Plasma textile materials for nanoparticle filtration

S. Rasipuram[1], W. Jasper[2], A.V. Kuznetsov[3], J.F. Levine[4], A.V. Saveliev[3]

[1]*Department of Mechanical Engineering, University of Louisville, Louisville, USA*
[2]*Department of Fiber and Polymer Science, North Carolina State University, Raleigh, USA*
[3]*Department of Mechanical and Aerospace Engineering, North Carolina State University, Raleigh, USA*
[4]*Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, USA*

Abstract: Plasma textile materials with integrated system of thin corona electrodes are developed and tested for nanoparticle filtration. The filtration efficiencies of plasma textiles based on woven and non-woven fabrics are evaluated at various discharge voltages. The results suggest that initiation of the corona discharge on a textile surface greatly enhances the filtration efficiency of the material. The filtration efficiencies higher than 99.99% and 99.999% were recorded for woven and non-woven textiles, respectively.

Keywords: filtration, nanoparticles, corona, plasma textile.

1. Introduction

Inexpensive, flexible, and efficient filtering materials are required to filter air streams contaminated by toxic nanomaterials and other hazardous dust particulates, such as nuclear dust and bacteriological agents. This study focuses on development and characterization of microplasma generating structures embedded in a textile fabric. These materials, known as plasma textiles [1,2], are capable to generate plasma sheaths for high efficiency filtering of aerosol particulates coming in contact with the fabric.

Two types of cold plasma discharges could be used for development of a plasma textile: a dielectric barrier discharge and a corona discharge [2]. A dielectric discharge is formed between two metal electrodes separated by a dielectric material. It is sustained by an alternating current flowing through a discharge gap. A corona discharge is sustained by ionization at high electric fields formed near high curvature electrodes. Corona discharges are widely used in electrostatic filtering systems for charging and capturing aerosol particles as they pass through.

Woven and non-woven fabrics could be used to support a system of metal wires embedded in a flexible plasma material. Small diameter metal wires can be introduced as threads in a woven fabric allowing precise separation and support of corona electrodes. Non-woven fabrics are felt-like structures formed by entangled fibers and filaments bonded together with chemical and mechanical methods. A system of electrodes can be placed on the surface of a non-woven material. Alternatively, a non-woven material can be formed around corona wires completely encapsulating them in the fiber web.

2. Experimental approach

Plasma textile samples composed of various non-conductive polymers and conductive wires were developed. Fabrics containing multi-filament wires showed the fraying of the filaments during fabrication causing electrical shorting in the system. As such, the tested textile samples incorporated mono-filament wires with a diameter of ~ 0.1 mm and a separation of ~ 12 mm. The pulsed and DC corona discharges were activated on the sample surfaces (Fig. 1).

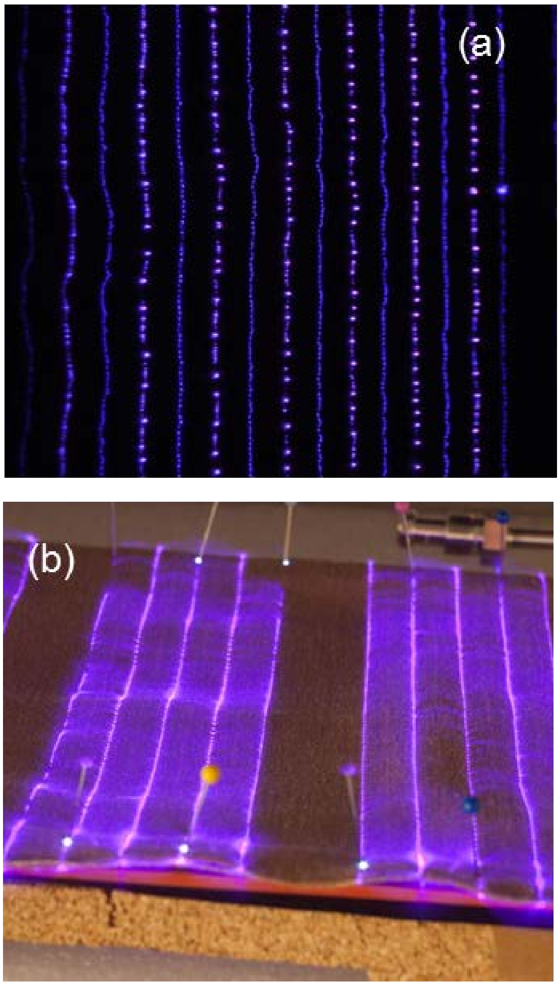

Fig. 1. Woven plasma textile: (a) DC activation, (b) nanosecond pulsed activation.

In order to quantify the filtration capabilities of corona textile, a system was built to generate, classify and count particles. The sodium chloride nanoparticles with sizes from 5 to 400 nm were generated by a constant output atomizer (Model 3076, TSI Inc.) After drying and pressure normalization, the particle seeded air stream was directed through the plasma filtration system, and flowed into the electrostatic classifier (Model 3080, TSI Inc.). The condensation particle counter (Model 3785, TSI Inc.) provided raw counts of nanoparticles in a given size range. The details of the experimental system are provided elsewhere [2].

3. Results and Discussion

Experimental studies were performed to measure the filtration efficiency of plasma textiles based on woven and non-woven fabrics. Three different configurations were studied: free corona discharge, woven plasma textile, non-woven plasma textile. Filtration efficiencies were measured for each of these configurations.

A free space corona configuration with the same spacing of the discharge electrodes was evaluated as a baseline (Fig. 2).

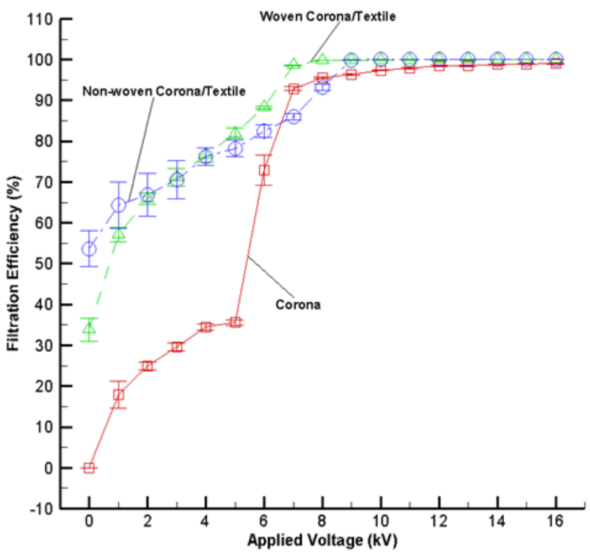

Fig. 2. Filtration efficiency for a free corona, woven corona textile and non-woven corona textile.

The corona discharge without fabric was initiated at ~ 6 kV. The corona ignition resulted in a sharp increase in particle capture. The initial increase of particle capture in the interval from 0 to 6 kV was attributed to a dielectrophoretic force acting on the particles in a non-uniform electric field. The filtration efficiency was further increased from 95% to 98% with increase of the discharge voltage from 7 kV to 16 kV. The corona discharge on the surface of the woven textile was initiated at ~ 9kV resulting in a rapid increase of the filtration efficiency above 99.99%. The non-woven corona textile was ignited at approximately the same voltage. The combination of the non-woven fabric and the corona resulted in even higher filtration efficiencies (above 99.999%) at lower power densities and voltages.

Woven fabrics usually have dense yarns and opens gaps in between. This reduces the overall filtration efficiency. Non-woven fabrics with a high uniform fiber density have better filtration characteristics. In non-activated textiles, the main mechanisms of particle capture include diffusion, intersection and inertial impaction. The plasma activation of the fabric adds additional electrostatic mechanisms of particle capture. The corona discharge results in charging of the incoming particle stream, and also in charging and polarization of textile fibers. The charging efficiency of nanoparticles is increased with the ion density and corona current. The free surfaces of textile fibers are also exposed to charged species and can be charged to the same polarity as nanoparticles. However, textile fibers located inside the fabric probably remain uncharged. The mechanisms of charging and electrostatic capture require additional experimental and numerical studies.

The results show that filtration efficiency increase with the surface power density. The surface power densities recorded for DC coronas in woven and non-woven textiles are close 1 mW/cm^2. The surface power densities are increased to 100 mW/cm^2 in pulse activated corona textiles. These power levels could be used for deactivation and decontamination of plasma-based textile filters.

Plasma textile materials rely on the unique antimicrobial and catalytic properties of cold non-thermal plasmas for inactivation and decomposition of toxic and biologically active particulates. Airborne pathogens and toxic compounds captured on the plasma textile fibers have a long time exposure to active plasma species.

4. Conclusions

Plasma textile materials with integrated system of thin wire electrodes have been developed and tested for filtration of nanoparticles with diameters from 10 nm to 300 nm. The filtration efficiencies of plasma textiles based on woven and non-woven fabrics are evaluated. A free corona discharge with the same electrode geometry is used as a baseline. The results suggest that initiation of the corona discharge on a textile surface greatly enhances the filtration efficiency of the material. The filtration efficiencies higher than 99.99% and 99.999% are recorded for woven and non-woven textiles, respectively. This forms a basis for creation of low cost flexible air filters with on-demand activation, tunable efficiency, and active self-decontamination features.

5. References

[1] I.A. Kuznetsov, A.V. Saveliev, S. Rasipuram, A.V. Kuznetsov, A. Brown, W. Jasper, AIP Conference Proceedings, **1453**, 265 (2012).

[2] S.C. Rasipuram, M. Wu, I.A. Kuznetsov, A.V. Kuznetsov, J.F. Levine, W.J. Jasper, Journal of Physics D: Applied Physics, **47**, 025201 (2014).