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Exposure-response Relationship and Chemical Characteristics of Atmospheric Odor Pollution from a Cigarette Factory

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ABSTRACT

Odor pollution is one of the most complained environmental problems in China. At present, the odor control is mainly aimed at municipal facilities. There is a lack of reports on the atmospheric odor pollution produced by some special industrial emissions. This paper studied the odor impact of a cigarette factory on surrounding residents in order to obtain the exposure-response relationship, which can provide a scientific basis for odor control of cigarette production. Exhaust emission measurement, sample collection and laboratory analysis, as well as community survey were carried out. The air dispersion model Aermod was used to simulate the olfactory odor concentrations in surrounding residential areas. Face-to-face questionnaire was used to collect the information of residential responses to the cigarette odor. The exposure-response relationship between the percentage of highly annoyed people (%) and the 98th percentile of odor concentrations was analyzed using the univariate binomial logistic model. In addition, the typical odor pollutants were found by odor activity value. The results showed that the proportion of highly annoyed people in the residential area was ranged from 5% to 64%, and the acceptable level of exposure odor concentration was 4 OU m^{-3} at the 98th percentile. The main odor substances of the cigarette factory were oxygenated organic substances including esters, fatty acids and ketones. Based on the chemical composition and the odor character of each substance, the odor wheel of cigarette factory was established for the first time.

Keywords: Odor exposure, Annoyance, Typical odor pollutant, Odor wheel

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1 INTRODUCTION

Odor is one of the environmental stress issues with the biggest cause of complaints for a variety of industries (Marlon *et al.*, 2019; Chaignaud *et al.*, 2014; Rappert and Müller, 2005; Gostelow *et al.*, 2001; Hayes *et al.*, 2014; Henshaw *et al.*, 2006). In order to avoid the negative impact caused by odor pollution, some countries have formulated special laws, regulations and standards. Although ambient air quality has improved significantly over the past few decades, residents' tolerance of odor impacts seems to be reduced (Li *et al.*, 2018; Zhang *et al.*, 2021). Continuous or intermittent odor emitted form industrial sources will lead to nuisance and negative evaluations among the residents living in this environment, which will increase the possibility of community complaints (Perng *et al.*, 2011; Hayes *et al.*, 2017).

Regulations and guidelines on odor control are based on quantification of impacts and criteria for acceptable exposure to odors (Brancher *et al.*, 2017; Blanes-Vidal*et al.*, 2014). The first sector to be regulated on a national level specifically for odor impacts was the intensive livestock sector. In 1971, Netherlands imposed a practical guideline on new and existing livestock operations (Harreveld and Klarenbeek, 1995). In 1984, a quantitative air quality guideline for odors from industrial sources was introduced. Taking into account the differences in offensiveness of various odors (e.g., the smell of bread and sewage), a more flexible National Emission Guideline was imposed in 2000, which set different criteria for different odor sources (Infomil, 2000). The approach in the Netherlands was typical for a trend in other Northern European countries, such as Germany and Denmark. In the UK H4 guidance, an indication of possible criteria was provided, which range from $C_{98.0,\ 1\text{-hour}}$ = 1.5 OU_E m^{-3} for more offensive odors to $C_{98.0,\ 1\text{-hour}}$ = 6 OU_E m^{-3} for odors with a low annoyance potential (Environment Agency, 2011).

Learned from the research in these countries, the formulation of environmental odor standards requires impact assessment research to master the exposure-response relationship between environmental exposure and residential annoyance, so as to determine a reasonable acceptable level of odor concentration. Dispersion models are widely used to quantify ambient odor concentrations exposed near odor sources (Pandey and Sharan, 2018; Schauberger *et al.*, 2012; Sironi *et al.*, 2010; Dresser and Huizer, 2011). In this work, the odor release was calculated by steady-state plume model—Aermod model, which can predict and evaluate the concentration distribution, risk range, and duration of pollutants. Aermod model has been widely used to quantify the environmental odor concentration near odor sources such as industrial enterprises, livestock, wastewater treatment plants and other sources (Jeong, 2011; Latos *et al.*, 2011; Huang and Guo, 2019; Perry *et al.*, 2005). Meanwhile, the assessment of odor annoyance was done by means of direct interviews before the odor measurements. An area was determined around source where odor exposure was expected to vary from maximal to hardly detectable.

In addition, to accurately represent and mitigate potential odor impacts, key odorants emitted throughout processing need to be identified (Kamarulzaman *et al.*, 2018). There is a wide range of odor sources, odor substances and their characteristics emitted from different sources vary greatly. The compositions of odor are complex with distinct odorous species, common types of odor substances include sulfur-containing compounds, nitrogen-containing compounds, aromatic hydrocarbons, aldehydes, ketones and volatile fatty acids, etc. (Ubeda *et al.*, 2014). Studying odor characteristics is an important method to identify the typical odor pollutants.

The tobacco industry occupies an important position in the national economy in China. With the development of the tobacco industry, the off-flavor gases generated during the cigarette processing will have a certain impact on the living atmospheric environment of the surrounding residents. At present, few studies have been conducted on the compositional characteristics of odous from cigarette factories and its effects on surrounding sensitive localities. In this work, a representative cigarette factory was selected, through measurement of odor emissions, followed by dispersion modeling with the Aermod model, the time series of exposure odor concentration in the surrounding residential areas were obtained. Community questionnaire was surveyed to obtain odor annoyance in eleven sub-areas around the cigarette factory. A logic model was used to study the expose-response relationship to derive a certain acceptable concentration level. The chemical composition of cigarette odors were further to identify the key odor-causing substances.

2 MATERIALS AND METHODS

2.1 Introduction of the Cigarette Factory

The cigarette factory investigated in this work was located in northern China, it covered an area of about 0.19 km^2, including tobacco drying workshop (TDW) and tobacco blending workshop (TBW). The odor generated from the workshop was discharged through the emission stack (ES) after treatment. The sensitive areas like school, hospital, residential area around cigarette factory often occurred odor complaints.

2.2 Sample Collection

Odor sampling was conducted in July, 2017. The selection period was based on the fact that the number of odor complaints in summer was much higher than that in other seasons (according to the complaint data from the Local Ecology and Environment Bureau). Sampling sites were set at the discharge outlet of the production facility in two workshops, while set at the center of the emission stack pipe in the two emission stacks.

The samples were collected according to ‘‘Emission from stationary sources-Sampling of volatile organic compounds-Bags method (MEE, 2014)'' and ''Technical specification for environmental monitoring of odor (MEE, 2017)''. A 3 L Tedlar bag was used for constant flow sampling of the exhaust gas, and each sampling time was 3 min. The sampling pipeline was made of low-adsorption materials such as Teflon. A filter head was installed between the pipeline and the Tedlar bag to filter impurities such as particulate matter and water. All samples were collected while the production facility was operating normally. Three parallel samples were collected at each point. In total, 12 air samples were gathered for chemical and sensory analyses. All samplings were light-free stored and analyzed within 24 h.

2.3 Experimental Method

2.3.1 Detection of odor compounds

Compounds analyses were performed by using GC-MS 7890A-5975C (Agilent Technology Co., Ltd.). 200 mL air sample was first injected into the pre-concentration system (Entench 7100, USA) and get concentrated by cryogenic liquid nitrogen, then the gas passed through a chromatographic column DB-5MS (60 m × 0.32 mm × 1.0 mm) with the high-purity helium gas (purity greater than 99.999%) as the carrier gas. The mass spectrometer was operated in full scan for qualitative analysis and selected scan for quantitative analysis, in the m z^{-1} range of 15–300. The temperature program had three ranges as following: 35°C–150°C with a step rate of 5°C min^{-1}, 150°C–220°C with a step rate of 15°C min^{-1} and then hold for 7 min at 220°C; the temperature of injection port was 100°C; the flow rate of carrier gas was 1.5 mL min^{-1}. Compound concentrations were quantified by the internal standard method.

Identifying the main odor-causing substances is the key step to control odor pollution. The main odor-causing substance is not the substance with the highest concentration but with the highest OAV (Wu *et al.*, 2015). The OAV is the mass concentration of the substance divided by the odor threshold of the substance, see Eq. (1), that is, the lower the odor threshold of the substance, the more likely it is contribute to odor. The OAV is a dimensionless factor.

$$OAV_i = C_i/OT_i \tag{1}$$

C_i is the concentration of the compound (mg m^{-3}), and OT_i refers to odor threshold concentrations, OT used in this study was derived from Nagata (2003) which was determined based on panel' average threshold through standard procedures. Compounds with an OAV > 0.1 in emissions were identified as potential odorants. This method can be used to initially assess the sensory and olfactory effects of the odorants.

2.3.2 Determination of odour concentration

Odor concentration was measured according to the Air Quality-Determination of Odor-Triangle Odor Bag Method (MEE, 1993a, GB/T 14675-93). The odor concentration of air sample was determined by a sniffer group which was consist of at least 6 well-trained sniffing panelists. During the determination, two of the three 3L odorless bags were filled with neutral gas, the third bag was filled with neutral gas and sample gas at a certain dilution ratio. The panel needed to sniff the further diluted sample gas after correctly identifying the odorous bag. When the odor concentration of the diluted sample was lower than the sniffer' olfactory threshold, the test for this panel was considered finished. Odor concentration was calculated based on the olfactory threshold. Each sample was measured twice in parallel. For parallel samples, select the maximum odor concentration as the final result.

2.4 Odor Exposure

The Aermod dispersion model was used to estimate the odor concentration at the respondents' home address. Aermod is the preferred air quality model by the U.S. Environmental Protection Agency (U.S. EPA) to demonstrate regulatory compliance in the near field (< 50 km). The model is essentially a steady-state Gaussian plume model and combines the Monin-Obukhov similarity theory to describe atmospheric stability in a continuous manner. The basic equation for predicting downwind odour concentrations is expressed in Eq. (2):

$$C = \frac{Q}{\pi \sigma_y \sigma_z \mu} \exp\left(-\frac{y^2}{2\sigma_y^2}\right) \exp\left(\frac{H^2}{2\sigma_z^2}\right) \quad (2)$$

where C is the downwind odor concentration, OU m^{-3}; Q is the odour emission rate of point source, OU s^{-1}; σ_y, σ_z is the Pasquill-Gifford plume spread parameters based on stability class; u is the average wind speed at pollutant release height, m s^{-1}; H is the effective height above ground of emission source, m; V is the vertical term used to describe vertical distribution of the plume; x is the upwind direction, m; and y is the cross wind direction, m.

The product of the odor concentration and exhaust volume per minute of emission stack was termed in the odor emission rate (OER). OER is one of the essential input parameters in air dispersion model. The value of OER directly determines the atmospheric impact of odor source on the surrounding environment. The OER calculation method for point source pollution is shown in Eq. (3).

$$Q = OC \times V \quad (3)$$

where Q is the odor emission rate of point source, OU s^{-1}; OC is the odor concentration, OU m^{-3}; V is the flow rate measured by the gas flow meter, m^3 s^{-1}.

The meteorological data used for the study area was consisted of two parts, surface meteorological data and upper-air meteorological data. Surface meteorological data was collected from the study area using ground-based weather stations for 2017. The datasets included observations of atmospheric pressure, air temperature, wind direction, wind speed, relative humidity, total cloud cover and low cloud cover. The weather station was about 10 kilometers from the cigarette factory, which could better reflect the atmospheric meteorological parameters of pollution source. In 2017, the dominant wind direction was southwest, the annual average wind speed was 1.55 m s^{-1}, and the static wind frequency (wind speed less than 0.5 m s^{-1}) was 1.44%, about 126 hours. The frequency between 0.5 m s^{-1} and 2 m s^{-1} was the highest (71.1%). Upper-air meteorological data was generated by WRF (Weather Research and Fore-casting) model with 1 km resolution relevant to the studied area.

2.5 Questionnaire Data Collection

Questionnaire survey was conducted in eleven residential areas (Fig. 1), according to the annual dominant wind direction of the pollution source and the distribution of odor complaints in surrounding sensitive areas. About 50–80 households were investigated in each residential area based on the population distribution of the area. Face-to-face survey was mainly carried out with fully trained interviewers. The interviewees were residents over the age of 18 who had lived at least 3 months.

Questionnaire survey was mainly composed of two parts, based on Likert-scales. The first part mainly investigated the general social and demographic data, such as the age, gender, address and residence years of the respondents, while the second part mainly involved environmental stress factors, including satisfaction of living environment and pollution sources (i.e., noise, cooking fume, waste, sewage or others). There were several alternative answers at the bottom of each question for respondents to choose. Regarding the impact of the cigarette smell on the surrounding residents, the five most important questions were shown in Table 1. Data processing was mainly completed using SPSS 21.0, Visio 2007 and Excel 2016. Arithmetic means and 95%-confidence intervals were calculated to describe respondents' odor annoyance.

2.6 Exposure-response Relationship Analysis

Binomial logistic regression analyses had been used to estimate the association between the odor exposure and the odor annoyance from questionnaires. For binomial models, the outcome variables of odor annoyance degrees were dichotomized into two levels (the outcome "score = 0" represents the following response categories "not annoyed", "slightly annoyed"; and the outcome "score = 1" represents the following response categories "moderately annoyed", "very annoyed" and "extremely annoyed"). The odor exposure data had been transformed into natural logarithms

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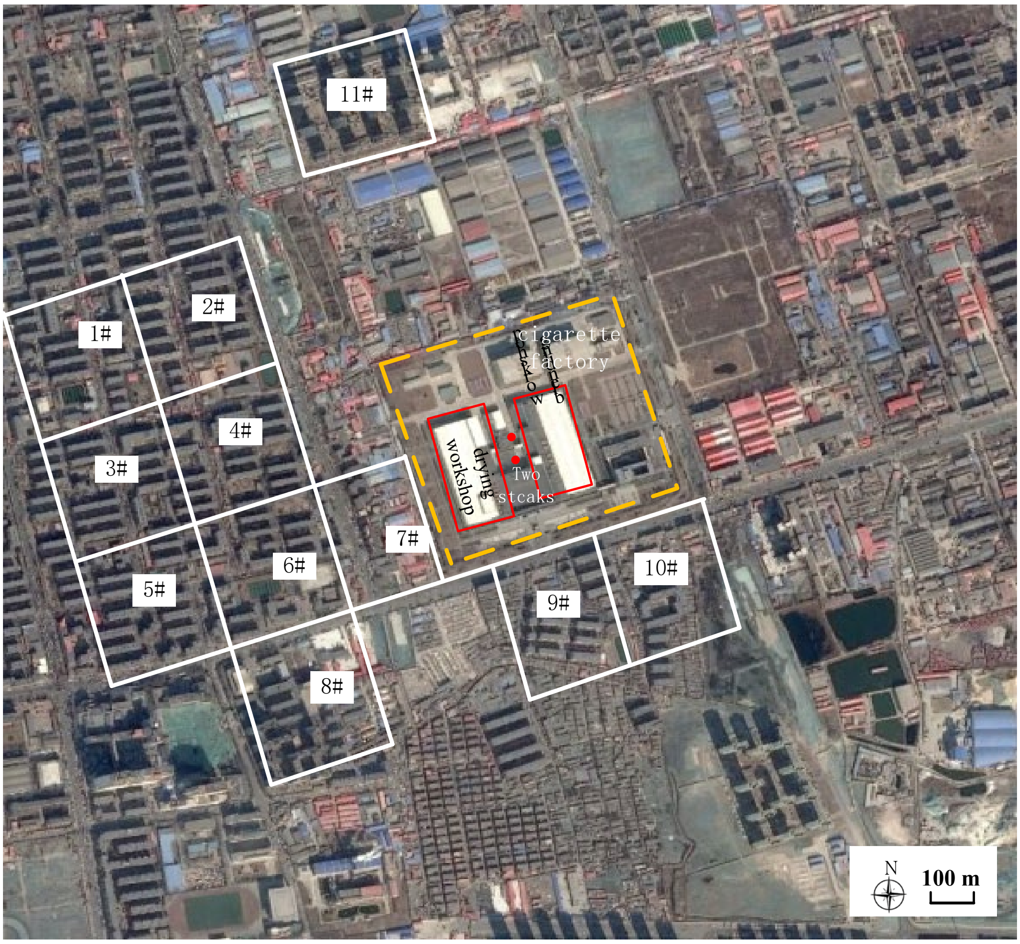

Fig. 1. The eleven regions of study around the cigarette factory.

Table 1. The most important questions from the questionnaire.

Question	Answer
How often do you smell odor from industry or sites?	□never □every day □once a week □2–3 times /month
How strong do you feel odor from industry or sites?	□no odor □very faint strength □faint strength □moderate strength □strong strength □very strong strength
How do you rate that odor with respect to annoyance?	□none annoyed □slightly annoyed □moderately annoyed □very annoyed □extremely annoyed
In most cases, when did the strongest cigarette odor occur?	□morning □noon □afternoon □evening □midnight
Which season has the highest frequency of odor?	□spring □summer □autumn □winter

values, basing on the logarithmic fit was found to be closer than a linear fit in previous studies (Sucker *et al.*, 2008).

3 RESULTS AND DISCUSSION

3.1 Odor Impact Assessment

Odor problems are generally, caused by many kinds of malodorous substances at low concentration, so it is almost impossible to analyse the whole components of the odor completely by any instrumental method, not only qualitatively but quantitatively. In addition, odor pollution also has the characteristics of subjectivity and complexthere. Therefore, the odor concentration value obtained by sensory test method is used to reflect the impact of odor pollution generated by enterprise on human senses. The maximum odor concentration in TDW was 1318, whlie the

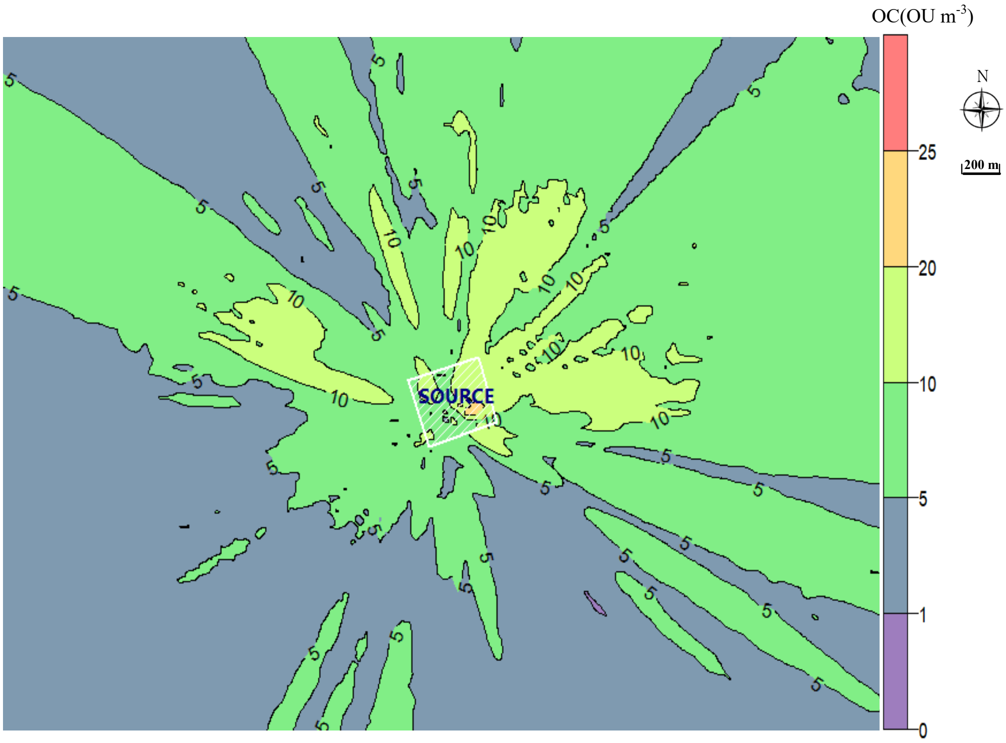

Fig. 2. The result of the odor dispersion simulation using the Aermod model system.

maximum odor concentration in both ES and TBW was 5495 (dimensionless) which exceeds the current odor emission standard in China (MEE, 1993b, GB 14554-93). The odor concentration cannot be reduced to an acceptable range through atmospheric diffusion, and it still had a sensory impact on the surrounding residents after landing.

The result of odor diffusion simulation was shown in Fig. 2. The odor concentrations (C98) was ranged from 1 to 45 OU m^{-3}, based on 98th percentile hourly averages of the odor concentration. Odor concentration was greater than 10 OU m^{-3} within approximately 1300 m from the east, northeast, north, and northwest sides of the cigarette factory. There was no residential area on the east side of 1 km from the cigarette factory, the impact on the east side can be temporarily ignored.

3.2 Socio-demographic Characteristics of Respondents

In this survey, there were 199 valid questionnaires. The age group and gender characteristics of the respondents are shown in Table 2. The number of men and women respondents was basically the same. The age of respondents were mainly more than 45 years old, about 61.8%, which was mainly because most of them were retiring at home during the daytime of the survey.

Odor annoyance levels were reported by 199 respondents from surrounding residential areas. To the question "How do you rate that odor with respect to annoyance?", the answers should be selected from the descriptive rating scale (no annoyance, very little annoyance, moderately annoyance, very annoyance, extremely annoyance). The percentage of highly annoyed people (HA%) in this study was defined as the proportion of people who chose the answer "moderately annoyance", "very annoyance" and "extremely annoyance" to the total number of people.

Table 2. Age and gender distribution of respondents.

Age (years)	Male (number)	Female (number)	Total (number)
18–45	38	38	76
> 45	62	61	123
Total	100	99	199

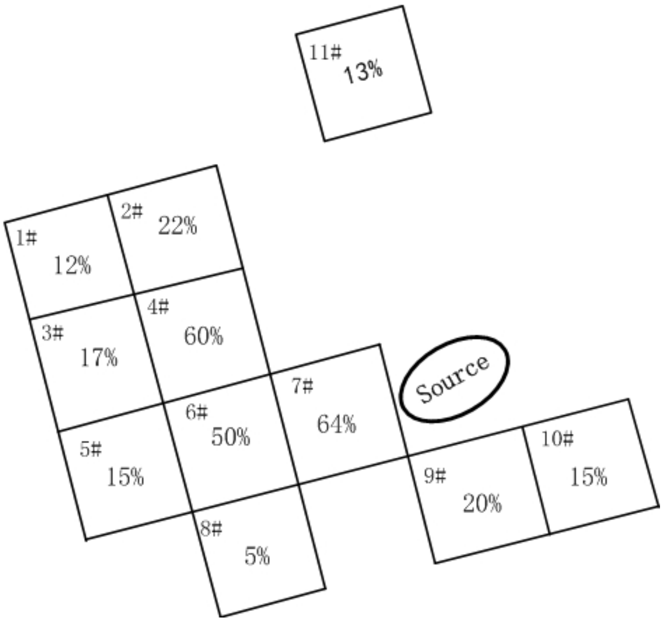

Fig. 3. The HA% of respondents disturbed in 11 sub-areas.

Comprehensively analyzed the subjective annoyance of respondents on cigarette odor, the HA% in 11 sub-areas are shown in Fig. 3.

It can be seen that in 11 sub-areas, HA% varied from 5% to 64%. The 7# residential area was relatively close to the cigarette factory, with HA% reaching 64%. The respondents said that they often smelled the odor from the cigarette factory, sometimes odor intensity was very strong. The distance from 6# and 4# residential area to the factory was less than 500 m, and the residents were more troubled by the cigarette smell affected by the local predominant wind direction. On the whole, as the distance increases, the level of HA% residents gradually decrease. The odor emitted from the cigarette factory had a significant impact on the surrounding residents. Long-term household odor exposure had a positive and significant association with increased frequency of reported odor annoyance in residential communities, which was consistent with other researches (Boers *et al.*, 2015; Lowman *et al.*, 2013; Brancher *et al.*, 2019).

3.3 Exposure-response Relationship

The univariate binomial logistic model was used to characterize the exposure-response relationship between HA% and the 98th percentile of the odor concentrations, and the probability density function was shown in Eq. (4). The exposure-response association can be graphically represented by an S-shaped curve as illustrated in Fig. 4.

$$P = \frac{1}{1 + \exp\left(-2.889 + 3.655 \ln C_{98}\right)} \tag{4}$$

where p is the probability of odor annoyance, 0%–100%; C_{98} is the 98th percentile of the odor concentrations, calculated by Aermod model throughout the whole year.

The curve showed that an individual at the residence exposed to the probability of being moderately annoyed, very annoyed or extremely annoyed from the cigarette factory. As the exposure concentration increases, the proportion of the probability annoyed residents significantly increased. In order to limit the percentage of people who experienced some form of odor-induced annoyance to 10% or less (Invernizzi, 2020), the acceptable level of odor concentration was 4 OU m^{-3} at the 98th percentile of the odor exposure from cigarette factory calculated by exposure-response relationship curve. This value can be used as the acceptable level of odor concentration for this cigarette factory. It has important reference significance for related departments to set a reasonable odor protection distance and determine the degree of annoyance of residents by odor.

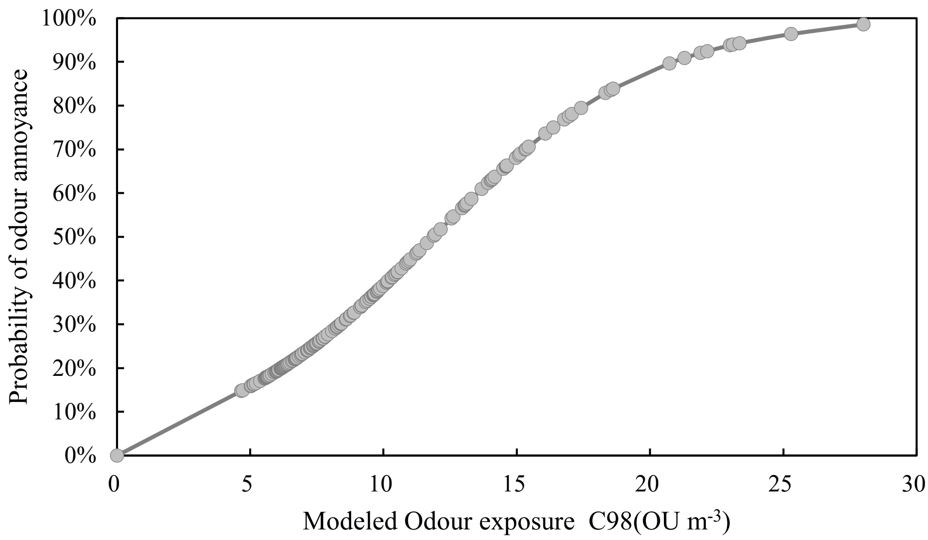

Fig. 4. Exposure-response univariate binomial logistic model between the 98th percentile of the odor concentrations and probability of odor annoyance.

However, there were also uncertainties in this research. First, the questionnaire data we used to investigate the odor annoyance of surrounding residents would have deviation. Some residents thought that the surrounding company would have a bad effect on their health, they hoped these surrounding company to be relocated or shut down. When answering questionnaire, some people exaggerated the degree of annoyance from factory odor, which would result in a higher proportion of the annoyed population.

The second problem was that the odor exposure model had uncertainties: (1) The Gaussian equations simulated atmospheric physics had inherently uncertainties. (2) The assumption by AERMOD that meteorological data from the weather station which was about 10 kilometers from the cigarette factory were representative of the wind fields throughout the entire modeling grid was a source of uncertainty in the representative of the model input data. (3) The input data of OER were derived from the sampling data in the July, which had a certain degree of uncertainty.

3.4 Chemical Characterization of the Cigarette Factory

Chemical composition analysis was performed on each sample collected. According to the analysis results of the instrument, a total of 39 odor compounds were detected with concentrations ranging from 1.9 to 78147.2 µg m^{-3}, mainly including aromatic compounds such as benzene, toluene, xylene and ethylbenzene, halogen compounds such as dichloromethane and tetrachloroethylene, hydrocarbons such as propane and butane, oxygenated compounds such as ethanol, acetone and butanone, organic sulfides such as carbon disulphide and terpenes such as limonene. The average concentrations of compounds detected in sampling units were shown in Table 3.

Oxygenated compounds had the greatest concentration proportion of the total VOCs in each unit (more than 95%). Ethanol accounted for 33.4% of the total concentration of oxygenated compounds in ES, followed by valeric acid (23.6%) and isovaleric acid (18.3%). Oxygenated compounds were the dominant oxygenated components in TDW and TBW where the ethanol reached 78147.2 µg m^{-3} and 50710.0 ± 178.3 µg m^{-3}, respectively.

By calculating the OAV of the detected compounds, as shown in Table 4, the typical odor pollutants were ethyl acetate, styrene, pyridine and ethanol in TBW, propyl acetate, 2-butanone. valeric acid, isovaleric acid and ethanol in TDW, and valeric acid, isovaleric acid, butyric acid, isobutyric acid, propionic acid and ethanol in ES. Butyric acid, isobutyric acid and propionic acid can cause a strong sour odor even at low concentration, due to their low odor threshold. Alcohols have a certain influence on the aroma and taste of cigarettes. The detected concentration of ethanol was relatively higher due to it is often used as a solvent for cigarette flavors (Perestrelo *et al.*, 2012). Ester mainly affect the aroma and taste of cigarette. Among the detected compounds, Ethyl acetate and propyl acetate were the main sources of fruity flavour (Forney *et al.*, 2016).

Table 3. Concentration of the odor compounds in each unit (μg m^{-3}).

Compounds	ES	TDW	TBW	Compounds	ES	TDW	TBW
m-ethyltoluene	ND	4.1 ± 0.8	ND	propane	28 ± 9.8	ND	ND
toluene	15.5 ± 4.7	8.8 ± 4.3	199.0 ± 42	isobutane	ND	ND	61.0 ± 4.6
benzene	11.9 ± 0.3	6.2 ± 0.4	210.0 ± 0.7	butane	ND	ND	135.0 ± 9.8
ethylbenzene	5.3 ± 2.4	2.8 ± 1.3	141.0	2-methylpentane	ND	ND	61.0 ± 0.6
m-xylene	13.6 ± 3.1	7.0 ± 0.9	110.0	isoprene	ND	3.6 ± 0.8	ND
p-xylene	13.7	7.5 ± 1.5	ND	propene	ND	ND	153.0 ± 29.5
o-xylene	6.2 ± 2.3	2.9 ± 1.1	122.0	limonene	79.8 ± 5.6	ND	ND
4-ethyltoluene	ND	6.5 ± 2.1	135.0 ± 2.1	acetone	ND	209.4 ± 31.5	3238.0 ± 123
n-propylbenzene	ND	4.8 ± 0.5	ND	2-butanone	271.3 ± 17.3	296.0 ± 61.2	1911.1 ± 13.6
naphthalene	375.8 ± 35.4	20.3 ± 1.4	ND	ethyl acetate	ND	ND	3260.4 ± 40.6
styrene	ND	6.25	210.0	propyl acetate	ND	173.1 ± 5.9	ND
Dichlorodifluoromethane	ND	1.9 ± 0.5	ND	methyl methacrylate	22.7 ± 1.6	ND	ND
methyl chloride	ND	ND	208.0	ethanol	21069 ± 103.1	78147.2 ± 134	50710.0 ± 178
trichlorofluoromethane	ND	3.3 ± 0.7	ND	propionic acid	4648.2 ± 241	ND	16110.2 ± 42
chloroform	ND	4.2	ND	isobutyric acid	3927.4 ± 79.6	ND	ND
dichloromethane	ND	26.0 ± 0.5	505.0 ± 17	butyric acid	6475.3 ± 45.7	ND	16354.5
tetrachloroethylene	3.3 ± 4.3	9.3 ± 1.4	61.0 ± 11.2	isovaleric acid	11601.6 ± 11	17312.1	ND
1,2-dichloroethane	ND	3.9 ± 0.5	ND	valeric acid	14104.5 ± 867.5	21292 ± 165	ND
1,4-dichlorobenzene	ND	35.6 ± 6.1	ND	pyridine	ND	ND	2.1 ± 0.1
carbon disulphide	ND	3.5	ND				

ND: not detected.

Table 4. the potential odorants with an OAV > 0.1 in each unit.

ES			DW			BW		
Compounds	C_{max} (μg m^{-3})	OAV	Compounds	C_{max} (μg m^{-3})	OAV	Compounds	C_{max} (μg m^{-3})	OAV
valeric acid	14981	404897	valeric acid	21457	579941	ethanol	50888	97
isovaleric acid	11612	148872	isovaleric acid	17312	221950	styrene	210	6
butyric acid	6521	34323	ethanol	78281	150	ethyl acetate	3301	4
isobutyric acid	4007	2671	2-butanone	4	0.2	pyridine	2.2	0.1
propionic acid	4889	858	propyl acetate	179	0.2			
ethanol	21172	40						

Pyridine can produce Maillard reaction with other substances (Chansataporn *et al.*, 2018), which will affect the aroma of cigarette smell.

In combination with the characteristics of the typical potential odor pollutants and odor types from the cigarette factory, the odor wheel chart of the cigarette factory was obtained, as shown in Fig. 5. The determination of the hedonic tone refers to the research of Li *et al.* (2019).

The inner circle of the wheel represents the hedonic tone of odor, divided into pleasant, unpleasant and neutral. The outer circle represents the variation of each of the major odor categories, for example, the primary odor in the cigarette factory was sour, wine, fragrant, fruity, medicinal, spicy. The outermost layer of specific chemicals associated with each sub-group represents these sub-categories. The odor wheel is dynamic and evolves according to the specific odor (Suffet and Rosenfeld, 2007). The odor wheel diagram is an effective way to describe odor problems. It links sensory information with possible odor substances, which will improve the accuracy of odor identification, and help the factory to select suitable treatment technologies.

4 CONCLUSIONS

In addition to enriching the existing literature on the odor compound emissions from cigarette factory, this research should be the first study aimed at determining an acceptable level of exposure odor concentration for industrial sources. The results of this study indicate a strong relation between modeled odor exposure and odor annoyance from cigarette factory. The

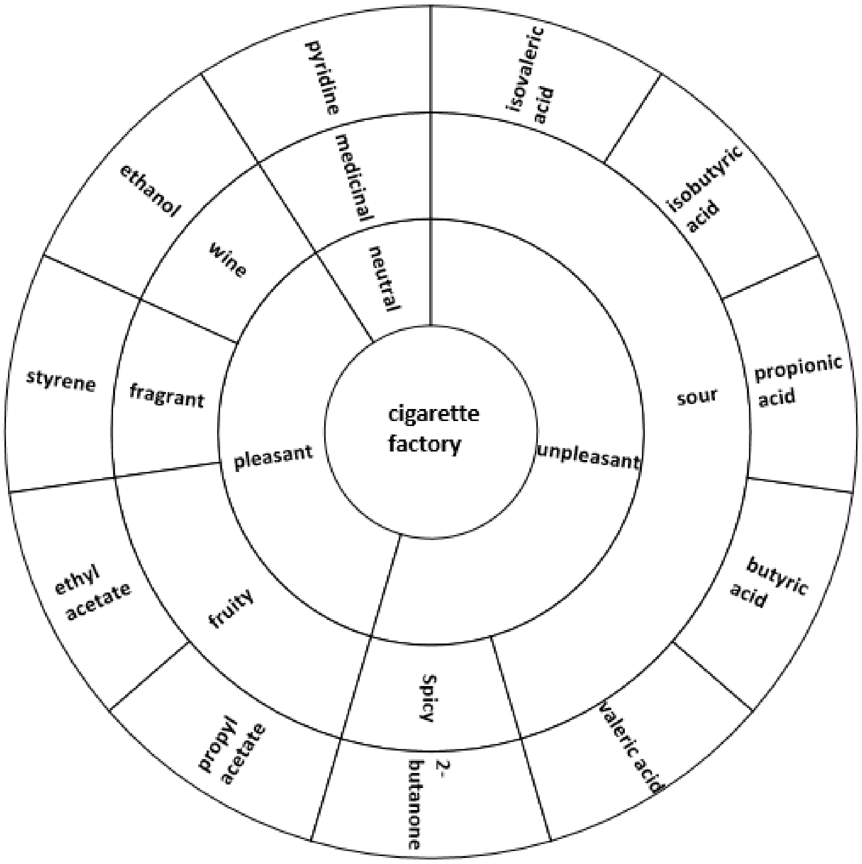

Fig. 5. The odor wheel of cigarette factory.

exposure-response relationship between the percentage of highly annoyed people (HA%) and the 98 percentile of odour concentrations ($C_{98.0,\ 1\text{-hour}}$) was established, and $C_{98.0,\ 1\text{-hour}}$ = 4 OU m^{-3} was identified as the acceptable level for the cigarette production. The typical odor pollutants for the cigarette factory were ethyl acetate, styrene, pyridine, valeric acid, isovaleric acid, butyric acid, isobutyric acid, propionic acid, ethanol, propyl acetate, 2-butanone. Combined the chemical composition and odour character of each substance, it's the first time to establish the odour wheel of cigarette factory. The odor wheel of cigarette factory can be used to characterize and manage onsite malodorous.

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