Review on landfill leachate treatment methods

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Abstract. In most countries, sanitary landfill is the most commonly used method to eliminate municipal and industrial solid waste, but landfill produces seriously polluted landfill leachate. Landfill leachate contains many kinds of pollutants: such as refractory organic compounds and heavy metals. In general, there are three methods to treat landfill leachate: leachate transfer, biological processes, chemical and physical methods and membrane processes. Membrane processes can be divided into four types: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). Membrane process has the advantages of stable effluent and high rejection rate for refractory organic matter. But high treatment cost and membrane fouling problem affect the applications of membrane in practice.

1. Introduction
Landfill is a kind of solid waste treatment method widely used in the world, which has been used for a long time in urban and industrial waste treatment[1]. However, landfilling is not a sustainable method because if the landfill fails, it will release methane gas and produce liquid (leachate) by-products.

Methane gas recovery is converted into electric energy to control gas diffusion and reduce environmental odor and explosion risk. In addition, electricity is also a valuable commodity[2].

The formation of leachate is attributed to rainfall passing through the landfill. When the rotten material is decomposed by rainwater, the landfill will continuously produce contaminated leachate, which can last for 30-40 years. The leachate is composed of high concentration biodegradable refractory organic matter, ammonia nitrogen, heavy metals, chlorinated organic salts and inorganic salts as well as some important humus components[3].

2. Landfill leachate characteristics
The characteristics of the landfill leachate can usually be expressed by the basic parameters COD, BOD, the ratio BOD/COD, pH, suspended solids (SS), ammonium nitrogen (NH₃-N), total Kjeldahl nitrogen (TKN) and heavy metals. The compositions of leachate from different sanitary landfills are reported in literatures, which shows great differences. In general, The quality of leachates can be affected by many factors, such as landfill age, precipitation, seasonal weather variation, waste type and composition, but three types of leachates have been defined by landfill age[4]. As shown on Table 1, with the increased age of leachates, the concentration of COD decreased below 3.0g/L but the ammonia nitrogen concentration increased over 400mg/L. It can be seen that the water quality of young landfill leachate is characterized by high organic matter content and strong biodegradability, the water quality of old landfill leachate is characterized by high ammonia nitrogen content and poor biodegradability. The quality of medium landfill leachate is between the young stage and the old stage.
Table 1. Landfill leachate classification vs. age.

|                | Young | Medium | Old  |
|----------------|-------|--------|------|
| Age (a)        | <1    | 1-5    | >5.0 |
| pH             | <6.5  | 6.5-7.5| >7.5 |
| COD (g L⁻¹)    | >15   | 3.0-15 | <3.0 |
| BOD₅/COD       | 0.5-1 | 0.2-0.5| <0.1 |
| TOC/COD        | <0.3  | 0.3-0.5| >0.5 |
| NH₃-N (mg L⁻¹) | <400  | 400    | >400 |
| Heavy metals (mg L⁻¹) | >2.0 | <2.0 | <2.0 |
| Organic compound | 80% VFA | 5-30% VFA+ | HA+FA |

3. Treatment methods of Landfill Leachate

According to the composition of landfill leachate, the removal of organic matter is the general premise of leachate treatment, including chemical oxygen demand (COD) removal, biological oxygen demand (BOD) removal and ammonia nitrogen removal. Before the leachate is discharged into the natural water body, toxicity analysis should also be carried out by testing various organisms. At present, there are three kinds of convenient methods for leachate treatment: leachate transfer method, biodegradation method and physical and chemical method[5].

There are two types of landfill leachate transfer, one is combined treatment with domestic sewage, the other is recycling leachate. The advantages of combined treatment with domestic sewage are easy maintenance and low operating costs. However, due to the existence of low biodegradable organic compounds and heavy metals in leachate, the treatment efficiency may be reduced and the effluent concentration may be increased, this method is questioned. Recycling leachate has been widely used in the past decade due to low cost. However, if the recycling volume of leachate is very high, saturation, ponding and acid problems will occur.

Physical and chemical processes include flotation, coagulation/flocculation, adsorption, chemical oxidation, and reduction of suspended solids, colloidal particles, floats, colors, and toxic compounds[6]. Physical/chemical treatment of landfill leachate is also used for treatment line (pretreatment or final purification) or for treatment of specific pollutants (ammonia stripping).

Biological treatment usually helps to remove a large amount of leachate with high BOD concentration. It also helps to remove organic and nitrogenous substances from young leachate. When the ratio of BOD/COD is greater than 0.5, biological treatment is very effective because of less refractory substances. Biological treatment can be divided into anaerobic biological treatment process and aerobic biological treatment process. Anaerobic biological treatment process occurs in a closed container without air. It is possible to remove some metals, refractory and organic matters. However, after anaerobic treatment, the leachate still contains high concentrations of dissolved methane, ammonia nitrogen, sulfide and amines, which can not meet the surface water discharge standards. Due to the risk of methane gas and sulfide, leachate cannot be discharged into the sewer. Therefore, it is necessary to adopt aerobic treatment after anaerobic treatment. The process of aerobic treatment helps to oxidize organic matter into carbon dioxide and water, and helps to remove ammonia nitrogen by oxidation to nitrate.

Although a universal solution to treat leachate has not been found all over the world and it still exist the treatment problems of landfill leachate, the conventional biological treatment method and the classical physical and chemical methods are considered to be the most appropriate technologies for the treatment and management of high-strength effluents such as landfill leachate for many years. When treating young landfill leachate, biological treatments has an effective treatment on COD, NH₃-N and heavy metals. When the stable (less biodegradable) leachate is treated, it is found that physical and chemical treatment can be regarded as a more suitable refining step for the biological treated leachate.
to remove the organic refractory substances.

The integrated chemical–physical–biological processes can reduce the disadvantages of single process and improve the efficiency of the overall treatment. However, with the continuous improvement of discharge standards in most countries all over the world and the aging of landfill with more and more stable leachate, conventional treatment methods (biological, physical and chemical treatment) are not enough to completely reduce the purification level required by sewage discharge and the negative impact of landfill leachate on the environment. Therefore, a new treatment method based on membrane technology has gradually become the choice of most countries.

4. Membrane processes

In recent years, due to the complex composition of the landfill leachate, the bio-chemical treatment is difficult, and various membrane materials have developed rapidly. According to the pore size of membrane materials, membrane processes can be divided into four types: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). Because the pore size is too large to reduce the efficiency of microfiltration, the microfiltration has few applications in leachate treatment and the last three membrane materials are widely used in landfill leachate treatment. In the treatment of landfill leachate, membrane technology is generally put at the end of the treatment process. One side membrane processes can effectively eliminate macromolecule refractory organic matter and total nitrogen and ensure effluent quality. The other side membrane processes has the characteristics of stable effluent quality.

Microfiltration (MF) can be used to remove colloids and suspended solids. Microfiltration just can be used in the pretreatment of other membrane processes (UF, NF or RO) or to assist in chemical treatment, but cannot be used alone.

Ultrafiltration (UF) membrane has been successfully used in large-scale membrane bioreactor, which can effectively remove macromolecules and particles in landfill leachate. Ultrafiltration can be used as a tool to separate organics and evaluate the preponderant molecular mass of organic pollutants in a leachate. In general, ultrafiltration can be used as pre-treatment of reverse osmosis or placed after biological treatment.

Nanofiltration (NF) membrane can filter organic, inorganic and microbial contaminants. It has a high rejection rate for sulfate ions and dissolved organic matter, and a very low rejection rate for chloride and sodium, reducing the volume of concentrate. Regardless of the geometry of the membrane material (flat, tubular or spiral damage), nanofiltration can remove nearly 60-70% of COD and 50% of ammonia. If the physical method is combined with nanofiltration effectively, 70-80% COD in landfill leachate can be removed. However, nanofiltration membrane may be polluted by many kinds of substances during the treatment processes: dissolved organic and inorganic substances, colloids and suspended particles.

Reverse osmosis (RO) is a process that by pressure-driven between the two sides of the semipermeable membrane[7]. The pressure difference between the two sides can make the solvent penetrate the membrane and realize the separation of solvent and solute. Reverse osmosis membrane does not involve phase change and has low energy consumption. It plays an important role in desalination of brackish water and preparation of ultra pure water. Reverse osmosis used in desalination accounts for more than 50% of the new desalination capacity in the world. But reverse osmosis has two disadvantages: membrane fouling and the generation of large volume of concentrate. Membrane fouling may lead to the short service life of membrane and reduce the productivity of reverse osmosis process, which requires extensive pretreatment or chemical cleaning of membrane. When a large amount of concentrate is generated, reverse osmosis cannot be used, so concentrate must be discharged or further treated.

5. Conclusion

How to discharge landfill leachate up to standard is a recognized problem in water treatment industry all over the world. Landfill leachate contains high concentration of organic and inorganic constituents
which can cause persistent and potentially hazardous to environmental. There are four methods to treat landfill leachate: leachate transfer, biodegradation, chemical and physical methods and membrane processes. Reverse osmosis can be regarded as the most promising membrane filtration, but it has the disadvantages such as: high treatment cost, membrane fouling and the generation of large volume of concentrate. In the future, if the economy of membrane processes can be improved, it will have a positive impact on landfill leachate treatment.

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