Fibrous Membranes in Personal Protective Applications

by

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Abstract

Personal protective equipment (PPE) is a collection of devices and garments that protect the wearer from hazards and threats. An important type of PPE is respiratory protection devices that reduce the exposure of the respiratory system to aerosols, which may contain harmful components that can cause infection or other health problems. Mechanical protective clothing is another type of PPE that protects against bruises, cuts, and injuries from sharp objects or even ballistic impacts. Fibrous materials of different forms have found their uses in both respiratory protection and protective clothing. For example, when used as filters in respirators and face masks, fibrous membranes can act as excellent barriers to aerosols without resulting in unreasonably high air resistance. The application of strong and tough fibrous textiles in protective clothing has continued to grow since the 1970s, replacing traditional metal and ceramic plates in many use cases because of the flexibility and the improved comfort of wearing of the textiles.

This thesis focuses on the applications of fibrous materials, particularly electrospun ultrafine fiber (UFF) membranes, in aerosol filters and protective clothing. The electrospun UFF membranes are first studied for their ability to alter the chemical composition of aerosols to explore the possibility of reducing human exposure to harmful aerosol constituents by selective filtration. Filtration using the UFF membranes is shown to change both the size distribution and the chemical composition of a binary liquid aerosol. The size selectivity and the chemical selectivity are correlated by the composition-size relationship of the aerosol and can be tuned by adjusting membrane morphology and configuration. Then, an extensive investigation is conducted on the filtration performance and mechanism of the melt-blown filters in medical respirators, as well as those of alternative fibrous materials for face mask filters, including electrospun UFF membranes. This study demonstrates that the level of electrostatic charges play an important role in the effectiveness of the melt-blown filters. Variation in the level of the electrostatic charges results in inconsistent filtration efficiency across respirators. Electrospun membranes, on the other hand, appear to be a promising alternative to the melt-blown filters due to their stability and potential reusability. Finally, to improve fluid retention in a potential material for protective clothing consisting of shear-thickening fluid (STF)-impregnated fabrics, electrospun UFF membranes are used as the fabric phase and impregnated with STFs to form a composite. The UFF-STF composites are shape-stable and have excellent STF retention capability due to the high capillary forces provided by the electrospun membrane. The addition of STF is shown to improve the mechanical responses of the membranes under impact by hindering fiber movements and increasing inter-fiber friction.

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