

# Optimizing the selection of small-town wastewater treatment processes

**Jianping Huang\*** and **Siqi Zhang**

School of Environmental and Municipal Engineering, North China University of Water Resources and Electric Power, Zhengzhou 450046, China

**Abstract.** Municipal wastewater treatment is energy-intensive. This high energy consumption causes high sewage treatment plant operating costs and increases the energy burden. To mitigate the adverse impacts of China's development, sewage treatment plants should adopt effective energy-saving technologies. Artificial fortified natural water treatment and use of activated sludge and biofilm are all suitable technologies for small-town sewage treatment. This study features an analysis of the characteristics of small and medium-sized township sewage, an overview of current technologies, and a discussion of recent progress in sewage treatment. Based on this, an analysis of existing problems in municipal wastewater treatment is presented, and countermeasures to improve sewage treatment in small and medium-sized towns are proposed.

## 1. Introduction

At the 2015 United Nations General Assembly, the 2030 Agenda for Sustainable Development was adopted and 17 Sustainable Development Goals were established. Goal 6, "Water and sanitation for all and its sustainable management", is considered a necessary step towards ensuring sustainable development in the area of water quality improvement <sup>[1]</sup>. As such, China has implemented a stringent water resources management system. The process of water user participation should be promoted, and the appropriate technology, processes, and modes should be selected in consideration of prevailing opinions and local conditions. In 2016, water consumption per 10,000 yuan of Gross Domestic Product dropped 5.6%.

The development of new sewage treatment capacity has been exceeded by China's rapid industrial growth and urbanization. From 2009 to 2015, the number of urban sewage treatment plants in China increased from 1878 to 3542, a compound annual growth rate of 11.25%, with a corresponding daily sewage treatment capacity increase from 105 to 170 million tons/day. Although the number of sewage treatment facilities in China has increased substantially, there remains a big gap between sewage treatment capacity and the overall societal demand for improving the water environment. In particular, the sluggish development of sewerage networks has led to inadequate utilization of sewage treatment facilities in many cities <sup>[2]</sup>. Compared with larger cities, small and medium-sized cities have invested



much less in sewage treatment, and most of the wastewater has been discharged directly into surface water bodies. Worse still, in rural areas, basic sewage collection and treatment infrastructure often is nonexistent.

Among the cities in China, large cities generally have abundant resources and specialized management systems, funds, and personnel<sup>[3]</sup>. Furthermore, environmental protection policies have typically been in place for a long time, sewage treatment facilities are relatively mature, and treatment standards are relatively high. Conversely, small and medium-sized cities are generally just now in the midst of the process of adequately treating sewage. Regarding treatment facilities, certain new construction and reconstruction inputs have been put forth in recent years. Due to the relative lag in development funds in county towns, there are problems such as inadequate sewage treatment infrastructure and low treatment standards for existing facilities. Thus, in consideration of the collective development potential of county towns, wastewater treatment facility construction and transformation are likely to soon reach a peak phase.

## **2. The status of urban sewage treatment technology**

### *2.1. Water pollution situation*

Urban sewage is an important source of water pollution, and the proper collection, treatment, and discharge of municipal sewage is a very important countermeasure to reduce and prevent water pollution<sup>[4]</sup>. Sewage treatment plants play a critical role in this process. Based on survey (MOHURC 2010), the mostly adopted treatment technologies in municipal WWTPs of China include oxidation ditch (30.5%), the anaerobic/anoxic/oxic (16.2%), conventional activated sludge (10.0%), anoxic/oxic (8.2%), and sequencing batch reactor (6.8%)<sup>[5]</sup>. Small towns using these processes often face high construction and operating costs, along with difficulty in ensuring adequate technical support and other issues. As such, small towns often cannot effectively build or operate normal sewage treatment plants.

The main problems facing small to medium-sized urban sewage treatment systems include: (1) low population, low water consumption, and small sewage treatment plants; (2) specific regional differences, affected by the rainy season and the amount of water when the coefficient of change is large, such that changes in sewage water output result in water quality changes; (3) low levels of economic development, low affordability, and few applicable technologies; (4) construction and operating costs are high relative to the populated served; and (5) maintenance and technical personnel management, including a serious lack of operations and management experience can pose additional challenges.

### *2.2. The characteristics of urban sewage technology*

Currently in China, it is difficult to treat urban sewage, domestic sewage, and industrial wastewater separately. Therefore, industrial wastewater comprises a considerable part of urban sewage, and urban sewage water quality often has higher suspended solids and organic matter concentrations than would be expected if these wastes were handled separately. However, urban drainage systems are imperfect, so rainwater and groundwater infiltrate into the sewage pipe network, and the resultant concentration of organic matter COD<sub>Cr</sub> is likely to 250 mg/L or less. Therefore, to meet China's urban sewage treatment needs, future systems must have a higher suspended solids and organic treatment efficiency, a better nitrogen and phosphorus removal capacity, a strong impact load capacity, lower infrastructure

investment needs, the provision of infrastructure funds, and must be easier to operate and manage [6]. The existing biochemical treatment-based processes in large-scale urban sewage treatment plants have solved some of the problems of urban sewage treatment, but they are not well-suited to the characteristics of urban sewage.

The state has a plan to invest more funds for urban environmental management. An increase in small-town sewage treatment is an excellent opportunity for the development of the environmental protection industry. However, in light of the current status of urban sewage treatment processes, the development of the environmental protection industry has certain difficulties. Chiefly among them is that current sewage treatment technology cannot meet the requirements put forth by the current level of industrialization. Due to the limitations inherent in the available processes, the sewage retention time is too long, such that, to ensure sufficient pool capacity, steel and concrete structures must be used. As such, the sewage treatment plant construction period is lengthy and requires a long-term investment. Furthermore, it is difficult for the sewage treatment facilities to acquire the appropriate equipment, in complete sets, and especially when constructed in a serial fashion. Therefore, the relevant supplier industry is scattered and small, and competition is fierce. Based on similar experience from other industries, the environmental protection industry must fully develop, and this development must be led by a systematic production of the necessary equipment. Such an undertaking would enable the development of the entire industry. Therefore, a focus in the development of sewage treatment-related industries is the efficiency and miniaturization of treatment facilities.

### 3. Urban sewage treatment process analysis

At present, the sewage treatment technologies commonly used in small town systems include: artificial wetlands, Constructed Rapid Infiltration (CRI), Continuous-flow Intermittent Biological Reactor (IBR), Alternated Internal Cyclic System (AICS), and Rotating Biological Contactor (RBC). A comparison and analysis of suitable processes for sewage treatment in small towns was performed (table 1).

**Table 1.** Comparison and analysis of suitable process for sewage treatment in small towns

Item	Technology	Infra- stru- cture costs	Opera- ting Cost	Manage- -ment difficult y	Occupied area	Sludge quantity	Treatme- -nt effect	Environmen- -tally sensitive area
Artificial reinforce- ment of natural water treatment	Artificial wetland	low	low	low	big	few	worse	Affected by the climate
	CRI process	lower	low	low	big	few	worse	
Activated sludge process	IBR process	medium	medium	big	medium	big	good	Suitable for low temperature areas
	AICS process	higher	high	high	medium	big	good	
Biofilm process	RBC process	medium	lower	low	medium	less	better	

#### 3.1. Artificial wetlands

Constructed wetlands are ecosystems with high pollutant removal capacity that simulate natural wetlands, including water, plantings, and other aquatic organisms. Filtration is generally provided from the soil, sand, gravel, and other components. Some pollutants are filtered, while others provide a growth medium for plants and microorganisms. Plants are selected for their treatment performance, high survival rate, and strong anti-load ability, thus enabling them to improve water quality, secure the bed surface, prevent wetland blockage, and provide a good root zone environment for microorganisms. Microbes can remove some of the pollutants as the season and plant growth changes, and are thus an important part of constructed wetlands. This treatment process keeps infrastructure costs low, requires low energy consumption during operation, has low operating costs, and there are no complex mechanical, electrical, or automatic control equipment needs, and operations and management have low technical requirements [7]. The disadvantage of this approach is that it necessitates a large land area, plus the sewage treatment efficacy changes based on the season, as its resistance to bad weather is low.

### *3.2. Constructed Rapid Infiltration (CRI)*

CRI treatment processes use the high permeability of natural river sand, add a certain amount of special filler as a filter for seepage after re-infiltration, and offer wet and dry alternate operating modes to remove water pollutants. Due to the growth of organisms and the sedimentation of suspended solids, excessive clogging of the surface of the percolation tank can be prevented, thus effectively restoring the permeability of the system. Furthermore, a redox (nitrification and denitrification) environment can be formed in the shallow section of the system, achieving the effect of removing pollutants [8]. The CRI process treatment efficacy is good and stable. Initial project investment and operating costs are lower, and system management is easy. There is less sludge production, practically eliminating sludge disposal problems, and thus also nearly eliminating the problem of secondary pollution. With CRI, it is easy to split the facility into modular construction systems, thus offering both scalability and flexibility.

### *3.3. Continuous-flow Intermittent Biological Reactor (IBR)*

IBR reaction tanks are divided into reaction zones (middle pool) and sedimentation zones (pool on both sides). The reaction zone is equipped with submersible pumps. Wave mass transfer devices and agitators reduce the blower room and aeration pipeline by jet aeration. The mixture containing activated sludge passes through the three-phase separator on both sides of the bottom of the tank for gas, solid, and liquid separation. Inclined pipe packing is installed in the settling zone, and the precipitated sludge can flow back to the reaction zone by itself to complete the inner cycle without power. Aged sludge is discharged through the mud tank bottom, and water is discharged from the top of the tank. Characteristics of the IBR process include less structural components and a smaller footprint. With changes in the influent sewage quality, quantity, temperature, and seasons, adjustments can be made to the reaction tank aeration, mixing, and precipitation cycles to achieve maximum simultaneous nitrogen and phosphorus removal at the lowest energy consumption and lowest operating costs [9].

### *3.4. Alternated Internal Cyclic System (AICS)*

AICS systems combines SBRs with activated sludge and oxidation ditch technology and are one of the most widely used methods in cold areas. They include hydrolytic acidification, with anoxic, anaerobic, and aeration units for nitrogen and phosphorus removal. They consist of alternating long-term and short-term processes, and the operating cycle of the system is generally 4-8 h. For the long-term process, the system has two aeration pools that can be used as sedimentation tanks. One acts as the influent to the aeration tank, while the other as the effluent for the sedimentation tank. The two aeration tanks in the middle always maintain the aeration state during both long-term and short-term processes. For the short-term process stage, the pond that is preparing to enter the sedimentation stage must maintain a short aeration and 0.5-h static precipitation to meet the final water quality requirements. This also ensures that the initial effluent water quality meets the appropriate standards when entering the long-term process. AICS systems have the advantage of good nitrogen and phosphorus removal and good system stability in cold areas, as they are minimally affected by temperature [10]. However, they require a larger land area, higher investment costs, and higher maintenance costs.

### 3.5. Rotating Biological Contactor (RBC)

RBCs developed on the basis of biofilters are widely used in small-town sewage treatment facilities across China. Microorganisms in the wastewater attach to the turntable disk as biofilm [11]. About 40-45% of the disk surface is immersed in the sewage. With each rotation of the disk, the biofilm absorbs the oxygen in the air and the nutrients in the sewage for one absorption-decomposition cycle. As the disk keeps turning, the sewage is purified. The RBC process is adaptable to fluctuating water quality and quantity, consumes little energy, has lower operating costs, is easy to manage; and is adaptable to lower temperatures.

## 4. Conclusion and prospects

Process optimization in small towns should meet the following principles:

- (1) Lower investment costs. Practitioners should try to adopt money and energy-saving processes and equipment, minimize the number of processing facilities, use appropriate treatment processes to reduce excess sludge emissions, and reduce the required dosages to reduce certain chemical costs.
- (2) Lower operating costs. Practitioners should choose shorter processes, fewer operating units, easier maintenance, and fewer operators, in order to reduce ongoing operations and maintenance costs.
- (3) Stable and reliable influent quality and quantity. For small-town sewage water quality, changes in the influent characteristics can be quite large. As such, practitioners should seek anti-impact loads, highly able to regulate the process, with mature and reliable processes, and, if necessary, should include some nitrogen and phosphorus removal capability to prevent eutrophication.
- (4) Simple operation, easy management. Due to the often-limited expertise of managers of small town sewage treatment facilities, these facilities should be conducive to operations and management by the available management staff.
- (5) Low environmental impact. The construction and operation of sewage treatment facilities in small cities can have an adverse impact on the surrounding environment. Especially true with constructed wetlands given their large area, certain impacts on the residents near where the facilities are located may exist, and may even harm the local environment and ecology.

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### References

- [1] UNESCO (United Nations Educational, Scientific and Cultural Organization), 2015. Water for a sustainable world. The United Nations World Water Development Report 2015. Available from: <http://unesdoc.unesco.org/images/0023/002318/231823E.pdf> (accessed 27.09.2015, in Chinese).
- [2] Sun, Y., Chen, Z., Wu, G., Wu, Q., Zhang, F., Niu, Z., Hu, H. Y., 2016. Characteristics of water quality of municipal wastewater treatment plants in China: implications for resources utilization and management. *Journal of Cleaner Production*, 131, 1-9.
- [3] BWA, 2013. *Water Resources Bulletin of Beijing 2012*. BWA, Beijing, China.
- [4] Bagatin, R., Klemeš, J., Reverberi, A.P., Huisingsh, D., 2014. Conservation and improvements in water resource management: a global challenge. *J. Clean. Prod.* 77, 1–9.
- [5] MOHURC, 2012. *Management information system on wastewater treatment in 2012*, Beijing, China (unpublished, in Chinese).
- [6] Wang, T., Liu, S., Qian, X., Shimizu, T., Dente, S. M., Hashimoto, S., Nakajima, J., 2017. Assessment of the municipal water cycle in China. *Science of the total Environment*, 607-608, 761-770.
- [7] Hussein, A., Scholz, M., 2017. Treatment of artificial wastewater containing two azo textile dyes by vertical-flow constructed wetlands[J]. *Environmental Science and Pollution Research*, 2017(7):1-20.
- [8] Zhu, W. T., Sima, X. F., Yu, L. P., 2012. Optimizing operational parameters of new constructed rapid infiltration system in villages and towns wastewater treatment[J]. *Chinese Journal of Environmental Engineering*, 2012, 6(5):1459-1466.
- [9] Wang, Y. C., 2016. Design of ibr process for wastewater treatment plant in a small town. *China Water & Wastewater*. 18:60-63.
- [10] Cui, Z. F., Wang, K. J., Jia, L. M, et al. Application of Alternated Internal Cyclic System[J]. 2004. *China Water & Wastewater*, 20(9):56-58.
- [11] Daudpoto, M. R., Talpur, G. H., Rind, U. A., et al. 2017. Response Surface Methodology for the Removal of Chemical Oxygen Demand through Rotating Biological Contactor[J]. *Sindh University Research Journal-SURJ (Science Series)*. 49(3): 617-620.