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AEROSPACE & DEFENSE

Understanding Carbon-Based Chemical Filtration Systems For Aircraft Cabins

Improving cabin air quality is becoming an increasingly higher priority as part of a broader push to enhance airline comfort.

As a result, aircraft manufacturers are integrating advanced cabin air filtration technology on new-generation aircraft, and operators are upgrading current aircraft with more advanced filters with chemical filtration capabilities purposely built for their fleets.

In 2011, the Boeing 787 became the first transport-category aircraft designed with a system that included both particulate filtration and chemical filtration for removal of odors from recirculated cabin air. The system, Donaldson Company's Air Purification System (APS™), combines a HEPA particulate filtration stage with an adsorbent that uses a gas-phase adsorption process that independent tests on similar systems have shown to be more effective than other chemical filtration methods.

Developing and validating an effective, efficient chemical filtration system for aviation requires significant and consistent investment in research and development. It also requires a high level of understanding of how certain variables affect adsorption processes.

A detailed testing program paired with an evaluation of in-service filters allows Donaldson to develop effective filtration systems, verify the systems' performance and make improvements based on in-service evaluations.

The Push For Cleaner Cabin Air

As demand for air travel rises, aircraft manufacturers and airlines are increasingly focused on making airline travel more comfortable. While many of the transformative comfort improvements—from advanced premium-cabin seating to mood lighting—are clearly visible, some are subtler. The progress made on improving cabin-air quality is a prime example of the latter.

The push to improve cabin air began to gain momentum following a 1986 report from the National Research Council (NRC) that helped convince the U.S. Federal Aviation Administration (FAA) to ban smoking on U.S. domestic flights. When complaints about cabin air persisted during the next decade, a follow-on study was commissioned. Released in 2002, it recommended that the FAA should investigate and publicly report on the need for and feasibility of installing air-cleaning equipment for removing particles and vapors on all aircraft to prevent or minimize the introduction of contaminants into the cabin.

While both studies identified potential areas for improvement and established new regulations, the industry was already making strides to improve cabin air quality beyond the mandates. The 2002 report noted that typical mid-life aircraft at the time, such as the McDonnell Douglas MD-80, had filter efficiencies of about 40% (Mil Std 282). Newer models, such as the Boeing 777 introduced in 1995, carried HEPA filters, which have an efficiency of at least 99.97% for 0.3-μm particles.

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HEPA filters are effective at removing airborne pathogens and other particulate matter, but they are not designed to remove gaseous contaminants. In 2000, some suppliers offered optional, early-generation chemical adsorption filters that worked alongside the HEPA filters to capture organic gases, but, the NRC noted, they were "not widely used." Many of these early-generation chemical filtration systems were packed bed filters that were heavy, costly and had a high pressure drop across the system. Since that time, advancements have been made in the design of chemical filters.

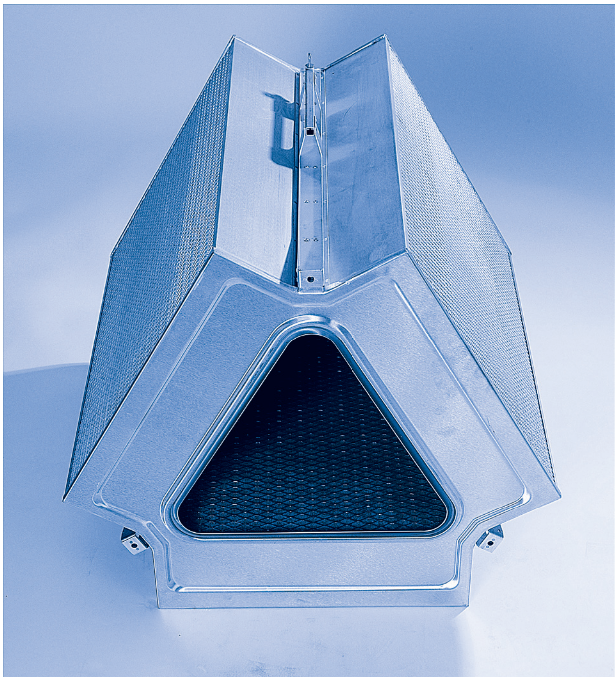
Carbon's Role In Chemical Filtration

As demand for more advanced filtration systems increased, Donaldson was developing what would become its APS technology. The company's chemical filtration product development focused on maximizing the adsorption performance for the airplane cabin environment. In a carbon-based system, this requires factoring in many variables that affect system performance.

Most chemical filtration systems for removing VOCs (Volatile Organic Compounds) use highly activated carbon. The activation process involves steps to increase the effective surface area of the base carbon through the creation of pores within the carbon structure. Contaminants can adsorb to these active surfaces within the carbon pores through physical and chemical adsorption processes.

Adsorption is a complicated process and is dependent on many factors such as the environmental conditions (e.g. temperature, pressure and humidity), VOC concentration, the chemistry of specific VOCs to be adsorbed, the chemistry of the adsorption surface and the amount of surface area available for adsorption. Based on these factors, adsorption is also a competitive process. VOCs compete for the active surface and the amount of a particular VOC adsorbed will depend on its concentration and chemistry relative to other contaminants within the filtration environment.

Since adsorption is a surface relevant process, performance of a chemical filtration system using specific adsorbents is closely tied to the total surface area of the adsorbent and the manner in how this surface area is distributed. It is generally believed that higher surface area adsorbents, such as activated carbons, always perform better than lower surface area adsorbents. However, we note here that this is not always the case.



Donaldson has published a technical paper that shows in many cases lower surface area versions of activated carbons can outperform higher surface area carbons when VOCs are present at low (e.g. ppb) concentrations. It has also been noted that higher surface area for activated carbon does not necessarily mean an increase in the number of small pores.

Therefore, understanding how carbon pores vary—and accounting for these variances—is another important element in developing the most effective chemical filtration system.

The pore-size distribution in carbon varies by carbon source and can influence a system's performance based on several factors which can be evaluated by determining the adsorption isotherm of specific VOCs. Where there is a low concentration (parts per billion, or ppb) of contaminants in the air, the adsorption isotherm suggests the adsorption capacity will be extremely low. This is commonly believed to be the result of diffusion limitations. It is generally understood that the carbon with the most micropores will adsorb the highest amount of VOCs since these pores have the highest adsorption potential. Conversely, with a high concentration (parts per million, or ppm or greater) of contaminated air, the adsorption isotherm indicates the adsorption capacity is significantly increased.

Developing an effective carbon-based chemical filtration system requires a deep understanding of several key factors.

Since a filter's capacity is determined by the amount of surface area within the adsorbent, system efficiency decreases over time as adsorption sites and pores are filled. Efficiency for each chemical contaminant can be different because each has a relatively specific energy of adsorption.

If a filter is exposed to many different contaminants, molecules with a higher specific energy of adsorption can block lower-energy molecules from adsorbing on the surface or replace ones that have already been adsorbed. As a result, the rate at which removal efficiency declines for specific contaminants can vary. This means that understanding the specific contaminants likely to be present in an environment (and their concentrations) is key to maximizing a chemical filtration system's efficiency.

Real-World Testing

Developing an effective carbon-based chemical filtration system requires a deep understanding of several key factors, principally the aircraft cabin environment and activated carbon's properties as an adsorbent.

The absence of specific regulations governing aircraft cabin filtration contributes to the importance of developing a full understanding of the cabin environment. In the U.S., FAA regulations (14 CFR 25.831) require cabin air to be "free from harmful or hazardous concentrations of gases or vapors."

Donaldson has developed innovative new testing methods that can be adapted to simulate variables potentially found in aircraft environments. The test method introduces contaminants at low-concentration (ppb) and high concentrations (ppm). Additionally, the Donaldson developed multi-contamination chemical test bench introduces contaminants in specific profiles rather than all contaminants simultaneously.

The test takes the average block time for an aircraft and segments it into specific flight phases, such as ground, climb and cruise. Expected and potential in-flight events are also factored in, such as meal services. In each phase, the test introduces contaminants representing VOC families in various concentrations. Each test is run in real-time; for example, re-creating a 787's 12-hour block time requires a 12-hour test.

Product Development: New Aircraft

The Boeing 787 represented a significant leap forward in aircraft design, and many of its innovative features are aimed at enhancing passenger and aircrew comfort. Boeing determined that it wanted to maximize onboard air quality, and evaluated several methods, including an air cabin filtration system that removed VOCs as well as possible changes in humidity.

In 2003, Boeing sponsored an independent study to evaluate the individual and combined effects of both gaseous filtration and increased humidity. The study tested the gas-phase adsorption process found in Donaldson's APS units against other chemical filtration methods, including Ultraviolet Photocatalytic Oxidation (UVPCO) systems.

The study, conducted by the Technical University of Denmark (DTU), involved two years of subjective and objective testing that included simulating long-haul flights in aircraft with and without air purification systems, with varied airflow and humidity levels. Mass spectrometry was used to monitor and record the presence of gaseous contaminants during the tests.

After each of these simulated flights, participants rated air quality and reported on perceived symptoms such as dry eyes and throats, headaches and general cabin comfort. Medical evaluations confirmed perceived conditions.

Based on the evaluations, DTU concluded that gas phase absorption (like that used in Donaldson APS) performed optimally and avoided several notable problems that were identified in connection with the other chemical filtration methods, such as the generation of unacceptable levels of acetaldehyde under certain conditions.

In June 2005, Boeing announced that the Donaldson APS would be included as standard equipment on the 787.

Product Development & Evaluation: In-Service Aircraft

Following the successful APS product development for the 787, Donaldson began to apply the core system technology to filters designed for other in-service aircraft. In early 2011, Donaldson began working on a customized APS filter for in-service Airbus A320s. The filter design had to fit into the same envelope as the original particulate-only filter. The product is FAA PMA-approved and has been installed on more than 300 A320s.

As of 2018, Donaldson has more than 900 APS units in service. As part of its in-service evaluation and product-improvement research, Donaldson developed a rigorous evaluation process, the Flight Return program, for monitoring filter performance and implementing changes such as service-interval extensions.

The program takes filters removed from service and analyzes both the particulate and chemical sections to evaluate performance, remaining capacity and other parameters.

The particulate section is visually inspected to understand the loading conditions experienced and to note any anomalies, such as exposure to liquids. The filter is then subjected to the rated air flow to determine the pressure drop at the time of removal.

The chemical filter is analyzed by taking a section of the adsorbate and running it through the real-time testing protocol. Test data is evaluated against a set of expected parameters and previous flight-return data to determine the filter's remaining capacity and actual performance. The results, which are unique to each operator because of variations in flight profiles, cabin-cleaning protocol, and other factors, help determine when service intervals should be adjusted.

Because the particulate and chemical concentration can vary greatly from operator to operator, the flight-return analysis helps determine the optimal replacement interval based on in-service conditions. In many cases, intervals can be extended from the baseline with no performance loss, which saves operators both time and money.

Carbon-based gas-phase adsorption systems are emerging as the preferred technology.

Conclusion

The desire to increase passenger and aircrew comfort is driving technology improvements in cabin air filtration systems. While highly effective particulate-removal filtration is standard, the industry has only recently begun to adopt chemical filtration solutions for both new and in-service aircraft. Carbon-based gas-phase adsorption systems are emerging as a preferred technology.

Selecting the appropriate chemical filtration system requires a detailed understanding of the aircraft cabin environment. In the case of carbon-based systems, it also requires extensive understanding of how activated carbon's attributes can vary based on the material's source, how those attributes affect system performance and the role VOC concentration plays in designing an optimal system.

Evaluating filter performance requires both extensive in-service data and a testing environment capable of simulating the aircraft cabin environment.

About Donaldson Company

Donaldson's Aerospace & Defense business unit is a leading worldwide provider of filtration systems for the aerospace and defense industry. Its filtration solutions protect fixed wing aircraft, rotorcraft, military ground vehicles, electronic equipment, space vehicles, missiles, military shipboard systems and amphibious vehicles. Donaldson, committed to advancing filtration technology and providing quality products and prompt customer service, serves customers from its many sales, engineering and manufacturing locations around the world.

For more information, visit www.donaldson.com.

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