MERV Filter Models for Aerobiological Applications

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Recent concerns about bioterrorism and existing concerns about indoor air quality have raised interest in technologies that can remove indoor biological contaminants. Chief among these air cleaning technologies is filtration, and the ability of filters to remove microorganisms can be better understood thanks to the new standard for testing air filters, ASHRAE 52.2-1999. This ASHRAE standard provides a methodology for testing filter performance that includes measuring filter performance in the 0.3-10.0 micron size range and assigning a MERV rating to these filters. This size range includes all spores and most bacteria but it is necessary to know how well these filters will remove airborne microorganisms smaller than 0.3 microns, which includes all viruses and the smaller bacteria. Either additional test results or mathematical modeling can be used to determine or estimate the removal rates of microorganisms below the test range of MERV filters. In this article a modified classical model of filtration is described and used to generate filter performance curves that can be fit to MERV data in the 0.3-10.0 micron size range and that can be extended down to the size range of viruses. Coupled with the summary of logmean diameters of airborne microorganism included here, these models will enable estimation of filtration rates for viruses and bacteria, including those that might be used as bioterrorist weapons.

The Classical Filter Model

The following equation defines overall filter efficiency (E) for any particle size and set of conditions.

$$E = 1 - e^{-(E_D + fE_R)S} \qquad (1)$$

where S = fiber projected area, dimensionless
E_D = single fiber diffusion efficiency, fractional
E_R = single fiber interception efficiency, fractional
f = fiber correction factor (typically = 0.615)

The computation of the component parameters in equation (1) is mathematically intensive, but has been addressed in detail in the references and is not re-addressed here (Kowalski et al 1999). The fiber correction factor represents an adjustment to theoretical filter models to account for filter inhomogeneity, but can also be used to fit the filter model to specific manufacturer's filters. The two components, diffusion and interception, combine to produce the theoretical performance curve as shown in Figure 1.

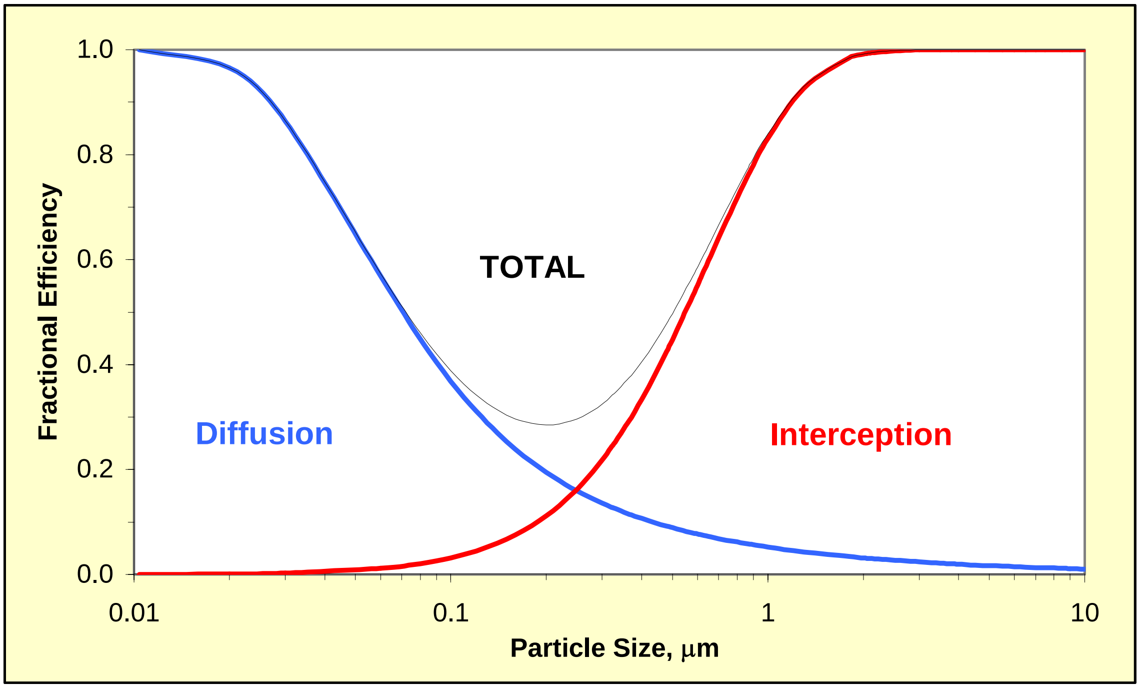

Figure 1: Generalized performance curve for a MERV 15 filter showing components.

Two problems are evident with this theoretical filter model when compared with actual data on filter performance. First, the diffusion efficiency approaches 100% efficiency near 0.01 microns and will actually reach 100% efficiency for smaller particles. Not only is it unlikely that particles smaller than 0.01 microns will be completely removed, but published data demonstrates that removal rates for submicron sized particles never reach 100%, even for HEPA filters (Ensor 1988).

The second problem is that many filters, especially in the MERV 6-10 range, often never reach 100% removal efficiency on the high end, contrary to theoretical filter model predictions. For some manufacturers' filters, the upper limit of efficiency often plateaus at less than 100% in the 5-10.0 micron size range.

The modified classical model presented here corrects both these deficiencies in a way that facilitates the modeling of filters based on MERV data. The diffusion component, E_D in equation (1), is corrected with a factor that reduces the removal efficiency as a function of particle mean diameter. This diffusion efficiency correction factor, called D_f, is based on a Gompertz curve with constants set by least squares curve fitting of data from Ensor (1988). This data and the fitted models for four DSP rated filters are shown in Figure 2. This curve can be observed to provide an improved fit compared with the curve fits in the source that were obtained without a diffusion correction factor (Kowalski et al 1999).

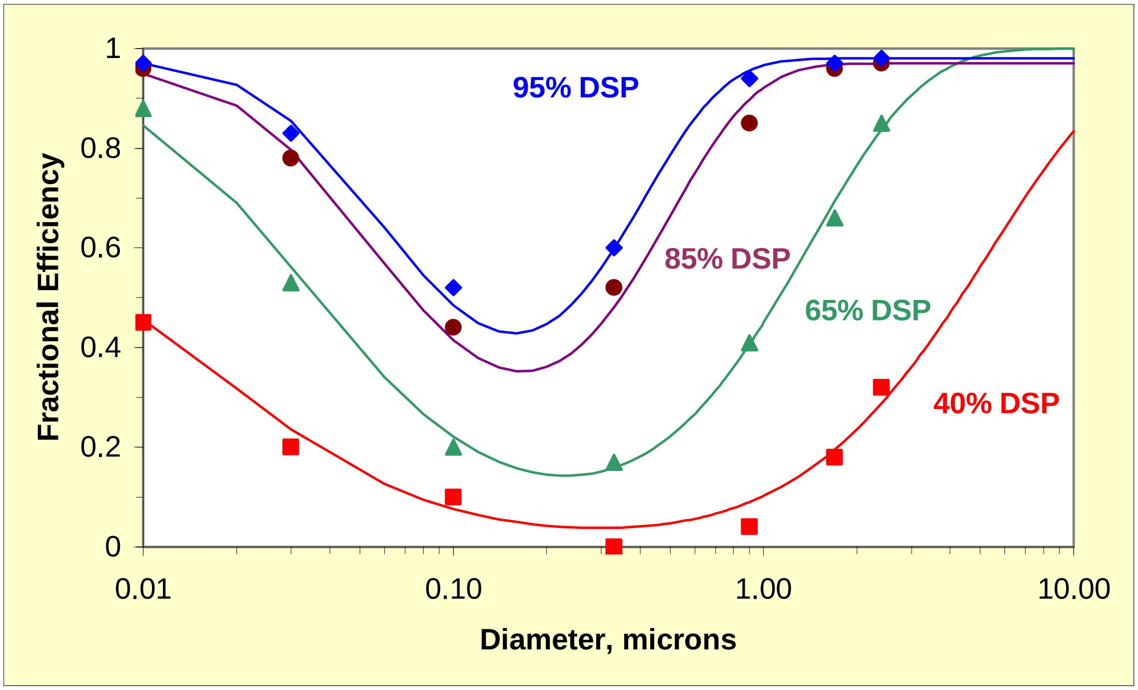

Figure 2: Comparison of four DSP rated filters modeled with a diffusion correction factor and compared with data from Ensor (1988).

The diffusion efficiency correction factor, called a counter-diffusion factor, used to fit the models in Figure 2 is as follows:

$$D_f = 1 - z^{(d_p - g_m)^{3/4}} \tag{2}$$

where d_p = particle diameter, microns

z = a constant, 1×10^{-10}

g_m = gas molecule size, 0.003 microns

Equation (2) is strictly a mathematical curve fitted to a limited data set and is presented here without derivation. Since it is purely a function of the particle diameter, it cannot be manipulated and is identical for all filters and operating conditions. It mathematically defines the fact that diffusional efficiency decreases towards zero as a particle approaches the size of a gas molecule.

The correction factor for the interception parameter, called L_U, defines the upper limit of the curve efficiency in the interception range. Both correction factors are now applied to equation (1) to produce the following modified filter model:

$$E = L_U (1 - e^{-(D_f E_D + f E_R) S}) \tag{3}$$

Equation (3) can now be used to fit a performance curve to any filter

based on a single mean fiber diameter. The two correction factors, L_U and *f* provide considerable flexibility in matching the model to MERV data. The factor L_U can be set equal to the highest efficiency in the MERV test results. The factor *f* can then be used to make further curve-fitting adjustments if necessary. It should be noted that the variation in filter efficiency for any given MERV rating is probably on the order of at least +/-20%, and therefore it may not be critical that a tight curve fit is obtained. Manual adjustment of parameters can be used to fit a curve although the most accurate approach would be to use a least squares curve fit.

Most filters today filters use a range of filter fiber diameters, typically 0.6-20 microns in diameter, and it is therefore preferable to model a filter with multiple (i.e. three) fiber sizes. This latter approach provides considerable flexibility in matching the filter model to MERV or vendor data. The parameters L_U and C_D can be used to adapt the curve to match the idiosyncrasies of any manufacturer's filter. Consult the source reference for additional specific details on modeling.

Modeling MERV Filters

MERV test results include particle removal rates for size ranges between 0.3-10.0 microns. Test results typically efficiencies at several filter conditions including an initial test, a conditioning step, and several dust loading steps. An example of such data is shown in Table 1. The results of the test are summarized as a composite of the minimum efficiencies at each mean diameter.

Table 1: Tabulated ASHRAE 52.2-1999 Test Results -- MERV 10 Filter

Mean Diameter	0.35	0.47	0.62	0.84	1.14	1.44	1.88	2.57	3.46	4.69	6.2	8.37
Initial	6.4	6.9	18.4	19	35.7	57.9	65	76.8	87.1	91.2	92.4	93
Conditioning step	11.7	14.9	30.8	37.5	57.9	74.4	84.1	94.4	97.8	98.3	97.8	99
First Dust Load	0	0	16.5	27.7	47.9	65.2	78.9	92.5	96.4	98	97.6	97.8
Second Dust Load	0	0	0	7	19.2	43.3	63.6	90.4	96.4	95.3	95.4	95.3
Composite Minimum	0	0	0	7	19.2	43.3	63.6	76.8	87.1	91.2	92.4	93

The choice of which conditions to use for modeling is somewhat arbitrary since initial conditions will be conservative but the final conditions may be more realistic. The composite minimum data may represent different loading conditions and therefore the data may be scattered or may not produce a naturally smooth curve. Most of the time the composite minimum data will represent the initial conditions and the question becomes moot. In the fitted curves shown in Figures 3a-j, the initial condition data is used for all filters. All filters are based on MERV data except the MERV 13 filter, which is an 80-85% DSP filter model based on data from Ensor (1988).

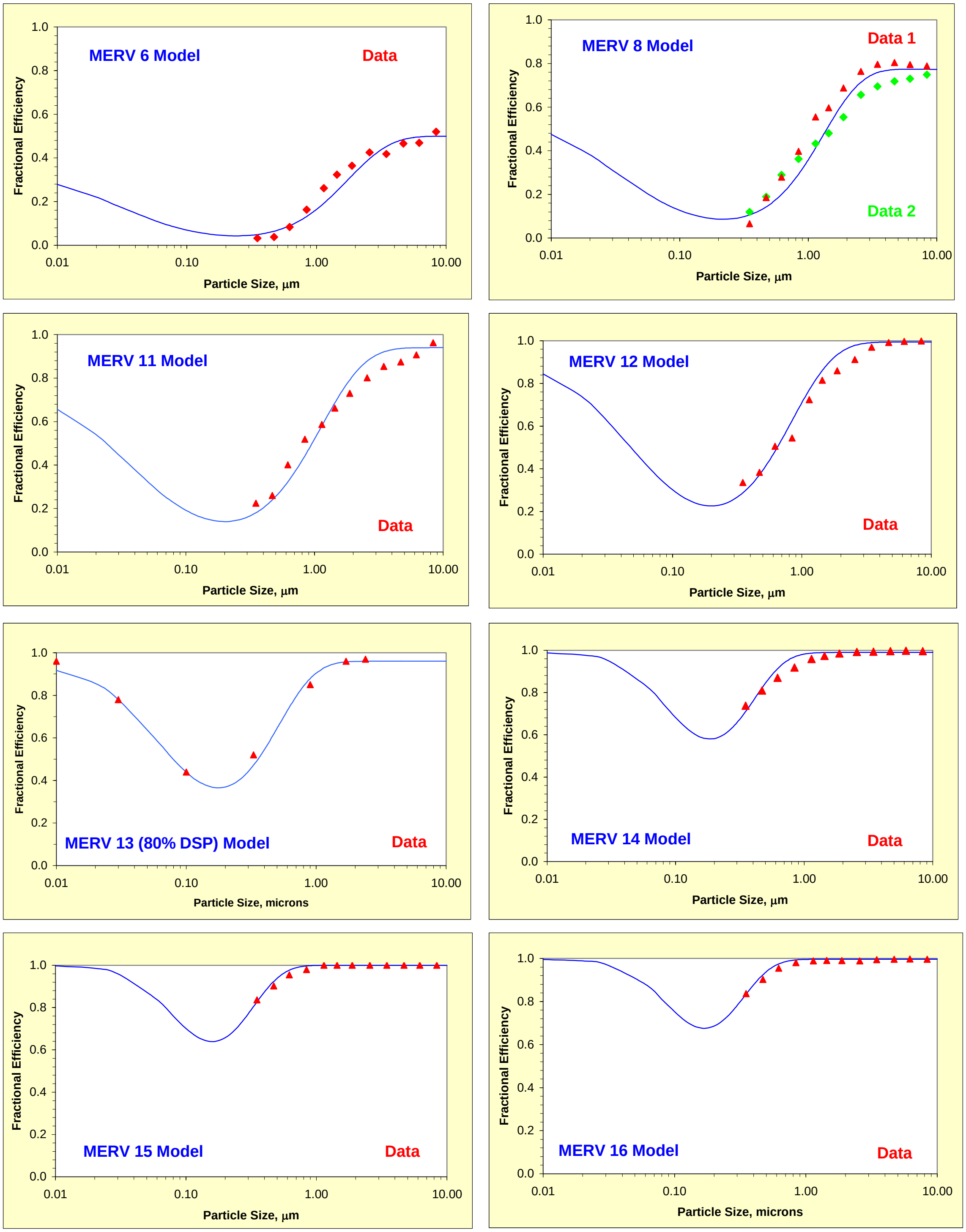

Figure 3: MERV Filter models compared with test data.

The performance curves summarized above represent curves fitted to particular manufacturer's filters, based on the MERV test results. These cannot be considered to be generally applicable to other filters of identical MERV ratings because curvature can vary considerable between manufacturers.

Figure 4 shows a composite of all the MERV models from Figure 3a-j. It is obvious that the performance curves could even cross, as for the MERV 10 and MERV 8 filters in Figure 4, since the MERV rating does not truly define the entire performance curve, but only a single point on the curve.

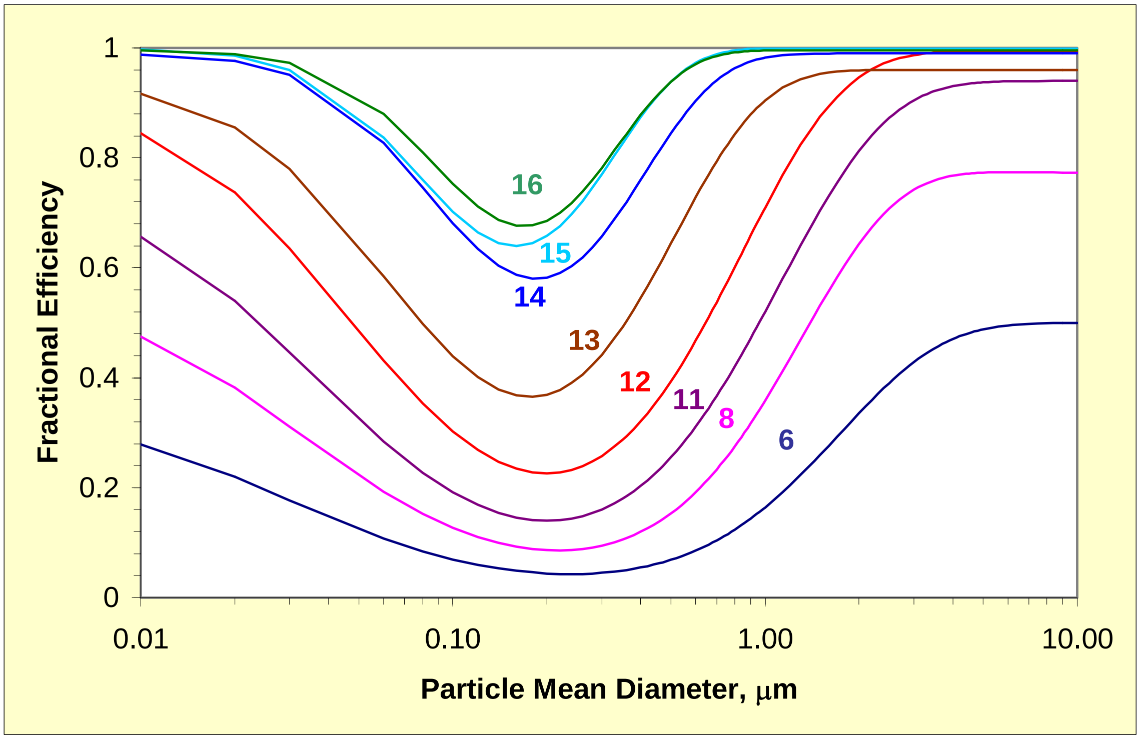

Figure 4: Composite of all MERV filter models, based on initial conditions.

The models presented are only generally representative of the entire array of MERV filters since considerable variation is possible by different filters with the same MERV rating. If it is necessary to model a specific filter for microbial filtration applications, MERV data for that particular filter should be used as a basis in preference to using any of the above models.

This filter model should provide reasonably accurate estimates of filter performance at other operating velocities, although no corroboration with empirical data is yet available. Figure 5 shows an example of a MERV 12 filter operated at various velocities. Obviously, penetration in the virus and bacteria size range can be greatly affected by changes in filter operating velocity.

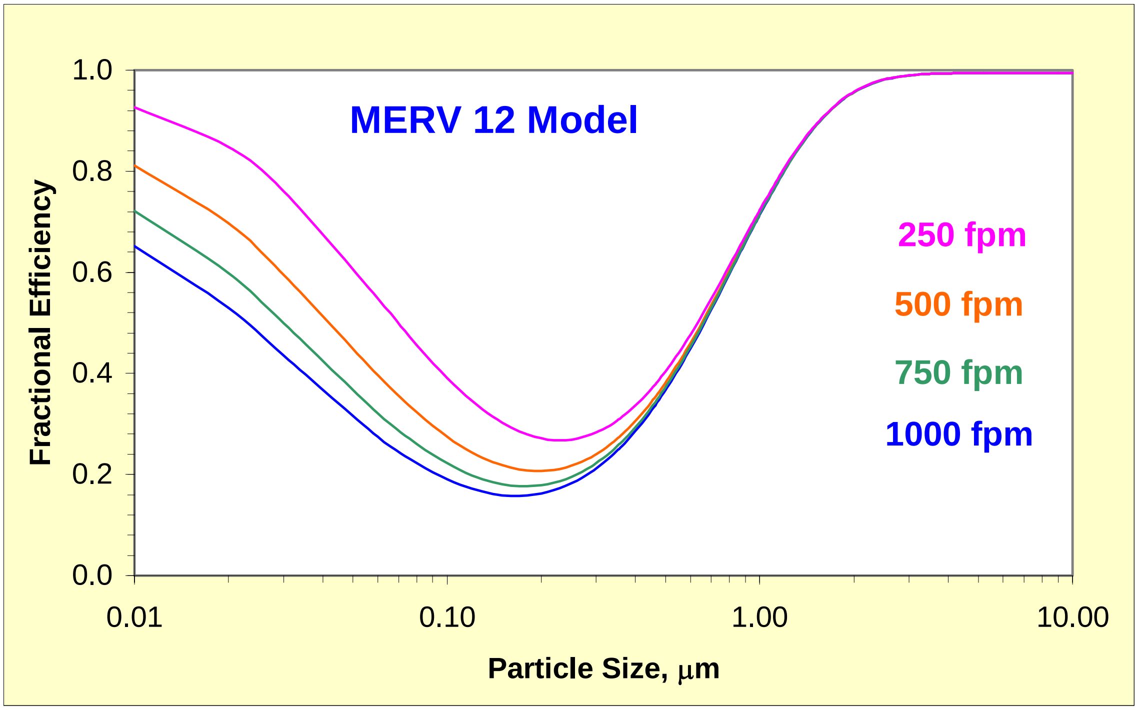

Figure 5: MERV 12 filter model at various operating velocities.

Microbial Filtration

Airborne microbes can be removed by filters at rates that depend on the filter performance curve and the mean diameters of the microbes. Each microbial species has a characteristic range of sizes that forms a lognormal distribution between the minimum and the maximum. Most microbes are spherical or ovoid and can be approximated as spheres. Some bacteria and spores are rod-shaped and can be conservatively approximated by spheres representing their minimum dimensions. Exceptions to this rule include rod-shaped bacteria that are smaller than the most penetrating particle size range of filters, and bacteria that have aspect ratios greater than about 3.5. Above this aspect ratio an empirical correction factor is used to adjust the maximum length. The equivalent logmean diameter of all airborne pathogens and allergens has been estimated and these values are available from the references (Kowalski et al 1999).

The mean diameters of airborne bacteria, fungi, and viruses are shown in Figure 6a-c superimposed on their size distribution. The microbes shown include all common airborne pathogens and allergens as well as a number of potential biological weapon agents. The logmean diameters are shown in Figure 6a-c are based on prior computations (Kowalski et al 1999). These logmean diameters can be used along with the previous MERV filter models to estimate removal rates. However as stated previously, these particular models apply only to the specific manufacturer's filters on which they were based and will not necessarily produce accurate predictions for other manufacturer's filter models even if the MERV rating is the same..

Figure 6a-c: Mean diameters and size distribution for bacteria, fungi, and viruses.

Conclusions

This article has summarized a new filter model that has the capability of being fitted to any manufacturer’s filter model based on MERV data. The examples of filter models presented here illustrate the kind of performance that might be expected from different MERV rated filters. The comparison of the MERV filter model performance curves also shows how the MERV rating is not necessarily an absolute indicator of removal rates since some filters with lower MERV ratings may actually remove particles at higher rates in some size ranges. The examples presented here should not, therefore, be considered to represent performance curves of each MERV rating in anything but a general fashion since considerable variation can occur for different manufacturer’s filters even though they have the same filter rating. It is expected that as more MERV data sets become available, curves can be produced that will more truly represent average performance of MERV rated filters.

The summary of logmean diameters of airborne pathogens and allergens provide a resource that engineers can use to select or size filters for particular applications. These can be used in conjunction with the filter models presented to estimate removal rates, or they can be used with new models developed for specific manufacturer’s filter models to obtain more accurate and realistic predictions. The classical filter model correction factors presented here should be considered curve-fitting tools only. The authors hope to refine this research and develop a complete model of filtration with a more solid theoretical basis in the future.

References

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