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Development and trial operation of small-scale integrated wastewater treatment equipment

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Abstract: *A set of small-scale integrated anaerobic-anoxic-aerobic wastewater treatment equipment was designed and produced, and the anaerobic-anoxic treatment link adopts vertical folding and the addition of filler, effectively improving the volume utilization rate and the degree of mud-water mixing. Through trial operation, the tank structure is optimized to effectively address the problem of sludge accumulation in the anaerobic area. The equipment has a high degree of integration, is easy to operate and manage, and is suitable for application in rural decentralized sewage treatment.*

Keywords: *small integrated wastewater treatment plant; vertical folding flow; rural decentralized wastewater*

1. Preface

According to "Yearbook of Urban and Rural Construction Statistics 2022" published by the Ministry of Architecture, as of 2022, 3636 townships treating domestic wastewater, accounting for 45.68% of the total; there were 2,456 township wastewater treatment plants nationwide, with wastewater treatment capacity of 1,460,800 m3/d, and wastewater treatment installations with a capacity of 1,278,300 m3 /d, and a national township wastewater treatment rate of 31%[1]. Year-on-year 2021 slightly improved, but the proportion of rural sewage treatment and treatment rate is still unsatisfactory. Then, China's rural areas are scattered, sewage centralized collection and treatment difficulties, management and maintenance difficulties, economic backwardness, and other characteristics, resulting in China's rural domestic sewage treatment accounted for the proportion of sewage treatment and the relatively low treatment rate.

Integrated rural domestic wastewater treatment facilities have become the mainstream approach for treating rural domestic wastewater due to their high integration, small footprint, minimal construction workload, and short construction periods. However, numerous issues currently exist in their practical applications, including unstable effluent quality, high operation and maintenance costs, difficulties in equipment selection, and challenges in equipment transportation, which hinder their promotion and utilization in rural areas[2].

Therefore, the present study is small integrated treatment equipment generally applicable to decentralized wastewater in rural and remote areas. This equipment can effectively improve the volume utilization rate and mud-water mixing, increasing the distance traveled by sewage in the limited space and increasing the reaction time between microorganisms and wastewater. At the same time, the design is hoped to provide a reference basis for designing and improving small-scale integrated domestic sewage treatment equipment in rural areas.

2. Design Principles

1) Only small-scale integrated wastewater treatment is suitable based on the rural layout and wastewater characteristics, considering limited economic conditions.

2) The layout plan should be compact with a minimal footprint.

3) The wastewater treatment process should be simple and practical, conducive to operation,

management, and maintenance.

4) The equipment is convenient to manufacture and install, with relatively low costs.

5) The wastewater treatment exhibits good performance, with low sludge production and relatively low energy consumption[3].

3. Process flow

Based on the design principles for rural wastewater treatment, this design incorporates the Vertical Flow Labyrinth (VFL) process. VFL represents a novel and highly efficient biological treatment unit. Inside the reactor, vertical baffles are installed to divide the reactor into several serially connected reaction chambers. Each chamber constitutes a relatively independent upflow-downflow sludge bed system, where sludge exists in granular or flocculent form. Guided by the baffles, the water flow zigzags up and down, sequentially passing through the sludge beds in each reaction chamber. It ensures thorough contact between the substrates in the influent and the microorganisms, facilitating degradation and removal[4]. The VFL process is characterized by low sludge discharge (near-zero emission), simultaneous wastewater and sludge treatment, and high efficiency with low energy consumption[5]. The process flow diagram of the equipment is illustrated in Figure 1.

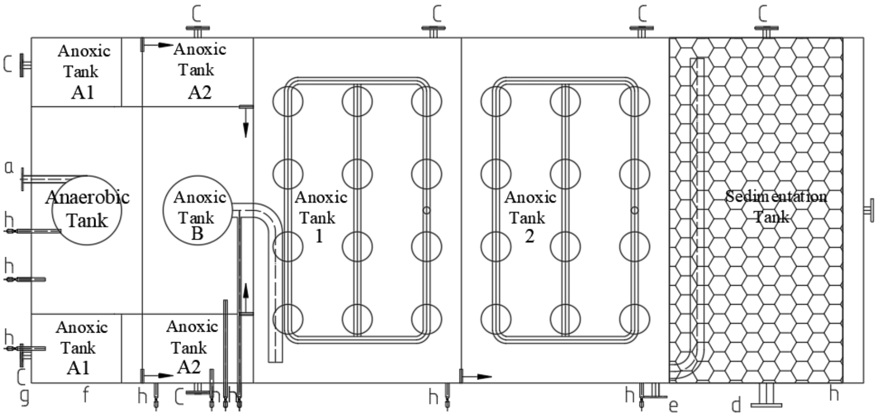

Figure 1: Profile flow diagram of integrated equipment

The flow path of wastewater inside the equipment is as follows: Wastewater enters the central flow zone of the anaerobic tank through inlet a at the bottom, rises and overflows the top of the cylinder into the external packing zone, and then enters the anoxic tank A1 zone on both sides through the bottom of the external packing zone. The anoxic tank A1 zone wastewater flows out from the upper outlet weir into the A2 zone on both sides. Then, it flows together from the outlet pipes at the bottom of the anoxic tank A2 zone on both sides into the external packing zone of the anoxic tank B zone. The wastewater continues to ascend and flows into the central flow zone of Zone B of the anoxic tank from the top of the cylinder in the same zone. Subsequently, the wastewater flows out from the outlet pipe at the bottom of the cylinder into aerobic tank 1. The wastewater flows from the bottom, rises and overflows the outlet at the top of Aerobic Tank 1 into Aerobic Tank 2. Aerobic tank 2 also has an outlet at the top to discharge wastewater into the sedimentation tank, with supernatant flowing from the upper outlet weir b. Inlet c is at the lower end of each tank and is the drain port. Inlet d at the lower end of the sedimentation tank is the sludge return port, connected to inlet a. Inlet e at the lower end of aerobic tank 2 is for wastewater recirculation. Each tank is equipped with inlet h, a wastewater sampling port.

4. Process description

4.1 Structure of the equipment

This equipment is fabricated using steel plates made of Q235-A.F material and is manufactured and tested according to JB/T4735-1997 "Steel Welded Atmospheric Pressure Vessels" to ensure equipment quality. The equipment's inner and outer walls undergo corrosion protection treatment, with a cover on top and a maintenance hole reserved. The equipment has a treatment capacity of $50m^3/d$, installed power of 1.708kw, and overall dimensions of L×B×H=6.0m×2.5m×2.5m. The hydraulic retention times are as follows:

· 1.44h for Anaerobic Zone A with dimensions (L×B×H=0.8×1.5×2.5)m

· 1.44h for Anoxic Zone A with dimensions (L×B×H=0.8×1.5×2.5)m

· 4.5h for each Aerobic Zone with dimensions (L×B×H=1.5×2.5×2.5)m

· 4.5h for the Sedimentation Tank with dimensions (L×B×H=1.4×2.5×2.5)m

4.2 Design Parameters of the Equipment

The wastewater treatment module of this equipment is designed for the biodegradation of organic pollutants in wastewater. It comprises a biochemical reaction tank, a sedimentation tank, power equipment, flow meters, and automatic controllers. The design parameters of the specific facilities and equipment for the biological treatment module are shown in the table 1.

Table 1: Design Parameters for Biological Treatment Module Facilities and Equipment

Title	Specification	Quantities	Note
Biochemical Reaction Tank	L×B×H=4.6m×2.5m×2.5m	1 seat	Steel equipment
Anaerobic Tank	L×B×H=0.8m×1.5m×2.5m	1 seat	Steel equipment
Anoxic Tank A	L×B×H=0.4m×0.5m×2.5m	4 seats	Steel equipment
Anoxic Tank B	L×B×H=0.8m×1.5m×2.5m	1 seat	Steel equipment
Aerobic Tank	L×B×H=1.5m×2.5m×2.5m	2 seats	Steel equipment
Sedimentation Tank	L×B×H=1.4m×2.5m×2.5m	1 seat	Steel equipment
Air Blower	YX3-80M2-4	1 unit	Power: 0.75kw Speed: 1415r/min
Elevator Pump	25WBZS3-18	1 unit	Maximum flow rate: 3T/h Maximum lift: 18m
Reflux Pump	YE2-80M1-2	2 units	Power: 0.75kW Speed: 2900r/min
Intelligent Flowmeter		1 unit	
Automatic Controller		1 set	

4.3 Anaerobic tanks and anoxic tanks

The internal design employs a nested cylindrical structure with multiple compartments based on a square-shaped structure, utilizing the same up-and-down flow deflection method as VFL. This setup extends the flow path of the wastewater, thereby increasing the reaction time between the wastewater and microorganisms, leading to enhanced wastewater treatment efficiency. To further improve treatment effectiveness on this foundation, One may also consider adding an appropriate amount of filler material in the biological treatment unit to increase the density of microorganisms. The design, as mentioned above, structure, and method of adding fillers achieve superior wastewater treatment within a limited volume, enabling thorough utilization of the capacity and maximizing nitrogen and phosphorus removal.

4.4 Aerobic tanks

The bottom of the aerobic tank is equipped with aeration disks, which increase the dissolved oxygen content in the water by aeration, thereby promoting the growth and metabolic activities of bacteria and other microorganisms in the water and accelerating the degradation of organics. Furthermore, the bubbles generated by the aeration device can form a bubble stream in the water, stirring the water body. The bubble stream facilitates the thorough mixing of microorganisms and dissolved oxygen, enhances the mass transfer efficiency of oxygen and organics, and increases the removal rate of organics.

4.5 Sedimentation tank

Inside the sedimentation tank, inclined tubes are installed. The sedimentation process within these tubes causes the water flow to adopt a laminar state, which helps enhance the sedimentation effect. This setup increases the sedimentation area for sludge, thereby improving treatment efficiency. Furthermore, the inclined tubes shorten the settlement distance for particulate sludge, reducing the settlement time. The material of the inclined tubes is non-toxic polyvinyl chloride, with a pore diameter of φ80, a height of 1m, and an inclination angle of 60°.

4.6 Fillers

The biochemical reaction tank utilizes φ80 suspended ball media and φ25 ± 2 Type A MBBR (Moving Bed Biofilm Reactor) media. The φ80 suspended ball filler represents the latest series developed among various types of fillers employed in domestic wastewater treatment and biofilm treatment technologies. It is made of high-density polyethene, with a mass of 17 to 18 grams per piece, a relative density of 0.93, and a specific surface area ranging from 170 to 230 square meters per cubic meter. Its advantages include moderate cost, strong biological adhesion, large specific surface area, high porosity, no need for fixation, easy biofilm formation, no clogging, good biochemical stability, durability, and convenient placement and installation, making it suitable for small-scale wastewater treatment.

The MBBR media selected is model XFTL-A-500-25×10. This media features rapid startup and short modification and commissioning periods. It boasts a large biomass and strong resistance to shock loads. It saves energy, space, and investment. It is versatile and can be used in aerobic, anoxic, and anaerobic sections. It can be directly added without the need for additional structures. It is particularly suitable for upgrading and retrofitting wastewater treatment plants and for advanced nitrogen removal. This technology is also used to construct integrated equipment, which can reduce the footprint by 1/3 to 1/2 compared to conventional processes and simplify management.

4.7 Automatic control systems

The facility is furnished with a control room containing a comprehensive control cabinet. This cabinet facilitates the automated starting and stopping of the lifting pump, blower, sludge recirculation pump, and wastewater return pump, guaranteeing seamless and reliable system operation and minimizing operational and maintenance expenses associated with the equipment.

5. Commissioning of equipment

This equipment relies on the Third Wastewater Treatment Plant in Lingchuan County, Guilin City. It utilizes sewage from the plant's primary sedimentation tank for a one-month trial—the equipment experiments with biochemical reaction processes without considering the post-treatment of sewage and sludge.

However, the initially designed equipment did not meet the expected goals. The experimental data could have been more promising, and the removal rate remained unstable. We have summarized and reflected on the following points:

1) In the square reactor, due to gravity, the activated sludge sinks to the bottom during the process of up-and-down flow, preventing it from flowing to the following reaction zone. This results in the short-circuiting of the sewage.

2) Difficulties in sludge recirculation may be attributed to clogging of the recirculation pipes or reduction in sludge volume caused by sludge settling at the bottom.

3) During the commissioning of the equipment, a reasonable arrangement must be made for the automatic operation of water inflow and aeration.

6. Equipment Optimization

6.1 Optimization of tank structure

The equipment has been modified from a square tank to a cylindrical tank for both anaerobic and anoxic tanks, with nested cylinders adopted inside and a disk-type swirling water distributor installed in the central water flow area A. These modifications help address the issue of dead corners in square treatment tanks. The water distributor can enhance the upward velocity of water flow in the central water flow area A within the reaction tank, reducing sludge accumulation at the bottom of the reaction tank and affecting the effectiveness of wastewater treatment.

The hydraulic retention time (HRT) for each tank is as follows: 2.94 hours for a single anaerobic tank with dimensions of (R×H=0.625×2.5) m; 2.94 hours for a single anoxic tank with dimensions of (R×H=0.625×2.5) m; and 4.5 hours for a single aerobic zone with dimensions of (L×B×H=1.5×2.5×2.5) m. The optimized design diagram is shown in Figure 2.

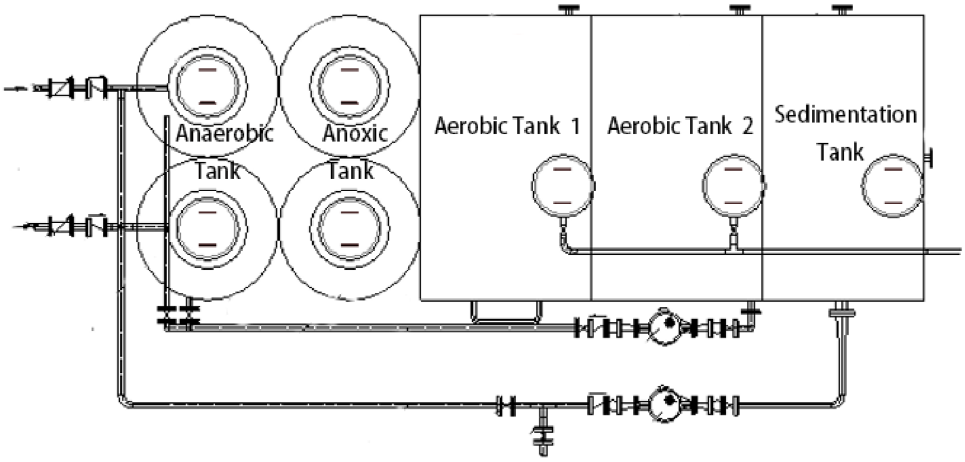

Figure 2: Optimized Design Diagram of Equipment Structure

6.2 Optimized overall structure

There are two anaerobic and anoxic tanks on the left side of the device; the two leftmost are anaerobic tanks, followed by anoxic tanks, then two aerobic zones are set up, and lastly, an inclined tube sedimentation tank. Said anaerobic tank and said anoxic tank are both cylindrical tanks, and the cylindrical tanks are nested from inside to outside with a central water flow area and an external filler area. An anaerobic tank and an anoxic tank are designed as a group, and two groups of side-by-side anaerobic anoxic tanks are designed in the wastewater treatment plant, each connected to an aerobic tank at the back end. Since the size of the volume of the packing area affects the amount of packing, and the amount of packing affects the effluent treatment effect, to realize the adjustment of the volume of the external packing area B of the anaerobic tank 1, the ratio between the cross-sectional diameter of the centre water flow area of the anaerobic and anoxic tank and the cross-sectional diameter of the whole anaerobic tank is set to N. N is more excellent than 1/4 and less than 1/2, and preferably, N may be 1/3. The overall structural diagram of the equipment after optimization design is shown in Figure 3.

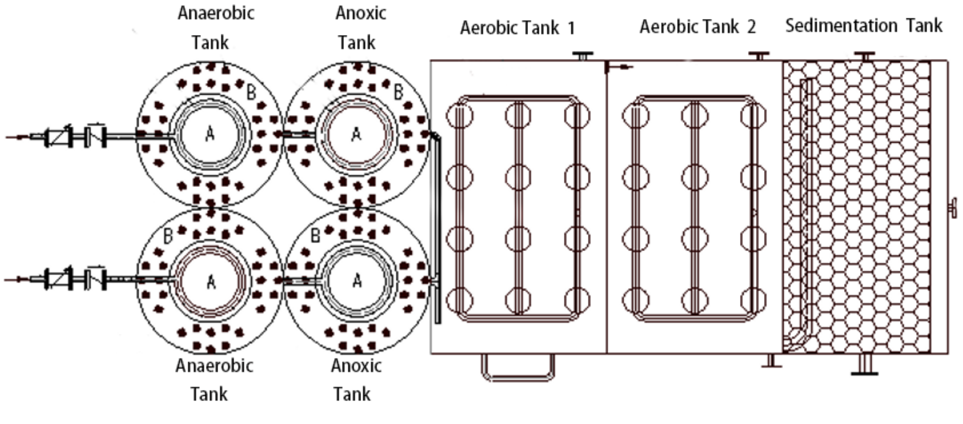

Figure 3: The overall structure after equipment optimization

7. Conclusion

This paper combines the status quo of rural sewage treatment in China for the optimization of rural integrated sewage treatment equipment for the study, putting forward a sewage process with a long, small footprint, low energy consumption, operation and management and maintenance of simple features of the integrated small sewage treatment equipment. It has good potential in rural sewage treatment from the process and structure. However, continuous improvement and optimization could improve the trial operation. Then, after follow-up further experiments to enhance the treatment effect, practical engineering applications are more likely. The design will provide a reference basis for the design and improvement of integrated small-scale rural sewage treatment equipment and strengthen rural water management, hand in hand with protecting the water environment.

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