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Analysis and removal of the stench emitted from indoor dust

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Abstract−The offensive odor produced from indoor dust accumulated inside a vacuum cleaner is quite unpleasant to the user. In this study, the odor of dust samples prepared under various conditions was examined using an olfactory method that employs the human sense of smell. In addition, the odorous compounds were analyzed by GC-MS. The odor intensity of the dust collected inside the vacuum cleaner increased in proportion to not only the humidity and temperature of the dust, but also to the cleaning period of the container where indoor dust was accumulated. GC/MS confirmed aldehydes to be the main odorous compounds. The dilution ratio at which the stench of the indoor dust was not detected was determined by using the triangle odor bag method.

Key words: Olfactory Method, Dust, Stench, Odor Measurement, GC-MS

INTRODUCTION

In general, people do not notice the smell of weak scents in the air. However, if the concentration is increased the smell can become unpleasant. Many studies have examined the cause of emitted odors and how to remove them in order to protect the public health. The odorous materials consist of tens of thousands of organic compounds, most with a low molecular weight as well as high volatility and chemical reactivity [1-4]. Therefore, odorous materials produce the sensation of smell by various interactions, such as synergism and offset action between each ingredient.

Sometimes an offensive odor that occurs from a household vacuum cleaner is produced from the dust accumulated inside it due to the long cleaning period of the container in which indoor dust is collected. The stench is affected by the life habit of the consumers and the smell occurs continuously with propagation of the mold and corruption of the dust. Useful methods for removing the unpleasant odor include the use of activated carbon or artificial fragrant materials in order to remove or hide the bad smell. However, with these methods, the adsorbent must be replaced with a new one periodically, and if an artificial aromatic is used, not all fragrances will satisfy all consumers. Therefore, research into effective methods for removing odor as well as the conditions in which the stench of dust occurs is necessary. However, there are no reports identifying the components produced from indoor dust collected inside a vacuum cleaner using instrument analysis. Thus, we examined the odorous components that produce offensive odors from a vacuum cleaner using quantitative analysis. In addition, the conditions for the occurrence of bad smell were examined by instrumental and olfactometry analysis in order to propose a method for removing or reducing the stench emitted from the dust.

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EXPERIMENTAL

1. Analysis of Indoor Dust with Odor

Indoor dust collected from a vacuum cleaner was kept in polyester bottles, which do not emit any volatile organic compounds, to determine when the stench occurs. In the case of the samples for the cleaning period of the cyclone, dust samples whose weight was constant were stored for a different number of days. In addition, many indoor dust samples were prepared to examine the effect of humidity and temperature on the stench emitted from them.

The following procedure was used to prepare the samples under different humidity and temperature conditions. Indoor dust (2 g) was placed into polyester bottles and deionized water was then added with a glass-syringe to control the humidity in range of 50% to 90% by using an electronic hygrometer. After the bottles were sealed, they were stored at room temperature as well as in an oven at 30 to 50 °C for 1 week. The intensity of the odor from samples was tested using a direct sensory-test method and classified into six grade odor measurement according to a method reported elsewhere [1]. Before the direct sensory test, a panel test was performed using four standard odors with an olfactory sensibility of grade 3 or 4 [1-3].

2. Quantitative Measurements of Malodorous Substances

In many cases, malodorous substances can be sensed as a smell even at extremely low concentrations. Accordingly, it is necessary to introduce an odor to the detector in concentrated form when measuring offensive odor substances. The components of the odor are in a gaseous state and contain many components mixed together. Therefore, accurate characterization of the odor emitted from indoor dust inside a vacuum cleaner was carried out by gas chromatography-mass spectrometry (GC-MS). All organic solvents were of chromatographic grade and purchased from Sigma-Aldrich.

The indoor dust was collected using a vacuum cleaner with a cyclone that is popularly used in houses in Korea. The dust kept in a polyester bottle at the humidity of 90% and 50 °C for seven days

Table 1. Procedure for the air dilution sensory test method in Korea

1. Sampling
- Collection of 3-20 liters odor using a Polyseter sampling bag for less than 5minutes.
2. Preparing odor-free air
3. Panelist screening test
- Test the olfactory sensitivity using 4 standard odors
- More than five persons
- Select people with an olfactory sensitivity of 3rd or 4th grade and sense all standard odors
4. Performing the sensory test
- Prepare diluted odor samples using odor-free air (dilution ratio 3, 10, 30, 100, 300 times, etc.) using the method of descending series
- Prepare odor samples that consist of 2 bags filled with odor-free air and 1 odor-injected bag
- Allow a break period to maintain the olfactory sensitivity after the first phase of the test
- Stop the test if all panelist do not sense any odor from the diluted odor samples
5. Calculation of odor using the sensory test results
- Calculate the odor concentration using the statistics equation, and disregard the extraneous data

was placed inside a polyester bag (10 L), and then purified nitrogen gas (10 L) without any VOC (purity, 99.99%) was introduced into the bags. After that, the bags were heated to 60 °C for 20 minutes to emit VOC (volatile organic compounds) from the indoor dust and then the VOC from the odor sample was adsorbed to the Tenax-TA tube using an oil-free electric vacuum pump until the extraction volume adsorbed onto the tube was 3 L. Finally, the adsorbed tube with the odorous compounds was connected to the heat and desorption equipment (Aero Trap SD-2000), and the concentrated odor sample was then analyzed by GC-MS [4-6].

GC-MS was performed on a GC (HP 5890 series II, USA) with a MSD (HP 5971 series, USA). A HP-PONA (50 m×0.2 mm×0.5 µm film thickness) column was used to analyze the malodorous compounds from the indoor dust. The operating conditions were as follows. The oven temperature program for the HP-PONA column was 30 °C (15 min)→3 °C/min→150 °C→10 °C/min→200 °C (10 min). The carrier gas (He, 99.9995%) was adjusted to a flow of 0.7 mL/min. The transfer line temperature and MSD temperature were 200 °C and 280 °C, respectively, and the mass range was 30 to 450 amu.

The components of indoor dust without the odor were also analyzed by the same method given above and the operating conditions were the same as those of the HP-PONA column in order to determine the odor-free volatile compounds of indoor dust in comparison to the retention time and EI (electron-impact) mass spectra of the malodorous volatile substances.

3. Measurement of Odor Threshold and Removal of Stench

Of all the senses, the sense of smell is the most complex and unique in both structure and organization. Human olfaction is a protective sense, providing protection from potential infection caused by tainted food and matter, such as rotting vegetables and fecal matter. Hence, the odor threshold is also important to customers using a vacuum cleaner, and the problem of the odor emitted during use affecting the health needs to be solved. In general, the odor threshold is the minimum detectable concentration of additives and subtractive effects of individual chemicals in a mixed system. Therefore, the threshold for a particular compound may not be useful. A sensory test using an air dilution method has been adopted recently by researchers as a method for identifying the cause of odor in wide open spaces. The odor threshold of indoor dust was measured by using a triangle odor bag method in order to determine the threshold concentration of the odor [1,4,6,8-13]. Table 1 details the procedure for the air dilution sensory test method in Korea [1-3].

Activated carbon is generally used as an adsorbent to remove odors. Thus, we evaluated how effectively activated carbon reduced the offensive odors emitted from the indoor dust. Activated carbon was attached to the emission part, i.e., the back of a vacuum cleaner, to collect the filtered VOC of indoor dust. The feasibility of activated carbon in removing stench was also examined by comparing the components and concentrations of the malodorous substances before and after filtering them through activated carbon by GC-MS.

RESULTS AND DISCUSSION

1. Conditions of Stench Occurrence

When the odor intensity of indoor dust inside a vacuum cleaner was measured by the direct sensory test immediately after collecting the indoor dust into polyester bottles, there was no stench with a >2nd grade odor intensity. The conditions required for the occurrence of stench were investigated under a variety of conditions. Sam-

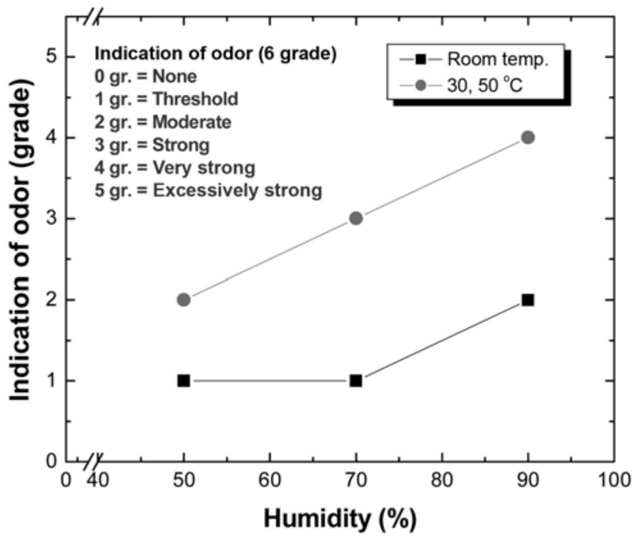

Fig. 1. The effect of the humidity and temperature of indoor dust on the odor intensity.

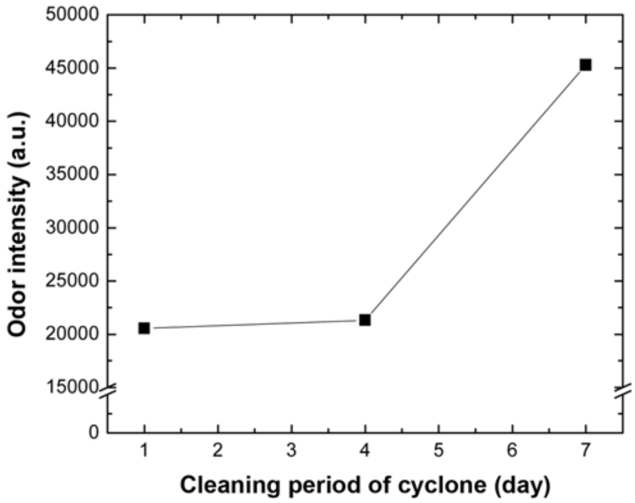

Fig. 2. The effect of the cleaning period of cyclone on the odor intensity of indoor dust.

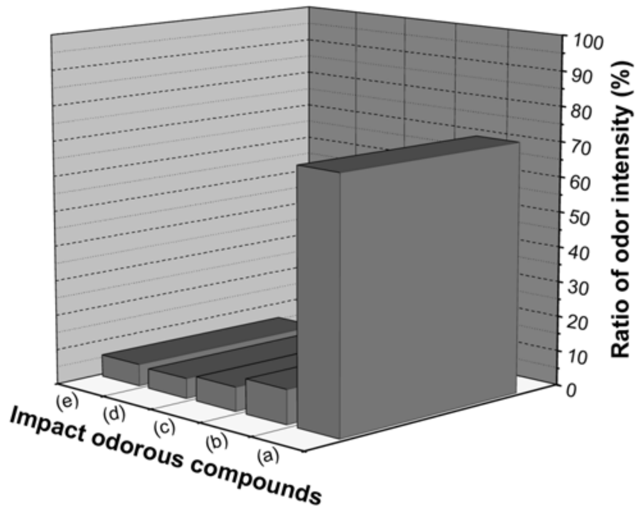

Fig. 3. Ratio of the odor intensity in impact odorous compounds analyzed by GC-MS.
(a) iso-Valeraldehydr (d) Butyraldehyde
(b) Propionaldehydr (e) Etc.
(c) n-Valeraldehydr

ples were prepared at different humidity, temperatures, and cleaning periods of the cyclone to determine when the stench occurred. Fig. 1 shows the effect of humidity and temperature of the indoor dust on the odor intensity. The odor intensity increased with increasing humidity and temperature inside the polyester bottle, and was particularly more sensitive to temperature. This suggests that the odor of indoor dust was mainly caused by microorganisms and mold because they are very active in warm and humid conditions [14-16]. As shown in Fig. 2, the intensity of the odor increased with increasing cleaning period of the cyclone because the microorganisms on the dust would become more active. Thus, it is believed that many kinds of microorganism cause the stench inside a cyclone by rapidly propagating and decaying the dust [15,16].

2. Analysis of Impact Odorants

The volatile odorous components were identified by comparing their retention times and the EI mass spectra of an odor-free sample in order to exclude the peaks of odor-free sample. The spectra of the unknown peaks were matched with the NIST (National Institute of Standards and Technology) and Wiley libraries to identify each unknown compound. Finally, real odorous substances of indoor dust were determined by comparing many odorous compounds reported by many other researchers [17-20]. After confirming them, the odorous compounds were considered because although the stench of dust consisted of many chemical compounds, only some odorous components with high odor intensity caused an unpleasant smell. Therefore, both the odor intensity and ratio of the causative compounds were calculated from each odor concentration using the following Eq. (1) and (2) [9,20].

$$\text{Odor intensity} = \frac{\text{Concentration of odorous substance (ppb)}}{\text{Threshold of a odorous substance (ppb)}} \quad (1)$$

Ratio of odor intensity (%)

$$= \frac{\text{Odor intensity of a odorous substance}}{\text{Total odor intensity of odorous substances}} \times 100 \quad (2)$$

In the case of the odor intensity, the well known thresholds of odorous substances were used to convert each concentration to the odor intensity [17-20]. Main odorous components were i-valeraldehyde, propionaldehyde, butyraldehyde, and n-valeraldehyde. The odor intensity of the i-valeraldehyde, propionaldehyde, butyraldehyde, n-valeraldehyde, and the other components was estimated to be 5.7×10^4, 7.9×10^3, 4.5×10^3, 5.5×10^3, and 5.0×10^3, respectively. Based on the ratio of odor intensity, it was found that i-valeraldehyde was the major component that caused the stench and its ratio of odor intensity was approximately 71%, as can be seen in Fig. 3.

3. Removal of Offensive Odor

A panel was set up consisting of the members who passed the screen test with using four kinds of standard odors. The test for knowing the detectable maximum dilution ratio was carried out using a triangle odor bag method until none of panelists could sense the diluted odor, as shown in Table 1. After the test was completed, the mean of the threshold values calculated for each panelist using Eq. (3) excluding the minimum and maximum values was taken as the threshold value for a group of all panelists [1,11,13,20].

$$Y = \sqrt[n]{(X_a \times X_b \times \ldots \times X_n)} \quad (3)$$

Where, n is the number of panelists applicable to calculating the mean of threshold values. X_a is the correct maximum dilution ratio measured by the first panelist (for example, panelist A) and X_n is the correct maximum dilution ratio for the last panelist. Therefore, Y is the threshold value for a group of all panels. Of the panelists, two people who reported the highest and lowest dilution ratio, respectively, were excluded when calculating the threshold value for a group of all panelists. The minimum detectable odor concentration was also calculated by converting the threshold value obtained in Eq. (4) as follows:

$$Z\,[\text{ppm}] = \frac{10^6}{Y} \quad (4)$$

Where, Y is the threshold value for the group of all panels and Z is detectable minimum odor concentration. The threshold detectable odor concentration evaluated was 1,035.74 ppm. Consequently, for the odor emitted from the indoor dust, if it is diluted with air at a 1 : 966 ratio or higher, people will not sense any odor.

As another method for eliminating odor, the effectiveness of activated carbon on removing the stench was examined by using the impact odorous compounds. Four types of main odor substances, same as in the dust, purchased from Sigma-Aldrich were used. The standard odors collected in a polyester bag with a constant odor concentration were injected into the vacuum cleaner with and without activated carbon through a pipe connected the body of the machine and the gaseous odor substances were collected into another polyester bag. The collected gas was then concentrated and adsorbed onto the Tenax-TA tube using an oil-free electric vacuum pump. The components of the gas were then analyzed by GC-MS. Fig. 4 shows that a large number of the odorants were removed after filtering the odor using activated carbon. Some of the aldehydes had changed to fatty acids, such as propionic acid, n-butyric acid and valeric acids, and most of the aldehydes injected except for a type of valeraldehyde had been totally removed, even though the level of both n-valeraldehyde and i-valeraldehyde remained below 8% after filtering them. Table 2 shows how efficiently each odorous component was eliminated in detail. Based on this result, it can be concluded that activated carbon is effective in reducing the emission of the main odorants caused by the indoor dust.

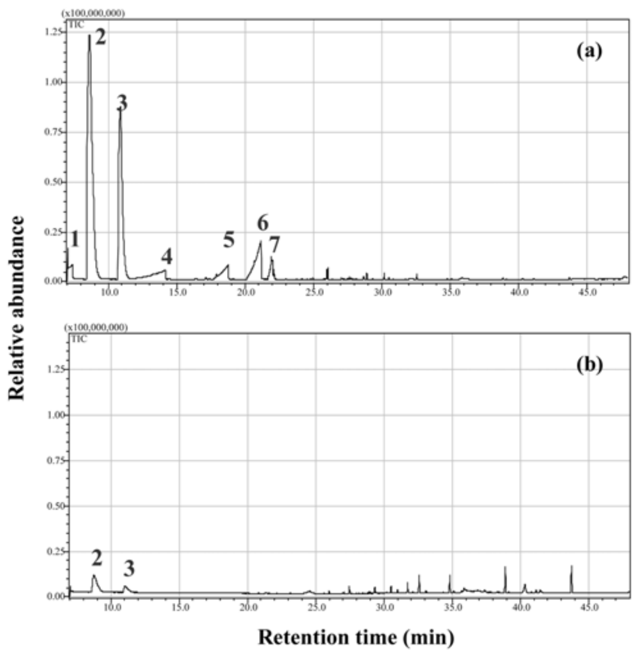

Fig. 4. Change in the concentration of odorous compounds using GC-MS; (a) before and (b) after filtering odors by activated carbon, respectively [17-20].

1. Butyraldehyde
2. iso-Valeraldehyde
3. n-Valeraldehyde
4. Propionic acid
5. n-Butyric acid
6. iso-Valeric acid
7. n-Valeric acid

CONCLUSIONS

The dust kept at high humidity and temperature inside a vacuum cleaner tends to show a higher intensity of the offensive odor. In addition, the intensity of the odor increases with increasing cleaning period of the cyclone. The main malodorous compounds identified by GC/MS were i-valeraldehyde, propionaldehyde, butyraldehyde and n-valeraldehyde with a contribution ratio >93%. It was found that the dilution ratio of the odor to purified air would need to be greater than 1 : 966 to keep the concentration of the malodorous compounds below the detection limit by a human. Activated carbon was found to be effective for removing the odor.

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Table 2. Difference between the concentration of odorous compounds before and after filtering the odor by activated carbon

Composition	Retention time (min)		Peak height		Predicted mean ratio of removing the odor
	Before filtering	After filtering	Before filtering	After filtering	
Butyraldehyde	7.388	none	5,883,935	none	100%
iso-Valeraldehyde	8.638	8.749	122,382,857	9,403,626	92.32%
n-Valeraldehyde	10.891	11.018	86,329,293	3,548,125	95.89%
Propionic acid	14.188	none	4,418,110	none	100%
n-Butyric acid	18.756	none	7,153,577	none	100%
iso-Valeric acid	21.152	none	17,863,172	none	100%
n-Valeric acid	21.957	none	9,793,441	none	100%

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