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Evaluation Method of Odor Pollution in Urban Sewage Treatment Plants Based on Electronic Nose Technology

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In order to track the odor source and odor fingerprint characteristics of the sewage treatment plant, this study makes quantitative analysis and evaluation. Based on the advantages of odor sensory evaluation and odor source identification of electronic nose technology, this study focuses on the odor pollution of urban sewage treatment plants. This study firstly introduces the principle and application of electronic nose technology, then takes an urban sewage treatment plant in Wuhan as the sampling point and the (Malodorous Volatile Organic Compounds (MVOCs) in the odor pollution as the research object; evaluates the fingerprint characteristics of single component in MVOCs with electronic nose sensor, and tests the quantitative evaluation relationship of odor. Finally, the contributions of each pollution source to the odor concentration in each sewage treatment plant are analyzed through forecasting the odor in the surrounding environment. The theoretical research and practical application of electronic nose technology in odor evaluation has a forward-looking guiding significance for odor detection and management of sewage treatment plants in the future.

1. Introduction

Urban sewage treatment plants are the treatment centers of urban living and production sewage. Due to the complex chemical composition of sewage, it is inevitable to produce various malodorous gases after a series of complex reactions. The odor pollution of volatile organic compounds is the most serious (Belhaj et al., 2016). At the same time, with the expansion of urban population and the expansion of urban living space, sewage treatment plants that were originally far away from urban areas are gradually surrounded by urban residents (Kim et al., 2012). The detection, evaluation and treatment of odor gas in urban sewage treatment plants is an urgent task. In order to ensure the quality of life and health of residents, the research on odor pollution has become a hot spot (Ye et al., 2014).

Rich achievements have been made in the measurement and evaluation of odor pollution at home and abroad. Some scholars have studied the odor waste gas of sewage treatment plants by using chemical analysis method and Triangle Odor Bag Method, and introduced the trial scope of the detection method (Nolan, 2010). Some scholars have evaluated the concentration of each component of MVOCs and the concentration of malodor quantitatively and found that there is a linear relationship between the concentration of MVOCs and the concentration of malodor at a certain interval (Ough and Stone, 2010). In the research of foreign urban sewage treatment plants, the electronic nose technology has realized the better qualitative identification of unknown odor gas samples (Wu et al., 2015; Wang and Zhang, 2018). The traditional testing method is still used in the evaluation of odor gases in China and there are some defects in the measuring accuracy and range. This study draws on the experience of domestic and foreign researches to develop a synchronization study of the concentration of odor gas and the fingerprint characteristics of odor gases (Röck et al., 2008).

The electronic nose technology is mainly used to detect three single odor gases (DMS, DMDS and TMA) or mixed odor gas in MVOCs. Appropriate electronic nose sensors and analysis methods are selected to realize the identification and quantitative evaluation of typical odor gases in urban sewage treatment plants, and determine the main pollution process of urban sewage treatment plants.

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2. Introduction of Electronic Nose Technology and Experimental Sampling

2.1 Electronic nose technology

The electronic nose is an odor sensory method simulating the process of human olfactory formation. Its composition mainly includes a gas sensor array and a data analyzer. The gas sensor array simulates the olfactory reaction cells to form the overall information and fingerprint information of the test gas, and the data analyzer is similar to the human brain to distinguish the fingerprint characteristics of the test gas and establish a memory database after identification (Wilson and Baietto, 2009).
Electronic nose technology has been developed for more than 20 years since it was formally put forward in 1994, and widely used in food industry, fine chemical industry, tobacco industry, medicine, environmental safety and detection (Sysoev et al., 2007). In terms of environmental detection, the electronic nose technology has begun to replace the artificial nose odor detection gradually due to the toxic and harmful substance such as SO2, H2S, CH4 and VOC contained in the domestic production waste gas. It carries out the right evaluation and control of environmental pollution based on the fingerprint characteristic and concentration of odor gases (Dutta et al., 2003).

2.2 Sewage treatment plant sampling

The experimental research object selected in this study is a sewage treatment plant in Wuhan with the total treatment capacity of 1.4 ×106m3/d. It mainly treats domestic sewage, serving a population of 3.4 million people. The main buildings of the plant include grid, sand tank, aeration tank, biochemical pool, sludge concentration tank and dewatering plant room (Fenner et al., 1999; Sabeen et al., 2018, Characteristics of the effluent wastewater in sewage treatment plants of malaysian urban areas, Chemical Engineering Transactions, 63, 691-696 DOI:10.3303/CET1863116). The basic technological process of sewage treatment is that sewage enters the factory through the outgoing pump, removes larger suspended substances and particles through the grid, transfers to the sand tank through the centrifugal pump, enters the biological reaction treatment stage, and then is discharged after the secondary treatment and disinfection.

2.3 Experimental content

2.2.1 External field MVOC concentration detection experiment

External field inspection began in September 2017, and fixed-point sampling and inspection are carried out on Grid 3, Horizontal Sedimentation Tank 4, A-stage Aeration Tank 5, Biochemical pool 6, Concentration Tank 7 and Sludge Dewatering Room 8 of the sewage treatment plant. Sampling sample record format: point + date + time.

2.2.2 Simulation experiment of chemical composition analysis

According to the Emission Standard for Odor Pollutants issued by the State, this study takes the main chemical constituents of MVOC such as dimethyl sulfide (DMS), dimethyl disulfide (DMDS) and trimethylamine (TMA) as research objects. The electronic nose technology is used to quantitatively evaluate the odor pollution.

2.4 Electronic nose analysis method

The electronic nose technology is used to evaluate the chemical composition and concentration of the odor gas. The analytical instrument is the aFOX2000 electronic nose of Alpha M.O.S. The electronic nose is equipped with 6 electronic nose sensors: T30/1, P10/1, P10/2, P40/1, T70/2 and PA/2 (Sannmann et al., 2013). Table 1 shows the performance of the sensor.

Table 1: The property of sensors

Array serial number	Sensor name	Property	Reference substance
1	T30/1	Sensitive to organic compounds	Organic compounds
2	P10/1	Sensitive to combustible gases	Combustible gas
3	P10/21	Sensitive to flammable gases	Flammable gases
4	P40/1	Sensitive to gases with strong oxidizing power	Gases with strong oxidizing power
5	T70/2	Sensitive to volatile organic compounds	Volatile organic compounds
6	PA/2	Sensitive to toxic gases	Toxic gases

According to the flow rate of 1L/min and with the injection time of 15s, a single sample is analyzed repeatedly for 5 times by passive injection. After the sensor is detected, the odor signals are classified by data preprocessing and pattern recognition method information processing (Heer et al., 2013). Principal Component Analysis (PCA) optimizes and screens electronic nose sensors by studying the differences in samples of odor sources. The model established by eliminating the outliers and optimizing the sensor array can effectively reflect the difference between the samples of each source discharge outlet, with the DI value reaching 99.035%, and has better detection accuracy. Therefore, this study uses PCA method to evaluate the difference of odor gas concentration at each point of urban sewage treatment plants.

3. Odor Simulation Test and Quantitative Evaluation Based on Electronic Nose

3.1 Fingerprint characteristics of odor gases of single-component MVOC

Figures 1 to 3 show the corresponding change curves of three odorous VOCs (DMS, DMDS and TMA) at different concentrations.

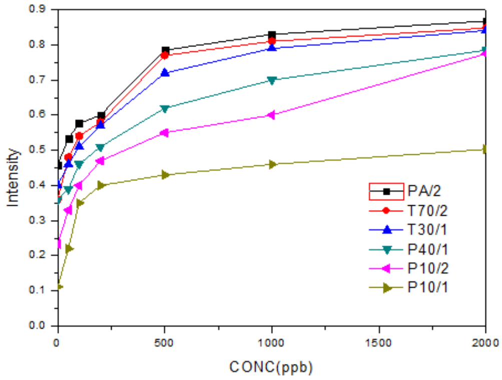

Figure 1: Response curve of DMS in different concentrations

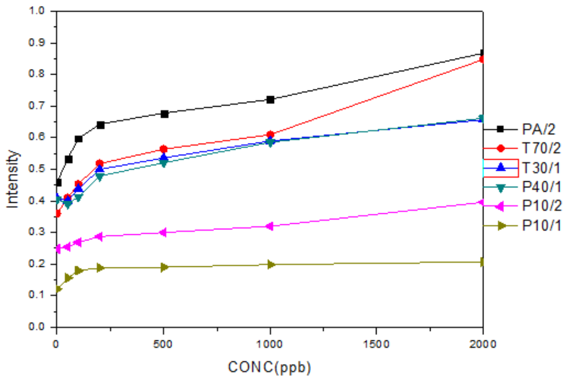

Figure 2: Response curve of DMDS in different concentrations

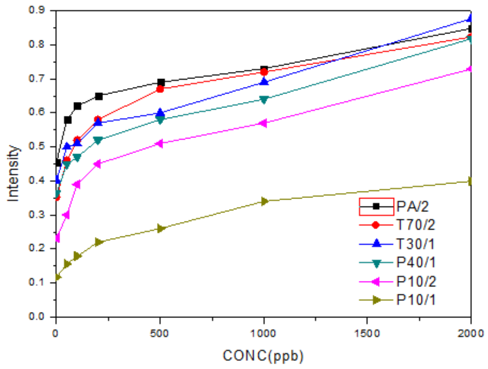

Figure 3: Response curve of TMA in different concentrations

It can be seen from the figure that the electronic nose sensor has higher sensitivity to MVOC components. The overall sensor response sequence is TMA>DMS>DMDS. The corresponding curve of the electronic nose sensor changes more obviously when the concentration is lower but gently in areas with higher concentration (Yamada et al., 2007). Table 2 shows the response change of each sensor.

Table 2: The intensity variation of each sensor

Sample	T30/1	P10/1	P10/2	P40/1	P70/2	PA/2
DMS	0.401-0.841	0.118-0.511	0.223-0.775	0.356-0.781	0.359-0.849	0.456-0.857
DMDS	0.409-0.656	0.121-0.205	0.238-0.389	0.403-0.662	0.332-0.635	0.497-0.739
TMA	0.401-0.876	0.114-0.389	0.231-0.728	0.358-0.816	0.349-0.813	0.448-0.837

From the table, T70/2 and P10/2 have the largest changes, among which T70/2 is sensitive to sulfur-containing MVOC of DMS and DMDS, and P10/2 is sensitive to TMA.

3.2 Quantitative evaluation of MVOC component content and odor in various process units of the sewage treatment plant

There must be a correlation between the chemical components of odor gases and the fingerprint characteristics of odor gases in each process unit of the urban wastewater treatment plant. The quantitative evaluation model is established by using symbolic MOVCs of DMS, DMDS and TMA, combining the odor gas fingerprint characteristics of samples at each sampling point and selecting T70/2 according to the sensitivity of the sensors.

Table 3: The qualitative evaluation model of each processing unit

Process unit	Fitting equation	Correlation coefficient (R2)
Grating	y=0.0712Ln(x)+0.3319	0.9836
Detritor	y=0.0498Ln(x)+0.4326	0.8537
Aeration tank	y=0.0353Ln(x)+0.4823	0.8928
Biochemical pool	y=0.0782Ln(x)+0.2859	0.9792
Sludge thickening tank	y=0.0969Ln(x)+0.221	0.9056
Dehydration room	y=0.0862Ln(x)+0.0913	0.996

The data in the table show that the correlation coefficient of the evaluation model based on the symbolic MVOC content of each unit of the municipal wastewater treatment plant and the fingerprint characteristics of the electronic sensor is above 85%. Among them, the correlation among sludge dewatering room, biochemical pool and grid is very significant, reaching 97% or more, indicating that the correlation between the concentrations and odor of DMS, DMDS and TMA in three sampling points is obvious and that the concentration of MVOCs in the three sampling points is the highest in the process of urban sewage treatment, with the most serious odor pollution.

3.3 Identification and evaluation of mixed component odor gas

The recognition rate of electronic nose technology for single component odor gas is very high, and the recognition rate reaches 100% in the experiment. Then, the gas composition in the surrounding environment of the urban sewage treatment plant is very complex. Therefore, this study takes MVOC of DMS, DMDS and TMA as the representative, which is detected after mixing two by two, and the corresponding results are obtained by Principal Component Analysis. The accuracy of identification and evaluation of mixed component odor gas by electronic nose technology is verified by the analysis results.

Three groups of experimental objects, at the scale of 0:10, 1:9, 2:8, 3:7, 4:6, 5:5, 6:4, 7:3, 8:2, 9:1 and 10:1, are DMS: DMDS, DMS: TMA, and TMA: DMDS. The false rate of various samples of mixed gas as shown in Table 4 is obtained.

The false rate of identifying two-component gas by the electronic nose technology is 5.45%, 5.45% and 7.27% respectively, which shows that the electronic nose technology has a good effect on the identification and evaluation of mixed gas. At the same time, it can be seen from the data in the table that when the concentration ratio of the two components is similar, the false rate is higher, which is because the fingerprint characteristics of odor gas is more complex and prone to be false under the condition of equal ratio mixing.

In order to evaluate the surrounding gas environment of the urban sewage treatment plant, four samples are randomly selected from the sampling sample of each process flow, totally 24 samples, and the qualitative analysis results of 100% accuracy and the quantitative analysis result of 77.89% -100% are obtained by electronic nose technology. The results show that the electronic nose sensor and the principal component analysis method have a good effect on the evaluation of odor gases. The evaluation results show that the electronic nose model in biochemical pool and grid has the best evaluation effect and the deviation from the actual measurement value is the smallest. The prediction result is consistent with that of the two-component MOVC, which shows that the biochemical pool and grid are the regions with the largest odor contribution in the sewage treatment plant.

Table 4: The False rate of mixed samples

Mixture	Proportion										
DMS: DMDS	10:0	1:9	2:8	3:7	4:6	5:5	6:4	7:3	8:2	9:1	0:10	Total
False positive rate	0	20	0	0	0	20	20	0	0	0	0	5.45
DMS: TMA	10:0	1:9	2:8	3:7	4:6	5:5	6:4	7:3	8:2	9:1	0:10	Total
False positive rate	0	20	0	0	0	20	20	0	0	20	0	7.27
TMA: DMDS	10:0	1:9	2:8	3:7	4:6	5:5	6:4	7:3	8:2	9:1	0:10	Total
False positive rate	0	20	0	0	0	20	20	20	0	0	0	7.27

4. Conclusions

With the expansion of urban scale, the urban sewage treatment plants in the remote suburbs are gradually surrounded by residents, and the contradiction between the odor gas and the quality of life of the residents is becoming more and more serious. The application of traditional odor evaluation method has some limitations in odor evaluation of urban sewage treatment plants, especially for the detection of toxic and harmful gases. In order to better evaluate the odor gases in urban sewage treatment plants, the electronic nose technology has been gradually introduced to detect and evaluate the odor gases in China. This study firstly introduces the electronic nose technology and its application, then evaluates the odor pollution of urban sewage treatment based on the electronic nose technology, and takes a sewage treatment plant in Wuhan as the research object to sample each process and carry on the experiment research, with the typical MVOC gas as the representative to carry on the quantitative evaluation and analysis. The main conclusions and significance of this study are as follows:

(1) Biochemical pools and grids are the processes in which MVOC gas components contribute the most to urban sewage treatment plants.

(2) The fingerprint characteristics of odor components and sensory odor of each processing unit are preliminarily studied. The quantitative relationship between chemical components and malodor based on the electronic nose sensor has a higher correlation (R2 > 85%).

(3) The study is of great promoting significance to the application of electronic nose technology in sewage treatment detection and evaluation in China.

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