NEW METHOD CALIBRATION FOR CALIBRATION OF A BODY BOX

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Biography

Rajan (Raj) Jaisinghani is a chemical engineer with over 30 years of R&D experience related to fluid mechanics, particle science, including colloid and aerosol science, filtration and cleanroom technology. Raj has a BS in Chemical Engineering from BHU, India and a MS with additional graduate work from the University of Wisconsin. He is widely published in the above fields and holds 12 patents. Currently Raj is President and CEO of Technovation Systems, Inc.

Abstract

A rational method for the calibration or validation of Body Boxes (BB), which are used for garment cleanliness measurement in accordance to IEST-RP-CC003.3, is presented here. Without such calibration or validation the Body Boxes may be space biased and may not even be valid for comparative evaluation of garments. The method presented here involves point source aerosol generation within a tube, dilution and comparison of calculated dilution concentrations, based on tube concentration measurements, to actual measured BB sampler values. The ratio of these two values then results in the BB calibration factor for that point or zone within the BB. By repeating the process an average calibration value and variation or range is determined. Results of two such validations of actual BBs are presented in the paper.

Keywords

Body box, garments, validation, calibration, clean garments, IEST-RP-CC003.3, garment

Introduction and Scope

The Body Box (BB) test as described in IEST-RP-CC003.3 [1] is used to evaluate the cleanliness of garments. Essentially, the BB consists of a 4'x4' cross section clean enclosure with typically better than ISO Class 2 (in accordance to ISO 144661 [2]) supply of clean air and a means to collect, mix and sample the air in a manner such that particles released from the garment, during a series of exercises conducted by a test subject, are measured. In order to account for release of very few particles within the BB the particles released must contribute to the increase in the concentration of particles measured at the BB sampler. This means that the air must be perfectly mixed prior to sampling. This is difficult to achieve to say the least. Recognizing this, the IEST-RP-CC003.3 is intended to be used as a comparative test. However, if the BB has a spatial bias in detecting released particles then the test may not even be valid as a comparative test method. If the mixing of air prior to sampling is not complete then it is likely that particles generated in one spatial position within the BB may contribute to the sampler concentration either to a higher or lower degree. This means that orientation of the operator within the BB could affect results and hence the results are likely to be neither comparative nor repeatable. Hence, it is important that the BB be calibrated or validated in terms of accurately measuring the generation of particles independent of spatial position. This paper presents a method for such a calibration or validation of the BB.

Prior work on determining the BB calibration factor at the University of Arizona (3) used an aerosol dispersion technique to uniformly spread the aerosol in the BB and then measured the mixed concentration in a multi position sampling device to calculate the calibration factor. The calibration factor was reported as 320 for the device at the University of Arizona, indicative of losses or poor mixing. This method is not described in detail, and it does not appear to evaluate the spatial integrity of the results of the BB.

The method presented here not only determines the spatial effects of particle generation but is also a quantitative measurement of the loss of particles or the accuracy of the BB. It also enables determination of a calibration factor, which can be used to determine realistic values of concentrations measured for different garments. This should greatly reduce variations between BB measurements at different laboratories.

Calibration or Validation Method

The method basically consists of:

a) Introduction of a “point” source of aerosol, via a mixing aerosol injection tube (see Figure 1) in a spatial zone of the BB. This is diluted by the clean supply entering the mixing tube, or by using a pre diluted aerosol stream.
b) Measurement of this well mixed diluted concentration of the aerosol leaving the tube.
c) Measurement of the average BB airflow rate (the BB should be adjusted to have uniform velocity).
d) Calculation of the total dilution achieved by the total clean air diluting the aerosol leaving the tube.
e) Measurement of the BB sampler concentration and comparison to the calculated value in d) to determine the spatial Calibration Factor (CF).
f) This procedure is repeated at other spatial locations and then the average CF and standard deviation is calculated.

The key component for the calibration is the mixing aerosol injection tube. This is shown in Figure 1. A low concentration aerosol source (this can be an atomizer that generates a diluted PSL (Poly Styrene Latex) aerosol or simply room air from a non cleanroom source or partially filtered compressed air from a large tank or source of compressed air) is used to inject an aerosol into the top of the tube. Due to the low volume of air required for the procedure there is typically almost no variation (for the time frame of the procedure) in the influent concentration entering the tube when the aerosol source is air from an unconditioned space or from a compressor with a normal compressed air tank size. The aerosol enters the tube and so does clean air from the filters at the top open end of the tube. The tube is typically 36”-40” long, has a diameter of 2”-4” and has at least three triangular mixing elements within it. Other mixing elements that have low static pressure loss may also be used. These mixing elements ensure that the aerosol is fully mixed with the room air flowing through the tube. No special care is taken to minimize the losses on the mixing elements since such losses do not affect the procedure since they do not enter the BB and the BB sampler. It is important to note that there should be a minimal length of at least 6” between the last mixing element and the velocity probe opening (which is simply a hole large enough to accept the velocity probe – this hole being capped off when not in use) in order to ensure accurate velocity measurement.

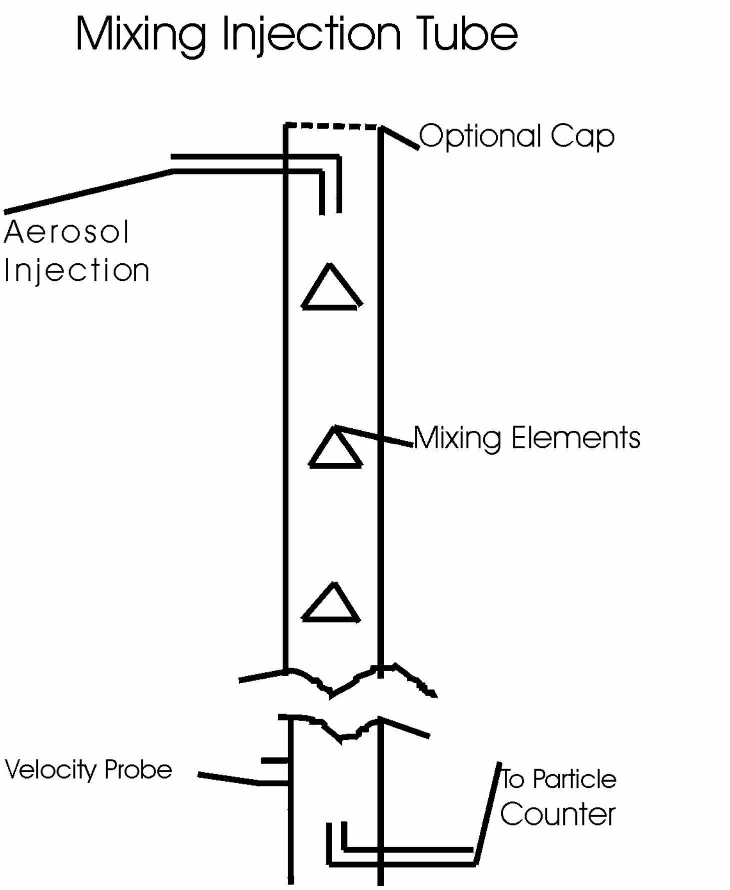

Figure 1 – Mixing Injection Tube Schematic

Although there is no theoretical limit to what the tube concentration should be, for better particle counting accuracy the tube concentration was adjusted so as to achieve about 100 – 200 counts per ft3 of ideally mixed aerosol, Ci, (see equation 3 below) at the calibration particle size. Depending on the calibration conditions (viz. room velocity and tube size) this translates to a tube concentration of about 30,000 – 100,000 particles per ft3 greater than 0.3 Um. It is important to note that a diluted aerosol may also be injected into a mixing injection tube without an opening on the top (as shown by the dotted line in Figure 1). However, it is important that the concentration be measured within the injection tube and not a prior. If the concentration entering were measured prior to injection in the BB, the cumulative losses in a metering devices, mixing devices and the injection tubing would then need to be taken into account since such losses will deduct from the amount being injected into the BB. Accounting for such losses is complicated and hence instead, it is better to measure the concentration leaving the mixing injection tube. In the measurements here, the cleanroom airflow has been used as a dilution stream, enabling a simpler aerosol injection method using a coarsely filtered compressed air source.

The tube is placed (using clean particle non shedding tripods) at a height of about 6”-12” off the ceiling filters. By means of particle counting around the top end of the tube, it is essential to confirm that there is no back flow of aerosol from the top of the tube. This is easily done because outside the BB the concentration of 0.3 Um particles should essentially be zero. In addition to the concentration leaving the mixing aerosol tube, the velocity exiting the tube is also measured. Additionally the airflow rate and hence the average velocity in the BB is also determined a prior. It is best if the BB is adjusted so that the spatial velocity distribution is very narrow and that the spatial velocity is almost constant. This is typically done by adjusting the dampers in the HEPA filters or other dampers in the supply ducts to the filters. The velocity is measured typically using a hot wire anemometer device or other calibrated means. Knowing the aerosol concentration, the tube exit velocity and the average room velocity, enables calculation of the actual ideal mixed concentration that should be measured at the BB sampler as follows.

The amount injected into the BB is given by:

$$I = Ct \times Vt \times At \qquad (1)$$

where,

Vt is the tube velocity and At is the internal cross sectional area of the mixing aerosol injection tube.

The dilution factor, DF, (dilution of injected aerosol by the BB clean air) is given by:

$$DF = Qb / (Vt \times At) \qquad (2)$$

where,

Qb is the BB airflow rate and is equal to Vb, the average BB velocity times Ab, the BB cross sectional area.

The ideally mixed calculated concentration at the BB sampler, Ci is then given by:

$$Ci = Ct / DF \qquad (3)$$

where,

Ct is the measured aerosol injection tube exit concentration.

The spatial BB calibration factor, CF is then given by:

$$CF = Cb / Ci \qquad (4)$$

where,

Cb is the aerosol concentration measured at the BB sampler with respect to that particular placing of the mixing injection tube.

It is important to confirm that the mixing injection tube aerosol concentration does not change significantly during the measurement. In the case of use of one particle counter this is done by first measuring Ct followed by measurement of Cb and then re-measurement of Ct. If the two values of Ct differ by more than say 5%, or another acceptance criteria, then the measurements are not accepted. This confirms the constancy of the aerosol injection. Alternately two different particle counters may be used simultaneously – one for measurement of Ct and one for the measurement of Cb. It is important however, that the two particle counters be calibrated in a consistent manner and be tested with a constant aerosol source for cross variance. Even in the case of the use of two particle counters it is important to confirm, at least once, the time constancy of the aerosol source.

This procedure is repeated at various positions in the BB and different values of CF are determined for different aerosol injection tube positions within the BB. At each position the measurements are repeated three to five times and then the mean and standard deviation of the CF values for the BB are determined.

Calibration of Two BBs and Results

The calibration of two BBs is described here in detail. Both the BBs are manufactured by Technovation Systems, Inc., Midlothian, VA and incorporate their high accuracy averaging aerosol sampler (HA^{3}S^{TM}). Both BBs are integrated within the walls of cleanroom laundries. The BBs are identical in size with the internal size being 4'x4' in cross section, a 12" raised floor with about 8' height over the raised floor. Both BBs operated at ISO Class 2 or better environments. An important distinction between the University of Arizona BB (3) and these BBs is that the University of Arizona BB utilizes multiple sampling ports reaching the cross section of a mixed section of the return duct, while the Technovation Systems, Inc. BBs each utilize a thorough mixing device (that apparently does not trap particles – as will be clear from the results presented herein) with only a single sampling point. The thorough mixing ensures that the single point is representative of the return airflow. In fact this is experimentally confirmed during installation, by sampling across the width of the duct. The main advantage of single point sampling of a well-mixed source is that during actual garment measurement there is no significant time lag between sampling and release of particles. With multipoint sampling release from sporadic sources on the garment tend to be not accounted for, keeping in mind that garments tend to release particles sporadically.

Table I BB #1 Calibration Results

BB #1

Qb	1829.28 scfm	Vb	114.33 fpm		
At	0.087266			Area Ratio	0.005454
Ab	16				

Based on 0.3 Um particle size   Particle counter sample volume = 0.1 ft3

Position	Sample #	Vt fpm	Vt/Vb	DF	Cb #/ft3	Ct #/ft3	Ci #/ft3	CF
P1	1	65	0.5685	322.5	111	35148	109	1.02
	2	65	0.5685	322.5	130	38532	119	1.09
	3	65	0.5685	322.5	128	41647	129	0.99
	4	65	0.5685	322.5	134	40462	125	1.07
P2	1	51	0.4461	411.0	162	40891	99	1.63
	2	51	0.4461	411.0	172	42737	104	1.65
	3	51	0.4461	411.0	142	44007	107	1.33
	4	51	0.4461	411.0	147	41765	102	1.45
P3	1	36	0.3149	582.3	101	76744	132	0.77
	2	36	0.3149	582.3	114	73649	126	0.90
	3	36	0.3149	582.3	128	82578	142	0.90
	4	36	0.3149	582.3	120	87145	150	0.80
	5	36	0.3149	582.3	118	89526	154	0.77
P4	1	39	0.3411	537.5	86	58046	108	0.80
	2	39	0.3411	537.5	98	63450	118	0.83
	3	39	0.3411	537.5	96	67033	125	0.77
	4	39	0.3411	537.5	93	59292	110	0.84
							Sum	17.60
							Mean	1.04
							Std	0.30
							%Std	28.93

Prior to calibration and aerosol injection the particle counts at the body box sampler were measured (Cb) to confirm that the counts at the sampler were essentially zero at 0.3 Um. This established that the BB airflow conduits and raised floor were not releasing or contributing to the particle counts. This was confirmed for both BBs.

The BB #1 was calibrated at 114 fpm average BB velocity, while the BB #2 was calibrated at 100 fpm. There are some differences in the mixing injection tubes and aerosol sources used for each of the BBs. These are described below.

For BB #1 a 4” ID clean rigid tube was used. The a low volume of aerosol from an atomizer was injected into the tube and hence the bulk of the driving force to overcome the resistance of the mixing elements was provided by the suction of the particle counter and the due to the BB airflow in the axial direction of the tube. By particle counter sampling around the top of the injection tube, it was confirmed that there was no back flow of aerosol. This was easy to validate because the counts in the BB were essentially zero at all locations. The particle counter used was a 0.3 Um HIAC PORTABLE manufactured by Pacific Scientific. The counter operated at 0.2 scfm. Due to this lower flow rate (as compared to BB #2) the flow velocity through the tube was significantly lower than the average value of the BB flow velocity. Further, the tube airflow rate was relatively more sensitive to local variations in the airflow in the BB itself (see Table I). Clearly, BB #1 has a higher variation (than BB #2) of air supply velocity.

Table II BB #2 Calibration Results

BB #2

Qb 1600 scfm Vb 100 fpm
At 0.02322 Area Ratio 0.00145
Ab 16
Based on 0.3 Um particle size Particle counter sample volume = 0.1 ft3

Position	**Sample #**	**Vt fpm**	**Vt/Vb**	**DF**	**Cb #/ft3**	**Ct #/ft3**	**Ci #/ft3**	**CF**
P1	1	115	1.1500	599.7	120	84218	140	0.85
	2	120	1.2000	574.7	198	103459	180	1.10
	3	123	1.2300	560.7	187	101961	182	1.03
P2	1	114	1.1400	605.0	171	91710	152	1.13
	2	117	1.1700	589.4	210	104090	177	1.19
	3	123	1.2300	560.7	113	78935	141	0.80
P3	1	120	1.2000	574.7	214	110241	192	1.12
	2	126	1.2600	547.3	201	107323	196	1.03
	3	129	1.2900	534.6	176	100541	188	0.94
P4	1	119	1.1900	579.5	124	87846	152	0.82
	2	122	1.2200	565.3	140	90684	160	0.87
	3	126	1.2600	547.3	155	94864	173	0.89
P5	1	119	1.1900	579.5	117	81143	140	0.84
	2	122	1.2200	565.3	126	81616	144	0.87
	3	121	1.2100	570.0	168	90763	159	1.05

Sum	14.53
Mean	0.97
Std	0.13
%Std	13.58

BB #2 used a more refined mixing and injection tube made using 2” ID clean rigid tubing. The aerosol source used was coarsely pre-filtered (estimated pre-filtration level of about 95% at sub micrometer sizes) compressed air from a large compressed air tank. The compressed air tank was pressurized to its maximum level and then the compressor was shut off so that the compressor did not turn on during the measurements. Additionally, a 1 scfm 0.3 Um particle counter, Model 500, by Climet Instruments, was used. Due to the higher aerosol volume, smaller diameter of the tube and the higher drawing power of the Climet counter, as compared to the BB #1 case, the tube velocity was typically higher than the average BB velocity. Further, the tube velocity varied less with respect to the position of the tube within the BB (see Table II) due to a) the BB #2 had a narrow range of velocities in the supply (ranging from 103 fpm to 116 fpm) and b) the constant compressed airflow contributed to a higher fraction of the total airflow within the tube, than did the air supply from the BB. Once again, it was confirmed, by particle counter sampling around the top of the injection tube, that there was no back flow of aerosol around the top of the tube.

Tables I and II show the measurements and calculations for the calibration of the two BBs. The following are the salient observations evident upon examination of Tables I and II.

1. At each position multi measurements for Ct and Cb were made. However, in the case of the BB #1 for each position the tube velocity Vt was only measured once at that tube. The measurement of Vt consisted of measurements of velocity at a minimum of three different positions within the injection tube and the reported values are average values.
2. As discussed before the BB #1 has a large variation in Vt. BB #2 calibration exhibits lower variation in Vt due to the fact that the compressed air is a larger fraction of the air flow through the injection tube. Additionally, the primary motive force for airflow through the tube are the compressed air and the higher vacuum of the particle counter. The airflow due to supply to return pressure gradient plays a smaller role and the BB #2 also has a narrower distribution of airflow ranging from 103 fpm to 116 fpm.
3. The BB #1 has an average CF of 1.04 while the BB #2 has an average CF of 0.97. Both BB have an excellent average value of CF – both very close to the ideal case of 1.0.
4. The BB #1 has a higher standard deviation in the positional values of CF than BB #2 – approximately 29% versus 13%. This is probably due to higher variation in airflow velocities within the BB #1 and due to slight differences in the mixing devices. The BB #2 had a more refined mixing device, which is reflected in the higher measured accuracy.
5. BB #2 has a range of spatial CF of 0.8 to 1.19, while BB #1 has a range of 0.77 to 1.77.
6. The calibration method does reflect the efficacy of the more advanced mixing sampler.

Summary

In summary the method presented here is able to determine the spatial variation and average values of the calibration factor for a BB in a convenient and practical manner. The use of a compressed air steady source for aerosol injection is also a convenient aerosol injection method that provides a practical on site steady source of aerosol. Calibration of BBs can result in the determination of spatial bias of the sampling system, and also can establish confidence in the use of the results for garment classification.

In terms of future work, this method should be investigated with many more BBs and the relative results should be compared by means of a “standard” set of garments that have approximately the same values of particle shedding. Additionally, values for calibration factor acceptability in terms of average CF and percent standard deviation should be established. Until this is done the BB results will be highly suspect - even as a comparative tool. Such work is best undertaken by the IEST working group connected to IEST-RP-CC003.3.

References

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