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Chapter 1
Insight into the Removal of Pollutants by Various Treatment Technologies from Swine Wastewater in China

Rongxuan WANG

Abstract: Swine wastewater is a type of livestock and poultry breeding wastewater that contains high concentrations of organic matter, nitrogen, and phosphorus. Improper disposal of wastewater poses significant risks to both the environment and human health. China, as a leading livestock and poultry breeding nation in Asia, has been actively exploring and developing swine wastewater treatment technologies to prevent pollution of surface and groundwater. However, the applicability of various technologies for treating swine wastewater remains a challenge. In this study, the applicability of wastewater treatment technologies in pig farming was investigated in China. Several full-scale case studies were reviewed, focusing on different treatment processes, including anaerobic, aerobic, and combined systems. Additionally, the current status of livestock farming, management practices, and the technologies used for wastewater treatment are discussed in detail. Finally, the challenges and key strategies for improving swine wastewater treatment, as well as future perspectives for the field, are highlighted, with emphasis on the importance of selecting appropriate treatment technologies based on factors such as the scale of the pig farming, local environmental conditions, and economic feasibility. Anaerobic treatment processes, such as biogas production, have proven effective in reducing organic matter and producing renewable energy. Aerobic processes,

on the other hand, are efficient in removing nitrogen and phosphorus but require more energy input. Combined systems, integrating both anaerobic and aerobic treatments as well as natural treatment such as constructed wetlands (CWs), offer promising results in addressing the diverse challenges associated with swine wastewater. Furthermore, the research emphasizes the need for policy support, livestock farmer awareness, and technological innovation to enhance the sustainability of wastewater management in China's pig farming industry.

Keywords: *swine wastewater, treatment technologies, anaerobic and aerobic systems, constructed wetlands, sustainability*

1. Pork and Feed Production in China

Swine wastewater is a byproduct of pig farming, one of the most significant sectors in global livestock production. As intensive pig farming continues to grow, particularly in countries and regions with large agricultural industries such as China, the United States, Europe, and Southeast Asia, the management of swine wastewater has become a critical environmental challenge. Swine wastewater is rich in organic matter, nitrogen, phosphorus, and pathogens due to the high volume of feces and urine produced by pigs. It also contains a variety of other pollutants, including suspended solids, heavy metals, and pharmaceutical residues like antibiotics used in pig farming. These contaminants can severely impact water bodies and even human health if not properly treated before disposal or reuse.

Consequently, this study provides an overview of the pig farming status, management practices, and swine wastewater treatment technologies in China. It supplies valuable data for scientists or technical staff to understand the utilization status of these technologies, assists

in selecting suitable swine wastewater treatment methods, and aids engineers in the design and operation of swine wastewater treatment facilities. The status of technologies and their applications for swine wastewater treatment in China has not yet been extensively examined.

Therefore, this study aims to (i) investigate pork and feed production in China; (ii) describe the current challenges related to swine wastewater in China, including issues associated with antibiotics, total nitrogen (TN), total phosphorus (TP), and chemical oxygen demand (COD); and (iii) evaluate the application of swine wastewater treatment technologies at full scale.

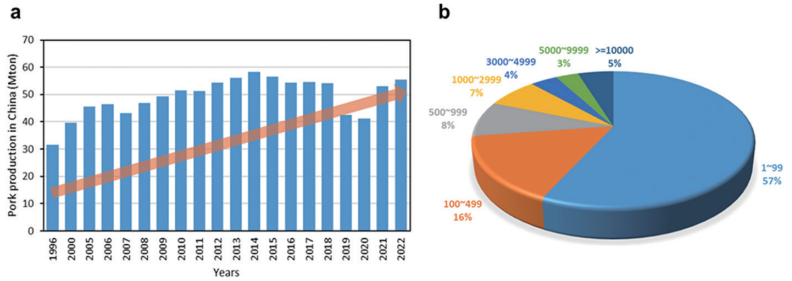
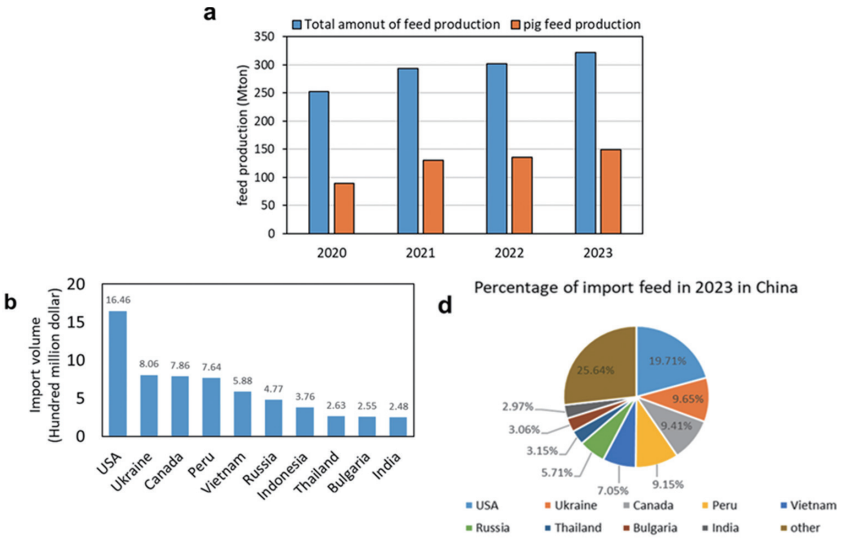


Figure 1. (a) Pork production from 1996 to 2022 and (b) percentage of pig breeding scale in China. Source: (National Bureau of Statistics of China 2023; Discharge Standard of Water Pollutants for Livestock and Poultry Breeding GB18596 2011).

The amount of feed and pig feed production in China is significant due to the country's large-scale pig farming industry. China is the largest pig producer in the world, which accounts for 50% of global pork production, reflecting its vast pig population. From 1996 to 2022, pork production in China has shown a fluctuating trend, with periods of growth and decline influenced by various factors such as policy changes, market demand, outbreaks of diseases (such as COVID-19), and

advancements in farming technology (Figure 1a). Moreover, China's pig farming industry is primarily composed of small-scale farms. An annual number of 1 to 99 pigs accounted for the largest proportion, which is 57% of the total number of pigs slaughtered in 2008, while those with more than 500 pigs accounted for only around 27% (Figure 1b). Therefore, Livestock and poultry breeding is still dominated by small and medium-scale operation in China. However, with the progress of agricultural modernization, it is expected that small-scale family farming will gradually decrease, while large-scale industrial farming will become more dominant. This shift toward large-scale farming is likely to enhance production efficiency and support the continued growth of pork output.



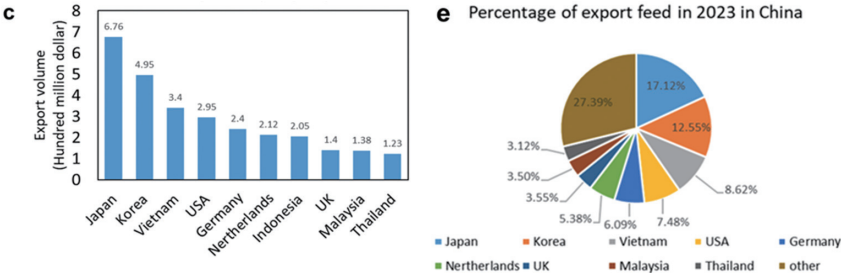


Figure 2. Total amount of feed and pig feed production in China from 2020 to 2023; The percentage of feed import and export feed in 2023 in China. Source: (CFNA 2023).

China's industrial feed production in 2022 reached 302.2 million metric tons (MMT), marking a 3% increase compared to 2021 (Figure 2a). The feed production remained relatively stable in 2023, with only minor fluctuations expected. During this period, corn usage in feed increased significantly, while the utilization of other grains like wheat and barley decreased. The feed production in China comprises various ingredients, including corn, soybean meal, and other grains, tailored to meet the nutritional requirements of pigs at different growth stages. This robust feed production sector plays a crucial role in ensuring a consistent supply to pig farms across the country, thereby contributing to the stability and growth of China's pork industry.

In 2024, China's feed production has been influenced by several factors, leading to an expected decline in total production due to reduced demand from the poultry and livestock sectors. This trend is largely attributed to fluctuations in the corn and wheat markets, although corn production is anticipated to increase slightly due to improved yields. Despite these challenges, China remains one of the largest global producers of pig feed, although demand has been volatile, particularly due to disease outbreaks and changing consumer preferences.

The development of the feed industry and the percentage of feed imports/exports in China are illustrated in Figure 2b, 2c, 2d and 2e. In 2023, the total feed production amounted to 321.627 MMT, with pig feed production totaling 149.752 MMT (CFNA 2020–2023). Overall, China's feed market is more import-dependent, with the United States being the most significant source of feed imports, valued at US$1.646 billion. Conversely, Japan is China's most important market for feed exports, with an export value of US$676 million (CFNA 2023).

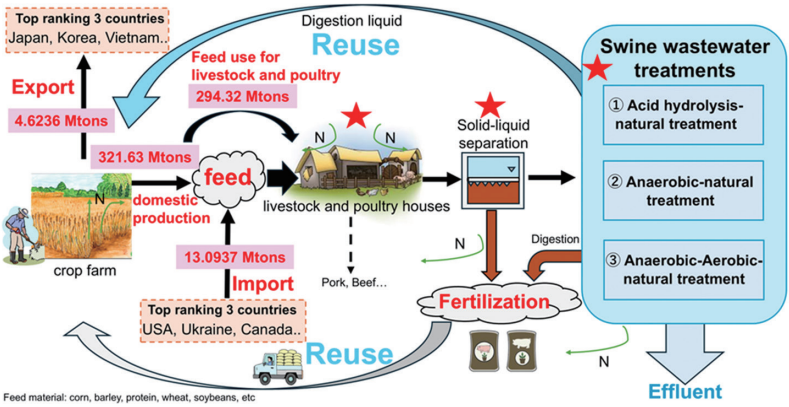


Figure 3. Flow diagram for feed use and swine wastewater in China 2023. Source: Author

2. Pretreatment of Swine Wastewater

Livestock manure is predominantly produced by cattle, pigs, and poultry. According to statistics, approximately 551 million tons of livestock manure (dry weight) were produced in China in 2014 (Jia et al. 2018). In this study, three main types of pig farming models are identified in China: (i) Open Pig Houses: these have a simple construction, which saves materials, ensures good ventilation and

lighting, and facilitates the easy discharge of harmful gases. (ii) Closed Pig Houses: these offer excellent thermal insulation and high space utilization, but their complex structure leads to higher construction costs. (iii) Greenhouse-style Pig Houses: these have constant temperature, good lighting, and are particularly convenient for daily disinfection and epidemic prevention. Regarding the management of feces and urine produced in pig houses, liquid components account for a large portion, reaching 56%. Pig slurry (a combination of urine and feces) accounts for 36%, which contains a lot of water. Therefore, the method of treating the liquid is important. Furthermore, solid waste makes up 8% of the amount of waste which is treated and used as fertilizer. It is evident that urine management plays a significant role in the overall waste treatment process in pig farming, with about 12% of the liquid waste flowing into sewage treatment facilities. Additionally, mechanical separation, which is used for treating mixed manure, accounts for 24% of the waste management methods employed.

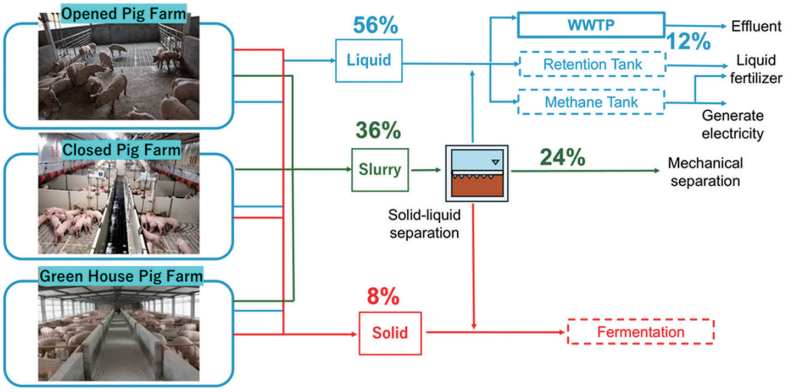


Figure 4. The three types of opened, closed and greenhouse pig house. Source: Author

3. Swine Wastewater Pollution Problems on Organic Matters and Antibiotics

(1) Bibliometric Analysis in Swine Wastewater

A comprehensive search of the Web of Science database of the time between 2010 and 2025 was conducted using the keywords "swine wastewater," while the search terms were screened in the "subject" of the publication. A "title, summary" analysis was performed using Vosviewer software to determine the keyword evolution of swine wastewater treatment (Figure 5). The size of nodes in the figure represents the frequency of keywords used. From the analysis of keywords, we note that the treatment of swine wastewater by water quality parameters is closely related, which mainly involves some treatment technologies to remove pollutions. The main keywords in terms of swine wastewater are COD, production, antibiotic, bacterium, wetland, etc.

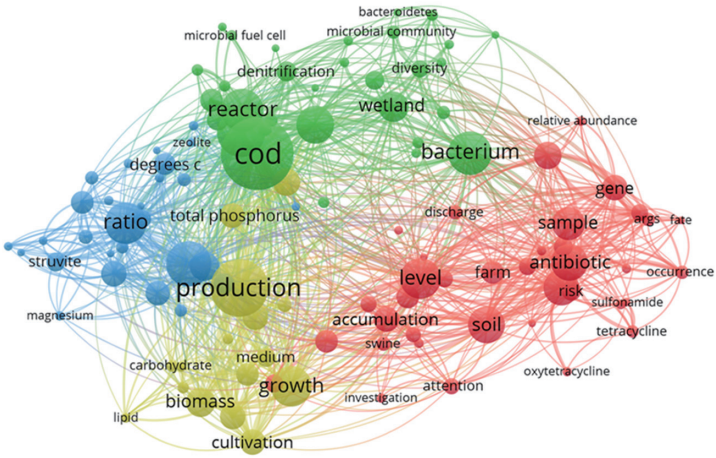


Figure 5. Network analysis of relevance keywords related to swine wastewater. Source: Author

(2) Organic Matters in Swine Wastewater

The pig industry is the largest polluter among all livestock and poultry breeding industries. The manure and urine produced are as follows: 0.55 kg/head/day and 1.14 kg/head/day for nursery pigs, 1.17 kg/head/day and 2.87 kg/head/day for fattening pigs, and 1.73 kg/head/day and 6.42 kg/head/day for sows (Table 1). Livestock and poultry breeding wastewater primarily includes urine, manure, and flush water. Each pig generates 10 to 15 liters of wastewater. Consequently, the wastewater concentrations of TN and TP are 1.43 g/L and 0.27 g/L for nursery pigs, 3.84 g/L and 0.73 g/L for fattening pigs, and 4.99 g/L and 1.25 g/L for sows. Furthermore, swine wastewater contains high pollutant concentrations, with biochemical oxygen demand (BOD_5), COD, and ammonia nitrogen (NH_3-N) generally being 10 to 100 times higher in intensive pig farms compared to municipal wastewater (Table 3). The high concentration of organic matter poses a significant pollutant risk to the water environment. In China, the amount of manure and wastewater discharged by swine accounts for 76.8% of the total manure and wastewater from all livestock and poultry (Wu et al. 2018). Therefore, it is essential to treat and utilize swine wastewater.

Table 1. Average daily feces and urine production per pig in China

Pig type	Feces (dry weight base) (kg/head/d)	Urine (kg/head/d)	TN (g/head/d)	TP (g/head/d)	Wastewater (L/d/head)
Nursery pig	0.55	1.14	14.26	2.74	
Fattening pig	1.17	2.87	38.42	7.29	10–15L
Sow	1.73	6.42	49.89	12.46	

Table 2. Cleaning methods and concentration of pollutants in pig wastewater in average mg/L

Feces cleaning	CODcr	NH_3-N	TN	TP	pH
Water flushing	21600	590	805	127	6.3–7.5
Dry collection	2640	261	370	43.5	

(3) Concentration of Antibiotics in Swine Wastewater

In the livestock and poultry breeding process, some antibiotics are used in animal therapy, while others enter the animal body through feed additives. In 2020, the total amount of veterinary antibiotics used in China was 32,776.298 tons, representing a 6.06% increase compared to 2019. Of this total, 9,000 tons were used as feed additives to promote animal growth, and 23,000 tons were used for animal therapy (Ministry of Agriculture and Rural Affairs of the People's Republic of China 2021). The top three veterinary drugs in terms of usage are tetracyclines, sulfonamides, and β-lactams and inhibitors, accounting for 30.52%, 13.08%, and 12.55%, respectively (Figure 6a). Unmetabolized veterinary antibiotics directly contribute to antibiotic residues in wastewater (Robles-Jimenez et al. 2022). The average concentration of major veterinary antibiotics in swine wastewater is approximately 1,145 μg/L. Among these, sulfonamides are the most dominant antibiotics in swine wastewater in China (Wan et al. 2021). Furthermore, Chen et al. (2012) reported high concentrations of tetracycline and sulfadiazine, detected at 41.6×10^3 and 98.8×10^3 ng/L, respectively, in swine wastewater in East China (Figure 6b). Consequently, the large discharge of antibiotics facilitates the spread of antibiotic resistance genes (ARGs) in swine wastewater, which can lead to microbial risks and contamination of reused water.

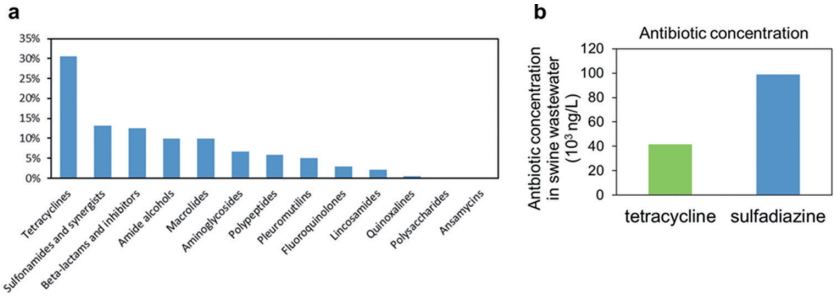


Figure 6. (a) Proportion of use of various types of veterinary antibiotics in China and (b) antibiotic concentration in swine wastewater. Source: (a) Ministry of Agriculture and Rural Affairs of the People's Republic of China 2021; (b) Chen et al. 2012.

4. Treatment of Swine Wastewater in Various Processes

In China, there are two main types of agricultural and livestock wastewater treatment methods. One is the anaerobic and natural treatment approach, while the other is the anaerobic and aerobic treatment approach. Both methods are widely used and promoted for their effectiveness in removing pollutants from agricultural and livestock wastewater.

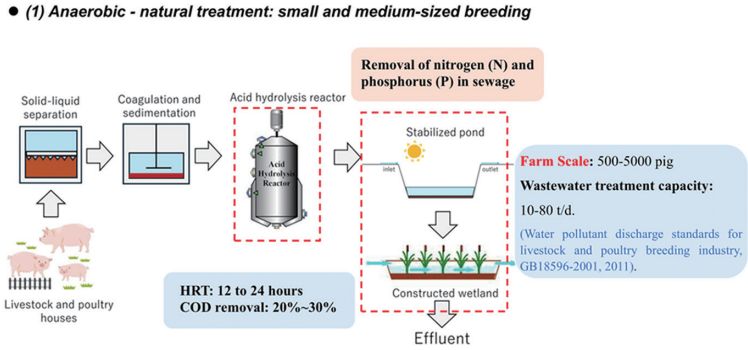


Figure 7. Anaerobic (acid hydrolysis reactor)-natural treatment in the small and medium-sized breeding farms. Source: (Discharge Standard of Water Pollutants for Livestock and Poultry Breeding GB18596 2011)

In 500–5,000 pig farms with a daily wastewater volume of 10 to 80 tons, the treatment process begins with a hydrolysis reactor. This reactor, equipped with a biological filler, provides an environment where wastewater is held for 12 to 24 hours. During this time, the reactor reduces the COD by 20% to 30%, which helps to break down organic pollutants. After the initial treatment, the wastewater proceeds to the subsequent treatment stage, which combines stabilization techniques with CWs. The stabilization processes help to further reduce contaminants and stabilize the wastewater quality. The final step involves passing the wastewater through CWs. These wetlands are effective in removing nitrogen and phosphorus, which are critical for meeting discharge standards and minimizing environmental impact (Discharge Standard of Water Pollutants for Livestock and Poultry Breeding GB18596 2011). By employing this multi-stage treatment approach, pig farms ensure that their wastewater is managed effectively, reducing pollution and adhering to regulatory standards.

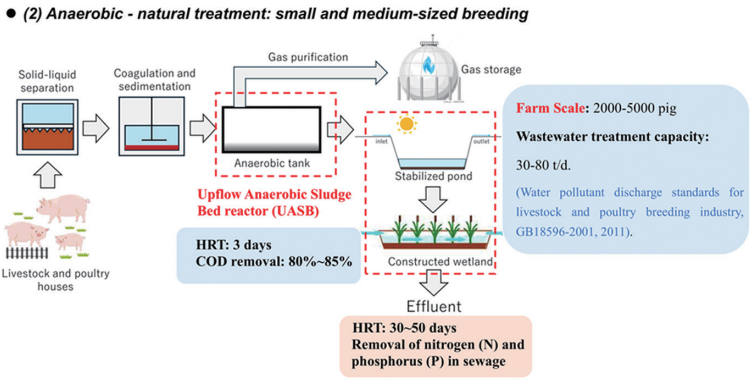


Figure 8. Anaerobic (upflow anaerobic sludge bed reactor)-natural treatment in the small and medium-sized breeding farms. Source: (Discharge Standard of Water Pollutants for Livestock and Poultry Breeding GB18596 2011)

In pig farms with capacities ranging from 2,000 to 5,000 pigs, where daily wastewater treatment capacities range from 30 to 80 tons, an efficient treatment process is crucial for managing environmental impact and adhering to regulatory standards. The treatment process begins with an anaerobic stage using an Up flow Anaerobic Sludge Bed (UASB) reactor. This reactor operates with a hydraulic retention time (HRT) of approximately 3 days. The UASB reactor is designed to facilitate the anaerobic digestion of organic matter in the wastewater, where microorganisms break down the organic pollutants in the absence of oxygen. This stage achieves a substantial reduction in the COD, with removal rates ranging from 80% to 85%. This significant reduction helps in mitigating the load of organic contaminants before the wastewater moves on to the next treatment stages. After the anaerobic treatment, the wastewater proceeds to the secondary treatment stage. This stage typically involves a combination of stabilized ponds and CWs. The wastewater first enters stabilized ponds, where it undergoes natural biological processes that further stabilize and reduce contaminants. This stage has an HRT of 30 to 50 days, allowing for thorough treatment through sedimentation and microbial activity. Following stabilization, the wastewater is directed to CWs. These wetlands are specifically designed to remove nitrogen and phosphorus from the wastewater, which are critical for meeting discharge standards and reducing the environmental impact. CWs utilize natural processes involving plant roots, soil, and microorganisms to effectively treat the water. The combination of the anaerobic UASB reactor and the stabilization + CWs approach ensures comprehensive treatment of the wastewater. This multi-stage process not only meets the stringent water pollutant discharge standards for the livestock and poultry breeding industry (Discharge Standard of Water Pollutants for Livestock and Poultry Breeding GB18596 2011) but also minimizes the potential

environmental impact. By efficiently removing organic matter, nitrogen, and phosphorus, the treatment system helps to prevent pollution and supports sustainable waste management practices.

In summary, this well-structured treatment process — starting with anaerobic digestion, followed by stabilization ponds, and concluding with CWs — ensures that wastewater from pig farms is managed effectively, reducing pollution and complying with environmental regulations.

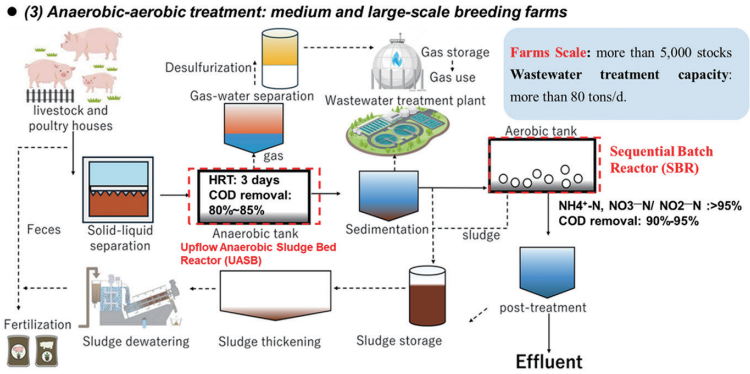


Figure 9. Anaerobic-aerobic treatment in the medium and large-scale breeding farms. Source: (Discharge Standard of Water Pollutants for Livestock and Poultry Breeding GB18596 2011)

For farms with over 5,000 animals and a daily wastewater treatment capacity exceeding 80 tons, a comprehensive and multi-stage treatment process is essential to effectively manage and reduce wastewater pollutants. The treatment process begins with an anaerobic stage using a UASB reactor. This reactor operates with an HRT of 3 days. During this period, the UASB reactor facilitates the anaerobic digestion of organic matter, where microorganisms break down the organic pollutants in the absence of oxygen. This stage achieves a

significant reduction in the COD, with removal rates ranging from 80% to 85%. This initial treatment effectively reduces the organic load of the wastewater before it progresses to the next treatment phase. Following the anaerobic treatment, the wastewater undergoes further treatment using a Sequential Batch Reactor (SBR). The SBR is an advanced aerobic treatment process that operates in batch mode, allowing for efficient removal of COD, nitrogen, and phosphorus. The SBR provides aeration and mixing in a controlled environment, which enhances the degradation of organic matter and the removal of nutrients. The SBR achieves a high COD removal rate of 90% to 95%, ensuring that the organic pollutants are effectively reduced. The SBR is also highly effective in removing ammonia and nitrogen, with removal rates exceeding 95%. This is crucial for meeting discharge standards and minimizing environmental impact. This multi-stage treatment process, combining anaerobic digestion with advanced aerobic treatment, ensures comprehensive management of wastewater. It not only meets the stringent water pollutant discharge standards for the livestock and poultry breeding industry (Discharge Standard of Water Pollutants for Livestock and Poultry Breeding GB18596 2011) but also minimizes the potential environmental impact by efficiently removing organic matter, nitrogen, and phosphorus. Overall, the wastewater treatment process for large-scale farms involves an initial anaerobic treatment using a UASB reactor followed by advanced aerobic treatment with an SBR. This approach provides effective pollution control and ensures compliance with regulatory standards, supporting sustainable waste management practices.

Table 3. Livestock wastewater parameters from intensive pig farm

Wastewater type	pH	SS (mg/L)	BOD_5 (mg/L)	CODcr (mg/L)	NH_3-N (mg/L)
Pig farm	7.5–8.1	5000–12000	2000–6000	5000–10000	100–600
Municipal wastewater	8.1	211.8	67.7	320.1	–

Source: (Guidelines for Best Available Techniques for Pollution Prevention and Control in Livestock and Poultry Farming 2011)

Table 4. The highest daily concentration of water pollutants discharged from the intensive livestock and poultry breeding industry.

Item	BOD_5 (mg/L)	COD (mg/L)	SS (mg/L)	NH_3-N (mg/L)	TP (mg/L)	Ecoli (CFU/mL)	Ascaris eggs (No./L)
Discharge Standard	150	400	200	80	8.0	1000	2.0

Source: (Discharge Standard of Water Pollutants for Livestock and Poultry Breeding GB18596 2011)

TN and TP are the two primary concerns in manure management due to their significant impact on environmental pollution (Cahoon et al. 1999). Table 3 and Table 4 show the pollution indicators for centralized pig houses and the highest daily discharge limits, respectively. Effective management of these nutrients is crucial to mitigate their adverse effects on water quality and ecosystem health. The 13th Five-Year Plan in China highlights the importance of controlling the discharge of pollutants, including COD, NH_3-N, TP, and TN. This plan aims to address and co-control these pollutants to reduce their environmental impact (State Council of the People's Republic of China 2016). Over 60% of farms in China lack proper dry and wet separation systems for manure management. This deficiency hinders the efficient handling and treatment of manure, exacerbating pollution issues. More than 80%

of large-scale livestock and poultry farms are deficient in essential pollution control facilities and investments. This lack of infrastructure impedes effective waste treatment and management. The extensive and often inadequate management practices in livestock and poultry farms contribute to significant environmental challenges. Despite regulatory efforts to control key pollutants, the current state of infrastructure and investment in pollution control remains a critical barrier to achieving effective manure management and environmental protection.

5. Perspectives

From a broader perspective, improving feed availability to increase self-sufficiency in pig farming presents significant opportunities for the agricultural sector in China. As one of the largest producers and consumers of pork globally, China faces immense pressure to ensure a stable and sustainable supply of pork to meet domestic demand. Enhancing feed availability contributes to reducing reliance on feed imports, promoting agricultural self-sufficiency, and stabilizing production costs for farmers. However, while the benefits of this approach are evident, it also introduces a new set of challenges that need to be addressed to ensure the sustainability of the pig farming industry in China. One of the key challenges is the environmental impact associated with the expansion of pig farming operations. As production scales up to meet increasing demand, the generation of waste, particularly wastewater, also increases significantly. This wastewater, if not properly managed, can lead to serious environmental issues, including water pollution, soil contamination, and the degradation of local ecosystems. The environmental footprint of pig farming is further exacerbated by nutrient runoff and greenhouse gas emissions, making it a critical area of concern for policymakers, researchers, and industry stakeholders.

Effective wastewater treatment is fundamental to addressing these environmental challenges. In China, the need for robust wastewater management systems is particularly urgent given the scale of pig farming activities and the potential for environmental harm if waste is improperly handled. Constructing and maintaining efficient treatment facilities that are specifically designed to address the unique characteristics of wastewater from pig farming is key to mitigating these impacts. Such systems must not only treat pollutants effectively but also be economically viable and adaptable to the varying scales of farming operations across different regions in China.

Ensuring the proper operation and maintenance of wastewater treatment facilities is another crucial aspect of sustainable pig farming practices in China. Regular upkeep and technical support are necessary to optimize system performance, prevent failures, and ensure compliance with environmental regulations. In many cases, small- and medium-scale farmers may require additional support in terms of training, resources, and financial assistance to implement and sustain these measures.

Evaluating and adopting the most effective wastewater treatment technologies is essential to achieving sustainable pig farming practices. In the context of China, it is important to consider solutions that are tailored to the specific needs and conditions of the region. Technologies that integrate low-cost materials, utilize locally available resources, and align with the environmental and economic goals of the country are particularly promising. For example, green technologies such as CWs, which use natural processes involving plants, microorganisms, and substrate materials to treat wastewater, could offer a cost-effective and environmentally friendly alternative for small-scale farmers.

6. Conclusion

These findings highlight that pork production and pig feed demand show an overall upward trend. Therefore, the issues related to feed supply and subsequent farm management present new challenges. Mechanical separation is a crucial method for pre-treating pig feces and urine and helps reduce the environmental burden of subsequent wastewater treatment. Swine wastewater treatment typically involves two main approaches: anaerobic-natural treatment for small to medium-scale operations and anaerobic-aerobic treatment for medium to large-scale operations. Selecting appropriate wastewater treatment technologies based on the scale of pig houses helps ensure compliance with safety discharge standards. This study gives a perspective and thus supports the safe reuse of water and its safe discharge into water environments.

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Chapter 1. Insight into the Removal of Pollutants by Various Treatment Technologies from Swine Wastewater in China

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