject, then Basu's design, which captures particles that are size 10 microns and larger, could operate at a lower energy consumption rate than HEPA filters, while still providing the same level of safety.

"We are basically optimizing between what particles we want to capture," Basu said. "The designs are being inspired by nature, and from our initial research, we see that those designs are going to be energy efficient while sucking in air and separating the air from those harmful particles."

As Basu notes, there is a significant gap between his team's research and air filter industry production, but it is exciting to see that the science for this development is there.

More information: Jisoo Yuk et al, Morphology of pig nasal structure and modulation of airflow and basic thermal conditioning, *Integrative and Comparative Biology* (2023). DOI: 10.1093/icb/icad005

Provided by South Dakota State University

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