A Humidity Compensation Method for On-line Odor Detection System in the Vehicle

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Abstract. The paper introduce a humidity compensation method for the on-line detection system of odor in the vehicle. The method is based on theoretical model of dilution and humidity control, and the gas concentration of the sample to be measured under different dilution multiples is measured, and then the original gas concentration is calculated by linear fitting with the gas concentration data under the condition of low humidity, so that the humidity compensation of the measured sample gas can be carried out. After the humidity compensation method, the relative error of VOCs concentration of the sample A is about 15%, which is close to its real value, which significantly improves the accuracy of sample’s VOCs concentration measurement.

1. Introduction
With the rapid development of society and increase of car parc, more and more plastic, rubber, leather, adhesive and other chemical products are widely used in the production of automotive interior because of their excellent mechanical properties and low-cost advantages. These products not only improve the safety and comfort of vehicles in terms of touch, vision and hearing [1], but also cause air pollution in vehicles due to the volatile organic compounds (VOCs) contained in them, which greatly affects the health of consumers. At the same time, odor complaints occur frequently, which seriously damaging the corporate image.

At present, the method of odor evaluation in the vehicle is still based on the sniffer. In addition to possible occupational health hazards, large subjective impact and poor statistics, there are also other technical problems that can not meet the requirements of online odor detection. The electronic nose system with gas sensor as detector has the advantages of fast, online and real-time measurement, so it has a wide application prospect. However, due to the reasons of gas sensor itself, its output signal will fluctuate with environmental factors (i.e. drift phenomenon) [2]. Experimental results show that when the humidity exceeds a certain critical value, with the increase of humidity, the gas sensor will show abnormal changes or even zero, so it is unable to accurately measure the gas concentration [3]. There are two common methods of sensor humidity compensation, hardware compensation and software compensation. Hardware compensation is mainly realized by using some components to compensate the temperature and humidity when building hardware circuit. Generally, it is realized by parallel connection or series connection of humidity sensitive resistor on load circuit. However, this method has a general effect and is not flexible. Software compensation refers to the algorithm. According to the humidity characteristic curve of the gas sensor, the corresponding correction curve or function formula can be obtained by interpolation or fitting method [4]. Although simple, it has some disadvantages, such
as irregular humidity characteristic curve of different gases, less prior information of humidity characteristic and so on.

The humidity compensation method of the on-line odor detection system in this paper is to measure the gas concentration of the sample under different dilution multiple (i.e. different humidity concentration). Then, the original gas concentration is calculated by linear fitting method using the gas concentration data under low humidity with negligible humidity effect. Thus, the humidity compensation of the sample gas is completed. The method is flexible in use, simple in operation, suitable for various gas types, and can significantly improve the accuracy of sample gas concentration measurement.

2. On-line Odor Detection System in Vehicle

The on-line odor detection system in the car mainly consists of sampling system (sampling bottle, gas path module, filter module), detection system (UV lamp, light ion sensor), power system and processing system (embedded development board and other related circuits and other peripheral modules). As show in Fig 1.

![Diagram of on-line odor detection system in vehicle](image)

**Figure 1.** Composition of on-line odor detection system in vehicle.

In the system, the functional structure for humidity compensation is composed of Venturi tube, needle valve, filter, VOCs detector (UV lamp and photo ion sensor), VOCs adsorption tube, drying tube, sample gas inlet, carrier gas inlet, pump, normally open solenoid valve and normally closed solenoid valve. Among them, the normally open solenoid valve is open circuit when it is not energized, and the normally closed solenoid valve is open circuit when it is not energized, and the energized solenoid valve is open circuit. As show in Fig 2.

![Diagram of functional structure of humidity compensation](image)

**Figure 2.** Functional structure of humidity compensation of on-line odor detection system in vehicle.

When the system is working, solenoid valve 4 is energized and solenoid valves 1, 2 and 3 are not energized. As show in Fig 3.

![Diagram of system operation](image)
3. **Humidity Compensation Model of On-line Odor Detection System in Vehicle**

3.1. **Model Principle**

In order to realize humidity compensation, a hypothesis model is proposed in this paper——the dilution and humidity control model. Under the condition of low humidity, the VOCs concentration is not affected or less affected by the humidity factor. But under the condition of high humidity, the VOCs concentration is greatly affected by the humidity factor. It is assumed that the dilution ratio of sample gas is positively correlated with the detected VOCs concentration.

Figure 4 shows that if the humidity of the original sample gas (the original sample gas is dry) is high, the higher the dilution ratio, the lower the humidity of the diluted sample gas, so the less the influence of the humidity factor is, the more accurate the VOCs detection concentration is; otherwise, the lower the dilution ratio, the higher the humidity of the diluted sample gas, so the more significant the influence of the humidity factor is, the more inaccurate the VOCs detection concentration is. In order to obtain the accurate VOCs detection concentration of the original sample gas, only the VOCs detection concentration of the diluted sample gas in the dilution ratio A-B section needs to be obtained, and the VOCs detection concentration of the original sample gas needs to be inversely deduced.

3.2. **Model Validation**

In order to verify the reliability of the model, the diluted foam simulation gas is tested for VOCs concentration, and the VOCs concentration under different dilution multiple is plotted as shown in Figure 5.
Figure 5. VOCs concentration of foaming simulation gas at different dilution multiple.

As shown in Figure 5, the VOCs concentration of foaming simulation gas at different dilution times is positively correlated with dilution multiple, and the correlation coefficient $R^2$ of fitting line is 0.9964, which proves that the fitting effect is good. Therefore, the theoretical model of dilution and humidity control can be used to predict the VOCs concentration of the original sample gas.

4. Experimental Method

4.1. Sample Acquisition

Before humidity compensation, the VOCs concentration of sample A under different humidity conditions needs to be detected. PGM7340 VOCs detector (RAE Systems) is used as VOCs standard measuring instrument. In order to ensure the consistency of the environment, the experiment is carried out in the odor evaluation room. The sealed box is used as the gas storage device, and the humidifier is used to adjust the humidity value in the sealed box. The humidity regulation range is between 0-90%. Each humidity will be measured several times to avoid the experimental contingency [5].

Table 1. VOCs concentration of sample gas at 3.6% RH.

| Dilution multiple | VOCs concentration/ppm |
|-------------------|-------------------------|
| 27                | 0.15                    |
| 14                | 0.35                    |
| 10                | 0.498                   |
| 7                 | 0.769                   |
| 5                 | 1.204                   |
| 4                 | 1.503                   |
| 1                 | 6.506                   |

Table 2. VOCs concentration of sample gas at 41.5% RH.

| Dilution multiple | VOCs concentration/ppm |
|-------------------|-------------------------|
| 27                | 0.142                   |
| 14                | 0.352                   |
| 10                | 0.478                   |
| 7                 | 0.739                   |
| 5                 | 1.012                   |
| 4                 | 1.404                   |
| 1                 | 5.214                   |

Table 3. VOCs concentration of sample gas at 73.1% RH.

| Dilution multiple | VOCs concentration/ppm |
|-------------------|-------------------------|
| 27                | 0.142                   |
| 14                | 0.352                   |
| 10                | 0.471                   |
| 7                 | 0.741                   |
| 5                 | 0.997                   |
| 4                 | 1.235                   |
| 1                 | 2.585                   |
4.2. Build model
In this paper, the humidity compensation model is established by Excel tool, and the humidity compensation of VOCs concentration of the original sample A is realized by linear fitting. Specifically, take the reciprocal of dilution multiple in Table 1, table 2 and table 3 as the x-axis, and the VOCs concentration data as the y-axis to establish the correlation, as shown in Figure 6 to 8.

![Figure 6. Humidity compensation model of sample gas’s VOCs concentration at 3.6%RH.](image1)

![Figure 7. Humidity compensation model of sample gas’s VOCs concentration at 41.5%RH.](image2)

![Figure 8. Humidity compensation model of sample gas’s VOCs concentration at 73.1%RH.](image3)

![Figure 9. Humidity compensation model curve of sample A under different relative humidity](image4)

As can be seen from the figures, the established humidity compensation model formula are as follows:

\[ y=6.4657x-0.1178, \quad R^2=0.9971 \]  
\[ y=5.7473x-0.0797, \quad R^2=0.9941 \]  
\[ y=5.1163x-0.027, \quad R^2=0.9971 \]

From the formula, we can see that the correlation coefficient \( R^2 \) of the model is above 0.99, which proves that the model is effective.

In order to prove that the correction result of humidity compensation model is more accurate, we use the model to compensate the humidity of sample A with different concentrations. The specific results are shown in Table 4 and Figure 9.
Table 4. Three Scheme comparing.

| Relative humidity/ % RH | VOCs concentration before humidity compensation/ppm | VOCs concentration after humidity compensation/ppm | Relative error % |
|-------------------------|-------------------------------------------------|-------------------------------------------------|-----------------|
|                         | Group 1  | Group 2  | Group 3  | Average value | Without humidity compensation | Group 1  | Group 2  | Group 3  | Average value |
| 3.60%                   | 6.506   | 6.347   | 6.470   | 6.455        | -0.1%                  | -2.5%   | -0.6%   | 0.6%     | -0.8%        |
| 14.30%                  | 6.153   | 6.145   | 6.045   | 6.075        | 6.088                  | -5.5%   | -5.6%   | -7.1%    | -6.7%        |
| 21.70%                  | 6.142   | 5.802   | 6.021   | 6.121        | 5.981                  | -5.7%   | -10.9%  | -7.5%    | -6.0%        |
| 28.80%                  | 5.974   | 5.732   | 5.912   | 5.967        | 5.870                  | -8.2%   | -12.0%  | -9.2%    | -8.3%        |
| 36.30%                  | 5.595   | 5.707   | 5.867   | 5.967        | 5.847                  | -14.1%  | -12.3%  | -9.9%    | -8.3%        |
| 41.50%                  | 5.214   | 5.667   | 5.867   | 5.897        | 5.810                  | -19.9%  | -12.9%  | -9.9%    | -9.4%        |
| 49.90%                  | 4.483   | 5.507   | 5.797   | 5.850        | 5.718                  | -31.1%  | -15.4%  | -11.0%   | -10.1%       |
| 55.80%                  | 3.958   | 5.367   | 5.767   | 5.818        | 5.650                  | -39.2%  | -17.6%  | -11.4%   | -10.6%       |
| 62%                     | 3.527   | 5.220   | 5.728   | 5.798        | 5.582                  | -45.8%  | -19.8%  | -12.0%   | -10.9%       |
| 68.10%                  | 2.745   | 5.120   | 5.712   | 5.786        | 5.539                  | -57.8%  | -21.4%  | -12.3%   | -11.1%       |
| 73.10%                  | 2.585   | 5.089   | 5.709   | 5.781        | 5.526                  | -60.3%  | -21.8%  | -12.3%   | -11.2%       |

Table 4 shows that under the condition of low humidity, the VOCs concentration value of uncompensated sample A is closer to the real value than that of compensated sample A, but the difference is not significant; under the condition of high humidity, the VOCs concentration value of compensated sample A is closer to the real value than that of uncompensated sample A, and the difference is large. In addition, the relative error of VOCs concentration of sample A after humidity compensation is about 15%, which is close to the real value, and the higher the relative humidity is, the greater the relative error is, the highest is 21.8%; while the relative error of VOCs concentration of sample A without humidity compensation varies greatly with the humidity, and the relative error of VOCs concentration of sample A under low humidity is only 5%, and it can reach 60.3% at high humidity. Table 4 shows that under the condition of low humidity, the VOCs concentration value of compensated sample A is closer to the real value than that of uncompensated sample A, but the difference is not significant; under the condition of high humidity, the VOCs concentration value of compensated sample A is closer to the real value than that of uncompensated sample A, and the difference is large. In addition, the relative error of VOCs concentration of sample A after humidity compensation is about 15%, which is close to the real value, and the higher the relative humidity is, the greater the relative error is, the highest is 21.8%; while the relative error of VOCs concentration of sample A without humidity compensation varies greatly with the humidity, and the relative error of VOCs concentration of sample A under low humidity is only 5%, and it can reach 60.3% at high humidity. Figure 9 shows that the humidity characteristic curve of VOCs concentration of sample A after humidity compensation is more stable than before, and is less affected by humidity. The humidity compensation effect of this method becomes more and more obvious with the increase of humidity. In addition, the average value of VOCs concentration after humidity compensation can effectively avoid the accidental error caused by single group results and improve the accuracy of humidity compensation, because the humidity characteristic curve of the average value after compensation is less affected by the humidity than that of the first group after compensation.

5. Conclusion
Compared with the existing humidity compensation technology, the advantages and characteristics of the humidity compensation method based on the on-line odor detection system in the vehicle are as follows:
(1) The method is to detect the VOCs concentration of sample under different dilution multiple (i.e. different humidity concentration), and then calculate the VOCs concentration of the original sample by fitting the VOCs concentration value under the condition of lower humidity (the humidity effect can be ignored), so as to realize the humidity compensation of sample.

(2) Taking the average value of VOCs concentration after humidity compensation of multiple groups of samples can effectively avoid contingency and enhance the accuracy of humidity compensation results.

(3) The method can realize the function of humidity compensation without changing the system structure by increasing the use steps. It can not only improve the performance of the system, but also increase the use flexibility.

(4) The method is more suitable for the humidity compensation of sample’s VOCs concentration at high humidity.

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