Study on upgrading and engineering design of leachate treatment facilities in a landfill in Beijing

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Abstract. This paper systematically introduces the technical route and engineering design practice of upgrading and reconstruction of a landfill leachate treatment station in Beijing. The Water balance tank+ Two-stage A/O external MBR+ Nanofiltration+ Reverse osmosis process is adopted to realize that the effluent quality of landfill leachate treatment meets the requirements of B emission limits in Table 1 of Beijing local standard DB11/307-2013, which can provide reference for engineering design and research on the selection of technical route for upgrading landfill leachate treatment.

1. Introduction
Since January 2014, Beijing has implemented the Integrated discharge standard of water pollutants (DB11/307-2013), which requires that the sewage discharged into Beijing's Class IV and V water bodies must comply with the B discharge limits[1]. At present, many leachate treatment facilities in operation are difficult to meet the requirements of the new standard, and have to reduce the operation treatment load, resulting in a large amount of leachate accumulation in the landfill. The leachate treatment system is urgent to be upgraded to meet the requirements of the new standard.

Taking the upgrading project of leachate treatment facilities in a landfill in Beijing as an example, this paper introduces the technical route research and practical engineering design in the upgrading project, so as to provide engineering design reference for the upgrading project of landfill leachate treatment.

2. Overview
2.1. General situation of the existing landfill
The landfill is mainly responsible for waste treatment of the East and West urban areas of Beijing and one township of Changping District. The landfill area covers an area of 43hm², with a design capacity of 12million cubic metres and a design treatment capacity of 2000t/d. It has been landfilled close to the design capacity. The leachate is collected and sent to the leachate treatment station in the landfill site. At present, the average daily output of leachate in the landfill is about 600 cubic meters.
2.2. Basic design of original leachate treatment facilities

2.2.1. Processing scale. The designed treatment capacity of the original system is 600 m$^3$/d, and the actual treatment capacity is 300 m$^3$/d.

2.2.2. Designed Water quality of influent and effluent. After being treated by the original treatment system, the leachate is discharged into the surface water body and its catchment area after reaching the secondary standard limits of Discharge standard of water pollutants (DB11/307-2005) [2].

| Influent quality | CODcr (mg/L) | BOD$_5$ (mg/L) | NH$_4$-N (mg/L) | TN (mg/L) | SS (mg/L) | pH |
|------------------|--------------|----------------|----------------|-----------|-----------|----|
| ≤20000           | ≤10000       | ≤3000          | ≤3500          | ≤2000     | 6~9       |

2.2.3. The original leachate treatment process. The original leachate treatment process is “Pre-treatment + UASB + A/O + Internal ultrafiltration + NF + RO treatment system”[3].

2.2.4. The original leachate treatment structures and facilities

| Name                         | Specifications (length × width × height) | Material         | Number | Remarks         |
|------------------------------|------------------------------------------|------------------|--------|-----------------|
| 1 Regulating pool            | 60.00m×30.00m×4.80m                       | Steel concrete   | 2      | Semi-underground|
| 2 Anaerobic pool             | Φ 6.10m×8.00m(h)                         | Steel tank       | 2      | Above ground    |
| 3 Anoxic tank                | Φ 6.10m×8.00m(h)                         | Steel tank       | 1      | Above ground    |
| 4 Aerobic tank               | 50.00m×10.0m×5.50m                        | Steel concrete   | 1      | Semi-underground|
| 5 Sedimentation tank         | 5.40m×5.40m×4.70m                        | Steel concrete   | 1      | Semi-underground|
| 6 Mud storage tank           | Φ 5.00m×2.30m(h)                         | Steel concrete   | 1      | Underground     |
| 7 Mud sump                   | 3.00m×1.40m×3.10m                        | Steel concrete   | 1      | Underground     |
| 8 Membrane treatment workshop| 32.40m×15.0m×5.50m                       | Frame structure  | 1      | Above ground    |

2.2.5. Design Water quality of influent and effluent of the upgrading project. At present, the landfill belongs to the middle and later stage of landfill, and no fresh leachate is produced after the waste incineration plant is put into operation. The water quality of leachate is relatively stable in the later stage. After treatment, the leachate of the project can be discharged to the fourth main channel of Changping District. The discharge shall comply with the B discharge limits of the Integrated discharge standard of water pollutants (DB11/307-2013). According to the actual test statistics of influent water quality and considering a certain amount of treatment surplus, the design water quality of influent and effluent are as follows:

| Influent quality | CODcr (mg/L) | BOD$_5$ (mg/L) | NH$_4$-N (mg/L) | TN (mg/L) | SS (mg/L) | pH |
|------------------|--------------|----------------|----------------|-----------|-----------|----|
| Influent quality | 8000         | 3000           | 4000           | 4500      | 2000      | 6~9|
| Effluent quality | ≤30          | ≤6             | ≤1.5           | 15        | 0.3       | 6~9|
3. Analysis of current problems and study on Upgrading

3.1. Increased emission standards
According to the requirements, the original leachate treatment system discharged the leachate to the fourth main channel of Changping after reaching the standard, which belongs to class IV water body. The secondary standard limits of water pollution discharge to surface water body and its catchment in Beijing water pollution discharge standard (DB11307-2005) is implemented, and the water quality requirements of B discharge limits in Table 1 of comprehensive discharge standard of water pollutants (DB11/307-2013) are implemented after 2014.

According to the comparative analysis of emission standards, it can be seen that the new standard has extremely strict requirements on the emission of ammonia nitrogen and total nitrogen, and the existing process is difficult to meet the emission limits of DB11/307-2013, so it is necessary to strengthen the removal of total nitrogen. The capacity of the existing biochemical tank can not meet the requirements of total nitrogen removal rate, yet the biochemical treatment capacity is the key factor to remove total nitrogen, so the biochemical tank needs to be expanded.

3.2. The C/N ratio seriously out of balance
The COD of influent is about 6000~10000mg/L, and the total nitrogen is about 4000~4500mg/L, so the C/N ratio is about 1.2~2.5, the organic matter is seriously insufficient, and the nitrogen removal effect is limited. To solve the problem of insufficient carbon source, on one hand, the UASB unit needs to be cancelled, because the COD value of leachate raw water is low, so the anaerobic treatment is not needed; on the other hand, carbon source dosing system needs to be added to make sure that the C/N ratio of raw water is more than 5.

3.3. The conductivity of leachate is high
The conductivity of leachate from the landfill is about 40000 μs/cm due to the annual recharge of membrane concentrate of nanofiltration and reverse osmosis in leachate treatment system. As a result, the actual water production rate of the system is low and the yield of membrane concentrate is high. As the membrane concentrate of this upgrading project is treated in the form of purchasing service, the treatment cost is high, and reducing the production of membrane concentrate as far as possible is conducive to reducing the treatment cost. So the disc tube reverse osmosis is considered to reduce the concentration of reverse osmosis.

3.4. Emergency support requirements
The construction of the project must be started in February 2019, and the commissioning and operation need to be completed before the rainy season in June 2019. It is very urgent to carry out the upgrading project. Therefore, the tank construction is considered for the expansion and reconstruction of biochemical reaction tank. The enamel assembly construction needs less operation site, the tank wall does not need anti-corrosion treatment, and the overall construction period of tank is short. Therefore, the enamel assembly tank is used for the expansion and reconstruction of biochemical reaction tank.

4. Treatment process
At present, the characteristics of leachate quality include high conductivity, serious imbalance of C/N ratio, high index of total nitrogen in influent and strict requirement of total nitrogen in effluent. In view of these water quality characteristics, the anaerobic treatment unit was removed, the carbon source dosing system was added, the biochemical reaction volume was expanded, and the two-stage A/O external MBR was adopted to ensure the high removal rate of ammonia nitrogen and total nitrogen in the biochemical section. The advanced treatment unit was replaced and the nanofiltration and reverse osmosis units were expanded to reduce the impact of membrane module cleaning on the daily treatment capacity.
The process of the upgrading project is determined as follows: Water balance tank + Two-stage A/O external MBR + Nanofiltration + Reverse osmosis process. The nanofiltration concentrate produced by the membrane treatment system and the reverse osmosis concentrate after DTRO treatment are treated in the form of purchasing services, and are handed over to the professional concentrate treatment contractor for treatment, which is not included in the upgrading project.

The leachate is collected by the existing regulating tank and then lifted into the water balance tank. After water quality regulation and homogenization, it enters the two-stage A/O external MBR to remove the main pollutants. After the MBR effluent is treated by nanofiltration and reverse osmosis, the clean water production can meet the discharge requirements, the overall clean water recovery rate of leachate treatment system diagram is about 65%.

5. Design parameters of process

5.1. Water balance tank

The leachate from the existing regulating tank is firstly lifted into the water balance tank to achieve the effect of carbon source dosing, mixing and homogenization. The COD of the water quality is about 27000mg/L, which is about 6 times of the total nitrogen of the influent, and the alkalinity is about 16000 mg/L. The effective volume of the water balance tank is 300 cubic meters, and enamel assembled tank is adopted.

Equipment configuration and parameters: 4 water balance tank inlet pumps, 2 for use and 2 for standby, q=40m³/h, H=20m, screw pump; 2 water balance tank submersible mixer, 4.0kW; 3 MBR inlet pumps, 2 for use and 1 for standby, q=25m³/h, H=20m, screw pump; 2 primary carbon source dosing pumps, 1 for use and 1 for standby, q=2m³/h, H=15m, screw pump; 2 biochemical alkali dosing pumps, 1 for use and 1 for standby, q=2m³/h, H=20m, centrifugal pump; 2 self-cleaning filters, 1000μm.

5.2. MBR biochemical system

The MBR biochemical system adopts two-stage A/O design, which operates in one line according to the limited site and construction period. Two denitrification tanks and three nitrification tanks are designed for first stage biochemical design, all of which are enamel assembled tanks; one denitrification tank and one nitrification tank are designed for the second biochemical design, which are separated into denitrification tank and nitrification tank by existing oxidation ditch.

The first stage denitrification tank has a diameter of 16.80m, a height of 12.6m, a design effective water depth of 11.5m, a single tank effective volume of 2500m³, and a total denitrification volume of 5000m³. The first stage nitrification tank has a diameter of 16.80m, a height of 12.6m, a design effective water depth of 11.4 m, a single tank effective volume of 2500m³, and a total denitrification volume of 7500m³.

Equipment configuration and parameters of the first stage A/O biochemical system: 8 first stage denitrification agitators, 4 set/tank, 11kW/set; 4 magnetic suspension fans, 3 for use and 1 for standby, q=5000m³/h, 1.2bar; 3 first stage nitrification jet circulating pumps, q=600m³/h, H=15m; 3 nitrate reflux pumps, q=300m³/h, H=10m; 2 counter current cooling towers, q=500m³/h, Δt=5°C, wet bulb temperature 27°C; 2 cooling sludge circulating pumps, q=500m³/h, H=16m; 2 cold water circulating pumps, q=500m³/h, H=13m; 2 layout heat exchangers, q=500m³/h, 1600kW, 200m².

The second stage denitrification tank is transformed from the existing oxidation ditch. It uses half of the tank capacity, with the size of 50m×10m×5.2m (H), effective water depth of 4m and effective volume of 2000m³. The second stage denitrification tank is transformed from the existing oxidation ditch. It uses half of the tank capacity, the size is 45m×10m×5.2m (H), effective water depth 4m and effective volume of 1800m³. It uses the existing microporous aeration system and the existing roots blower. The designed sludge concentration is 15g/L, and the designed denitrification rate is 0.128kgNO₃-N/[kg(MLSS)·d]
Equipment configuration and parameters of the second A/O biochemical system: 4 sets of the second stage denitrification submersible agitators, 4kW/set; 2 sets of the second stage microporous aeration fans (existing), 1 for use and 1 for standby, q=4200m$^3$/h, 0.6bar.

5.3. MBR ultrafiltration system
The second stage nitrification effluent is lifted into the ultrafiltration system by the ultrafiltration feed pump. Three horizontal centrifugal pumps, two for use and one for standby, q=400m$^3$/h, H=16m, are used for ultrafiltration water inlet pump.

The designed treatment capacity of ultrafiltration system is 600m$^3$/d, with three sets of units, two for use and one for standby. Each unit is equipped with two loops. The designed ultrafiltration flux is 50LMH, the area of a single membrane module is 27.2m$^2$, and the number of membrane tubes in each loop is 5.

5.4. Nanofiltration system
The designed treatment capacity of nanofiltration system is 600m$^3$/d, and the designed water production rate is 75%. A total of 2 sets of units are set up for 2 uses. Considering the influence of membrane cleaning on daily treatment capacity, the actual treatment water volume of each unit is 800 m$^3$/d.

Each unit is equipped with 3 loops, the designed membrane flux is 12LMH, the area of a single membrane module is 37m$^2$, the number of parallel membrane shells in each loop is 2, and the number of membrane elements in each loop is 4.

5.5. Reverse osmosis system
The 450m$^3$/d of nanofiltration effluent and 65m$^3$/d of DTRO clear liquid are treated by reverse osmosis system. The treatment capacity is 600m$^3$/d and the designed water production rate is 70%. A total of 3 sets of units are set up, 1 set is new and 2 sets are old ones.

Each unit is equipped with three loops, the designed membrane flux is 10LMH, the area of a single membrane module is 34.4m$^2$, the number of parallel membrane shells in each loop is 2, and the number of membrane elements in each loop is 5.

5.6. Reverse osmosis concentrate treatment system
The reverse osmosis concentrate is treated by high pressure reverse osmosis. The treatment scale is 200m$^3$/d. A total of 1 set is designed. The designed water production rate of the system is 40% and the operating pressure is 90bar.

The design flux of high-pressure reverse osmosis membrane is 10LMH, the area of single membrane column is 9.405m$^2$, and the number of membrane columns is 36.

5.7. Sludge treatment system
The excess sludge yield of leachate treatment system is about 200m$^3$/d, and the moisture content of sludge is 98.5%. The dewatered sludge with 80% moisture content is transported to the sludge truck by shaftless screw conveyor, and then transported to the existing landfill site for landfill. The dewatered supernatant is lifted to the water balance tank by submersible pump for further treatment.

A screw stacking dehydrator with a capacity of 35m$^3$/h is designed and a sludge tank with a diameter of 6.8m, a height of 6.6m, an effective height of 5.5m and an effective volume of 200m$^3$ is set. In order to prevent anaerobic floating of sludge, a submersible mixer with a capacity of 7.5kW is set in the sludge tank; an existing sludge tank with a diameter of 3.5m, an effective water depth of 3.2m and an effective volume of 30m$^3$ is used for dewatering and night cleaning.

Main equipment parameters: 2 screw pumps for sludge feeding, one for standby, q=40m$^3$/h, H=20m, frequency conversion; 1 screw stacking dehydrator, with treatment capacity of 35m$^3$/h, sludge moisture content of 98.5%; 1 shaftless screw conveyor; 1 PAM automatic dispensing machine, 0~3000L/s; 2 PAM dosing pumps, one for operation and one for standby, q=3000L/h, H=30m.
6. Other research and design key points

6.1. Reflux ratio
The reflux ratio of leachate treatment system is much larger than that of municipal sewage treatment system (3~5), generally no less than 20[4]. Due to the high concentration of organic matter in the denitrification tank of leachate treatment system, the dissolved oxygen brought into denitrification by high reflux ratio will be consumed quickly. In this project, the influent ammonia nitrogen and total nitrogen concentrations of leachate are higher, and the required removal rate is also higher. Higher denitrification removal requires higher reflux ratio. However, due to the higher sludge concentration and smaller biochemical volume of leachate treatment system, too high reflux ratio will bring a large amount of dissolved oxygen in nitrification tank to denitrification, which will inhibit denitrification.

The total nitrogen of RO fresh water mixing is required to be controlled below 10mg/L. Therefore, the total nitrogen of effluent of two-stage A/O in biochemical section should be controlled below 300mg/L in process design. According to the calculation method of Du Yu [5], the total reflux ratio, that is, the sum of internal reflux ratio and sludge reflux ratio, needs to be designed as 70, in which the sludge reflux ratio is 11 and the internal reflux ratio is 59. The total reflux flow is 2300m³/h, and the HRT of the first denitrification is only 0.9h. According to the feedback from the field operation tests of several projects, when the reflux flow is large, especially when the reflux ratio reaches above 40, the dissolved oxygen concentration of denitrification begins to increase and the biochemical nitrogen removal efficiency begins to decline. According to the actual operation feedback, the reflux ratio is set to the maximum of 40, in which three internal reflux pumps are set, and one frequency converter is used to adjust the reflux flow according to the inflow water. According to the feedback of actual operation effect, when the maximum reflux ratio is 40, it can well meet the requirements of denitrification treatment.

6.2. The two stage A/O water level control
The usable area of this project is very small, and the area is reduced as far as possible under the condition of meeting the effective biochemical volume. The first stage A/O biochemical tank adopts the way of heightening the effective water depth, and the maximum effective water level is 11.5m, which is 12m relative to the outdoor floor elevation. The second stage A/O is to transform the existing oxidation ditch, the effective water depth is 4m, and the relative outdoor floor elevation is 2m. Therefore, the maximum height difference between the first and the second A/O systems is 10m.

In order to make full use of the tank volume, two overflow levels are set between the primary A/O biochemical tank and the secondary A/O biochemical tank. The high overflow level is used for full load operation, and the low overflow level is used for debugging and low load operation. The electric valve is set on the outlet pipe of low overflow liquid level, and the biochemical operation liquid level is adjusted by opening the valve to meet the requirements of different water treatment.

6.3. The Economy of magnetic suspension fan
In this project, the design aeration air volume is 13000m³/h, 4 fans are selected, three for use and one for standby, the parameters of the fans are 4=5000m³/h, 1.2 bar.

For the same fan parameters, the power of magnetic suspension fan is 200kW, while the power of Roots fan is 250kW. Under the maximum operating condition, a single magnetic levitation fan can save (250-200) × 24 = 1200kWh per day compared with Roots fan. The industrial power price is calculated as 0.65 yuan/kWh, and the maximum annual saving is 284700 yuan. The investment cost can be recovered in six years.

6.4. Rapid construction and installation of enamel assembly tank
This project is an upgrading project, the main purpose of which is to deal with the leachate accumulated in the landfill. It takes about 6 months from the project approval to the completion of design, construction and commissioning, and it needs to reach the production capacity before the rainy season. The reason why the project has been carried forward relatively fast is that the biochemical reaction tank
adopts enamel assembly tank, and the construction period is short. The construction of enamel assembled tank can achieve two layers a day on average. The casing of tank body is processed in the factory, and is connected with other standard enamel steel plates with bolts and sealed with sealant.

Taking denitrification tank as an example, there are 11 layers of enamel steel plate wall and one layer of capping. The construction period is about 7 days. The construction period of concrete circular foundation is about 5 days, and the total period is about 2 weeks. Multiple tanks can be installed at the same time.

The enamel layer of the enamel assembly tank is smooth, highly inert, no adhesive surface, wear-resistant and corrosion-resistant. After the installation, there is no anti-corrosion work except for the sealant seal at the bolt joint. The external insulation of the tank is made of 100 mm thick glass wool board and coated with colour steel plate, which is implemented in the later stage of commissioning, without affecting the early construction and commissioning.

7. Operation effect
The project was completed and put into operation in August 2018. Up to now (January 2021), it has been running stably for over 2 years. The monitoring data of treatment effect is shown in Table 4, and the treated effluent can meet the design emission limits.

|          | CODcr (mg/L) | Conductivity (μs/cm) | NH3-N (mg/L) | TN (mg/L) | PH  |
|----------|--------------|----------------------|--------------|-----------|-----|
| Influent | 70000~       | 31000~               | 2800~        | 3700~     | 7.9~8.2 |
|          | 10000        | 42000                | 4100         | 4800      |     |
| Effluent | ≤ 10         | ≤ 2000               | ≤ 0.5        | ≤ 10      | 6.5~7.5 |

8. Technical and economic indicators
The total investment of the project is estimated to be 65.2 million yuan, and the plant area for upgrading and expansion is 2380m². The total installed capacity is about 2600kW and the working capacity is 2200kW. The cost of leachate treatment per cubic meter includes labour cost, power cost, material cost, maintenance cost and operation management cost. The unit treatment cost excluding concentrated solution treatment is about 30yuan/m³. The entrusted treatment cost of concentrated liquid is 300yuan/m³.

9. Conclusion
On the basis of strengthening the biochemical treatment and advanced treatment measures of leachate, the project has achieved the effluent quality standard requirements of the B discharge limits in Table 1 of Beijing local standard Integrated discharge standard of water pollutants (DB11/307-2013). The effluent ammonia nitrogen can be stabilized below 1mg/L, and the effluent total nitrogen can be stabilized below 10mg/L, reducing the accumulation of leachate in landfill. The stable operation of the project provides a new transformation idea and technological route selection for the upgrading and transformation of landfill leachate treatment.

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