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Odor Recognition and Control Measures of Harmful Substances in Drinking Water Sources in Irrigated Area of Yellow River

Wei Wang[a,b]*, Jianxia Chang[a], Shuya Wang[c]

[a]Xi'an University of Technology, Xi'an 710048, China

[b]Xiaolangdi Project Construction & Management Center Ministry of Water Resources, Zhengzhou 450000, China

[c]Henan Institute of Science and Technology, Xinxiang 453600, China

fairunicorn@163.com

At present, the pollution of drinking water sources in many areas of China is becoming more and more serious, which has a great impact on people's health. It is especially necessary to effectively identify the odors in drinking water sources and to master the removal technologies of odors and harmful substances in water sources. This paper takes the irrigated area of Yellow River as an example to study the identification of drinking water odors and the control of harmful substances. The results show that the total phosphorus and total nitrogen concentrations in drinking water of the irrigated area of Yellow River are basically maintained between Class II and Class III, and the ammonia nitrogen concentration changes with seasons, and there are big differences. In drinking water sources of the irrigated area of Yellow River, odorous substances with higher content mainly are: 2-methylisoborneol, β-cyclocitral, β-ionone, and geosmin. In recent years, the content of major odor substances has decreased significantly, indicating that the quality of drinking water sources is improving year by year. The highest contribution to the total organic carbon (TOC) concentration removal rate in the water sample is sand filtration, and the removal rate is 21%. The effect of ozone oxidation on TOC removal is not obvious.

1. Introduction

With the improvement of economic development level and the continuous improvement of people's material living standards, the quality requirements of drinking water for the general public are also constantly improving. However, the pollution (Yang et al., 2018) problem of drinking water sources in many areas of China is becoming more and more serious, which has a great impact on people's daily life and physical health (Bayoumi et al., 1991). Among these problems, the problem of odors in drinking water sources is one of the problems that happens frequently. Common odors in drinking water sources include fish-like smell, rotten smell, grass-wood smell, chlorine smell, earthy-musty smell, etc., the main substances are: 2-methylisoborneol, heptyl diene aldehyde, geosmin, etc. (Lee et al., 2008). It is especially necessary to effectively identify the odors in drinking water sources, master the water sources odor and harmful substances removal technologies, thereby effectively reducing the occurrence of odors in drinking water sources and responding to incidents caused by harmful substances, so as to reduce economic losses (Kang et al., 2008).

At present, for the research of the control of odors and harmful substances in drinking water sources, a large number of experts and scholars at home and abroad have conducted long-term research and formed numerous research results. Some scholars have studied the detection of odorous gases in drinking water sources (Kang et al., 2007); some scholars have studied the removal methods of odor gases (Adouani et al., 2013; Zhang 2017); and some scholars have studied the odors and odorous substances in drinking water (Bol'shakov et al., 2016). This paper takes the irrigated area of Yellow River as an example to study the identification and control of drinking water odors and harmful substances, which is of high application value and strong demonstration effect for the treatment of drinking water odor in other areas.

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2. Introduction of relevant theories

2.1 Odorous substances in drinking water

Generally, odor substances in drinking water mainly include two categories: organic odor substances and inorganic odor substances. Among them, inorganic gases such as NO_2, NH_3, SO_2, H_2S and other gases have a strong smell; most VOCs have odors, organic odorants are mainly aliphatic hydrocarbon oxygenated derivatives, sulfur compounds, nitrogen compounds and aromatic compounds (Blanka Kutnerová et al., 2004). There are many kinds of odor substances in the drinking water, sulfur-containing proteins can be decomposed and converted into substances such as mercaptans, thioethers, H_2S and NH_3.

Odorous substances are mainly produced by a large number of microorganisms performing aerobic and anaerobic reactions in the water. For example, in an anaerobic environment, sulfate-reducing bacteria can oxidize organic matter by sulphate instead of molecular oxygen (Lin et al., 2014). The electron and hydrogen donor materials that can be utilized by the sulfate-reducing bacteria are mainly pyruvic acid, lactic acid, and hydrogen. Desulfovibrio can use lactic acid as an electron donor for reducing sulfate. The main reaction formula is:

$$2CH_3CHOHCOOH + SO_4 + 3H \rightarrow 2CH_3COO^- + 2H_2O + HS \quad (1)$$

In addition, the mercaptan is easily oxidized with oxidant and converted into symmetrical disulfide. The reaction formula is:

$$\mathrm{RSH} + O_2 \rightarrow \mathrm{RSSR} + H_2\mathrm{O} \quad (2)$$

2.2 Detection of odorous substances in drinking water

The detection of odorous substances in drinking water mainly includes sensory analysis, instrumental analysis, and sensory instrument analysis (Sodaeizadeh et al., 2009). The sensory analysis mainly judges the type of odors in drinking water and the intensity of odors through various olfactory organs of human beings, including the olfactory threshold method and the Flavor Profile Analysis (FPA). In FPA, it mainly divides odors into 7 levels, see Table 1 for details. Instrumental analysis mainly uses chemical detection instruments (gas chromatograph, GC/MS, etc.) to detect and analyze the type and concentration of odorous substances in drinking water (Patikorn et al., 2018). The sensory instrument analysis mainly uses chemical detection instruments to separate the odorous substances in the water sample, and then judges the type and intensity of the odorous substances emitted by the human olfactory organs at different times (Valent et al., 2002).

Table 1: The representation of the intensity unit of FPA

Numerical value	0	1	3	5	7	9	11
Strength	Nothing	Very weak	Weak	Weak- Medium	Medium	Medium- Strong	Strong

2.3 Removal of odorous substances in drinking water

At present, it’s difficult to effectively remove odorous gases in drinking water by using conventional treatment processes. Commonly used methods are: activated carbon adsorption, oxidation removal, UV and its combined-process removal (Weins and Jork, 1996). Among them, the cost of activated carbon adsorption is lower, it is the most commonly used method for removing odorous substances in drinking water; the removal effect of oxidant is better. At present, the method of treating odor with ozone as oxidant has been more common in practical applications, The oxidation mechanism only using ozone as oxidant is shown in formula (3)-formula (7):

$$O_3 + OH^- \rightarrow HO_2^- + O_2 \quad (3)$$

$$O_3 + HO_2^- \rightarrow \cdot\mathrm{OH} + O_2^- + O_2 \quad (4)$$

$$O_3 + Target \rightarrow Intermediate \quad (5)$$

$$O_3 + Target \rightarrow Intermediate + H_2O \quad (6)$$

$$O_3 + Target \rightarrow Intermediate + OH^- \quad (7)$$

In the UV and its combined-process removal method, the ultraviolet radiation can not only disinfect the drinking water, but also remove the odor in the water. The combination of vacuum ultraviolet (VUV) and UV can effectively improve the removal rate (Rosgarcía et al., 2012).

3. Detection of odors and control of harmful substances in drinking water sources in the irrigated area of Yellow River

3.1 Analysis of drinking water quality in the irrigated area of Yellow River

Under normal circumstances, the quality of surface water can be divided into five categories according to the level of function. The main categories suitable for drinking water are Class II and Class III. The concentrations of phosphorus, nitrogen and ammonia nitrogen contained in each category are shown in Table 2.

Table 2: Environmental quality standard for drinking water

Item	Class II	Class Ⅲ
Total phosphorus(mg/L)	0.1	0.3
Total nitrogen(mg/L)	0.2	0.4
Ammonia nitrogen(mg/L)	0.6	1.1

At present, in the irrigated area of Yellow River, the main pollutants in the raw water of a drinking water source are the total nitrogen, total ammonia and ammonia nitrogen etc. The content of total phosphorus, total nitrogen and ammonia nitrogen of the raw water of the drinking water source are all above the Class II standard throughout the year, and the water quality of some years even exceeds the Class III standard. The content of various substances in the raw water of the drinking water source in 2017 is shown as Figure 1.

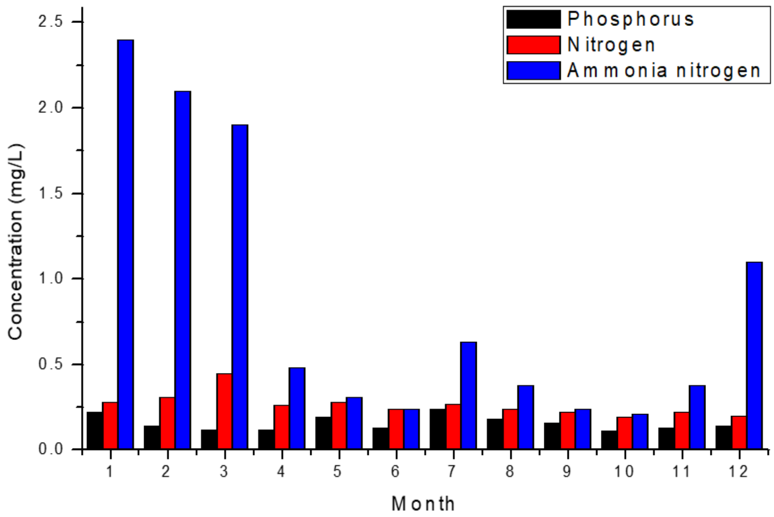

Figure 1: The concentration of various substances in water source of drinking water in 2017

From the data in the figure, it can be found that the total phosphorus concentration and total nitrogen concentration of drinking water sources in the irrigated area of Yellow River are basically maintained between Class II and Class III in 2017. The concentration of ammonia nitrogen varies greatly with the seasons, there are many differences among the seasons, and the concentration in winter is much higher than the Class III standard, but except winter, the concentration of ammonia nitrogen does not even meet the Class II standard.

3.2 Analysis of odorous substances in drinking water sources of the irrigated area of Yellow River

To detect odorous substances in drinking water sources in the irrigated area of Yellow River, first we need to separate the odorous substances in the selected water sample by odor gas chromatography, then by smelling the odors to initially determine the odor substances contained in the sample water body. Thereafter, perform full scan measurement of the water sample by GC-MS to detect the odors in the water body. Through water body testing, it can be found that the high content of odor substances in drinking water sources of the irrigated area of Yellow River mainly include: 2-methylisoborneol, β-cyclocitral, β-ionone, and geosmin. See Figure 2 for details. The annual average value of the main odorous substances in drinking water sources in the irrigated area of Yellow River from 2014 to 2016 is statistically analyzed, details are shown in Figure 3. From the data in the figure, it can be found that the main odor substances in the drinking water source in the irrigated area of Yellow River have been greatly reduced, which indicates that the quality of drinking water sources in the irrigated area of Yellow River has been improving year by year.

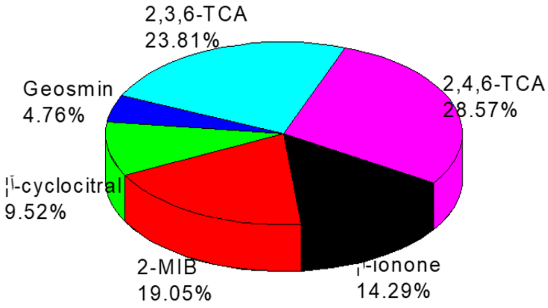

Figure 2: Detection of odor substances in drinking water sources of the irrigated area of Yellow River

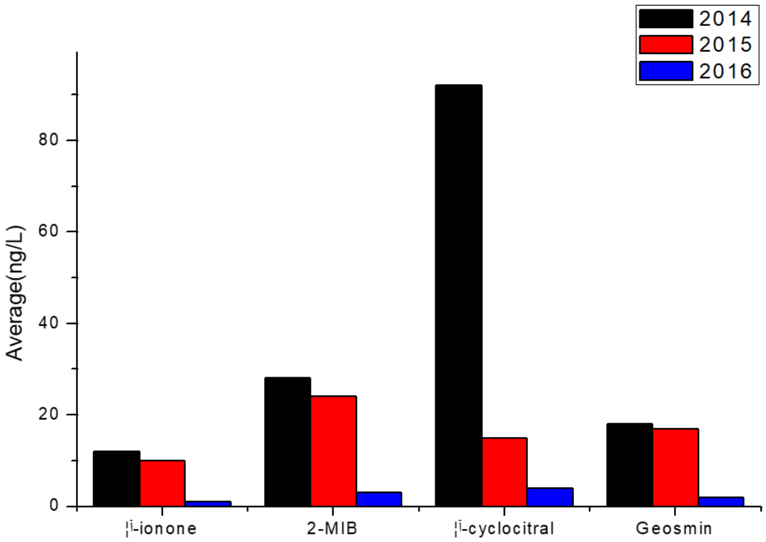

Figure 3: Annual mean change of main odor substances in drinking water sources in the irrigated area of Yellow River during 2014-2016

3.3 Removal and control of harmful substances

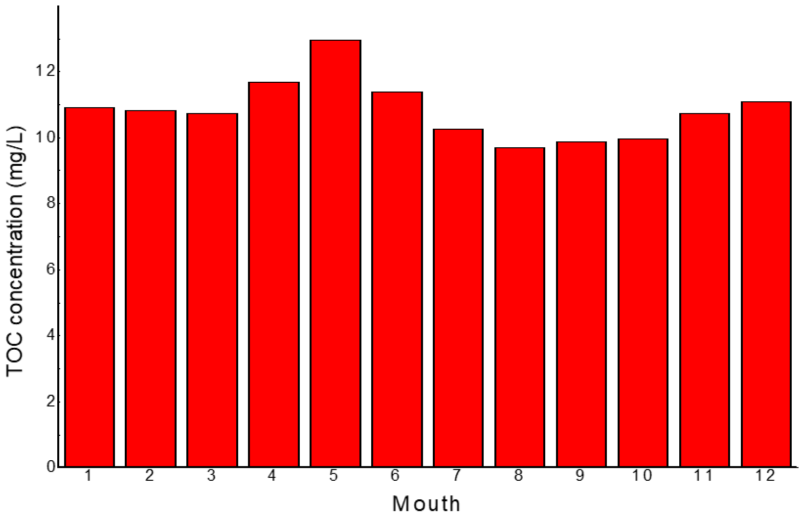

Figure 4: The concentration of TOC in the irrigated area of Yellow River in 2017

In the process of removing odorous substances from water sources, it is mainly affected by some external factors, including PH value, temperature and ozone concentration. In the process of water sample detection in

the irrigated area of Yellow River, the total organic carbon concentration (TOC) of the water sample is also measured. TOC is a comprehensive indicator which uses carbon content to indicate the total amount of organic matter in the water body, it can reflect the extent to which the water body is contaminated by organic matter. Through the water sample detection in the irrigated area of Yellow River in 2017, the organic carbon concentration was found to be about 10 mg/L, as shown in figure 4.
The TOC in the water source of the irrigated area of Yellow River was removed by various processes such as ozone oxidation and sand filtration. The specific removal effect is shown in Figure 5.

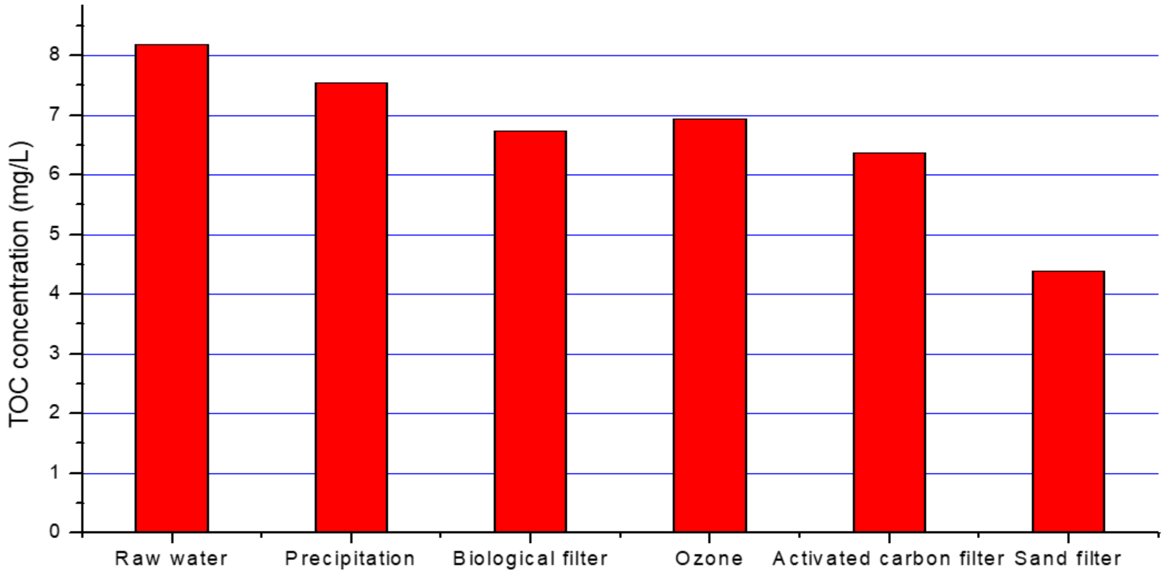

Figure 5: The concentration of TOC in the effluent of each process

From the data in the Figure 5, it can be found that except for the effect of ozone oxidation on the removal of TOC is not obvious, other processes have obvious removal effects on TOC in the water. Among them, the highest contribution to the TOC removal rate is sand filtration, and the removal rate is 21%. Through the removal of various processes, the TOC concentration in water can be reduced to about 4%.
Besides TOC, the pH value and dissolved oxygen in the water sample of the irrigated area of Yellow River are also examined. The test results show that the pH value of the water sample is basically stable between 8.1 and 8.6, presenting weak alkaline, and does not fluctuate greatly with the change of season and temperature. At the same time, the odor treatment process does not have much influence on the pH value of the water sample. The dissolved oxygen in the water sample will change with season, this is mainly because the solubility of oxygen in water has a reverse relationship with temperature. Generally, the higher the temperature, the lower the solubility of oxygen in water. Therefore, in summer, the solubility of oxygen in water is generally less than 2mg/L, and in the winter, it is about 10mg/L. In addition, the solubility of oxygen in water is also related to the quality of water. Generally speaking, the better the water quality, the higher the solubility of oxygen in the water.

4. Conclusion

(1) In the irrigated area of Yellow River, the main pollutants in raw water of a drinking water source are total nitrogen, total phosphorus and ammonia nitrogen. The total phosphorus and total nitrogen concentrations in drinking water sources in the irrigated area of Yellow River are basically maintained between Class II and Class III. The ammonia nitrogen concentration varies greatly with the season, and the concentration in winter is much higher than the Class III standard, except winter, the ammonia nitrogen concentration does not even reach the Class II standard.
(2) The main contents of odorous substances in drinking water sources in the irrigated area of Yellow River are: 2-methylisoborneol, β-cyclocitral, β-ionone, and geosmin. In recent years, the content of major odorous substances has decreased significantly, which indicates that the quality of drinking water sources in the irrigated area of Yellow River has been improving year by year.
(3) The effect of ozone oxidation on the removal of total organic carbon (TOC) in drinking water is not obvious, and other processes have obvious effects on the removal of TOC. Among them, the highest contribution to the TOC removal rate is sand filtration, and the removal rate is 21%.

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