Big Data Analysis on the State of Automotive Cabin Air Filters in China

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Abstract: Under the influence of the COVID-19, consumers pay more and more attention to the safety and health of the air in the car. As the core component of the air purification in the car, the performance of the cabin air filter is a hot topic for vehicle enterprises and parts enterprises. This paper introduces the inspection and data analysis of cabin air filter products in China by China Automotive Technology And Research Center, which includes the product geographical distribution, brand compliance rate, the compliance rate of different testing items. Based on the analysis of fractional efficiency of 0.3 μm, 2.5 μm and 10 μm particle sizes and particle sizes distribution in the atmosphere, this paper puts forward the view that it is necessary to pay more attention to the fractional efficiency of particulates which below 1 μm. In addition, the existing problems of cabin air filter are studied by data and its development direction is prospected.

1. Introduction
In 2020, COVID-19 swept the globe. Masks became a necessity for daily life. It can reduce the number of droplets and particles from the mouth and nose to some extent, and reduce the chance of infection. The air exchange in the car also needs a "Mask" to prevent harmful substances from entering the car. The cabin air filter is the "Mask" of the car. It can block the droplets and suspended particles, which can greatly reduce the harmful substances entering the car.

On March 6, 2020, J.D POWER officially released a survey report on the impact of COVID-19 on consumers' willingness to buy cars. At the same time, on March 11, 2020, China Automobile Industry Association and automobile House released COVID-19 China automobile consumption insight report. It shows that the willingness of respondents to choose public transport has decreased from 29.5% to 10.5%; at the same time, due to the impact of the epidemic, the safety and health of the air inside the car has become another important consideration (46.5%). On-board air purification system with disinfection and sterilization function(71.9%), APP remote control of in car air circulation(65.6%) and in-car air quality monitoring device(61.3%) are the health functions and configuration most concerned by prospective buyers. For those who have cars, they hope to add air purification and air quality monitoring devices in their cars. In addition, health monitoring function, online doctor and other health-related functions and configurations are increasingly valued. According to the data, 70% of the respondents think that car air purification system is very important. Among them, 84% of the survey users are willing to pay for the "air purification system, anti-virus" function, but only 17% of the users expect to spend less than 3000 yuan. Therefore, in the case of virus rampant and serious environmental pollution, the cabin air filter is particularly important.
2. Product market research scope
Since February 2020, China Automotive Technology And Research Center has carried out large-scale product testing and data analysis on Chinese automotive cabin air filter products. There are 200 kinds of testing products, covering the original products of private vehicle enterprises, original products of joint venture vehicle enterprises, supporting products of front assembly parts enterprises, and after-sales market products. The test items include pressure loss, fractional efficiency and dust-holding capacity and other key performance indicators. It covers 49 filter manufacturers, 56 filter material manufacturers and 200 different models.

![Regional distribution of detection units](image1)

![Inspection quantity of each province](image2)

Figure 1. Geographical distribution of inspection products

As shown in figure 1, the geographical distribution of the selected products basically conforms to the distribution of China's automobile industry. There are as many as 26 complete vehicle enterprises in Guangdong, Shanghai, Jilin, Chongqing and Beijing. At the same time, as the major parts manufacturing provinces, there are as many as 38 parts enterprises involved in Shanghai, Guangdong and Jiangsu.

3. Certification standards and compliance rate
3.1. Certification standards
The test was carried out according to GB/T 32085.1-2015 Road vehicles-Air filters for passenger compartments-Part 1-Test for particulate filtration, MOD[1], VDA270-2018 Determination of The Odour Characteristics of Trim Materials in Motor Vehicles[2] and CAC-PV18-019:2020 Implementation rules of CATARC mark certification - filtration grade of automotive cabin air filter[3], which is promulgation by CATARC-cert. Specific rules and requirements are shown in tables 1-3.
Table 1. Implementation rules of CATARC mark certification - pressure loss

| Test air flow, m³/h | Initial pressure loss, Pa |
|--------------------|---------------------------|
| 150                | ≤30                       |
| 300                | ≤70                       |
| 450                | ≤130                      |
| 600                | ≤220                      |

Table 2. Implementation rules of CATARC mark certification - fractional efficiency

| Aerodynamic diameter, μm | Classification fractional efficiency, % |
|--------------------------|-----------------------------------------|
|                          | CN60 | CN70 | CN80 | CN90 | CN95 |
| ≥0.3                     | ≥60  | ≥70  | ≥80  | ≥90  | ≥95  |
| ≥2.5                     | ≥75  | ≥85  | ≥90  | ≥95  | ≥95  |
| ≥10                      | ≥90  | ≥90  | ≥95  | ≥95  | ≥95  |

Table 3. Requirements for odor emission of automotive interior materials

| Grade  | Odor evaluation                                      |
|--------|------------------------------------------------------|
| 1 point| Imperceptible                                       |
| 2 points| Aware, but not uncomfortable                      |
| 3 points| Direct detection, but still not uncomfortable      |
| 4 points| It makes people feel uncomfortable.                |
| 5 points| It makes people very uncomfortable.                |
| 6 points| Unacceptable                                       |

3.2. Product compliance rate

The compliance rate of 200 products reached 55%, with the increase of market attention and consumer demand, the compliance rate also showed an increasing state.

It can be seen from figure 2 that the qualified rate of original products and pre installed products was much higher than that of after-sales market products due to strict supervision by automobile enterprises, high requirements for production consistency and perfect product testing. Among them, the joint venture brand automobile enterprises, due to their high degree of concern and forward-looking, have reached the target rate of 70%. Due to the low market access threshold and the lack of market supervision, the compliance rate of after-sales products was only 38%.
As shown in figure 3, for different detection items, the pressure loss under the flow rate of 150-600m³/h, the classification fractional efficiency of 0.3-10 μm particle size, and the dust-holding capacity, fractional efficiency was the most difficult test item to pass.

As shown in figure 4, according to the testing and certification time, the data was divided into six stages. It can be seen that with the passage of time, the market attention and consumer demand increase, the manufacturers' technical improvement, and the market elimination of low-quality products, the fractional efficiency of each particle size was generally improving.
4. Analysis on fractional efficiency of particulate

4.1. Mechanism of particulate filtration

Before COVID-19, people realized the harm of PM2.5 due to smog. PM2.5 refers to the particles with aerodynamic equivalent diameter less than or equal to 2.5 μm in ambient air, also known as fine particles [4]. However, due to novel coronavirus pneumonia sweeping the globe, PM0.3 has entered the field of vision. Compared with PM2.5, which can only enter the lung and block the alveoli by breathing, PM0.3 can not only reach the deepest part of the lung by breathing, but also enter the human blood tissue through the alveoli, and also enter the blood directly through the skin, which is much more difficult to prevent than PM2.5. Therefore, it is necessary to introduce the concept of 0.3 μm for the filtration efficiency of cabin air filter.

Because the particle size of PM0.3 is very small, if only use the mechanical filtration method commonly used to PM2.5, the pressure loss will be greatly increased. The same electrostatic adsorption filtration method as N95 mask is introduced into cabin air filter products. Mechanical filtration can intercept particles through interception effect, gravity effect and inertia effect, as shown in figure 5.

![Figure 5. Mechanical filtration](image)

(a) Interception effect  (b) Gravity effect  (c) Inertia effect

However, the small particles such as PM0.3, they can't move along the determined route as the larger particles do in air, but do irregular movement, i.e. Brownian motion. Therefore, it is necessary to melt blow the product to filter the small particles through electrostatic adsorption function, as shown in figure 6.

![Figure 6. Single Fiber Filtration Model](image)

4.2. Fractional efficiency of particulate

Three typical particle sizes of 0.3 μm, 2.5 μm and 10 μm were selected to analyze 600 groups of data.
As shown in figure 7, figure 8 and figure 9, for 2.5μm (fine particles) and 10μm (inhalable particles), the products had high consistency and excellent performance, and the passing rate reached 97.44% and 99.30% respectively, which can filter out most harmful substances. However, the products for 0.3 μm particles were mixed, especially for the after-sales market products, the passing rate is only 58.8%.

In order to enrich the data of products, in addition to the above mentioned particle sizes of 0.3 μm, 2.5 μm and 10 μm, another 11 different particle sizes of 0.2 μm, 0.4 μm, 0.5 μm, 0.6 μm, 0.8 μm, 1.2 μm, 1.5 μm, 3 μm, 4 μm, 5 μm and 7 μm were selected for recording and statistics.

600 groups of data were statistically analyzed, and the average values of different particle sizes under the same test conditions were selected, as shown in figure 10. It can be seen that the smaller the particle size is, the lower the filtration efficiency is, and the more difficult it is to control the process.
However, the amount of small size particles in the air is the largest, as shown in figure 11, which is the most harmful to human body and the most difficult to remove. Therefore, we need to focus on the filtration efficiency of particles below 1μm. In order to reduce the harm of small particle pollutants to human body, the cabin air filter needs to improve the filtration efficiency of small particles.

![Figure 11. Distribution of particles with different sizes in air](image)

5. Comprehensive consideration of filter performance

5.1. Relationship between pressure loss, fractional efficiency and dust-holding capacity

Another important index of cabin air filter is pressure loss, which need manufacturers put forward higher requirements. Pressure loss is an important indicator of filter failure. The increase of pressure loss will decrease air volume of air conditioning, bring the high oil consumption, raise air outlet noise, and reduce comfort of drivers and passengers. Compare the class II indexes of combination filter in QC/T 998-2015 [5] with the indexes requirements in CAC-PV18-019:2020 [3], as shown in table 4.

| Test items      | Pressure Loss, Pa | Fractional Efficiency, % |
|-----------------|-------------------|--------------------------|
| Test air flow rate, m³/h | Particle optical diameter, μm |

|                  | QC/T 998-2015 | CAC-PV18-019:2020 |
|------------------|---------------|-------------------|
| ≤30              | ≤70           | ≤220              |
| ≤130             | ≤220          | ≥95               |
| ≥65              | ≥80           | ----              |
| ≥80              | ----          | ≥90               |
| ≥95              |                | ≥95               |

![Table 4. Comparison of technical indexes](image)
It can be seen from table 4 that the filtration efficiency, especially the filtration efficiency of small particle size, has been greatly improved under the condition that the pressure loss has not changed. But blindly improving the filtration efficiency of the cabin air filter will cause the pressure loss to increase. The dust-holding capacity of cabin air filter is the weight of test dust captured on the test sample when reaching the specified termination condition (pressure loss increase 200Pa). It is an important indicator for cabin air filter to be replaced. This project had the highest passing rate in this test, reached 81%.

How to balance the pressure loss, fractional efficiency and dust-holding capacity is particularly important. In the early stage of the test, due to the lack of technical reserves of new products, a number of products with high pressure loss, high efficiency and low dust-holding capacity appeared. As shown in figure 12, the filtration efficiency of such products was very high, and the filtration efficiency reached or exceeded the agreed value. However, in-depth study found that its pressure loss was huge, the external circulation and internal circulation wind can not smoothly enter the cockpit; and the dust-holding capacity was very low, which was more like a layer of film to rebound the particles completely, which can not be used on the vehicles.

![Figure 12. Performance comparison of five typical products](image-url)
5.2. Combination filter

Cabin air filter is generally divided into two categories, particle filter and combination filter, as shown in figure 13. Filter paper is a kind of fiber material, including wood pulp paper (plant fiber), glass fiber paper (glass fiber), PP paper (polypropylene), etc. Among them, the filter paper with PP paper as raw material is the so-called non-woven fabric. In order to further enhance the filtering effect, the filter paper will be treated by electrostatic electret to enhance the adsorption performance of small particles. Combination filters add activated carbon components in the filter paper to absorb carbon oxides, sulfides, formaldehyde, etc. At present, there are cabin air filters with special antibacterial and antiallergic coating, which can prevent the breeding of bacteria and allergy, and improve the quality.

![Particle filter and combination filter](image)

Figure 13. Internal structures of particle filter and combination filter

At the same time of improving efficiency and function, the pressure loss of cabin air filter will be increased correspondingly, and the dust-holding capacity will be decreased accordingly. As shown in figure 14, the analysis of 44 types of combination filters on the market showed that there were 19 products failed to meet the "CN95" standard due to high pressure loss, and the failure rate reached 43%, which was far higher than 14% of the particle filters that failed to meet the standard due to pressure loss.

![Failure rate of cabin air filter pressure loss](image)

Figure 14. Failure rate of cabin air filter pressure loss

Due to the gas adsorption capacity of the combination filter, it can not only intercept harmful gases such as SO\(_2\) and NO\(_x\) entering the vehicle, but also absorb benzene and aldehydes emitted from the seats, door panels and decoration of the car when the air conditioner is turned on for internal circulation. Therefore, the combination filter is the trend of future development, and at the same time, it is also the direction of consumers' attention to increase various antibacterial and antiallergic functions.

6. Conclusion

1. This market research covered a wide range. It covered 49 filter manufacturers, 56 filter material manufacturers and more than 200 different vehicle models.

2. There were great differences in the product passing rate among different enterprises, testing projects and testing stages. Joint venture products and original products had higher passing rate than those of independent brands and after-sales market products; the passing rate of fractional efficiency
test items was the lowest; the passing rate of products in early testing stages was low, but with the implementation of "CN95" certification and the improvement of manufacturer's process, the passing rate of products in stages was higher and higher.

3. The cabin air filter needs to further enhance the filtration efficiency of small particles. The existing products had excellent performance for 2.5 μm particles and 10 μm particles, with the passing rate reaching 97.44% and 99.30%, respectively. However, the performance for 0.3 μm particles was mixed, with the passing rate of after-sales products only reaching 58.8%. The data showed that the smaller the particle size, the lower the filtration efficiency. The small particles which sizes less than 1 μm in the air have the largest amount, with the most harm to human body.

4. Cabin air filter should pay attention to the balance of pressure loss and dust-holding capacity while improving fractional efficiency and functions. Blind improvement of fractional efficiency will lead to high pressure loss, low dust-holding capacity, high fuel consumption, increased noise and reduced service life. The failure rate of combination filter pressure loss was 43%, far exceeding 14% of particle filter. However, due to the gas adsorption capacity, antibacterial and antiallergic functions of combination filter, it is still the development direction in the future.

References
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