Air filters

An introduction to air filter applications involving activated carbon

Activated carbon's adsorptive properties have been exploited since ancient Egyptian civilisation when it was used for medicinal purposes. Modern day usage covers a wide range of applications, including air filtration.

Air filters are used to remove unwanted compounds from the air we breathe that cause foul odours as well as fumes and vapours that would otherwise cause a nuisance or have an adverse effect on health. Inhalation of these compounds could lead to health problems being particular dangerous to those with underlying respiratory breathing problems such as asthma. Other minor symptoms that are likely to be experienced include irritation to the eyes, headaches and a blocked or runny nose. More serious problems can arise over long term exposure to certain compounds that have toxicity and carcinogenicity associated with them.

Sometimes it is necessary to treat the ambient air for process reasons, especially during the production of electronics and pharmaceuticals, or for preservation reasons, especially for delicate or aged items and specimens.

Activated carbon for air filtration duties is manufactured to have a high micropore volume, making it ideal for the adsorption of a variety of unwanted chemicals. In this process, the polluting chemical(s) is/are firmly bound via weak electrostatic forces to the surface of the activated carbon pores. When considering an activated carbon for an air filtration application the following have to be taken into account:

1. Adsorbate concentration; maintain concentration at <25% of the lower explosive limit (LEL) of the adsorbate

2. Oxidation of unsaturated organic compounds; heat of adsorption and ambient humidity can lead to oxidation reaction with ketones, which is highly exothermic. Promoted by the alkali mineral ash content of the carbon. For example, ketones.

3. Relative humidity; activated carbon will adsorb moisture blocking access to pores for target species.

4. Temperature; adsorption is improved at lower temperatures as kinetic energy is removed from target molecule.

These filters can be used in the following applications:

- IAQ (Indoor Air Quality): room cleaners, e.g. cigarette smoke, cooking odours, coal/gas/wood burners
  > For removing noxious and objectionable odours from air. Can use a combination of filters to tackle particles and odour. Combined with impregnated grades to treat formaldehyde and sulfur compounds
- Cabin air: trains, automobiles
  > Control of odours and toxic compounds in automotive, industrial and commercial applications
  > For removing volatile organic compounds (VOCs) and sulfur dioxide (SO_2)
- Whole building systems (heating, ventilating and air conditioning/HVAC): offices, museums, archives
  > Removing unwanted chemicals from air supply
  > Treating air conditioning intakes usually from traffic fumes
  > Treating acidic fumes that could cause irreparable damage to specimens, documents etc.

Powder, granular and extruded activated carbons are used in this application, with extruded carbon preferred as it offers the lowest pressure drop of the 3 types of activated carbon mentioned. This usually involves the filling of a vessel of unit to generate a carbon bed. For powder, this presents problems. As soon as air is introduced to the bed, the powder is blown about and is no longer settled, and the bed is said to be fluidised. To combat this, the powder is immobilised on a non-woven fabric, giving added benefits such as improved kinetics. However, this does mean that there is a reduced capacity due to the lower weight loading per unit volume.

Indoor Air Quality refers to the air quality within buildings and structures. It is an important measure as it there is believed to be a direct relationship of the occupants of a building and their health and comfort with the quality of the air they breathe.

HVAC (heating ventilating and air conditioning) filters follow the principle of IAQ but applies to whole building systems. These systems must adhere to ISO 16813:2006 which establishes the general principles of building environment design, including a healthy indoor environment and protecting the environment outside the building for future generations. This standard highlights the considerations needed when designing HVAC systems in new buildings and retrofitting older ones. Activated carbon can be considered during the design and detail stages (stage II and III). These stages specify the components that make up the environmental control systems, which could include an activated carbon filter if considered in the design process:

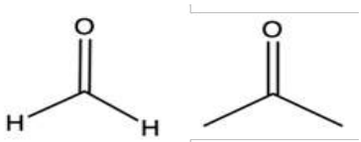
- Stage II- General; "The objective of stage II is to determine the schematic framework of the building and its environment systems as requested by the client. Once a design problem is defined, the following processes concentrate on a solution. Stage II focuses on the concepts and scheme concerning the building and its environment systems, whose structure determines the following process, i.e., stage III. The framework concerning how the design problem as formalised in the previous step is solved shall be determined. The framework is expressed in terms of the building scheme, i.e., the zoning, the circulation, the prospected use, and the diagrams to describe the building environment systems such as HVAC, lighting, water service, etc. What building environment systems are employed is determined in this process."

- Stage III- General; "Stage III is the main stage of the design process where detailed design is performed. The structure of the building, i.e. the shape and dimension of the building elements and the relationship between them, as well as the components of the building environmental control systems shall be specified. The structure of a building is determined during this process, and is expressed in terms of shape, dimensions, and the material of the building components and spatial relations and/or the functional relations among the structural elements. All system design shall be included."

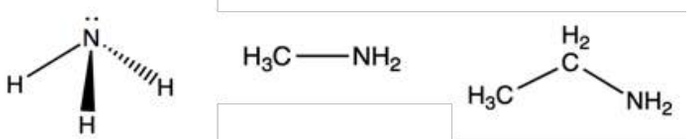
The efficiency of filters is hugely important in ensuring that effective capture of target species and treatment of air that is subsequently inhaled by humans. This is imperative as the air is often recirculated and/or chilled by air conditioning. Recirculation is particularly important in cabin air application where the air often has to be recycled. This recirculation involves air that has passed through the engine compartment and then combined with fresh air and passed through a suitable filter to remove contaminants. An increase in heat causes volatility of odour molecules and an increase in humidity. This exacerbates the nuisance caused by odours, as the increased humidity helps carry odour compounds around a given space. These criteria highlighted above can be met by using activated carbon as part of the filter system. This is because activated carbon has a high surface area with a large microporous volume making it suitable for adsorption of a variety of compounds, but also in retaining these compounds if there is small variations in ambient conditions, i.e. natural changes in temperature and humidity within the room.

The list below highlights the potential compounds (or class of compounds) that could be treated using an air filter:

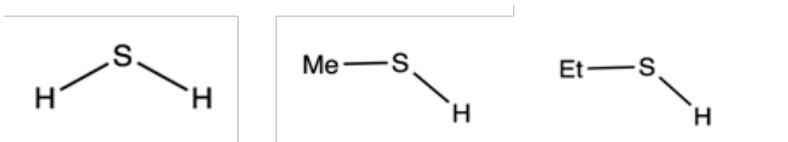
• Aldehydes and ketones; formaldehyde, acetone, methylethylketone, methylisobutylketone. L-R; formaldehyde (methanal), acetone (propanone)



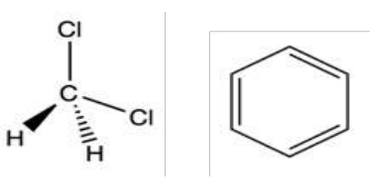
• Ammonia and amines (methylamine, ethylamine). L-R; ammonia, methylamine, ethylamine.



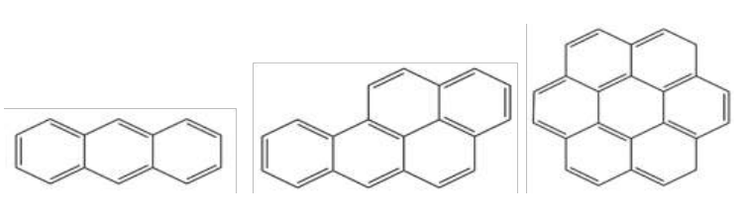
• Hydrogen sulfide and mercaptans (methylmercaptan/methanetiol, ethylmercaptan/ethanethiol). L-R; hydrogen sulfide, methylmercaptan (methylamine), ethylmercaptan (ethylamine).



• VOCs (volatile organic compounds); a group of chemicals that have a high vapour pressure and low boiling points at room temperature. This applies to any chemical that will evapourate or sublimate at room temperature (for liquids and solids respectively). The EU defines a VOC as "any organic compound with an initial boiling point less than or equal to 250°C measured at a standard atmospheric pressure of 101.3 kPa". L-R; dichloromethane, benzene.



• PAHs (polyaromatic hydrocarbons); a group of organic compounds containing only carbon and hydrogen arranged in multiple aromatic rings (electrons are delocalised over all atoms). These are non-volatile and non-soluble in water (highly lipophilic). Found dispersed in oil droplets and bound to particulate matter such as soot. Small PAHs may be volatilised (e.g. anthracene). L-R; anthracene, benzo[a]pyrene, coronene.



Typical applications include the following:

• Tobacco smoke- tobacco smoke contains more than 4000 chemicals, the list below contains the compounds that are of the most concern:

Compound Name	**Compound Type**
acetaldehyde	carbonyls
acetone	carbonyls
ammonia	inorganics
benzene	organics
benzo[a]pyrene	polycyclic aromatic hydrocarbons
formaldehyde	carbonyls
hydrogen cyanide	inorganics
methyl ethyl ketone	carbonyls

• These all volatilise when cigarettes are burned.

o Formaldehyde is treated by impregnated carbons to generate a polymer that is fixed on the surface of the activated carbon.

o Ammonia is treated with acidic impregnated carbons, fixing the reacted salt onto the surface of the activated carbon.

• Outgassing from furnishings- formaldehyde used in manufacture of resins used in furniture and in the production of carpets. Can volatilise at room temperature.

o Formaldehyde is treated by impregnated carbons to generate a polymer that is fixed on the surface of the activated carbon.

• Pet odours- odours from urine are usually due to ammonia. Typically used in cat litter.

o Ammonia is treated with acidic impregnated carbons, fixing the reacted salt onto the surface of the activated carbon.

• Human odours- Odours from sewage waste are due to production of hydrogen sulfide, methanethiol, ammonia and trimethylamine. Odours from humans are typically associated with organic acids, like butyric acid, propanoic acid and 3-methylbutanoic acid.

o Hydrogen sulfide is reaction catalytically with a basic impregnation to give elemental sulfur

o Thiols (mercaptans) are treated through physical adsorption

o Ammonia is treated with acidic impregnated carbons, fixing the reacted salt onto the surface of the activated carbon.

o Organic acids are treated through physical adsorption.

- Fumes from cooking and wood/coal/gas burners with incomplete combustion leads to formation of PAHs.
    - o PAHs are treated with a non-impregnated carbon and removed through physisorption.
- Odours from cooking food such as garlic, onion and fish. Onions and garlic are associated with compounds like allicin and allyl methyl sulfide and fish odours are usually attributed to amines.
    - o Complex sulfur based compounds such as allicin and allyl methyl sulfide are large enough to be treated through physisorption to the activated carbon surface.
    - o Trimethylamine can be treated with an acidic impregnation forming a salt that is then retained on the carbon surface.
- Smog- NO_x is a major component of photochemical smog. Prevalent in Asia and a major risk to respiratory health.
    - o NO_x is treatment involves oxidising NO and dissolving NO_2 in water and neutralising the resultant acid.

The following list highlights technical documents that further explain the applications and the treatments for the compounds mentioned in this document:

1. Sewage Odour Control (Jacobi-TIS-ADDSORB-Odour Control-A4-ENG-A0815)
2. NOx removal (Jacobi-TIS-ADDSORB-NOX-A4-ENG-B1015)
3. Ammonia and Activated Carbon (Jacobi-TIS-ADDSORB-Ammonia Removal-A4-ENG-A1015)
4. Formaldehyde (Jacobi-TIS-ADDSORB-Formaldehyde-A4-ENG-A1015)
5. Chlorinated and polyaromatic cyclic compounds; dioxins, furans and PAHs (Jacobi-TIS-ECOSORB-Chlorinated and Polycyclic Aromatics-A4-ENG-A0216)

Particulate matter is not readily removed by activated carbon (AC). These are relatively large particles that clog up the macropores of AC and thus reducing the efficiency of the AC to adsorb harmful airborne chemicals. Clogged up pores significantly reduces the lifetime of the AC and thus breaks the rules outlined in ISO 16813:2006 above. There are a number of particulate matter filters that can be employed to combat this issue.

EPA (efficiency particulate arrestance), HEPA (high efficiency particulate arrestance) and ULPA (Ultra-low particulate air) filters can be used to remove particulate matter found in smoke and smog. HEPA are effective at reducing airborne pathogens and used in conjunction with AC filters in cabin air applications. To be classified as HEPA filters they must remove at least 99.97% of airborne particles that are 0.3 µm or larger in diameter. ULPA can remove 99.99% of airborne particles that are 0.1 µm or larger. These types of filters are composed of randomly arranged fibreglass fibres of 0.5-2.0 µm. Bag filters are also used in conjunction with AC filters. Again, this has the capacity to capture particulate matter and harmful airborne chemicals and can be made from fibreglass or synthetic fibre to create a woven fabric that is then manufactured into bags. Issues with vibrations due to air passing through the AC filter, disturbs the dust on the surface of the granular AC or disturbs the whole bed if a powder is used which then soils the treated air.

To minimise this effect for powdered AC, the carbon can be immobilised into a block or the use of a pre-filter, such as those mentioned above are used to filter air before treatment with AC and significantly prolong bed life (a pre-filter before a particulate matter filter and AC filter significantly increases the lifetime of both filters). The employment of both a particulate and AC aren't limited to separate units. Combination filters combine the benefits of both filters into one unit.

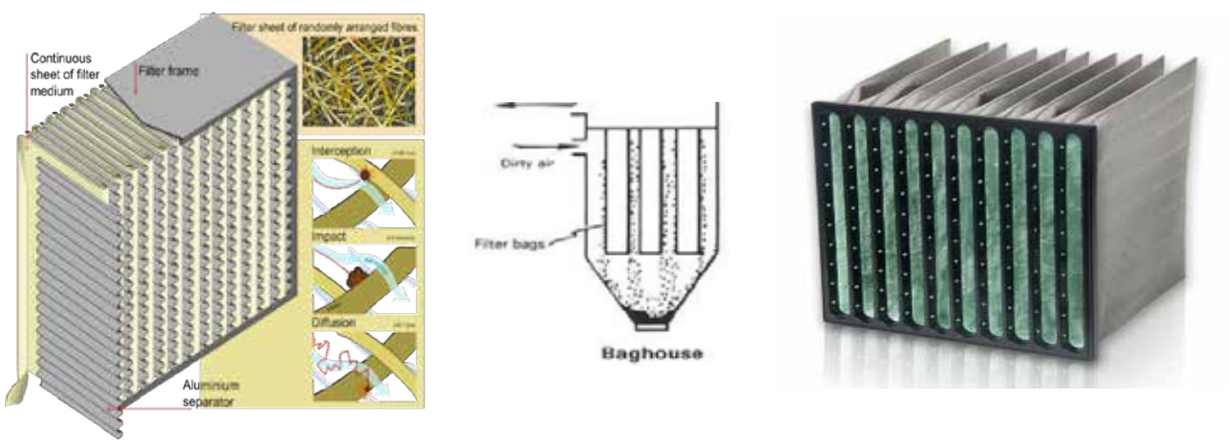


Figure 1: (Left): HEPA with function depicted. Interception; where particles in the line of flow in the air stream adhere to a fibre when in close proximity. Impact; larger particles are unable to avoid fibres when following the air flow and so are forced to adhere to it. Diffusion; An enhancing mechanism seen for the smallest particles, gas molecules in the air collide with the smallest particles which impedes and delays their path through the filter medium (Image Source (Accessed 18/01/2016 at 9:20 am): https://en.wikipedia.org/wiki/HEPA). (Middle): Bag filter with function explained. Particles in airstream cannot pass filter membrane and collects inside the filter. (Image source (Accessed: 18/1/16 10:55 am): https://en.wikipedia.org/wiki/Dust_collector). (Right): An example of a bag filter.(Image Source (Accessed 18/1/16 09:41am): http://www.camfil.co.uk/Products/Bag-filter-products/Bag-filter--2-in-one-solution-IAQ1/City-Flo-XL-en/).

Figure 2: L-R; Housing for cylindrical carbon filter; Housing for HEPA filters; Housing for bag filters. (Image sources (Accessed 18/1/16 09:57 am): http://www.camfil.co.uk/Products/Filter-housings-air-intakes-and-mounting-systems/Housings/CamCube-AC-filter-housings-for-HEPA-filters-en/; http://www.camfil.co.uk/Products/Filter-housings-air-intakes-and-mounting-systems/Housings/CamCube-HF-filter-housings-for-bag-filters-en/; http://www.camfil.co.uk/Products/Filter-housings-air-intakes-and-mounting-systems/Housings/CamCube-CC-filter-housings-for-cylindrical-carbon-filter-en/).

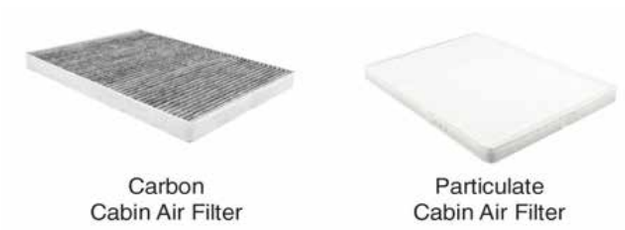


Figure 3: Visual comparison of cabin air filters between activated carbon and particulate matter. (Image source (Accessed: 26/1/16 15:14 pm): http://www.baldwinfilter.com/TechTips201304.html).

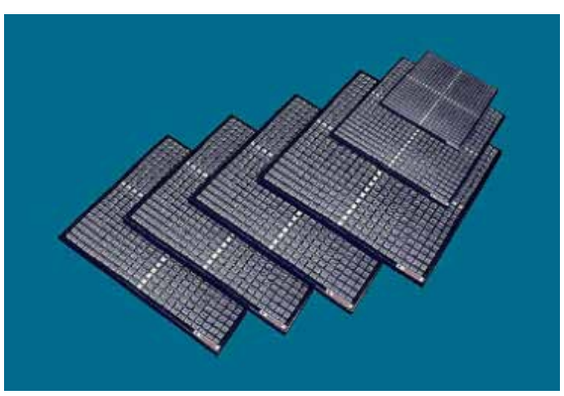


Figure 4: Carbon filter panels for IAQ and HVAC. Activated carbon is not fixed. Contains granular carbon within the structure of the filter panel. (Image source (Accessed: 27/1/16 09:45 am): http://www.emcelfilters.co.uk/carbon-filters/replacement-carbon-filter-cells/).

Figure 5: Carbon filter cells for the adsorption of gaseous odourous compounds, hydrocarbons and trace inorganics from recirculated air. Can fit into existing fittings and activated carbon can be tailored to application needs (i.e. use of impregnated activated carbon). Cartridge type filters (far right) are easily replaceable and easy to dispose of. Used in IAQ and HVAC applications. (Image source (Accessed 02/02/16 11:02 am): http://www.troxuk.co.uk/filter-elements-and-filter-units/activated-carbon-filters-53e6bb17af9e3274).

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