Evaluation and analysis of wastewater treatment technology applied in highway service area

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Abstract. The selection of wastewater treatment technology in service area should be adapted to the features of the wastewater quality and quantity. Also, the construction investment, the operating energy consumption, and the system simplicity should be considered as the demands of highway service area construction and maintenance. Based on investigations, this article analyzed the limitations of conventional treatment processes currently represented by contact oxidation. Evaluation and discussion for typical applicable processes were conducted from aspects of low energy consumption, treatment and discharge in cold regions, and reclaim water reuse.

1. Introduction
By the end of 2018, the total mileage of expressways in China had exceeded 140,000 kilometres, and the number of service areas was close to 2,900 pairs. Except for a few service areas near towns and cities, where wastewater is discharged into the municipal sewage pipe network, most service areas have independent wastewater treatment facilities, and most of which, however, are not effective in actual operation[1-2]. Of course, there are problems in operation and management, but defective technology is also a critical reason.

In the last two years, documents have been issued by the Ministry of Transport to explore and implement the construction of service areas for national and provincial trunk roads. And it can be predicted that with the rapid growth of the number of service areas in the future, the wastewater treatment facilities to be built will be more widely distributed.

In Jan.2018, the Measures for the Administration of Pollutant Discharge Permit has been put into effect, and the wastewater discharge from service area will be included as fixed pollution sources. This means that environmental protection requirements for wastewater treatment in service area will be more stringent in the future.

Under this situation and requirements, it is very necessary to conduct in-depth summary analysis of the technical problems on the operation of wastewater treatment facilities in service areas of existing expressways, so as to provide reference for related construction and transformation activities.

2. Features of wastewater discharge in service area
A combination method of general survey and key survey was used to conduct the survey of wastewater discharge and operation of treatment facilities in service areas from seven representative provinces nationwide. The general survey effectively collected wastewater treatment data from 239 pairs of service areas. And on-site investigations on actual operation status of wastewater treatment facilities were conducted in 42 service areas. Based on this, the features of wastewater quality and quantity in service
areas are analysed. This is because the flushing sewage accounted for a large proportion of wastewater in service area. According to the survey results, it reached 40% to 80%. Therefore, the pollution load is higher.

2.1. High pollution load for discharged wastewater
Intake wastewater quality of typical treatment facilities were monitored, and representative data is shown in Table 1. The actual COD can be as high as 700 mg/L, and the ammonia nitrogen can reach 100 mg/L. The pollutant index is much higher than that of municipal sewage.

| Location of service area       | COD  | BOD₅ | SS   | NH₃-N | Total P | pH  |
|--------------------------------|------|------|------|-------|---------|-----|
| Xibao Expressway, Shaanxi      | 289-497 | 164-234 | 143-238 | 46.5-109.3 | 1.9-5.8 | 7.03-7.87 |
| Yingsong Expressway, Jilin      | 428-618 | 82-237  | 156-273 | 48.2-82.6  | 3.4-6.9  | 7.32-7.57  |
| Jinggangao Expressway, Henan    | 314-736 | 121-318 | 217-376 | 42.3-94.7  | 5.6-14.3 | 7.39-8.12  |
| Lianhuo Expressway, Henan       | 349-836 | 164-363 | 234-417 | 52.4-142.6 | 4.7-12.1 | 7.24-7.76  |
| Hurong Expressway, Anhui        | 352-640 | 138-256 | 220-369 | 34.2-53.7  | 4.8-15.7 | 7.08-7.22  |
| Wuhe Expressway, Anhui          | 286-689 | 168-354 | 184-357 | 39.8-61.4  | 1.9-5.7  | 7.07-7.89  |
| Shenhui Expressway, Guangdong   | 236-789 | 168-354 | 104-257 | 19.8-57.9  | 2.9-6.7  | 7.07-7.89  |

* Monitoring water samples were taken from the inlet adjustment tank of wastewater treatment facilities.

2.2. Large fluctuations in discharged wastewater
The survey found that, due to the large difference of the main line traffic, wastewater discharge volume of different service areas in different regions fluctuate a lot. The daily wastewater discharge from one side of service area varies from 30 to 200 m³/d. And the daily and seasonal fluctuations of wastewater discharge in same service area are also very large. In some service areas, wastewater discharge increased significantly on weekends and holidays, even five times higher than average daily value.

3. Technical requirements for wastewater treatment facilities in service area
The selection of wastewater treatment technology in service area should be adapted to the features of the wastewater quality and quantity. Also, the construction investment, operating energy consumption, and system simplicity should be considered as the demands of highway service area construction and maintenance. Therefore, the following requirements are essential.

3.1. Strong shock load resistance and stable operation
The wastewater quality in the service area is worse than that of municipal sewage, and the discharge volume fluctuates much greatly. Therefore, the treatment process should have better impact load capacity in terms of wastewater quality and quantity.

3.2. Easy to operate, manage and maintain
As service areas generally lacking skilled stuff for the operation of the treatment facilities, the treatment process should be simplified as much as possible, the application of complex mechanical and electrical equipment should be reduced, and the manual cleaning workload of slag and sludge should be lower. Also, the process should be at high level of automation and be reliable. Generally speaking, it is better to choose a wastewater treatment process that is easy to operate, manage and maintain.

3.3. Reasonable investment and low operating cost
High operating costs of the treatment facilities have always been a major problem for managers of service areas. In the absence of special operating capital guarantees, low operating expense is an important condition to promote the normal operation of wastewater treatment facilities.

3.4. Full consideration of natural conditions such as climate and geology.
It is necessary to select a suitable wastewater treatment process in accordance with local climate, geology and other natural conditions. For example, in cold regions, treatment process suitable for low-temperature seasons or reliable in low-temperature condition after appropriate technical measures should be adopted. In places with high groundwater levels and poor geological conditions, it is not suitable to use structures with large water depth or difficult construction requirements.

3.5. Prioritize the reuse processes if it would be possible
As the domestic water used in the service areas must come from groundwater or municipal water supply, the water for toilet flushing, greening, car washing, and pavement washing could all use recycled water after strict treatment. Wastewater treatment and reuse can not only save water resources, but in some cases could be more economical than standard discharging.

4. Analysis of wastewater treatment technology in service area

4.1. Conventional treatment processes typified by contact oxidation
The investigation found that structural forms of the treatment facilities are mainly two types: buried integrated devices and split reinforced concrete structures, each accounting for 82.3% and 17.7% respectively. From the perspective of the specific wastewater treatment process, the processes using the buried integrated devices are in types of hydrolysis acidification-contact oxidation, anaerobic-aerobic (A/O) and anaerobic-hypoxic-aerobic (A^2/O), accounting for about 85%, 10%, and 5% respectively; the processes using split reinforced concrete structures are mainly in types of hydrolytic acidification-contact oxidation and A/O, accounting for more than 60% in total. In service areas from central and southern regions of China, as long as the wastewater treatment facilities are well managed and maintained to ensure the normal operation of these processes, they can usually meet the first-level standards in the Integrated Wastewater Discharge Standard.

However, the investigation also found that the conventional treatment processes represented by contact oxidation also has the following three limitations: First, the treatment facilities have high operating costs. For example, the facilities with power consumption of more than 4kWh/t are usually shut down by the manager of service areas. Second, in cold regions such as Northeast China, wastewater usually stay in the buried integrated device for a long time in winter, and the water temperature could be lower than 10°C, inhibiting the effect of microbial biochemical reaction and leading to discharge failure[3]. Third, the effluent from the conventional treatment process represented by contact oxidation can be discharged in compliance with the standards, but it cannot meet the reuse standards, while some service areas having real demands for wastewater treatment and reuse[4]. In order to solve these three types of problems, related research has been carried out.

4.2. Low energy consumption and low maintenance treatment process combining biochemical and ecological methods
As a simple and effective wastewater ecological treatment technology, artificial wetland has the advantages of strong resistance to pollution load, simple operation and management, and good green landscape effects. However, it also has the prominent problem of easy clogging when the inflow pollution load is high[5]. From the perspective of reducing operating energy consumption and improving treatment effects, biochemical treatments such as contact oxidation and artificial wetlands can be combined in series to form a combined process with complementary advantages[6-7]. Biochemical treatment is used as pre-treatment of artificial wetland, which can reduce the pollution load and save energy consumption during operation. Through biochemical pre-treatment, the load of influent pollutants in artificial wetlands can be greatly reduced, and the problem of clogging of artificial wetlands due to high organic matter load can be effectively solved.

The author has conducted a study on a wastewater treatment facility with capacity of 30 m^3/d in a small service area in southern region using "contact oxidation + artificial wetland" as the core process. The HRT of contact-oxidation pond is about 8 hours, the hydraulic load of the artificial wetland is about
0.4 m³/(m²·d), and the BOD5 load is about 100 kg / (hm²·d); the artificial wetland adopts upward flow water distribution with water enter from the bottom and out from the top; the depth of the packed bed is 1.2m, and the layers from the bottom to the top are 0.4 m gravel (16-32 mm particle size), 0.25 m gravel (15-10 mm particle size), 0.25 m ceramsite (5-10 mm particle size), 0.25 m planting soil, and 0.05 m gravel (5-10 mm particle size); and the plantings are calamus, windmill, and canna.

Most of the actual intake water fluctuates from 12 to 20 m³/d, but it can reach more than 40 m³/d in holidays; the operating power consumption is less than 1 kWh/ton of water. The artificial wetland has not been blocked for three years, and the daily maintenance works are all about cleaning of grille slag and seasonal harvesting of wetland plants. The effluent COD, ammonia nitrogen, and total phosphorus are stable below 60 mg/L, 5 mg/L, and 1 mg/L, respectively, and can reach the Class B standard of “Pollutant Discharge Standard for Urban Sewage Treatment Plants” (GB18918-2002).

4.3. Treatment process of aerated biological filter combined with Thermal insulation measures
For the service areas in the cold regions of northern China, it is also a long-standing problem that wastewater cannot be properly discharged due to low temperatures. Research was conducted on a wastewater treatment facility in a service area in Northeast China with an improved aerated biological filter as the core process and designed to handle 60 m³/d of wastewater. Measures, such as thermal insulation of pipes, setting aerated biological filters indoors, and directional cultivation of highly active and low-temperature-resistant microorganisms on filter materials, were comprehensively applied. And the discharge in low temperature achieved to meet the standards[8]. After three years of operation, the treatment effect is still stable with the -18°C outdoor temperature and the high-pollution load wastewater (COD is 791mg/L, ammonia nitrogen is 152 mg/L, total phosphorus is 10 mg/L). And it can reach Grade B standard of “Emission Standard of Pollutants for Urban Sewage Treatment Plants” (GB 18918-2002).

4.4. Reuse process with additional reclaimed treatment
The reuse of treated wastewater in service areas as reclaimed water is an important way to achieve efficient and economical use of water resources. There are mainly two types of wastewater treat and reuse technologies. The first type is the MBR process, but because of its high operating costs and the membrane module's fouling, the service area managers do not accept it very willingly[9]. Therefore, this process is suitable for service areas with relatively high level of operation and maintenance, and it can provide with better effluent quality. The second type is to set a combination of coagulation, sedimentation, filtration, disinfection and other units after the conventional secondary biochemical treatment process to further remove organic matter, suspended matter, bacteria and so on. Research was conducted on wastewater treatment and reuse facilities with "A/O + biological sand filtration + multi-media filtration + disinfection" as the core process.

The actual average treatment capacity in this service area is 110 m³/d, and the effluent after treatment fully meets the requirements of "Urban Wastewater Reuse and Urban Miscellaneous Water Quality" (GB/T 18920-2002). With comprehensively reusing for toilet flushing, greening, and ground washing, the reclaimed water reuse rate reaches to 70% throughout the year. The annual operating cost of the treatment facilities is 77,800 yuan, and the actual operating cost per ton of wastewater is 1.86 yuan. As this service area is adopting 52 m depth self-provided wells for water supply, wastewater treatment and reuse can save 28,100 tons of underground water each year, directly saving 28,100 yuan for groundwater resources (the groundwater resource fee in this area is 1 yuan/ton) and 96,000 yuan for water extraction costs. The actual increased annual operation cost is only 37100 yuan if the costs for water supply were removed, and the actual increased operation cost converted into tons of water is only 0.92 yuan. Generally, the direct operation cost of wastewater treatment is about 1 yuan/ton, so the operation cost for the treatment and reuse process is not increased.

At present, it is widely believed that reclaimed water reuse in service areas is not economical, and few cases are applied. However, the above case study shows that it is economical to reuse reclaimed water in some service areas in consideration of its water supply cost[10]. In addition, it should be pointed
out that with the improvement of reuse rate or the increase of underground water depth, the economy of reclaimed water reuse will be further revealed.

5. Conclusion
Wastewater treatment facilities in service areas are important auxiliary facilities for water pollution prevention and control during highway operation period. The treatment process should be reasonably selected in combination with the features of wastewater discharge in the service area and the requirements for the construction and management of highway auxiliary facilities:

For now, the widely used underground integrated devices mostly adopt the conventional treatment process represented by contact oxidation. As this treatment process is often used at service areas in the central and southern regions of China, it is necessary to strengthen the daily management and maintenance to meet the discharge standards.

The process of "contact oxidation + subsurface flow constructed wetland" has excellent effluent quality, low operation cost and convenient management, which is suitable for service areas with large site space. Moreover, the constructed wetland can be arranged with landscape green space to achieve good landscape effect.

Biological aerated filter (BAF) is suitable for indoor construction due to its high-volume load and small land occupation. It can be used in service areas in cold regions with the help thermal insulation measures, so that the sewage can be discharged up to the standard.

The effluent of "A/O + biological sand filtration + multi-media filtration + disinfection" process can meet the reclaimed water reuse standard; considering the water resource fee and power consumption of water supply, the process can be used economically in service areas with deep water wells.

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