Recent scientific interest in nanofibers have many people exploring their use in filter media. One of the advantages of nanofibers for gas phase depth filtration is the slip-flow phenomena. The purpose of this article is to describe what is meant by the slip-flow phenomena and how it applies to filtration.

Suppose you have a hypothetical camera that can take an instant snapshot of the distribution of molecules in air. What you might see is something like that shown in Figure 1, where the molecules are more or less randomly distributed in the photograph. Also in the photograph is a 50 nm nanofiber and the edge of a 50 micron fiber.

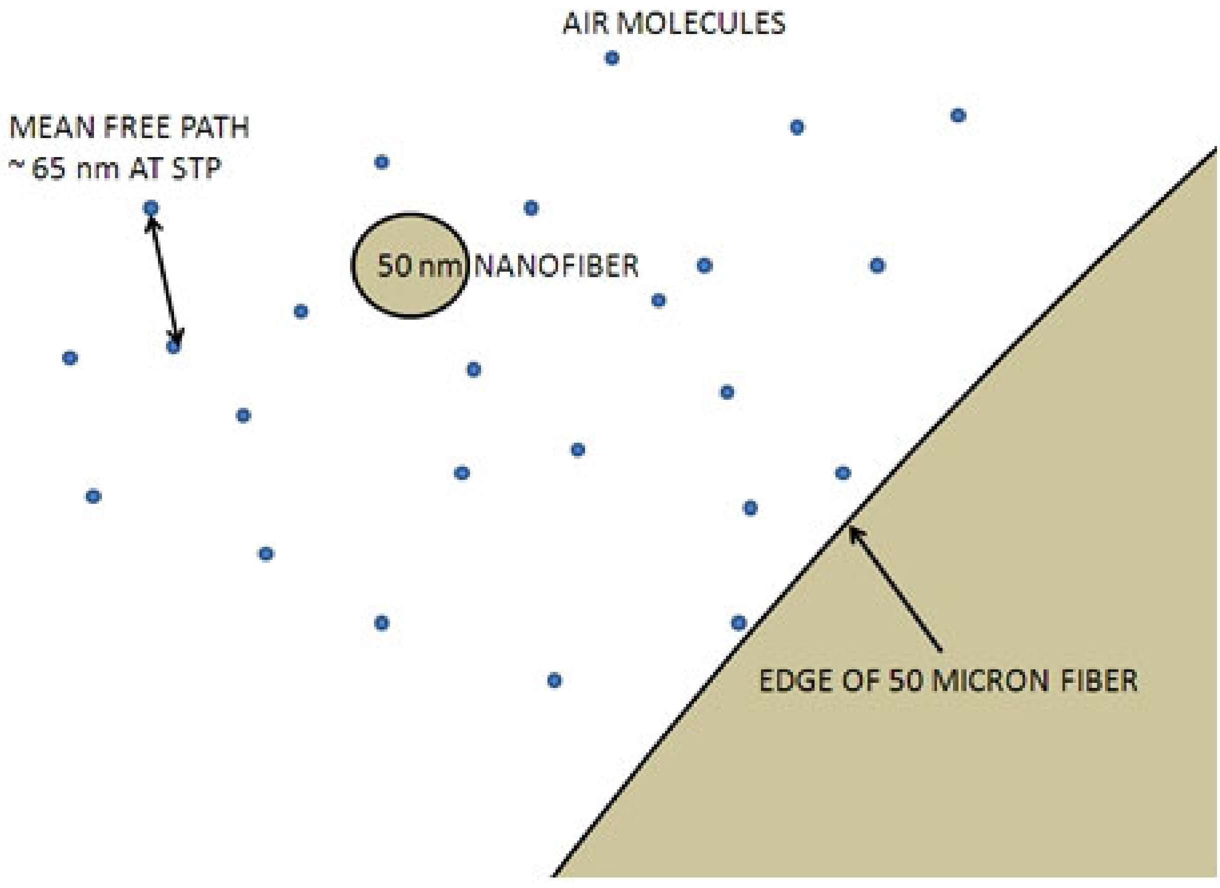

Figure 1. Hypothetical photograph snap-shot of air molecules near a 50 nm nanofiber and a 50 micron diameter fiber.

As the air flows past the 50 micron fiber, the molecules collide with the fiber and stick to the surface long enough for the air molecules to acquire the velocity of the micro fiber plus a random motion associated with their thermal energy. If the microfiber is stationary, then the air molecules at the surface of the fiber have only the random motion due to temperature.

The motion of a continuum is the average velocity of all of the molecules in a small volume element with the average velocity assigned to the centroid of the volume element. Near the surface of the microfiber, because the air molecule velocities are random, by definition the sum of the velocity vectors of the molecules must be zero.

In contrast, the nanofiber is so small that when the air passes it, only a fraction of the air molecules actually contact the nanofiber. As a result, only this fraction of the molecules have their velocities modified to the random motion due to their thermal energy. The remaining air molecules that do not collide with the nanofiber surface retain their bulk flow motion (plus the random motion due to temperature). In this case, the continuum velocity near the nanofiber surface is not zero. The movement of the molecules past the nanofiber without colliding with the nanofiber is referred to as “slip flow.”

This slip flow phenomena affects filtration in two important ways. First, because fewer molecules exchange momentum with the fiber, there is less air drag on the fiber. This means that for flow through a filter medium of nanofibers and a medium of microfibers of equal fiber lengths, the pressure drop the pressure drop through the nanofiber medium will be less.

However, a comparison of media of equal masses of nano and microfibers may result in greater pressure drop for the nanofiber medium. In practice, the nanofibers are not applied alone. The nanofibers may be applied by augmenting microfiber media by mixing the nanofibers with microfibers or by adding a layer of nanofibers to the surface of the microfiber medium. On a surface area basis, when nanofibers are mixed with the microfibers, the surface area increases faster than the pressure drop increases and so for media of equal fiber surface areas the media augmented with the nanofibers will generally have less pressure drop. Media with a surface layer of nanofibers may have a higher pressure drop if the nanofiber layer acts like a membrane with small holes that restrict the gas flow.

The second way that slip-flow is important is it improves the single fiber capture efficiency of small particles on the nanofibers. Because of the slip-flow phenomena, the gas flow streamlines pass much closer to the surface of the nanofiber than the microfiber. This means that direct interception of small particles in the gas stream improves because more of these particles pass close enough to collide with the nanofiber than with the microfiber.

More information on slip-flow and its effect on filter performance may be obtained in literature such as RC Brown, Air Filtration, Pergamon Press, Oxford, 1993.

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