Design and application of sewage treatment process in expressway service area

Kewu Duan¹, Chengyuan Ai¹ and Fang Chen²*

¹Yunnan infrastructure investment co. Ltd, Kunming 650501, China
²China Merchants Ecological Environmental Protection Technology Co., Ltd, Chongqing 400067, China
*Corresponding author’s e-mail: 56174286@qq.com

Abstract. In order to improve the efficiency, impact resistance and purification effect of sewage treatment in service areas, the composition and quantity of sewage water quality in expressway service areas were studied. A highway service area in Yunnan Province uses a combined process for sewage treatment, and the scale has been reached 4000m³/d. The specific process is “multi-point water inlet A/O process + denitrification sand filter + phosphorus removal filter + chlorine dioxide disinfection + activated carbon filter”. The actual effluent quality meets the “Discharge standard of pollutants for municipal wastewater treatment plant” (GB18918-2002). And the first-class standard meets the requirements of “The reuse of urban recycling water-Water quality standard for urban miscellaneous water consumption” (GB/T18920-2002). The engineering practice proves that it is completely feasible to use this combined process to treat sewage in the highway service area, which can be used for reference and reference by similar projects.

1. Introduction
The sewage generated by the expressway operation mainly comes from the service area, and the sewage generated in the service area has become an urgent problem to be solved urgently in the water pollution control in China[1-2]. The sewage in the service area is quite different from the domestic sewage, and its composition is complicated. Due to the uncertainty of human flow, the water quality and water volume vary greatly, the suspended solids and ammonia nitrogen content are high, and the water quality fluctuates with the seasons, which is difficult to effectively treat[3-4]. Usually the highway service area is far away from the city, and the sewage generated by it cannot be discharged into the city's sewer network. Therefore, a small sewage treatment system needs to be set up separately in the service area[5-7]. In this paper, based on the example of domestic sewage treatment project in a highway service area in Yunnan Province, under the condition of high ecological function protection area and high demand for sewage treatment, a number of successfully operated service area sewage treatment processes were selected. This paper proposes a combination process of “multi-point water inlet A/O process + denitrifying sand filter + phosphorus removal filter + chlorine dioxide disinfection + activated carbon filter” and successfully applied in the service area.

2. Water quality and quantity
The sewage in the expressway service area mainly comes from public toilets, shops, restaurants, parking (car wash) and gas stations. The composition of sewage water is complex and uncertain. The
relevant data of the service area and the sewage monitoring data of the adjacent service areas in recent years were collected, and the water quality of the sewage inflow was determined as shown in Table 1.

| pH  | COD  | BOD₅ | ρ(NH₃-N) | ρ(SS)  | Animal and vegetable oil | ρ(TN) | ρ(TP) |
|-----|------|------|----------|--------|--------------------------|-------|-------|
| 6~9 | 110~230 | 30~150 | 30~80 | 80~180 | 10~60 | 30~80 | 2~25 |

Since the service area is expected to have relatively large traffic volume and passenger flow, and considering the large fluctuation of the sewage volume and the long-term demand and construction cost, it is determined that the sewage in the service area is concentrated on one side, and the treatment scale is designed to be 400m³/d.

3. Process flow
Based on the current successful operation of small sewage treatment process, this paper proposes a combination process of "multi-point water inlet A/O process + denitrifying sand filter + phosphorus removal filter + chlorine dioxide disinfection + activated carbon filter" for improving the efficiency of treatment, impact resistance and purification. The process is shown in Figure 1.

Figure 1. Service area sewage treatment process.

The specific process flow is as follows:
(1) Most of the suspended matter and floating matter are removed after passing through the grid of different specifications.
(2) After entering the adjustment tank, the processing rate of the subsequent functional units is controlled to reduce the instantaneous impact, and the sewage is diverted into three A/O tanks for biological treatment.
(3) Denitrification in an anoxic environment by denitrifying bacteria in the anoxic environment to achieve the purpose of biological nitrogen removal. Since the denitrifying bacteria reacts with carbon sources in the water, the organic matter in the water is effectively reduced.
(4) After entering the oxic tank, under oxic conditions, the oxic microorganisms oxidatively decompose the organic matter of the sewage.
(5) Considering that the single passage of sewage through the A/O tank will be incompletely treated, most of the unreacted pollutants are in the sludge and sludge mixture, and the sludge mixture is refluxed by gravity sedimentation in the secondary settling tank. The sewage treatment is continued to the anoxic tank, and the sludge enters the sludge tank.
(6) In the sludge tank, due to the high moisture content of the sludge, it is difficult to treat. By gravity sedimentation and mud-water separation, the supernatant is introduced into the regulating tank to continue to participate in the subsequent reaction, and the remaining sludge passes through the
sludge drying tank. After drying, it is transported by vehicle.

(7) After entering the mud, the sewage secondary sedimentation tank passes through the intermediate tank and enters the denitrifying sand filter relatively stably after controlling the water output. Not only can the fine particles and colloidal impurities in the water be removed through the gravel canister, the filter tank is added. Sodium acetate is used as a carbon source for nitrification and denitrification treatment using biofilm on gravel.

(8) Considering the efficiency and limitations of biological phosphorus removal, the phosphorus removal filter is added with polyacrylamide and other flocculants intermittently, and backwashing with gas water is used, and the backwash water enters the regulating tank to continue to participate. Follow-up reaction.

(9) After the disinfection pool containing chlorine dioxide, the disinfected water is absorbed by activated carbon filter and then entered the backwater pool. Finally, according to the specific situation of the service area to choose recycling or outflow.

4. Main structures and design parameters

(1) Grille. The grille adopts a steel truss structure, and three common grilles of different specifications are provided. The common grille grid width is 500 mm, the grid gap is 70 mm, 30 mm, 10 mm, and the mounting angle is 65°. There is also a mechanical fine grid, the mechanical fine grid is a rotary fine grid, the grid width is 500mm, the grid gap is 3mm, the power is 0.75kw, and the installation angle is 65°.

(2) Regulation tank. The adjustment tank is designed as a steel truss structure with a specification of 8m×8m×4m, an effective water depth of 3.5m and a quantity of one. The effective volume is 224m³ and the design residence time is about 13.44h. There are 4 AS-type submersible sewage pumps in the adjustment tank, 2 use and 2 standby. Its head is 15m, design flow is 18m³/h and power is 1.1kw. The AS type submersible sewage pump uses liquid level control for automatic operation.

(3) Anoxic tank. The anoxic tank is designed as a steel truss structure, a buried tank with a size of 2m×6m×4m, an effective water depth of 3.5m, a number of 3 seats, and a design residence time of 7.56h. The single-seat anoxic tank has an effective volume of 42m³ and three high-speed submersible mixers with a diameter of 150mm and a power of 2kw.

(4) Oxic tank. The oxic tank is designed as a steel truss structure, an underground tank with a size of 4m×8m×4m, an effective water depth of 3.5m and a number of three. The single-station oxic tank has an effective volume of 112 m³ and a design residence time of 15 h. The oxic chamber air diffusion system adopts HC-1002 cyclone aerator, with a volume load of 1.3kg BOD₅/(m³·d), and a single oxic tank with two mixed liquid return pumps, 1 use and 1 standby. Its head is 15m, design flow is 18m³/h and power is 1.1kw.

(5) Secondary settling tank. The secondary sedimentation tank is designed as a steel truss structure and a buried basin. The number is one, the specification is 4m×6m×4m, the effective water depth is 3.5m, the effective volume is 84m³, and the surface load is 0.74m³/(m²·h). There are 2 sludge pumps at the bottom, 1 use and 1 standby. Its head is 12m, design flow is 15m³/h and power is 1.1kw.

(6) Intermediate tank. The middle tank is designed as a steel truss structure with a number of 3m×5m×4m, an effective water depth of 3.5m and an effective volume of 60m³. There are 2 submersible sewage pumps, 1 use and 1 standby. Its head is 12m, design flow is 25m³/h and power is 1.6kw.

(7) Denitrifying sand filter. The denitrification sand filter adopts carbon steel anticorrosive material, the quantity is 2 sets, 1 use and 1 standby. The tank is equipped with quartz sand filter material. The filter material has a particle size of 0.3-1mm, the filtration speed is 16m/h, and the specification is Φ1.5m× 4.0m, by adding sodium acetate as a carbon source, the biofilm on the gravel is used for nitrification and denitrification treatment, which can intercept the solid suspended matter in the sewage and convert the organic components to remove suspended solids, colloidal impurities and ammonia nitrogen in the sewage.
(8) Phosphorus removal filter. The flocculation and phosphorus removal filter adopts carbon steel anticorrosive material, the quantity is 2 sets, 1 use and 1 standby, and 2 sets of 0.22 kw pressure pump are equipped, 1 use and 1 standby. The flocculation and phosphorus removal filter is fed from the upper part and the bottom is effluent. The filling material in the tank is quartz sand filter material, the filter material has a particle size of 0.3-1 mm, and polyacrylamide (non-ionic high-molecular flocculant) is added at 1.85 kg/d. The filtration rate is 16 m/h. In the batch process of the phosphorus removal filter, the gas and water backwashing was adopted, and the backwashing rate was 22 m/h, water washing for 12 min, and air washing for 6 min.

(9) Disinfection tank. The disinfection tank is designed as a steel truss structure with a specification of 3m×5m×4.00m, an effective water depth of 3.5m and an effective volume of 52.5m³. A chlorine dioxide generator was installed at the entrance of the disinfection tank, the power was 1.5 kw, and the chlorine gas production amount was 325 g/h, which was disinfected.

(10) Activated carbon filter. The activated carbon filter adopts carbon steel anticorrosive material, the quantity is 2 sets, 1 use and 1 standby. 2 sets of 0.22 kw pressure pump are equipped, and the specification is Φ1.5m×4.0m, and the filter material particle size is 0.5~2mm. Activated carbon, the filtration rate is 16m / h.

(11) Reuse tank. The reused tank is designed as a steel truss structure with a capacity of 4m×10m×4.5m, an effective water depth of 4m and an effective volume of 160m³.

(12) Sludge tank. The sludge tank is designed as a steel truss structure with 2 seats, the specification is 2m× 4m× 4m, the effective water depth is 3.5m, and the effective volume is 56 m³. There is a supernatant reflux device inside, and there are 2 sludge pumps at the bottom, 1 use and 1 standby. Its head is 8m, design flow is 8m³/h and power is 2.0kw.

(13) Sludge drying tank. The sludge drying tank is a concrete structure with a quantity of 4m×4m×2.5m, an effective water depth of 2.0m and an effective volume of 32m³.

5. Operational effect and economic analysis

The sewage treatment station of the service area was completed in 2018. The actual sewage inflow rate is 170-220m³/d, and the sewage treatment load reaches 42.5-55% of the designed treatment capacity. The actual effluent quality meets the first-class standard of“Discharge standard of pollutants for municipal wastewater treatment plant”(GB18918-2002), and meets the requirements of “The reuse of urban recycling water-Water quality standard for urban miscellaneous water consumption” (GB/T18920-2002). It can be used as reclaimed water for toilets, car washes, irrigation, etc. The test results of various pollution control indicators for the effluent of this project are shown in Table 2.

Table 2. Influent water quality test results. mg·L⁻¹

| Serial number | Project | COD  | BOD₅ | ρ(NH₃-N) | ρ(SS) | Animal and vegetable oil | ρ(TN) | ρ(TP) |
|---------------|---------|------|------|----------|-------|--------------------------|-------|-------|
| 1             | Influent| 188.3| 71.1 | 49.1     | 112   | 35.7                     | 57.1  | 5.3   |
|               | Drain   | 43.4 | 7.1  | 7.4      | 6.2   | 0.9                      | 21.2  | 3.1   |
| 2             | Influent| 176.8| 66.3 | 51.9     | 72    | 16.1                     | 44.3  | 7.4   |
|               | Drain   | 24.8 | 8.0  | 4.2      | 8.3   | 0.8                      | 17.9  | 2.7   |
| 3             | Influent| 192.5| 59.2 | 63.2     | 89    | 42.0                     | 67.4  | 5.9   |
|               | Drain   | 27.4 | 7.7  | 2.5      | 9.4   | 1.3                      | 22.5  | 3.0   |
| 4             | Influent| 156.3| 61.4 | 45.3     | 142   | 37.9                     | 77.5  | 8.2   |
|               | Drain   | 31.5 | 5.4  | 3.4      | 3.6   | 0.6                      | 32.6  | 2.8   |
| 5             | Influent| 173.7| 46.9 | 55.5     | 123   | 22.5                     | 51.8  | 3.5   |
|               | Drain   | 47.0 | 9.1  | 3.5      | 6.7   | 1.5                      | 28.4  | 2.7   |
Table 3. Pollutant emissions before and after operation.

| Parameter           | Average emissions/mg·L⁻¹ | Average removal rate/% |
|---------------------|--------------------------|------------------------|
|                     | Before running | After running |                      |
| COD                 | 177.5          | 34.8          | 80.4                  |
| BOD₅                | 61.0           | 7.5           | 87.7                  |
| NH₃-N               | 53.0           | 4.2           | 92.1                  |
| SS                  | 107.6          | 6.8           | 93.7                  |
| Animal and vegetable oil | 30.8      | 1.0           | 96.8                  |
| TN                  | 59.6           | 24.5          | 58.9                  |
| TP                  | 6.1            | 2.9           | 52.5                  |

The total construction cost of the sewage treatment system and equipment in this service area is about 2.8 million yuan, and the annual operating cost is about 110,000 yuan, which mainly includes electricity, labor and pharmacy fees for equipment operation. The treatment cost is about 1.1 Yuan/m³.

If the commercial water price is 3 yuan/m³ and calculated according to the design processing amount, it can save 760 yuan for the service area every day, and save 274,400 yuan a year. The entire sewage treatment system is highly automated and requires no dedicated personnel. As shown in Table 3, the ecological environment around the treated service area will be significantly improved, and the environmental function will be improved.

6. Conclusion

(1) Most of the structures and equipment required for the sewage treatment process proposed in this paper are underground, with the advantages of small land occupation, low investment and operating costs.

(2) The removal rate of COD, BOD₅, NH₃-N, SS, animal and vegetable oil in the service area sewage treatment system is over 80%, and the removal rate of TN and TP is over 50%. The actual effluent quality meets the first-class standard of “Discharge standard of pollutants for municipal wastewater treatment plant” (GB18918-2002), and meets the requirements of “The reuse of urban recycling water-Water quality standard for urban miscellaneous water consumption” (GB/T18920-2002).

(3) "Multi-point water inlet A / O process + denitrifying sand filter + phosphorus removal filter + chlorine dioxide disinfection + activated carbon filter" combination process is a cost-effective sewage treatment process, with strong impact resistance, High degree of automation and stable operation.

(4) The engineering practice proves that it is effective to use the combined process to treat sewage in the highway service area, and has reference value for the design of sewage treatment project in the high-speed service area.

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