Engineering design of landfill leachate treatment system in a waste incineration plant in Chengdu

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Abstract. The engineering design and operation of landfill leachate treatment system in a waste incineration plant in Chengdu are systematically introduced. The engineering design experience of UBF+MBR+NF+RO process for leachate treatment of incineration plant and advanced oxidation process for treatment of nanofiltration concentrate are summarized, which provides reference for engineering design of leachate treatment in incineration plant. The operation results show that the effluent can meet the “make-up water for open circulating cooling water system” in The Reuse Of Urban Recycling Water―Water Quality Standard For Industrial Uses (GB/T19923-2005), and the effluent treated by nanofiltration concentrate can meet the corresponding standards in Table 2 of Standard For Pollution Control On the Landfill Site Of Municipal Solid Waste (GB16889-2008).

1. Introduction
A waste incineration plant in Chengdu is located in Wanxing Township, Longquanyi District, Chengdu City. The plant area is close to the Chengdu solid waste sanitary disposal site in the East and about 29km away from Chengdu urban area in the West. The project covers an area of 127730 square meters. This paper systematically introduces the engineering design and operation of landfill leachate treatment system, and summarizes the engineering design experience of MBR+NF+RO process for treating leachate from incineration power plant and advanced oxidation process for treating nanofiltration concentrate, which provides engineering design reference for leachate treatment in waste incineration plant.

2. Designed processing scale and water quality

2.1. Designed processing scale
The waste incineration capacity of the plant is 2400 tons per day. The leachate treatment scale of the project is designed according to 30% of the waste treatment capacity, and the design scale of the system is set as 850m³/d considering the requirements of the owner and the emergency treatment of the leachate from the landfill outside the plant.

2.2. Inlet and outlet water quality
The effluent from leachate system must meet the requirements of “make-up water for open circulating cooling water system” in The Reuse Of Urban Recycling Water―Water Quality Standard For Industrial Uses (GB/T19923-2005).
Uses (GB/T19923-2005)[1] and the table 2 requirements of Standard for Pollution Control on the Landfill Site of Municipal Solid Waste (GB16889-2008)[2]. The qualified produced water is reused in the circulating cooling water system of incineration plant. The nanofiltration concentrate is treated on site and meets the table 2 of Standard for Pollution Control on the Landfill Site of Municipal Solid Waste (GB16889-2008).

Table 1. Water quality of influent and effluent

|                  | COD\textsubscript{cr} (mg/L) | BOD\textsubscript{5} (mg/L) | NH\textsubscript{4}-N (mg/L) | TN (mg/L) | SS (mg/L) | pH   |
|------------------|-------------------------------|-----------------------------|-----------------------------|-----------|-----------|------|
| Influent water   | 80000                         | 40000                       | 2500                        | 2800      | 10000     | 6~9  |
| Reuse water      | 60                            | 10                          | 10                          | 40        | 30        | 6.5~8.5 |
| Discharge water  | 100                           | 30                          | 25                          | 40        | 30        | 6~9  |

3. Treatment process

The leachate treatment process: Regulating tank→Anaerobic reactor→MBR (two-stage A/O+ external ultrafiltration)→Nanofiltration (NF)→Reverse osmosis (RO)→reuse. The water production rate of the system is not less than 75%, and the remaining 25% of membrane concentrated solution is discharged after reaching the standard.

4. Process plan and design parameters

4.1. Pretreatment system

A spiral grid machine with separation grid diameter of 1 mm is designed in front of the regulating tank. The spiral grid machine is equipped with automatic washing and pressing system, and the moisture content of slag is less than 70%. After slag removal, leachate flows into pre-sedimentation tank by gravity.

Equipment configuration and parameters of pre-treatment system: 1 set of spiral grid machine, q=50 m\textsuperscript{3}/h, grid gap of 1mm; 1 set of sludge discharge pump of pre sedimentation tank, single screw pump, Q=15 m\textsuperscript{3}/h, H=20m; 5 sets of anaerobic inlet pump (2 for use and 3 for standby), single screw pump, Q=25 m\textsuperscript{3}/h, H=20m.

Designed parameters and dimensions of structures: 3 pre-sedimentation tanks, underground reinforced concrete structure, surface loading of 1.75 m\textsuperscript{3}/(m\textsuperscript{2}.h), size of 4.5m× 4.5m; 2 regulating tanks, underground reinforced concrete structure, surface loading of 0.024 m\textsuperscript{3}/(m\textsuperscript{2}.h), size 38.0m×20.0m×4.5m.

4.2. UBF anaerobic system

The UBF anaerobic reactor of the project is designed as a medium temperature anaerobic reactor, and the temperature is controlled at 35℃[3]. The steam from the incineration plant is used to heat the medium in the anaerobic reactor. Soft strip membrane packing is used as filler, and ferric chloride dosing system is designed to avoid the toxic inhibition of hydrogen sulfide produced in anaerobic process [4].

Table 2. Designed parameters of anaerobic process

|                  |                 |
|------------------|-----------------|
| Water flow       | 850 m\textsuperscript{3}/d |
| Temperature      | 35°C            |
| Influent COD concentration | 80000 mg/L     |
| Anaerobic COD removal rate | 80%             |
| Anaerobic effluent COD concentration | 16000 mg/L     |
| Designed volume loading | 7.5 kg COD/m\textsuperscript{3}.d |
| Anaerobic reactor effective volume | 9200 m\textsuperscript{3} |
| Anaerobic reactor | 2 seats, each with an effective volume of 4600 m\textsuperscript{3}. The size is Ø19.60 m×15.9 m(h) |
Equipment configuration and parameters of anaerobic system: anaerobic circulation pump, 2 horizontal centrifugal pumps, \( q=20\, \text{m}^3/\text{h}, H=20\, \text{m} \); double membrane dry gas storage tank, \( V=1500\, \text{m}^3 \); biogas booster conveying device, \( Q=1000\, \text{m}^3/\text{h}, P=12\, \text{kpa} \); biogas emergency flare combustion capacity \( 1000\, \text{m}^3/\text{h} \).

![Figure 1. 1# UBF anaerobic tank](image1)

![Figure 2. 2# UBF anaerobic tank](image2)

### 4.3. Two stage A/O-external MBR biological treatment system

The external membrane biochemical reactor designed in this project consists of primary denitrification, nitrification, secondary denitrification, nitrification and external ultrafiltration unit. The external tubular ultrafiltration is adopted in the external membrane bioreactor instead of the traditional secondary sedimentation tank, which completely realizes the separation of sludge and water, and makes the sludge concentration in the biochemical system reach 15-30g/L \([5]\).

#### Table 3. Biochemical process parameters

| Parameter                             | Value                                      |
|---------------------------------------|--------------------------------------------|
| First-stage denitrification tank      | 2 seats; 750m³/seat, 8.6m×11m×9.5m         |
| First-stage primary nitrification tank| 4 seats; 1100m³/seat, 12.5m×11m×9.5m       |
| Second-stage denitrification tank     | 2 seats; 420m³/seat, 4.8m×11m×9.5m         |
| Second-stage nitrification tank       | 2 seats; 275m³/seat, 3.2m×11m×9.5m         |
| Biochemical pool water temperature    | 35°C                                       |
| Biochemical reactor sludge concentration | 15g/L                               |
| Designed denitrification rate         | 0.128kg NO\textsubscript{3}-N/ kgMLSS /d   |
| Total denitrification rate            | 98.6%                                      |
| Denitrification reflux ratio          | 20:1                                       |
| First-stage denitrification tank      | 2 seats; 750m³/seat, 8.6m×11m×9.5m         |
| First-stage primary nitrification tank| 4 seats; 1100m³/seat, 12.5m×11m×9.5m       |

Equipment configuration and parameters of two-stage A/O system: 2 sets of MBR inlet pumps (2 for use and 1 for standby), screw pump, \( Q=25\, \text{m}^3/\text{h}, H=20\, \text{m} \); 2 bag filters, \( Q=25\, \text{m}^3/\text{h} \), filtration accuracy of 600-1000μm; 4 primary denitrification agitators, 3KW; 8 primary nitrification jet circulating pumps, \( Q=500\, \text{m}^3/\text{h}, H=13\, \text{m} \); 4 sets of primary nitrification jet aerators; 6 sets of roots blowers (4 for use and 2 for standby), \( Q=50\, \text{nm}^3/\text{min}, H= 8\, \text{m} \); 4 secondary denitrification agitators, 1.5KW; 2 secondary nitrification jet circulating pumps, horizontal centrifugal pumps, \( Q=150\, \text{m}^3/\text{h}, H=13\, \text{m} \); 2 sets of secondary nitrification aerators; 2 sets of nitrate reflux pumps, horizontal centrifugal pumps, \( Q=200\, \text{m}^3/\text{h}, H=13\, \text{m} \); 2 ultrafiltration water inlet pumps, horizontal centrifugal pumps, \( Q=200\, \text{m}^3/\text{h}, H=16\, \text{m} \).
Compared with the traditional biochemical treatment process, microbial cells are separated from the effluent by high-efficiency ultrafiltration system to ensure that the particles larger than 20nm, microorganisms and suspended solids related to cod are safely retained in the system. Due to the separation of sludge and water by ultrafiltration, the sludge concentration in the biochemical reactor can reach 15~30g/L.

Table 4. Main process parameters of ultrafiltration

| Parameters                        | Value                                      |
|-----------------------------------|--------------------------------------------|
| Number of ultrafiltration loops   | 4 bars                                     |
| Number of ultrafiltration membrane modules | 24 sticks                                  |
| Membrane structure, filtration method | Tubular, cross-flow filtration            |
| Membrane material                 | PVDF                                       |
| Membrane filtration pore size     | 20-30nm                                    |
| Total membrane area               | 652.8m²                                    |
| (The area of a single membrane is 27.2m² ) |                                        |
| Design membrane flux              | 68L/m²·h                                   |
| Daily water production            | 865m³/d                                    |
| Loop circulation flow             | 275m³/h                                    |
| System operating pressure         | 4.4-6bar                                   |

4.4. Nanofiltration system

According to the material balance calculation, the clear liquid yield of nanofiltration system needs to reach more than 91%. Therefore, this project designs two-stage nanofiltration for treatment, and the second-stage nanofiltration is used to treat the concentrated liquid of primary nanofiltration.

The integrated modular device is adopted for nanofiltration. Two sets of first-class nanofiltration integration equipment and one set of two-stage nanofiltration integration equipment are set in the project. Each set of primary nanofiltration system is equipped with three loops, each loop is paralleled with two pressure membrane shells, each pressure membrane shell is equipped with five/four coiled nanofiltration membrane elements, and each loop is equipped with an independent circulating pump for internal circulation of concentrated water. There is one loop in the secondary nanofiltration system. Two pressure membrane shells are paralleled in the loop. Four coiled nanofiltration membrane elements are set in each pressure membrane shell. The loop is equipped with an independent circulating pump for the internal circulation of concentrated water.

Table 5. Parameters of nanofiltration system

| Parameters                        | Parameters of first-stage nanofiltration process | Parameters of second-stage nanofiltration process |
|-----------------------------------|--------------------------------------------------|--------------------------------------------------|
| Inlet water flow                  | 36.0m³/h                                         | 5.04m³/h                                         |
| Serum yield                       | 86%                                              | 35.5%                                            |
| Design filtration flux            | 18L/(h·m²)                                       | 8L/(h·m²)                                       |
| Total membrane area required      | 1722m²                                          | 223m²                                           |
| Unit membrane element area        | 37m²                                            | 37m²                                            |
| Number of membrane elements required | 46.5                                          | 6.04                                            |
| Number of NF devices              | 2                                                | 1                                                |
| NF-loop number                    | 3                                                | 1                                                |
| Number of parallel membrane shells for each loop | 2                                              | 2                                                |
| Number of membrane elements per tube | 5+5+4                                      | 4                                                |

4.5. Reverse osmosis system

The COD and salt content of the effluent from two-stage nanofiltration has not reached the effluent standard. The reverse osmosis system is designed as advanced treatment process in this project to ensure that the effluent meets the discharge standard. The reverse osmosis is medium pressure roll reverse osmosis, the average working pressure is 30~50 bar, and the maximum working pressure limit of
medium pressure reverse osmosis is 55 bar. As the influent is nanofiltration supernatant, the yield of reverse osmosis supernatant can reach more than 80%. Reverse osmosis is equipped with two sets of reverse osmosis devices, each set of reverse osmosis device has three loops, each loop is equipped with two pressure membrane shells, and each pressure membrane shell is equipped with five or six coiled reverse osmosis membrane elements.

Table 6. Parameters of reverse osmosis process

| Parameter                              | Value           |
|----------------------------------------|-----------------|
| Inlet water flow                       | 32.8m³/hr       |
| Serum yield                            | 81%             |
| Design filtration flux                 | 14l/(h·m²)     |
| Total membrane area required           | 1897.2m²       |
| Unit membrane element area             | 34.4m²         |
| Number of membrane elements required   | 55.2            |
| RO device number                       | 3               |
| RO- number of loops                    | 3               |
| Number of parallel membrane shells for each loop | 2        |
| Number of membrane elements per tube  | 5+5+6           |

4.6. Nanofiltration concentrate treatment system

4.6.1. Water quality analysis of nanofiltration concentrate
Due to the fact that nanofiltration hardly intercepts the univalent salt, the nanofiltration concentrate contains a lot of refractory organic matters (mainly humus) and divalent salts such as calcium, magnesium and barium. The conductivity is mainly contributed by divalent salt ions such as calcium, magnesium, barium and sulfate ions.

Table 7. Designed influent and effluent water quality of nanofiltration concentrate treatment

| Parameter              | COD₉₅ (mg/L) | BOD₅ (mg/L) | NH₄-N (mg/L) | TN (mg/L) | SS (mg/L) | Conductivity (ms/cm) |
|------------------------|--------------|-------------|--------------|-----------|-----------|----------------------|
| Influent water quality | 80000        | 40000       | 2500         | 2800      | 10000     | 24                   |
| Effluent water quality | 60           | 10          | 10           | 40        | 30        | --                   |

4.6.2. Treatment process of nanofiltration concentrate
Advanced oxidation combined process is proposed for the treatment of nanofiltration concentrate in this project, and the specific process flow is "denitrification treatment + coagulation sedimentation + Shas (AOP + BAC + MAC)". The process flow chart is as follows:
The total nitrogen in the concentrate was removed by nitrogen removal. Considering that the COD in the concentrate was difficult to degrade and the organic matter was difficult to be denitrified, it was necessary to add carbon source to complete the denitrification reaction. After denitrification, part of the divalent salt ions and refractory organics are removed by coagulation sedimentation. Under the conditions of ferric chloride, sodium hydroxide, sodium carbonate and polymer coagulant aid, the removal rate of organic matter (COD) in coagulation sedimentation process section is about 85%, and about 20% sludge layer is produced per ton of concentrated liquid. The sludge produced by sedimentation is mixed with biochemical excess sludge for dehydration treatment.

The concentration of COD in the concentrated nanofiltration solution after coagulation and sedimentation treatment is about 1230mg/L, most of which are macromolecular organic compounds which are difficult to be biodegraded. The SHAS combined process is designed for deep oxidation treatment. The SHAS combined process includes three-stage AOP process, two-stage BAC process and MAC heavy metal removal process. Through the Shas combined process, the effluent can be guaranteed to meet the table 2 standard of “pollution control standard for domestic waste landfill” (GB 16889-2008).

The AOP first stage uses the strong oxidation ability of ozone to preliminarily degrade some organic substances, and makes the refractory organic substances (such as unsaturated acids, polycyclic aromatic organic compounds, etc.) into biodegradable small molecules easily decomposed organic matters, providing carbon source for subsequent biological denitrification system, reducing the amount of carbon source supplement required for nitrogen removal, and directly converting organic nitrogen into organic nitrogen by using the strong oxidizability of ozone. The formation of NO$_3^-$-N makes TN removal only through biological denitrification. In the second and third stages of AOP, a large number of hydroxyl radicals are produced by the combined reaction of ozone and catalyst. The catalyst (H2O2 is selected for this project) is added to the sewage to make it cooperate with ozone. Through the catalytic chain reaction of the two substances, a large number of hydroxyl free radicals are generated, which are oxidized with organic components in the wastewater, so as to promote the rapid reaction and higher reaction efficiency.

The BAC(biological activated carbon technology) is to use granular activated carbon (GAC) with huge specific surface area and developed pore mechanism, which has strong adsorption characteristics for organic matter and dissolved oxygen in water. It is used as biological carrier instead of traditional biological filler, and makes full use of the synergistic effect of activated carbon adsorption and microbial
organic decomposition in activated carbon layer to achieve the purpose of advanced wastewater treatment.

A new type of composite material is used for heavy metal capture. The mechanism of the material is to combine the inorganic materials based on physical adsorption with the organic materials based on ion exchange in water treatment, and make up for each other, so as to provide a composite material composed of inorganic materials and nano organic materials, so that it can have the functions of physical adsorption enrichment and ion exchange at the same time.

Figure 4. Coagulation treatment  
Figure 5. Sedimentation treatment

Figure 6. AOP reaction tower  
Figure 7. Ozone tail gas absorption and decomposition device

4.6.3. Water quality analysis of nanofiltration concentrate.  
The effluent indexes of each process unit treated by nanofiltration concentrate are shown in Table 8.

| Processing unit   | PH  | CODcr (mg/L) | BOD5 (mg/L) | SS (mg/L) | NH4-N (mg/L) | TN (mg/L) |
|------------------|-----|--------------|-------------|-----------|---------------|-----------|
| Raw water        | 6~8 | 8200         | 150         | 100       | 10            | 80        |
| Denitrification  | 6~8 | 8200         | 75          | 100       | 10            | 32        |
| Coagulation      | 6~8 | 1230         | 60          | 100       | 5             | 28.8      |
| SHAS system      | 6~8 | 86.1         | 6           | 20        | 3             | 27.36     |
4.7. Reverse osmosis concentrate treatment system

4.7.1. Inlet and outlet water quality of reverse osmosis concentrated solution treatment system.
The reverse osmosis system of the project treats the water produced by nanofiltration. The main pollutants in the nanofiltration clear liquid are monovalent salt and a small amount of small molecular organic compounds. The rejection rate of organic pollutants, monovalent salt and divalent salt by reverse osmosis membrane is more than 99%. Therefore, most of the salts, a small amount of refractory or non-biodegradable organic compounds and residual nitrogen-containing compounds such as ammonia nitrogen and nitrate nitrogen are enriched in the reverse osmosis concentrate. After meeting the requirements of Table 2 of Standard For Pollution Control On The Landfill Site of Municipal Solid Waste (GB16889-2008), the effluent from RO concentrated solution treatment is discharged into municipal sewage pipeline through a high-level pool.

Table 9. Inlet and outlet water quality of reverse osmosis concentrated solution treatment

|                  | COD$_{cr}$ (mg/L) | BOD$_5$ (mg/L) | NH$_4$-N (mg/L) | TN (mg/L) | SS (mg/L) | Conductivity (ms/cm) |
|------------------|-------------------|----------------|-----------------|-----------|-----------|----------------------|
| Influent water quality | 400               | 50             | 40              | 150       | 40        | 55                   |
| Effluent water quality   | 100               | 30             | 25              | 40        | 30        | --                   |

4.7.2. Reverse osmosis concentrate treatment process.
The A set of integrated high-pressure DTRO reverse osmosis concentration reduction system is set up. The treatment scale is 150m$^3$/d, and the concentration can be reduced by 50%. The DTRO concentrated water enters the DTRO concentrated liquid pool. The DTRO concentrated liquid is lifted to the incineration plant for fly ash solidification through the reverse osmosis concentrate transfer pump.

Table 10. Designed DTRO process

| Inlet water flow | 6.25m$^3$/h   |
| Water production rate | 50%         |
| Filtration flux      | 20L/(h·m$^2$) |
| Total membrane area required | 156.25m$^2$ |
| Unit membrane area    | 9.405m$^2$   |
| Number of membrane elements required | 17          |
| Number of DTRO devices | 1 set       |
| Total number of membrane elements | 20          |
| Total filtration area of membrane | 188.10m$^2$ |
| Maximum pressure      | 75bar        |
| Temperature requirements | ≤ 30℃       |

5. Operation effect
The project was completed and put into operation in August 2018. Up to now (August 2020), it has been running stably for 2 years. The monitoring data of treatment effect is shown in Table 11, and the treated effluent meets the designed emission concentration limit.

Table 11. Actual water quality of influent and effluent

|                  | COD$_{cr}$ (mg/L) | BOD$_5$ (mg/L) | NH$_4$-N (mg/L) | TN (mg/L) | pH         |
|------------------|-------------------|----------------|-----------------|-----------|------------|
| Influent         | 50000~65,000      | 25000~30000    | 2000~2500       | 2100~2700 | 7.9~8.2    |
| Effluent         | ≤ 10              | ≤ 5            | ≤ 0.5           | ≤ 10      | 6.5~7.5    |
6. Conclusion
This project has a large scale of leachate treatment and strict effluent quality requirements. The stable operation of the system provides a new design idea and technological route selection for the treatment of leachate and membrane concentrate in the waste incineration plant. The two-stage nanofiltration process can make the overall recovery rate of the nanofiltration system reach 91%, and the treatment of the concentration solution can meet the table 2 of Standard For Pollution Control On The Landfill Site Of Municipal Solid Waste (GB16889-2008). For RO concentrate, DTRO treatment is used to reduce 50% and then to reuse. The water produced by the leachate system meets the water quality requirements of the “make-up water for open circulating cooling water system” in The Reuse Of Urban Recycling Water—Water Quality Standard For Industrial Uses (GB/T19923-2005), and the overall recovery rate is about 82%.

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