Dynamic measurement of particle production rate of an operator with different garment arrangement in Cleanrooms

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Abstract

There are many possible sources of contamination in the cleanroom environment, including: operators, equipment, structures, and any surface that can generate particles through friction, heat, exhaust, outgassing, and static electricity charge. The operators working in the cleanroom are the major sources that release the most of particles. As cleanroom operators are working, they elucidate millions of particles with every movement. Particles migrate up through the cleanroom garment toward the head and fall down to the legs during cleanroom activities. Specialized textile fabrics have been used in cleanroom garments for many years. The need for this type of fabric has increased mainly due to the increasing need in protecting critical operations in cleanrooms as well as creating comfort for operators and other personnel. Previous studies were limited and only used small number of particles. Previous methods were also poor and unclear. This study covers the general static method of wind-driven and Helmke Drum in regards to the filtration efficiency of cleanroom fabrics and garments. Furthermore, it introduces dynamic method of body box for testing fabrics as well as cleanroom garments. It is more practical and sensitive as being compared to traditional methods and based on a more concise technical approach for the life-time of these products to be examined and controlled, especially when the garments have to be sterilized prior to the use

Key words: wind-driven, Helmke Drum, dispersal chamber, garment testing, particle size distribution, penetration.

1. Introduction

There are many possible sources of contamination in the cleanroom environment. Equipment, structures, and surfaces can generate particles through friction, heat, exhaust, outgassing, and static electricity. Incoming production components may introduce contaminants. Moreover, people working in the cleanroom can generate particles that are shown mostly. Of these, humans are the easiest to control, by less releasing particles into the air.

However, a lack of uniformity in the application of methods and instrumentation, a lack of repeatability (most significantly), and a lack of correlation of the data to actual cleanroom classification mean that research in this area is actually more sophisticated and should be reproducible in all kinds of cleanroom environment. Thus, the aim of the study evaluate the three tests were: the particle penetration tests (**IEST-RP-CCOO3.2**), the Helmke drum test (**IEST-RP-CCOO3.2**), and dispersal chamber test (**US Federal Standard 209**). Multiple tests were performed on woven fabrics and garments under varying conditions.

2. Methods

2.1 Particle Penetration Test

The tests were performed in a noncleanroom environment using the ambient (i.e., room) aerosol as the challenge. The test fabric was mounted in a filter holder which had a 25-cm (10-in.) diameter active filtration region. A vacuum pump was used to establish flow through the fabric at a rate that yielded a pressure drop of 9.5mm H_2O. An aerosol particle counter was used to sequentially obtain ten 1-min upstream and ten 1-min downstream samples. From the particle counter data (MetOne 237B), the filtration efficiency of the media was computed for two size ranges: > 0.1 □m and > 5 □m. The test was repeated, and a second set of filtration efficiency values were computed. If the efficiency values from the two sets were not within 15 percent, the test would be repeated until two values reach the goal to be within 15 percent. The average of the two efficiency values was then computed and reported. The arrangement is shown schematically in **Fig. 1**.

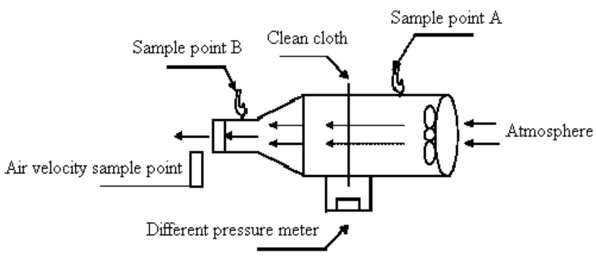


Figure 1. Schematic diagram of the wind-driven test method

2.2 Particle Shedding Test-Helmke Drum Tumble Test

The apparatus was set up in a 0.3□m and Class-10 modular cleanroom. The end of the sampling tube for an airbome particle monitor was mounted to pull the air from the inside of the rotating drum. The number of airborne particles was determined using a particle counter (MetOne 237B). The arrangement is shown schematically in **Fig. 2**.

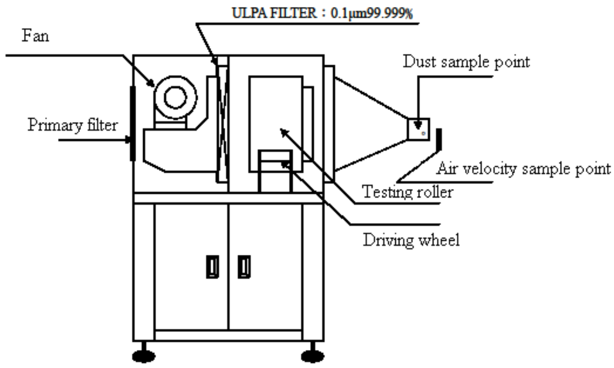


Figure 2. Schematic diagram of Helmke Drum test method

2.3 Dispersal Chamber Test

A specially designed dispersal chamber (120cm(L)× 120cm(W) × 310cm(H)) with HEPA-filtered air supply and separate make-up air unit has been qualified for the evaluation of clean room clothing systems. The apparatus was set up in a Class-1 modular cleanroom. The arrangement is shown schematically in **Fig. 3**. The vertical unidirectional air velocity was adjusted at 0.35 m/s and the dispersal chamber is pressurized relative to the adjacent area. Room temperature and relative humidity are not controlled since the indoor environment was quite stable, with 23±3°C and 25-55 % RH during the tests. The total number of airborne particles was determined using a particle counter (DPC; Hiac Royco 245) and viable particles were collected primarily using a slit-sampler (brand name FH3). In some cases, they were additionally measured using a sieve-sampler (Andersen 6-stage Sampler).

Characteristics of the test person and movement patterns

The test person: Female, 58 kg, 160 cm tall. No facial hair and has long black hair.
Cleanroom garment: A coverall and hood (100% polyester), single use facial protection and latex gloves. The coverall and hood were produced in a cleanroom environment which were new and had subjected to washing prior to use.

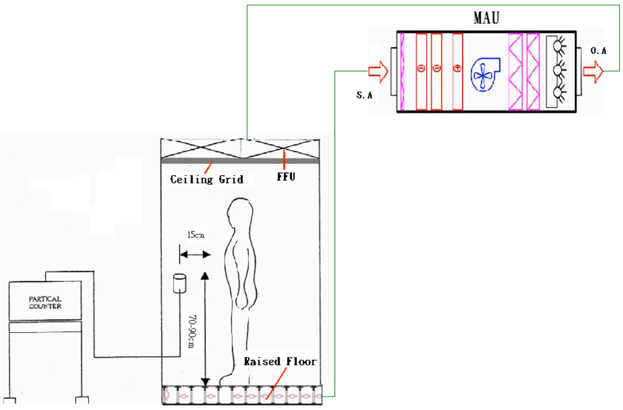


Figure 3. Principal arrangement of dispersal chamber(body-box).

Movement

Standing while performing arm movements: One arm at a time was moved at an angle of 90°, back and forth in a sweeping motion. The original position of the arm was directed straightly ahead with a 90° bend at the elbow. The movement frequency was one second for one arm for moving back and forth.
Standing with cross beat: Both hands beat the chest from side to side, as far as possible in each direction. The time for turning from one side to the other was one second.
Standing with rotating torso: Both hands grabbing the waist and rotating the upper body from side to side, as far as possible in each direction. The time for turning from one side to the other was one second.
Walking on the spot: Walking on the spot at a rate of two steps per second.

3. Results

3.1. Particle Penetration Test

Fig. 4 presents the experimental results of particle penetration for the test fabrics. In general, particle penetration increased with decreasing particle size from 1 to 0.3 □m. Maximum penetration varied from 96% to nearly 87%, at the highest face velocity tested (0.4 cm/s). It is interesting to note that the lowest face velocity (0.2 m/s) that was used as personal protection garments had low particle penetration (Foarde et al. 2000).

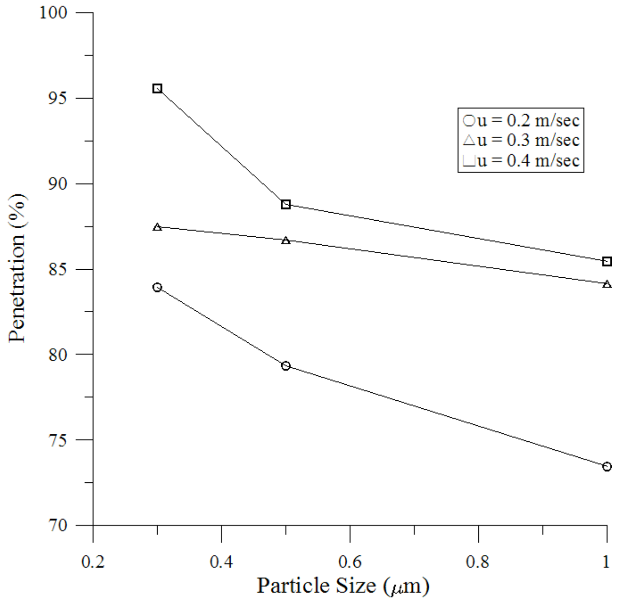


Figure 4. Experimental penetration results using the wind-driven method and the filtration method.

3.2. Particle Shedding Test-Helmke Drum Tumble Test

Fig. 5 shows the results of the Helmke drum tests for the garment. All three particle size curves showed a drop in particle count over the first forty minutes, which is typical for woven garments. Steady higher counts for the particle of 0.3 □m on laundered garment during the latter part of the test indicated possible breakdown in the fabric. Data for the particle of 1 □m on laundered suits showed no increase in counts.

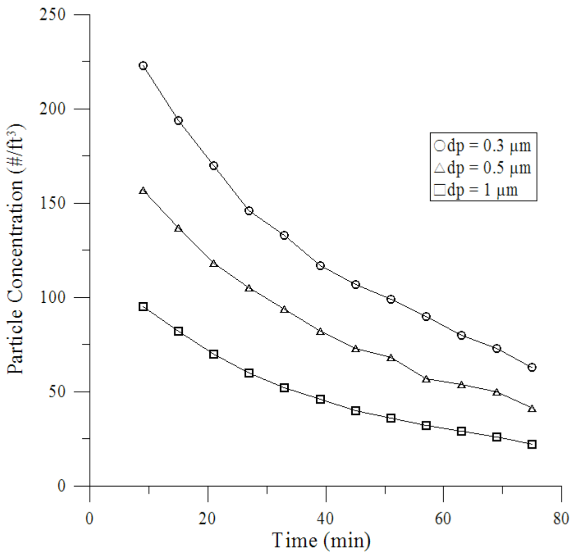


Figure 5. Particle shedding for garments using Helmke Drum Tumble Test.

The levels of the particle generation depend on the particle size. As shown in **Fig. 6**, the power law curve is well correlated to the particle generation for the data sets. Generally the slope of the curve did depend on the particle size as expected. The garment appeared to have a slope of less than 1 (**Ensor et al. 2001**).

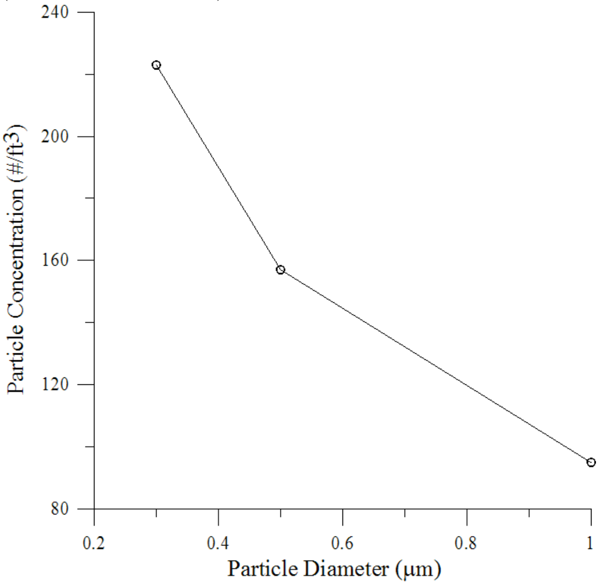


Figure 6. Particle concentration versus aerodynamic particle diameter using Helmke Drum Tumble Test.

3.3. Dispersal Chamber Test

The strength of source was determined for eight subsequent times in a series of experiments carried out in the test which the person was wearing coverall and performing four activities (see **Fig. 7**). The results showed that a stable total particle release concentration after showering was first obtained after about 150 seconds (**Ramstorp et al. 2005**). The data showed that the strength of source values for particles shed of the activity followed the order arm movement＞hand cross beat＞rotating torso＞walking. **Table 1** summarized particle number concentration versus time for four activities. Each decay coefficient was an average over five repeats; standard deviations of decay coefficients were less than 10 %. The mean particles size distribution at this steady state condition is shown in **Fig. 8**. **Table 2** summarized particle number concentration versus aerodynamic diameter for four activities. Each decay coefficient was an average over five repeats; standard deviations of decay coefficients were less than 10 %.

(a)

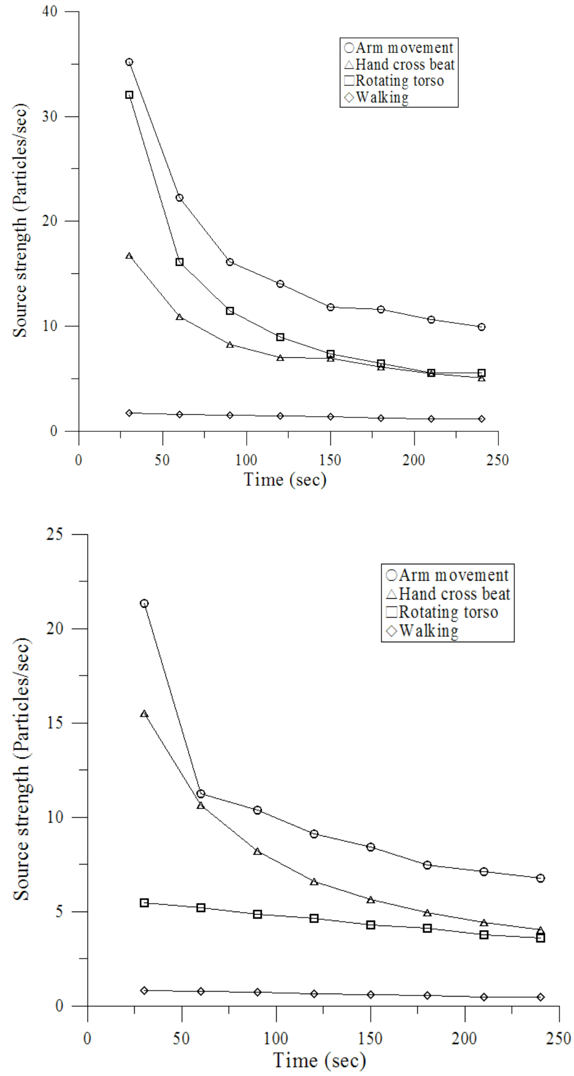
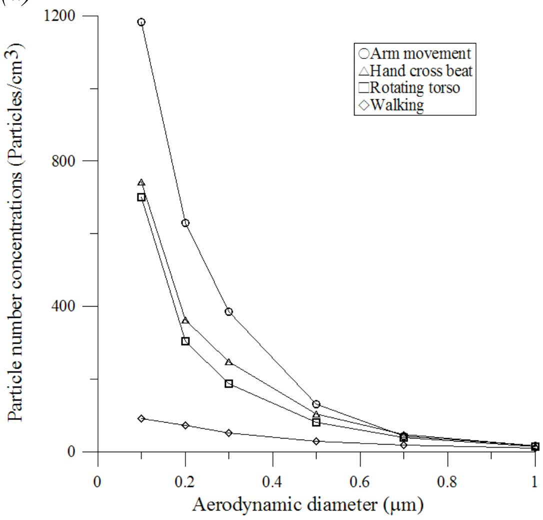


Figure 7. Particle strength of source as a function of time. (a)H=70cm, D=15cm, (b)H=90cm, D=15cm

Table 1. Particle strength of source for the test person performing various physical activities and wearing cleanroom garment.

Particle diameter (μm)	Particle concentration vs time (t)
	H=70cm,D=15cm
Air movement	$y=6.2623x+904.21$, $R^2 = 0.9905$
Hand cross beat	$y=1.5829x+885.68$, $R^2 = 0.9258$
Rotating Toroso	$y=3.1583+456$, $R^2 = 0.9757$
Walking	$y=1.0222x+35$, $R^2 = 0.9757$
	H=90cm,D=15cm
Air movement	$y=4.9329x+468.43$, $R^2 = 0.9851$
Hand cross beat	$y=2.1881x+488.11$, $R^2 = 0.9229$
Rotating Toroso	$y=3.275x+121$, $R^2 = 0.9754$
Walking	$y=0.3849x+24.286$, $R^2 = 0.9335$

(a)



(b)

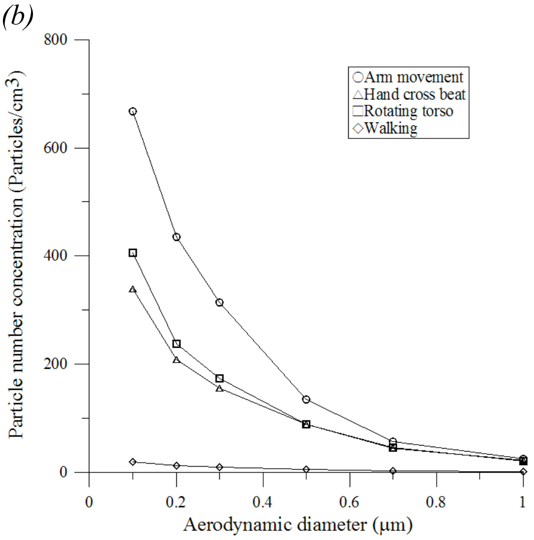


Figure 8. Particle concentration versus aerodynamic particle diameter for body-box test.

Table 2. Particle strength of source for the test person performing various physical activities and wearing cleanroom garment.

Particle diameter (□m)	Particle concentration vs particle aerodynamic diameter
	H=70cm,D=15cm
Air movement	$y=1658.6e^{-4.851x}$, $R^2 = 0.9901$
Hand cross beat	$y=900.52e^{-4.098x}$, $R^2 = 0.9902$
Rotating Toroso	$y= 756.63e^{-4.117x}$, $R^2 = 0.9772$
Walking	$y=112.73e^{-2.516x}$, $R^2 = 0.9911$
	H=90cm,D=15cm
Air movement	$y=928.75e^{-3.777x}$, $R^2 = 0.9941$
Hand cross beat	$y=402.02e^{-3.003x}$, $R^2 = 0.9916$
Rotating Toroso	$y=480.67e^{-3.245x}$, $R^2 = 0.9906$
Walking	$y=24.43e^{-3.302x}$, $R^2 = 0.9904$

4. Conclusions

The overall results of the particle penetration tests, the Helmke drum test, and dispersal chamber test provide an overall comprehensive evaluation of the fabrics and the garments. The combined data also provide a much clearer picture of the potential behavior of these fabrics and garments in an actual cleanroom environment.

The IEST particle penetration test is a straightforward test with modest equipment requirements. The use of room aerosol simplifies the test setup, although it often limits the useful upper particle size to less than 5 □m because of insufficient particle counts. The variability of particle size distribution and concentration of room aerosol is an uncontrolled parameter. An additional deficiency is the lack of requirement to measure and report the face velocity through the fabric at the 9.5mm H_2O pressure drop. Use of the face velocity, either by reporting it alongside the penetration value or combined with the penetration to yield the penetration velocity, can add significantly to how the data are interpreted and what conclusions are drawn.

However, by combining these tests with the Helmke drum test of the full garment, a reasonable picture of the garment as a whole is provided. The Helmke drum test is a useful tool for quickly finding problems with garments and for characterizing the shedding of fabrics and other soft materials. A recommended upper particle-size limit should be 5 μm. The size distribution of particles released from the garment follows a power law distribution, with a slope of less than 1.

In conclusion, the main contamination source in the indoor environment, humans, have been evaluated with new cleanroom clothing systems. Clearly, it is essential to have a true picture of how the garment will perform over its lifetime.

Acknowledgement

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