Case Studies of Air Filtration at Microscales: Micro- and Nanofiber Media

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ABSTRACT
In this work, 3-D fibrous geometries are developed to resemble the microstructure of spun-bonded and electrospun filters media and used here to simulate their filtration efficiency and pressure drop. For the sake of simplicity, a continuum flow theory was considered to prevail for the case of spun-bonded media (microfiber media) whereas our electrospun media (nanofiber media) were assumed to be in a free molecular flow regime.

Our simulations results are in good general agreement with the experimental data. Especially, in predicting media's pressure drop, our results show better predictions when compared to some of the existing models. We also quantitatively demonstrated that by decreasing the fiber diameter, the minimum collection efficiency of the media having identical pressure drops increases. This effect is accompanied by a decrease in the particle diameter associated with these minimum efficiencies – the most penetrating particle diameter. Studying the influence of the gas temperature, we showed that filter's efficiency increases as the gas temperature increases. Conversely, the filter's pressure drop decreases by increasing the gas temperature.

INTRODUCTION
Filtration science dates back to the work of Happel [1] and Kuwabara [2]. Their works were later on continued by Stechkina and Fuchs [3], Lee and Liu [4], Henry and Ariman [5], Rao and Faghri [6], and Brown [7] among many others. In most of the previous studies the filter geometry has been simplified to rows of regularly arranged fibers, often in 2-D geometries, perpendicular to the flow direction [1-8]. To this end, our group has been the first to model aerosol filtration in 3-D geometries [9-10]. The work has generally been focused on simulating collection efficiency and pressure drop of virtual filters made up of micro- or nanofibers and comparing the results with both phenomenological and analytical models. The present paper outlines our previous studies [9-11] and discusses them in a condensed form.

<u>Modeling Filters' Microstructure</u>
Most of nonwovens used in filtration industries can be assumed to be 3-D layered structures. Such structures consist of a large number of fibers randomly distributed in a horizontal plane and sequentially deposited on top of each others to build up a 3-D geometry. In order to simulate a layered fiberweb (an un-bonded assembly of fibers), we considered the fibers to be circular cylinders with a given diameter. For simplicity, we assumed that fibers lie horizontally in the plane of web and do not bend at crossovers.

To generate a 3-D web, first a new fiber is generated at an altitude greater than the current thickness of the web. If there are no fibers underneath the new one, it is directly positioned on the plane $z = 0$. The next step is to lower the new fiber on the web or, in other words, to find the smallest vertical translation which will bring the new fiber in contact with the web as shown in *Figure 1*.

By repeating the above procedure for every new fiber one can produce a 3-D fibrous structure as shown in *Figure 2*. For more detailed information on this procedure, readers are referred to our previous publications [9-11]. Note that the above algorithm does not include any additional compaction, such as the one imposed by compaction rolls, for instance. Interested readers are referred to [12-13] for our work on modeling fibrous materials under compaction.