Filter installation leak testing by the photometer method

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This article is the second of a short series of extracts from Bill Whyte's new book Cleanroom Testing and Monitoring and is reproduced here with the kind permission of the author, Bill Whyte, the publisher, Euromed Communications, and the owner of the copyright, the Cleanroom Testing and Certification Board – International (CTCB-I). The objective in publishing these extracts is to give readers a flavour of the content and depth of the book which is recommended as a comprehensive textbook and an essential reference for cleanroom managers, cleanroom test engineers, cleanroom service engineers, cleanroom designers and specifiers and anybody who is concerned with cleanrooms. All too often testing and monitoring are insufficiently considered until an installation is physically complete. If you design and build an installation to achieve a certain performance, it is essential that you understand and plan at an early stage for how that performance will be verified and monitored throughout the life of the installation.
Editor

Chapter 8 Filter installation leak testing by the photometer method

The air supply to a cleanroom should be free of significant amounts of airborne contamination. This is achieved by installing suitable air filters and, in particular, high efficiency filters (HEPA and ULPA) at the entry of the supply air to the cleanroom. However, leaks can occur in the high efficiency filter installations and allow unfiltered air to enter the cleanroom. How these leaks are located is discussed in this chapter.

There are two methods used to locate leaks in high efficiency air filter installations that are described in ISO 14644-3: 2019. These are by use of a photometer, or by a light scattering airborne particle counter (LSAPC). The photometer method is discussed in this chapter and the LSAPC method is discussed in Annex D.

Information on types of high efficiency air filters and their particle removal efficiency has been given in Chapter 3. In this chapter, it is assumed that the filters installed in a cleanroom have the correct particle removal efficiency and have been individually tested by the manufacturer to ensure they are free of leaks. However, owing to possible damage during transportation and installation, the high efficiency filters must be tested after installation. They should also be tested periodically, to locate any leaks that have developed over time.

8.1 Types of leak

The type of leaks found in high efficiency air filters are the type shown in Figure 8.1, and these will now be discussed.

A. filter media.

B. filter media-to-filter casing interface.

C. gasket or gel seals.

D. filter casing joints.

A – Leaks in filter media

Leaks can occur in the filter media. Many of these leaks are found where the filter media is folded to produce pleats.

B – Leaks at filter media-to-filter casing

Leaks can occur where the filter media pack is sealed into its filter casing and these are often in the corners. This type of leak is usually found when the filter is scanned during manufacturing, but damage can occur when the filter is installed. Uneven fitting of the filters into their housings or ceiling grids, and over-zealous tightening, can cause these leaks. Problems can also occur during use, such as damage by people walking on lightweight ceilings that causes the filter casing to flex. This can cause the sealant that holds the filter media to the casing to give way and allow leakage.

C – Leaks at gasket and gel seal

Leaks can occur at the seal between the filter and its housing or ceiling grid. The two systems used to prevent this are gaskets and gel seals.

Synthetic rubber gaskets: Gaskets are a common type of seal used between a filter and its housing, or between a filter and a ceiling grid. Show in Figure 8.2 is the arrangement when a filter is inserted into its housing.

Filter gaskets are usually made from synthetic rubber foam, such as neoprene, and are about 6 mm thick when uncompressed. They are glued onto the surface of the filter casing where it contacts the filter housing or ceiling grid. The filter is drawn down by clamps and the gasket is compressed so there should be no leakage between the filter casing and its housing or ceiling grid. Gaskets are also produced by dispensing foam onto the filter casing as a continuous gasket material. A thin film of silicon

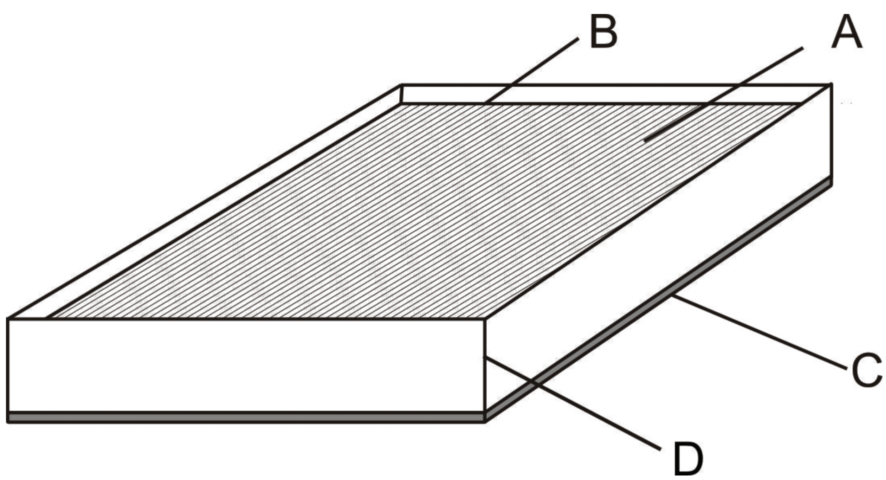

Figure 8.1: Leakage areas in a high efficiency filter

grease is often applied to the gasket surface when mounting the filter to help seal it and ensure that the filter comes away cleanly when the filter is changed. Gasket leaks often occur at corners. Leakage occurs because of poor quality or damaged gaskets, or because the mounting surface is distorted, or uneven.

Gel-seal method: In a UDAF cleanroom, filters are often installed into a suspended ceiling grid. Gaskets can be used, but an alternative approach is to use gel seals. In this approach, the ceiling grid is made from extruded aluminium channels which contain a jelly-like fluid that should not flow out of the channel. When a filter is fitted, knife-edges in its casing enter the channel and the gel flows round the knife-edge to prevent airborne contamination passing into the cleanroom. A typical arrangement is shown in Figure 8.3. Similar arrangements are available for individual filter housings used in non-UDAF cleanrooms.

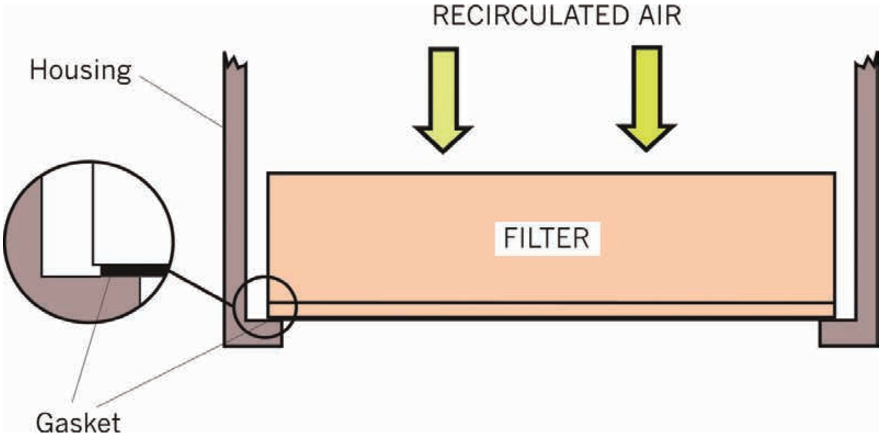

Figure 8.2: High efficiency filters with gaskets in a suspended ceiling grid. Filters inserted from above the ceiling grid

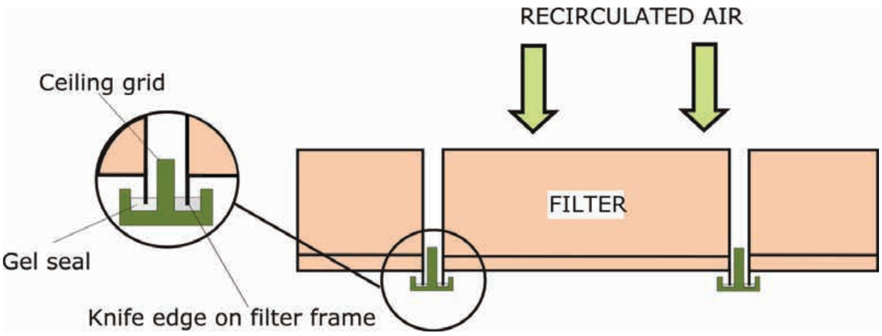

Figure 8.3: Filter housing gel-seal method

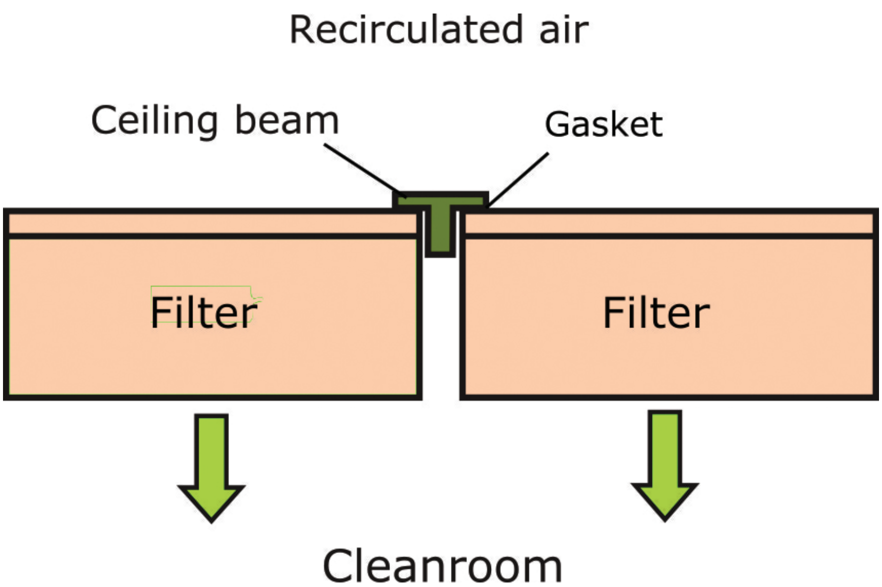

Figure 8.4: Ceiling (and gasket) leaks from a cleanroom inserted filter

D – Leaks from filter casings

Filter casings are made from a variety of materials but aluminium is a common material for high efficiency filters. If the casing is poorly manufactured, or insufficient care taken during transportation or installation, leaks can occur, often at joints. If the filter is inserted from above the ceiling, then, as can be understood from inspection of Figure 8.2 and Figure 8.3 that casing leaks are unimportant, as any contamination coming from leaks in the casing will have to pass through the filter before entering the cleanroom. However, if the filter is inserted upwards from the cleanroom (see Figure 8.4), then leaks of contaminated air from the casing can directly enter the cleanroom.

Testing high efficiency filter installations for leaks is usually carried out by challenging the filter with an artificial test aerosol. This test aerosol is introduced upstream of the filter at a suitable and even concentration. Any leaks are found by scanning downstream of the filter installation with a photometer probe to locate and measure any penetration of the test particles.

8.2 Requirements of leak testing

Type of aerosol challenge

There are two methods of generating artificial aerosols for testing filter installations with a photometer. These are either cold or hot (thermal) aerosols generated from specially selected liquids. Di-octyl phthalate (DOP) was the original material used to produce aerosols to test filters. However, because of reported toxic effects, it is no longer used in many countries, and oils with similar properties, such as poly-alpha olefin (PAO), di-ethyl hexylsebacate (DEHS) which is also known as dioctyl sebacate (DOS), and pharmaceutical and food grade oil such as Shell Ondina oil, are used.

In certain cleanrooms, such as these used for semiconductor manufacturing, inert test particles are specified. This is to ensure that no 'outgassing' of chemical products that are harmful to the product or process can come from test aerosol deposited on filters or air ducts. Microspheres, made from polystyrene latex are often used with an LSAPC. They are not discussed in this chapter but in

Annex D of this book, where the LSAPC method of locating and measuring filter installation leaks is described.

Aerosol generators

Laskin nozzle generators: To create a cold-generated test aerosol, a Laskin nozzle is used with an oil of the type previously discussed and compressed air at a pressure in the range of 140kPa to 170kPa (20-25psig). Figure 8.5 shows an aerosol generator with one Laskin nozzle, although generators are available with up to six nozzles. It should be noted that the oil level should be kept above the top of the nozzle.

The output of one Laskin nozzle is less than 0.5g/min when using an air pressure of 170kPa (25psig). This provides a concentration of approximately 10 mg/m^3 (10µg/L) in 0.8m^3/s of airflow, which can only be used to test a small air supply system like that found in an isolator, RABS, or UDAF workstation. To test a larger system, multiple nozzles are needed.

Thermal generator: The thermal generator uses an inert gas as a propellant, and oil of the type previously discussed is injected as a mist or aerosol into a heated evaporation chamber operating at an appropriate temperature. In this chamber, the oil mist is vaporised in the inert gas. When this mixture exits the generator and meets the cooling effect of the surrounding air, the oil condenses into an aerosol with particles of a size that is suitable for testing high efficiency filters. Particle size will be discussed in the next section.

Thermal generators are able to generate the large quantities of test challenge needed for high volume air supply systems and, for that reason, they are often used in preference to Laskin nozzles. A thermal generator does not need an air compressor to generate the high pressure required by a Laskin nozzle, although it needs a cylinder of inert gas, usually carbon dioxide or nitrogen, as the propellant. The inert gas is used to remove the flammability risk in the heated chamber where the heater block operating temperature is above the flashpoint of the oil. If the challenge aerosol from a thermal generator is to be introduced into a positive pressure duct or plenum, then a separate fan or blower is required. The generator is not connected directly to the intake of the duct or plenum but an air blower draws in condensed aerosol from the generator and mixes it with ambient air and pushes it into the duct or plenum. This arrangement is shown in Figure 8.6.

Thermal generators can typically produce from about 1g/min to around 20g/min of aerosol. If a test challenge of about 10mg/m^3 is required for use with a photometer, then sufficient aerosol will be generated to test a ventilation system with an air volume supply rate of about 30m^3/s.

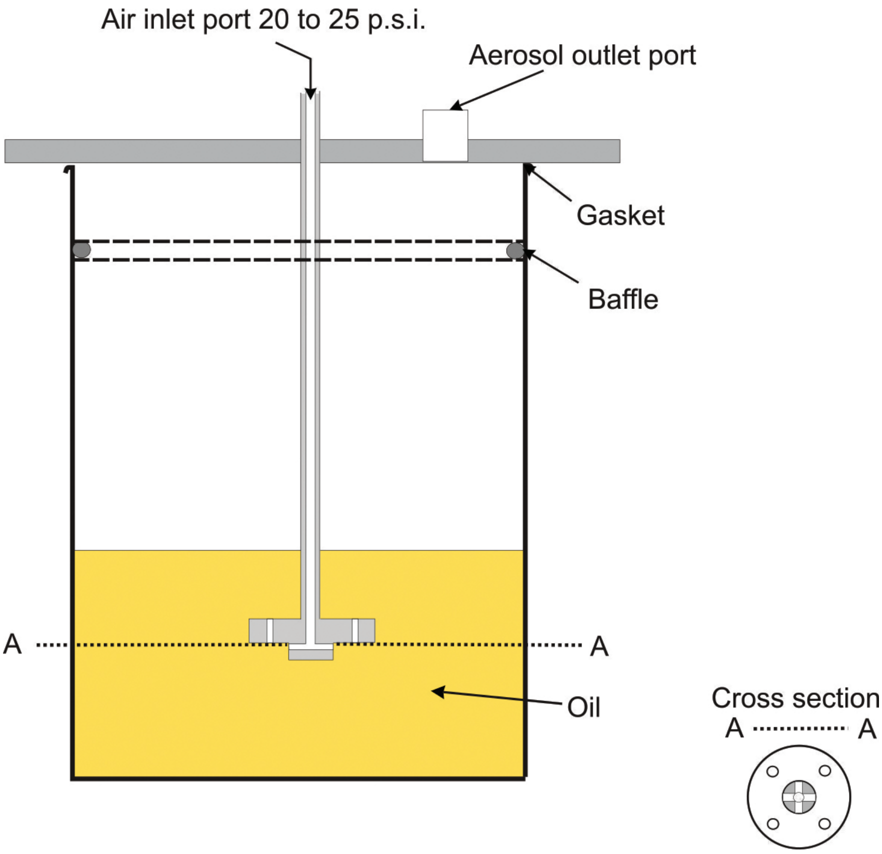

Figure 8.5: Cold aerosol generator with Laskin nozzle

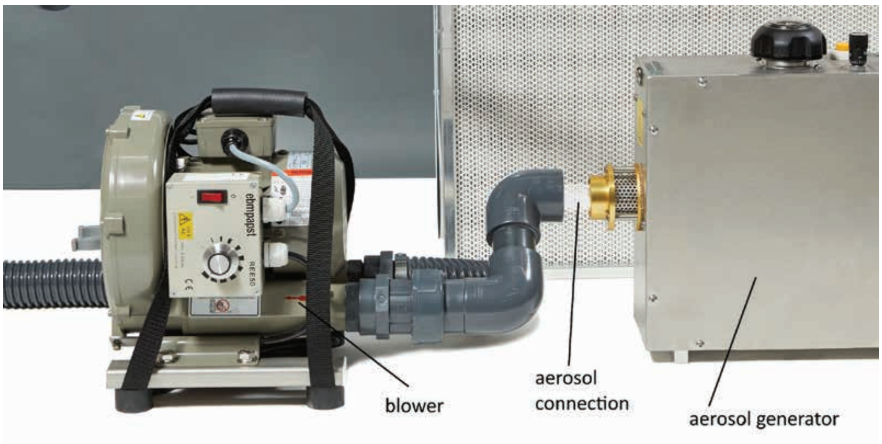

Figure 8.6: Thermal generator passing smoke to an air blower

Size distribution of the test challenge particles

ISO 14644-3: 2019 suggests that the mass median diameter of the aerosol test particles used to test high efficiency air filters will typically be between 0.3 µm and 0.7 µm with a geometric standard deviation of up to 1.7 µm. The FDA Guidance suggests that *'the challenge involves use of a polydispersed aerosol usually composed of particles with a light-scattering mean droplet diameter in the submicron size range, including a sufficient number of particles at approximately 0.3µm. Although the mean is normally less than one micron, it is greater than 0.3µm'.*

The above specifications are achieved by both a Laskin nozzle and a thermal generator, although thermal generators usually produce a slightly smaller size of particle.

Photometers

A photometer is used in conjunction with a sample probe to locate any high concentrations of test particles that indicate a leak. An air sample is drawn from the probe into the photometer (see Figure 8.7) and as the airborne particles pass through a beam of light in the photometer, they scatter light. The amount of forward-scattered light is measured by a photomultiplier tube and converted into an electrical signal. This signal is shown on the display panel of the photometer in the required units of measurement (mg/m^3 or µg/L); the more particles, the higher the signal and displayed value. It is worth noting that the value of mg/m^3 is identical to µg/L but ISO 14644-3; 2019 uses mg/m^3.

A photometer usually measures a test particle concentration of between 0.0001mg/m^3 and 100mg/m^3. It measures the total amount of light reflected by the particles and is, therefore, different from an LSAPC which sizes and counts each single particle.

The general method of using a photometer to locate leaks is as follows:

1. Ensure all switches and connections on the instrument are in their default positions. Switch on the instrument, and ensure the sample selection switch or valve is in the required position,
2. Set up the instrument according to the manufacturer's instructions,
3. Measure the upstream challenge using the valve selector switch,
4. Set the instrument to measure the percentage filter penetration and the concentration of the upstream challenge aerosol (mg/m^3) as the 100% reference,
5. Scan the surface of the filter for leaks. When a leak is located, the penetration is calculated as follows by the instrument and shown on the display as a percentage of the challenge aerosol.

$$Leak\ penetration\ (\%) = \frac{Y}{X} \times\ 100$$

where:
Y is the measured leak in mg/m^3,
X is the average upstream challenge concentration in mg/m^3.

6. If the penetration reading is over the agreed value, which is usually 0.01%, a leak has been found. Its location should be noted.

Figure 8.7: Photometer being used with probe and printer

Probe type

ISO 14644-3: 2019 recommends two standard types of probe. The most common is known as a 'fish tail' probe, with intake dimensions of 1cm x 8cm. This type of probe is shown in Figures 8.7 and 8.8. The other type of probe is a circular probe with an intake diameter of 3.6cm. These probes are used with photometers that have an air sample flow rate of 28.3L/min (1ft^3/min).

Scanning with probe

The scanning speed of the probe across the filter face is important. If the scanning speed is too quick, a leak can be missed. ISO 14644-3: 2019 suggests a scanning speed of approximately 5cm/s. The scanning should be carried out by means of overlapping passes over the filter face. The overlap should be about 1cm and the probe held 3cm, or less, from the filter face or filter installation.

What is a filter leak?

It is necessary to decide what particle penetration of the filter installation is considered a leak. ISO 14664-3:2019 suggests a penetration exceeding 0.01% of the upstream concentration should be used for filters with overall efficiencies of ≥99.995% (as classified by the ISO 29463 and EN 1822 method). However, if the overall efficiency of the filters is ≥99.95% and <99.995%, then the acceptable penetration is 0.1%. Where the overall efficiency is <99.95% then the penetration that defines a leak should be decided between the customer and supplier.

8.3 Method of testing filter installations

Preliminaries

Before starting any testing with an aerosol generator, it will be necessary to consider whether smoke alarms can be set off by spillage of smoke. If this is likely to be a problem, it is best to turn off any smoke alarms rather than suffer the embarrassment of the arrival of the fire brigade. Sealing the alarms (temporarily) with plastic film and tape, so that they cannot detect the aerosol particles, is another possibility. Alarms that are set off by a temperature increase can be ignored.

Release of test challenge particles

The test particles that challenge a filter should have an even concentration across the back of the filter. If this is not done, uneven concentrations may cause the filter to incorrectly pass or fail the leak test. ISO 14644-3: 2019 suggests that the variation in the aerosol concentration over time should not exceed +/–15 %. However, the same standard provides no information about the allowable variation in the challenge concentration across the back of the filter, although it is often considered that this should also not exceed +/–15%.

In some situations, the test aerosol can be introduced just after the air conditioning plant. If this is done, then by the time the aerosol reaches the terminal high efficiency filters, it should be well mixed and the concentration of test particles across the back of the terminal filter will be even. However, if the aerosol is injected into the ductwork leading to the filter, it should be introduced at a distance no closer than 15 to 20 duct diameters before the filter. To ensure good mixing, the test aerosol should be injected into the centre of the duct but a good method of introducing the test aerosol is to use a pipe across the duct that has a series of holes along its length. This pipe is known as a 'sparge' pipe and is shown later in Figure 8.13. The evenness of the filter challenge should be measured at multiple points before the filter before testing starts.

Prior to scanning a filter, it is necessary to set the concentration of test particles in the air immediately upstream of the filter. A concentration of between 1mg/m^3 and 100mg/m^3 should be used. To reduce the potential for blockage of the filters with test particles, it is best to use a concentration at the lower end of this range but this should be consistent with the capability of the photometer, as not all photometers can work at lower concentrations.

The length of tubing between the aerosol generator and its entry point to the ventilation system should be as short as possible. This will minimise particle deposition in the tubing and changes in the particle size distribution.

Scanning for leaks

Once it has been established that the particle concentration behind the filter is even, the concentration should be measured by the photometer and its reading is set as the 100% challenge. The filter face can then be scanned for leaks which will show as >0.01%, or other agreed penetration.

The normal scanning method is to use a probe to scan over the whole filter installation for leaks. It will be necessary to decide where to start scanning. It is usually best to start at the gasket area, rather than the filter face, so that any spillages of test particles from the gasket area do not show up as false leaks in the filter media. After checking the gasket, it is best to move on to check the sealing between the filter media pack and its casing, and then finish with the filter face.

Scanning for gasket leaks: There are different types of gasket leaks to be considered. These are gasket leaks from filters inserted from above the ceiling of the type shown in Figure 8.2, and gasket leaks from cleanroom-inserted filters of the type shown in Figure 8.4. Scanning for gasket leaks in a filter inserted from above the ceiling is a relatively simple procedure as the gasket interfaces are visible and accessible. Scanning a cleanroom-inserted filter for gasket leaks is a more difficult procedure and this is now discussed.

A filter that is inserted from the cleanroom into a ceiling grid or housing will have a space between the filter and adjacent filters where the air is stagnant. To locate a gasket leak in these situations can be difficult, and Figure 8.9 illustrates the problem in a cleanroom-inserted filter in its housing. The particles from a gasket leak will spread out and fill the space between the filter and its housing and give a high concentration of particles that can cause

Figure 8.8: Scanning a filter

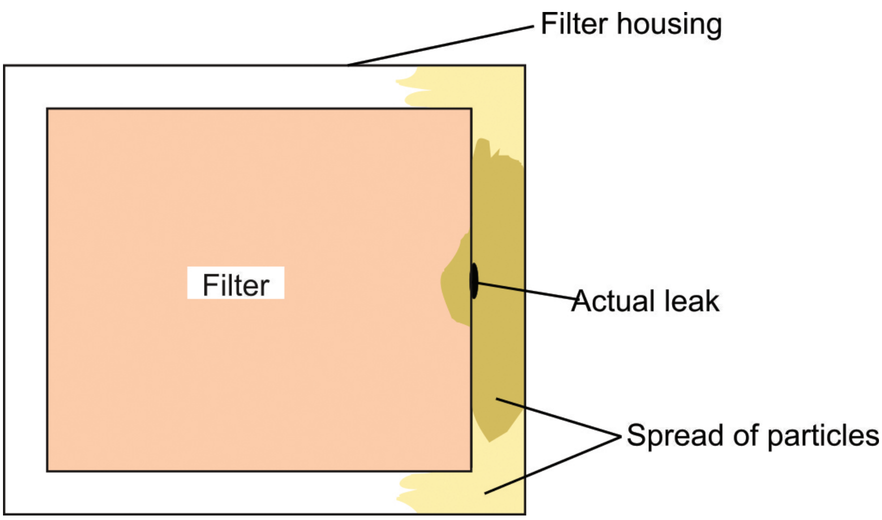

Figure 8.9: Spread of particles from a gasket leak in room inserted filter

the position of the leak to be thought to be away from its actual position. Ascertaining the exact position of the leak is time consuming and may be considered unnecessary but, if required, the probe from the sample tube can be removed and the tube used to locate the leak, although this will give a penetration value greater than had a probe been fitted. To assist in the location of the gasket leak, a particle-free jet of air can be used to clean out particles but a few wafts of air from a baffle plate may be sufficient.

If a gasket leak is found, the filter should be removed, and the seating area of the housing or ceiling grid inspected for distortions or unevenness. If the seating area is satisfactory, the filter can be re-seated using a thin layer of silicon grease. If that does not succeed in stopping the leak, the filter gasket should be replaced; this could be the first option. If that does not succeed, mastic could be carefully used between the gasket and the housing or ceiling grid. If none of these suggestions work, the filter, filter housing, or section of the ceiling grid may need to be replaced.

Checking for leaks from filters that use the gel seal method may also be required. The expectation is that gel seals will be free of leaks, but that may be incorrect.

Distinguishing between gasket and casing leaks: A difficulty with cleanroom-inserted filters is that, if there is a leak in the casing, it can be difficult to distinguish from a gasket leak. This has been illustrated in Figure 8.4. Access to the casing to check for leaks is also a problem. A method that can be used to locate leaks in the filter casing is to use a test rig similar to that shown in Figure 8.10. This allows access for scanning for leaks round the casing when the filter is challenged by a test aerosol.

The test rig shown in Figure 8.10 can also be used to speed up the fitting of filters when a cleanroom has a large area of filters to be tested. Each filter is tested on the rig for leaks in both the filter casing and the filter media. The filter is then carefully fitted into its housing or ceiling grid and, when all filters have been fitted and the ventilation switched on, the filters can be checked for gasket or gel seal leaks.

It should be noted that if the test rig is used in a cleanroom during construction and the ventilation has not been switched on, the cleanroom air will have a high particle concentration that might interfere with the recognition of leaks. In that situation, the test rig should be contained in a temporary clean enclosure which can be assembled from 25mm square box steel sections that is covered with plastic film or sheet. There is no need to ventilate the enclosure, as air coming from the filter being tested will produce a low particle concentration.

Scanning the filter face: When scanning the filter face, the probe should be held 3 cm from the filter face and the filter scanned with overlapping strokes at 5 cm/s. If a leak is found, it will be necessary to return to the leak, and pass slowly over it, so the exact position can be ascertained. If a fish tail probe is used, it is common to scan in one direction, turn the probe and scan again at 90° to the original direction so as to locate the position of the leak. It may be necessary to pass slowly over the leak several times from different directions before the exact position is ascertained. Removing the probe and using only the tube is another way of accurately locating the position of the leak. However, this method is likely to give a higher value of the leak penetration and the fish tail probe should be used to obtain the true value.

If the filter face is scanned when there is also a leak at the gasket then, as previously discussed, particles from the gasket leak can spill over onto the filter face. This can occur in the right hand

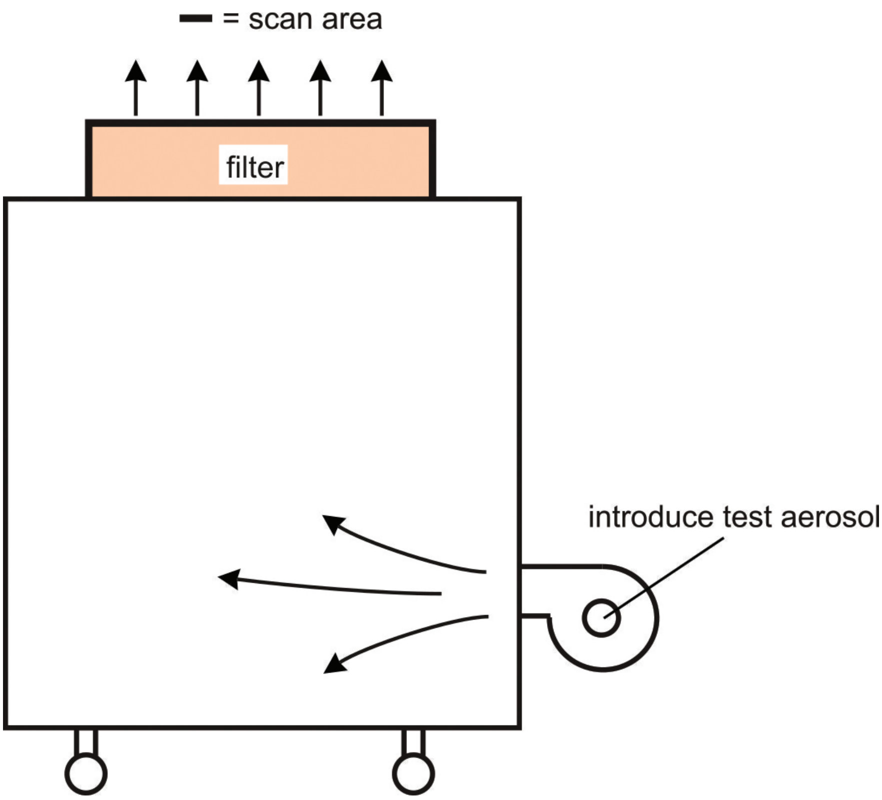

Figure 8.10: Test rig for distinguishing leaks

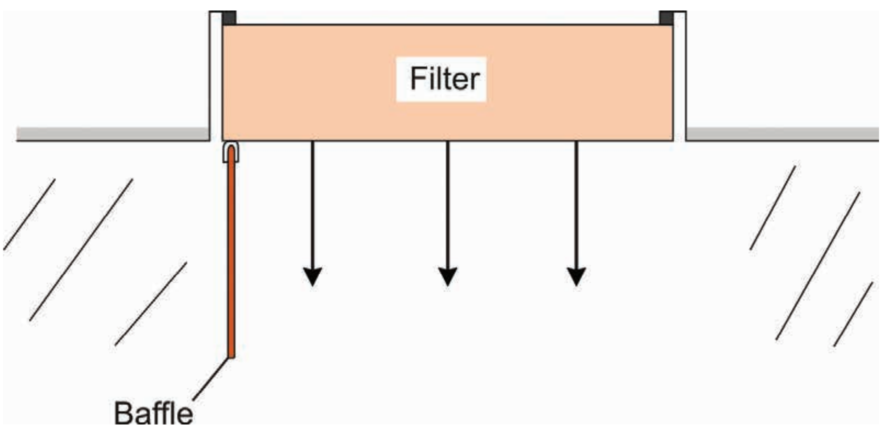

Figure 8.11: A baffle plate used when scanning a filter with leakage coming from the gasket

side of the drawing in Figure 8.11. Leaks can then be erroneously reported as being from the filter face. This problem can be largely overcome by use of a baffle plate held on the filter casing as the adjacent filter face is scanned. This approach is shown in the left hand side of Figure 8.11.

8.4 Influence of filter face velocity on particle penetration

The chance of a leak being found in a high efficiency filter is influenced by the filter face velocity. If the filters are used at a higher velocity than when tested during manufacture, the filter may unexpectedly fail the leak test. The reason for this is shown in Figure 8.12.

Figure 8.12 shows the removal efficiency of different particle sizes at different air velocities through filter media used in a HEPA filter. It should be noted that the velocities are through the filter media and not from the complete filter. Figure 8.12 shows that doubling of the velocity can reduce the filter removal efficiency by almost 10 fold. This information may be an explanation of an unusual failure of the leak test.

8.5 Additional considerations when testing filters

Testing filters in non-UDAF cleanrooms

If a ceiling diffuser is used to distribute the air supply in a non-UDAF cleanroom, it should be removed. If this is not done, it will be impossible to satisfactorily scan the filter installation for leaks. Scanning should then be carried out as previously described.

Testing filters in UDAF cleanrooms

A problem encountered when checking a complete filter ceiling of a vertical UDAF cleanroom is that the total area of the filter face is so large that leak testing can take several days. This testing may be carried out just prior to the cleanroom being opened for manufacturing and the testers can be under pressure to quickly complete the testing. To reduce the testing time, it is possible to scan by use of several photometers placed on a trolley, with their inlet probes 3cm from the filter face, and carrying out scanning by moving the trolley, which can be motorised, about the room.

It is also possible to reduce the testing time by scanning each filter on a rig of the type shown in Figure 8.10 to demonstrate that the filter face and casing is free of leaks. The scanned filter is then carefully placed into the ceiling grid. When the whole filter ceiling is in place and the ventilation system switched on, the gaskets or gel seals can be checked for leaks.

Testing filters in UDAF workstations, RABS and isolators

Isolators, RABs and UDAF workstation filters can be tested using the methods previously described. However, because of the short distance between the location where test aerosol is introduced and the filter, it may be difficult to obtain an even challenge across the back of the filter. Tapings into the plenum behind the filter in at least two positions that are well spaced apart should be provided by the manufacturer of the clean air device so that the evenness of the aerosol challenge can be checked. If they are not provided, they can be installed while on site.

The test aerosol is often introduced into the air intake of a clean air device with the hope that the fan will mix the aerosol so it is uniform across the back of the filter. This will often not work, and it may be best to introduce the test aerosol by means of a manifold or sparge pipe that will spread the test aerosol across the intake (Figure 8.13). Sparge pipes have small holes of about 2mm diameter drilled at regular intervals along the length of the pipe in order to spread the test challenge across the rear of the filter, or filters. A manifold or sparge pipe that is permanently fitted in an isolator, RABS, or UDAF workstation is a useful design feature.

8.6 Repair of leaks

The ISO 14644-3: 2019 standard accepts that repairs can be made to any part of the filter as long as this is acceptable to the customer. The FDA guidance suggests replacement of the HEPA filter or, when appropriate, a repair of a limited area of the filter. ISO 29463 suggests that 5% of the filter face area can be repaired, although the maximum length of repair should not be greater than 3cm.

An effective repair can often be achieved between the media pack and the filter casing, and between the filter casing and the housing or ceiling grid. However, the repair of filter media leaks may be difficult to implement and, because of blockage, can have adverse effects on the uniformity of airflow. In a non-UDAF cleanroom, the air supply will quickly mix with room air and a repair may be satisfactory. However, in UDAF workstations, the unidirectional flow of air may take airborne contamination from the leak directly to a critical area and, in this situation, it may be best to replace the filter.

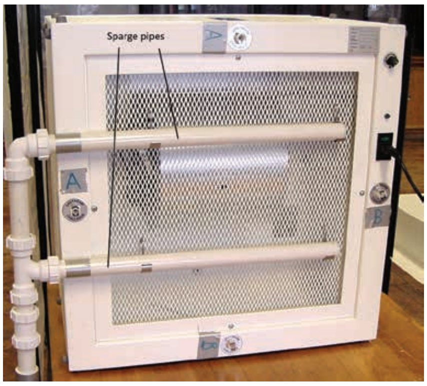

Figure 8.13: Sparge pipes used to spread the test challenge in an air intake

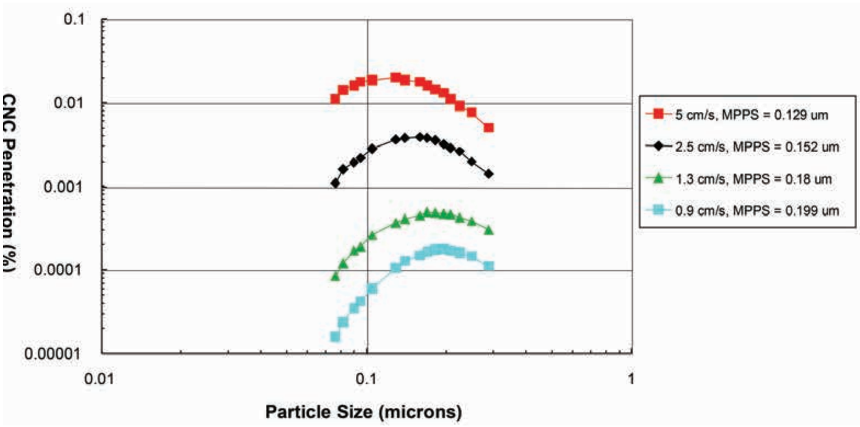

Figure 8.12: Filter penetration with respect to particle size at different velocities

Acknowledgement

Figures 8.6 and 8.7 are reproduced by permission of Air Techniques International.