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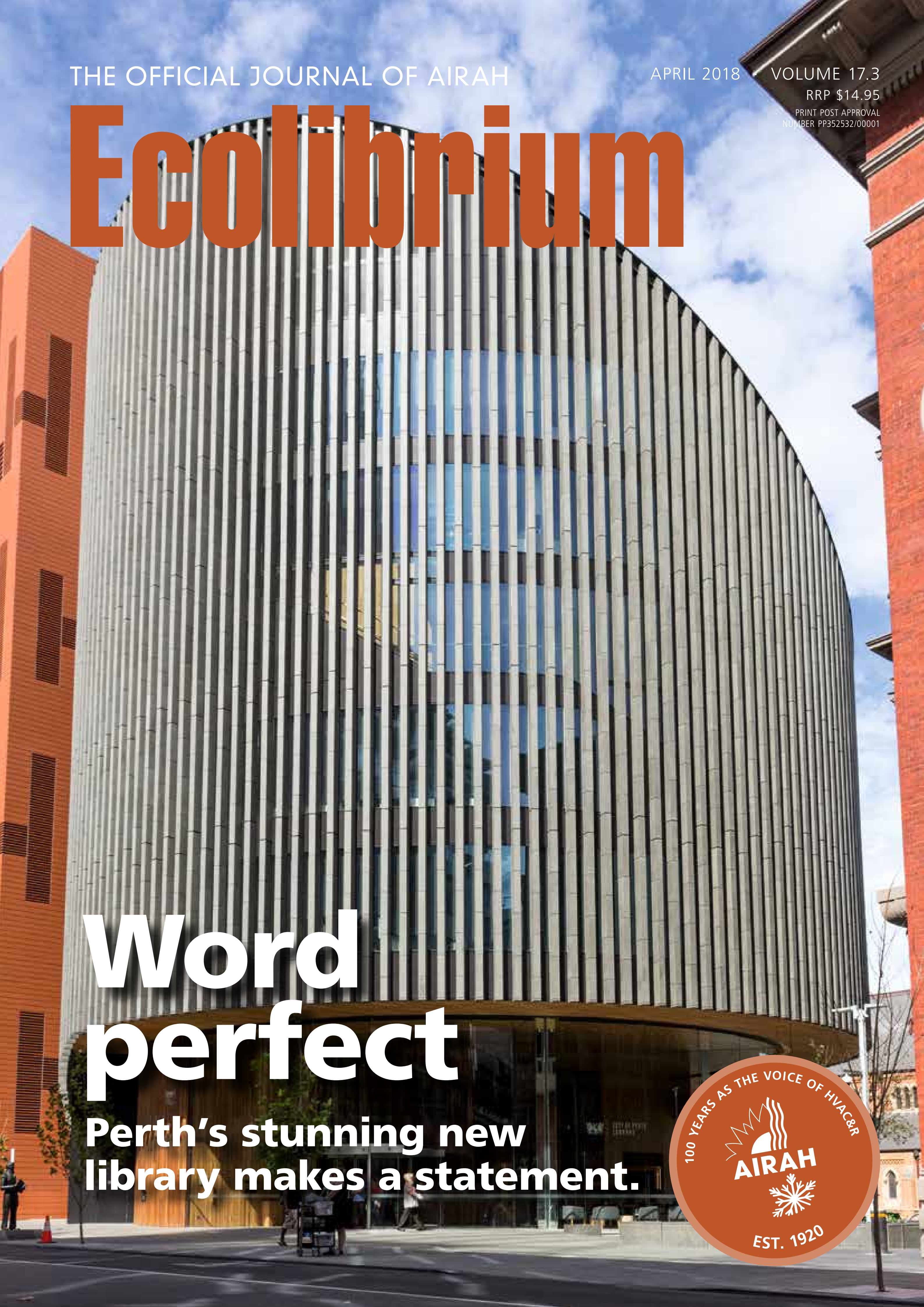

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Kitchen exhaust filtration design Part 2

Following on from our first article on kitchen exhaust filtration (Ecolibrium March 2018), this second part of the series analyses common filtration methods used for kitchen exhaust as supported by scientific analysis. It aims to uncover economic and effective choices for kitchen exhaust applications that will meet the proposed design parameters from part 1.

Different cuisine types produce varying amounts of moisture, grease, smoke and odour, and the resulting cooking fumes comprise a combination of solid particles, liquid droplets and vapour/gaseous-phase contaminants. Various kitchen exhaust treatment technologies are available, each with pros and cons affecting cost and performance.

The technologies analysed in this article include kitchen exhaust hoods, hood filters, ultra-violet (UV), multi-stage filter packs, electrostatic precipitators (ESPs), gas filtration media and ozone.

KITCHEN EXHAUST HOODS

The major function of a kitchen exhaust hood is to ensure all the cooking fumes and heat generated by cooking processes are captured and removed.

AS 1668.2 prescribes a minimum exhaust airflow rate through kitchen hoods depending on the size of the hood, the type of hood and the appliances under the hood. Alternatively, AS 1668.2 offers a more detailed calculation based on VDI 2052, DIN18869 or other tested engineered solutions[1]. These are often based on the amount of heat and plume volume generated from specific kitchen appliances. These tailored calculations can significantly reduce the airflow required to be exhausted, and therefore the capital and operating costs of kitchen exhaust systems.

Effective treatment of kitchen exhaust using any method requires air temperature in the duct to be under 50°C. At higher temperatures particulates can pass through filtration in the gas phase, overpower gas filtration systems,

and condense back into particulate matter when exhausted to colder outside air. This is normally not a problem if the hood is designed as per AS 1668.2 or any other allowable standard that specifies the amount of dilution air required to reduce temperature in the exhaust to below 50°C. However, care should be taken to consider this temperature when creating a design.

> Another important aspect of the hood filter is fire safety

If the temperature in the exhaust duct is expected to exceed 50°C – common if there is a solid fuel application – additional measures should be taken. High temperature is one of the most likely reasons for failure of kitchen exhaust filtration.

Solutions include the incorporation of a cold-water mist injection hood, in-duct wet scrubber, or any other form of airstream cooling prior to filtration.

HOOD FILTRATION

The first and often the most underutilised part of a successful kitchen exhaust filtration system is effective particle load reduction at the hood. Removing a significant load of particles here will reduce the maintenance costs on equipment downstream.

Metal mesh/baffle filter

As grease-laden air passes through metal mesh/baffle filters with various obstructions to the airflow, the air constantly changes direction.

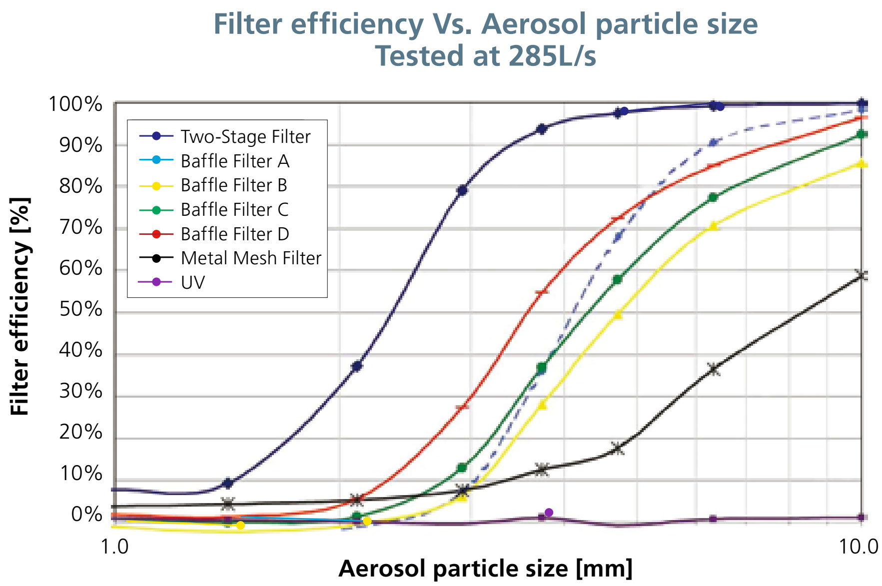

Figure 1: Particle capture efficiency comparison of six commercially available filters vs UV[9].

The resultant change in inertia causes the grease to be separated from the air and gather on the metal surface. All metal hood filters vary in the way they obstruct the airflow, but generally the greater the obstruction, the greater the pressure drop and efficiency. Baffle filters can have an advantage as they are often self-draining and rigid, unlike honeycomb/mesh filters, which collect and hold grease in place and can be harder to clean.

Figure 1 shows common hood filters and their efficiency between 1–10µm. A similar diagram showing the efficiency of hood filtration between 1–10µm should be available and requested from suppliers. While hood filters don't offer much filtration at 0.3µm (smoke), they can significantly reduce the load on downstream filtration and the frequency of duct cleaning required.

Another important aspect of the hood filter is fire safety. According to AS/NZS 1668.1:2015 clause 6.2.9[2], if kitchen exhaust ductwork inside the building is longer than 10 metres and there is a flame under the hood, either from solid fuel or gas, the hood must have a UL1046-rated filter.

The UL1046 test determines the ability of hood filters to "Limit the projection of flames downstream when subjected to flames on the upstream face, after having been loaded with grease in a manner representative of cooking that produces a grease-rich exhaust"[3]. A mesh/honeycomb filter that works by holding and capturing grease in place may not be effective, because this grease may act as a medium for the fire to pass through. Instead, look for a self-draining filter with plenty of obstructions to the airflow, as these obstructions can also limit the passage of flames.

Please check with your hood filter supplier and ask for a UL1046 certificate if required to ensure compliance.

Despite baffle filters being more expensive and having a higher pressure drop, they should be considered for fire safety, ease of cleaning and their higher efficiency, which lowers overall operating costs of the kitchen filtration system. Maintenance documentation for these designs should clearly identify the purpose of the selected filters, avoiding future substitution with inadequate alternatives.

Ultraviolet (UV) light

UV technology uses the energy from UV light to perform a process called photolysis, which is the decomposition or separation of molecules by light. The aim is to decompose and break down grease, smoke and odour, leaving simple, common odourless gases such as CO_2, N_2, H_2O and O_2.

However, as discussed previously in Part 1, the grease and smoke particles are often simply too large and the concentration too high to break down to simple odourless gases given the short residence time in kitchen exhaust filtration and the power of UV lights. Figure 1 illustrates this.

Additionally, UV lights can become coated in grease and smoke, which reduces their impact on particles in the kitchen exhaust air. UV also generates ozone, which is harmful to human health and must be controlled.

As with ozone filtration, UV lights may require downstream carbon filtration to remove ozone prior to discharge. UV lights need to be automatically switched off when hood filters are removed for maintenance, to prevent exposure of human eyes to UV light.

Other hood technologies

Other hood filtration technologies such as cold-water misting hoods and hood-mounted electrostatic precipitators may also form part of a performance-based alternative to a deemed-to-satisfy design, however, make sure performance at 1–10µm is checked if it is considered a load-reducing mechanism. If it is designed to clean the air of all particulates, check the filtration efficiency at 0.3µm to a relevant standard as discussed in Part 1.

PARTICLE FILTRATION

After the particulate load has been reduced at the hood, there are three types of common particle filtration systems designed to achieve 95 per cent efficiency at 0.3µm: the multi-stage filter pack, an automatic wash ESP and a manual clean electrostatic precipitator (ESP).

All filtration systems perform best with a straight duct run of 2–4 duct diameters before and after the system. This allows the contaminants and airflow to be spread evenly over the filters.

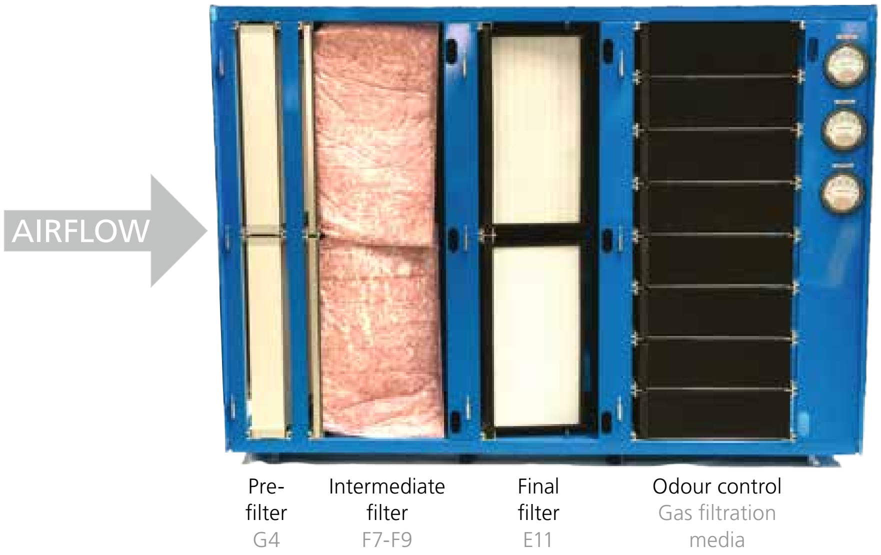

Figure 2: A typical multi-stage filter pack.

Multi-stage filter pack

These systems typically offer a low capital-cost solution with medium operating costs from the filter change-outs.

These systems are typically designed with four stages of filtration consisting of three sequential stages of particulate filtration and one final stage of odour control (covered later).

- **Pre-filter – sacrificial:** Main contaminant filtered is coarse grease. Typically a low-cost G4 filter, with the shortest lifespan.
- **Extended surface filter – high capacity:** Main contaminant filtered is fine grease. Typically a F7-F9 filter with a medium lifespan.
- **Final filter – efficiency:** Main contaminant filtered is smoke. Typically an E11 (HEPA) filter with a minimum efficiency of 95 per cent at 0.3µm with a long lifespan.

Filters are chosen to be resistant to moisture and grease. The material of choice for the second filter and final filter is therefore often fibreglass. The pre-filter is best constructed with a metal frame and rigid, thick, well-supported media.

The velocity of air through filter-pack systems should be below 1.85m/s. A higher velocity leads to an excessive pressure drop, poor contaminant-to-filter surface area ratio, less stability of moist filter mediums, and likely poorer performance of downstream odour-control systems.

A multi-stage filter pack filtering 2,500L/s of air has a surprisingly large media surface area of $100m^2$. This allows the system to filter a large amount of grease and smoke before filters need to be replaced. However, if the expected load of grease and smoke is high, an automatic wash ESP should be the preferred choice due to a potentially lower lifecycle cost.

Electrostatic precipitator (ESP)

ESPs use electrostatic forces to initially charge particles with a given polarity before collecting them downstream on plates of the opposite polarity.

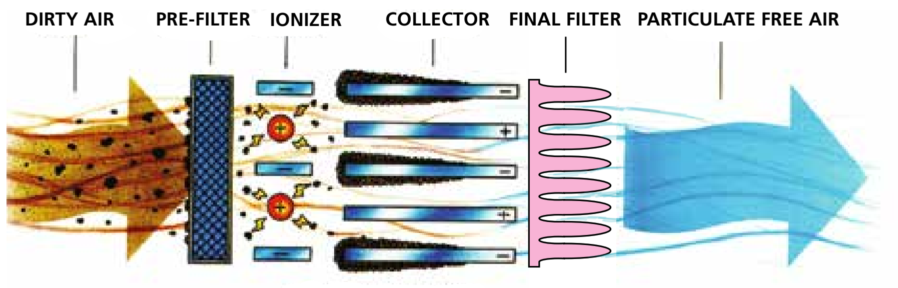

Figure 3: Electronic air cleaning with an electrostatic precipitator.

Sometimes the collection plates are grounded with opposing plates of the same polarity as the initial charge, to repel the particles to the grounded plate.

Larger particles can hold a larger charge relative to their mass, and therefore migrate faster towards the collection plate[4]. The speed of radial movement towards the collection plates is known as the migration velocity, and faster migration velocities result in higher filtration efficiency. However, like mechanical filtration discussed in Part 1 of this series, once particles are smaller than 1µm the effect of the direction of bulk airflow on the particle is negated due to diffusion and the particles can move radially to bulk flow[4] more easily, ensuring more residence time in the filter. In fact, particles of 0.01µm are as easy to catch as particles of 100µm (Figure 4), further highlighting the need to compare products at 0.3µm to understand how they really perform.

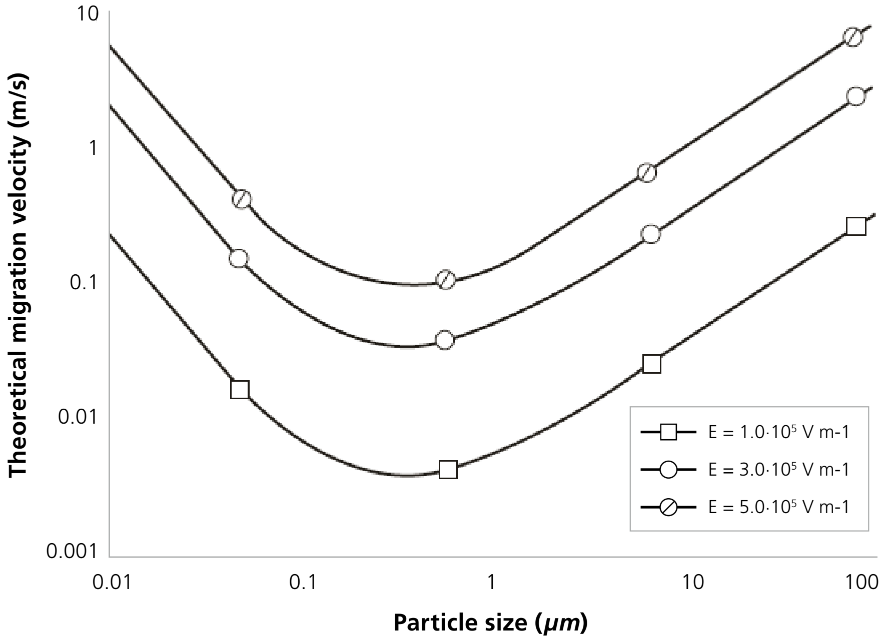

Figure 4: Migration velocity vs. particle size at various voltage gradients[4].

ESPs have been maximised with respect to the laws of physics for 60-plus years, and we cannot simply "turn up" the power to achieve better filtration through higher levels of charging. If we do this, it results in an excessive voltage gradient between the plates.

For typical air in kitchen exhausts, a voltage gradient greater than 1kVdc/mm will result in the breakdown of air[5], and therefore immediate transfer of current from the charged plate to the ground plate. This is known as arcing and is responsible for the ticking noise that may be heard from malfunctioning ESPs. When arcing occurs, the whole system becomes grounded and its efficiency immediately becomes zero. This will have a severe effect on downstream odour filtration systems.

The main differences between various ESPs therefore is in the thickness and type of construction materials, and whether the unit has an automatic wash system. Due to physics being maximised, there is limited scope for a differing filtration performance for 0.3µm particles at a set velocity.

The last piece of the puzzle with ESPs is to determine a system velocity slow enough to ensure that 95 per cent of particles of size 0.3µm (which have the slowest migration velocity) will have enough residence time in the filter to be captured.

Studies completed by Dalmon and Lowe[6] show the migration velocity as a function of axial velocity through the electrostatic filter.

From Figure 5 we can see that the optimal axial velocity through an ESP that will generate the highest migration velocity is 2m/s. The migration velocity relative to axial velocity is largely affected by a parameter called particle mobility. At low velocities the effective migration velocity is reduced due to the large amount of turbulence that is generated by an energised field with low airflow, whereas at high velocities the net migration velocity is reduced due to re-entrainment and scouring of particles[7].

Single cell ESPs are therefore normally designed with enough depth to offer the sufficient residence time to achieve 95 per cent efficiency at 0.3µm, and take advantage of a higher migration velocity around 1.8–2.0m/s.

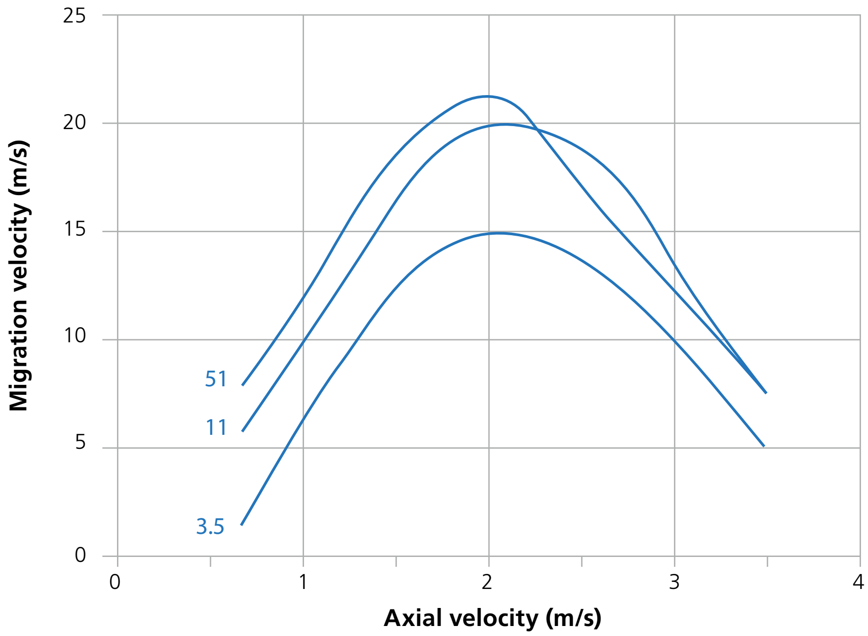

Figure 5: Effect of gas velocity on ESP performance for differing particle sizes of 3.5, 11 and 51µm diameter[6].

Although there is a lot more to it, such as the "stickiness" and resistivity of particles, if the volume of throughput air is doubled for the same size filter, the effective migration velocity is lowered significantly. A unit may need to be up to six times longer to capture the same particle due to a net migration velocity that is three times slower (Figure 6) – an inefficient use of materials and space.

Double-pass ESPs (two single cell ESPs arranged in a series) do not necessarily allow you to double the airflow and maintain 95 per cent efficiency at 0.3µm. Because of this, it is always advisable to increase the face area of the filter to reduce the velocity to below 2.0m/s, preferably 1.85m/s, instead of putting single-cell ESPs in a series.

It is possible to increase the velocity above 1.85m/s and achieve 95 per cent at 0.3µm by placing a HVAC particulate filter after a single-stage ESP.

The reduction in efficiency from the ESP due to an increased velocity will increase the loading on the HVAC filter, and it will therefore require more frequent replacement. It will also introduce extra static into the system.

If the ESP is doing its job and is correctly sized, there will be extensive contamination trapped on the plates. These must be cleaned/regenerated periodically to remove grease and smoke particles. An ESP can clean air of all contaminant levels; however, the required frequency of cell cleaning directly relates to the contaminant load.

A higher contaminant load means more frequent washing of the cells to maintain performance.

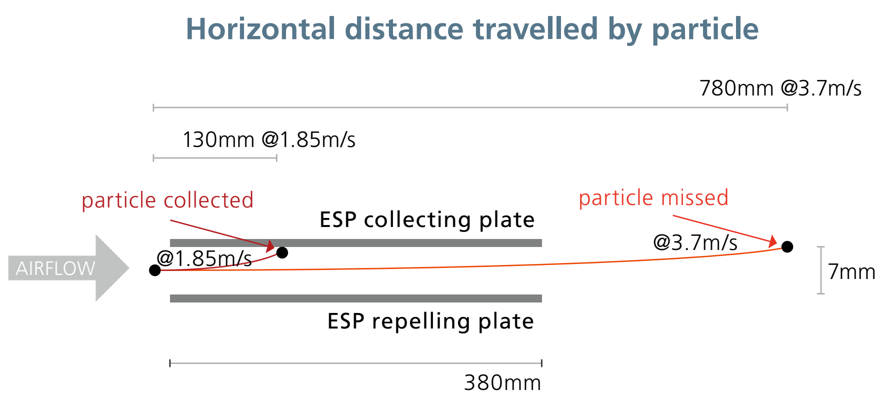

Figure 6: Calculated particle pathway through an ESP cell using the Dalmon and Lowe study[6].

Figure 7: Extensive grease build-up on an ESP due to poor maintenance, directly connecting the charged and the ground plates and grounding the whole unit.

Figure 8: A typical automatic wash ESP.

ESPs require washing anywhere from daily to weekly, making a manual cleaning system prohibitive due to labour costs and the automatic wash system a must. If the plates are not cleaned, the gap between the plates becomes smaller and smaller, which increases the voltage gradient. As mentioned above, once the voltage gradient is above 1kVdc/mm, arcing occurs, and the ESP efficiency drops to zero.

Automatic wash ESP

The automatic wash ESP is a high capital-cost solution, but has the lowest operating costs due to the self-cleaning mechanism. Despite the automatic wash system, a manual clean will still be required every three to 24 months depending on the cooking load. Additional infrastructure is required, including a hot water supply and a drain to a grease trap.

Large scale, self-washing ESP systems may include the following options:

- **Pre-filter:** Typically a mesh filter to capture large particles which may short-circuit the ESP cell. It also assists with providing laminar flow over the ESP.
- **ESP cell:** Removes smoke and grease particulates and requires regular cleaning to maintain performance.
- **Auto-wash function:** Typically a programmable automatic wash and fan-dry function that sprays the ESP cell with a hot water and detergent mix to keep it running effectively and extend manual cleaning intervals.
- **Final filter:** Typically a F7/8 extended surface filter used to temporarily protect the odour-removal systems from poorly maintained ESPs or increase filtration performance.

Manual clean ESP

The manual clean ESP typically offers a medium capital-cost solution with high operating costs due to the labour required to manually service the system. As the efficiency degrades with loading, the ESP must be cleaned every one to seven days to keep it operational, depending on grease and smoke load. As the capital cost is higher than a filter pack, and the operating costs are also likely to be higher given the same quantity of grease and smoke filtered,
it is seen an undesirable choice for kitchen exhaust filtration.

GASEOUS ODOUR FILTRATION

Gaseous odours in kitchen exhaust consists of many different compounds, and the composition and quantity vary depending on the type of cuisine. Cooking fumes consist of n-alkanes and fatty acids with n-alkanols, aldehydes, ketones, sterols, polycyclic aromatic hydrocarbons (PAHs) and aromatic amines (AAs), among many others also present [8] [9] [10]. The two most common methods of odour control are adsorbent/chemisorbent media and ozone.

The effectiveness of both are covered in this article.

As discussed in Part 1 of this series, both gaseous odour control mechanisms require the air to be filtered to 95 per cent at 0.3µm prior to gaseous odour filtration.

Adsorbent/chemisorbent media

The most common gaseous odour adsorbent media is activated carbon, however, there are various types of media including impregnated activated alumina known as chemisorbent media. Chemisorbent media reacts with contaminants ensuring they are not released; adsorbent media can re-release trapped contaminants if a preferred contaminant is present or the temperature is too high.

The various types of media and impregnations focus on effective removal of particular contaminants, whereas plain activated carbon is seen as a general odour adsorbent media. Often plain activated carbon is initially used, however, if certain odours from the cooking are not consistently trapped to a desirable level, it is replaced with a mixture of activated carbon and activated alumina impregnated with sodium or potassium permanganate.

Gaseous odour filtering media is a mature technology, but there are still many key design parameters that need to be addressed to ensure cost-effective efficient performance. Empty bed residence time, the quality of the media and the pressure drop are the three components of an effective system. Care must also be taken to ensure that the air temperature is not above 50°C, because the adsorption/chemisorption of contaminants at these temperatures is severely inhibited.

The empty bed residence time (EBRT) is the volume of media in the filtration system divided by the volumetric flow rate of air. A minimum value of 0.06 seconds is recommended with 0.08 seconds preferred. This results in an initial contact efficiency above 99 per cent, which providing the filter is well sealed, will also result in an initial contact/removal efficiency greater than 99 per cent. When the active sites on the media are consumed by gaseous odours, the removal efficiency drops below the contact efficiency, because the active sites in the media may already be occupied when contact is made. Eventually, too many active sites are full, and gaseous odours begin to pass through. This is when the media needs to be replaced.

Residence Time, (sec.)	$E = (1-2^{-100n}) \times 100\%$
0.01	50%
0.02	75.0
0.03	87.5
0.04	93.75
0.05	96.88
0.06	98.84
0.07	99.22
0.20	99.9999
0.40	99.9999999999

Figure 9: Theoretical relationship between EBRT and contact efficiency on adsorbent media.

There are various configurations of media that can achieve an ERBT of 0.08 seconds, the most common being a 25mm thick, 450mm deep V-bank arrangement with a duct velocity of 1.85m/s. Cost and pressure drop are obvious considerations, and specifying a minimum ERBT is the simplest way to ensure you are getting high efficiency with gas-filtration media.

Ozone

Ozone works by breaking down molecules into smaller and smaller molecules via oxidation until simple, common odourless gases such as CO_2, N_2, H_2O and O_2 are left. This process is known as ozonolysis. There are two commonly used methods to generate ozone:

- Corona discharge
- Ultraviolet (UV) radiation

Both methods involve drawing air through a modular unit attached to the side of a duct that is under negative pressure. The negative pressure in the duct creates a flow of outside air through a unit containing high-voltage plates (corona discharge) or 185Nm UV lamps (ultraviolet radiation) generating ozone in the airflow that enters the main duct.

A unit is designed to treat a volumetric amount of air, and generally a minimum residence time of 2–5 seconds is specified to allow the ozone to clean the specified volume of air with a moderate gaseous odour loading before exhausting outside.

The exact science between ozone concentration, residence time, gaseous odour concentration, and filtration efficiency leaves a lot to be desired, with rules of thumb of unknown origin – including the 2–5 second residence time – still dominating designs.

There is a major concern relating to residual amounts of ozone exhausted to occupied spaces. Ozone exposure in humans has been associated with dizziness, insomnia, coughing, chest pain, reduction in lung function and irreversible obstructive airway diseases [11]. In particular, ozone exposure is damaging to the undeveloped lungs of children [12]. Ozone has been found to be injurious to health at levels consistently above 50ppb [13], and Safe Work Australia enforces a 100ppb peak limit for human exposure [14]. AS 1668.2 recommends that no residual ozone beyond ambient levels remains in the final exhaust air.

To obtain compliance for a system, there should be an assurance that it has been engineered to ensure no excess ozone will be exhausted.

To prevent residual ozone discharge, the first option is to install an ozone detector just prior to the building kitchen exhaust point. The ozone level detected here can control the amount of ozone generated upstream. As the odours from the cooking load increase and decrease, the amount of ozone consumed varies, and therefore the amount required also changes. Care must be taken to ensure the reliability and calibration of these sensors over time, as failure generates a serious health risk.

The second option is to install a carbon trap at the discharge point to capture remaining ozone in the stream. Again, care must be taken to replace media regularly to prevent any possible discharge of ozone to external locations.

SUMMARY

We can significantly improve the effectiveness of kitchen exhaust filtration using the design principles proposed in Part 1:

- Particle filtration should always occur prior to gaseous odour filtration
- Particle filtration performance should be based on performance at 0.3µm (within the most penetrating particle size range of 0.1-0.4µm)
- Minimum performance of 95 per cent particle filtration at 0.3µm should be targeted.

When carefully considered, there are many filtration technologies that effectively and economically meet the proposed design principles and the requirements of the National Construction Code (NCC). The laws of innovation suggest that this list will continue to evolve and grow.

By adopting these principles, and diligently testing and auditing products in the market, we can improve the ambient air quality, reduce visual pollution and reduce odour complaints. ■

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About the Authors

Written by:

- Jonathan Bunge, Affil.AIRAH, national product manager, Airepure Australia.

Technical review by:

- Brett Fairweather, M.AIRAH, mechanical engineering consultant, It's Engineered.
- Peter Mathieson, F.AIRAH, technical director, Aurecon Australia.