The measurement of air supply volumes and velocities in cleanrooms
Part 2: Anemometer readings at the filter face

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Abstract

Air supply velocities in cleanrooms are monitored by anemometers but these can be inaccurate if used incorrectly. In particular, vane anemometers give inaccurate readings at the face of high-efficiency supply air filters. It was found that the most accurate reading was obtained about 15 cm from the filter face. The number of readings required across the filter face to obtain an accurate average velocity was investigated, as was a scanning method using overlapping passes.

The air supply volume from a ceiling diffuser in a cleanroom can be measured by removing the diffuser and obtaining the average velocity of the supply filter, and multiplying that result with the 'active' area of the filter face. The velocity of the air coming from the filter face of unidirectional airflow benches or enclosures, isolators, and mini-environments is also routinely measured in a similar manner to ensure that they supply the correct air velocity. The accuracy of measurement of the average velocity of the air coming from a high efficiency filter in such situations was investigated by consideration of (1) uneven velocity distribution across the filter face (2) type of anemometer used and (3) measuring distance from the filter face.

Within the filter manufacturing industry, a filter is considered acceptable for use in a cleanroom if the velocity distribution across its face is less than +/- 20% of the average velocity. This variation is likely to cause difficulties in obtaining an accurate average velocity if insufficient velocity readings are taken across the filter face, but it is unclear how many measurements are needed. ISO 14644-3:2005[i] suggests a single reading in the middle of the filter. This would be sufficient if the airflow were even across the filter face, but in two fan-filter units investigated the value was underestimated by 10% and 17% compared to the average obtained from 16 measurements distributed evenly across the filter face. Our experiments suggest that to obtain a result within about 5% of the correct result, for a filter of a nominal size of 600mm x 600mm, the filter face should be divided into at least two equal areas, preferably four. Velocity readings should then be taken at the centre of these areas, and averaged. A 1200mm x 600mm filter would need twice the number of readings. Care has to be taken to ensure the anemometer velocity has reached a maximum before the readings are taken and the readings should be taken 15cm from filter face. An alternative method is to place the vane anemometer 15cm from the filter face, wait until the velocity reading has reached a constant value and then scan over the whole filter face in slow parallel passes. A minimum time of 30s should be used for scanning a 600mm x 600mm filter, and 60s for a 1200mm x 600mm filter.

A single reading of velocity obtained by a thermal anemometer samples about 5mm^2 of the filter face compared to about 8000mm^2 when a vane anemometer is used. As the air velocity across a high efficiency filter face is uneven, a vane anemometer should be a better choice than a thermal anemometer for ascertaining the correct average velocity of air coming from a filter.

When a vane anemometer was placed up against the grill on the filter face, the velocity reading was found to be about 25% greater than the true velocity, and the velocity dropped off as the distance away from the filter increased, until a constant and correct velocity was reached. It is assumed that this is caused by the greater air turbulence at the filter face. It has been industrial cleanroom practice for many years to obtain the correct velocity by measuring 10cm from the filter face. ISO 14644-3:2005 recommends a distance of 15cm to 30cm from the filter face. Our experiments suggest that 15cm is the best choice.

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Introduction

As described in Part 1 of this article[ii], cleanrooms minimise the contamination of products made in manufacturing industries, as well as bacterial infection of patients in hospitals. In 'unidirectional airflow' cleanrooms particle-free air is supplied from a complete HEPA filter ceiling and moves down through the room in a piston-like manner at a velocity of about 0.45/s before exiting through a perforated floor. A fuller description of cleanrooms, and how they are tested and operated is given by Whyte (2010)[iii].

The particulate air cleanliness of unidirectional airflow cleanrooms is directly related to the air supply velocity (Whyte 2010). Air supply velocities should be monitored throughout the life of the cleanroom, and monitoring intervals are suggested in ISO 14644-2:2000[iv].

An anemometer is used to measure air velocity and there are two types generally used in cleanrooms. The vane anemometer is the most popular type, having a set of vanes of about 10cm diameter that revolve at a speed dependant on air velocity. The second type is a thermal anemometer which measures velocity using the electrical resistance of a heated thermistor (about 2mm in diameter) that is cooled by the air flow.

It has been reported that the measurement of air supply velocities in a cleanroom may give inaccurate readings (Anonymous, 2006)[v]. As this parameter is of prime importance in determining and maintaining the cleanliness of unidirectional airflow cleanrooms, the reasons were investigated.

Description of test rig and instruments

A simple test rig was set up, incorporating a variable speed fan-filter unit, with a 5 metre low velocity wind tunnel upstream to allow accurate measurement of the air volumes required for the tests. How this was done is described in greater detail in Part 1 of this article.

The downstream side of the fan-filter unit had a high efficiency particulate air (HEPA) filter with an 'active' filter face area of 0.54 m x 0.54 m, i.e. 0.29 m^2. (The 'active' area of a high efficiency filter is considered to be the area of the filter media where the air passes through, and does not include the frame). The air filter was protected by a grille.

In addition, for this series of tests, the downstream side of the fan filter unit was extended by two alternative tunnels, 1m in length or 15cm in length. These were to prevent the air moving sideways during investigations of airflow from the filter.

By varying the fan speed, an exact filter face velocity, could be obtained.

The vane anemometer used in the experiments was an Airflow LCA 501 and the thermal anemometer was an Airflow Developments Model TA2. Both anemometers were calibrated using the low-velocity wind tunnel.

Measurement of air velocities and air supply volumes by anemometers

When the average air velocity of the air coming from a filter is multiplied by the area of the filter face to calculate the air supply volume, the result can be incorrect (Anonymous, 2006). As the measurement of the area of the filter face is unlikely to be incorrect, it must be assumed that the velocity measurements are the problem. The possible reasons for the problem were investigated by carrying out the following experiments.

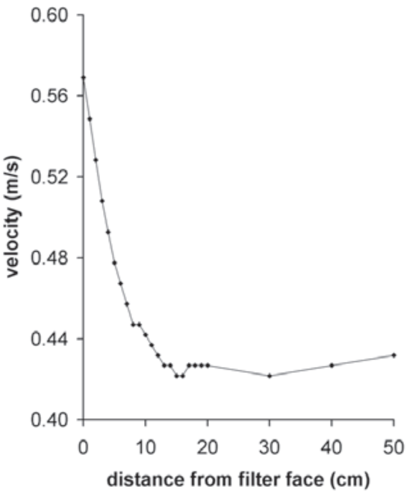

Figure 2 Air velocity with respect to distance from filter face

Air velocities with respect to distance from the filter face

Air velocities were measured with a vane anemometer at various distances from the filter face. To ensure that a drop in velocity was not caused by the airflow from the filter flowing sideways, the 1m tunnel was attached to the fan/ filter unit to constrain the airflow. The air velocity at the filter face was set at 0.45m/s and measured at zero distance from the filter's protective grille and at 1cm intervals up to 20cm, and then at 10cm intervals. Measurements were carried out at four points evenly distributed over the measurement plane and the overall average velocity calculated. This was done at each distance from the filter face, and the results up to 50cm are shown in Figure 1. The drop in apparent velocity at 10cm and 15cm from the filter grid, compared to the velocity at the filter face, was found to be 21% and 25%, respectively. The velocity reading more or less levelled out after 15cm. Readings taken after 50 cm (not recorded on the graph) continued in the same pattern.

Air velocity distribution across the filter face

To obtain information on air velocities across the filter face, a small area was measured using the thermal anemometer. The velocity was measured at 1mm intervals in a horizontal line across the filter, the line passing over areas where the air velocity was likely to be at its

Figure 1 The vane anemometer

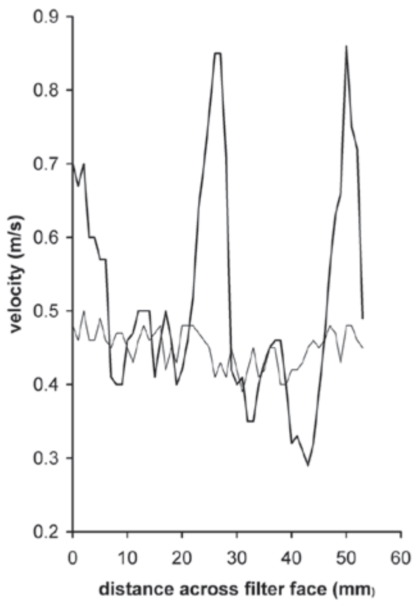

Figure 3 Air velocity with respect to distance across the filter face. The thick line shows velocities at the filter face. The thin line shows velocities 15 cm away from filter face.

highest and lowest because of both the filter and protective grille construction. These velocities are shown in Figure 2. The average velocity was 0.51m/s and the maximum and minimum velocities were 0.86m/s and 0.31m/s, respectively.

Also shown in Figure 11 is the velocity measured along the same line but 15 cm away from the filter face. It can be see that the velocity was less variable with an average, maximum and minimum of 0.45m/s, 0.50m/s, and 0.40m/s, respectively.

Methods of obtaining the average velocity at the filter face

To ascertain how to correctly obtain the average value of the air velocity coming from a filter, two fan-filter units from different manufacturers were investigated. To constrain the air flowing from the filter, the 15cm tunnel was attached to the downstream side of the fan/filter unit. The tunnel opening, which was the same area as the filter (540mm x 540mm), was divided into 16 equal areas by means of fine nylon threads strung across the face. The velocities were then measured 15cm from the filter face and in the centre of 16 areas, and then at 8, 4 and 2 equal areas, as well as in the middle of the filter.

The vane anemometer used in these experiments took over 40s to build up from stopped to the correct speed. Therefore, to obtain accurate readings, the anemometer was allowed sufficient time to build up to speed, and then consecutive readings, averaged over 5s, were taken until a constant reading was obtained.

It is clear that the more velocity measurements taken across the filter face the closer the average result will approach to the true result. Sixteen measurements would be considered an excessive and impracticable number if used in cleanrooms to test filters with a nominal area of 600mm x 600mm. However, sampling 16 points with a vane anemometer will sample a total area of about 0.13m^2, which is about half of the total filter area. It was therefore assumed that an average of 16 points gave a good estimate of the true average velocity. The average velocities from 8, 4, 2, and 1 points were then calculated as a percentage of the average velocity obtained from 16 points. These results are shown in Table 1. It may be seen that if only one measurement is taken at the centre of the filter, the average velocity was underestimated by 10% in one of the fan-filter units and by 17% in the other. Inspection of the results in Table 1 shows that two velocity measurements would give a result a little above 5% of the estimated true average obtained from 16 measurements, four measurements would give an average velocity a little above 4% of that, and 8 measurements a little above 3% of that.

An alternative method of obtaining the average velocity of the air coming from a filter face is to scan the whole area of the filter face over a given time interval. This method is not normally used when testing a cleanroom, but in view of the difficulty in obtaining an average velocity, as demonstrated in this article, it seems a possible alternative. The vane anemometer used in these experiments had a 'time constant' facility that allowed it to average the readings over a selected time period of 5s, 10s, 20s or 30s. To obtain an average velocity, the anemometer was placed 15cm from the filter face and the velocity reading allowed to build up to a constant value, which could take 40 to 50 seconds. The filter face was then scanned backwards and forwards in slow parallel sweeps in a manner that would sample the complete filter face as adequately as possible within the time period selected. Time periods of 5s, 10s, 20s, 30s and 60s were investigated and it was found that a time period below 30 seconds gave results that were inconsistent and greater than +/-5% of the true result, and a scan of at least 30s was required to give repeatable and accurate readings (<5% of the average value) from a filter of a nominal size of 600mm x 600mm.

Table 1 Average velocity from a filter obtained from different numbers of measurements

	Number of measurements				
	16	8	4	2	1
Fan filter unit A					
Average velocities (m/s)	0.48	0.46	0.45	0.45	0.43
% difference	-	-4.2	-6.3	-6.3	-10.4
Fan filter unit B					
Average velocities (m/s)	0.48	0.47	0.47	0.46	0.40
% difference	-	-2.1	-2.1	-4.2	-16.7
Average difference from the two fan/filter units	-	3.2	4.2	5.3	13.6

Acknowledgements

Scottish Society of Contamination Control (S2C2) who donated the cost of the materials to build the low-speed wind tunnel.

AAF who donated the fan-filter unit used in the low speed tunnel.

Jim Carmichael of Clean Air Containment Services who loaned the vane anemometer.

International Journal of Ventilation who very kindly gave permission for the adaptation of an article originally published in March 2010, Volume 8, pages 325 to 336.

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