Effects of Carbon Filtration Type on Filter Efficiency and Efficacy: Granular Loose-Fill vs. Bonded Filters

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Abstract

Activated carbon is used in a wide variety of purification techniques including gas and water purification, metal extraction, water purification, pharmaceutical manufacturing, gas masks, and air filters. Several physical forms of activated carbon exist, including powdered, bead, and extruded, yet granular activated carbon is one of the most commonly used for air filtration.

Activated carbon filters are produced in two main styles, granular multi-layer free fill and bonded filters. Granular multi-layer carbon filters contain loose fill carbon media layered to meet specific chemical filtration needs. Bonded filters utilize various chemical processes to bond the carbon particles into a rigid matrix.

This study tested the hypothesis that granular activated carbon filters, specifically Air Science filters utilizing the Multiplex™ Filtration System, have a longer useful life and greater filtering efficiency with no associated performance defects than bonded filters.

To test this hypothesis, a third-party laboratory (IBR Laboratories) analyzed the adsorption efficiency of an Air Science granular loose fill filter and a dimensionally identical bonded carbon filter from RSE Incorporated based on the SEFA 9 (2010) benchmark testing methods.

The Air Science ASTM-001 granular filter retained 1709.7 grams of isopropanol at a run time of 450 minutes before reaching 1% threshold limit value (TLV). The bonded filter ASTM200-001 retained 1348.8 grams of isopropanol after 355 minutes before reaching 1% TLV. This difference of 360.9 grams represents a 26.8% greater efficiency than a comparable bonded filter. The Air Science filter took 95 minutes longer to reach the 1% TLV saturation, suggesting a significantly longer useful life than that of the bonded filter.

The results of this study verify that under similar laboratory settings, Air Science granular carbon filters have a higher filtering efficiency and will maintain safe operating conditions for a longer period of time than similarly-sized bonded filters. Air Science granular carbon filters are also easier for operators to change out, have greater stability in shipping / packaging, and offer a variety of chemical impregnation options to meet specific filtration needs.

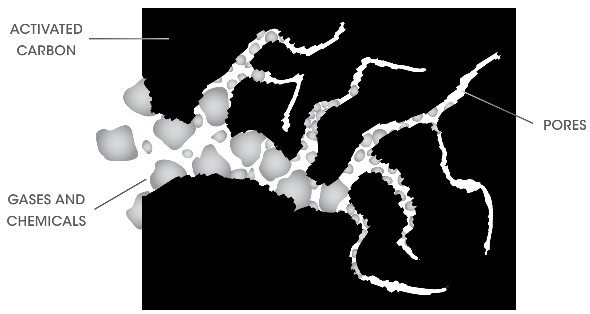
Background

Activated carbon includes a wide range of amorphous carbon-based materials prepared to exhibit a high degree of porosity and an extended interparticulate surface area. These qualities give activated carbon excellent adsorbent characteristics that make carbon very useful for a wide variety of processes including filtration, purification, deodorization, decolorization, purification and separation.

The effectiveness of activated carbon as an adsorbent is attributed to its unique properties, including "large surface area, a high degree of surface reactivity, universal adsorption effect, and pore size" (Figure 1). Due to its increased porosity, a single gram of activated carbon contains 500-2,000m² aggregate surface area.[1]

Activated carbon is widely used in critical purification techniques in gas purification, metal extraction, water purification, medicine, gas masks, and air filters.

Figure 1: Internal Pore of Activated Carbon Granule



Production

Activated carbon is produced from a wide variety of carbon-rich raw materials, including wood, coal, peat, coconut shells, nut shells, bones and fruit stones. New materials are currently under investigation as sources for activated carbon.

The two primary types of activation are:

- **Chemical Activation.** This technique is generally used for the activation of peat and wood based raw materials. The raw material is impregnated with a strong dehydrating agent; typically phosphoric acid or zinc chloride mixed into a paste and then heated to temperatures of 500 - 800°C to activate the carbon. The resultant activated carbon is washed, dried and ground to powder.
- **Steam Activation.** This technique is generally used for the activation of coal and coconut shell raw material which is usually processed in a carbonized form. Activation is carried out at temperatures of 800 - 1100°C in the presence of steam.

Principles of Adsorption

The main principle on which the filtration of gas molecules is based is the concept of adsorption. Two main processes by which adsorption take place are physical adsorption and chemisorption.[2]

Physical Adsorption

Physical adsorption is non-specific and adsorption of the gas molecule is by diffusion (Brownian movement) or adsorption/condensation using Van Der Waals' forces. The gas molecules move into an empty area and diffuse into the pore where they impact the walls and are trapped. The number of pores present in the carbon is vast and therefore the total surface area is extremely large. Depending on the carbon used and the type of filter, aggregate surface area can be in the range of 2,000m2/g (roughly equivalent to about 4 football fields).[3]

Chemisorption

The physical process of adsorption is followed by chemical adsorption (chemisorption). This is a chemical reaction in which the two substances react together and the resultant chemical is trapped on the filter material. The impregnation of filter media can greatly extend the range of gases that can be removed from the air stream.

A number of physical forms of activated carbon exist, including powdered, bead, and extruded, yet granular activated carbon is the most commonly used for air filtration. Compared to powdered activated carbon, granular activated carbon has a much larger particle size with a small external surface, which increases its diffusion rate and makes it the carbon of choice for vapor adsorption. Activated carbon filters can be manufactured in a number of forms, including bonded, multi-layer free fill, and hybrid which can be impregnated with chemicals to assist in the adsorption process and increase filter efficacy.

1 *Value Added Products from Gasification – Activated Carbon, By Shoba Jhadhav, The Combustion, Gasification and Propulsion Laboratory (CGPL) at the Indian Institute of Science(IISc).*

2 *Value Added Products from Gasification – Activated Carbon, By Shoba Jhadhav, The Combustion, Gasification and Propulsion Laboratory (CGPL) at the Indian Institute of Science(IISc).*

3 *www.airscience.com/22*

Regulations / Compliance

Carbon filter manufacturers can perform testing and compliance reviews for a number of state, local, and internal company standards; however the methods most widely used as general industry guidelines are the Scientific Equipment & Furniture Association (SEFA) 9-2010 Recommended Practices for Ductless Enclosures. Manufacturers will typically request a questionnaire be completed during the purchase of a filter to ensure that the list of chemicals to be used in the fume hood are sufficiently compatible with the filter type based on SEFA 9-2010 standards.[4]

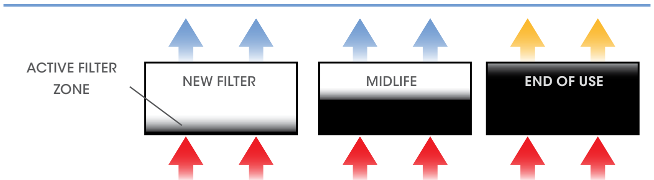
The SEFA 9-2010 guidelines provide recommended benchmark testing for ductless fume hood filtration according to three classifications:

- **DH I:** Nuisance odors and non-toxic vapors only. No testing required.
- **DH II and DH III:** General laboratory fume hoods containing noxious or potentially harmful fumes. Testing, hood maintenance, and calibration must be closely monitored and recorded.[4]

Filter monitoring should aim to detect the period of initial break-through (Figure 2) and in all cases should warn the operator well before the permissible exposure level (PEL) is reached.[5] For the purposes of this study, reaching 1% threshold limit value (TLV) was a sufficient benchmark in both concentration and temporal monitoring to determine the efficiency of carbon filtration under normal operating conditions. Threshold limit value is the level at which the American Conference of Governmental Industrial Hygienists (ACGIH) believes a worker can be exposed to a chemical daily for a working lifetime without adverse health effects.[5]

A concentration of 1% TLV captured for most chemicals is determined an accurate measure of filter efficiency, as determined by SEFA 9-2010, 4.3.1 (for more information on benchmark testing procedures see SEFA 9-2010, 4.3.1 and ASHRAE 110-1995 for instrumentation setup).

Figure 2: Chemical Adsorption and Breakthrough of Carbon Filter



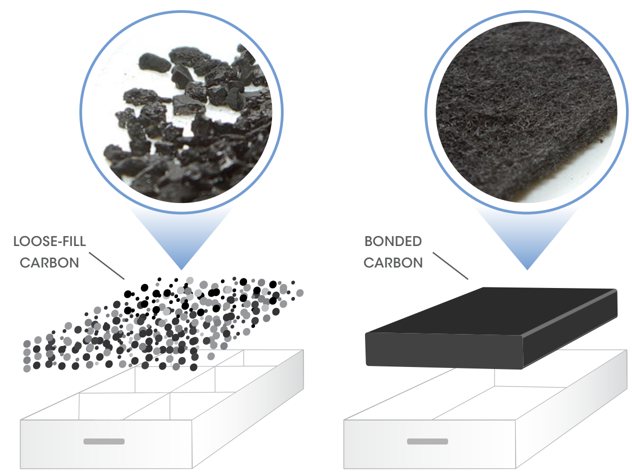
Adsorption takes place in a filter bed in what is known as the active filter zone (represented above as dark saturated area). As the filter is used this active zone progressively moves up the filter bed until it approaches the top surface of the filter. At this point there is an initial breakthrough by the contaminant vapor(s), and thereafter the percentage of contaminant gas that escapes filtration increases.

Types of Carbon Filters

Activated carbon filters are constructed in two main styles, granular multi-layer free fill and bonded filters. Granular multi-layer carbon filters contain loose fill carbon media layered to meet specific filtration needs. Granular carbon media is filled into a solid filter frame which allows minimal media settling for optimal airflow through the loose carbon fill. Granular activated carbon filters can contain carbon impregnated for a single target analyte or can be layered with carbon impregnated for a number of analytes, increasing the range of containment. Granular filtration maintains the original physical and chemical properties of the carbon and offers the greatest amount of surface area for chemical bonding sites.

Bonded filters utilize the same granulated carbon as loose-fill carbon filters, but use various chemical processes to bond the carbon together into a solid matrix. This creates a rigid carbon filtration system that is often chosen for its convenience of handling. Bonded filter manufacturers claim that due to the solid nature of the filter, there is less chance of user exposure to the chemicals contained within a used filter. Bonded filters are also typically claimed to be "dust-free" because the carbon particles are bonded together in a solid form. It is possible, however, that as a result of the brittleness of the bonded filter, that partial filter erosion may take place in shipping and allow fine particles to be exhausted during initial fume hood start-up following a filter change out.

Figure 3: Granular Loose-Fill vs Bonded Carbon Filter Construction



4 *Recommended Practices for Ductless Enclosures. Scientific Equipment & Furniture Association (SEFA) 9-2010. Fourth Edition, Version 1.0.*

5 *www.acgih.org*

Issues with Bonded Carbon Filters

Bonded carbon filters are widely marketed as having equal, if not better efficacy than loose fill granulated carbon filters. Manufacturers claim that a solid filter matrix minimizes dead zones in the filters and maximizes capacity. Others in the industry, however, have questioned the effect that a solid matrix has on filter performance.

Regardless of the proprietary process, to create a solid matrix from loose granulated carbon, the physical and chemical properties of the carbon particles must be altered. These alterations likely have detrimental effects on the ability of the carbon particles to bond with target compounds and could also decrease flow rate compared to a loose fill filter.

The Bonding Process

The bonding process typically requires the activated carbon be soaked in water for approximately 24-hours prior to being bonded. This soaking can leach out the impregnated chemicals required to effectively manage certain types of vapors, decreasing the efficacy of the final filter.

Additionally, the bonding agents used to create bonded carbon filters are normally a type of resin, such as polystyrene. The amount of resin used has a critical impact on the adsorption capacity of the filter and it is not inconceivable that over half of the space on the carbon granules can be covered with the bonding agent. This renders the filtering capacity of the carbon granules at least temporarily useless and may have long term effects on filter efficiency.

This study was derived to test the efficacy and performance of granular loose fill filters (specifically Air Science Brand, ASTM001 filters) against that of a general purpose bonded filter (RSE Incorporated) based on all of the aforementioned performance issues with bonded filters.

Hypothesis

Granular Activated Carbon filters, specifically Air Science filters utilizing the Multiplex Filtration System, have a longer useful life than bonded filters with none of the associated performance defects. Granular loose fill filters will have a greater filtering efficiency (higher retention capacity) than bonded filters do and will have a longer life before reaching 1% of TLV.

Granular loose fill filters may also have additional performance benefits in the form of ease of handling, more stability in shipping / packaging, and fewer chemical impregnation issues compared to bonded filters.

Methods

To test this hypothesis, a third-party laboratory (IBR Laboratories) analyzed the adsorption efficiency of an Air Science granular loose fill filter compared to a dimensionally identical bonded carbon filter from RSE Incorporated based on the SEFA 9-2010 benchmark testing methods.

The carbon filters were loaded into a Purair 10 Advanced Ductless Fume Hood and 99.9% isopropanol was evaporated from a hot plate placed inside the hood. Total mass of isopropanol evaporated and the concentration of isopropanol in downstream sample air (parts per million or ppm) was measured over time by a MIRAN® SapphIRe Ambient Air Analyzer placed 18 inches above the center of the exhaust grid. Air concentration readings were recorded every 15 minutes until the reading measured 1% of TLV as determined by SEFA 9-2010 recommendations.[6,7]

Similar cabinet conditions were maintained throughout testing for both the granular loose fill filter and the bonded filter. Table 1 depicts environmental and equipment conditions maintained during testing of both filter types.

Table 1: Conditions of Ductless Fume Hoods During Testing

	Granular Filter	Bonded Filter
Temperature °F	71	70
Relative Humidity %	46	49
Barometric Pressure mm Hg	739	737
Face Velocity FPM	100	100

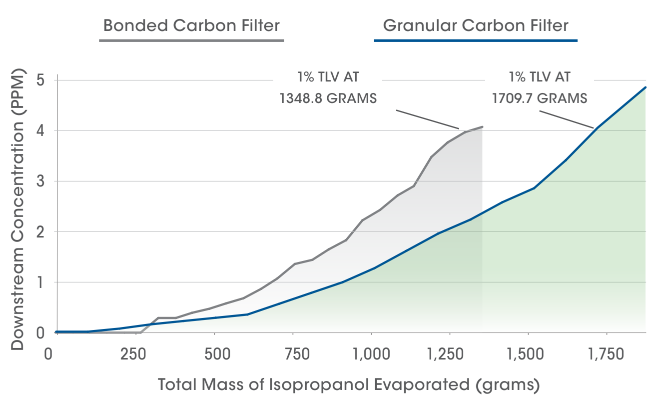
6 *IBR Test Report: Job Number 14709, January 11, 2014. IBR Laboratories.*

7 *IBR Test Report: Job Number 113576A, January 21, 2013. IBR Laboratories.*

Results

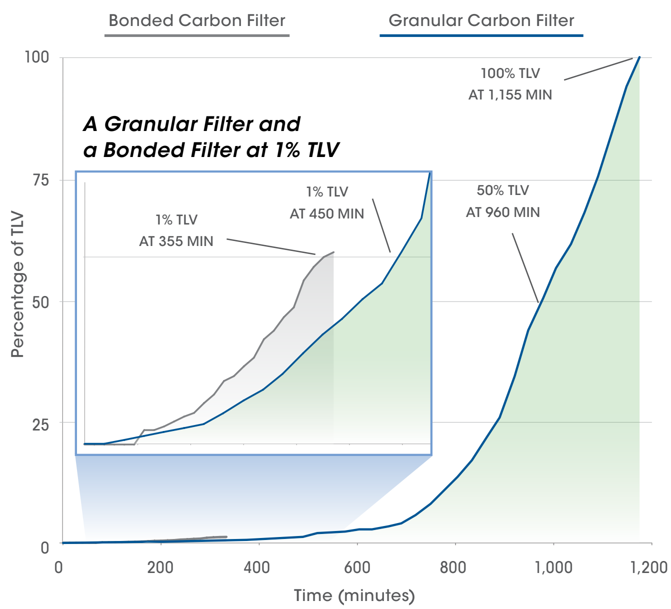
The graphs below depict the concentration of isopropanol absorbed over time by each of the two filters. The Air Science ASTM-001 granular filter was able to retain 1709.7 grams of isopropanol at a run time of 450 minutes before reaching 1% TLV. The bonded filter ASTM200-001 retained 1348.8 grams of isopropanol after 355 minutes before reaching 1% TLV. This difference of 360.9 grams represents a 26.8% greater efficiency than comparable bonded filter. Additionally, the Air Science filter took 95 minutes longer to reach the 1% TLV saturation, indicating a significantly longer useful life than that of the bonded filter.

Graph 1: Filtration Efficiency of a Granular Loose-Fill Carbon Filter Compared to a Bonded Carbon Filter



Graph developed from the provided IBR Laboratories data, showing concentration of isopropanol over time for both filters comparatively.

Graph 2: Time to Reach TLV for a Granular Loose-Fill Carbon Filter and a Bonded Carbon Filter



Graph showing 1% TLV, 50% TLV, and 100% TLV for granular loose-fill carbon filter as determined by SEFA 9-2010 testing.

Discussion

The results of this study verify that under similar laboratory settings, granular carbon filters will maintain safe operating conditions for a longer period of time than bonded carbon filters. Bonded manufacturing causes some of the pores on the carbon (sites of reaction) to be crushed or destroyed, which decreases the adsorption capabilities. This can lead to additional negative effects, including a noticeable pressure drop in the fume hood and less efficient air filtering capabilities over the life of the filter.

Additional Downsides to Bonded Carbon Filters

Bonded filters tend to weigh more than granular filters (34 lbs. for the bonded filter versus 22 lbs. for the granular carbon filter in this test) which can make filter change out more difficult, while their brittle nature can lead to quality issues in the shipping and handling process.

Additionally, bonded filters are typically only offered with a single type of impregnation due to the difficulty associated with leaching during the bonding process. This can limit the use of the fume hood in which bonded filters are installed and increase the expense of maintaining compliance for certain laboratory operating procedures.

Benefits of Air Science Granular Carbon Filters

Air Science granular carbon filters have none of the issues associated with bonded filters, and provide a higher retention capability over the useful life of the filters. This decreases the frequency and associated downtime and expense of filter change outs.

Air Science granular carbon filters utilize the Multiplex Filtration System, which consists of a pre-filter, main filter and optional safety filter to create a combination of chemical and physical architecture customized to each application. The multiplex option permits one or more filtration types to be combined within a single filter housing to meet a wider range of multiple-use applications. Multiplexing allows for the capture of acids, bases, and when paired with HEPA or ULPA filters, particulates such as biological aerosols.[8]

An additional benefit of the Air Science granular carbon filter is fire suppression. Granular carbon filters used in enclosure fire tests resisted ignition and helped suppress the fire. It is suspected that under similar test conditions, bonded filters would display some ignition due to the various chemical resins used to bond the carbon particulates together.

The Air Science granular carbon filter outperforms bonded filters in nearly every way. Air Science granular carbon filters are self-contained assemblies sized to fit the specified product model number, and configured to optimize air flow across 100% of the filter surface area for maximum efficiency, prolonged filter life, optimal diffusion and saturation capacity, and enhanced user safety.

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8 www.airscience.com

Andre Chambre

Andy Chambre is the founder and CEO of Air Science, LLC and has been associated with the ductless fume hood industry for more than 25 years. He was formerly the US Vice President for Captair Labx and President of Astec Microflow US. He was named President of Filtco Corporation in 2003 and currently also serves as a Director of Air Science Technologies Ltd. in the UK.
Mr. Chambre has written numerous articles on fume hood safety and assisted in the development of safety standards by serving on various committees such as the Canadian Standards Association subcommittee on fume hoods and the SEFA 9 Ductless Enclosures Committee.

Acknowledgements

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Sources

- Value Added Products from Gasification – Activated Carbon, By Shoba Jhadhav, The Combustion, Gasification and Propulsion Laboratory (CGPL) at the Indian Institute of Science(IISc).
- Recommended Practices for Ductless Enclosures. Scientific Equipment & Furniture Association (SEFA) 9-2010. Fourth Edition, Version 1.0. Accessed: www.sefalabs.com/files/public/SEFA-9-2010-Ductless.pdf.
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- IBR Test Report: Job Number 113576A, January 21, 2013. IBR Laboratories.

Additional Information Sources

- www.airscience.com/22
- www.acgih.org

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