MODULE 147 HVAC&R SKILLS WORKSHOP

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FILTER PERFORMANCE PARAMETERS

Skills summary

What?
Properties to consider when selecting air filters.

Who?
Relevant for designers of HVAC systems and maintenance technicians.

PULLOUT

This Skills Workshop discusses the four key properties that must be considered when designers are selecting air filters – airflow, resistance, efficiency and dust-holding capacity – as well as the concepts of size/penetration curves, particle adhesion and electrostatic effects.

The concepts of filter resistance, filter efficiency (arrestance), filter penetration and the factors that affect the dust-holding capacity of a filter are explained. A method for estimating the filter service life is also provided.

Filter performance properties

In order to compare the performance of various products, filter manufacturers have to rate the performance of their equipment in accordance with a recognised test or standard.

Every air filter has four key properties:

- Manufacturer's recommended airflow
- Airflow resistance characteristic of the filter
- Efficiency/arrestance at removing dust and contaminants from the airstream
- Dust-holding capacity at particular test conditions (initial pressure versus final pressure and dust loading).

Each of these four properties must be considered when selecting or comparing air filters for a particular application.

Air capacity

Air filters are rated by the manufacturer to handle a maximum quantity of air (L/s), or to have a maximum face velocity (m/s). This is a limit of the filter performance rating.

All other performance factors have little meaning unless referred to this airflow rate, as each filter performance property is dependent on the other three.

The required size of an air filter bank can be selected using the continuity equation and the recommended face velocity for the filter/media.

Air resistance

The efficiency of a filter generally increases as the filter loads with particulate.

If the filter is loaded beyond the manufacturer's recommended final resistance, the efficiency will usually decline rapidly due to agglomerated particles being dislodged from the fibres.

Filter resistance affects fan selection, size of plant and ongoing energy consumption.

Fan capacities are generally selected based on anticipated final filter resistance (prior to change-out). As a result, there may be (unacceptably) high airflow rates when filters are clean unless there is an automatic variable fan speed control available to compensate, i.e., a higher fan speed to compensate for the increased filter resistance to provide the same airflow rate.

Resistance varies according to the degree of air turbulence in the media. The resistance/flow relationship varies with filter type generally as follows:

- For some fabric and most metal filters, resistance increases as the square of the velocity
- For laminar airflow through HEPA filters, the resistance is nearly proportional to velocity
- For most air conditioning filters, when velocity increases, resistance increases exponentially with a power between 1.3 and 1.8.

Clean filter resistance can be easily read off performance graphs of filter resistance for different flows.

Most filter manufacturers publish initial resistance (clean filter) and final resistance values that are verified by certified test reports.

Blocked air filters drastically reduce air conditioning and ventilation system performance, so filters must be serviced at the proper time. Pressure differential sensors should be fitted to monitor filter resistance. The filters/system should be marked with the design final resistance and checked regularly. Unattended air conditioning systems may be equipped with remote alarms to indicate that the air filter has reached its pre-determined final resistance.

Efficiency and arrestance

Efficiency and penetration

The efficiency or arrestance of an air filter may be defined as the proportion of dust retained (or arrested) by the filter, expressed as a percentage of the total dust carried by the airstream to the filter, see Figure 1. Conversely, penetration is the proportion of dust that passes through the air filter.

In gravimetric tests the efficiency measurement is called synthetic dust weight arrestance (often simply referred to as arrestance) to distinguish it from efficiency measured using sub-micron tests.

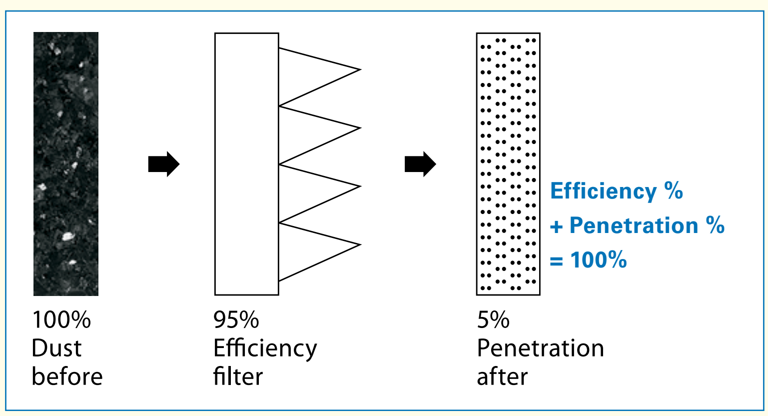


Figure 1: Air filter efficiency and penetration.

The stated efficiency of a filter is meaningless unless other related factors are also quoted, including:

- Standard dust or **size of particles being filtered** (filter test standards typically use synthetic particles to enable reproducibility and fair comparison)

- Filter identification (characteristics such as dimensions, configuration, model, media type)
- Type of **test method** used
- Airflow rate (L/s) or velocity (m/s).

When assessing or comparing data for different filters, care must be taken to ensure comparisons of test data are valid, i.e., tests should be at the specified face velocity and data should be compared for the same final resistance.

Different test dusts, different results

The performance of the filter with one test dust is not a reliable predictor of performance with another test dust or with the local ambient dust. Different filters can only be reasonably compared under similar test conditions.

Relationship between classifications

A notional relationship between the various filter classification systems of AS 1324.1, ISO 16890, EN 779 and ASHRAE 52.2 is shown in Table 1. The ASHRAE legacy 52.1 standard ratings are also shown for reference. Because the test methods are similar but not identical, the relationships mapped in Table 1 are approximate not exact and are provided for comparison only. For this reason inter-test standard comparisons are not a sound practice on which to base a design. Specific filter/test results are required.

Note: *At the time of publication it was not clear which test standard would become dominant in Australia, ISO 16890 or ASHRAE 52.2.*

In particular ISO 16890 defines filtration efficiency for three different sizes of particles (PM_{10}, $PM_{2.5}$ and PM_1) whereas other classification systems are based on a specified particulate size. Table 1 outlines notional or approximate ISO 16890 ePM_x ratings, and highlights where the various classification systems align and where they do not. For example, it is theoretically possible that an EN 779 G4-rated filter could be rated as an F5 filter if tested to AS 1324.2, because the test processes and test particle sizes differ. Based on the classifications of EN 779:2012 and ASHRAE 52.2 the reliability of sub-micron filter efficiency requires at least a minimum F7 or MERV11 classification. A manufacturer or supplier needs to have test reports (for the specific test standard) to substantiate any performance claims.

Dust-holding capacity

The fact that all of the key performance parameters of air filters are inter-related is most obvious when considering the dust-holding capacity of an air filter.

Dust-holding capacity is the total mass of dust held by an air filter at a particular final resistance. This is very dependent on the airflow rate applied.

Filter tests fall into two types:

1. Tests of flat media samples only
2. Tests of complete filter units, i.e., media fitted into frames to give an extended surface.

The dust-holding capacity of flat panel media samples is most usefully expressed in grams per square metre of free area (g/m^2). Predictions for other panel sizes are then simplified.

The dust-holding capacity of complete filter units is better expressed as grams held for that particular configuration, or grams held divided by test airflow rate.

Because ISO 12103-1 A2 Fine Test Dust has a closer size spectrum to office dusts than other test dusts, this holding capacity best indicates the anticipated time between filter replacements in offices and other buildings with similar dust characteristics. This is most valid when the test airflow rate and filter final resistance are the same as in the intended application.

Factors affecting dust-holding capacity include:

Media area – dust-holding capacity of a filter is approximately proportional to the area of media exposed to the airstream.

Media construction – graduated density media increases dust-holding capacity since large particles will collect in the first stages of the media profile while finer particles will collect in the denser stages. This type of media is common in air conditioning filters.

Media air velocity – reducing media air velocity will increase dust-holding capacity for the same final resistance. Increased surface area reduces velocity through the filter media.

Media compression – media will be ineffective for dust holding where it is compressed. For example, media compression at folds around wires in V form filters reduces dust holding at the folds. This is particularly the case with 50mm V-form panel filters where a substantial proportion of the media is affected by folds.

Table 1: Notional relationship between the filter classification systems

Note: *These technical comparisons are not always or entirely valid and any filter must be type-tested in accordance with the appropriate test standard before any particular performance can be claimed.*

AS 1324* Rating	ISO 16890 Rating (approximation)	EN 779 Rating	ASHRAE 52.2 MERV Rating*	ASHRAE 52.1 Rating	
				Arrestance	Efficiency
G1	ISO Coarse> 50%	G1	MERV 1 – 4	60 – 80%	< 20%
G2	ISO Coarse> 65%	G2	MERV 1 – 4	60 – 80%	< 20%
G3	ISO Coarse> 80%	G3	MERV 5	80 – 90%	< 20%
G4	ISO Coarse> 90%	G4	MERV 6	90 – 95%	20 – 30%
		G4	MERV 6 – 7	95%	25 – 30%
	ISO ePM_{10} > 50%	G4/M5	MERV 7 – 8	95 – 98%	30 – 40%
F5		M5	MERV 8 – 9	98%	40 – 50%
		M5	MERV 9 – 10	99%	50 – 60%
F6	ISO ePM_{10} > 50%	M6	MERV 10 – 11	99%	60 – 70%
	ISO ePM_{10} > 60% ISO $ePM_{2.5}$ > 50% to 65%	M6	MERV 12 – 13	99%	70 – 80%
F7	ISO ePM_{10} > 85% ISO $ePM_{2.5}$ > 65% to 80% ISO ePM_1 > 50% to 65%	F7	MERV 13 – 14	99%	80 – 90%
F8	ISO ePM_{10} > 90% ISO $ePM_{2.5}$ > 80% ISO ePM_1 > 65% to 80%	F8	MERV 14 – 15	99%	90 – 95%
F9	ISO ePM_{10} > 95% ISO $ePM_{2.5}$ > 95% ISO ePM_1 > 80%	F9	MERV 16	99%	> 95%

* MERV A rating (i.e., on the discharged filter to be consistent with the other methods)

PULLOUT

Pinhole defects

Careless construction or handling of high-efficiency filters, especially where thin sheets of media are used, may result in small tears or pinholes.

The effects of pinhole leaks are accentuated at low face velocities. Testing at normal face velocities does not always show a significant increase in penetration by sub-micron particles in the presence of these pinhole leaks.

Penetration through high-efficiency filters decreases with decreasing air velocity; however, this characteristic is altered in the presence of pinhole leaks. At very low velocities the proportion of flow through a hole increases relative to the rest of the filter, and penetration rises steeply. This effect is explained if the hole is considered as an orifice where airflow rate is proportional to the square root of the pressure drop, while flow through the main body of the filter is directly proportional to pressure drop.

This increase in penetration is most serious in the biological field where near absolute filtration is necessary, and low air velocities are used to favour low penetration. Clumps of bacteria, or particles with bacteria attached, could easily pass through pinholes. Scan testing of the filter pack will detect pinhole leaks and should be used for all critical applications.

Filter service life

One of the most important economic considerations for an air filter in general ventilation and air conditioning is its service life. Filter service life can be estimated from Equation 1:

$$L = \frac{k \times G \times 10^9}{(C \times Q \times E \times 3{,}600)} \qquad \textit{Equation 1}$$

Where:

- L Life in hours
- k A factor that relates the actual dust held in the field to the dust held under test for the same final resistance and airflow
- G Dust held (g) by the filter when tested with the representative test dust to the application's final resistance and at the application airflow
- C Concentration of dust in the airflow, as annual geometric mean (µg/m^3)
- Q Airflow rate (L/s)
- E Efficiency rating as a decimal, not percentage (Not HEPA/ULPA efficiency) – average efficiency is used for the service life estimation.

Example – estimation of filter service life

A filter has a 95% efficiency rating and a dust-holding capacity of 1,100 grams when tested at a final resistance of 125Pa at 1000L/s. The dust concentration in the air is 45µg/m^3 and we assume a good quality filter with a k factor of 1.0.

G = 1,100g

C = 45µg/m^3

I = 1,000L/s

E = 0.95

L = 1.0 x 1,100 x 109 / (45 x 1,000 x 0.95 x 3,600) = 7,148 hours

For 10 hours per day, 5 days per week, 50 weeks per year = 2,500 hours of operation per year.

Estimated filter service life is 2.8 years for an average supply air dust challenge of 45 µg/m^3.

Sizing filter banks on air capacity

Air filters are rated by the manufacturer to handle a maximum quantity of air (L/s) or have a maximum face velocity (m/s). Other performance factors are determined at this flow rate.

The required size of air filter bank and housing can be determined from the required system airflow and the recommended face velocity for the filter type and application.

Continuity of flow

In a duct with varying cross-sectional area the velocity changes along the duct as shown in Figure 2, i.e., in direct proportion to the change in area. The continuity Equation 2 can be used to determine the dimensions of a duct-to- filter bank transition, sized to target a required maximum air velocity at the face of the filter bank.

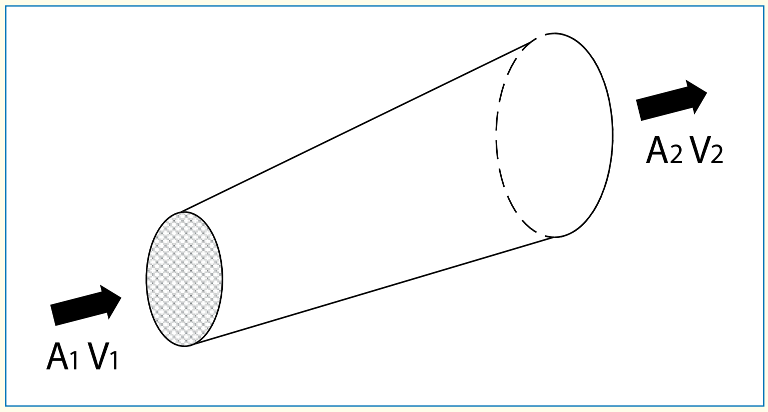


Figure 2: Duct transition to filter bank.

For incompressible, steady flow:

$$A_1 \,.\, V_1 = A_2 \,.\, V_2 = Q/1{,}000 \qquad \textit{(Equation 2)}$$

Where:

- $A1$ Area of duct at section 1 (m^2)
- $V1$ Velocity of air at section 1 (m/s)
- $A2$ Area of duct at section 2 (m^2)
- $V2$ Velocity of air at section 2 (m/s)
- Q Airflow rate (L/s).

Equation 2 states that for a fixed airflow Q, the product of area (A) and velocity (V) will remain the same. As "area" increases "velocity" reduces, as "velocity" increases "area" reduces.

Where Q is known and V_2 is the recommended face velocity for the filter type and application (or lower), the required face area of the filter media bank (A_2) can be determined.

Where V_1 is the recommended air velocity in the duct, the cross-sectional area of the duct A_1 can be determined. This calculation will provide the general dimensions of the filter bank (face area and transition from duct size).

Example 1: Calculate face area

Given flat panel air filters with openings of 500 x 500mm and a recommended face velocity of 1.5m/s, determine how many panels are required to handle 3,000L/s.

From Equation 2, for each panel

$$Q = A \text{ x } V \times 1{,}000 = 0.25 \text{ x } 1.5 \times 1{,}000 = 375L/s$$

(maximum airflow, one panel)

$$3{,}000 / 375 = 8$$

Therefore 8 panels will be required to handle 3,000L/s.

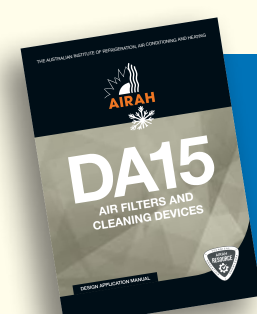
Example 2: Calculate velocity

Given a flat media surface area of 1.2m^2 and total air quantity of 2,000L/s, determine the velocity of airthrough the panel.

From Equation 2

$$V = Q/(A \times 1{,}000) = 2{,}000/(1.2 \times 1{,}000) = 1.67m/s$$

Filter manufacturers normally select the velocity of air across the media to achieve optimum performance relative to the fibre diameter, packing density, thickness of medium and anticipated dust load. The recommended maximum air quantity for any filter or system should not be exceeded unless performance is verified by tests. ■



This skills workshop is taken from *DA15 – Air Filters and Cleaning Devices*. For more information go to ***airah.org.au/da_manuals***

Next month: Refrigeration piping – Suction lines