

Ozone Control in High-Flying Jet Aircraft

PLATINUM CATALYST ENSURES DECOMPOSITION

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To conserve fuel whenever practicable, and to limit cost increases resulting from world-wide increases in oil prices, passenger aircraft are now flying at higher altitudes than previously. This frequently takes them into the ozone-containing layer of the atmosphere, and when this is drawn into aircraft by air conditioning systems it may cause physical discomfort and irritation to aircrews and passengers. Catalytic decomposition, using a metal supported platinum catalyst, provides an economic practical solution in this problem by reducing to an acceptable level the amount of ozone entering the aircraft cabins.

Ozone—from the Greek *ozein*, to smell—is a blue coloured gas with a peculiar pungent odour and a vapour density which corresponds to the molecular formula O_3 . Chemically it is characterised by its high oxidising power and its tendency to decompose exothermically to molecular oxygen even at ambient temperatures. At elevated temperatures decomposition is rapid and at 300°C or above it is almost instantaneous.

In nature ozone occurs in a colourless layer in the earth's atmosphere between about 30,000 and 150,000 feet above the earth's surface. Its concentration in the atmosphere tends to be greater in the northern latitudes, especially from late February to early May, during which time concentrations of the gas may descend to as low as around 25,000 feet.

Ozone may also frequently be detected at ground level because of its synthesis from atmospheric oxygen by the action of electrical sparks and corona discharges. It is thus frequently associated with the operation of electrical apparatus.

The odour of ozone is very characteristic and is perceptible at concentrations of as low as

0.3 ppm in air. Ozone is classed as a deep lung irritant and is extremely toxic; symptoms of ozone poisoning include nausea, coughing, headaches, fatigue, dizziness, shortness of breath, chest pains, burning sensation in the nose and throat, loss of co-ordination and decreased ability to concentrate.

Ozone in a Working Environment

The need to protect people in a working environment from the effects of ozone has been recognised for a number of years. In 1968 the American Conference of Government Industrial Hygienists (A.C.G.I.H.) adopted a Threshold Limit Value (T.L.V.) of 0.1 parts per million by volume (ppmv) for ozone in air, this being the maximum time weighted average concentration for a normal eight hour workday or forty hour working week, to which nearly all workers may be repeatedly exposed without adverse effect. This limit became an official U.S. federal standard for industrial air in 1971 and it is now also used by the U.K. Factory Inspectorate as the basis for the control of ozone in a working environment.

The attention of the public at large was

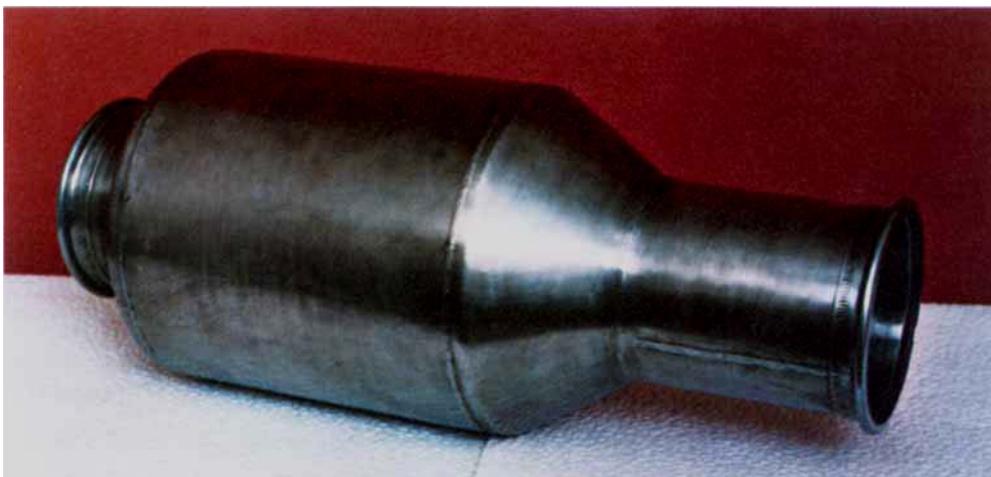


Fig. 1 The ozone contained in the air drawn into the cabin environmental control system of high-flying passenger aircraft can be successfully decomposed in an ozone control unit utilising a platinum catalyst. The canister of the prototype shown here is made from stainless steel, although titanium may also be used with advantage. In addition to the initial requirement for wide-bodied passenger jet aircraft, smaller units can also be made to suit both older passenger and executive jet aircraft. A unit of 9 inches external diameter and 20 inches overall length will treat a contaminated air flow of approximately 2000 standard cubic feet per minute

drawn to the existence of ozone in the earth's upper atmosphere by reports in the mid-nineteen seventies on the effects of chlorofluorocarbons (CFC), used as propellants in aerosol sprays, on the ozone layer. It was postulated that the continued and increasing use of these propellants could result in a serious depletion of ozone in this layer due to chemical reaction between the ozone and CFC; this would allow more of the sun's harmful ultra-violet rays to penetrate to the earth's surface and thereby increase the incidence of skin cancer in humans. Since these reports were published industry has embarked on a search for substitutes for CFC as aerosol propellant and the U.S.A. has barred their use in this application entirely. Canada, Sweden and Norway have also indicated that it is their intention to follow this example.

Ozone Contamination in Aircraft Cabins

The undesirable toxic effects of ozone itself, however, did not come to the general public's attention until 1977. Prior to the first oil supply crisis in 1973 the majority of commercial passenger carrying aircraft operated at cruising

altitudes of about 25,000 to 35,000 feet where the ambient ozone concentration in the air is relatively low. However, airliners now regularly cruise at much higher altitudes, up to 45,000 feet, in order to gain the benefit of lower fuel consumption, and at these altitudes the ambient ozone concentrations are much higher. It is therefore reasonable to expect that the ambient ozone concentration in aircraft cabin air is now higher than was previously the case.

During the winter of 1976 the U.S. Federal Aviation Administration (F.A.A.) began to receive an increasing number of complaints of physical discomfort from crew members and passengers in wide-body jet aircraft on high-altitude long-distance flights.

By the beginning of 1977 information received from F.A.A. airline inspectors, airlines and aircraft manufacturers led the F.A.A. to believe that ozone was the probable cause of many of the complaints. This prompted them to issue an advisory circular—Ozone Irritation During High Altitude Flight—which defined ozone irritation, discussed its causes and symptoms and described a means of dealing with the problem should it occur in flight.

Almost simultaneously the F.A.A. initiated a research project to study the health effects of exposure to ozone in the aviation environment with special reference to haematological, visual, respiratory and performance parameters.

In September of 1977 the F.A.A. issued an advance notice of proposed rule-making (ANPRM) which sought information concerning ozone contamination from airlines, aircraft manufacturers, aircrew unions, high altitude research organisations, health organisations and other interested parties.

Meanwhile Pan-American World Airlines in conjunction with the Boeing Commercial Airplane Company had undertaken as a matter of urgency the development of a charcoal based ozone filtration system which was claimed to eliminate 90 per cent of the cabin ozone. These filters were fitted to all Pan-Am's B-747 SP aircraft—the specially developed long range, high-flying version of the Boeing 747—and the problem was considered solved.

The F.A.A. received a large number of comments in response to their ANPRM including data from the U.S. National Aeronautics and Space Administration which shows that, for example, an average ambient ozone concentration at 37,000 feet above New York City to be 0.16 ppmv with peaks to 0.58 ppmv during the high ozone season of March, April and May. Measurements taken over Anchorage, Alaska, for the same period and conditions show a mean of 0.48 ppmv with peaks up to 0.66 ppmv. Measurements confirmed that ozone concentrations varied according to differences in altitude, latitude, season and weather patterns.

Ozone contamination symptoms in aircrews and passengers were primarily reported on long flights and were associated with the newer high-flying wide-body jet aircraft.

It will be noted that in every case discussed above where measurements were taken the maximum ozone concentrations were all many times higher than the 0.1 ppmv T.L.V. for worker exposure, and even the average concentrations exceeded the T.L.V. in most cases.

Comments on questions dealing with possible aircraft design changes and the best solution to

the aircraft cabin ozone contamination problem nearly all indicated that a mechanical fixture, rather than an aircraft operational change, was called for. Two basic ozone reduction design concepts were submitted, these being charcoal filters and catalytic converters.

U.S. Federal Aviation Regulations

On the basis of this and other evidence, and with due consideration of the T.L.V. for ozone adopted by the U.S. Occupational Safety and Health Administration (O.S.H.A.), the F.A.A. issued a formal notice of proposed rulemaking in October 1978 suggesting an amendment of Federal Aviation Regulations in order to limit the maximum allowable ozone concentration in aircraft cabin air to 0.3 ppmv, with a maximum time weighted average during any 2 hour flight period limited to 0.1 ppmv for aircraft flying above 18,000 feet.

Interested parties were invited to comment on these proposals and it was noted that they could be changed in the light of comments received. Based on a review of these comments, and the results of the F.A.A.'s research project on health effects, the proposals were slightly modified and eventually issued as a Final Rule which became effective on February 20th, 1980. This rule states that after February 20th, 1981 no U.S. certificate holder may operate a transport category aircraft above 18,000 feet unless it has successfully demonstrated to the Federal Aviation Administrator that the ozone concentration inside the cabin will not exceed:

- (1) 0.25 parts per million by volume, sea level equivalent, at any point in time; and
- (2) for each flight segment that exceeds 4 hours, 0.1 parts per million by volume, sea level equivalent, time weighted average over that flight segment.

There are four basic methods available for purifying air contaminated with ozone:

1. Gas scrubbing using liquids, such as alkaline solutions.
2. Thermal decomposition.
3. Gas adsorption using solids, for example activated charcoal.
4. Catalytic decomposition.

Gas scrubbing is not a practical proposition for use in aircraft. Thermal decomposition does offer a practical solution but the need to raise the contaminated air supply to the cabin to around 300°C for effective ozone decomposition means that such a system would be very energy intensive, and thus much of the fuel saving achieved by flying aircraft at high altitudes would be lost. Thermal decomposition is used at present, however, in Concorde aircraft. This is made possible by the fact that the air bleed from the engine compressors, which provides the cabin air supply is at a temperature in excess of 300°C compared with temperatures of 150 to 200°C in the more conventional design of aircraft.

Gas adsorption usually entails periodic regeneration or replacement of the solid adsorption surface. In the case of activated charcoal there is the added disadvantage that ozone-adsorbed-activated charcoal dust may deflagrate or even detonate. Reference has already been made to the charcoal filtration system developed by Boeing for use in Pan-Am's fleet of B-747 SP aircraft. The weight added to the aircraft by the installation of the original filtration system was about 800 pounds although a later version reduced this to approximately 480 pounds. This weight addition represents a significant loss of payload and an increased fuel consumption penalty. Furthermore the charcoal filter system tends to be rather large and replacement of the charcoal is required at about six monthly intervals. These factors contribute significantly to aircraft maintenance costs.

Catalytic Decomposition

Of all the alternative methods available for dealing with the problem of ozone in air, catalytic decomposition offers probably the most elegant and the simplest solution without most of the disadvantages associated with the other methods.

Before the emergence of the problem of ozone in aircraft cabin air, the principle of catalytic decomposition of ozone had already been successfully applied in a wide variety of other industrial applications such as the treat-

ment of waste gases containing ozone from water and sewage treatment installations, the removal of ozone from arc-lamp cooling systems and the treatment of ozone emissions resulting from the operation of electrophotographic duplicating machines.

Catalytic materials used in these applications are many and varied, and include a large number of base metal and base metal oxides as well as a number of noble metal elements such as platinum, palladium and silver. Of these materials it would be reasonable to expect that the noble metals, by virtue of their intrinsically higher catalytic activity and resistance to poisoning, would offer the most cost effective solution to the problem of catalytic decomposition of ozone.

Johnson Matthey Chemicals Limited involvement in the specific problem of ozone in aircraft cabin air began in early 1978 when the company was contacted by Burnley Engineering Products Limited, a long established manufacturer of precision aerospace components and assemblies. This company had been approached at the end of 1977 by the Lockheed Aircraft Corporation with a view to their participating in a programme to develop a catalytic decomposition unit for use in the environmental control system of the L-1011, Tristar, aircraft. Johnson Matthey Chemicals were known to Burnley Engineering Products as a major supplier of platinum group metal catalysts and were therefore invited to co-operate in this development programme.

Following some preliminary laboratory work involving screening tests of a range of existing catalyst systems under simulated aircraft cabin air flow conditions, a prototype unit comprising a Johnson Matthey Chemicals metal honeycomb supported noble metal catalyst contained in a canister designed and manufactured by Burnley Engineering Products was submitted for testing by Lockheed in a full size test rig.

The selection of the catalyst type was based largely on Johnson Matthey Chemicals experience in the field of automotive exhaust emission control technology and in particular on the proven advantages of very high catalyst

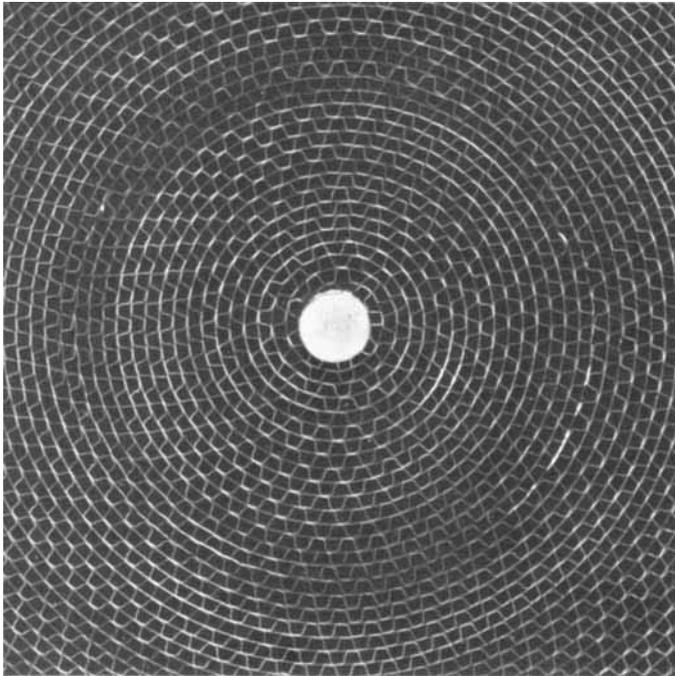


Fig. 2 The catalytically active platinum is supported on a metal honeycomb which typically has approximately 500 channels through each square inch of cross-section. Relatively light in weight with a high catalytic surface area to weight ratio, the catalyst is capable of withstanding severe thermal and mechanical shock and is expected to achieve a service life of several thousand hours under normal operating conditions

surface/volume ratio, low resistance to gas flow, and immunity to thermal and mechanical shock offered by metal honeycomb supported catalysts.

Test results produced by Lockheed during 1978 confirmed the pressure drop advantage of the Johnson Matthey Chemicals metal substrate, which was only about 50 per cent of that exhibited by many of the other competing systems based on the use of the more conventional ceramic honeycomb substrates. However, it was found that the ozone decomposition efficiency was rather below the target, which required above 90 per cent decomposition.

Research Activity

This observation prompted a programme of intense activity at the Johnson Matthey Research Centre to investigate alternative catalyst formulations. Some thirty different formulations were prepared, including both base metal and noble metal types, all supported on a metal honeycomb substrate. Small scale functional tests under simulated aircraft condi-

tions were carried out on all the various formulations and it was established that a special pure platinum catalyst formulation was readily capable of achieving greater than the required minimum of 90 per cent ozone decomposition efficiency.

A second prototype unit containing a catalyst with the new formulation was subsequently submitted for full scale simulated flight tests. These tests were performed during the latter half of 1979 and established that the Johnson Matthey/Burnley unit was fully capable of achieving the desired ozone decomposition efficiency. This second prototype has now been ground evaluated by all three American manufacturers of wide-body passenger jet aircraft and their tests have confirmed the high performance efficiency of the unit.

Discussions are continuing with the aircraft manufacturers and airlines operating aircraft affected by the F.A.A. ruling with a view to optimising the performance and design of the Johnson Matthey/Burnley catalytic ozone decomposition unit. Prospects for the full commercialisation of the unit are excellent.