CABIN AIR FILTRATION SYSTEMS – Novel Technological solutions for Commercial Aircraft

Karen Bull and Paul Roux
Pall Corporation, Portsmouth, Hants. PO1 3PD, United Kingdom

There is mounting evidence that Volatile Organic Compounds (VOCs) and other aerosolised condensates and vapours related to contamination of breathing air in modern aircraft could have health and safety implications for both the passengers and the air crew. This presentation provides a review of the technologies currently available for aircraft cabin air treatment; disposable carbon adsorbent filters, photocatalytic oxidation, catalytic converters and non-thermal plasma oxidation. It explains the basic principles of each existing technology and then focuses on the Pall Photocatalytic Regenerable Adsorption (PCRA) system. The PCRA system uses a unique combination of adsorbent and catalyst technologies to remove particulate and gaseous contamination from the cabin air supply.

I. Introduction

This paper focuses on the technologies that can be installed for the treatment of the cabin air supply on commercial and military aircraft.

In modern aircraft the air in the cabin is provided by the environmental control system (ECS) which is designed to control the cabin pressure, cabin temperature, maintain air quality and filter/dissipate any particulate matter, smoke and odours that are present in the cabin[1].

In a typical commercial cabin air recirculation system, the air supplied into the cabin consists of approximately 50% outside air from either the engine's compressor stage (engine 'bleed air') or the Auxiliary Power Unit (APU) which is mixed with approximately 50% of filtered, recirculated air. (Note however, that some aircraft designs are now moving to 'bleed air free' ECS).

Cabin air particulate filters are normally located in the recirculation loop and these are usually rated at 99.99% sodium flame test efficiency or the equivalent 99.97% D.O.P. (Di-Octyl Phthalate) efficiency. In certain cases a lower level of filtration may be in use, but generally there is an option of upgrading to HEPA filtration (equal to or greater than EU grade H13[2]). Filters manufactured to this 'true HEPA' specification provide excellent standards of particulate contaminant removal and control of micro-organisms from the recirculated cabin air[3].

However, some particulate contamination, odour causing compounds and volatile and semi-volatile organic compounds (VOCs and SVOCs) may enter from the outside air system where filtration is not normally provided.

In order to provide a safe, healthy and comfortable environment for the passengers and crew, consideration needs to be given to providing adequate purification of both the outside air ('bleed air'), as well as the recirculated air, for both existing and future aircraft designs.

II. Existing Technologies

The following section provides a review of the technologies currently available for cabin air treatment.

A. Carbon Adsorbent for VOC/Odour Removal

For aircraft cabin air and other industrial transport systems, gaseous removal is currently performed using adsorption devices, which are usually configured as a disposable filter element similar to particulate filter elements.

Adsorption filters consist of solid, non-combustible adsorbents which are chosen based on the gaseous contaminants that need to be removed or separated. (Note that *Adsorption* is the accumulation of gases, liquids, or solutes on the surface of a solid, whereas *Absorption* is a process in which one substance permeates another; a fluid permeates or is dissolved by a liquid or solid).

The advantages of adsorption filters are that they are suitable for low temperature applications (e.g. carbon adsorption filters can work effectively up to 70°C, 158°F), they have a high adsorption efficiency for a wide variety of gaseous contaminants and no electrical power is needed. However, the filter efficiency decreases as contaminants accumulate on the adsorbent, so the elements require removal and replacement at regular maintenance intervals.

At present, Pall supplies combined HEPA/odour adsorbent filters as an option on the Airbus A320 family and Airbus A330/A340 family where they are fully inter-changeable with the existing particulate HEPA cabin air filter elements. Pall is also carrying out an in-service evaluation of a combined particulate/VOC filter on a commercial aircraft where it is designed to filter the cockpit supply air.

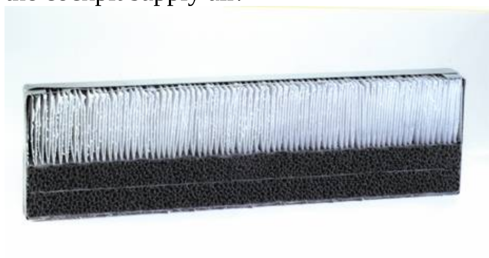

Figure 1: Cross-section through combined particulate/odour removal filter

B. Catalysts for VOC/Odour Removal

Catalytic oxidation works on the principle of oxidizing the contaminants rather than adsorbing them. Ozone Converters (OZC) have been standard equipment on long haul aircraft for over 10 years and combined VOC/ozone converters (VOCZ) are now available as optional equipment for the Airbus A320, A330/A340 families and the A380[4]

The catalytic converter consists of a metal vessel housing a metal or ceramic structure (either honeycomb or ceramic beads) which is coated with a suitable catalyst. Catalyst selection depends on the contaminants that are to be treated and can include materials such as manganese dioxide, platinum and palladium amongst others. As well as dissociating any ozone present to oxygen gas, an appropriate catalyst can convert hydrocarbon based VOCs/odour compounds to carbon dioxide and water.

These units are located in the high temperature zones of the aircraft ECS, such as the outside air supply or downstream of the APU. A VOCZ unit requires a minimum operating air temperature of 150 °C (302°F), and preferably operating temperatures of above 200 °C (392°F) to ensure effective oxidation of a wide range of contaminants.. At temperatures of below 150°C (302°F) oxidation performance is dramatically reduced and it is possible for some contaminants to either become partially oxidised or not oxidised at all..

Figure 2: Range of Catalytic Converters

Since the units are installed downstream of the engines or APUs (auxiliary power units), they are addressing the problem as close to the source as possible. However, based on the aerospace industry experience with ozone converters, it is known that catalytic converters accumulate contaminants and gradually lose efficiency as they accumulate operating hours and cycles. In addition, these units may be poisoned by "episodic" fume events, when a high concentration of oil contamination enters the air system in a short time interval. Poisoning or masking of the catalyst requires the catalytic converters to be either completely replaced or the catalyst has to be regenerated or recored.

C. Non-thermal Plasma Oxidation for Removal of Particulate and VOC/Odour Compounds

Non-thermal plasma oxidation is suitable for the treatment of gas streams with low VOC concentrations and can be used for the simultaneous destruction of different airborne pollutants, such as dust and microbes.

Plasma is a distinct gaseous state of matter containing a mixture of ions and free moving electrons. The highly reactive free radicals and ozone present in the plasma reactor, oxidise the airborne contaminants, such as VOCs and odour compounds to convert them into carbon dioxide and water.

The advantage of the plasma unit is that it maintains a constant efficiency throughout its life. However the design of the plasma reactor has to be carefully considered to reduce the amount of electrical power needed and to ensure that the level of ozone generated is at acceptable levels.

However, it should be noted that the residence time of the contaminated gas in the plasma reactor has to be long enough to allow complete oxidation of the VOCs/odour compounds. If the residence time is too short, partially oxidised reaction intermediates will be returned to the aircraft cabin in the recirculated air stream and it is possible that these new compounds will be equally as unwanted as the original compounds. Additionally, if molecules other than hydrogen and carbon are present in the VOCs, e.g., chlorine, compounds such as hydrochloric acid may be generated. Therefore, for any oxidation system, it is vitally important that the nature of the cabin air contaminant is known before the treatment is applied in order to avoid the production of unwanted oxidation products

Figure 3: Non-Thermal Plasma Oxidation Unit

III. Pall Photocatalytic Regenerable Adsorption (PCRA) system

The PCRA system uses a unique combination of adsorption and photocatalytic oxidation to remove particulate and gaseous contamination from the cabin air supply. As described in section C, the disadvantage of chemical oxidation is that there is a potential to generate unwanted bi-products and this could degrade rather than improve the cabin air quality. The PCRA system solves this problem.

D. Principle of Operation – PCRA System

The PCRA system contains a proprietary adsorbent based on an adsorbent/photo-catalyst material. Its operation comprises of two phases:

Phase one - the adsorbent adsorbs the gaseous contaminants.

Phase two - the system oxidises the contaminants on the adsorbent (see section E) and they are purged overboard into atmosphere.

The advantages of the PCRA is that it is a fully regenerable adsorbent system therefore maintaining high efficiency throughout its period of operation, it removes the contaminants from the air stream rather than oxidise them, it can operate at ambient cabin temperatures, it does not generate ozone, it has minimal pressure loss and low power consumption.

E. Basic Principle - Photocatalytic Oxidation (PCO)

Photocatalysis is an oxidation process in which the catalyst is activated by UV radiation, resulting in the oxidation of gaseous contaminants to water and carbon dioxide. One of the most common catalysts used is titanium dioxide (TiO_2), but other products can be used (e.g., ZnO, ZrO_2).

When the photocatalyst is irradiated with photons, electron-hole pairs (e- and h+) are formed. These react with water vapour and oxygen molecules adsorbed on the catalyst surface to create highly reactive radicals, mainly hydroxyl (OH*):

$$OH^- + h^+ \rightarrow OH^*$$

$$O_2 + e^- \rightarrow O_2^-$$

Finally, these highly reactive oxygen ions and hydroxyl radicals oxidise the gaseous chemical pollutants adsorbed on the catalyst surface to form carbon dioxide and water.

$$VOC + O2- + OH^* \rightarrow CO2 + H2O$$

A typical Photocatalytic Oxidation (PCO) device consists of two essential components; a photocatalytic grid (e.g., a pleated filter media or adsorbent bed coated with a thin layer of catalyst, such as TiO_2) and an ultraviolet light source (e.g. UV tubes installed between the filter panels). The basic PCO principle is an established technology and many units have been produced for industrial and domestic use.

For the Pall PCRA device, prototype units have been tested in laboratory conditions where the test results showed VOC removal efficiencies of greater than 90%. Further work is ongoing to develop and certify an aircraft approved unit.

Figure 4: Prototype PCRA unit for laboratory testing
(courtesy of Mazyck Technology Solutions)

IV. Conclusion

In a typical cabin air recirculation system, the air supplied into the cabin consists of approximately 50% outside air from the engine's compressor stage (engine 'bleed air') or APU which is mixed with approximately 50% of filtered, recirculated air.

Most commercial aircraft have HEPA filters or adsorbers located in the recirculation loop but some particulate, odour compounds and trace chemical VOCs may enter from the outside air system via the mixing chamber where filtration is not normally provided.

Therefore, in order to provide a safe, healthy and comfortable environment for the passengers and crew, consideration needs to be given to providing adequate purification of both the outside air and the recirculated air for both future and existing aircraft. This paper describes some of the technological solutions that are currently available.

Acknowledgments

Some of the information contained in this paper was sponsored by the European Commission (EC) as part of the CabinAir project (EC Contract No.GRD1-2000-25033).

References

1 Elwood H. Hunt, Dr. Don H. Reid, David R. Space, and Dr. Fred E. Tilton: "Commercial Airliner Environmental Control System - Engineering Aspects of Cabin Air Quality", *Boeing web site* (2007), http://www.boeing.com/commercial/cabinair/ecs.pdf

2 European Standard, EN1822:2002. "High Efficiency air filters (HEPA and ULPA)"

3 Centre for Applied Microbiology & Research (CAMR); "Determination of Microbiological efficiency", Report references 443/98, 391/98, 675/00. 1998 and 2000.

4 C Nurcombe: "Airbus Cabin Air Quality Still the Best", *FAST Airbus technical magazine No.37 December 2005*