CHEMICAL ENGINEERING TRANSACTIONS
VOL. 54, 2016

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Selena Sironi, Laura Capelli

ISBN 978-88-95608-45-7; **ISSN** 2283-9216

Evaluation Index System of Odour Pollution for Kitchen Waste Treatment Facilities in China

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This paper was based on the survey of odour emission characteristics of Chinese kitchen waste treatment facilities and olfactory thresholds of 40 odorants which were measured by State Environmental Protection Key Laboratory of Odor Pollution Control. An evaluation index system of odour pollution which is composed of theoretical odour concentration, odorant indicators and theoretical odour intensity was established for kitchen waste treatment facilities. Xining kitchen waste treatment facilities were chosen as the typical object for applying to this system. Finally, methyl mercaptan, ethyl sulfide, sulfuretted hydrogen, ethyl alcohol, α–pinene, limonene, and dimethyl disulfide were considered as the primary indicators in this enterprise. In addition, the value of theoretical odour concentration and theoretical odour intensity are 59832.13 and 5. This system set up theoretical foundation for the prediction, simulation and control of odour pollution and provide technical support for mastering the public impact degree of odour pollution.

1. Introduction

The output of municipal solid waste is increasing rapidly with the rapid growth of economy and the accelerated process of urbanization. The output of Kitchen waste which is accounts for almost 50% in municipal solid waste has exceeded 90,000,000 tons per year in China (Zhang et al., 2012). At present, there are lots of research about kitchen waste treatment facilities emission characteristic, but the research on evaluation index system of odour pollution still is not so much and it has not yet been formed into a scientific evaluation method (Rumsey et al.,2012; Scaglia et al., 2011; Agus et al., 2012; Zhang et al.,.2011). In the current study, Wang Pan has studied and detected 66 kinds of odorants on the emission characteristic of the main process for kitchen waste treatment facilities, and the value of H_2S concentration was higher than its olfactory threshold in every sampling point (Wang et al.,2014). Schuetz and Dincer detected 37 kinds and 53 kinds of odorants in the domestic waste landfill, respectively (Schuetz et al., 2003; Dincer et al., 2006).
There are great difficulties in evaluation system of odour pollution because the species of odorants are multitudinous and the impacts of odorants are different (Phan et al., 2012; Liu, et al., 2013). This research established an evaluation index system of odour pollution for kitchen waste treatment facilities. On one hand, it could set up theoretical foundation for the assessment, monitoring, modeling and control of related facilities odour pollution. On the other hand, it also could provide technical support for the environmental management department to master the public impact degree of odour pollution.

2. Odour threshold of typical odorants

Based on the odour emission characteristics survey in Chinese kitchen waste treatment facilities and the existed analytical techniques, 40 typical odorants were selected to measure their odour threshold values by Triangle Odour Bag Method, the measurement results were shown in table 1. In the past, Chinese odour threshold data have never been measured and Japanese odour threshold data were usually applied to related studies because both China and Japan use Triangle Odour Bag Method as national standard method. It shows that the Chinese odour threshold values of 40 odorants are very different compared with the corresponding Japanese odour threshold data (Nagata, 2004; Nagata, 2003) from table 1.

Table 1: Measurement results of odour threshold of 40 typical odorants (volume fraction) 10^{-6}

Odorants	Chinese odour threshold	Japanese odour threshold	Odorants	Chinese odour threshold	Japanese odour threshold
Hydrogen sulfide	0.0012	0.00041	Acetaldehyde	0.018	0.0015
Methanthiol	0.000067	0.000070	Propionaldehyde	0.016	0.0010
Dimethyl sulfide	0.0020	0.0030	Butyraldehyde	0.00085	0.00067
Dimethyl disulfide	0.011	0.0022	Isobutyraldehyde	0.00045	0.00035
Carbon disulfide	0.17	0.21	N-Valeraldehyde	0.0016	0.00041
Carbonyl sulfide	0.46	0.055	Isovaleraldehyde	0.00030	0.00010
Ammonia	0.30	1.50	Isoprene	0.025	0.048
Trimethylamine	0.00090	0.000032	Limonene	0.016	0.038
Styrene	0.034	0.035	α–Pinene	0.0010	0.018
Toluene	0.098	0.33	β–Pinene	0.50	0.033
Ethylenzene	0.018	0.17	Ethanol	0.10	0.52
m-xylene	0.28	0.38	Isopropanol	3.90	26.00
o-xylene	0.091	0.041	1-Butanol	0.066	0.038
p-xylene	0.12	0.058	Isobutanol	0.014	0.011
1,2,4-trimethyl benzene	0.30	0.12	Acetone	7.20	42.00
Propionic acid	0.0087	0.0057	2-Butanone	0.17	0.44
N-Butyric acid	0.0013	0.00019	Methyl isobutyl ketone	0.11	0.17
Isobutyric acid	0.0031	0.0015	Ethyl acetate	0.84	0.87
N-Valeric acid	0.0025	0.000037	Butyl acetate	0.0079	0.016
Isovaleric acid	0.00016	0.000087	Isobutyl acetate	0.29	0.0080

3. Evaluation Index System of Odour Pollution

Odour concentration and odour intensity which must be gotten by sampling on the spot and measuring in the laboratory can directly reflect perceived degree of people, but it is difficult to be directly applied to forecast, simulate and evaluation of odour pollution. Therefore, an evaluation index system of odour pollution which consists of the theoretical odour concentration and odorant indicators and theoretical odour intensity was proposed to be set up basing on odour activity value (OAV) of odorants which have linear relationship with odour threshold value.

3.1 Theoretical odour concentration

3.1.1 Calculation method of theoretical odour concentration

Theoretical odour concentration basing on OAV is a comprehensive odour evaluation index of odour pollution. The calculation method of theoretical odour concentration combines combined model method and the maximum model method, the method is as follows:

(1) For all the odorants in a certain sample recording *m*, determine the odorants concentration as C_i, respectively;

(2) Calculate the OAVs of every odorant, D_i

(3) Ignore some odorants whose OAVs are less than 1. Because a large number of studies showed that these odorants almost could not cause odour pollution;

(4) Arrange the odorants whose OAVs are greater than 1 in descending order, denoted by D_1~D_m,

(5) Divide D_{n+1} by D_n till the value less than 5%

(6) Choose D_1~D_n and add them together, then the sum is the value of theoretical odour concentration

$$\mathrm{OU_T} = \sum_{i=1}^{n} D_i \tag{1}$$

3.1.2 Verify the calculation method of theoretical odour concentration

The continuous pilot-scale two-phase anaerobic fermentation experiment that active volume of acidification-phase reactor is 12L and active volume of methane-phase reactor is 30L were conducted under mesophilic condition (35℃), using kitchen waste as fermentation substrates. This experiment selected 4 kinds of feed quantities that were 0.5 L/d, 1.0 L/d, 1.5 L/d and 2.0 L/d and the time period of every feed quantity lasted at least 2 weeks (Huang et al., 2014). The gases that totally included 44 samples generated in the methanogenic stage were sampled at different time segments, odour concentration and odorants concentration were analysed to verify the calculation method of theoretical odour concentration. SPSS software were used to analyse the correlation between the theoretical odour concentration and corresponding measured odour concentration. Calculated Pearson correlation coefficient was 0.902 that means the trend consistency between theoretical odour concentration and measured odour concentration are high, the trend graph was shown in Figure 1.

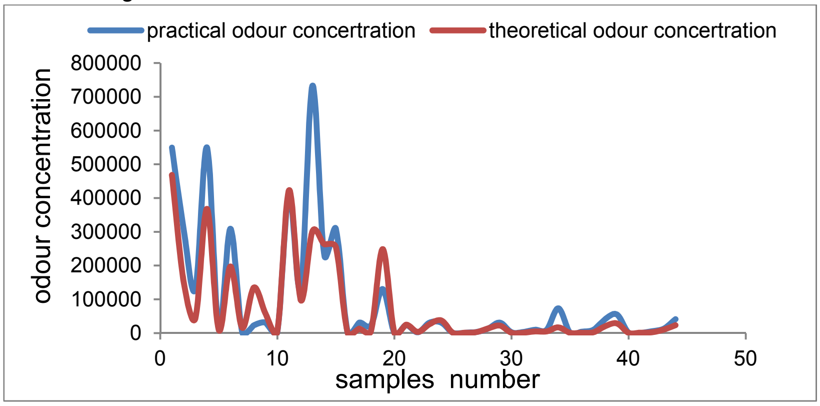

Figure 1 theoretical odour concentration compared with the measured odour concentration trend line

3.2 Odorant indicators

Odour pollution contribution that is shown by OVA, odorants concentration, health toxicity are the important aspects in the assessment of odour pollution. Therefore, the odorant primary indicators that are OAVs and the odorant auxiliary indicators that are odorants concentration and health toxicity were set up in order to comprehensively master the odorants pollution status.

3.2.1 Odorant primary indicators

For a simple sample, use 1~5 step calculation methods of theoretical odour concentration, then select D_1~D_n as the odorant primary indicators. For a set of kitchen waste treatment facilities, the screening method is as follows:

(1) Use the mentioned method to determine odorant primary indicators in simple samples;

(2) Count the frequency of odorant primary indicators in all samples, arrange them in descending order, then select the top *j* high frequency odorants (usually *j*≤6, in a certain situation *j*≤10) as the odorant primary indicators in this set of facilities.

3.2.2 Odorant auxiliary indicators

Odorant auxiliary indicators include odorant concentration indicators and health toxicity indicators. The screening method of odorant concentration indicators is similar to odorant primary indicators. For a simple sample, odorant concentration indicators are selected by the top 10 odorants concentration. For a set of kitchen waste treatment facilities, top *j* high frequency odorants by odorant concentration (usually *j*≤6, in a certain situation *j*≤10) are selected as the odorant concentration indicators.

For a simple sample, health toxicity indicators were screened by "National Pollutant Environmental Health Risk List". For a set of kitchen waste treatment facilities, top *j* high frequency odorants by health toxicity (usually *j*≤6, in a certain situation *j*≤10) are selected as the odorant concentration indicators.

3.3 Theoretical odour intensity

This study analysed 679 odour samples through standard odour intensity measurement and odour concentration measurement in order to establish the quantification relationship of odour sensory evaluation. The samples were collected from more than 20 enterprises which were composed of more than 10 typical industries of odour pollution, including sewage treatment, garbage disposal, perfume and fragrance, coatings and so on. The measurement method of Japanese 6 level intensity was used to determine odour intensity. Intensity-concentration relationship formula that is $Y=0.5893 \ln X - 0.7877$（$R^2=0.9965$）was calculated according to the odour concentration value and corresponding intensity value. The logarithmic relationship of this formula matched with Weber—Fechner Law. The odour concentration zone corresponding odour intensity was proposed based on odour sense measurement particularity. Odour intensity 0 level corresponds to <10 odour concentration, 1level corresponds to 10~49, 2 level corresponds to 49~234, 3 level corresponds to 234~1318, 4 level corresponds to 1318~7413, 5 level corresponds to >7413. Theoretical odour intensity is more suitable to react public olfaction sense.

4. The application example of evaluation index system of odour pollution in kitchen waste facilities

This study selected Xining kitchen waste enterprise as an object basing on the comprehensive investigation for kitchen waste enterprises in China. Xining kitchen waste enterprise was founded in 2006 and was awarded as" An Example of China Habitat Environment Prize" for the first time in this field by MOHURD. This enterprise uses the physical and biological treatment technology and its maximum processing capacity is 200 tons. The facilities of this enterprise can automatic classify the kitchen waste and harmlessly process them, then the part of solid waste can be used to produce high protein feed, the part of liquid waste can be used to produce methane by anaerobic fermentation, and the part of grease can be used to produce quite clean biodiesel. At last, the odour gas which are gathered from all the technological facilities by draught fan are processed to standard gas by biological deodorization.

6 monitoring spots that are sorting facility, solid-liquid separation facility, crushing facility, storage container, drying facility and odour gas receiver facility were sampled in Xining kitchen waste enterprise in spring 2013. Gas samples were collected by SOC-01 type sampling equipment, stored in special plastic bags and then sent for analysis within 24 hrs. These samples were collected in every 2 hrs for 4 times per day and the sampling time period lasted 2 days, so the amount of total samples is 48. The determination methods of VOCs are EPA TO-15.

4.1 Odour pollution evaluation for simple sample

Take a sample from solid-liquid separation facility of Xining kitchen waste enterprise as an example, the determined values of odorant concentration and odour threshold values are shown in table 2. In this sample, 37 kinds of odorants were detected, arranged their OAVs whose greater than 1 in descending order, then divided the adjacent OAVs and the calculation results were all less than 5%. So the odorant primary indicators were ethyl sulfide, acetaldehyde, ethyl alcohol, methyl mercaptan, butyraldehyde, a-pinene, hydrogen sulfide, dimethyl disulfide, dimethyl sulfide, limonene, propionaldehyde and ammonia. Added this OVAs together, the value of theoretical odour concentration was 1494.According to the formula of section 3.3, the value of theoretical odour intensity was 3.5. Odorant concentration indicators were selected by the top 10 odorants concentration, they were Butane, propane, methylene chloride, carbon tetrachloride, propylene, trichloroethylene, chloroform, 2, 3-dimethyl pentane, acetone and nonane. Health toxicity indicators were screened by "National Pollutant Environmental Health Risk List", they were toluene, methylene chloride, chloroform, xylene, ethylbenzene, benzene and o-xylene.

Table 2: Odorants concentration values and OAVs from a sample of solid-liquid separation facility in Xining kitchen waste enterprise

No.	Odorants	Concentrations (mg/m^3)	Odour thresholds (mg/m^3)	OAVs
1	Ethyl sulfide	0.055	1.33E-04	416
2	Acetaldehyde	12.24	3.54E-02	346
3	Ethyl alcohol	68.84	2.68E-01	257
4	Methyl mercaptan	0.029	1.44E-04	202
5	Butyraldehyde	0.45	2.74E-03	163
6	a -pinene	0.25	6.08E-03	42
7	Hydrogen sulfide	0.048	1.83E-03	27
8	Dimethyl disulfide	0.24	9.25E-03	25
9	Dimethyl disulfide	0.043	5.55E-03	8
10	Limonene	0.61	9.73E-02	6
11	Propionaldehyde	0.090	4.15E-02	2
12	Ammonia	0.24	2.28E-01	1

4.2 Odour pollution evaluation for Xining kitchen waste enterprise

This study selected 8 samples from odour gas receiver facility which can represent odour emission of the whole workshop. Odorant primary indicators and odorant auxiliary indicators were gotten according to the screening method. They were shown in table3.

Methyl mercaptan, ethyl sulfide, hydrogen sulfide, ethyl alcohol, a-pinene, limonene, dimethyl disulfide, dimethyl sulfide were selected as odorant primary indicators in this enterprise by the frequency of OAVs in 8 samples. These odorants which had higher emission frequency and odour pollution contribution can be considered as the important odorants for monitoring guidance in Xining kitchen waste enterprise. Ethyl alcohol, limonene, a-pinene, β-pinene and so on were selected as odorant concentration indicators by the

frequency of odorants concentration. These odorants had higher emission frequency and emission concentration, but they had different contributions for odour pollution because of the different odour threshold values. In addition, a few toxic and harmful substances which are included in "National Pollutant Environmental Health Risk List" were detected frequently, such as methylbenzene, dichloromethane, benzene, m-Xylene and so on. Above all, sulfide, terpene, ethyl alcohol, ethyl acetate and benzene series were the most concerned odorants in Xining kitchen waste enterprise.
This study respectively calculated all the theoretical odour concentration values and theoretical odour intensity values in the 8 samples, and then respectively selected the maximal values as the evaluation consequences. The maximal theoretical odour concentration was 59832 and the maximal theoretical odour intensity was 5. It shows this set of facilities had high odour pollution level which can provide scientific support for the degree of odour pollution treatment in Xining kitchen waste enterprise.

Table 3: Odorants primary and auxiliary indicators in Xining kitchen waste enterprise

No.	Odorants Primary indicators	Odorant concentration indicators	Health toxicity indicators
1	Methyl mercaptan	Ethyl alcohol	Methylbenzene
2	Ethyl sulfide	Limonene	Dichloromethane
3	Hydrogen sulfide	a-pinene	Benzene
4	Ethyl alcohol	β-pinene	m-xylene
5	a-pinene	Propylene	o-xylene
6	Limonene	Ethyl sulfide	p-xylene
7	Dimethyl disulfide	Dimethyl disulfide	Ethylbenzene
8	Dimethyl sulfide	Dimethyl sulfide	
9		Ethyl acetate	

5. The shortage of odour pollution evaluation index system

This study proposed an evaluation index system of odour pollution that can provide a quantitative and scientific method for modelling and evaluating odour pollution for kitchen waste treatment facilities. However, there are some problems to discussion in this evaluation index system.
The calculation method of theoretical odour concentration synthesized the maximum model method and combined model method, and it neglected the cooperation effect and antagonism effect among different odorants. However, some studies shown that there are no reliable scientific regulations and conclusions for this two effects because the regulations of them are too complicated. So it is acceptable that the maximum linear superposition was awarded as the basic assumption in this study.
There are some differences between theoretical odour concentration which was calculated from this study and practical odour concentration which was determined by triangle odour bag method of national standard (GB/T 14675-93). There was a high correlation between the two methods in the experiment from section 3.1, but theoretical odour concentration generally lower than practical odour concentration. For one thing, there are differences between laboratory samplings and field samplings, the laboratory samples can be determined immediately, but the field samples may produce other chemical reactions or reduce some substances because of longer transportation time period. For another thing, the determination methods of VOCs are EPA TO-15 which can quantify 115 kinds of materials, but there is no way to guarantee all the odorants in kitchen waste can be detected.

6. Conclusions

On the basis of odour thresholds, an evaluation index system of odour pollution was established for kitchen waste treatment facilities. The index system mainly includes theoretical odour concentration and its calculation method, theoretical odour intensity with its calculation method and screening method of odorant indicators.
Monitoring results of odour pollution can be analysed by using this index system in Chinese kitchen waste enterprise so that odour pollution level and odorant indicators can be confirmed clearly. This research and the corresponding index system provide a quantitative and scientific method for modelling and evaluating odour pollution from kitchen waste treatment facilities.

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