The Measurement and Control Research of Non-metal Material Volatile Organic Compound in Civil Aircraft

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Abstract: The paper expounds the source of volatile compounds in the air of civil cabin. By measuring the air quality in civil cabin and volatile organic compound (VOC) content of typical non-metal material, in addition, comparing domestic control laws and standards of VOC in civil airplane cabin air with which in overseas, the paper attend to offer recommendations to control civil airport non-metal material VOC and provide a reference for control of non-metal material in civil airplane cabin to related enterprises. The research is aimed to create a foundation to produce a new representation of green and safe domestical civil airplanes. It is very meaningful to motivate domestical civil airplane industry and the international progress of enormous industrial chain that influences.

1. Introduction
Greenness is one of important directions of “Made in China 2025”. Country advocates considering the effect which products will cause to environment and sources when the products are design. In this way, sustainable development should be considered in the overall life cycle of raw material selection, production technology, green consumption, and effective recycling. In recent years, China's civil aircraft equipment manufacturing industry has developed rapidly. The subsequent control of hazardous substances in aircraft components has a profound impact on aircraft cabin safety and environmental protection.

The awareness of environmental protection of international community was awakened earlier than China. Many governments have jointly formulated a series of environmental protection conventions successively, such as the “Vienna Convention” in 1985, the “Montreal Protocol” in 1987, and the” Stockholm Convention” in 2001. Which enhanced the management of chemicals, including chlorofluorocarbons and toxic and hazardous chemicals in industrial products. Among them, the relevant provisions concerning persistent organic pollutants (POPs) in the “Stockholm Convention” went into effect in China in November 2004.

The international development puts forward higher requirements for China's civil aircraft industry. For the development of China's civil aircraft manufacturing industry, it is the general trend to export to foreign markets. It has always been a key to be concerned by countries, airlines and passengers to control harmful substances and volatile toxic substances in aircraft components item. In order to calmly respond to the air quality testing and other green production and green product requirements of the European Union and other countries, and avoid huge losses due to technical trade barriers, aircraft manufacturers need to make preparations in advance, establish relevant corporate standards, reduce the release of environmental volatility sexual VOC actively and the set standard of the release of VOC substances in production process.
In conclusion, the research and control of civil aircraft non-metallic materials VOC management have a significant impact on the green and sustainable development of China's civil aircraft manufacturing industry and related industries, and improving the international voice of domestic aircraft in related fields.

2. Current status of air quality VOC control of civil aircraft at home and abroad

The air in the cabin of a civil aircraft usually contains solid particles, VOC, carbon dioxide, carbon monoxide, ozone, bacteria and viruses. The unpleasant odors inside the cabin are mainly from cabin materials, such as VOC continuously emitted by cabin interior parts, paint, disinfectants and pesticides. In addition, CO, exhaust gas, solid particles, hydraulic fluid, engine oil or other toxic compounds produced by the combustion of extra-cabin fuel will also enter the passenger cabin with the bleed air from the engine [1]. In fact, cabin parts and interior materials, such as fabrics, plastic and rubber parts, paints, thermal insulation materials, adhesives, sealants and other materials used in cabins contain organic solvents, additives, auxiliaries and other materials that are volatile and harmful Substances (including benzene, toluene, xylene, formaldehyde, etc.) are the main causes of cabin VOC pollution [2].

With the popularization of the green idea, all walks of life around the world, such as ship industry, automobile industry, rail transit, electronics and electrical appliances, and foreign civil aviation, have issued environmental protection management and control standards and regulations, aiming to reduce environmental load and related hazards to the human body [3]. To reduce the potential impact of hazardous substances contained in civil aircraft products on the industry or its customers, relevant international organizations, associations and major aircraft manufacturing companies are committed to formulating relevant industry standards and strictly implementing them.

2.1 The current status of foreign civil aircraft air quality VOC control

With the gradual tightening of air quality regulations worldwide, strengthening the management of gaseous hazardous substances in space has become an inevitable trend in the development of the civil aircraft industry. In order to effectively control harmful substances in aircraft components, the European Association of the Aviation Industry has issued EN4618 "Aerospace Series-Air Quality Standards, Conditions and Measurement Methods for Aircraft Interior Air Quality" for common air pollutants in the cabins of some civil aircraft, and classifies the air quality of aircraft cabins. According to the safety value, health value and comfort value, different items in the aircraft cabin are controlled. The American Society for Testing and Materials issued ASTM D 6399 "Standard Guide for Air Quality Testing Instruments and Testing Methods in Aircraft Cabin".

2.2 The current status of air quality VOC control of domestic civil aircraft

In stark contrast to the already effective control of aircraft air quality in developed countries, my country’s current air quality standards for aircraft cabins only have the "Public Transport Sanitary Standards" (GB 9673-1996) [4], while aircraft cockpits and cabins are used as workplaces. And public places testing methods can only refer to "Indoor Air Quality Standards" (GB/T 18883-2002) and "Public Places Hygienic Standard Testing Methods" (GB/T 18204-2000). Among them, GB 9673-1996, due to the relatively early establishment of the standard, the limit specified by the standard is no longer compatible with the international standard limit. In addition, the GB/T 18883-2002 standard regulates the evaluation method of air quality inside residential and office buildings. However, some control items are not applicable to the aircraft cabin environment. Therefore, there is a trend of research on the testing methods and evaluation standards of aircraft cabin air quality. The main manufacturer should pay attention to the air quality control in the aircraft cockpit, and all suppliers should also cooperate in implementing air quality standards and management in product design.
3. Air VOC detection and result analysis in the cabin of civil aircraft

3.1 The location and requirements of sampling points for air testing

In this test, the galley, first class, economy class and other locations were selected for testing. The sampling test points are arranged in the kitchen and first-class space respectively, and 5 points are arranged diagonally in the economy class space. There are 7 points in the cabin as a whole, and the height of the sampling points is 1.2 m.

3.2 Sampling equipment and conditions

The gas sample collection device consists of a constant flow gas sampling pump, a first-stage flow meter, a packed column sampling tube, and a sampling conduit. The sampling tube includes VOC sampling tube (Tenax sampling tube is usually used) and aldehyde and ketone sampling tube (sampling tube filled with DNP (2,4-dinitrophenylhydrazine) silica gel). The sampling flow rate of the Tenax tube is 100 ml/min, the sampling time is 30 min, and the sampling volume is 3 L; the sampling flow rate of the DNPH tube is 400 ml/min, the sampling time is 30 min, and the sampling volume is 12 L.

3.3 Preparation time and arrangement of aircraft under inspection

When the aircraft is normally stopped and flameout, in accordance with the conditions of GB/T 18883-2002, close the door of the inspected aircraft for at least 12 hours before the test.

Starting from the preparation of the aircraft to be inspected, a total of 2 days will be required for the airtight phase test. The test cabin is sampled in turn. Each sample time is 30min; The temperature is also recorded every half hour.

3.4 Analysis of air test results

Mainly test the total volatile organic compounds (TVOC (C6-C16)), formaldehyde, acetaldehyde, acrolein, acetone, methyl ethyl ketone, methylene chloride, benzene, toluene, xylene, ethylbenzene in the air in the aircraft. The top ten substances with the highest content in total volatile organic compounds. The analysis method of volatile organic compounds is ISO16000-6:201, the analysis instrument is thermal desorption gas mass spectrometer (TDS-DC/MS); the analysis method of aldehydes and ketones is ISO16000-3:2011, the analysis instrument is high performance liquid chromatograph (HPLC), the test results are shown in Table 1, the unit is mg/m3.

| Item         | Cab. | Door | Front one | Front two | Middle | Right | Tail | Limits |
|--------------|------|------|-----------|-----------|--------|-------|------|--------|
| TVOC         | 0.536| 0.359| 0.724     | 0.718     | 0.800  | 0.844 | 0.850| 0.004  |
| Formaldehyde | 0.030| 0.023| 0.034     | 0.037     | 0.040  | 0.040 | 0.041| 0.004  |
| Acetaldehyde | 0.022| 0.021| 0.026     | 0.029     | 0.028  | 0.027 | 0.027| 0.004  |
| Acetone      | 0.099| 0.091| 0.130     | 0.143     | 0.150  | 0.141 | 0.146| 0.004  |
| 2-butyl ketone| 0.021| 0.018| 0.029     | 0.034     | 0.037  | 0.034 | 0.035| 0.004  |
| Toluene      | 0.030| 0.027| 0.048     | 0.048     | 0.055  | 0.055 | 0.058| 0.004  |
| Ethyl benzene| 0.008| 0.008| 0.012     | 0.012     | 0.013  | 0.013 | 0.014| 0.004  |
| Inter-toluene| 0.023| 0.021| 0.034     | 0.035     | 0.038  | 0.038 | 0.039| 0.004  |
| Phthalates   | 0.010| 0.009| 0.014     | 0.016     | 0.015  | 0.015 | 0.016| 0.004  |
| Xylene       | 0.033| 0.030| 0.048     | 0.049     | 0.054  | 0.053 | 0.055| 0.004  |

By comparing my country's indoor and car air quality and European aircraft cabin air quality limit requirements, the total volatile organic compound (TVOC) content in the aircraft cabin tested this time meets my country's indoor air quality standard GB/T 18883-2002 The limit is 0.6mg/m³, but the TVOC content in the cabin slightly exceeds the limit requirement of GB/T 18883-2002.

The content of other single substances in the aircraft cabin tested this time, such as formaldehyde, acetaldehyde, acrolein, acetone, methyl ethyl ketone, dichloromethane, benzene, and toluene, meets the air quality limit requirements of European aircraft cabins. It also meets the limit requirements of GB/T 18883-2002.
4. Civil aircraft non-metallic materials VOC test and analysis

4.1 Identify high-risk non-metallic materials

Conduct bottom-up tests on the components and materials used in the cabin, determine the main sources of cabin VOC materials, and conduct post-processing and rectification studies on high-risk materials to provide a basis for the establishment of control limits.

On the basis of a unified test method, the interior materials used in the passenger cabin are tested to determine the current level of VOC emission of non-metallic materials, it is proposed to formulate a larger amount of VOC emission in the interior materials of the aircraft cabin List of high-risk non-metallic materials. According to the results of the preliminary research, the selected components and materials should be in the mass production stage as far as possible, so as to match the results of the cabin test in the later period.

4.2 Non-metallic materials testing methods

According to the EN4618 standard issued by the European Aviation Industry Association of Europe, the sampling and analysis of VOC substances in the cabin refers to the ISO16000 series standards issued by the International Organization for Standardization. In order to ensure the continuity and comparability of the results, the test standards for parts and components refer to Part 9 of the ISO16000 series, "Testing Chamber Method for Testing of Volatile Organic Compounds in Furniture and Building Materials". The specific test plan is shown in Table 2.

| Table 2 Components and material test plan |
|------------------------------------------|
| sample | standards | Sample dosing | Test the project |
| Carpet | ISO16000-9:2006 | 0.024 m² (60L Test chamber) | Benzene, toluene, xylene, ethyl benzene, styrene, formaldehyde, acetaldehyde, acrylic, aceton, butyl ketone, dichloromethane, total volatile organic matter (TVOC) and the top ten substances with the highest content |
| Floor | ISO16000-9:2006 | 0.024 m² (60L Test chamber) | |
| Soundproofed cotton 1 | ISO16000-9:2006 | 0.024 m² (60L Test chamber) | |
| Wall panels | ISO16000-9:2006 | 0.024 m² (60L Test chamber) | |
| Soundproofed cotton 2 | ISO16000-9:2006 | 0.4 m² (1m³Test chamber) | |
| Seat mask | GB 18401-2010 | 10g | Formaldehyde content |

4.3 Analysis of material test results

4.3.1 Seat cover

The seat cover is tested in accordance with the provisions of GB 18401-2001 "National Basic Safety Technical Specifications for Textile Products". The standard specifies the formaldehyde content in textiles. The control limits and test results are shown in Table 3.

| Table 3 Test results of seat cover |
|-----------------------------------|
| The name of the sample | Controlled substances | Control limits | The test results |
| Seat mask | Formaldehyde content | Category A (infant textile products) ≤20 mg/kg | 15 mg/kg |

The formaldehyde content of the seat cover is 15mg/kg, which is in line with the control limit requirements for Class B (products that directly contact the skin) in the GB18401-2010 standard.

4.3.2 Carpet and sound insulation cotton

The carpet test is carried out in accordance with the ISO 16000-9:2006 test chamber method. GB18587-
2001 stipulates the emission limits of total volatile organic compounds (TVOC), formaldehyde, styrene and 4-phenylcyclohexene emitted from carpets. Table 4 lists the test result of carpet and sound insulation cotton, unit mg/m³.

| The number of test days | Carpet | Soundproofed cotton1 | Soundproofed cotton2 |
|-------------------------|--------|----------------------|----------------------|
|                         | 1 day  | 3 days               | 7 days               |
| TVOC                    | 0.013  | 0.010                | 0.008                |
| Formaldehyde            | 0.063  | 0.080                | 0.058                |
| Toluene                 | 0.013  | 0.010                | 0.008                |
| Acetone                 | 0.013  | 0.020                | 0.013                |

The test results of carpet and sound insulation cotton showed that the main substances released by carpet and sound insulation cotton were not detected except for formaldehyde, toluene and acetone. According to the limit requirements of GB18587-2001, styrene, 4-phenylcyclohexene and TVOC released from carpets and sound insulation cotton meet the limit requirements, but the amount of formaldehyde released is relatively high. Among them, after the carpet was placed in the test cabin for 7 days, the formaldehyde emission was still higher than the limit (0.05mg/m²·h); the sound insulation cotton had a higher formaldehyde emission after being placed for 1 day and 3 days. The release amount complies with the limits. Therefore, it is necessary to strengthen the control of formaldehyde in carpets and sound insulation cotton.

4.3.3 Floor and wall panels
The volatile organic compounds emitted from the floor and wall panels are also studied with reference to the ISO 16000-9:2006 test chamber method. The method is similar to the method used in this study, so this study refers to the limit regulations in GB 18580-2017 to determine the formaldehyde released from the floor and wall panels. Table 5 lists the test results of the floor and wall panels in mg/m³.

| The number of test days | The floor | Wall panels |
|-------------------------|-----------|-------------|
|                         | 1 day     | 3 days      | 7 days      |
| TVOC                    | 0.011     | 0.037       | 0.003       |
| Formaldehyde            | N.D.      | N.D.        | N.D.        |
| Toluene                 | 0.007     | 0.020       | 0.003       |
| Acetone                 | 0.017     | 0.015       | 0.009       |

The main release substances in the floor are toluene and acetone. In addition, it also contains a small amount of other volatile organic compounds (such as n-hexane). No formaldehyde is detected, which meets the requirements of GB18580-2017 "Limits for Formaldehyde Release in Indoor Decoration Materials and Wood-Based Panels and Products" The limit value of formaldehyde emission in wood-based panels and its products is 0.124 mg/m³. The siding is evaluated with reference to GB18580-2017. In addition to toluene and acetone, the main release substances of siding also contain a higher content of formaldehyde. Especially after being placed in the test chamber for 1 day, the formaldehyde content is as high as 0.181mg/m³, which exceeds the limit amount specified in the standard. After being placed for 3 days and 7 days, the formaldehyde emission is still high. Therefore, it is necessary to strengthen the formaldehyde content in the siding Content control.

5. Non-metallic materials control measures for civil aircraft
In order to meet the environmental protection requirements of the air quality in the cabin of civil aircraft and improve the air quality in the cabin, the main engine factory and its suppliers at all levels need to take different improvement measures from the three levels of materials, components, and complete aircraft to achieve gradual optimization.
5.1 Suggestions and measures for rectification of raw materials

Through the detection of high-risk non-metallic materials, it is found that the formaldehyde content of some parts and materials (such as carpets, sound insulation cotton, siding) exceeds the limit required by the standard, so it is necessary to strengthen the control of the formaldehyde content in these parts and materials. For the rectification of formaldehyde in materials, source control needs to analyze the source of formaldehyde in components. By selecting raw materials with low or no formaldehyde content, control the product from the source Environmental protection quality.

For product formulas, high-purity substrates and optimized formulas can be used, pure production and processing techniques, and post-processing methods such as ventilation or high-temperature baking can be used. In the production of materials, choose low-VOC environmentally friendly materials, or add VOC catalysts and adsorbents to the materials to effectively remove alkanes, alkenes, phenols, aldehydes, ketones and other small-molecule VOC substances.

5.2 Suggestions and measures for manufacturing

In the process of manufacturing parts, making sure the environment is clean and pollution-free. The environmental performance of the parts is optimized by improving the storage environment of the parts. Direct ventilation can also have a greater impact on the volatile organic compounds of non-metallic materials, and the VOC emission can be significantly reduced by extending the ventilation time. The use of high-temperature post-treatment can quickly release some of the low-boiling or small-molecule VOC substances which are contained in the component, thereby reducing the VOC emission of the component during use.

In terms of post-treatment, use of activated carbon and photocatalytic oxidation technology have become a hot spot in formaldehyde purification treatment. In addition, studies have shown that the formaldehyde emission of sound insulation cotton and wall panels decreases with the prolongation of the time in the test chamber, so extending the ventilation treatment time can effectively reduce the formaldehyde content of the material.

6. Summary and Prospect

In the management and control of non-metallic materials VOC of civil aircraft, China still has a big gap with the international developed countries. Only by establishing relevant industry standards as early as possible and strictly controlling non-metallic materials VOC, will it be enough to calmly respond to the high export requirements in the future and fully grasp the new opportunities in the civil aircraft market. As the global economy is highly integrated today, only by creating a safe and green new business card for Chinese civil aircraft can we promote the internationalization of the Chinese civil aircraft industry and the huge industrial chain.

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