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Sensory characteristics analysis for typical odor emission sources

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Abstract: The hedonic tone of an environmental odor is a powerful predictor of annoyance. Pertinent field surveys combined with laboratory analysis of landfill, pharmaceutical factories and rubber factories have been conducted, with the purpose of obtaining a behavior curve of the hedonic tone for specific odor emissions, and comparing the annoyance potential and odor persistence of the sources under investigation. The 9-point scale was used to determine the hedonic tone, and the odor concentration was measured using the Triangle Odor Bag Method. The concentration to be presented to panel members comprises a range of 5 or 6 dilution steps which differ by a factor of approximately 3. Using a suitable curve fitting procedure, a line can be fitted through the points obtained in the experiment. Characteristic H values at any concentration can be derived from the hedonic behavior curve. The relationship between the hedonic tone and lgOC conforms to the quadratic polynomial for the three sources. The persistence of odor is expressed as a dose (concentration) response and (intensity) function. According to the rate of change in odor intensity, the pharmaceutical odor is the strongest, followed by the landfill odor, and then the rubber odor. Annoyance potential is calculated by multiplying lgOC with the max hedonic value, meaning that the three sources are sorted as follows: rubber factory>landfill>pharmaceutical factory. This study will further the understanding of the sensory characteristics of different odor sources.

Introduction

Odor emissions can cause serious annoyance in neighborhoods with a presence of emission sources. The annoyance potential of an emitted odor depends on a number of parameters: frequency, intensity, duration, and, in a complex way, the hedonic tone (Nicell 2009). The hedonic tone is the subjective rating of the pleasantness or unpleasantness of an odor. It is the hedonic tone that makes the odor from bakeries very different from the odor that comes from rendering plants. As a matter of fact, odor annoyance not only includes quantitative parameters like concentration or intensity but also includes qualitative parameters like hedonic tone (Sucker et al. 2008).

The importance of the hedonic aspects of industrial odors was first reported by Winneke and Kastka (1987). They found that different levels of annoyance came from the vicinities around a chocolate factory, an insulation plant, a taroil refinery and a brewery, even though the four sources had similar odor exposure levels. It is shown that pleasant odors induced little to no annoyance, while both neutral and unpleasant ones did (Sucker et al. 2008). Chaignaud et al. (2014) proposed a method to determine the annoyance potential of odor emission sources by multiplying odor concentration by hedonic tone. Using this method, the annoyance potential of green waste, compost and fermentation was compared. The results showed that fermentation had the greatest annoyance potential. This approach permits a more realistic ranking of odor sources, as well as permitting for an effective discrimination of different kinds of sources with similar odor concentrations, by their annoyance potential level.

Mueller et al. (2015) studied the relationship of acceptability, perceived intensity, hedonic tone and PD-value. Hedonic tone and perceived intensity are not independent variables, as these parameters both depend on odor concentration. Nimmermark (2011) studied the relationship between odor concentration and the hedonic tone of odors from pig, poultry and dairy operations, in order to identify individual factors of importance for the rating of the hedonic tone. Li et al. (2020) studied the relationship between odor concentration and the hedonic tone in pig farms, and concluded that when the odor concentration was greater than 13 $OU_E.m^{-3}$, it would disturb the population. Yan et al. (2018) analyzed the sensory characteristics of a paint factory, cigarette factory and magnolia bakery using the hedonic tone and odor concentration. Fournel et al. (2012) reported a very strong correlation ($P < 0.0001$) between odor emission concentration and hedonic tone (0.50). The regression equations of typical odorous pollutants (dimethyl disulfide, limonene, butyl acetate, NH_3, hydrogen sulfide and methanethiol) showed a quadratic nonlinear function between the hedonic tone and OC (Li et al. 2019, Yan et al. 2019, Yang et al. 2018). The study of Miedema et al. (2000) indicates that odor standards may improve if they take the odor pleasantness into account. In some countries (Germany, Ireland, and Belgium), the odor impact criteria can be adapted according to the hedonic tone of an odor by using a weighting factor (Schauberger and Piringer 2015).

So far, neither the pleasantness nor offensiveness of various odors has been adequately characterized; thus the relationship between the odor and its hedonic tone is still only vaguely understood. The odor from landfills, pharmaceutical factories and rubber factories received more public complaints, with these three sources being typical odor pollution sources. Scholars both at home and abroad have conducted extensive research (Wang, D. et al. 2019) (Wang, Q. et al.2019) (Idris et al. 2017). Hence, the variation behavior of the hedonic tone of odors from landfill, and pharmaceutical and rubber factories have been investigated. Furthermore, their annoyance potential and persistence of odor intensity were compared. The purpose of this article is to improve the odor evaluation criterion used in China by studying the relationship between the hedonic tone and OC. The results can lay the foundation for a scientific odor pollution characterization method.

Material and methods

Sample collection

(1) Landfill (non-point source)

The sampling position of the **surveyed landfill** is a working place (waste dumping compaction area). The working place is a non-point source, and as per the VDI 3880 guideline (VDI 2011), the wind tunnel sampler is used for sampling. The wind tunnel system consists of a PET hood positioned over the emitting surface. The wind tunnel has a rectangular section inlet and outlet duct (0.042 m×0.024 m). The central body of the wind tunnel is a 0.5 m wide, 1.0m long and 0.13 m high rectangular chamber. When sampling, the air volume in the tunnel is kept at 60m^3/h and the sampling rate is kept at 0.04 m^3/h.

The sampling date ranged from September to October 2018 and two parallel samples were collected 8 times a month. The sampling period was 12:00–14:00. The meteorological conditions were as follows: temperature 30.7°C±3°C, air pressure 100.6 kpa±0.5 kpa, wind speed 1.45 m/s±1m/s, relative humidity 40%±5%.

(2) Pharmaceutical factory and rubber factory (point source)

The exhaust pipe outlet from the workshop production line was used as the sampling point of the **surveyed pharmaceutical factory**. The sampling position for the **surveyed rubber factory** was the exhaust pipe outlet from the internal mixing link for the rubber mixing process (internal mixing discharge port). Both are point sources, and as per the HJ905 guideline (2017), the soc-x1 device is used for „lung method" sampling (Tianjin Sin Odor Environmental Protection Science and Technology Development Co, Ltd., China)

The meteorological data was measured using "wind direction and anemometer" (model UT363BT, made in China). The sampling date ranged from July to August 2018, and two parallel samples were collected 8 times a month. The meteorological conditions were as follows: temperature 35.5°C ±3°C, air pressure 100.3 kpa±0.5 kpa, wind speed 1.39 m/s±1 m/s and relative humidity 47%±5%.

(3) In accordance with HJ 732 (2014) and HJ905 (2017), an 8L polyfluoroethylene (PVF) sampling bag was used to sample the gas waste, and Teflon and other low adsorption materials were used in the sampling pipeline.

The odor concentration of the samples collected from the three sources was calculated in accordance with GB/T14675 (1993). After sampling, the samples were sent to the laboratory ready for analysis to be undertaken within 24 hours. According to the HJ905 (2017), the maximum odor concentration determined by the three sources is used as the evaluation index for discussion and analysis.

Sample Preparation

The pollution source samples collected were diluted to 5–6 concentration gradients that differ by a factor of approximately 3. The lower limit must correspond to the panel threshold. The higher limit must be checked for toxicity, and all possible health risks to the panelists must be totally excluded. The dilutions were filled into odorless 8L polyester sampling bags and are to be considered as testing samples. Next, they were inserted into two bags of nitrogen, to be considered as the blank samples. The process was carried out with the help of a dynamic dilution apparatus (4600, Entsch, USA).

Testing Method

The determination of the **hedonic tone** refers to a 9-point scale with values ranging from "-4 being extremely unpleasant", to "+4 being extremely pleasant", and with "0 being neither pleasant nor unpleasant" (neutral) (Table 1).

To prevent interference factors, it should be ensured that the experiment room is odorless and has good ventilation. The temperature for all samples should be kept at 26~28°C, which is comfortable for the human body. The presentation of the odor samples, with different concentrations, was done at random, but the series of measurements could neither start with a blank sample nor with the maximum concentration. To avoid panelists' possible tendencies to guess, the presentations were interspersed with blank ones. There is no "right" nor "wrong" answer, the results just reflect personal reactions. The panel's hedonic tone is the average value of all the panelists.

Odor concentration (OC), defined as the dilution factor to the detection threshold of a sample, was determined by (GB/T 14675 1993). In China, the OC is dimensionless, and 1 dilution factor corresponds to 1 OU·m^{-3}. Based on the human psychological response to odors, the OC was transformed by the logarithm, which is referred to as the odor index:

$$C' = \log C \tag{1}$$

Here, C' is the odor index, and C is the OC.

Odor Intensity (OI) is a description of the degree of a strong or weak odor. In China, it is expressed as 0–5 (0, 1, 2, 3, 4, 5), with 0 being odorless, and 5 being a strong odor.

Annoyance potential is proposed for the evaluation of odor acceptability, and is calculated by multiplying odor concentration and the mean hedonic tone (Chaignaud et al. 2014).

Panel of Assessors

Assessors of odor concentration (OC)

The panel consisted of 6 qualified members who had passed the Sniffer Certification Test according to (GB/T 14675 1993). Their ages varied from 26 up to 40, with a mean age of 32. Two of them were female and four were male.

Assessors of hedonic tone

In order to avoid the differences between individuals that may occur when determining the hedonic tone, the panel consisted of 16 qualified members who had passed the Sniffer Certification Test according to (GB/T 14675-1993).

They were also all trained with two reference materials: vanillin (5 g/L, dipropylene glycol) and guaiacol (5 µL/L, distilled water). The assessors rated the hedonic tone according to the 9-point hedonic scale. The mean value of the results obtained from the entire panel must lie within a given range as follows: Vanillin must only range from 1.1 to 2.4, and Guaiacol must only range from -1.6 to -0.4. Eight of them were female and eight were male. Their ages varied from 22 up to 41, with a mean age of 30 (VDI 3882, 1997) (Li et al. 2018).

Results and discussion

Hedonic curves of three odor sources

For a certain odorous sample, its hedonic tone is not fixed but varies with the concentration. The behavior curves of the three odor sources were plotted in the study with the odor index as the abscissa and the hedonic tone as the ordinate. The data fitting module of "Origin" was used to analyze the relationship between the hedonic tone and OC. It is helpful for the determination of acceptable concentration levels.

The hedonic values for odor from the landfill were all negative, which means that landfill gas is unpleasant at different concentration levels, as shown in figure 1. Also, the offensive feeling is enhanced with increased concentration. For the undiluted sample gas, OC was 4169 $OU_{E.}m^{-3}$ (lgOC =3.62), with the average hedonic value of -4 indicating the maximum offensiveness. When diluted with 30 times clean air, the lgOC was 2.14 with H value of -2.4 corresponding to moderate unpleasantness. When diluted 100 times, the H value was -1.1 which means slight unpleasantness. At the dilution ratio of 300, the gas had almost no smell and the H value approached zero. Within this concentration range (14–4169 $OU_{E.}m^{-3}$), the relationship between the hedonic tone and lgOC conforms to the quadratic polynomial. The regression equation is shown in formula 1.

$$y=0.39x^2-3.38x+3.02 \quad R^2=0.96 \qquad (1)$$

Like the landfill odor, the perception of the pharmaceutical odor is also an unpleasant one, and the degree of unpleasantness is enhanced with increased concentration. For the undiluted sample gas, OC was 5495 $OU_{E.}m^{-3}$ (lgOC =3.74), with an average hedonic value of -3.7 indicating the maximum offensive level. When the gas is diluted with different ratios of clean air, the offensive feeling gradually decreases. At the dilution ratio of 3000, the perception of the gas is close to neutral with the H value at -0.08. The shape of the pharmaceutical hedonic curve is similar to that of the landfill, thus indicating the quadratic polynomial relationship between hedonic tone and lgOC, the regression equation is shown in formula 2.

$$y=0.30x^2-2.37x+0.81 \quad R^2=0.92 \qquad (2)$$

The perception of the odor from the rubber factory is offensive, and lgOC of the undiluted gas is 3.62 with the H value at -4. When diluted with clean air, the gas becomes less offensive. At the dilution ratio of 3000, perception of the gas comes close to neutral with the H value at -0.5. The regression equation (formula 3) indicates the quadratic polynomial relationship between hedonic tone and lgOC.

$$y = -0.08x^2-1.6x-0.15 \quad R^2=0.98 \qquad (3)$$

The perception of offensiveness toward an odor, measured in terms of hedonic tone, is one of the 5 basic factors (known as FIDOL) that contribute to the impacts of odor (Sucker et al. 2008). Based on the relationship between hedonic tone and the

Table 1. The 9 point hedonic scale

Hedonic Tone	Verbal description
-4	offensive
-3	unpleasant
-2	moderately unpleasant
-1	mildly unpleasant
0	neutral
1	mildly pleasant
2	moderately pleasant
3	pleasant
4	very pleasant

odor concentration from an emission source, the acceptable odor concentration level can be obtained. If the hedonic level -1 is defined as the acceptable level of an odor, the corresponding OC is 50, 5, 20 $OU_{E.}m^{-3}$for the landfill, rubber and pharmaceutical odors, respectively. It is shown that each type of odor source has a different hedonic curve. This result is consistent with Nimmermark (2011) who reported that at the hedonic level of -1, the corresponding odor concentration from livestock was 14–16 $OU_{E.}m^{-3}$, while it was 37 $OU_{E.}m^{-3}$ from a cow shed. This information may provide references in establishing appropriate odor impact criteria for different odor sources.

Odor intensity and odor persistence analysis

Odor intensity is often also used as an indicator to determine if intervention is required to reduce the impact of the odor. For example, the Puget Sound Clear Air Agency (Washington, USA) may choose to take action if a control officer detects an odor on a 0-to-4 scale at an intensity of 2 as this corresponds to a condition where the “odor is distinct and definite” and “any unpleasant characteristics recognizable” (Nicell 2009). In China, the ambient odor should reach 1 in sensitive regions surrounding a source (i.e., corresponding to “barely perceivable” on a 0-to-5 scale), and in Japan, an odor is deemed acceptable if it is less than 2.5 to 3.5 on a 0-to-5 scale.

The intensity of an odor relates to its perceived concentration. Taking the odor index as the independent variable and odor intensity as the dependent variable, the linear relationship between them was obtained. For the three sources in this study, the linear relationships between odor intensity and odor index are as follow:

(4) rubber factory $y = -2.01x + 7.99$ $R^2 = 0.99$

(5) pharmaceutical factory $y = -1.18x + 5.44$ $R^2 = 0.84$

(6) landfill $y = -1.36x + 4.50$ $R^2 = 0.91$

The persistence of an odor is related to its intensity, and the intensity of an odor varies with its concentration. However, the change rate of odor intensity versus concentration differs among odors. The change rate can be defined as odor persistence, which is expressed as a „dose-response” function. The slope of the straight line shows the persistence of the odor. The flatter the straight line, the stronger the persistence of the odor. From Fig. 2, it can be devised that the persistence of odors from the pharmaceutical factory is the strongest, followed by the landfill odor, then the rubber odor. That is to say, the pharmaceutical odor stays in the air the longest.

Annoyance potential of the three sources

Annoyance potential is a proposed attribute to quantify the propensity of an odor to cause annoyance. Mathilde Chaignaud et al. (2014) proposed a new method for the evaluation of the annoyance potential of various odors through the multiplication of odor concentration and hedonic tone. Using this method, the annoyance potential of the three sources was assessed.

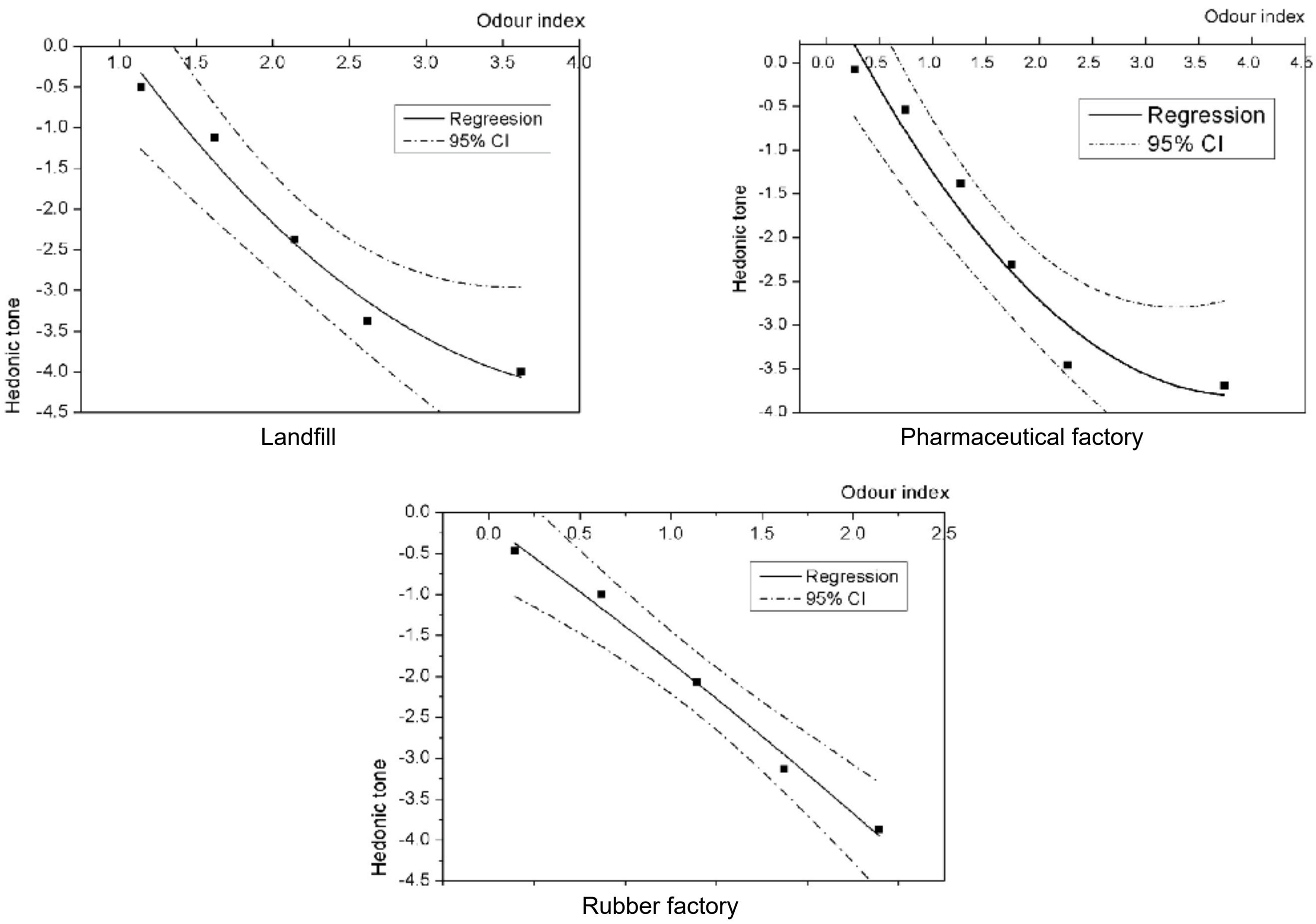

Fig. 1. Hedonic curves of three odor sources

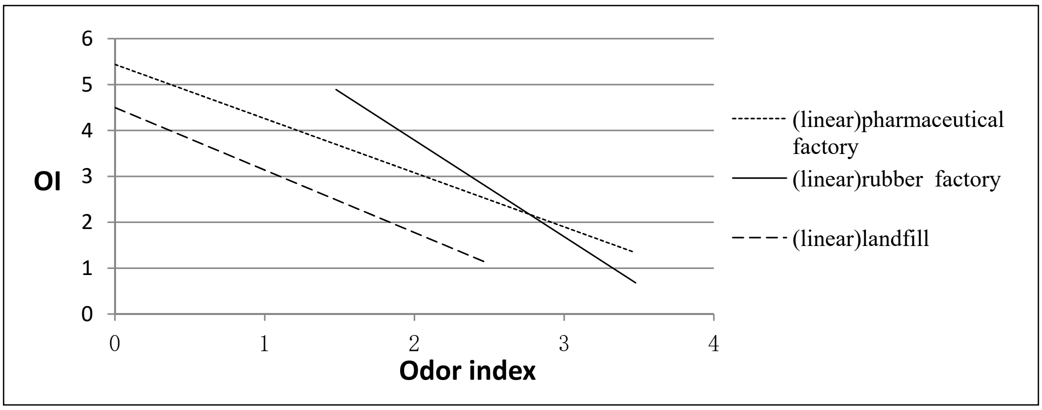

Fig. 2. Odor persistence of the three sources

Table 2. Odor index and hedonic tone for the three sources

Odor sources	Odor index	Hedonic tone
rubber factory	4.49	-4
landfill	3.62	-4
pharmaceutical factory	3.74	-3.69

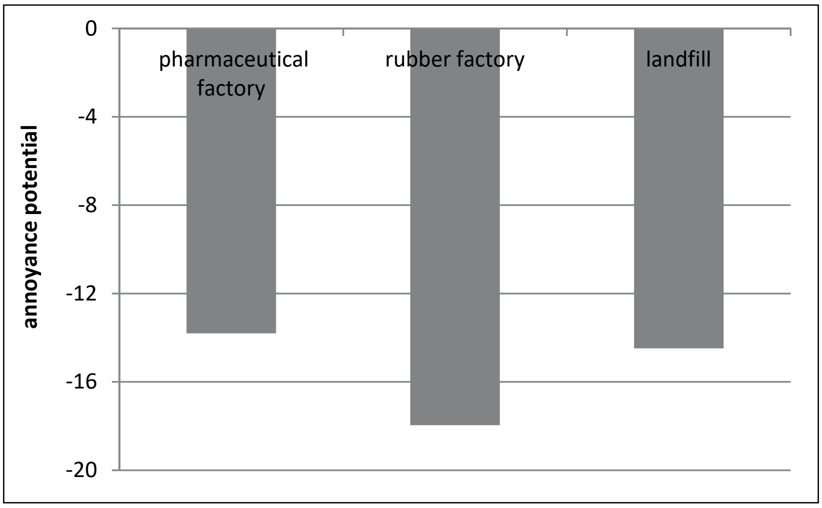

Fig. 3. Annoyance potential of the three sources

The odor index of the landfill is less than that of the pharmaceutical factory, but the hedonic tone of the landfill is greater than that of the pharmaceutical factory, indicating that the annoyance potential of the landfill is superior to that of the pharmaceutical factory, as shown in table 2 and figure 3. The three sources were evaluated for their annoyance potential, with the result sorted as follows: rubber factory >landfill> pharmaceutical factory. To conclude, this method can be more intuitive in distinguishing the impact that different odor sources have on the surrounding population and environment. And further to this, it is possible to accurate identification of the key emission sources.

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Conclusion

The odor characteristics from pharmaceutical, landfill and rubber sources were studied. The hedonic tone curve of each source was obtained through the sensory measurement of the assessors, which provided a reference for determining the acceptable odor concentration level.

In the range of concentrations studied, odor intensity and the logarithm of odor concentration from the three sources showed a linear relationship. According to the rate of change from the odor intensity, the pharmaceutical factory odor is the most persistent.

The evaluation of the annoyance potential of various odors through the multiplication of odor concentration and hedonic tone. The three sources' annoyance potential is as follows: rubber factory >landfill> pharmaceutical factory. This study will contribute to further understanding of the sensory characteristics that come from different odor sources.

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