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Catalytic Converter for Ozone Decomposition in Aircraft Cabins

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ABSTRACT

To conserve fuel whenever possible, and to limit cost increases resulting from world-wide increase in the oil prices, passenger aircraft are now fly at higher altitudes compared to previous. This probably takes them into the ozone containing layer of atmosphere and when this is drawn into the aircraft by air conditioning systems, they cause physical discomfort and irritation to aircraft crews and passengers. Catalytic decomposition, using a metal supported catalyst, provides an economic practical solution in this problem is to reduce an acceptable level the amount of ozone entering the aircraft cabins. Of all the methods available for dealing with the problem of ozone in air, catalytic decomposition offers probably the most elegant and the simplest solution. The principle of catalytic decomposition of ozone had already been applied in a wide variety of other industrial applications such as the treatment wastage gases containing ozone from water and sewage treatment installations and the removal of ozone from arc lamp cooling systems etc. The selection of the catalyst type was based on the proven advantages of very high catalyst surface/volume ratio, low resistance to gas flow, and immunity to thermal and mechanical shock offered by metal honeycomb supported catalysts.

Keywords - Ozone, Photo catalysis, Aircraft cabin, Decomposition.

1. INTRODUCTION

The need of protecting people in a working environment from the effects of ozone has been recognized for a number of years. This study explores how the atmospheric ozone enters the aircraft cabin and cause discomfort to aircraft passengers and Crew.

Ozone, derived from the Greek word ozein, means to smell. It is a blue coloured gas with a pungent odour and vapour density which corresponds to the molecular formula O_3 [3]. Chemically, it is characterized by its high oxidizing power and its tendency to exothermically decompose to molecular oxygen even at ambient temperatures.

Ozone occurs naturally in a layer about 30,000 and 150,000 feet above the earth's surface. The odour of ozone is very peculiar and is perceptible at concentrations of as low as 0.3 ppm in air. Ozone is a deep lung irritant and is extremely toxic; symptoms of ozone irritations include nausea, headaches, dizziness, coughing, fatigue shortness of breath, chest pain, burning sensation of nose and throat, loss of co-ordination and decreased ability to concentrate.

Before the first oil supply crisis occurred in 1973, most commercial Passenger-carrying aircraft operated at high altitudes of about 25,000 to 35,000 feet where the ambient concentration of ozone in air is relatively low. However, to save fuel consumption, airliners after 1977 regularly fly at high altitudes, up to 45,000 feet, where the ozone concentration is very much higher. Ozone can enter into the aircraft cabin together with the fresh-air supply. Since then, more passengers complained about physical discomfort when flying on high altitude on long-distance flights. Surveys have showed that ozone in air was the cause of passengers' complaints. Research has also shown that ozone concentrations vary with differences in, latitude, altitude, season, and weather patterns. When ozone concentration is greater than 0.214 mg/m3, it may cause discomforts such as headaches, irritation of eye, nose, and throat, and chest pain.

2. OZONE IN WORKING ENVIRONMENT

The attention of the public was very large drawn to the existence of ozone in the earth's upper atmosphere by reports in the mid-nineteen seventies on the harmful effects of chlorofluorocarbons (CFC), used as propellants in aerosol sprays, on the ozone layer. It was postulated that the continued and increased use of these propellants could result in a serious depletion of the ozone in the layer due to chemical reaction between the ozone and CFC; this would allow more of the sun's harmful ultra-violet rays to enter into the earth's surface and thereby increase the risk of skin cancer in humans.

Since these reports were published industry has made on a search for substitutes for CFC as aerosol propellant and the U.S.A. has banned their use in this application completely.

2.1 Ozone Contamination in Aircraft Cabins

The undesirable toxic effects of ozone did not come to the general public's attention until the year 1977. [3]. Before the first oil supply crisis occurred in 1973 the majority of commercial passenger carrying aircraft operated at increasing altitudes of about 25,000 to 35,000 feet where the ozone concentration in the air was relatively low. However, airliners now regularly fly at higher altitudes, up to 45,000feet, in order to obtain the benefit of lower fuel consumption, and at these altitudes the overall ozone concentrations are very much higher. It is therefore sure to expect that the ozone concentration in aircraft cabin air is now greater than was before the case. During the winter season of 1976 the U.S. Federal Aviation Administration (F.A.A.) began to receive an increasing number of complaints of physical discomfort from the crew members and passengers in wide-body jet aircraft on high altitude and long- distance flights.

2.3 U.S Federal Aviation Regulations

The United States (US) and the World Health Organization (WHO) imposed a law to limit the ozone concentration in air. The law (WHO, 2000) specifies that the maximum ozone concentration must not exceed 0.24 mg/m3 for 8-h exposure, and the average ozone concentration in 8-h exposure is limited to 0.12mg/m^3. Chinese "indoor air quality standards" (GB/T 18883-2002) also require that the indoor ozone concentration not exceed 0.214 mg/ m^3.

In 2008, Civil Aviation Administration of China enacted China Civil Aviation Regulations (CCAR-24-R4) for transportation category airplanes. The regulations require that cabin ozone concentration cannot exceed 0.535 mg/m^3 when flying above 9.6 km at any time, and not exceed 0.214 mg/m3 when flying at cruising altitudes of about 8.23 km within 3 h flying time. The U.S. Federal Aviation Administration (FAA) regulations require that the ozone concentration inside the cabin will not exceed [3]:

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

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

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

2.4 Catalytic Decomposition

Ozone decomposition has been extensively studied for its harmfulness to human health. Various methods, such as thermal decomposition, adsorption, and catalysis, have been proposed for ozone removal. Gas adsorption has the disadvantage of requiring the periodic regeneration or replacement of the solid adsorbent. Also, the additional weight of the adsorbent will cause an increase in the fuel consumption of the airplane.

Thermal decomposition requires the temperature of the contaminated air must be raised to 300^{o}C or above, which is much energy intensive. Therefore, the catalytic method was proved to be the most effective method for ozone removal. Catalytic removal of ozone in air includes catalytic decomposition and photo catalytic decomposition methods .The former has been extensively studied. The nanometer base metal catalysts, such as silver manganese, nickel and iron etc., and precious metal catalysts, such as palladium, platinum gold etc., have been used as the active catalyst component.

However, these precious metal catalysts are very costly, which limits the real application of these catalysts for the air purification. Meanwhile, the application of base metal catalysts for ozone decomposition has the disadvantage of deactivation due to the high oxidizing power of ozone, as has been confirmed by Heck and co-workers, who performed a detailed analysis of the in-flight performance of the early developed thermally sensitive catalysts for ozone removal in aging studies and found that base metal catalysts were easily deactivated.

Photo catalysis is a developing technology for indoor air purification. A variety of volatile organic compounds (VOCs) can be decomposed with help of the nanometer TiO2 as the catalyst under the illumination of UV rays. However, because the photo catalytic reaction is a surface reaction, contaminants are transferred directly to the catalyst surface, contact the catalyst, and can be then decomposed.

The higher the concentration of the contaminants, the higher is the photo catalytic reaction rate. But the concentration of contaminants in host air is relatively low and the adsorption of VOCs onto TiO2 is also weak; so an adsorbent, such as activated carbon, has been used as a catalyst support to remove the diluted concentration of pollutants from air in order to improve further the photo catalytic removal of VOCs, A combination of zonation and photo catalysis has been studied and shown that ozone often plays a vital role in removing some contaminants from air.

Although most research has been done on the photo catalytic decomposition of VOCs, some researches concentrated on the photo catalytic removal of ozone alone .In 1995, Bulanin studied that the adsorption of ozone onto the surface of anatase TiO2 and concluded that TiO3 is a site for ozone decomposition. Such finding was confirmed by the ESR (electron spin resonance) study. On the surface of TiO2, TiO4 was reduced to TiO3 by help of a photo induced electron (e^-), which enhanced the adsorption of ozone onto the surface of TiO2. The mechanism for the photocatalysis decomposition of ozone can be described as in Equations. (1) and (2).

$Ti^{4+} + e^- \rightarrow Ti^{3+}$

(1) $Ti^{3+} + e^- \rightarrow Ti^{4+} + O3^-$

(2) $TiO2 + hv \rightarrow h^+ + e^-$

However, research showed that photo-induced electrons (e–) and holes (h+) can be captured by the ozone and hydroxide ion (OH-) or water on the surface of TiO2, separately. The reaction mechanisms can be shown as follows.

(3) $O3 + e^- \rightarrow O3^-$

(4) $OH^- + h^+ \rightarrow OH^\cdot$

(5) $O3^- + H2O \rightarrow OH. + OH^- + O2$

(6) $O3^- + O3 \rightarrow O4^- + O2$

(7) $OH. + O3 \rightarrow O4^- + H^+$

(8) $O4^- + O3 \rightarrow 2O2 + O3^-$

(9) $H^+ + O3^- + O4^- \rightarrow 3O2 + OH^-$

The above reaction processes show that the photo- induced electron (e^-) can be captured more efficiently in the presence of O3 because of the electron affinity of O3 which (2.103 eV) is considerably larger than that of the oxygen molecule (0.44 eV) or the oxygen atom (1.46 eV), and the Reaction (4) is the rate determining step. In the above sequence of chain reactions (Reactions (5), (9)), ozone is decomposed [1].

The above discussion shows that several number of factors can affect the photo catalytic decomposition of ozone. However, even though the several of the above-mentioned studies looked at some of these factors, most studies are mainly focused on the photo catalytic removal of VOCs and on the ozone- enhanced photo catalysis. To the best of the knowledge, there have so far been no studies which have thoroughly analyzed the photo catalytic decomposition of ozone alone, especially on the feasibility of the application on bleed air purification in the aircraft cabins. The major differences between ground air and bleed air in aircraft cabin is the flow velocity ozone concentration. , and humidity. The flow velocity and ozone concentration in ground air are lower, but the humidity is very much higher. Conversely, the ozone concentration and flow velocity in aircraft cabin bleed air are higher, but the humidity is virtually be zero.

2.5 FACTORS AFFECTING PHOTO CATALYTIC DECOMPOSITION

2.5.1. The Effect of Flow Velocity

Fig. 1 shows the change in trend of ozone concentration with time using the TiO2/AC film with and without UV light radiation at an initial ozone concentration between 4.7 and 5.0 mg/m3.When the time is zero minute, ozone was introduced into the reactor and has reached equilibrium for more than one hour in the absence of theTiO2/AC film photo catalyst. When the time is higher than 0 min, the TiO2/AC film photo catalyst was put into the reactor, and the ozone concentration began to increase without UV irradiation, but when the UV light was turned on, the ozone concentration maintained almost unchanged. Ozone concentration was first dropped sharply probably due to adsorption of ozone onto the activated carbon and then went up high again at the time of 0 min. The unchanged ozone concentration, showed by the line with solid circles, indicates that the ozone concentration was in a dynamic equilibrium state between the adsorption onto the activated carbon and photo catalytic decomposition under the UV light irradiation. However, without the UV irradiation, as showed by the line with solid squares, ozone concentration rise continuously with an increase in time even after 3 h.

The results shows that the adsorption saturation existed on the adsorbent and the photo catalytic removal of ozone could delay the adsorption saturation. These results are similar to the photo catalytic removal of formaldehyde over TiO2/AC film. The results revealed that ozone can be effectively decomposed over TiO2. Mill et al. studied the photodecomposition of ozone over a film of TiO2 sensitized glass and also confirmed that ozone could be decomposed by photo catalysis. Fig.4 shows the variation of ozone concentration with time by photo catalysis at different flow velocity and initial ozone concentration of $4.7e^{5.0}$ mg/m3. It can be seen that the photo catalytic ozone decomposition was more affected by the flow velocity. Fig. 5 shows the effects of flow velocity on the ozone decomposition rate (ORD) and the ozone removal efficiency (F) at two different ozone concentrations.

The ozone decomposition rate increased at first with rise in flow velocity and reached a plateau when the flow velocity has exceeded a certain value. These observations had agreed with the photo catalytic oxidation rates of toluene, formaldehyde as reported by Yu and Lee.

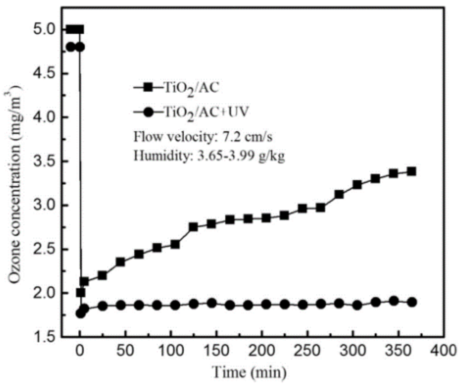

Fig. 1 Ozone concentration versus time using the TiO2/AC film with and without UV light irradiation.

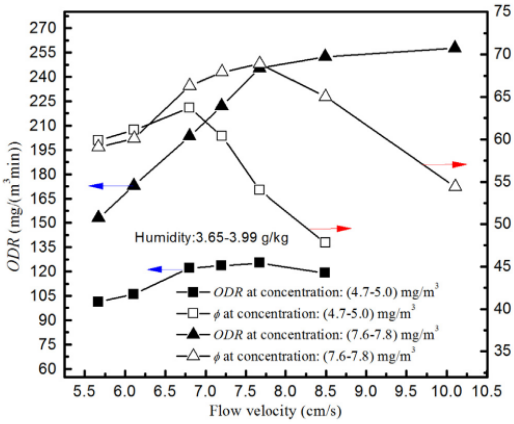

Fig. 2 Ozone concentration as a function of time at different flow velocities and initial ozone concentrations of 4.7-5.0 mg/m3.

2.5.2. The effect of initial concentration

Fig. 3 shows the effect of initial concentration on the photo catalytic removal of ozone. Before each experiment, the ozone concentration was adjusted at a specific level for about one hour, and then the catalyst film was placed onto the reactor for the first experiment measurement. The ozone concentration was decreased quickly after the TiO2/AC film was put into the reactor at the time of zero min due to the adsorption of ozone over the activated carbon. Subsequently, when the time is higher than zero min, the UV light was turned on and the ozone concentration almost remained at constant level for more than 1.5 hour under the photo catalytic reaction process. So ,it is clear that the outlet ozone concentration remain at a higher level when the initial concentration was higher because of a limited amount of ozone removal by photo catalysis.

Fig. 4 shows the effect of initial ozone concentration on the ozone decomposition rate and ozone removal efficiency at a flow velocity of 10.11 cm/s, disregarding the effect of mass transfer, and a humidity of 4.05e4.19 g/kg. The photo catalytic decomposition rate of ozone was increased with a rise in ozone concentration, but the ozone removal efficiency had decreased with it. When the ozone concentration was greater than 7 m g /m3, the reaction rate had changed little, but the ozone removal efficiency continued to be decreasing. The increase in initial ozone concentration resulted in an increase in the ozone amount (QCin) in the reactor inlet, but the ozone removal amount (Q(Cin - Cout)) was to be limited, which caused a decrease in the ozone removal efficiency. The results further confirmed that the photo catalytic decomposition of ozone at a flow velocity of10.11 cm/s was determined by the surface reaction.

2.5.3. The effect of humidity

From the photo catalytic reaction mechanism (Reactions (5), (6) and (8)), we can see that water molecules are indispensable for the photo catalytic decomposition of ozone. Fig. 9 shows the effect of humidity on the removal of ozone at a flow velocity of 10.96 cm/sand an ozone concentration between 3.32 and 3.48 mg/m3. The ozone decomposition rate had increased with an increase in the humidity until it reached a maximum. A humidity of zero was obtained by using synthetic air from high pressure gas cylinder. The ozone decomposition rate increased from 52.1 to 108.6 mg/ (m3min) when the humidity increased from zero to an optimal value of 4.1 g/kg, and then a further increase in humidity can result in a decrease in the ozone decomposition rate.

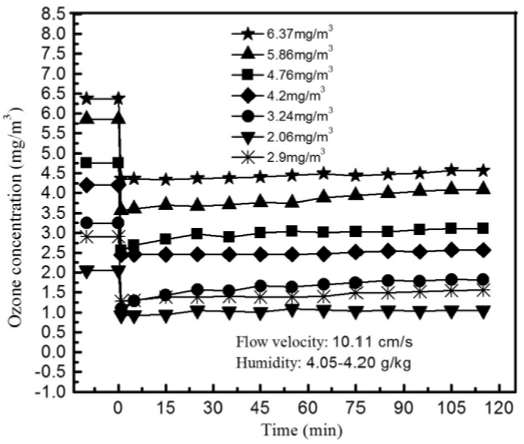

Fig.3. Ozone concentration versus time at different initial concentration.

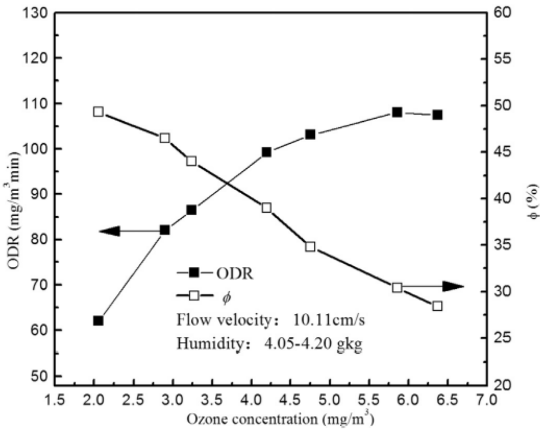

Fig. 4. The effect of initial concentration on ozone decomposition rate and ozone removal efficiency.

2.5.4. The effect of UV wavelength

The photo-induced electrons and holes, which can be affected by the UV light wavelength, are very important for the photo catalytic decomposition of the ozone. The effect of wavelength on ozone removal was investigated using two different primary UV light radiations of 253.7 nm and 365 nm with a fixed power of 8W.In general, the shorter the UV light wavelength is, the greater the irradiance energy .More photo-induced electrons and holes can be produced on theTiO2 surface when shining UV light with a wavelength of 253.7 nm.

3. CONCLUSION

(1) The processes of the photo catalytic decomposition of the ozone includes a gas phase mass transfer-limited step followed by a photo catalytic surface reaction limited step as the flow velocity increases. During the gas phase mass transfer limited step, an increase in the flow velocity can increase the ozone decomposition rate and the ozone removal efficiency; but in the photo catalytic surface reaction-limited step, ozone removal efficiency decreased with the rise in the flow velocity, which should be improved by prolonging the residence time of the ozone in the reactor.

(2) The effect of humidity on the photo catalytic ozone removal has an optimal value, and an appropriate increase in the ozone initial concentration can also increase the photo catalytic ozone decomposition rate. Therefore, try to improve humidity and the local ozone concentration over catalyst which can improve the photo catalytic degradation of ozone.

(3) Finding ways (such as enlarging the cross section of ozone converter to lower the flow velocity, use the UV light that cannot produce additional ozone, and choose appropriate installation site of ozone converter for higher humidity) to improve ozone decomposition rate will be necessary before this method can be practically employed.

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