Application Research on Objective Evaluation of Vehicle Interior Odor Based On Weber-Fechner Law

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Abstract. In this paper, four typical compounds of odorants were selected as the research objects. The mathematical model hypothesis is established which based on the Weber-Fechner law, and then the relationship between the concentration of odor substances and the odor grade is verified to judge whether this law is applicable to the objective evaluation of vehicle interior odor. The results show that: the concentration of single odor substance and odor grade, the concentration of two kinds of odor substances and odor grade are in accordance with this law. It is proved that the relationship between odor substance concentration and odor grade conforms to the law to a certain extent, which provides an important theoretical basis for objective evaluation of vehicle interior odor and control vehicle environment to create an environmental and healthy vehicle.

1. Introduction
The vehicle interior odor has become a hot topic for consumers to complain, and it is also the focus of vehicle manufacturers[1]. At present, the vehicle interior odor evaluation adopts a subjective method that uses the odor evaluator as a detector to test the air level in the vehicle. The method of supervisor evaluation has some limitations, because this method has strict requirements on people, and it is inevitable that people have subjective likes and dislikes for certain smells[2]. Based on the current status of the industry, it is imperative to objectively evaluate the odor in the vehicle.

Zhang[3] found that the pollution in new cars is more serious than that in old cars. The concentrations of formaldehyde, benzene, toluene and xylene are higher in new cars than in old cars. Huang[4] found that the vehicle interior odor has become the focus of consumers' attention. Hu[5] found that there are differences in the current domestic automobile manufacturers' standards for vehicle interior odor control and lack of uniform testing methods and limit standards. Li[6] showed that 7 kinds of air pollutants conform to the W-F law. Wu[7] showed that the W-F law is suitable for wetland ecosystem health assessment, and the mathematical model can be revised based on the W-F law, which has wide application. Based on the above research results, we have carried out basic research on the objective evaluation of vehicle interior odor based on W-F law.

In this paper, four typical compounds of odorants are selected as the research objects. Based on the basic principles of Weber-Fechner law, the research on the relationship between substance concentration and odor level was carried out. The results show that the relationship between the
concentration of a single odorant and the odor level, and the relationship between the concentration of
two odorants and the odor level comply with the Weber-Fechner law. The research results show that
this method is suitable for the study of the relationship between substances and odor levels, and
provides an important theoretical basis for the objective evaluation of vehicle interior odors.

2. Basic Principles of Weber-Fechner Law
Weber-Fechner law\(^{8-9}\) is a law that shows the relationship between sensory quantity and physical
quantity. German physiologist Weber found that the difference in the same stimulus must reach a
certain ratio in order to cause different sensations. The sensation quantity is proportional to the
logarithm of the physical quantity, that is to say, the physical quantity increases in a geometric
progression, and the mental quantity increases in an arithmetic progression. This empirical formula is
called the Weber-Fechner law. Basically expressed as:

\[
K = \alpha \log c
\]

Where:
- \(K\) is the sensation;
- \(\alpha\) is Weber's constant;
- \(c\) is the physical quantity.

The application of this law to vehicle odor is based on the above three assumptions:
(1) The sensation \(K\) in the Weber-Fechner law is regarded as the odor level;
(2) The Weber constant \(\alpha\) in the Weber-Fechner law is also used as a constant here, which is the odor
characteristic constant of the odor substance or the mixed odor;
(3) The physical quantity \(c\) in the Weber-Fechner law is regarded as the concentration of this odor
substance or mixed gas.

According to the above three assumptions, the Weber-Fechner law is applied to the field of vehicle
interior odor evaluation, expressed as:

\[
K_i = \alpha_i \log c_i + K_{c_i}
\]

3. Experimental research

3.1 Test equipment and reagents
Dynamic olfactory diluter, Olfactometer TO 8, Ecoma GmbH, Germany; high temperature oven,
Shanghai Espike; air-nitrogen, purity 99.999%; odorless bag; micro-injection needle, Agilent; N-
ethylpyrrolidone, 98.0%, GC gas chromatography pure, TCI Tokyo Chemical Industry Co., Ltd.; N,N-
dimethylformamide, 99.9%, Dr.Ehrenstorfer, Germany; 2-Butoxy ethanol, 99%, Tianjin Ciense
Biochemical Technology Co., Ltd.; Benzothiazole, 96%, CNW Shanghai Anpu Experimental
Technology Co., Ltd.; n-butanol, 99.9%, excellent grade purity, Tianjin Jinke Fine Chemical Research
Institute; Acetic acid, 99.5%, analytical grade, Tianjin Fengchuan Chemical Reagent Technology Co.,
Ltd.; Octanal and Nonanal, 98%, Tianjin Siense Biochemical Technology Co., Ltd.

3.2 Test method
Based on the analysis of a large number of car air data and material characteristics, four representative
odorants were selected for research: N-ethylpyrrolidone, N, N-dimethylformamide, 2-Butoxy ethanol,
and Octanal.

A single odorant is tested for odor levels with different odorant concentrations. First, a micro-
 injection needle is used to absorb a certain amount of odorous reagent (shown in Table 1) and inject
them into an odorless bag filled with nitrogen. Then we mix the internal gas uniformly by pressing and
tapping and connect the prepared odor bag to the connection port of the dynamic olfactory dilution
instrument. Finally, we set the initial dilution multiples of the four substances, and carry out the odor
level test of the dilution multiples (shown in Table 2) from large to small. The specific odor levels are
shown in Table 3.
### Table 1 Single odorant configuration parameters

| Substance name | Injection volume/μL | Filled with nitrogen volume/L | Initial dilution multiple |
|----------------|---------------------|-------------------------------|---------------------------|
| N-ethylpyrrolidone | 100                | 10                            | 831                       |
| N,N-dimethylformamide | 50                  | 10                            | 210                       |
| 2-Butoxy ethanol    | 50                  | 10                            | 14100                     |
| Octanal             | 1                   | 10                            | 14100                     |

### Table 2 Dilution multiple of single odorant

| Substance name                  | Dilution multiple                        |
|---------------------------------|------------------------------------------|
| N-ethylpyrrolidone              | 831, 394, 210, 105, 60, 30               |
| N,N-dimethylformamide           | 210, 105, 60, 30, 14.9, 7.5, 3.8         |
| 2-Butoxy ethanol                | 14100, 6299, 3383, 1846, 831, 394, 210, 105, 60 |
| Octanal                         | 14100, 6299, 3383, 1846, 831, 394, 210, 105, 60 |

### Table 3 Smell grade

| Smell grade | Description of odor intensity scoring standard |
|-------------|-----------------------------------------------|
| 1           | Odorless, not easy to feel                    |
| 2           | Smell, can be felt, slight intensity          |
| 3           | Obvious smell, can be clearly felt, medium intensity |
| 4           | Obvious smell and high intensity              |
| 5           | The smell is obvious and the intensity is great |
| 6           | Unbearable smell                              |

However, the air in the car is a mixture of various odorants, so it is necessary to verify whether the odorant mixture meets this assumption. Therefore, two groups of odorant substances were mixed in pairs. The verification tests of mixing N-ethylpyrrolidone with N, N-dimethylformamide, and mixing 2-Butoxy ethanol with octanal are carried out.

First, a micro-injection needle is used to absorb a certain volume (shown in Table 4) of odorant reagents and respectively inject them into an odorless bag filled with nitrogen. Then we mix the internal gas uniformly by pressing and tapping and connect the prepared odor bag to the connection port of the dynamic olfactory dilution instrument. Finally, we set the initial dilution factor according to the logarithm of the four odorant substance concentration and the linear relationship curve of the odor level. The dilution factor (shown in Table 5) is developed from large to small. The specific odor levels are shown in Table 3.

### Table 4 Configuration parameters of mixed odorants

| Mixed odorants                  | Single odorant | Injection volume/μL | Filled with nitrogen volume/L | Initial dilution multiple |
|---------------------------------|----------------|--------------------|-------------------------------|---------------------------|
| N-ethylpyrrolidone and N,N-     | N-ethylpyrrolidone | 100                | 9                             | 831                       |
| dimethylformamide               | N,N-dimethylformamide | 100                |                               |                           |
| 2-Butoxy ethanol and Octanal    | 2-Butoxy ethanol | 50                 | 9                             | 33480                     |
|                                 | Octanal         | 1                  |                               |                           |
Table 5 Dilution times of mixed odorants

| Substance name                                      | Dilution multiple          |
|-----------------------------------------------------|----------------------------|
| N-ethylpyrrolidone and N, N-dimethylformamide       | 831, 394, 210, 105, 60, 30, 14.9, 7.5 |
| 2-Butoxy ethanol and Octana                         | 33480, 14100, 6299, 3383, 1846, 831, 394, 210, 105, 60 |

4. Data analysis

\( \log C_i \) (The unit of \( C_i \) is ng/mL) is taken as the abscissa, and \( C_i \) is the concentration of a single odorant. The smell grade is taken as the ordinate. The relationship between the logarithm of the concentration of the four odorants and the odor grade are shown below:

Figure 1 The logarithm of N-ethylpyrrolidone concentration and odor grade curve

Figure 2 The logarithm of N, N-dimethylformamide concentration and odor grade curve

Figure 3 The logarithm of 2-Butoxy ethanol concentration and odor grade curve
The logarithm of the concentration of the four odorants and the odor grade form a linear relationship curve:

$$K_i = \alpha_i \lg C_i + K_{C_i} \quad (3)$$

The specific curve parameters are shown in Table 6.

Table 6 Parameters of the linear relationship curve between the logarithm of the concentration of four odorants and the odor grade

| Substance name         | $\alpha_i$ | $K_{C_i}$ | $R^2$  |
|------------------------|------------|-----------|--------|
| N-ethylpyrrolidone     | 1.7751     | -0.0280   | 0.9779 |
| N,N-dimethylformamide  | 1.3626     | -0.1373   | 0.9724 |
| 2-Butoxy ethanol       | 1.0769     | 2.3997    | 0.9947 |
| Octanal                | 0.8575     | 3.9271    | 0.9859 |

From the linear relationship between the logarithm of the concentration of the four odorants and the odor level and Table 4, it can be seen that when the concentration of the odorant changes by $10^9$, the perception of the odor level will change. And the logarithm of the concentration of the four odorants has a clear linear relationship with the odor level. It can be obtained that the hypothesis holds for the relationship between the concentration of a single odorant and the odor level.

$\lg C_i$ (The unit of $C_i$ is ng/mL) is taken as the abscissa, and $C_i$ is the concentration of two kinds of odorants after mixing. The smell grade is taken as the ordinate. The relationship between the logarithm of the concentration of mixed odor substances and the odor grade is shown below:
The logarithm of the concentration of the two mixed odorants and the odor grade form a linear relationship curve:

$$K_i = \alpha_i \lg c_i + K_{c_i} \quad (4)$$

The specific curve parameters are shown in Table 7.

| Substance name                          | $\alpha_i$ | $K_{c_i}$ | $R^2$  |
|-----------------------------------------|------------|-----------|--------|
| N-ethylpyrrolidone and N,N-dimethylformamide | 1.1195     | 0.4979    | 0.9726 |
| 2-Butoxy ethanol and Octana             | 0.7948     | 2.5306    | 0.9913 |

From the linear relationship curve of the logarithm of the concentration of the two odor mixtures and the odor level and Table 7, it can be seen that when the concentration of the mixed odor substance changes by $10^n$, it will cause a change in human perception of the odor level. It can be concluded that the hypothesis holds for the relationship between the concentration of the two mixed odor substances and the odor level.

5. Research application

5.1. Applied to objective evaluation of vehicle interior odor

At present, the principles of objective evaluation of vehicle interior odor can be roughly divided into two types. One is based on the test results of the overall concentration of the odor in the vehicle, combined with the evaluation of the supervisor to obtain the odor level in the vehicle. And the second is based on the test results of the concentration of each odor substance in the odor component, and the odor level in the vehicle is obtained by coupling calculation.

The first principle uses a combination of subjective and objective methods to establish a calibration curve using an external standard method or an internal standard method, and then calculate the odor level based on the overall concentration of the odor in the vehicle. This method is more suitable for the consistency control of the production line, and can quickly identify the odor level in the vehicle. The second principle uses an objective evaluation method, based on a single odorant concentration and algorithm, and finally calculates the odor level. The key to this method is the scientificity and accuracy of the algorithm. The algorithm is fitted based on the basic data of the database. The relationship curve between the concentration of odorous substances in the vehicle and the odor level is the basic data source of the database, which lays the theoretical foundation for this principle. Studies have shown that the logarithm of the odorant concentration has a significant linear relationship with the odor level.
However, the study also found that the linear correlation coefficient should be at least 0.995 in "HJ/T 400-2007 Determination of Volatile Organic Compounds and Carbonyl Compounds in cabin of Vehicles". In contrast to this there is still a certain gap in the linear correlation coefficients of some single odorants or mixtures of odorants. In future research, we will continue to explore the reasons for this gap, and then modify the test method to complete the follow-up research work.

5.2 Applied to the odor threshold test of odorants
The odor threshold plays a very important role in the process of improving the odor in the vehicle. According to the odor threshold value of the odorant, According to the odor threshold of the odorant, it can be analyzed how much a certain odorant can be added or at least reduced. In this way, consumers can't feel such odorous substances during the use of the vehicle, which improves driving experience.

The olfactory threshold is defined as the concentration of the substance that causes the smallest stimulus to the human sense of smell [10]. The olfactory threshold is mainly divided into the detection threshold and the confirmation threshold.

When the odor can be barely felt but it is difficult to distinguish what the odor is, the concentration of the odorant is called the detection threshold, and the corresponding odor level is level 2. When the odor can be barely felt but it is difficult to distinguish what the odor is, the concentration of the odorant is called the detection threshold, and the corresponding odor level is level 2. When the odor can be clearly felt and the odor can be distinguished, the concentration of the odorant substance is called the confirmation threshold, and the corresponding odor level is level 3. Unless otherwise specified, the odor threshold usually refers to the detection threshold.

By measuring the odor levels of a single odorant and two mixed odorants of different concentrations, the concentration of the odorant when the odor level is level 2 can be measured. The concentration of the odorous substance when the odor level is level 2 is the detection threshold of the odorous substance; the concentration of the odorous substance when the odor level is level 3 is the confirmation threshold of the odorous substance.

6. Conclusion
Through the study of Weber Fechner law, the application hypothesis of this law in the field of vehicle interior odor is proposed. By testing the odor levels of different odorants with different concentrations, the hypothesis is verified. This research provides a basic theoretical basis and basic data source for the algorithm in the objective evaluation of vehicle interior odor, clarifies the research direction for the objective evaluation of vehicle interior odor, and plays an active role in improving the work of vehicle interior odor.

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