Study provides new insights into N95's COVID-19 filter efficiency

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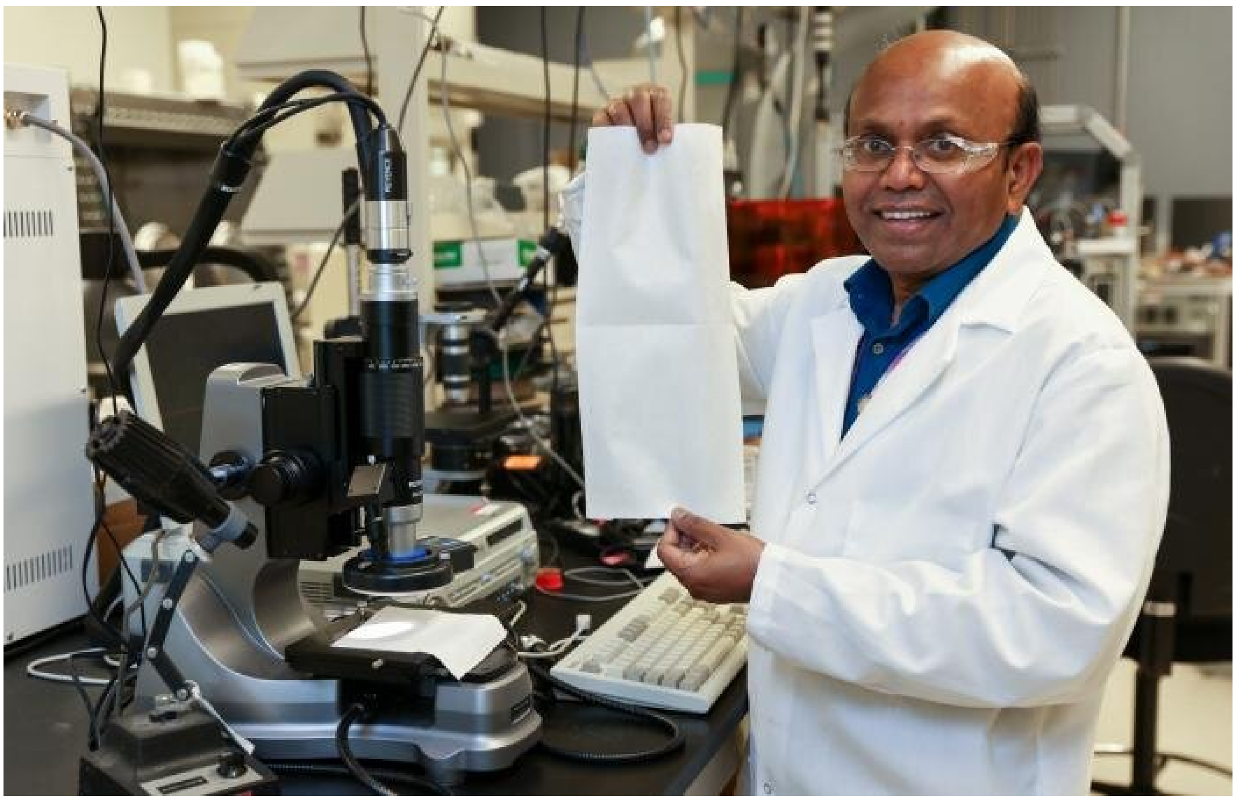

Parans Paranthaman, a researcher in the Chemical Sciences Division at ORNL, coordinated research efforts to study the filter efficiency of the N95 material. His published results represent one of the first studies on polypropylene as it relates to COVID-19. Credit: ORNL/U.S. Dept. of Energy

When COVID-19 was declared a pandemic in March 2020, Oak Ridge

National Laboratory's Parans Paranthaman suddenly found himself working from home like millions of others.

A Corporate Fellow in the lab's Chemical Sciences Division, he quickly realized his background in solid state chemistry and materials could benefit the healthcare community in need of equipment capable of filtering out COVID-19's nanometer-size particles.

"Merlin Theodore, who leads research efforts at the Carbon Fiber Technology Facility, called me and said, "I need to understand which material will perform best on our production line to make N95 mask filter media, and I need to know this yesterday,'" Paranthaman recalled. "And she asked if we could use neutrons and nanoscience facilities to prove it."

Theodore is part of a team led by ORNL Corporate Fellow Lonnie Love, who was coordinating a COVID-19 manufacturing research response as part of the Department of Energy's National Virtual Biotechnology Laboratory. The team also consulted Peter Tsai, a retired University of Tennessee professor who invented the electrostatic charging process for creating N95 filter media, to learn how to incorporate the capability at the CFTF.

"We had never attempted something like this before in this type of timeframe," Paranthaman said. "We were ramping up research that should have taken a year or more into a period of a few weeks with industry use by summer."

"But there's no challenge I haven't met yet. The purpose of my research is to find solutions."

Polypropylene focus

Paranthaman's research results on the N95 filter media, recently published in *ACS Applied Polymer Materials*, outline the science behind what led to ORNL's successful production of material on the CFTF's precursor production line. The technology was later transitioned under user agreements to two industry partners—Cummins and DemeTECH—for commercial use, leading to the supply of millions of masks throughout the U.S., as well as adding thousands of jobs.

As one of the first studies on polypropylene, also known as PP, in regard to COVID-19, Paranthaman's paper serves as a guide to understanding how a novel virus responds to polymer-based materials. PP has long been the industry standard material for filtration but understanding which commercial compounds or precursors of the material are best suited for mass production usually requires time-consuming trial and error.

"We had a unique situation with COVID-19. First, it's a novel virus with not much known about it. Second, it's small, ranging from 60 to 140 nanometers, which means the particles are capable of penetrating the tiniest of openings. And third, we had no time for mistakes," Paranthaman explained. "We had to have a material that could filter out more than 95 percent of these submicron particles. It had to be virtually impermeable, but at the same time, it has to be breathable."

The N95 mask is made of two-ply PP, a nonwoven material permanently electrostatically charged with millions of microfibers layered on top of each other to form a sheet. Theodore's team at the CFTF used melt-blowing, which makes microfibers into a fabric by extruding a polymer resin through a die at a high air velocity, to produce three samples of commercial-grade PP for Paranthaman to evaluate.

The N95 filter material — made of polypropylene — was produced on the melt-spinning precursor line at DOE's Carbon Fiber Technology Facility at ORNL. Paranthaman used neutrons and microscopy and analyzed three different blends of the material to determine the characteristics necessary for enhancing filter efficiency. Credit: ORNL/U.S. Dept. of Energy

"We used several characterization methods at ORNL to better understand the filter efficiency of PP and called upon the strengths of user facilities like the Center for Nanophase Materials Sciences and the Spallation Neutron Source," Paranthaman said.

Characterization methods included differential scanning calorimetry to measure the amount of energy transferred between the melt-blown fibers; X-ray diffraction to understand the crystal orientation or texture of the fibers; and neutron scattering to study the molecular vibration. Scanning electron microscopy was used to understand the arrangement of the melt-blown fibers and their microstructure and to characterize their diameters.

"It's important to understand how much of the particles the filter stops," Paranthaman said.

The team used sodium chloride aerosol particles mimicking the size of COVID-19 to penetrate the filter, then measured the particles as they encountered the PP. Two layers of the melt-blown fiber were stacked together for testing at an airflow rate of 50 liters per minute.

Crystal clear results

Paranthaman's research revealed that while the feedstock materials were almost identical in composition, they performed very differently when charged. The most notable difference was in crystallization, or how the material solidifies atoms and molecules into a structured form.

"We compared charged and noncharged PP material with an additive and without," Paranthaman explained. "Crystallization had a clear impact on the material's ability to filter in each example; a larger number of crystallites form a stronger electric charge, leading to more effective filtration."

Research results further determined that material that has higher crystallization onset temperatures, slower crystallization and a larger number of smaller, microscopic crystallites is more effective at filtration. Paranthaman's study of the PP samples showed which material was likely to meet the filtration target in fabric weight, efficiency, resistance, fiber diameter size and percent of electrostatic charging.

By the end of April, the CFTF was producing material that filtered 99% of the virus. By May, the technology was transferred to industry.

The research team won ORNL's Director's Award for Mission Support for the rapid development of the N95 filter media and technology transfer. But, Paranthaman said, the scientific work on N95 filter media is just beginning.

"This paper provided a three-dimensional look at the materials so we could see all the changes in charged fiber versus noncharged," Paranthaman said. "We knew the charging reduces the fiber diameter, for example, but it also changes the porosity, and that's critical to the material's performance. Our follow-up paper will clearly outline the differences between charged and noncharged and give even greater insight into N95 filter media."

The title of the *ACS Applied Polymer Materials* article is "Polymers, Additives, and Processing Effects on N95 Filter Performance."

More information: Gregory S. Larsen et al. Polymer, Additives, and Processing Effects on N95 Filter Performance, *ACS Applied Polymer Materials* (2021). DOI: 10.1021/acsapm.0c01294

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