

Status Quo and Resource Utilization Technology of Sludge Treatment and Disposal

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Abstract: With the development of China's economy and the improvement of people's quality of life, the per capita sewage output has increased, resulting in an increase in the treatment load of the sewage plant, which in turn will increase the sludge output of the sewage plant. Sludge contains a large number of recyclable substances, at present, China's sludge treatment and disposal technology, has not been completely completed the stabilization treatment, it is difficult to talk about the resource utilization of sludge. Moreover, there is a serious phenomenon of "heavy water and light mud" in China, with high treatment costs, imperfect treatment technology, and low resource utilization. This paper expounds the treatment effect of China's current treatment and disposal technology, analyzes the development trend of sludge treatment technology, improves the utilization rate of sludge resources and reduces treatment costs.

Keywords: Sludge treatment, Treatment and disposal technology, Recycling.

1. Introduction

China's urbanization process continues to accelerate, the sewage treatment industry has also developed rapidly, China's investment in the sewage industry increased from 105.5 billion yuan in 2013 to 267.57 billion yuan in 2020. According to the statistics of the Ministry of Housing and Urban-Rural Development, by the end of 2020, China has built 4,326 urban and rural domestic sewage plants, with a sewage treatment capacity of 220.4 million m³/d, of which there are 2,618 urban sewage treatment plants [1]. As a by-product of sewage treatment, sludge production gradually increases with the increase of sewage treatment, and the annual output of sludge will reach 74.36 million tons by 2020 [3] (moisture content is calculated as 80%). However, the harmless treatment rate of urban sludge in China is only 53% [4-5], and about 40% of pollutants enter the sludge with the sewage treatment system [2], which contains pathogens, bacteria, parasite eggs and other harmful substances, and the harmless treatment rate of sludge in China is low, and the

secondary pollution problem caused by sludge is serious [6]. Since 2018, the State Council has promulgated and implemented the Law of the People's Republic of China on the Prevention and Control of Water Pollution (Second Amendment), strengthening the protection of the environment and ecology, and the treatment of sludge has become one of the important problems to be solved by sewage plants.

2. Current Situation of Sludge in Sewage Plants in China

2.1. Sludge source and production

China's sewage plants are still dominated by activated sludge method, and urban sewage passes through water treatment structures such as primary sedimentation tank, grit tank, secondary sedimentation tank, etc., and forms raw sludge through deposition, adsorption and other effects. The amount of mud produced by each structure is shown in the table below [1]

Table 1. Empirical Data on Mud Production of Various Structures

Handling structures	Mud production/ (L·m ³)	Moisture Content%
Primary sedimentation tank	14~25	95~97.5
Grit tank	7~9	95~98
Secondary sedimentation tank	10~21	99.2~99.6

With the increase in China's investment in the sewage treatment industry, by the end of 2020, 4,326 urban and rural domestic sewage treatment plants have been built nationwide, with a treatment capacity of 220.4 million m³/d, compared with 3,240 sewage plants in 2013, with a treatment capacity of 154 million m³/d, an increase of 133.5% and 143.1% respectively. At present, China requires the quality of some urban sewage effluent to meet the Class IV water standard, and the effluent of most urban sewage treatment plants is

difficult to meet the requirements, and it is necessary to transform or build a new sewage plant.

According to the data of the Ministry of Housing and Urban-Rural Development, the number of sewage plants has increased linearly, and by sorting out the data, it is expected that by 2023, the number of sewage plants will increase to 4,727, the treatment capacity will reach 259.43 million m³/d, and the sludge production will exceed 88.74 million tons.

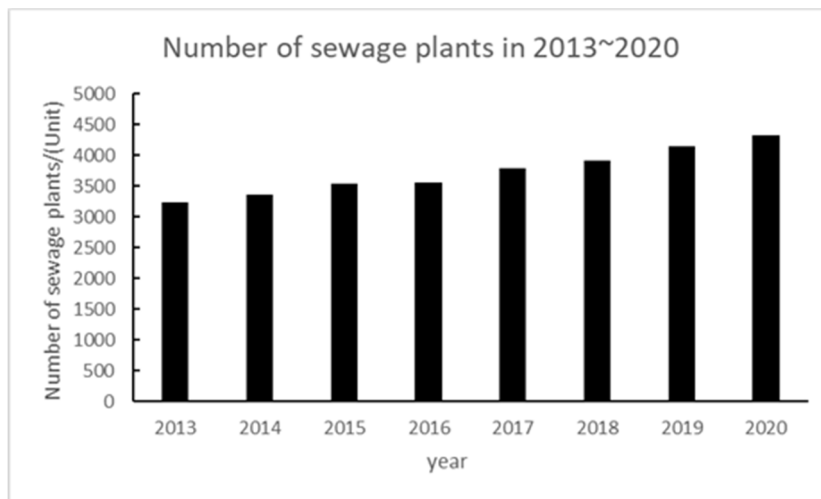


Figure 1. Number of sewage plants from 2013 to 2020

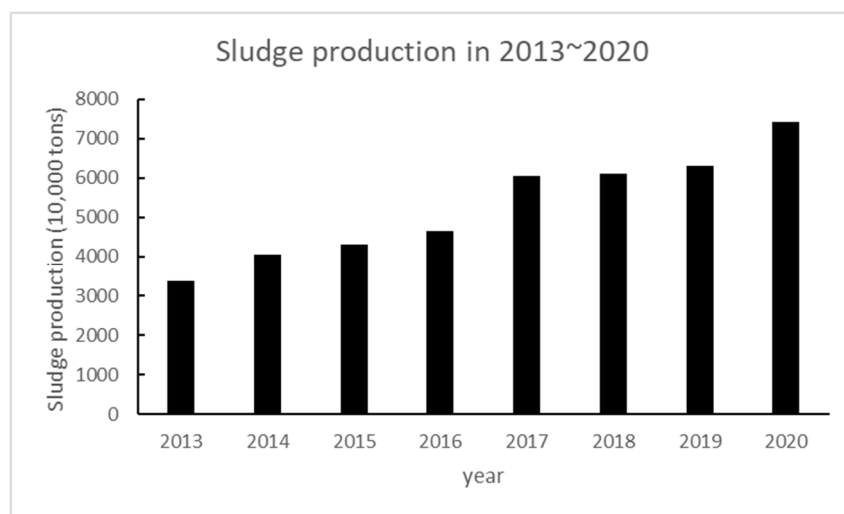


Figure 2. Sludge Production from 2013 to 2020

Through the collation and analysis of data, it is concluded that about 0.25 tons of mud per ton of water in 2013~2016, after the State Council issued the "Water Pollution Prevention and Control Plan", China's mud production began to rise. By

2017, the output of cement per ton increased to 0.3 tons, and with the improvement of effluent quality from Class A to Class IV water, China's sludge production is still in an upward trend.

Table 2. Sludge Production per Ton of Sewage from 2013 to 2020

Year	Sludge output per ton of water (tonnes)
2013	0.22
2014	0.25
2015	0.25
2016	0.26
2017	0.31
2018	0.3
2019	0.29
2020	0.32

2.2. Sludge properties

The semi-solid or solid matter intercepted by domestic sewage through the primary sedimentation tank, secondary sedimentation tank, biological filter tank and other semi-solid substances plus the metabolites left by activated sludge bacterial metabolism residue are formed after deposition, and the moisture content is usually about 95%. Due to the complex composition of urban sewage, sludge not only

contains sufficient water, N, P and other nutrients, but also contains a large number of macromolecular organic components, heavy metal ionic substances (such as Pb, Cr, Hg, Cu, etc.) and parasite eggs and other substances. If it is not properly treated, it is easy to cause environmental pollution [7]. The sludge composition of a sewage plant in Shanghai, a sewage plant in Guizhou and a sewage plant in Beijing was investigated, and the results are shown in the following table:

Table 3. Main Properties of Sludge

city	TN(mg/kg)	TP(mg/kg)	Pb(mg/kg)	Cu(mg/kg)	Cd(mg/kg)	Cr(mg/kg)
Shanghai	51.7	37.2	60.8	246	1.35	58.6
Guizhou City	45.3	41.4	40.57	121.09	2.71	23.81
Beijing	56.6	49.1	60.32	166.67	1.62	58.71

2.3. Hazards of sludge

It can be seen from the above table that the sludge contains a large number of heavy metal elements and nutrients such as nitrogen and phosphorus, which will cause environmental pollution if not effectively treated

1) Heavy metal pollution

The sludge contains high heavy metal ions, which are enriched in the sludge through precipitation, adsorption and other processes. Untreated into the soil, accumulated under the action of crops, animals, etc., through the food chain eventually endangering human health. Because industrial wastewater contains more heavy metals, the sludge produced is limited in land use.

2) Water pollution

The sludge that has not been effectively treated is washed by rainwater, and the organic matter and nutrients such as N and P in the sludge are dissolved into the water and flow into the lake, reservoir and other water bodies through surface runoff, which will cause eutrophication of the water body. Rapidly reproduce plankton in the water, reduce the content of dissolved oxygen in the water, lead to the death of fish in the water, and the water quality deteriorates [8]; At the same time, after osmosis, it is easy to pollute groundwater [9].

3) Pathogenic microbial contamination

The sludge contains hundreds of pathogens, and the total number of bacteria per kg of sludge is even millions, polluting soil, water sources, etc. [10]. They can be transmitted through the food chain and other ways, and ultimately endanger human life and health.

2.4. Status of sludge treatment

The sludge of China's urban sewage plant has the characteristics of large output, high moisture content, and contains a large number of pathogens, and the sludge needs to be treated "harmless, stabilized and reduced" to achieve recycling.

According to statistics, in 2019, China's sludge production has exceeded 60 million tons, of which incineration utilization accounts for 25.1% of these sludge (moisture content 80%), land use after anaerobic digestion and aerobic composting accounts for 25.5%, sanitary landfill accounts for 24.1%, building materials utilization accounts for 14.4%, and another 9.3% of sludge is treated by other means [11]. Western countries also deal with incineration and landfill [12-13]. However, sludge incineration will produce toxic and harmful gases such as dioxins and sulfur dioxide, and the leachate produced during the sludge landfill process is prone to secondary pollution if not properly treated.

In this era of resource scarcity, it is necessary to realize the recycling of resources, and the organic matter, nitrogen, phosphorus and other substances contained in the sludge are better reuse resources. From 2018 to 2019, China promulgated and implemented a number of rules and regulations, requiring the recovery of resource-based

substances in sludge.

In Europe, the European Union enacted the Solid Waste Land Landfill Act, which requires that the organic matter content of sludge used in landfills in European countries must be reduced year by year [14]. As of 2015, the United States produces an average of about 13.8 million tons of dry sludge per year, of which 50% of the sludge is recycled by sludge anaerobic digestion and land use [15], which is one of the countries with high sludge resource utilization rate in the world. Ireland has a well-developed agricultural model, with the main model being 80% agricultural and 20% compost[16].

3. Sludge Treatment and Disposal Technology

3.1. Dealing with the current state of technology

Sludge treatment is based on the principle of "reduction" and "harmlessness", and the sludge produced by the sewage plant is treated to meet the requirements of subsequent disposal [17]. In the sludge treatment stage, the commonly used treatment technologies in China include dehydration, anaerobic digestion and aerobic composting.

At present, sludge drying and mechanical dewatering are often used for sludge dewatering. Sludge drying is divided into natural drying and hot drying according to whether there is an external heat source or not. Natural drying of sludge is the use of gravity to infiltrate the water in the sludge and the water in the sludge into steam removal through evaporation. Due to the natural drying treatment, the dewatering rate of sludge is too low, the area is large, and the current domestic use of this technology treatment is less [18], solar drying is one of the natural drying technologies; Thermal drying of sludge refers to the process of using heat conduction to close the wet sludge to the heat source to achieve the purpose of removing water from the sludge. Mechanical dewatering is the removal of water from sludge by mechanical shear force. Commonly used mechanical dewatering methods are: vacuum filtration dewatering, press filtration dehydration and centrifugal dewatering.

Sludge anaerobic digestion refers to the process of decomposing biodegradable organic matter in sludge into carbon dioxide, methane and water by facultative bacteria and anaerobic bacteria under anaerobic conditions, so that the sludge is stabilized, which can be divided into three stages [20]: hydrolysis fermentation stage, hydrogen production acetic acid stage and methane production stage. Sludge anaerobic digestion mainly includes high-temperature anaerobic digestion, medium-temperature anaerobic digestion and two-phase anaerobic digestion. At present, the research hotspots are pretreatment of high-temperature hot water hydrolysis and high-solids anaerobic digestion, and there are mature technologies abroad.

Table 4. Comparison of sludge treatment technologies

Dehydration method		merit	shortcoming
Sludge drying	Solar drying	1) Low energy consumption and low operation and management costs; 2) After treatment, the volume of sludge can be reduced by 3~5 times, achieving stabilization and still retaining its original agricultural reuse value; 3) The system runs stably and safely, with low temperature and small amount of dust; 4) Simple operation and maintenance, long service life	1) Large area area; 2) The treatment effect is subject to weather and seasonal conditions; 3) Most of them operate under confined air conditions, and have high requirements for airtightness; 4) Deodorization equipment needs to be set.
	Heat drying	1) The volume of sludge is significantly reduced, and the volume can be reduced by about 4 times; 2) The sludge properties are greatly improved after drying; 3) Mitigate the negative effects related to sludge and make the treated product more acceptable; 4) Dried finished products have a variety of uses, such as fertilizer, soil amendment, alternative energy, etc	1) Large investment, high energy consumption and high operating cost; 2) The high temperature drying process and the product are easy to produce malodor after contact with water; 3) The dust control requirements of the drying process are strict, and there are potential safety hazards.
Mechanical dehydration[19]	Vacuum filtration	1) Able to operate stably; 2) High degree of automation	1) Large area area; 2) Complex operation 3) High operating costs
	Press filtration dewatering	1) Simple operation and low maintenance cost 2) Small footprint 3) Wide range of application	1) The airtightness is not good, and it is easy to produce malodorous gas 2) Small processing capacity.
	Centrifugal dehydration	1) Small footprint 2) Good airtightness 3) Easy to clean	1) High energy consumption and high noise 2) Human resources with specialized knowledge are required

Sludge aerobic composting refers to the ventilation treatment of sludge under manual intervention conditions, and the decomposition of macromolecular organic matter in the sludge through the fermentation of microorganisms, so that the sludge is converted into fertilizer [21-24]. The composting process generates a lot of heat, which can kill a large number of pathogens at high temperatures, and is a good soil amendment.

3.2. Status of disposal technology

Sludge disposal is the ultimate way to solve the sludge problem according to the standards stipulated in national laws and regulations, and realize the resource utilization and reduction of sludge [17]. Commonly used sludge disposal technologies include landfill, sludge incineration, building materials utilization, land use and other technologies.

Sludge sanitary landfill is divided into two ways: separate landfill and mixed landfill [25], and separate landfill needs to set up an independent sludge landfill for disposal; Mixed landfill is the landfilling of sludge together with household waste [26]. The sanitary landfill of sludge has the characteristics of simple operation and low operating cost, and is currently widely used in China. With the restriction of the use of land resources and the impact of environmental risks, sanitary landfills are gradually being replaced.

Sludge incineration is to burn dry sludge in a high temperature environment above 800 °C, and sufficient

oxygen is added to the reaction equipment in the process to ensure the full combustion of sludge. Although sludge incineration can reduce and stabilize sludge [28], in addition, sludge incineration will also produce CO₂ and some toxic and harmful gases, such as SO₂ and dioxins. Therefore, the waste gases generated need to be collected and treated during the incineration process.

The sludge contains a large number of metal elements and some inorganic compounds, which can be produced by calcination, filtration and other methods, and then add other auxiliary materials and additives to fire light aggregates [29], which are used to produce building materials such as bricks and lightweight plates.

The sludge contains abundant organic species, which can change the soil structure and improve soil fertility to a certain extent [30]. In addition, sludge increases the number of microorganisms in the soil while increasing soil organic matter and mineral nutrients, improves soil activity, and promotes biological reaction processes in the soil [31]. Since the sludge contains toxic and harmful substances such as heavy metal elements and polycyclic aromatic hydrocarbons, direct input into the soil will increase the content of soil toxic substances, which will be enriched with the growth of crops, and ultimately endanger human health. Therefore, national regulations stipulate that sludge disposal is not allowed to enter the soil if it does not meet the standard.

2.3 Sewage water quality of sewage plant

Table 5. Comparison of sludge disposal technologies.

Technical approach	merit	shortcoming
Sanitary landfill	1) Simple operation 2) Low operating cost	1) Large footprint 2) Easy to cause environmental pollution
Incineration	1) After the incineration method, the maximum distance can be reached Realize the "reduction and stabilization" of sludge; 2) According to the heavy metal content, the ash after incineration can be directly treated or treated with heavy metal chelating agent into the landfill, and can also be used as building materials or paving.	1) Large investment and high operating cost; 2) The sludge itself has a low calorific value and needs to be mixed with domestic garbage, coal, etc.; 3) High operation management requirements, improper treatment of incineration tail gas, easy to produce dioxins, causing secondary pollution
land use	1) Improve soil activity 2) Low energy consumption 3) It can be used for farmland and plant breeding	1) Heavy metals in sludge need to be treated 2) Strictly control the amount of application and the time of application during agricultural use
Utilization of building materials	1) Land is not required as the final destination for final sludge absorption 2) Some products can be used as building raw materials	1) The inorganic mineral components in the sludge are mainly used, and the organic matter in it cannot be fully applied, resulting in waste of resources 2) Preprocessing is required to increase operating costs

3.3. Technology trends

China pays more and more attention to environmental issues, and simple sludge treatment and disposal cannot fully realize the resource utilization value of sludge. With the improvement of China's technical level, a variety of treatment technologies are comprehensively treated to fully realize the resource recovery of sludge.

Anaerobic digestion + sludge dewatering + land use + biogas reuse technology is to first decompose the macromolecular organic matter in the sludge into methane and CO₂ through anaerobic treatment of the original sludge of the sewage plant, collect and treat the gas produced, CO₂ is directly discharged to the atmosphere, and methane can be recycled as fuel; Anaerobic digestion of sludge can improve the stability of heavy metals in sludge [32], so that the sludge treated by anaerobic digestion can be applied to the soil as a

good soil amendment to achieve the purpose of resource utilization of sludge..

Taking Gaoantun sludge hot water hydrolysis anaerobic digestion and resource utilization project as an example: the project adopts hot water lysis-anaerobic digestion-plate and frame dehydration-cogeneration-land use process, which has been in operation for 4 years, the current biogas yield is 300Nm³/thousand tons, the sludge reduction rate reaches 60%, and the annual power generation capacity is about 32.58 million kWh when running at full load, the self-sufficiency rate of electric energy can reach 66%, and it can also provide 28×,106 kcal of heat energy to realize resource recycling and save about 26,000 tons of standard coal per year. The biogas generated during the treatment process realizes sludge recycling through biogas treatment and biogas utilization system.

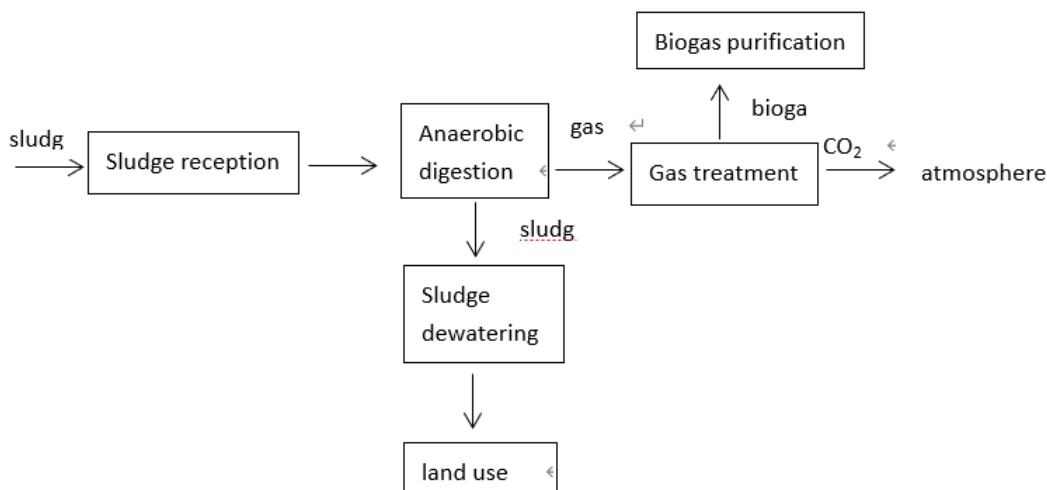


Figure 3. Technology roadmap

4. Conclusion

1) The Chinese port increases year by year, the output of sewage increases, and the output of sludge increases during the treatment process. The sludge contains more organic matter and some heavy metal elements, which has high resource utilization value.

2) At present, there are certain advantages and disadvantages in the resource utilization of sludge. Sludge treatment and disposal lacks certain government guidance, targeted resource utilization technology is not mature, resource utilization rate is not high, and there is a lack of sludge resource technology with a wide range of use.

3) The simultaneous application of a variety of sludge treatment and disposal technologies can not only improve the resource utilization rate of sludge, but also avoid environmental problems caused by a single treatment method and reduce operating costs. Sludge anaerobic digestion + land use + biogas reuse technology has become one of the hot technologies for sludge disposal in the future.

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References

- [1] LIU Xin, HUI Xiujuan, TANG Fengde. Analysis of the status quo and economic trend of treatment and disposal of typical urban sludge in China [J]. Environmental Protection and Circular Economy,2021,41(04):88-93.)
- [2] AN Ye, ZHANG Yibin, LI Pan, LU Ming. Current situation and experience summary of municipal sludge disposal in China [J]. Water & Wastewater, 2021, 57(S1): 94-98. XIE Kun, YIN Jing, CHEN Xing. Research progress of sludge disposal technology of urban sewage treatment engineering in China [J]. Industrial Water Treatment,2020,40(07):18-23.)
- [3] LIAO Kan, YANG Haowen, WANG Hao. Analysis of the status quo and suggestions of municipal sludge treatment and disposal in Guangdong Province[J]. Guangdong Chemical Industry, 2019, 46(04): 126-127+129.)
- [4] AN Ye, ZHANG Yibin, LI Pan, LU Ming. Current situation and experience summary of municipal sludge disposal in China[J]. Water Supply and Drainage, 2021, 57(S1): 94-98.
- [5] LIU Zhenyang, YANG Qian. Discussion on sludge treatment and resource development based on carbon neutrality[J]. Low Carbon World,2021,11(09):59-60.
- [6] Fu Xiujun. Research on the status quo and utilization of sludge treatment and disposal in sewage treatment plant[J]. Management Observation,2017(25):35-36.
- [7] Dai Xiaohu. Current situation and thinking of urban sludge treatment and disposal in China[J]. Water & Wastewater,2012,48(02):1-5.
- [8] JIANG Jing, LIU Lin. Soil phosphorus, nitrogen and water eutrophication [J]. Rural Practical Technology, 2020(01): 177-178.)
- [9] WANG Sheping, CHENG Xiaobo, LIU Xin'an, LI Lijun, WANG Yi, WANG Tongyue. Potential hazard analysis during sludge treatment in sewage treatment plant[J]. Municipal Technology, 2015,33(02):164-168.)
- [10] YAN Yingying, LIANG Yuan, SHA Xuehua, ZANG Xinghua, LIU Di. Thoughts on reducing pathogens in sludge under the new crown pneumonia epidemic[J]. China Water & Wastewater, 2020, 36(06):22-27.
- [11] XUE Chonghua, KONG Xiangjuan, WANG Sheng, et al. Current status, development and incentive policy requirements of industrialization of urban sludge treatment and disposal in China[J]. Water Purification Technology, 2018,37(12):33-39.
- [12] [Wang Kaijun. Adhere to the correct technical direction and steadily promote the sludge treatment and disposal work in China [J]. Water Supply and Wastewater, 2010, 36(10): 1-3,18.)
- [13] Seiple T E , Coleman A M , Skaggs R L.Municipal wastewater sludge as a sustainable bioresource in the United States [J]. Journal of Environmental Management, 2017, (197): 673-680.
- [14] LI Jinhong, HE Qunbiao. Overview of sludge treatment and disposal in Europe[J]. China Water & Wastewater, 2005(01): 101-103.
- [15] Shan Lingjie, Wang Songlin, Sun Yubo, et al. Analysis of sludge treatment and disposal status and resource utilization[J]. China Resources Comprehensive Utilization, 2020, 38(12): 192-194.
- [16] Chen Maozhe. Comparison of sewage sludge generation and treatment and disposal methods in 15 EU countries [J]. Energy and Environmental Protection ,2019, 33(01):6-12.) WEI Liang, JIN Xing, MA Liping. Research progress of residual sludge treatment and disposal technology of sewage plant[J]. Agriculture and Technology, 2021,41(08):8106-8108.
- [17] HUANG Hexun. Research on municipal sludge drying and pyrolysis based on microwave induction[D]. Huazhong University of Science and Technology, 2012.
- [18] XU Chunlian, JIANG Jinyuan, JIN Shunlong, ZHANG Zhao, ZHANG Wei, SHI Chenxi. Development status and prospect of sludge mechanical dewatering technology [J]. Environmental Engineering, 2016, 34(11): 90-93.
- [19] LIU Ting. Effect of combination of iron powder and hydrolysis on anaerobic digestion of sludge[D].Beijing University of Civil Engineering and Architecture,2020.)
- [20] YAN Hongtu, MENG Di, LIU Tianci, CHEN Chao. Analysis of aerobic composting treatment of urban sludge[J]. Building Materials and Decoration, 2018(49): 162-163.
- [21] LI Min. Aerobic composting technology of sludge and its application[J]. Smart City,2020,6(01):131-132.
- [22] GENG Xiaoshan, TANG Qingfeng, XING Meiyun, WANG Yin. Research progress of aerobic composting of urban sludge[J]. Journal of Anhui Agricultural Sciences, 2016, 44(18):107-110.
- [23] ZHU Gang. Research on aerobic composting control technology of residual sludge from urban sewage plant [D]. Jilin Jianzhu University,2014.
- [24] ZHOU Qianhui. Analysis of urban sludge disposal technology [J]. Science and Technology Wind, 2018 (01): 113.
- [25] Chen Y , Jiang X , Xiao K , et al. Enhanced volatile fatty acids (VFAs) production in a thermophilic fermenter with stepwise pH increase – Investigation on dissolved organic matter transformation and microbial community shift [J]. Water Research, 2017, 112(apr.1):261-268.
- [26] Li Zhixiang. Review on the disposal and resource utilization of municipal sludge[J]. Science and Technology Wind, 2021(07): 121-122.

- [27] Liu Yujie. Analysis of the current situation of urban sludge landfill technology[J]. Science and Technology Wind, 2017(06):167.
- [28] RU Lili, CHEN Gang, WANG Deyong. Introduction to the process of using sludge to produce ceramic pellets for building materials[J]. Brick and Tile, 2019(11):76-79.
- [29] Liu Xueya, Zhao Ya, Leng Pingsheng. Research progress on land use and environmental impact of urban sludge[J]. Journal of Agronomy, 2018, 8(06):21-27.
- [30] WANG Genmei, YANG Li. Effects of sludge application on basic soil properties and enzyme activities in forest land[J]. Ecology and Environmental Sciences, 2010, 19(8): 1988-1993.
- [31] XIE Jingliang, ZHANG Yanqing, SHEN Xiaonan. Conversion effect of sulfate on chemical form of heavy metals in anaerobic digestion system[J]. China Biogas, 2003(03): 22-25.