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Kitchen exhaust filtration design

Part 1

In the first half of a two-part series on kitchen exhaust design, we discuss kitchen exhaust filtration, and Australian standards compared to benchmark practices within the US. Using first-principle analysis, critical design parameters are provided for kitchen exhaust filtration design in Australia.

By **Jonathan Bunge, Affil.AIRAH.**

Primarily due to health concerns and odour complaints, the requirement to effectively filter kitchen exhaust discharge to a non-objectionable effluent is increasing. Research out of the US has shown that in the past emissions from barbeque grills in New York have been the sole attributor to 400 deaths annually[1]. Filtering kitchen exhaust could no longer be solely an aesthetic or comfort issue. But how do we approach kitchen exhaust filtration?

WHY FILTER KITCHEN EXHAUST?

Within Australia, there are standards that govern kitchen ventilation. These include council and state regulations, local, state and federal fire codes and most significantly AS/NZS 1668.1[2] and AS 1668.2[3] – all of which are referred to by the NCC (National Construction Code) for deemed-to-satisfy solutions.

AS 1668.2:2012 identifies all kitchen exhaust over 1,000L/s as “Type B Objectionable Effluent”. In addition to the exhaust discharge requirements for other exhausts, requires that this is then:

- Discharged vertically
- Discharged at no less than 5m/s
- Discharged at least 6m away from boundaries (including street boundaries), outdoor air intakes and natural ventilation openings.

> Are we just concerned about odour and the visual eyesore of smoke, or the health of the general population?

Failure to satisfy all of these requirements will result in a system that does not comply with AS 1668.2:2012.

These requirements aren’t always practical or cost-effective though, particularly when working with existing buildings. For these situations the NCC makes a performance solution pathway available to us, with a verification process prescribed for soundly engineered designs. AS 1668.2 offers some non-mandatory commentary to guide designers towards potential solutions.

The NCC and AS 1668.2:2012 also require designers to consider situations where exhaust may pose a danger or nuisance. Exhaust filtration systems can help manage these risks.

One of Australia’s motives for kitchen exhaust filtration is to avoid nuisance complaints and provide odour-free air discharge. Yet it is interesting that in the US (where kitchen exhaust regulation and technology is typically more advanced), certain places enforce the filtration of kitchen exhaust to improve ambient air quality and therefore the health of the population.

A study from the Department of Health and Mental Hygiene in New York estimated that emissions from char broilers (grills) in New York contributed to more than 12.5 per cent of PM2.5 attributable deaths annually in the period 2005–2007. This equates to 400 deaths per year[1]. If all char broilers had effective kitchen exhaust filtration installed and maintained, it is estimated nearly 350 of these deaths could have been prevented[1].

Another study completed at a similar time in New York suggested that 20 per cent of all PM2.5 particles in the air are from commercial cooking; this is more than the amount attributed to on-road vehicles at 17 per cent[4].

Separately, researchers at the University of California estimated that “the average diesel-engine truck on the road today would have to drive for 10 miles (16km) on the freeway to put out the same mass of particles as a single charbroiled (grilled) hamburger patty.[5]”

This in turn led to an amendment to New York law, effective as of May 6, 2016, that prohibits the operation of any new commercial char broiler (grill) and any existing chain-driven commercial char broiler (grill) to cook more than 875 pounds (400kg) of meat per week unless it has an emissions-control device that meets the requirements established by the Commissioner of the Department of Environmental Protection (DEP)[1].

WHAT IS SUITABLE FILTRATION FOR AN ENGINEERED SOLUTION?

Under AS 1668.2 the only deemed-to-satisfy solution is to provide an exhaust that complies with a type-B objectionable effluent as described above, in addition to all the requirements for non-objectionable discharges.

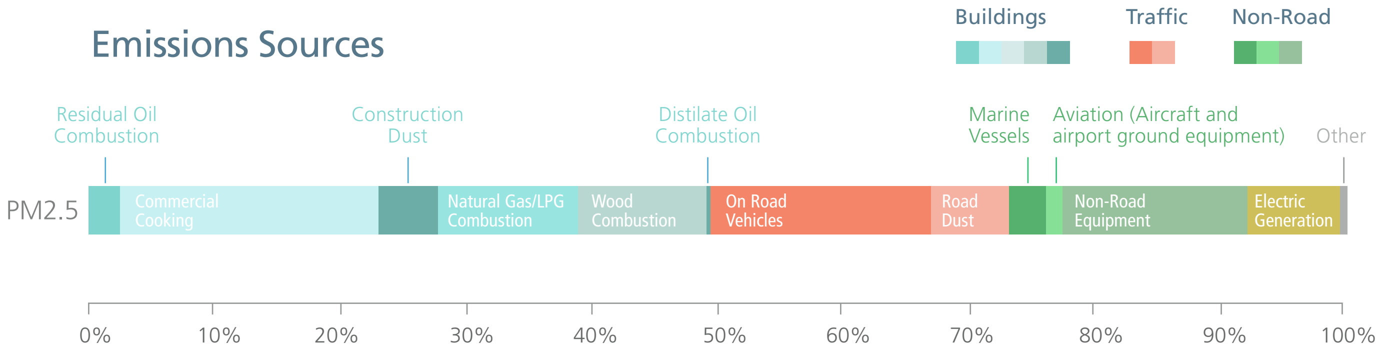

Figure 1: PM2.5 Emissions Sources in New York.

However, due to increasing urban density, and available space for mechanical services within buildings, exhausting vertically from the roof more than 6m away from a boundary is often not possible.

To overcome this, an engineered solution might include a filtration system to clean the air to a "required" level. The definition of this "required" level is unclear – while some recommendations are present as commentary after clause 3.10.3 in AS 1668.2, this still doesn't give us a clear deemed-to-satisfy solution. It also doesn't necessarily give us a concrete, repeatable engineered solution that will always be acceptable to neighbours, councils and building certifiers, especially given the variability in contaminant level of different commercial kitchen exhausts.

As an industry, we need to define a clearer picture of what the requirements for kitchen exhaust filtration are in Australia. Are we just concerned about odour and the visual eyesore of smoke, or the health of the general population (and PM2.5-related deaths)?

The most cost-effective method can actually address all three concerns.

THE SCIENCE BEHIND KITCHEN EXHAUST FILTRATION

Kitchen exhaust filtration can be broken up into two clear aspects: particulate filtration, which in this case includes grease, smoke and free moisture; and gaseous filtration, which includes odours.

The first rule for kitchen exhaust filtration is that effective and sustained gas-phase/odour filtration cannot be achieved without an adequate level of prior effective particulate filtration.

Additionally, particles (such as smoke) are also odorous. Therefore, to ensure that odours are removed to a reasonable level, a significant level of particle filtration also needs to be in place.

It turns out that the level of particle filtration required to produce cost-effective odour filtration is also the level required to eliminate smoke as a visual pollutant, and significantly reduce PM2.5 emissions.

The empirically successful number used in the US and Asia is a minimum particle filtration efficiency of 95 per cent at 0.3µm (micron).

WHY 0.3µm?

The rating of the performance of filters for kitchen exhaust filtration at the particle size of 0.3µm is for two reasons:

- 0.3µm is known as the most penetrating particle size (MPPS)
- 0.3µm is a common particle size for smoke.

Most Penetrating Particle Size (MPPS)

The particle size of 0.3µm (MPPS) is typically selected as the test point for rating filtration efficiency. This is because particles above and below this size (0.3µm) are generally easier to capture[6].

The science behind the capture of particles on a traditional HVAC filter illustrates why 0.3µm is the most penetrating particle size. There are three main filtration mechanisms: impaction, interception and diffusion.

The filtration mechanisms are best explained using a HEPA filter as an example. Despite having a filtration efficiency of 99.97 per cent+ at 0.3µm, HEPA filters don't operate as a sieve where only particles smaller than the smallest gap will pass through. Instead they comprise a mesh of fibres, with gaps between fibres over 1µm not uncommon[7] [8].

In a simplistic way, rather than acting as a sieve, the HEPA relies on the probability that as a particle passes through the fibres, they will either impact onto a fibre (A) or come within 1 particle diameter of a fibre and be drawn onto a fibre through interception(B).

Naturally as the particle size decreases, the probability of a particle passing through the filter without impaction or interception increases. However, as the particle size decreases below 1µm, the particle undergoes diffusion (C), otherwise known as Brownian motion[6].

Brownian motion is where the particle is becoming closer in size and mass to gaseous molecules in the air. This causes the effect of collisions and interactions of the particle with gas molecules to increase, causing the particle to move radially to the direction of bulk airflow. This results in a significant increase in residence time and randomness of path for the particle though the filter; and therefore, far greater opportunity for the particle to be captured in the filtration process.

Figure 3 shows the overall minima in fractional efficiency, which is between 0.1–0.4µm. This is where the improvements in filtration due to diffusion are yet to offset the reduction in interception and impaction due to smaller particle sizes.

Similarly, for an electrostatic precipitator (ESP), as the particle size decreases, the charge held decreases by a greater amount. This results in a lower filtration efficiency. However, when the particle size decreases past 1µm, this reduction in charge held is offset by the increased residence time in the ESP from the effects of diffusion and the minimum at 0.3µm remains.

We therefore cannot assume that an efficiency specified at 0.01µm indicates a higher efficiency for all particle sizes

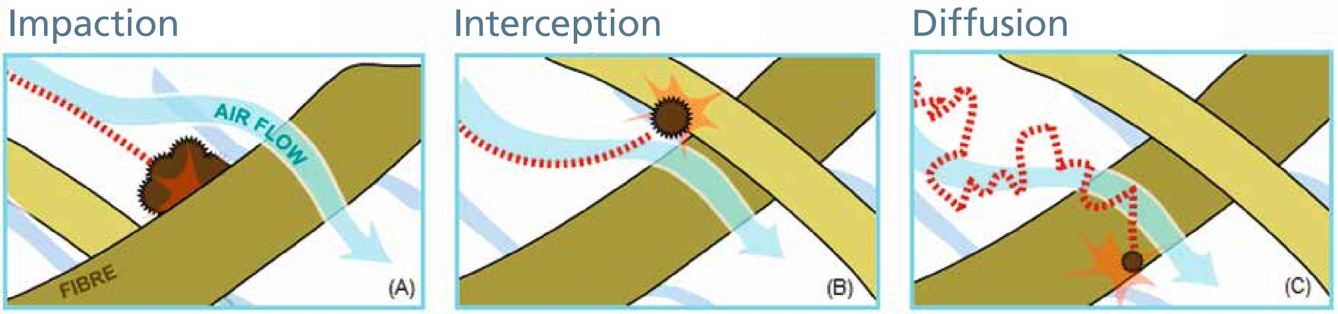

Figure 2: Filtration mechanisms.

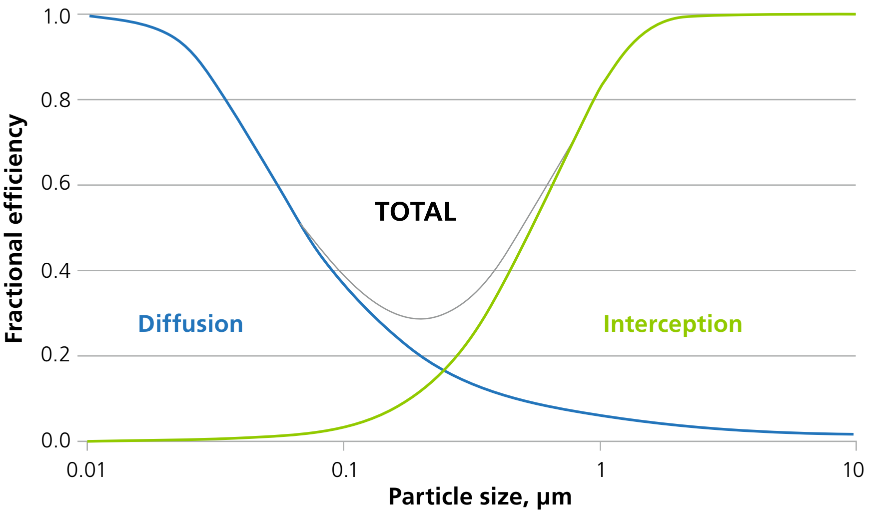

Figure 3: The impact of diffusion, interception and impaction on overall filtration efficiency.

larger than 0.01µm. We want to ensure we are testing products at their worst performing point – 0.3µm – and this principle may be applied to many types of particle filtration technologies. If you want to compare apples to apples, always compare system efficiency at a particle size of 0.3µm.

The EN1822:5 (2009)[9] is widely recognised as the best standard for testing a product at its MPPS, this is normally close to 0.3µm. The ASHRAE 52.2 (2017)[10] or EN779 (2012)[11] test products over the range of 0.3–10µm, so extracting the performance of the product at 0.3µm from these tests is also reasonable.

The ASHRAE 52.1 (1992)[12] standard is obsolete. ASHRAE has since released various versions of ASHRAE 52.2 to supersede 52.1, which reflects the growing understanding of filter testing methodology. ASHRAE 52.1 (1992) dust spot efficiency tested the filter's performance at approximately 0.7–0.8µm[13]. It has been shown mathematically that a filter with an ASHRAE 52.1 dust spot efficiency of 90–95 per cent would test 65 per cent efficient at 0.3µm[13], a critical difference given the importance of removing particles of this size for kitchen exhaust filtration.

It is also important to check that the velocity and/or airflow in the filtration system designed is the same as the test report, because most filtration products – especially ESPs – drop significantly in filtration performance as the velocity of air increases.

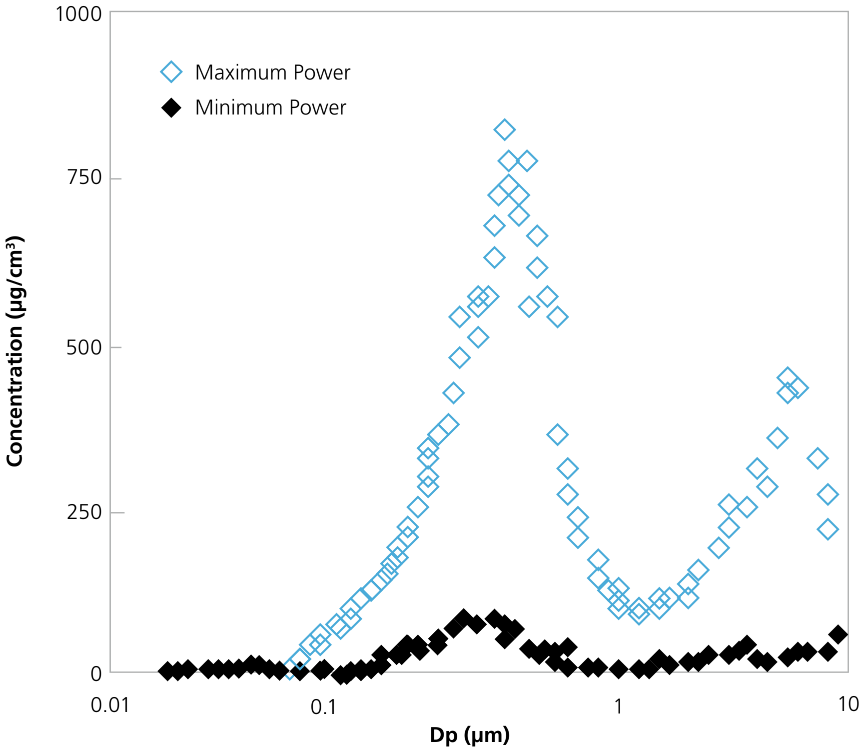

Figure 4: Particle mass distributions during the grilling of 50g of bacon on a gas stove[14].

Smoke particles

Smoke particles are normally 0.3-1μm in size[6],[14], and this is another significant reason why 0.3μm is chosen to compare system efficiency within kitchen exhaust filtration systems. A system that delivers poor efficiency at 0.3μm will lead to poor filtration of smoke, a common visual and odorous pollutant present in kitchen exhaust. Smoke can also be a significant health risk when present in ambient air.

Figure 4 shows the mass of particles generated when cooking bacon on a gas stove. There is a significant mass of particles, mostly smoke, generated at 0.3μm, which is particularly noticeable when the food is cooked at a high heat. The second peak of particles at 7–10μm is likely comprised of fine grease aerosols[15].

WHY 95 PER CENT?

The rating of the performance of filters for kitchen exhaust filtration of 95 per cent at the particle size of 0.3μm is done for three reasons:

- 95 per cent filtration of 0.3μm particles ensures the air is mostly clear of smoke and almost entirely clear of particles of a smaller and larger size as discussed previously with impaction, interception and diffusion.
- Common odour control/gaseous filtration mechanisms don't perform effectively or economically when there are too many particles present in the air.
- 99.97 per cent at 0.3μm while better for performance, poses economic and footprint issues. 95 per cent is regarded as the sweet spot for a high level of filtration before extensive design changes are required.

Gaseous filtration and particles

Below is a brief description of two common methods of gaseous filtration used to control odour, and how poor prior particle filtration will render them ineffective. Part 2 in the series on kitchen exhaust filtration design will go into further detail on these technologies.

Adsorbent/chemisorbent media

Adsorbent media, commonly activated carbon, consists of micropores within larger granules. Small odorous gas molecules find their way inside these pores where various forces adsorb the gas molecules to the media, therefore removing them from the airstream. If the media granule is subject to particle contamination, the outer surface of granule will become coated, creating a seal. This results in a poor performance due to the unused pores being inaccessible and going to waste.

Ozone

Ozone works by breaking down molecules into smaller and smaller molecules with oxidation until eventually simple, common odourless gases are left such as CO_2, N_2, H_2O and O_2, etc.

When relatively large particles such as grease and smoke are present in the air, which are 100 to 1,000,000+ times larger[15] than odorous gas molecules, the ability of the ozone to break down the small odour molecules can be reduced. This is because the oxidative power of ozone will be absorbed by large particles which may not be fully broken down to a simple odourless gas,

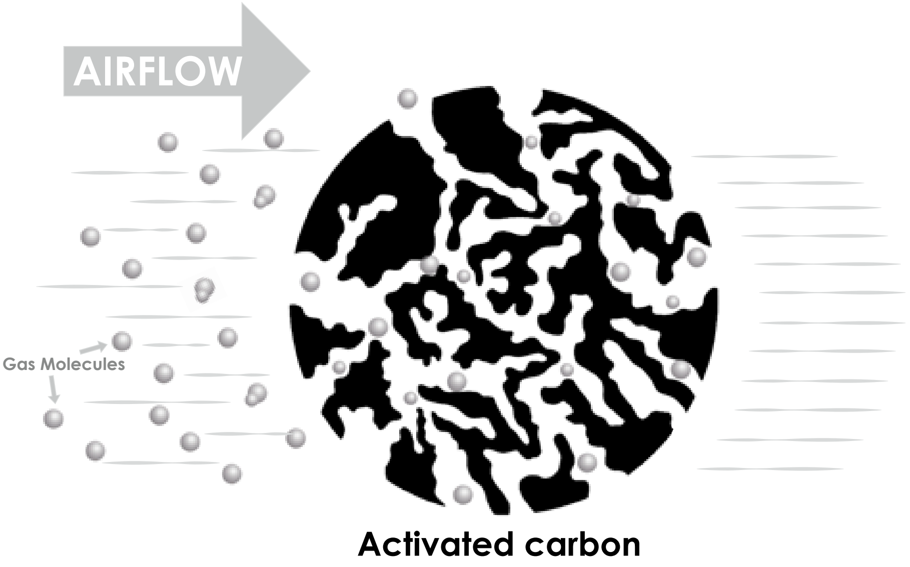

Figure 5: The adsorption of gas molecules within the pores of activated carbon.

particularly given the short residence time in kitchen exhaust filtration and available concentration of ozone. The tiny odorous molecules are therefore effectively "hidden" and can remain in the airstream along with the particles which are not fully broken down.

CONCLUSION

Nuisance odours are not the only factor when considering options to improve the ambient air quality from discharged cooking fumes. The health of the general population is now also being taken into consideration. By understanding the first principles of particle and gaseous filtration, we can make better decisions regarding kitchen exhaust filtration applications to form an economic and effective solution.

The World Health Organisation estimates that approximately 3 million deaths are attributable solely to ambient (outdoor) air pollution each year[16]. Kitchen exhaust has been identified in poor ambient air quality. Increasing awareness of the effect of poor ambient air quality on human health could see filtration of kitchen exhaust discharges becoming increasingly important in the future.

Part 2 in next month's Ecolibrium uses the first principles of filtration reviewed here to analyse some common kitchen exhaust filtration technologies including hood filters, ultra-violet (UV), multi-stage filter packs, electrostatic precipitators (ESPs), activated carbon and ozone. The focus will be placed on how we can economically and effectively achieve a particulate filtration efficiency of 95 per cent at 0.3μm with sufficient downstream odour control. ▮

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Peter Mathieson, F.AIRAH, is a mechanical engineer with over 30 years of mechanical services design experience. Over that period he has designed many kitchen exhaust installations, many with discharge filtration. Peter says his design of kitchen ventilation has improved with experience, and is with reference to the current ASHRAE research.

Would you like to know more?

Part 2 reviews the likely performance of common filtration methods for kitchen exhaust, and aims to uncover economic and effective choices for kitchen exhaust applications that will achieve the design performance parameters established in part 1.