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Evaluation of adsorption and desorption of chafing dish odor on woolen fabric

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Abstract: In order to remove the odor on the clothes when eating chafing dish, a kind of very popular foods in China with strong flavor, the odor removal method of non-water washing was studied. Firstly, an odor adsorption system with a saturation adsorption was developed, which simulates the scene that the consumers' clothes absorbed chafing dish smell during consuming hot pot. Secondarily, steam distillation and solid phase micro-extraction (SPME) (with air distillation) for odor desorption were investigated and the results showed that steam distillation removed more types of odorous components and larger quantities of these characteristic compounds than SPME. Steam distillation has application potential in laundry cleaning with lingering smell.

1. Introduction

Chafing dish soup is a prevailing type of hotpot that usually contains meat slices or meat balls, vegetables and spice[1]. The spice typically includes pepper, cinnamon, onions, ginger, garlic and fennel, all of which contain a large number of volatile compounds. Although the volatile compounds and fats make chafing dish soup especially delicious, oil droplets and volatile compounds released into the air can be adsorbed by clothing[2] during consumption the hot pot, and the most prosperous consumption season of hot pot is always in winter, and the clothes of consumers are thick clothes, such as sweaters or fur coats, and generally, consumers don't wash with water because of heavy clothes contaminated with chafing dish smell, so, it is necessary to develop a waterless cleaning method to eliminate chafing dish odor.

In the current study, wet-cleaning cleaning[3] and dry cleaning[4] is the most mainstream cleaning method for clothes. Professional wet-cleaning is the process of removing odor and stains from garments and other textile products using fresh water and other agents. Professional wet-cleaning is considered to be an energy-efficient cleaning process when compared with dry-cleaning processes. However, wet-cleaning is frequently used to clean the thick clothes will damage its quality in the winter. Professional dry cleaners have been using perchloroethylene(PERC) compound as a solvent since the 1950s[5]. PERC has a negative impact on human health and the environment. Thus, it is not a wise choice to use dry cleaning instead of wet cleaning in the winter. For those clothes with a strong odor, current, the latest research focused on the self-cleaning of fabrics[6], and few studies involve the removal of the odor of clothes alone. Therefore, low-temperature steam was used to clean those clothes with odor but no stains in this test. The aim of this study was to evaluate the cleaning effect of steam on the woolen with the smell of the hot pot.

In the present study, the adsorption of odor onto different types and sizes of fabric was determined by simulating the preparation of hotpot soup with different amounts of spice. GC (Gas chromatography) and GC-MS (Gas chromatography-mass spectrometry) were used to compare the adsorption of odor from boiled and dry hotpot spice and the subsequent desorption of these odor, respectively. The effectiveness of different experimental conditions was determined by sensory evaluation.

2. Materials and methods

2.1. Samples

Eighteen packets (235 g) of hotpot condiment (Little Sheep Group Ltd., Baotou, Neimenggu, China) and samples of 50% woolen cloth, cotton cloth and gauze were bought in the local supermarket.

2.2. Odor adsorption tests

The experiments were carried out in a home-made closed box (30 cm × 30 cm × 50 cm). In the first test, three packs of hotpot condiment were mixed with purified water (4.5 L) obtained using a MilliQ element A10 system (Merck Millipore, Billerica, MA, USA) in a 10 L container and heated to boiling using an induction cooker (Philips, Amsterdam,Netherlands). Clean fabric samples were suspended above the boiling soup in the heating pot, which was enclosed in the upper part of the box space. After 60 min, the fabric samples were removed and sealed in vial for later testing. In the second test, three packs of hotpot condiment were mixed with a little distilled water and stirred evenly (IKA, Hangzhou, China).The resulting paste was heated to 160 ℃ using the induction cooker and clean fabric samples (100 cm × 200 cm) were suspended above the heating pot, which was enclosed in the upper part of the box space. After 60 min, the fabric samples were removed and sealed in a vial for later testing.

2.3. Steam distillation

A sample of woolen cloth (2cm×2cm) containing the odor of the hotpot spice was placed in a conventional distillation apparatus (Pope Scientific, Inc., Milwaukee, WI,USA). The velocity of the droplets was controlled by adjusting the temperature. Steam distillation was carried out for 2 h and the fractions and distillates were analyzed using GC-MS (Agilent Technologies, Santa Clara, CA, USA).

2.4. Solid phase microextraction procedure

Extraction of volatile compounds was carried out by aheadspace solid phase microextraction (HS-SPME) procedure, using polydimethylsiloxane/divinylbenzene fibers (65μm film thickness) (Supelco, Inc., Bellafonte, PA, USA). Before analysis, the fibers were preconditioned for 5 min in the injection port of the GC equipment, as specified by the manufacturer. The SPME fibers were then introduced into the headspace above each of the samples prepared in above. After 30 min, with the samples maintained at 80 ℃, the SPME fibers were introduced into the GC injector and left for 5 min to allow thermal desorption of the analytes.

2.5. GC-MS analysis

An Agilent-6890 gas chromatograph (Agilent Technologies), directly interfaced with an HP 5973 MSD ion trap mass spectrometer, was used for the analyses. A DB-WAX column (30 m × 0.25 mm, 0.25 μm) was used for the separations. The injector temperature was 250 ℃ and the oven temperature was programmed as follows: 35 ℃ held for 3 min; increased to 100 ℃ at a rate of 3 ℃/min and held for 3 min; increased to 160 ℃ at a rate of 6 ℃/min and held for 2 min; and then increased to 270 ℃ at a rate of 12 ℃/min. The carrier gas was helium (purity > 99.999%), at a constant flow velocity of 1 ml/min.

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The mass spectrometer conditions were as follows: ionization mode, electronimpact (EI); electron energy, 70 eV; interface temperature, 280 ℃; ion source temperature, 240 ℃; quadrupole temperature, 150 ℃, mass scan range, 33–450 amu; emission current, 50 A.

2.6. Sensory assessment
Samples of odor-impregnated woolen fabric were packed in polyethylene (PE) bags, numbered and randomly grouped. Twelve students with a keen sense of smell were selected from the undergraduate students in the School of Food Science & Technology in Jiangnan University and trained using the sequential method.

2.7. Statistical procedures
All experiments were carried out in triplicate and average values with standard deviation errors are reported. Significant differences at 95% confidence were determined by Duncan's multiple range tests, using SPSS software (version 17.0; SPSS Inc., Chicago, IL, USA).

3. Results and discussion

3.1. Selection of optimum adsorption conditions

3.1.1. Selection of fabric varieties
After screening a range of odor-active compounds, 30% *p*-ethylbenzyl alcohol was chosen because it is very volatile after heating and is easy to detect. Three equally sized pieces of woolen cloth, cotton and gauze were suspended above the *p*-ethylbenzyl alcohol solution and adsorption was allowed to take place for 2 h. The amount of *p*-ethylbenzyl alcohol adsorbed by the three types of fabric was analyzed using peak areas determined by GC-MS (headspace sampling) (Figure.1D). The peak area of the woolen fabric was larger than those of cotton and gauze, indicating that its adsorption capacity for *p*-ethylbenzyl alcohol was the highest. Therefore, woolen fabric was selected as the best cloth for further experiments.

3.1.2. Selection of adsorption device
Two different odor adsorption devices, a tent and a closed wooden box, were compared. There was a significant difference ($P<0.01$) in the adsorption of odors by cloth using the two test devices (Figure.1B). It is thought that the adsorption of odors depends on air flow and/or interactions between the fabric surface and the odor components[7]. The concentration of the odorous compound and the time of interaction with the fabric influence the adsorption effect. The tent, which has a large air and is poorly sealed, was not conducive to the evaporation of volatile substances onto the fabric. On the other hand, the air in the closed wooden box is relatively stable and more suited to the adsorption of volatile substances onto the fabric. The closed wooden box was thus selected for further experiments.

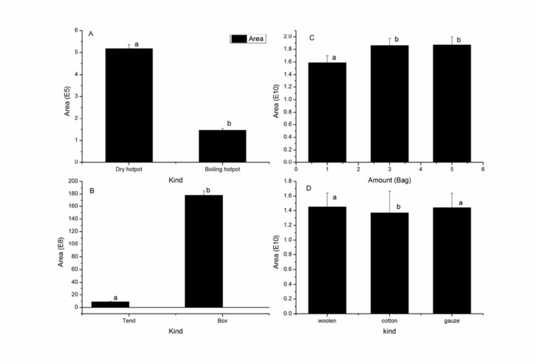

Figure 1. Comparison of gas chromatographic peaks under different conditions. A: different water (dry and boiling hotpot); B: different devices (tend and box); C: different amount (1, 3 and 5 bags); D: different fabrics (woolen, cotton and gauze).

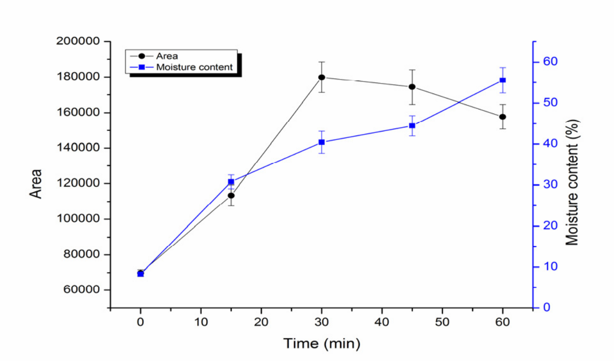

Figure 2. During the experiment, the peak area of gas chromatography and the moisture content of the fabrics changed with time.

3.1.3. *Impact of water vapor on the adsorption of odor components*

As discussed previously, the ability to adsorb odor depends on the time and/or interactions between the fabric surface and the odorous components. An upward trend was seen with the moisture content of the fabric and the total peak area increased over the first 30 min and then began to decrease (Figure.2). Both water molecules and odor molecules evaporate during the heating processand water may affect the interactions between the fabric surface and the odor components, resulting in reduced adsorption by the fabric after 30 min[8].

Both dry hotpot condiment and boiling hotpot were simulated in this test. A significant difference was observed when the number of peaks and peak areas was compared, indicating that fabrics with high moisture content did not efficiently adsorb odor components (Figure.1A). Dry hotpot condiment was thus chosen for further studies.

3.1.4. *Impact of the amount of spice on adsorption*

The amount of odor adsorption by the fabric increases with increases in the amount of spice (Figure. 1B). There was a significant difference ($P < 0.01$) between one bag and three bags, but nosignificant difference ($P > 0.05$) between three bags and five bags (Figure.1C). Taking into account the adsorption effect and economic costs, the best choice for further experiments was three bags.

3.1.5. *Impact of fabric size on adsorption of odor components*

Three different sizes of fabric (2cm×2cm, 5cm×10cm and 20cm×30cm) were used for the adsorption experiments. The adsorption of odor by the 2cm×2cm fabric sample was the worst. Although the types of odor compound adsorbed by the 5cm×10cm and 20cm×30cm fabric samples were similar, a significant difference was observed between the amounts of compound adsorbed (Table 1). Although the exact mechanism or reason for this phenomenon remains unclear, we speculate that the adsorption device and the size of the fabric sample influence the adsorption.

Table.1 The effect of different sizes of cloth adsorption

Size (cm*cm)	2*2	5*10	20*30
Peak amount	17^{a}	186^{b}	235^{c}
Area	$5.71*10^{5\ a}$	$1.97*10^{10\ b}$	$1.11*10^{11\ c}$

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3.2. Analysis of odor components in fabric

3.2.1. GC-MS

SPME and steam distillation were used for pretreatment of the samples. Data from the chromatograms are summarized in Table.2. Peak areas, which correspond to the concentration of the aroma compound, that were smaller than 0.1% were not taken into account for unidentified compounds[9]. In all, 99 major volatile compounds were identified and grouped in classes of substances: 12 alcohols, 17 aldehydes, 6 ketones, 12 esters, 37 hydrocarbons and 22 other compounds. Differences between SPME and steam distillation are shown in Table3, which presents the data as relative content and the type of corresponding aroma compounds identified in the fabric. Using steam distillation and SPME, 55 and 59 major volatile compounds, respectively, were identified, with 15 common substances These compounds make an important contribution to the flavor of the hotpot.

4-Isopropylbenzaldehyde (2.36%, 7.55%), diisobutyl phthalate (9.42%, 4.86%), cedrol (1.61%, 2.01%), lauryl alcohol (2.49%, 0.29%) and diphenylamine (3.76%, 3.32%) were present in the highest relative amounts (Table 2), leading us to speculate that these are the key flavor compounds of hotpot. To the best of our knowledge, this is the first time that 4-isopropylbenzaldehyde and diisobutyl phthalate have been reported in hotpot, although some of them have been found in other foods such as ham[10], chili shrimp paste[11], minced meat[12], beef[13] and sausages[14]. It is not surprising that 4-Isopropylbenzaldehyde was ranked first among our odorants since it is considered to be one of the products of esterification reactions that have the highest aromatic impact.

Table 2. A comparison table of the odorant material desorption composition on the cloth

Compounds	Steam Distillation		SPME	
	Kinds	Relative Content (%)	Kinds	Relative Content (%)
Aldehydes	6	4.48	14	22.79
Esters	6	18.84	7	11.85
Alcohols	7	8.15	6	3.86
Ketones	1	0.14	5	3.52
Amines	9	13.32	10	10.38
Ethers	1	2.48	2	0.7
Hydrocarbons	25	15.42	15	6.41
Total	54	62.83	59	59.51
The area of peak	$1.11*10^{11}$		$9.89*10^{9}$	
peak	235		247	

4. Conclusion

To the best of our knowledge, this is the first work to assess the adsorption and desorption of hotpot odor on woolen fabric by a simulation experiment, using sensory analysis, cleaning experiments and GC-MS analysis combined with steam distillation. The best results in the hotpot simulation experiment were achieved using a sample of woolen fabric (20cm×30cm), a closed wooden box and three bags of dry hotpot condiment. A total of 99 major volatile compounds were identified in the hotpot condiment by GC-MS analysis. The most abundant aroma components were 4-isopropylbenzaldehyde (2.36%, 7.55%) (Relative content), diisobutyl phthalate (9.42%, 4.86%), cedrol (1.61%, 2.01%), lauryl alcohol (2.49%, 0.29%) and diphenylamine (3.76%, 3.32%).

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