Research Article

Efficiency of the Integrated Nitrogen Removal Device to Remove Ammonia in a Hog House

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It is crucial to explore new methods to deal with ammonia pollution in hog barns. In this experiment, ammonia gas generated from the decomposition of nitrogenous organic matter, such as feed and manure in hog barns, was studied. Growing environmental parameters monitored included temperature, humidity, and ammonia nitrogen concentration. For 92 days between March and May, ammonia emissions were characterized by monitoring and collecting the ammonia concentration during the selected time. The results showed that the average temperature in the hog house was $18.2 \pm 2.7°C$, the humidity was $62.7 \pm 0.3\%$, and the average ammonia concentration range was $17.7\sim23.1 \, \mathrm{mg \, m^{-3}}$. The collected ammonia-nitrogen-containing wastewater that entered the denitrification device showed 173, 232, 201, and 280 $\mathrm{mgNH_4}$-N/L, respectively. An integrated denitrification device with anaerobic ammonia-oxidizing bacteria as a functional strain was used for denitrification treatment. Through the change of ion concentration in the incoming and outgoing water, an 85.5% average denitrification efficiency was calculated according to the denitrification reaction chemical formula. Thus, the results presented here provide data support for the future use of microbial denitrification equipment to treat ammonia in hog houses.

1. Introduction

The breeding environment of hogs is directly related to herd health. A good livestock house environment ensures livestock and poultry health, fully utilizes its production performance, and complies with animal welfare requirements. However, due to the rapid development of the large-scale breeding industry, the increasing density of hog farms and the harsh breeding environment have become fundamental problems restricting the development of the large-scale swine industry. The livestock productivity depends 20% on genetics, 40%~50% on nutrition, and 30%~40% on environmental conditions [1], where ammonia is one of the leading noxious gases in hog houses. Ammonia in hog houses mainly comes from the anaerobic degradation of organic matter in fresh manure, feed residue, and microbial waste. The ammonia effect on the health of pigs depends on

its concentration. When low concentrations of ammonia cause mild poisoning in pigs, its manifestation is not very noticeable; however, it reduces the resistance of pigs and hinders their growth. High ammonia concentrations directly cause pigs to die and affect the health of breeders [2]. Therefore, it is essential to pay more attention to ammonia, take measures to timely and effectively control the ammonia concentration in hog houses, and optimize the air quality of the hog house to maintain the health of pigs and promote production. At present, most research focuses on mechanical ventilation [3]. Although directly exhausting the turbid air from hog houses by ventilation is the most direct and effective method to reduce the ammonia concentration, it does not fundamentally solve the emission reduction of ammonia, which will react with oxides in the air to generate secondary particles such as ammonium sulfate and ammonium nitrate. These secondary particles are an important

source of PM2.5 formation. In summary, how to remove the ammonia produced by the livestock breeding process is the fundamental problem to be solved.

There are three aspects in controlling and treating ammonia pollution in animal husbandry: source prevention and control, emission reduction in the breeding process, and end treatment. More well-established research on controlling nitrogen emissions at the feed source can be adjusted through the entire diet stage, and standards have been established. Various feed additives that meet the production needs have been developed, yet the research continues on cost-effective and nonresistant additives. Emission reduction in the feeding process is closely related to feeding management, and it is difficult to unify standards and requirements for all farms. The end treatment of ammonia has excellent potential in the environmental protection of aquaculture, and the emission reduction effect is also rather satisfactory, which is the general trend of ammonia emission reduction in the future. The main technical challenge of ammonia end treatment is maintaining the emission reduction effect at a higher load rate, increasing the biofilter medium's service life, and increasing the abundance and number of microorganisms in the biofilter medium.

The Labfors fermenter in this experiment is an integrated denitrification device, which occupies a small area and contains a probe that can be flexibly configured according to the required measurement data. The open-air path makes it suitable for microbial cultivation, high-density cultivation, and anaerobic culture. It has also been used in nitrogen and phosphorus removal research and tailgas collection and analysis, but no research has been performed on the ammonia removal in swine houses. This study selected the temperature, humidity, and ammonia concentration of the pig growing environment as the main environmental parameters for monitoring. Ammonia concentration monitoring was conducted for 100 days, ammonia emission characteristics were analyzed, and the main environmental factors affecting ammonia emissions were comprehensively evaluated. Based on the performance of the integrated denitrification unit to effectively remove ammonia nitrogen wastewater, the ammonia gas collected in the hog house was passed to the integrated denitrification unit. The reactor parameters and NH_4^+, NO_2^-, and NO_3^- concentration changes in the inflow and effluent were monitored, and the denitrification efficiency of the device was optimized based on the stoichiometric method.

2. Materials and Methods

2.1. Hog House Layout.

An experimental hog house in Changchun City was selected as the test site. The hog house was a double-slope windowed structure 40 m in length, 12 m in width, and 3 m in height. The columns were arranged in two rows and a single walkway in the middle of the hog house. The test hog house was equipped with a storage room, a feeding area, and a tower. Figure 1 shows the layout of the hog house. Two ammonia sampling points (A/B) were set in the middle of the hog house corridor, and the ammonia

concentration at this point was calculated as the emission concentration. An atmospheric sampler (FCC-1000H, Yancheng Tianyue) was used to collect gas samples. The height of the sampler is 1.2 m above the ground, and the sampling flow rate is $100 \, \text{L} \, \text{h}^{-1}$. During the experiment, 190 pigs in the fattening hog house, aged about 100 days, were fed daily at 8:30 and 16:30.

2.2. Temperature and Humidity Collection.

The fattening hog house used mechanical ventilation with an automatic temperature sensor controlling the fan operation. Temperature and humidity data collectors (RS-YS-GPRS-B) placed at both ends and along the middle aisle of the longitudinal axis of the hog house automatically collected the temperature and relative air humidity at 10 min intervals.

2.3. Integrated Denitrification Device.

A Labfors bench fermentation tank composed of a tank body and a host served as the experimental reaction device (Figure 2). The host can use IRIS software to adjust the reactor parameters remotely, including stirring speed, temperature, pH, DO, and gas mixing ratio. The Environmental Engineering Laboratory of Suzhou University of Science and Technology provided the functional microorganism which was anaerobic ammonia-oxidizing bacteria. After 400 days of stable denitrification, the denitrification effect is good. During this experiment, the working volume of the bioreactor was 4.5 L, the working temperature of the reactor was 30°C, and the pH was 7.5 ± 0.5. For intermittent aeration, a mechanical agitator in the fermentation tank was used for the disturbance at a speed of 70 rpm with an airflow of 0.7–1.2 L/min during the aeration stage.

2.4. Test Methods

2.4.1. Determination Method of Ammonia Concentration.

Determination of ammonia nitrogen was performed according to the "Ambient Air and Exhaust Gas-Determination of Ammonia-Nessler's Reagent Spectrophotometry" Standard (HJ 533-2009). Briefly, 10 mL of $0.01 \, \text{mol} \cdot \text{L}^{-1}$ sulfuric acid absorption solution was prepared in the lab and added into the absorption tube. The mouth of the tube was sealed and sent to the experimental pig farm. The air in the hog house was collected at a flow rate of $100 \, \text{L} \, \text{h}^{-1}$ for 1 h. After sampling, the nozzle was sealed and returned to the laboratory. The sample analysis was completed on the same day. Simultaneously, blank parallel samples were tested throughout the process.

2.4.2. Ammonia Emission Measurement.

Combining the sampling time point and the fan running time, in this experiment, the hog house management activity time (7:00-17:00) was divided into 5 sampling periods (7:00-9:00, 9:00-11:00, 11:00-13:00, 13:00-15:00, and 15:00-17:00). The total amount of ventilation per period was multiplied by the corresponding ammonia concentration averages at 8:30, 10:
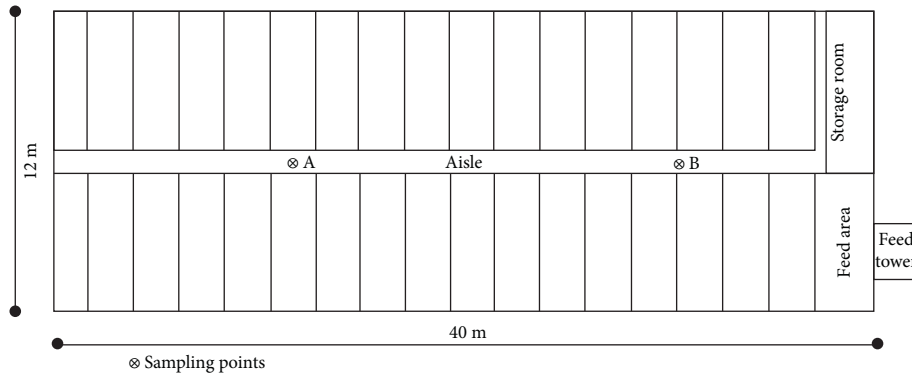
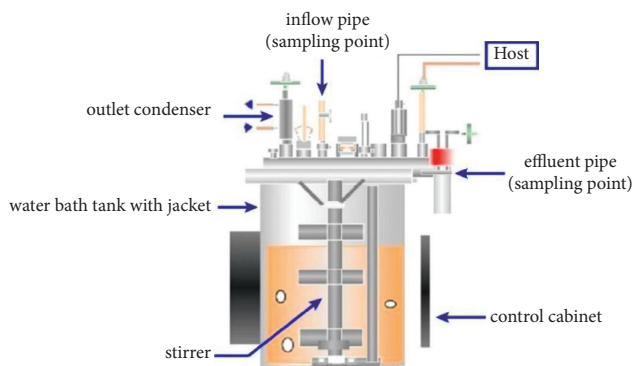FIGURE 1: Schematic layout of the fattening swine barn.

FIGURE 2: Schematic diagram of the integrated denitrification device.

30, 12:30, 14:30, and 16:30. The sum of the ammonia concentration averages represents the ammonia emissions during the day. On this basis, the ammonia emission at night was calculated by the night ventilation and ammonia concentration at 8:30, and the ammonia emission factor in the hog house was further calculated (E_{factor}, g·h·m^2) [4]:
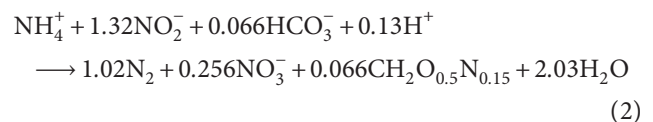
$$E_{factor} = \frac{\sum Q_j \times (C_{ji} - C_{jo})}{A \times t} \times 10^{-3}, \tag{1}$$

where Q_j is the total ventilation of the hog house during the j period in m^3; C_{ji} is the ammonia concentration in hog house in mg·m^{-3}; C_{jo} is the ammonia concentration in the atmosphere in mg·m^{-3}; A is the area of the hog house in m^2; and t is the time length of the j-th period in h.

2.4.3. Configuration of Ammonia Collection Solution. During the 92 days of the experiment, ammonia gas was collected every half a month a total of 4 times, and each sampling lasted for 7 days. Ammonia has a high solubility in water; thus, it was collected with a stock solution lacking only NH_4^+. The composition of the inflow water was $NaHCO_3$ (carbon source and alkalinity), 169.7 mg/L KH_2PO_4, 751.1 mg/L $MgSO_4·7H_2O$, 451.6 mg/L $CaCl_2·2H_2O$, 20.0 mg/L EDTA, 5.00 mg/L $FeSO_4·7H_2O$, 0.43 mg/L $ZnSO_4·7H_2O$, 0.24 mg/L $CoCl_2·6H_2O$, 0.99 mg/L $MnCl_2·4H_2O$, 0.25 mg/L $CuSO_4·5H_2O$, 0.22 mg/L $NaMoO_4·2H_2O$, 0.19 mg/L $NiCl_2·6H_2O$, and 0.21 mg/L $NaSeO_4·10H_2O$.

2.4.4. Inlet and Outlet Water Concentration Measurement. An ion-selective electrode (Labfors 3.6 L) measured the NH_4-N and NO_3-N concentrations in the incoming and outgoing water. The data were recorded online, and the specific data in operation in the IRIS online data acquisition system were selected. The NH_4-N and NO_3-N concentrations were also measured offline three times a week on average, and the online measured values were compared and calibrated. Throughout the experiment, the NO_2-N concentration was only measured offline with a colorimetric detection kit (BesetBio-470571). The chemical reaction would change the color intensity based on the concentration, and an ultraviolet spectrophotometer (722G-Jingke Shangfen) measured the concentration value. The denitrification efficiency was calculated using the measured changes in the inflow and outflow water concentration according to the stoichiometry equation (2) for autotrophic denitrification reactions.

$$NH_4^+ + 1.32NO_2^- + 0.066HCO_3^- + 0.13H^+$$
$$\longrightarrow 1.02N_2 + 0.256NO_3^- + 0.066CH_2O_{0.5}N_{0.15} + 2.03H_2O \tag{2}$$

3. Results and Discussion

3.1. Relationship between Ammonia Concentration and Temperature and Humidity in the Hog House. The livestock house environmental conditions mainly refer to the environmental temperature, relative humidity, light intensity, airflow speed, and air quality. Environmental temperature is an important factor affecting the normal production and life of pigs. Pigs are thermostatic animals that maintain body temperature within a specific range through heat production and heat dissipation [5]. The suitable temperature for fattening pigs differs by growth stages [6]. The suitable temperature for adult pig growth is 15~25°C, and heat stress will occur if the temperature exceeds 35°C. However, the suitable temperature for the newborn piglets is 34°C and then decreases 2°C every week, reaching 22~25°C at weaning. The suitable relative humidity (RH) is about 50%, and the ammonia concentration should be kept below 20 mg m^{-3} [7–11]; otherwise, bacteria proliferate in hog houses, and pigs get sick relatively quickly. Humidity is another

important environmental factor affecting the healthy growth of pigs. Studies have shown that when the humidity in the hog house is too low (<40%), the dust in the house can easily float in the air, inducing respiratory infections and causing respiratory diseases. Table 1 shows the daily average temperature and relative humidity during the 100 d of the experiment. Of the two ammonia sampling points (A/B) in Figure 1, the point with the least deviation from the average was chosen and given the shoulder mark.

The humidity in the hog house changes regularly every day, and the range of humidity changes is within the comfort range of pigs, consistent with previous studies [5]. Reports on livestock house humidity monitoring during summer showed that the fan running continuously for a long time maintained a low temperature, reducing humidity accordingly. Vanderstelt et al. [12] also reported that the temperature in the growth and fattening house showed noticeable daily rhythm changes in all seasons, with temperatures first increased and then decreased within a day. In spring and winter, the humidity standard error in the barn is relatively small, although there is a rather significant difference in humidity in the barn in spring. The higher ammonia volatilization in winter may be related to the dry matter content of manure in the house, the main characteristic factor affecting the volatilization of manure ammonia.

Figure 3 shows that, in the 92 days of spring, the temperature in the house varies from 14.5 to 21.9°C, and the humidity varies from 59.7–67.7%. The overall change is increasing due to the increase in outdoor temperature. The "Environmental Parameters and Environmental Management of Large-scale Pig Farms" (GB/T 17824.3-2008) promulgated by China in 2008 stipulates that the comfortable humidity for pregnant sow houses ranges from 60 to 70%, whereas that of growing and finishing houses is 60–75% [13]. The ammonia in hog houses comes from pig manure, and its production and discharge are affected by many factors, such as manure cleaning, feeding management, manure characteristics, environmental temperature, manure composition, and ventilation [12, 14]. The temperature in the hog house is maximized in summer (4~7°C) higher than that in other seasons, followed by spring. Spring is characterized by the highest humidity [4]. The possible reason for the positive correlation between ammonia concentration and humidity is that ammonia is highly soluble in water, so when the humidity is high, the air holds much ammonia; hence, the ammonia concentration is relatively high.

3.2. Ammonia Concentration in the Hog House.
Measurement statistics show that, in most small- and medium-sized pig farms in China, especially in closed barns, ammonia concentrations range from as low as 6–35 mg-m^{-3} to as high as 150–500 mg-m^{-3}, far exceeding the permissible concentration of ammonia in pig farms in China (25 mg-m^{-3}) [2]. Figure 4 shows the monthly change in ammonia during the test period.

The average daily ammonia concentration in the hog house is 17.7–23.1 mg m^{-3}, which does not exceed the GB/T 17824.3-2008 (25 mg m^{-3}). As shown in Figure 4, the highest ammonia concentration in the hog house in other months peaked at 8:30, while the lowest value appears at 12:30. At the same time point, the ammonia concentration does not vary significantly, and the daily variation of ammonia concentration in the pig barn is related to the ventilation in the barn. The ventilation rate at night in the hog house is low, and the ammonia concentration accumulates. Because the concentration is the highest at 8:30 and there is ventilation in the house afterward, the ammonia concentration decreases. The reduction in ammonia concentration in the house is related to the manual removal of manure. Zhang [15] studied that, for naturally ventilated and free intake of fattening hog houses, the ammonia concentration in the house dropped sharply after the first manure removal as the floor was washed after dry manure removal. Zhu et al. [16] studied that the ammonia concentration increased significantly after the first manure removal in natural ventilation and artificial feeding and fattening hog houses ($P < 0.05$). The reason is that the first feeding and manure removal is at the same period, which may also be related to whether the floor is washed after manure removal. In large-scale breeding farms, the ammonia concentration is lower in hog houses with better mechanical ventilation, such as the mechanical ventilation in fattening hog houses (3 months old fattening 91 d) reported by Wu et al. [17] studied with an ammonia concentration of 6.24 mg m^{-3}. The high ventilation frequency reduces the ammonia concentration in the hog house. Wu et al. [18] studied that the average ammonia concentration in mechanically ventilated fattening barns was 14.2 mg m^{-3}, and the ventilation of the barn in the early fattening stage was relatively small. Liu et al. [4] determined that the ammonia concentration range in the pigsty was 1.6~10.0 mg m^{-3}, but when the fan fails, the sampling point ammonia concentration reaches about 40 mg m^{-3}, exceeding the standard limit value of 25 mg m^{-3}. Zhu et al. [16] showed that the ammonia concentration during summer in a semienclosed fattening hog house in Jiangsu is 9-10 mg m^{-3}. The higher ammonia concentration in this hog house may be related to the stocking density and the age of the fattening pig during the experiment.

3.3. Ammonia Emission Rate in the House.
Studies showed that ammonia volatilization in feces and urine increases with temperature. When the environmental temperature increased from 4 to 20°C, ammonia volatilization increased by 3.6~5.8-fold [12]. The full-day ammonia emission value was the highest in summer, followed by winter. The reason was related to the higher temperature and greater ventilation in the hog house in summer. The increased ventilation is also conducive to the volatilization of ammonia in the blister manure tank, thereby increasing the ammonia emissions [19]. Ranbeeck et al. [20] used a multipoint gas sampler to continuously monitor the H_2S and CH_4 in the nursery hog house. Li et al. [21] used multipoint continuous gas sampling in a mechanically ventilated cow house to monitor CH_4 emissions continuously for a long time, and the system's accuracy was within 4.5%. Dai et al. [22] used a 1412i gas

TABLE 1: Daily change of temperature and humidity in the hog house.

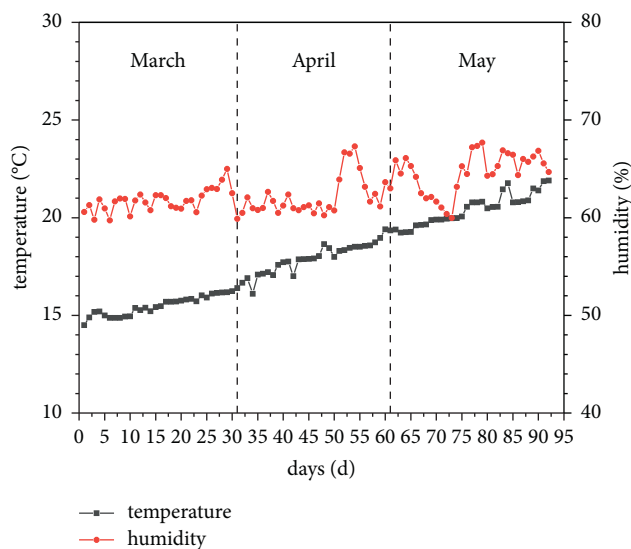| Season	Parameters	7:00	9:00	11:00	13:00	15:00	17:00	22:00	Standard error
Spring	Temperature (°C)	17.8[A]	18.2[A]	18.6[A]	19.3[A]	19.1[A]	18.5[B]	18.0	0.33
	Humidity (%)	63.5[B]	63.4[A]	62.4[A]	61.7[A]	62.5[B]	63.1[A]	63.2	0.25

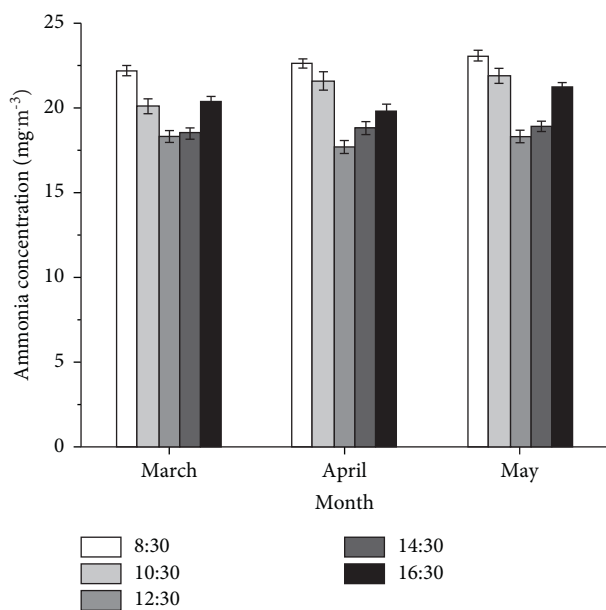FIGURE 3: Daily temperature and humidity in the hog house during the experiment.

FIGURE 4: Monthly changes in ammonia concentration.

analyzer and 1309 multichannel gas sampler to determine the emission rates of CH_4 and NH_3 in natural ventilated dairy houses. Tremblay and Masse [23] used multipoint continuous sampling to determine the odor emission of hog houses. Some scholars proposed that the multichannel gas collector could deliver multipoint gas samples to the gas analyzer, greatly facilitating the continuous monitoring of pollutants. However, the collector cost was high, not

conducive to popularization and application [3]. In this project, the air sampler FCC-1000H was used for gas collection.

As shown in Figure 5, the ammonia emission rate in the fattening hog house between March and May was $1.92 \sim 2.72\, g\, h^{-1}\, m^{-2}$, while the daily average ammonia emission rate was $1.51 \sim 2.61\, g\, h^{-1}\, m^{-2}$. Studies have shown that ammonia emission rates from fattening pigs progress from high to low in summer, winter, spring, and autumn. It has been reported that the average atmospheric ammonia concentration from January to July is $10–40\, \mu m\, m^{-3}$. The highest is in autumn, followed by summer, and the lowest is in spring, with $0.02\, mg\, m^{-3}$ [14, 24]. Therefore, the ammonia concentration $0.02\, mg·m^{-3}$ was selected for calculation as the atmospheric environmental background value. The research results of [4] show that the ammonia emission rate was $0.17 \sim 0.24\, g\, h^{-1}\, m^{-2}$, suggesting that higher emissions during the day might be related to the activities of pigs. Jacobson et al. [25] reported that the daily discharge rate of 12 h ammonia in the deep manure pit fattening hog house was $0.22 \sim 0.61\, g\, h^{-1}\, m^{-2}$, and its higher discharge was because the storage time of feces and urine in the manure pit was longer than the storage period of the experimental pig house (two months).

3.4. Denitrification Energy Efficiency of the Integrated Device. In this test, ammonia was collected from the house for seven consecutive days after obtaining the ammonia concentration and emission rate to ensure the influent concentration of the integrated unit in the future. The functional microorganism in the integrated denitrification device was anaerobic ammonia-oxidizing bacteria. The device maintained a pH of 7.5 ± 0.5 and a temperature of $28 \pm 2°C$. For intermittent aeration, a mechanical agitator in the fermentation tank was used for the disturbance at a speed of 70 rpm with an airflow of 0.7–1.2 L/min during the aeration stage. The solution in the gas collection device gas passed into the device for denitrification treatment. The influent concentrations of the four samples were 173, 232, 201, and 280 mg NH_4-N/L, respectively. Online monitoring and offline experiments were used, and a sampling test was performed every 15 min. During the operation, the various parameter indicators of the integrated device were controlled based on the denitrification reaction equation (2). The denitrification efficiency of the device was obtained through the change of the nitrogen ion concentration.

As shown in Figure 6, the four concentration change trends are the same, and the denitrification processes take 375, 405, 450, and 495 min, respectively. The concentration of NH_4^+ shows a downward trend with time and begins to stabilize in the last hour. The concentration of NO_3^- also shows an upward trend with time and stabilizes in the last half an hour. The concentration of NO_2^- is below 1 mg-N/L,
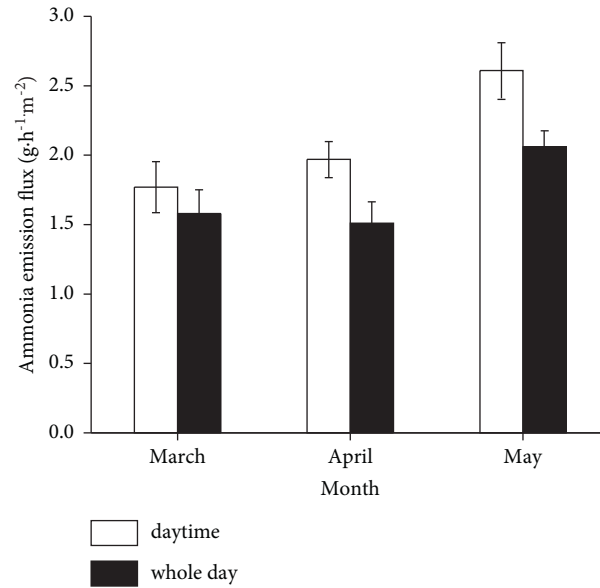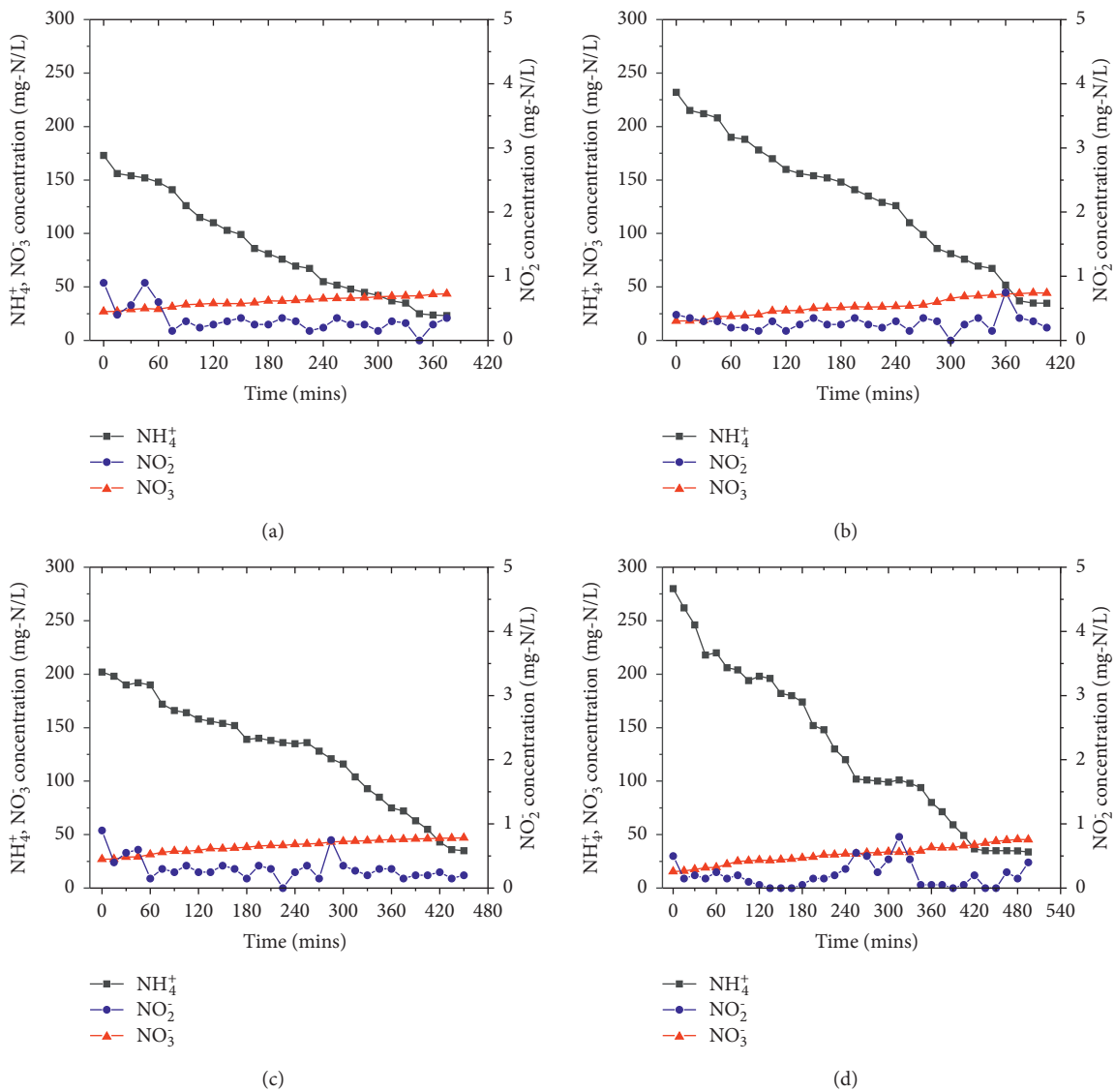
FIGURE 5: The emission rate of ammonia in different months.

FIGURE 6: NH_4^+, NO_2^-, and NO_3^- concentration changes in and out of water take influent concentration 173, 232,201, and 280 mg NH_4-N/L, graphs (a–d).

most of which is 0~0.5 mg-N/L. The nitrogen removal efficiency is 86.5%, 85%, 82.7%, and 87.9%, respectively, and the average nitrogen removal rate of the reactor is 85.5%. It can be seen that the reactor has a good nitrogen removal efficiency. It is feasible to remove ammonia gas in a hog house by this method.

4. Conclusions

In this experiment, the temperature, humidity, ammonia concentration, and emission rate in the hog house were monitored to study the monthly changes in the environmental indicators. The results showed that the average temperature and humidity in the test house were $18.2 \pm 2.7^{\circ}$C and $62.7 \pm 0.3\%$, respectively. The possible reason for the positive correlation between ammonia concentration and humidity is that ammonia is readily soluble in water, and with high humidity, the air retained much ammonia; hence, ammonia concentration was relatively high. The hog house ammonia concentration during the daytime management activities was $17.7–23.1 \, \mathrm{mg \, m^{-3}}$, which did not exceed the GB/T 17824.3–2008 ($25 \, \mathrm{mg \, m^{-3}}$) limit, and the ammonia emission rate was $1.92~2.72 \, \mathrm{g \, h^{-1} \, m^{-2}}$. Ammonia in the house was collected and passed to the integrated denitrification device with influent concentrations of 173, 232, 201, and 280 $\mathrm{mgNH_4}$-N/L, respectively. After running for 375–495 min, the final average denitrification efficiency reached 85.5%. The ammonia removal from swine barns with an integrated denitrification unit showed positive lab test results, providing data to support ammonia microbial denitrification devices for ammonia removal in swine barns. Future research directions should aim at the collection and processing of ammonia in swine houses. Jilin Province is an agricultural province, and it can promote the removal of ammonia in other livestock breeding houses within this province, which is conducive to the growth, development, and reproduction of livestock and poultry and improve the breeding efficiency.

Data Availability

The experimental data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

C.L. and N.L conceptualized the study and prepared the original draft of the manuscript; C.L. and M.L. formulated the methodology; M.L. and S.Z. varied out validation; C.L. M.L., and S.Z. conducted investigation; Y.L. and M.L. curated data; S.Z. reviewed and edited the manuscript; N.L. performed visualization; M.L. supervised the work; Z.L. was involved in project administration;and C.L. acquired funding. All authors have read and agreed to the published version of the manuscript.

References

[1] P. Yan and R. Li, *Livestock Environmental Hygiene*, Higher Education Press, Beijing, China, 2011.

[2] J. Cui, J. Guo, and X. Yang, "Harm and control measures of ammonia in pig house," *Animal husbandry and animal medicine*, vol. 20, pp. 13–15, 2017.

[3] J. Tian, Y. Bi, and T. Liu, "Design of multi-channel ammonia gas collector in mechanical ventilation breeding house," *Journal of Inner Mongolia Agricultural University (Natural Science Edition)*, vol. 40, no. 2, pp. 65–70, 2019.

[4] Y. Liu, B. Shang, H.-M. Dong, X.-p. Tao, W.-q. Xu, and P.-y. Yang, "Ammonia production and emissions from a mechanically ventilated fattening swine confinement building," *Journal of Agro-Environment Science*, vol. 39, no. 9, pp. 2058–2065, 2020.

[5] H. Gao, L. Jiang, J. Wang, and X. R. Che, "Study on the variation of temperature, humidity and CO_2 concentration in typical pig house in North China in different seasons," *Heilongjiang Animal Husbandry and veterinary*, vol. 7, pp. 83–87, 2018.

[6] K. Wang, X. Miao, S. R. Cui, C. M. Hogenboom, and R. Geers, "Effects of ambient temperature and relative humidity on physiological parameters and performance of growing pigs," *Transactions of the Chinese Society of Agricultural Engineering*, vol. 18, no. 1, pp. 99–102, 2002.

[7] J. Wang, "Study of management strategy for Pig breeding inhot season," *China Animal Husbandry & VeterinaryMedicine*, vol. 33, no. 6, p. 83, 2017.

[8] Y. Gao, Y. Diao, C. Lin, and Y. Liu, "Monitoring and analysis of thermal environment and harmful gases inmechanically ventilated multistory pig buildings," *Transactions of the Chinese Society of Agricultural Engineering*, vol. 34, no. 4, pp. 239–247, 2018.

[9] W. Wu, *A Study on Piggery Environmental Monitoring and Control System Based on Internet of Things*, Zhejiang University, Hangzhou, China, 2014.

[10] R. Chang, *Development of Environmental MonitoringSystem for Pig Breeding Based on Internet of Things*, Jiangsu University, Zhenjiang, China, 2019.

[11] Y. Gao, Z. Chen, Y. Wang, and X. Li, "Design for pigbreeding chamber under multiple environment variable control and analysis of internal flow field," *Transactions ofthe Chinese Society ofAgricultural Engineering*, vol. 35, no. 2, pp. 203–212, 2019.

[12] B. Vanderstelt, E. Temminghoff, P. Vanvliet, and W. Vanriemsdijk, "Volatilization of ammonia from manure as affected by manure additives, temperature and mixing," *Bioresource Technology*, vol. 98, no. 18, pp. 3449–3455, 2007.

[13] Standardization Administration of the PRC, *Environmental Parameters and Environmental Management of Large-Scale Pig Farm (GB/T17824.3-2008)*, China Standards Press, Beijing, China, 2008.

[14] J. Dong, C. Sun, Y.-g. Wang, X. Wang, M. Li, and J. Wu, "Dynamics of atmospheric ammonia concentrations over representative agricultural region in Beijing," *Journal of Environmental Engineering and Technology*, vol. 7, no. 3, pp. 262–267, 2017.

[15] B. Zhang, "Atmospheric distribution and variation of NH3 in Beijing," *Environment Science and Management*, vol. 41, no. 1, pp. 119–122, 2016.

[16] J. Zhu, L. Jacobson, D. Schmidt, and R. Nicolai, "Daily variations in odor and gas emissions from animal facilities," *Applied Engineering in Agriculture*, vol. 16, no. 2, pp. 153–158, 2000.

[17] W. Xu, X. Liu, L.-M. Meng, and K. Zheng, "Dynamics and pollution features of ammonia and particulate matter during different pig breeding stages," *Journal of Agro Environment Science*, vol. 37, no. 6, pp. 1248–1254, 2018.

[18] S. Wu, D. Shen, and Q. Tang, "Distribution of particulate matters and noxious gases in large-scale semi-enclosed swine houses," *Animal Husbandry and Veterinary Medicine*, vol. 50, no. 3, pp. 30–38, 2018.

[19] F.-X. Philippe, J.-F. Cabaraux, and B. Nicks, "Ammonia emissions from pig houses: influencing factors and mitigation techniques," *Agriculture, Ecosystems & Environment*, vol. 141, no. 3-4, pp. 245–260, 2011.

[20] N. V. Ranbeeck, H. V. Langenhove, and P. Demeyer, "Indoor concentrations and emissions factors of particulate matter, ammonia and green house gases for pig fattening facilities," *Biosystems Engineering*, vol. 116, no. 4, pp. 518–528, 2013.

[21] X. Li, Z. Ye, and B. Li, "Influence of different ventilation system on the environment of nursery piggery in winter," *Transactions of the Chinese Society for Agricultural Machinery*, vol. 51, no. 3, pp. 317–325, 2020.

[22] X. Dai, J. Ni, Q. Pan, and K. Wang, "Temperature, humidity and air quality monitoring of typical nursing pig houses in East China," *Journal of agricultural machinery*, vol. 47, no. 7, pp. 315–322, 2016.

[23] F. J. B. Tremblay and D. I. Masse, "Instrumentation for precise quantification of methane emissions form dairy herds," *Canadian Biosystems Engineering*, vol. 50, no. 7, pp. 21–28, 2008.

[24] N. M. Ngwabie, K.-H. Jeppsson, S. Nimmermark, C. Swensson, and G. Gustafsson, "Multi-location measurements of greenhouse gases and emission rates of methane and ammonia from a naturally-ventilated barn for dairy cows naturally-ventilated barn for dairy cows," *Biosystems Engineering*, vol. 103, no. 1, pp. 68–77, 2009.

[25] L. D. Jacobson, B. P. Hetchler, D. R. Schmidt et al., "Quality assured measurements of animal building emissions: odor concentrations," *Journal of the Air & Waste Management Association*, vol. 58, no. 6, pp. 806–811, 2008.