PENETRATION OF AMBIENT AEROSOLS THROUGH RESPIRATOR FACESEAL LEAKS

APPLICATION NOTE ITI-055

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Introduction

Research to determine the best particle size range for fit testing has been conducted by several researchers[1,2,3,4,5,6]. However, most of these works neglected to study particle sizes below a few tenths of a micron.

The TSI PORTACOUNT® Respirator Fit Tester has been shown to produce fit test results using ambient aerosol that are comparable to fit test data from light-scattering photometers using a generated aerosol[7,8,9,10,11]. With two exceptions[1,10], a particle size distribution analysis of the ambient aerosols used for these studies was not done. Since the TSI PORTACOUNT fit tester uses naturally occurring ambient aerosol in the range of 0.02 to 1.0 micron, a study to determine if particles at the low end of the ambient aerosol size range effectively penetrate respirator faceseal leaks was conducted. This data, along with the referenced research provides a full accounting of the effectiveness of ambient aerosol for quantitative respirator fit testing with particle counting instruments like the PORTACOUNT fit tester.

Test Setup and Equipment

The testing equipment consisted of the following items:

- Single-jet aerosol atomizer, TSI Inc. in-house design
- 1.75 ft × 1.75 ft × 1.75 ft steel enclosure
- Rubber headform with breathing port
- Half-mask respirators:
    - American Optical - 5 Star Series
    - MSA Comfo Elite
- TSI Incorporated Model 3934 Scanning Mobility Particle Sizer™ (SMPS™) with a 3002A Condensation Particle Counter
- Small vacuum pump connected to the headform

A simple diagram of the testing apparatus can be seen below in Figure 1.

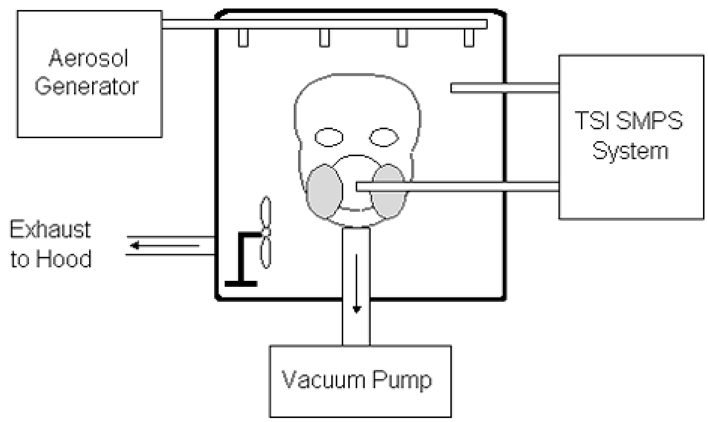

Figure 1

The setup consists of a positive-pressure test chamber which contains the headform centrally located inside. A polydisperse aerosol is generated outside the chamber and introduced evenly over the top of the headform through 9 separate inlets. The chamber contains a small muffin fan that mixes the aerosol throughout the chamber to produce a consistent number concentration around the headform. An exit port, with a tube attached to a fume hood, gives the aerosol an opportunity to leave the test chamber and maintain a steady concentration.

The aerosol is sampled from the test chamber through two separate stainless steel tubes. One tube is attached to a probe fitting on the respirator. The tube extends several inches into the breathing port of the headform to ensure that complete mixing of the sampled, mask aerosol occurs. The other stainless steel tube is positioned in front of the headform, near the respirator, and samples the aerosol inside the test chamber.

These sampling tubes are connected to a TSI Incorporated Model 3934 Scanning Mobility Particle Sizing (SMPS) System, which makes the aerosol measurement. The SMPS system uses a TSI Model 3071 Electrostatic Classifier with a TSI Model 3022A Condensation Particle Counter to determine the particle concentration for a specified size range based on the electrical mobility of the particles. The SMPS system scans the aerosol concentration inside or outside the mask and divides up the total number count into bins according to particle size. This allows simultaneous inside and outside particle concentration comparisons by particle size.

A vacuum pump is attached to the headform to provide a constant 12 liters per minute of airflow through the respirator. This constant airflow was maintained in order to provide a stable aerosol concentration inside the mask and simulate the most extreme condition where mask leakage can occur.

Test Procedure

The headform was first removed from the test chamber and adjusted for a known fit factor. This preliminary fit factor was determined using a TSI Model 8020 PORTACOUNT Plus respirator fit tester. The respirator fit was controlled by loosening the respirator straps or inserting small, single-strand wires between the headform and the faceseal of the respirator. This method allowed the adjustment of the fit factor between 50 and 500.

With the fit adjusted, the headform was placed inside the test chamber and the aerosol generation system started. The headform was hooked up to the vacuum pump and a constant 12 lpm was pulled through the respirator to simulate inhalation. The SMPS system was also started and its flows were established according to the user manual. The whole system was allowed to stabilize for 30 minutes before any measurements were taken. A series of data points was taken to check the stability of the aerosol concentration inside the test chamber with the results seen below in Figure 2.

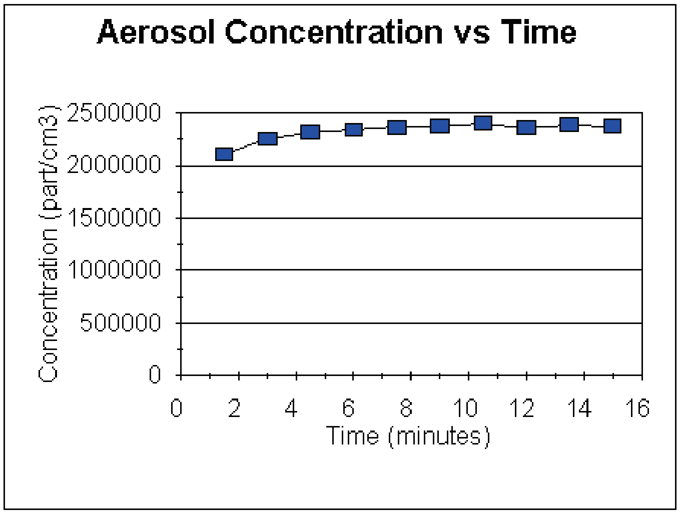

Figure 2

Figure 2 shows that the total concentration of the aerosol stabilized after 5 minutes from startup with changes of less than 2% after this stable value. This consistency in the ambient aerosol concentration was seen throughout the testing.

With the conditions inside the chamber at stable concentrations, a sample from the ambient aerosol was taken by the SMPS system. The sample time took a total of 4 minutes. After this time the SMPS system was switched to the respirator sampling tube. The system was given 15 minutes to stabilize to ensure a stable reading from inside the respirator. A 4-minute sample was then taken from inside the respirator. The SMPS system was switched back to the ambient aerosol, and another 4-minute ambient sample was taken to be used as an averaging term for the total ambient aerosol concentration. These steps were repeated three times for each respirator fit factor and particle size distribution.

The output of the SMPS system categorizes the number concentration of aerosol in particle size bins that increase log-normally in size. Since the aerosol is polydisperse and made up of many different sized particles, the resulting data has a large range of particle-sized bins. The range and size of these bins is determined by the flow rates into and the sample time length for the SMPS system. This data was saved to a file which was brought into a spreadsheet program where the actual fit factor analysis was performed. An example of the SMPS results can be seen below in Table 1.

Particle Size Range (Microns)	Mask Concentration (particles/cm^3	Ambient Concentration (particles/cm^3
.049-.056	49.83	4469.33
.056-.065	83.07	6575.78
.065-.075	106.51	9166.34
.075-.087	141.35	12326.40
.087-.100	177.14	15500.02
.100-.116	234.42	17701.02
.116-.133	208.63	17964.42
.133-.154	168.48	13182.16
.154-.178	156.57	12470.56
.178-.206	107.46	7830.39
.206-.237	60.28	4275.93
.237-.274	25.10	42170.63
.274-.317	14.71	1122.97

Table 1. Medium Aerosol and Low Fit Factor

The fit factors were determined individually for the different particle bins. This allowed the fit factors at different particle sizes to be compared directly for the same fit test.

Results

The results of this testing display the fit factor as a function of particle size for three different aerosol size distributions and two separate fit factor values. The fit factors were centered around 100 and 400 for each aerosol distribution. Due to the variables in the test setup, the fit factor for each test shown was independent of any other test, and should only be looked at separately.

The fit factor was determined by dividing the total number of particles counted outside the respirator per particle size bin, by the number of particles counted inside the respirator in the same bin. Thus, if the SMPS system determined there were 4 particles per cubic centimeter inside the respirator between the range of 0.05 micron and 0.06 micron, and 400 particles per cubic centimeter outside the respirator for the same size range, the fit factor would be computed as 100.

The first ambient aerosol distribution was made up of relatively small particles with a peak in the distribution around 0.08 micron. The ambient aerosol distribution had a high enough concentration of particles down to 0.03 micron to be statistically valid for calculating a fit factor at that low of a particle size. A graph of the ambient distribution, as determined by the SMPS system is seen below in Figure 3.

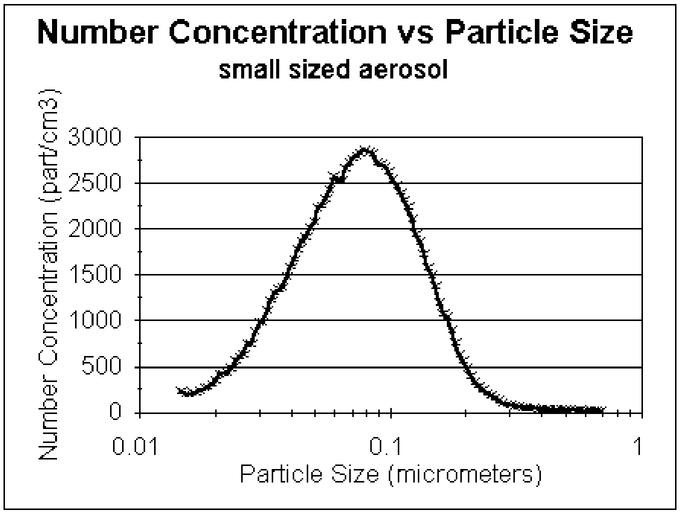

Figure 3

The results of a test with this smaller particle size distribution and lower fit factor can be seen below in Figure 4.

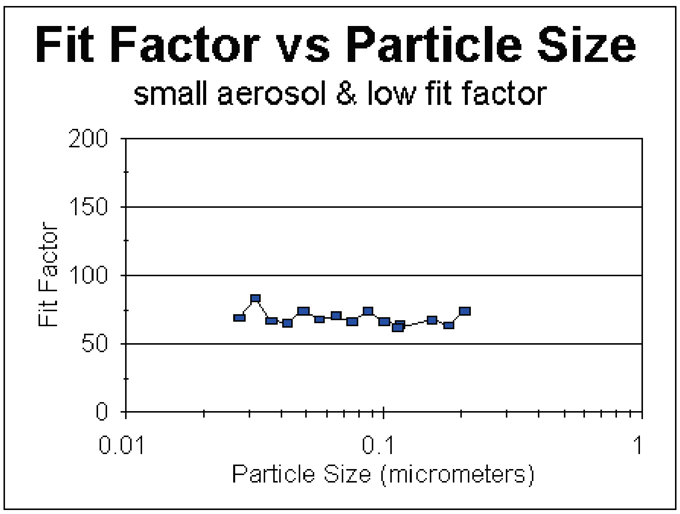

Figure 4

The results in Figure 4 show that the fit factor is very linear over the particle range shown, around 0.03 to 0.20 micron. The fit factor averaged 69 with deviations averaging less than 10%.

The results of a test with the smaller particle size distribution and a higher fit factor can be seen below in Figure 5.

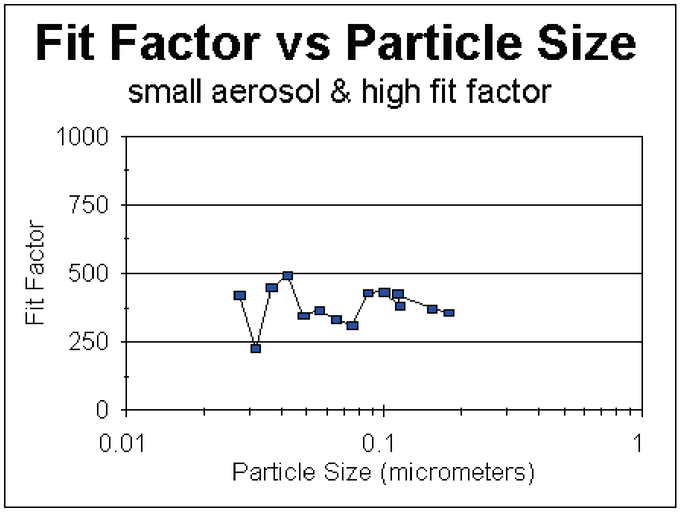

Figure 5

The results in Figure 5 show that the fit factor is linear over the particle range shown, around 0.03 to 0.20 micron. The fit factor averaged 355 with deviations averaging less than 20%.

The second ambient aerosol distribution was made up of larger particles with a peak in the distribution around 0.12 micron. A graph of the ambient distribution, as determined by the SMPS system is seen below in Figure 6.

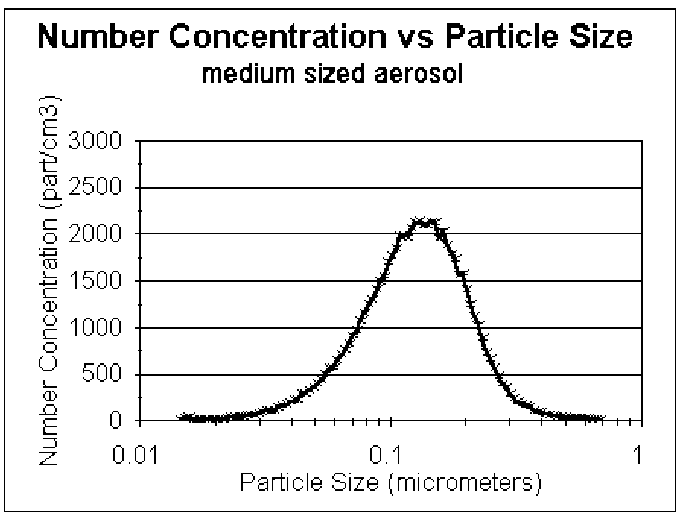

Figure 6

The results of a test with this medium particle size distribution and lower fit factor can be seen below in Figure 7.

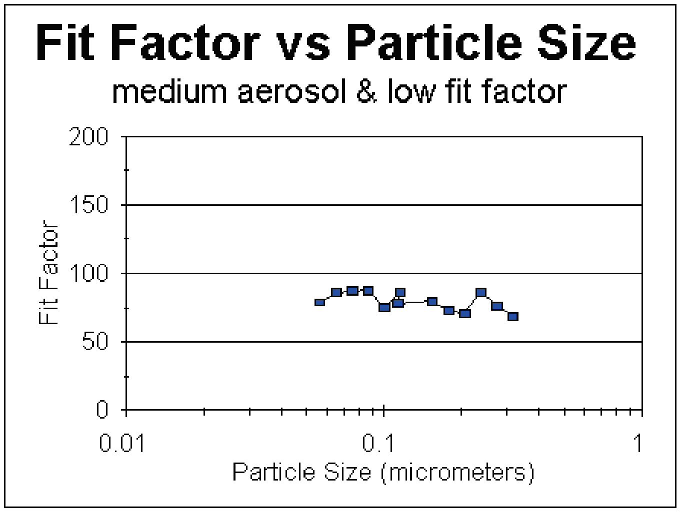

Figure 7

The results in Figure 7 show that the fit factor is very linear over the particle range shown, around 0.06 to 0.30 micron. The fit factor averaged 80 with deviations averaging less than 10%.

The results of a test with a medium particle size distribution and a higher fit factor can be seen below in Figure 8.

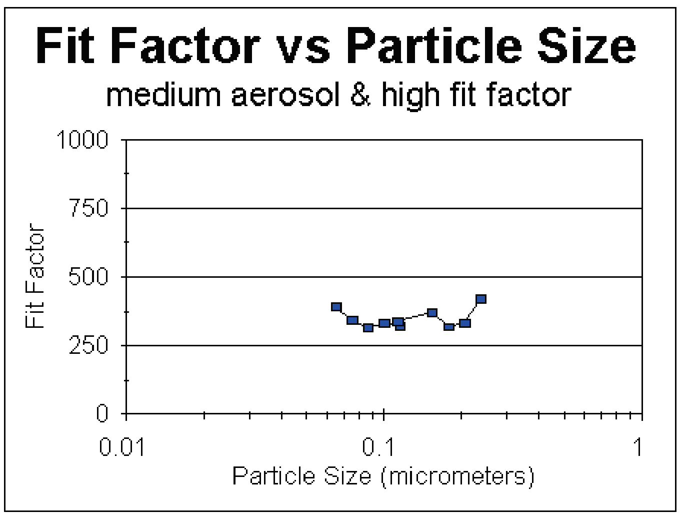

Figure 8

The results in Figure 8 show that the fit factor is linear over the particle range shown, around 0.06 to 0.30 micron. The fit factor averaged 302 with deviations averaging less than 15%.

The final ambient aerosol distribution was made up of large particles with a peak in the distribution around 0.30 micron. A graph of the ambient distribution, as determined by the SMPS system is seen below in Figure 9.

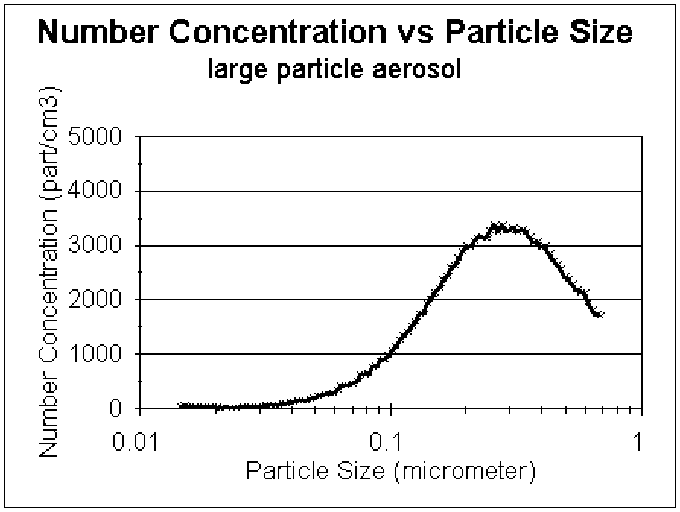

Figure 9

The results of a test with this large particle size distribution and lower fit factor can be seen below in Figure 10.

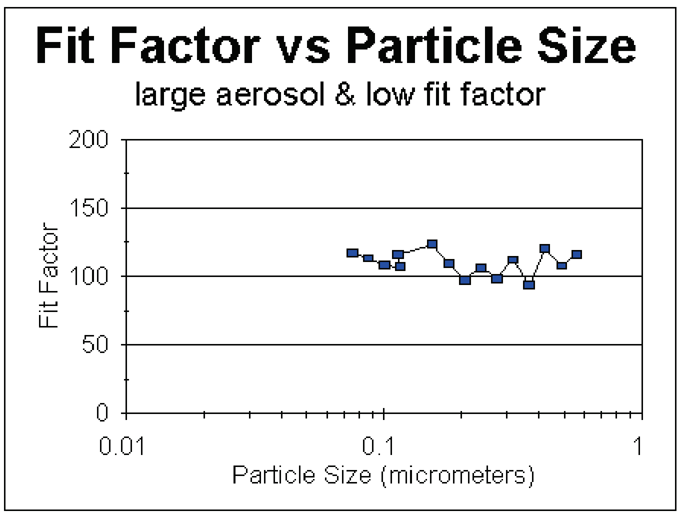

Figure 10

The results in Figure 10 show that the fit factor is very linear over the particle range shown, around 0.08 to 0.60 micron. The fit factor averaged 110 with deviations no greater than 15%.

The results of a test with a large particle size distribution and a higher fit factor can be seen below in Figure 11.

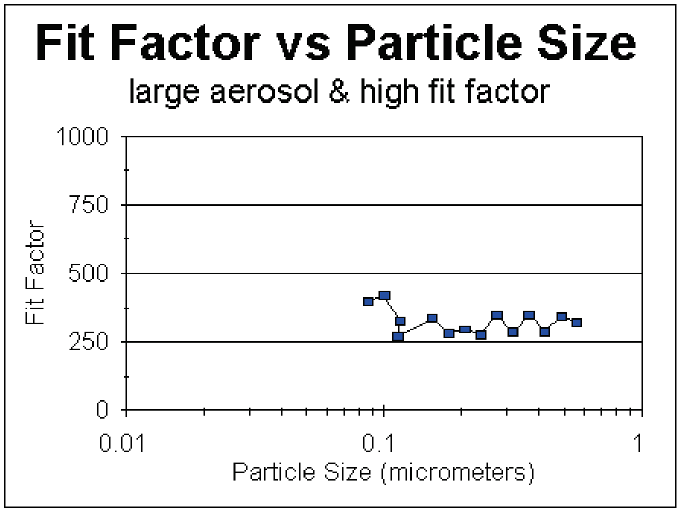

Figure 11

The results in Figure 11 show that the fit factor is linear over the particle range shown, around 0.08 to 0.60 micron. The fit factor averaged 303 with deviations averaging less than 15%.

Conclusions

The results of this study show that ambient air particles in the range from 0.03 to 0.6 microns are suitable for quantitative respirator fit testing with particle counting instruments like the TSI PORTACOUNT. Previous work[1,2,3,4,5,6] shows that particles from a few tenths of a micron to nearly 2 microns are also suitable. Particles between 0.03 and 1 micron cover the full size range typically found in ambient air[1,10] (in statistically significant quantity), and are the same size range detected by the PORTACOUNT.

(continued on next page)

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