The Comparison of Biotreatment and Chemical Treatment for Odor Control during Kitchen Waste Aerobic Composting

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Abstract: Odor emission has become an important issue in kitchen waste management. Ammonia and hydrogen sulfide are the two most important odor sources as they contribute malodor and can cause health problems. As biotreatment and chemical treatment are two majorly applied technologies for odor control, in this study, they were used to remove ammonia and hydrogen sulfide and the performance of each process was compared. It was found that chemical absorption could efficiently eliminate both ammonia and hydrogen sulfide, and the removal efficiencies of ammonia and hydrogen sulfide highly depended on the pH of the adsorbent, contacting time, and gas and solution ratio (G/S). The ammonia-removal efficiency reached 100% within less than 2 s at G/S 600 and pH 0.1. The complete removal of hydrogen sulfide was achieved within 2 s at G/S 4000 and pH 13. Biotrickling filter showed better ability for hydrogen sulfide removal and the removal efficiency was 91.9%; however, the ammonia removal was only 73.5%. It suggests that chemical adsorption is more efficient compared to biotreatment for removing ammonia and hydrogen sulfide. In the combination of the two processes, biotrickling filter followed by chemical adsorption, the final concentrations of ammonia and hydrogen sulfide could meet the Level 1 standard of Emission Standards for Odor Pollution (China). The study provides a potential approach for odor control during kitchen waste aerobic composting.

Keywords: odor control; kitchen waste treatment; aerobic composting; chemical adsorption; biotreatment

1. Introduction

Kitchen waste generation has grabbed great attention in the development of the catering industry. It is continuously generated in large quantity in China [1]. Currently, anaerobic digestion and aerobic composting are the two major processes for kitchen waste management. Both of the technologies are efficient in volume reduction and generate value-added products. However, they both simultaneously have an odor problem [2,3]. The odor is caused due to the emission of many compounds, including ammonia, hydrogen sulfide, volatile organic compounds (VOCs). Among these, ammonia and hydrogen sulfide are generated in a remarkable amount and classified as malodors [4,5]. Hence, the efficient removal of ammonia and hydrogen sulfide is significantly important for odor control. The traditional odor-removal technology includes physical methods, chemical methods and biological methods. The physical method is normally to cover the odor with a pleasant odor or dilute the odor, which does not really solve the problem.

The chemical method mainly includes scrubbing, catalytic oxidation, UV oxidation and thermal plasma [5–9]. It is based on a chemical reaction to grab or break odor compounds. It was reported that with 0.01% sulfuric acid as a scrubbing solution, ammonia removal efficiency reached up to 97.92% [10]). When scrubbing is used to treat hydrogen sulfide, alkaline solution is required. Photocatalytic oxidation has been given extensive attention...
as it demands low energy consumption and shows almost no secondary pollution. A floatable photocatalyst LFO/MEP composite was employed to degrade ammonia and a maximum ammonia degradation efficiency of 45.7% was obtained with nitrate and nitrite as the final products [11]. Many other types of photocatalysts including polyaniline (PANI) coupled CuBi$_2$O$_4$, TiO$_2$ and UiO-66 (Ti) -Fe$_3$O$_4$-WO$_3$ have been used for ammonia degradation [12–14]. These were mainly used for ammonia but not for hydrogen sulfide. Non-thermal plasma has been found to simultaneously remove ammonia and hydrogen sulfide. In addition, it is a low-energy consumption technology. As reported, the removal efficiency of ammonia and hydrogen sulfide with single plasma could reach 67.3% and 66.1%, respectively, and the removal was even better when plasma was coupled with catalyst, as it was found that the required energy was lower and the reaction time was shorter [3]. It can be seen that novel chemical methods are developed but scrubbing is still the most suitable one for practical application.

The biological method is normally more economical than the physical and chemical methods. Biological treatment mainly employs microorganisms to degrade odor compounds [15]. It involves the transportation of gas phase to liquid phase, liquid phase to biofilm surface, biofilm surface to cell before degradation. It suggests that the solubility of the target gas compounds has a great impact on their removal. Both ammonia and hydrogen sulfide can be easily solubilized at a suitable pH. Currently, the biotreatment in odor control includes biofilters, biotrickling filters and a bioscrubber [16–18]. In fact, biotreatment has achieved high efficiency for odor removal. Vitko et al. found that a biofilter could achieve 99.8% hydrogen sulfide removal within 45 s [18]. Ren et al. has achieved even better hydrogen sulfide removal by employing a biofilter with a special modification on the microorganism community, which has up to 100% removal efficiency [19]. Biotreatment has been found to be capable of simultaneously removing ammonia and hydrogen sulfide. A pilot-scale achieved almost stable ammonia and hydrogen sulfide removal during a 150-days operation, and removal efficiency was 100% and 91.96% for ammonia and hydrogen sulfide, respectively. Another study also reported that the removal efficiencies of ammonia and hydrogen sulfide were 97.9% and 100%, respectively, by employing two down-flow wood bark-based biofilters [16,20]. It can be concluded that biotreatment is potential technology for the removal of odor generated from kitchen waste management. Among them all, the biotrickling filter is considered to have a good performance [21].

From the above discussion, it can be learnt that scrubbing and biotreatment are the two technologies with the most potential for ammonia and hydrogen sulfide removal in practice. So far, there have been no studies directly evaluating which method would be more suitable for the removal of ammonia and hydrogen sulfide at the same influent gas concentration level. In this study, chemical scrubbing and a biotrickling filter were employed to investigate their suitability for the removal of ammonia and hydrogen sulfide generated during kitchen waste management. The treatment efficiency of the two processes was studied. Optimization of the removal for ammonia and hydrogen sulfide was conducted. The performance of the two processes was evaluated and compared. The study will provide an important basis for process selection for odor control in kitchen waste management.

2. Materials and Methods
2.1. Ammonia and Hydrogen Sulfide

The ammonia and hydrogen sulfide used in this study were purchased from a company in Shenzhen, China. The original gases have a purity of 99.99% and were filled in separated steel cylinders, respectively. The synthesized odor gas was made by mixing the ammonia gas or/and hydrogen sulfide gas, and air in a gas mixing column. The composition analysis of the odor collected from two kitchen waste treatment sites located in Shenzhen showed that the concentrations of ammonia and hydrogen sulfide were at the range of 0.13 to 1.64 mg/m$^3$ and 0.06 to 2.79 mg/m$^3$, respectively. Hence, in this study, ammonia or/and hydrogen sulfide in the synthesis odor gas were set at concentrations of 2 mg/m$^3$ and 3 mg/m$^3$, respectively.
2.2. Chemical Scrubbing for Ammonia and Hydrogen Sulfide Removal

The chemical scrubbing was performed in three columns: the water scrubbing column, acid scrubbing column and base scrubbing column. The columns were made of plexiglass with a diameter of 200 mm and working height of 800 mm. A sprinkler was placed on the top in each column to spray water or chemical solutions, and the odor gas was injected from the bottom of the column. The tap water was used in water scrubbing. Acid solution used in acid scrubbing was made by diluting H$_2$SO$_4$ and the pH was adjusted to 2–6 according to the demand. The base solution (base scrubbing) was obtained by addition of NaOH to tap water and pH was adjusted to 8–13.

The water or chemical solutions were atomized into micro-fog particles with a size of 10–50 µm, and met with the odor gas in the column and then, adsorbed odor gas. The synthesis odor gas passed through the water scrubbing column, acid scrubbing column or/and base scrubbing column, and the retention time was adjusted by varying the injection gas flow rate. The water and solutions were collected from the bottom and recycled back for scrubbing. The gas to solution ratio was adjusted between 2000 and 6000. Samples were collected from the end of the scrubbing (after the base scrubbing column), respectively.

2.3. Biotricking Filter for Ammonia and Hydrogen Sulfide Removal

The biotricking filter was made of plexiglass with a diameter of 100 mm and total height of 1000 mm. The filter was packed with a 600 mm height of ceramsite (10–12 mm) which was supported by a stainless steel sieve plate. Spray was set on the top for feeding nutrients.

Wastewater sludge collected from a local wastewater treatment of Shenzhen, China, was used as inoculum to the filter. The wastewater was firstly acclimatized by feeding Na$_2$S$_2$O$_3$ along with the nutrient solution at a rate of 5 L/h. The nutrient solution (per liter) was composed of 0.04 g of urea, 0.05 g of NaH$_2$PO$_4$, 0.1 g of MgSO$_4$, 0.1 g of CaCl$_2$, 0.01 g of FeSO$_4$. The aeration was provided for 7 h and then stopped for 2 h as a cycle. The concentration of SO$_4^{2–}$ was monitored and the preparation was considered as having succeeded when the concentration of SO$_4^{2–}$ was stable. Then, the odor gas was introduced from the bottom of the filter. Ammonia and hydrogen sulfide were in contact with biofilm for their removal.

In this study, the biotrickling filter was regenerated by stopping to introduce odor gas, and switching to aerating air only. Solution containing nutrient and Na$_2$S$_2$O$_3$ was sprayed to the ceramsite and aeration was provided in the same pattern as described above. Similar to the preparation, the regeneration was finished when the concentration of SO$_4^{2–}$ was stable.

2.4. Analytical Methods

In this study, ammonia samples were collected with a collection rate of 1 L/min for 5 min. Then, Nessler’s Reagent was used to adsorb ammonia. The ammonia concentration was determined by following Nessler’s Reagent Spectrophotometry method [22]. Ultrapure water was used as blank and the absorbance was determined at 420 nm. Hydrogen sulfide was determined by methylene blue spectrophotometry [23]: similar to ammonia sample collection, but the adsorption solution used was zinc acetate–sodium acetate solution. Ultrapure water was used as blank and the absorbance was determined at 665 nm. The concentration of SO$_4^{2–}$ was determined with the standard sulfate-barium chromate Spectrophotometer method (HJ/T 342-2007). The pH of the solution and samples was determined by a pH meter.

3. Results

3.1. Chemical Scrubbing

3.1.1. Ammonia Removal by Acid Scrubbing

The ammonia removal by acid scrubbing was to introduce the odor gas obtained by mixing ammonia gas with air into water scrubbing and acid scrubbing. The results are
shown in Figure 1. It can be seen that the ammonia was rapidly adsorbed by the scrubbing when the acid spray was set at pH 3 with a gas to solution ratio (G/S) of 2000 (Figure 1a). At a retention time of 10 s, the removal efficiency was 57% (from the initial 2 mg/m³ to 0.86 mg/m³), and with the retention time increased to 50 s, ammonia was not detected. The results proved that the retention time has a great impact on the ammonia removal as the retention time is related to the contacting time between the ammonia and scrubbing solution.

![Graph](image)

**Figure 1.** The ammonia removal by chemical scrubbing ((a): ammonia removal at pH 3; (b): the ammonia removal at different pH and retention time).

As ammonia is an alkaline gas, the pH of the scrubbing solution would be significant for ammonia removal. To further study the pH impact on the ammonia removal, the pH of the scrubbing solution in the acid scrubbing column was adjusted to 0.1, 0.5, 1, 2, 3, 4, 5. The ammonia removal efficiency showed that the removal efficiency reached 100% within a 10 s retention time at pH 0.1 and 0.5. The 100% ammonia removal was obtained within a 20 s retention time for the case of pH 1. With pH gradually increasing, the required time for complete ammonia removal was increased. However, the ammonia removal was lower than 80% when the retention time was even up to 60 s at pH 4 and 5, showing that pH...
has great influence on ammonia removal. To efficiently eliminate ammonia from odor gas, scrubbing solution with lower pH should be employed. For instance, the pH should be at least set at lower than 2 if the complete removal is demanded. According to the Emission Standards for Odor Pollution (China), the ammonia emission concentration should be lower than 1 mg/m$^3$ if the required emission level is Level 1 for the treatment plant. In fact, if the removal aim is to meet the Level 1 standard, utilization of scrubbing solution with pH 3 to treat for 10 s would be enough as the concentration of ammonia was reduced to 0.86 mg/m$^3$. 

In order to investigate the capacity of the acid scrubbing with pH 3, the ammonia concentration was elevated from 2 to 10 mg/m$^3$. It was found that the ammonia concentration was reduced to 0.93 mg/m$^3$ (meeting the Level 1 standard) when the retention time was set at 40 s at pH 0.1, but the ammonia removal efficiency was only 25% (final concentration 7.5 mg/m$^3$) even with retention time of 60 s when the acid scrubbing solution pH was 3. It reveals that the acid scrubbing could eliminate ammonia from odor gas but pH is crucial. A similar conclusion was reported by the other study [24].

In addition, the gas to solution ratio (G/S) is another important factor for ammonia removal. The ammonia removal with G/S was set at 2000, 3000, 4000, 5000 and 6000 at pH 3 and a retention time of 10 s. It was found that ammonia removal was increased with the increase of G/S, and the complete removal was achieved at G/S 4000. It is due to the fact that the solution for scrubbing gas was increased, which provides high chances for gas and solution to have contact. As the retention time would directly influence the column size, reducing the retention time would increase the treatment capacity by using the same size reactor. By varying the retention time, pH and G/S, it was found that at G/S 6000, complete removal was obtained within less than 2 s at pH 0.1. This suggests that increasing the contact chance between ammonia and scrubbing solution is the key for enhancing ammonia removal.

3.1.2. Hydrogen Sulfide Removal by Base Scrubbing

The hydrogen sulfide removal by base scrubbing was to inject the odor gas obtained by mixing hydrogen sulfide gas with air into water scrubbing and base scrubbing. The hydrogen sulfide removal was achieved in base scrubbing as shown in Figure 2. The removal of hydrogen sulfide is rather rapid. With the scrubbing solution pH at 12, the hydrogen sulfide removal efficiency increased with the retention time increase (Figure 2a). When the retention time was shorter than 20 s, the hydrogen sulfide concentration in the effluent was higher than 0.03 mg/m$^3$ which is the Level 1 standard of Emission Standards for Odor Pollution (China). It suggests that the retention time should be controlled at least at 20 s to meet the required emission standard. The hydrogen sulfide concentration was not detected after 30 s retention time, which can be considered as the complete removal. It suggests that the base scrubbing with pH 12 has great potential for hydrogen sulfide removal.

To verify the pH impact on the removal of hydrogen sulfide, the removal efficiency of hydrogen sulfide at different pH and retention time has been studied. The results are shown in Figure 2b. It can be seen that pH has great impact on the removal of hydrogen sulfide. With the pH increasing, the required time for complete removal of hydrogen sulfide was gradually reduced. At pH 8, the removal efficiency gradually increased to 90.5% with the retention time increasing. When the pH was set at 10, hydrogen sulfide was completely removed within 30 s, and the complete removal was only used 5 s when the pH was increased to 13. The study reveals that pH is significantly important as it determines the treatment efficiency and capacity of the process.
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Similarly as in ammonia removal, the G/S (2000, 3000, 4000, 5000 and 6000) was also investigated in hydrogen sulfide removal. It was found that the complete removal of hydrogen sulfide could be finished within 2 s at G/S 4000 and pH 13. It suggests that the removal would be efficient when the proper pH and G/S were set.

3.1.3. Ammonia and Hydrogen Sulfide Removal by Chemical Scrubbing

From the above study, it can be seen that the required retention times for complete removal of ammonia and hydrogen sulfide are different. According to the results obtained in a single system, compromising the two scrubbing is important for efficient removal of odor gas. At pH 13 and G/S 4000, 2 s retention time was enough for 100% H₂S removal, and at pH 0.5 and G/S 6000, the 100% removal efficiency on ammonia was achieved in 2 s. In fact, the two gases normally exist in the odor gas simultaneously. To remove them, acid and base scrubbing can be connected together. In this study, three columns, a water washing column, acid scrubbing column and base scrubbing column, were employed and

![Figure 2. The hydrogen sulfide removal by chemical scrubbing: (a) hydrogen sulfide removal at pH 12; (b) the hydrogen sulfide removal at different pH and retention time.](image-url)
the odor gas containing ammonia (2 mg/m³) and hydrogen sulfide (3 mg/m³) passed through the columns. The scrubbing solution pH was adjusted to 0.5 and 13 in the acid scrubbing column and base scrubbing column, respectively. The G/S of 6000 and 4000 was provided in the acid scrubbing column and base scrubbing column, respectively. The retention time was set at 2 s. The result shows that the ammonia and hydrogen sulfide were not detected after the chemical scrubbing. It suggests that the chemical scrubbing could completely eliminate the odor as long as the pH and retention time are set suitably. When the aim is to meet the Level 1 standard of Emission Standards for Odor Pollution (China), pH 3 and 12 would be enough for ammonia and hydrogen sulfide removal. It would thus reduce the acid and base consumption and thus reduce the cost.

Chemical scrubbing could efficiently remove the odor gas but it also generated wastewater. The wastewater was discharged when the pH cannot be increased to 7.5 by addition of NaOH in the base scrubbing and reduced to 6.5 by addition of H₂SO₄ in the base scrubbing. According to the experiment, 1 mL of wastewater was generated with around 25 m³ of the odor gas containing 3 mg/m³ of hydrogen sulfide, and the wastewater contained S²⁻ at a concentration of 68–74 g/L. In base scrubbing, 1 mL of wastewater was generated after treating 85 m³ of the odor gas containing 2 mg/m³ of ammonia, and the wastewater contained 160–185 g/L NH₄⁺.

3.2. Biotrickling Filter for Ammonia and Hydrogen Sulfide Removal
3.2.1. The Start-Up of the Biotrickling Filter

The wastewater sludge adapted with Na₂S₂O₃ was inoculated to the filter and the system was stood for 24 h to provide the sufficient contacting time for microorganisms and fillings (ceramsite). Thereafter, the hydrogen sulfide was injected from the bottom of the filter with a concentration of 3 mg/m³ and empty bed retention time of 10 s. The nutrient solution was sprayed from the top with a 4 L/h rate and collected from the bottom and recycled. It was found that the hydrogen sulfide concentration in the effluent was continuously declined from day 1 to day 5, and then became stable afterwards. The final concentration of hydrogen sulfide was 0.27 mg/m³. It is considered that the start-up succeeded.

3.2.2. The Ammonia and Hydrogen Sulfide Removal by Biotrickling Filter

The odor gas containing ammonia (2 mg/m³) and hydrogen sulfide (3 mg/m³) was injected to the biotrickling filter with empty bed retention time of 10 s. The ammonia removal was almost stable during the operation, which was around 63% (Figure 3). It was found that hydrogen sulfide removal efficiency was reduced from 91% to 75.3% in the presence of ammonia (Figure 3a). It would be due to the addition of ammonia having impacted on the pH of the nutrient solution. According to the pH monitoring, it can be seen that the pH gradually decreased from 5 to around 4.2 when hydrogen sulfide was the solo odor gas injected to the biotrickling filter. With the addition of ammonia, the pH slightly increased from 5 to 5.8 (Figure 3a). In biotrickling filter, pH at around 4 was found to favor the removal of hydrogen sulfide as the pH was suitable for related bacteria growth [25]. Thus, the elevation of pH with the addition of ammonia would be the reason for the removal reduction of hydrogen sulfide. To reduce the ammonia impact, the nutrient solution was adjusted to 4 and it was found that the impact was highly reduced and the removal efficiency of H₂S was kept around 90%.
Figure 3. The ammonia and hydrogen sulfide removal by biotrickling filter: (a) ammonia and hydrogen sulfide removal with empty bed retention time of 10 s; (b) the ammonia removal at different pH and empty bed retention time; (c) hydrogen sulfide removal at different pH and empty bed retention time.
The empty bed retention time impacts on the treatment capacity. The short empty bed retention time could treat more odor gas than the long one for the same sized filter. The pH of the nutrient solution has shown an impact on NH$_3$ and H$_2$S; therefore, it is predicted that the empty bed retention time can be reduced if proper pH is provided. To study the pH effect, the pH was maintained at 2, 3, 4, 5 and 6 by adjusting the nutrient solution pH according to real-time detection with a pH meter. For ammonia removal, the lower pH has shown a better performance (Figure 3b). This would be due to the fact that the ammonia removal in the biotrickling filter is mainly due to the adsorption, as the retention time is too short to accomplish nitrification and/or denitrification [26]. Ammonia is an alkaline gas and low pH could promote ammonia removal. Similar results have been reported by others as well [27,28]. At pH 2, 60% ammonia removal only took 2 s, but it required more than 10 s to achieve the similar removal at pH 5, and it would be longer at pH 6 (Figure 3b). In the removal of H$_2$S, it can be seen that the pH at 3 and 4 could greatly reduce the retention time to achieve similar removal efficiency compared to other pH (Figure 3c). More than 90% removal efficiency has been obtained within 3 s at pH 3 and 4, but it was still less than 80% at pH 2, 5 and 6 even with the retention time of 10 s. It is predicted that pH is important for the growth of the bacteria, which is responsible for H$_2$S removal, and suitable pH could enhance their growth [29,30].

Overall, it can be seen that the biotrickling filter can effectively remove hydrogen sulfide but not ammonia. To meet the Level 1 standard for ammonia, it would require more retention time which would cause high capital cost. In addition, it does not match with the removal of hydrogen sulfide. This suggests that it would waste resources and time if the proposal is to simultaneously remove hydrogen sulfide and ammonia. Moreover, for hydrogen sulfide, 90% removal efficiency would still have around 0.3 mg/m$^3$ concentration left in the gas stream, which still cannot meet the Level 1 standard of Emission Standards for Odor Pollution (China).

3.3. The Combined System for Ammonia and Hydrogen Sulfide Removal

From the results of chemical scrubbing and the biotrickling filter, it can be seen that chemical scrubbing can rapidly remove ammonia and hydrogen sulfide. At a suitable pH, no ammonia and hydrogen sulfide were detected after scrubbing, which suggests the complete removal of the two gases. Biotrickling filter showed better performance on hydrogen sulfide removal than on ammonia. However, it still cannot meet the requirement unless further increasing the empty bed retention time, which would thus induce the increase of capital cost. In fact, the combination of biotrickling filter and chemical scrubbing would be a preferred method for efficiently simultaneous removal of hydrogen sulfide and ammonia. The biological method is less costly compared to chemical scrubbing. Firstly, employing a biotrickling filter to remove most of the odor and then applying chemical scrubbing to ensure the effluent meets the standard would be a cost-effective approach for odor control, as it could highly reduce chemical consumption. Based on this consideration, in this study, a biotrickling filter followed by acid scrubbing and base scrubbing has been employed. The biotrickling filter firstly removed most of the odor gas, and then chemical scrubbing was applied. It thus reduced the chemical utilization and hence, reduced the cost.

The nutrient solution pH was set at 4 and the empty bed retention time was set at 3 s in the biotrickling filter, and the G/S was set at 6000 in acid scrubbing (pH 3) and 4000 in base scrubbing (pH 13). The final concentration of ammonia was 0.23 mg/m$^3$ (<1 mg/m$^3$) and hydrogen sulfide (<0.03 mg/m$^3$) was not detected. It reveals that the combination treatment on the given condition could meet the Level 1 standard of Emission Standards for Odor Pollution (China).

To further evaluate the ability of the combined process to adapt the fluctuation, the ammonia and hydrogen sulfide concentration was doubled (4 mg/m$^3$ and 6 mg/m$^3$) and tripled (6 mg/m$^3$ and 9 mg/m$^3$). It was found that the concentration of ammonia and hydrogen sulfide could finally be reduced to below the required standard with the increase of retention time (Figure 4). This reveals that the combination of biotrickling filter and
chemical scrubbing has great potential to deal with the concentration variation of ammonia and hydrogen sulfide in the odor gas stream.

![Graph](image)

**Figure 4.** The ammonia and hydrogen sulfide removal by combined process.

4. Conclusions

The study reveals that chemical scrubbing is more efficient than biotrickling filter for ammonia and hydrogen sulfide removal. Chemical scrubbing is targeted as acid solution for ammonia (alkaline gas) and base solution for hydrogen sulfide (acidic gas). Chemical scrubbing efficiency is highly dependent on the retention time, scrubbing solution pH and gas-to-solution ratio. At pH 0.1, the retention time required was less than 10 s for complete ammonia removal. In hydrogen sulfide removal, 100% removal efficiency was obtained at pH 13 within 5 s. It reveals that the suitable pH is significantly important for a successful process. Biotrickling filter efficiency is impacted by ammonia addition as it could cause the pH variation of the biotrickling. It was found that the biotrickling filter is more suitable for hydrogen sulfide compared to ammonia. Compared to employing only one of the processes (chemical scrubbing or biotrickling filter), the combination of biotrickling filter and chemical scrubbing would be a better choice, as it could reduce the chemical addition amount and reduce the biotrickling filter size.

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**References**

1. Peng, L.; Ma, R.; Jiang, S.; Luo, W.; Li, Y.; Wang, G.; Xu, Z.; Wang, Y.; Qi, C.; Li, Y.; et al. Co-composting of kitchen waste with agriculture and forestry residues and characteristics of compost with different particle size: An industrial scale case study. *Waste Manag.* **2022**, *149*, 313–322. [CrossRef]
2. Jin, C.; Sun, S.; Yang, D.; Sheng, W.; Ma, Y.; He, W.; Li, G. Anaerobic digestion: An alternative resource treatment option for food waste in China. *Sci. Total Environ.* **2021**, *779*, 146397. [CrossRef]
3. Yuan, J.; Yang, Q.; Zhang, Z.; Li, G.; Luo, W.; Zhang, D. Use of additive and pretreatment to control odors in municipal kitchen waste during aerobic composting. *J. Environ. Sci.* **2015**, *37*, 83–90. [CrossRef]
4. Qamaruz-Zaman, N.; Milke, M.W. VFA and ammonia from residential food waste as indicators of odor potential. *Waste Manag.* **2012**, *32*, 2426–2430. [CrossRef]
5. Wei, X.; Tao, Z.; Xinrui, J.; Huan, X. Degradation of mixed typical odour gases via non-thermal plasma catalysis. J. Hazard. Mater. 2022, 440, 129751. [CrossRef]

6. Yao, X.; Shi, Y.; Wang, K.; Wang, C.; He, L.; Li, C.; Yao, Z. Highly efficient degradation of hydrogen sulfide, styrene, and m-xylene in a bio-trickling filter. Sci. Total Environ. 2022, 808, 152130. [CrossRef]

7. Yang, J.T.; Pan, H.; Chen, J.; Su, Q.F.; Wang, D.H.; Shi, Y. Two-stage system of non-thermal plasma and adsorption for decomposition of hydrogen sulfide. Zhejiang Daxue Xuebao (Gongxue Ban) (Zhejiang Univ. Eng. Sci.) 2010, 44, 2411–2415. [CrossRef]

8. Lee, M.; Koziel, J.; Murphy, W.; Jenks, W.; Panahi, D. Evaluation of TiO2 Based Photocatalytic Treatment of Odor and Gaseous Emissions from Swine Manure with UV-A and UV-C. Animals 2021, 11, 1289. [CrossRef]

9. Sun, X.; Li, C.; Yu, B.; Wang, J. W. Removal of gaseous volatile organic compounds via vacuum ultraviolet photocatalysis: Review and prospect. J. Environ. Sci. 2023, 125, 427–442. [CrossRef]

10. Jafari, M.J.; Matin, A.H.; Rahmati, A.; Azari, M.R.; Omidi, L.; Hosseini, S.S.; Panahi, D. Experimental optimization of a spray tower for ammonia removal. Atmos. Pollut. Res. 2018, 9, 783–790. [CrossRef]

11. Khen, L.Y.; Mohtar, S.S.; Aziz, F.; Salleh, W.N.W.; Yusof, N.; Jaafar, J.; Ismail, A.F. Floatable photocatalyst LaFeO3 modified expanded perlite composite for photocatalytic ammonia degradation. J. Water Process Eng. 2021, 44, 102401. [CrossRef]

12. Ahmad, N.; Anae, J.; Khan, M.Z.; Sabir, S.; Campo, P.; Coulon, F. A novel CuBi2O4/polyaniline composite as an efficient photocatalyst for ammonia degradation. Hellyon 2022, 8, e012010. [CrossRef]

13. Rahman, M.; Dashian, K.; Mowla, D.; Esmaeilzadeh, F.; Ghaedi, M. UfO4-TiO2-WO3 photocatalyst for efficient photocatalytic degradation from wastewater into continuous flow-loop thin film slurry flat-plate photoreactor. J. Hazard. Mater. 2020, 393, 122360. [CrossRef]

14. Mohammadi, Z.; Sharifinia, S.; Shavisi, Y. Photocatalytic degradation of aqueous ammonia by using TiO2ZnO/LECA hybrid photocatalyst. Mater. Chem. Phys. 2016, 184, 110–117. [CrossRef]

15. Reyes, J.; Toledo, M.; Michán, C.; Siles, J.; Alhama, J.; Martín, M. Biofiltration of butyric acid: Monitoring odor abatement and microbial communities. Environ. Res. 2020, 190, 110057. [CrossRef]

16. Kawase, Y.; Hirata, A.; Kojima, T.; Ohmori, S.; Akutagawa, H.; Uehara, K.; Iwata, K.; Nakajima, T.; Yamamoto, K. Improvement effects among selected pollutants and microbial community change. J. Hazard. Mater. 2014, 265, 164–174. [CrossRef]

17. Ying, S.; Kong, X.; Cai, Z.; Man, Z.; Xin, Y.; Liu, D. Interactions and microbial variations in a biotrickling filter treating low concentrations of hydrogen sulfide and ammonia. Chemosphere 2020, 255, 126931. [CrossRef]

18. Vito, T.G.; Cowden, S.; Suffet, I.H. Evaluation of bioscrubber and biofilter technologies treating wastewater foul air by a new approach of using odor character, odor intensity, and chemical analyses. Water Res. 2022, 220, 118691. [CrossRef]

19. Ren, B.; Lyczko, N.; Zhao, Y.; Nzhou, A. Simultaneous hydrogen sulfide removal and wastewater purification in a novel alum sludge-based odor-gas aerated biofilter. Chem. Eng. J. 2021, 419, 129558. [CrossRef]

20. Rabbani, K.; Charles, W.; Kayaalp, A.; Cord-Ruwisch, R.; Ho, G. Pilot-scale biofilter for the simultaneous removal of hydrogen sulphide and ammonia at a wastewater treatment plant. Biochem. Eng. J. 2016, 107, 1–10. [CrossRef]

21. Sakuma, T.; Hattori, T.; Deshusses, M.A. Comparison of different packing materials for the biofiltration of air toxics. J. Air Waste Manag. Assoc. 2006, 56, 1567–1575. [CrossRef]

22. Zhang, Y.; Yin, S.; Li, H.; Liu, J.; Li, S.; Zhang, L. Treatment of ammonia-nitrogen wastewater by the ultrasonic strengthened break point chlorination method. J. Water Process Eng. 2022, 45, 102501. [CrossRef]

23. Chen, L.; Li, W.; Zhao, Y.; Zhou, Y.; Zhang, S.; Meng, L. Isolation and application of a mixotrophic sulphide-oxidizing Cohnella thermotolerans LYH-2 strain to sewage sludge composting for hydrogen sulfide odor control. Bioresource. Technol. 2022, 435, 126557. [CrossRef]

24. Cao, T.; Zheng, Y.; Zhang, Y.; Wang, Y.; Cong, Q.; Wang, Y.; Dong, H. Pilot study on gaseous pollution removal efficiency of acid scrubbing in a broiler house. Agric. Ecosyst. Environ. 2022, 335, 108021. [CrossRef]

25. Jia, T.; Zhang, L.; Zhao, Q.; Peng, Y. The effect of biofilm growth on the sulfur oxidation pathway and the synergy of microorganisms in desulfurization reactors under different pH conditions. J. Hazard. Mater. 2022, 432, 128638. [CrossRef]

26. Kawase, Y.; Hirata, A.; Kojima, T.; Ohmori, S.; Akutagawa, H.; Uehara, K.; Iwata, K.; Nakajima, T.; Yamamoto, K. Improvement of biodegradation in compact co-current biotrickling filter by high recycle liquid flow rate: Performance and biodegradation kinetics of ammonia removal. Process Biochem. 2014, 49, 1733–1740. [CrossRef]

27. Tsang, Y.F.; Wang, L.; Chua, H. Simultaneous hydrogen sulphide and ammonia removal in a biotrickling filter: Crossed inhibitory effects among selected pollutants and microbial community change. Chem. Eng. J. 2015, 281, 389-396. [CrossRef]

28. Sakuma, T.; Jinsiriwanit, S.; Hattori, T.; Deshusses, M.A. Removal of ammonia from contaminated air in a biotrickling filter–Denitrifying bioreactor combination system. Water Res. 2008, 42, 4507–4513. [CrossRef]

29. Zhang, B.; Wang, Y.; Huang, S.; Hu, H.; Yuan, H.; Wu, X.; Li, B.; Tang, X. Removal of H2S in an extremely acidic-biotrickling filter: Evaluation of removal performance and characterization of microbial communities. J. Environ. Chem. Eng. 2022, 10, 108504. [CrossRef]

30. Nhut, H.H.; Thanh, V.L.T.; Le, L.T. Removal of H2S in biogas using biotrickling filter: Recent development. Process Saf. Environ. Prot. 2020, 144, 297–309. [CrossRef]