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REVIEW

Perspectives on technology for landfill leachate treatment

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KEYWORDS

Landfill leachate;
Environmental protection;
Prospect

Abstract Landfills are designed to dispose high quantities of waste at economical costs with potentially less environmental effects; however, improper landfill management may pose serious environmental threats through discharge of high strength polluted wastewater also known as leachate. This paper focused on achievements on landfill leachate treatment by different technology, which contains biological treatment and membrane technology. Finally, development and prospect of landfill leachate treatment were predicted.

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1. Introduction

Landfill leachate is the liquid produced by natural humidity and water present in the residue of organic matter, the result of the biological degradation of organic matter present and by water infiltration in the covering and inner layers of landfill cells, supplementing dissolved or suspended material originating from the residue mass.

The chemical and microbiological composition of landfill leachate is complex and variable, since apart from being dependent upon features of residual deposit, it is influenced by environmental conditions, the operational manner of the landfill and by the dynamics of the decomposition process that occurs inside the cells (El-Fadel et al., 2002; Kjeldsen et al., 2002).

Landfill leachate is generally a dark coloured liquid, with a strong smell, which carries a high organic and inorganic load. One of its characteristic features is an aqueous solution in which four groups of pollutant are present: dissolved organic matter (volatile fatty acid and more refractory organic matter such as humic substances), macro inorganic compounds (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, $NH_4{}^{+}$, Fe^{2+}, Mn^{2+}, HCO_3^{-}), heavy metals (Cd^{2+}, Cr^{3+}, Cu^{2+}, Pb^{2+}, Ni^{2+}, Zn^{2+}), and xenobiotic organic compounds originating from chemical and domestic residue present at low concentrations (aromatic hydrocarbons, phenols, pesticides, etc.) (Christensen and Kjeldsen, 1991), and microorganisms that indicate, predominantly total and thermotolerant coliform (Moravia et al., 2013). Table 1 summarizes the classification of landfill leachate according to the composition changes. In this respect, young acidogenic landfill leachate is commonly characterized by high biochemical oxygen demand (BOD) (4000–13,000 mg/L) and chemical oxygen demand (COD) (30,000–60,000 mg/L) concentrations, moderately high strength of ammonium nitrogen (500–2000 mg/L), high ratio of BOD/COD ranging from 0.4 to 0.7 and a pH value as low as 4 (Wu et al. 2001; Morais and Zamora, 2005), with biodegradable volatile fatty acids (VFAs) appear to be its major constituents (Aziz et al. 2007). Table 1 represents classification of landfill leachate according to the composition changes.

2. Review and evolution of landfill leachate treatments

2.1. Biological treatment

Due to its reliability, simplicity and high cost-effectiveness, biological treatment (suspended/attached growth) is commonly used for the removal of the bulk of leachate containing high concentrations of BOD. Biodegradation is carried out by microorganisms, which can degrade organic compounds to carbon dioxide and sludge under aerobic conditions and to biogas (a mixture comprising chiefly CO_2 and CH_4) under anaerobic conditions (Renou et al. 2008). Biological processes have been shown to be very effective in removing organic and nitrogenous matter from immature leachates when the BOD/COD ratio has a high value (> 0.5). With time, the major presence of refractory compounds (mainly humic and fulvic acids) tends to limit process's effectiveness (Kargi and Pamukoglu, 2003; Vilar et al., 2011).

Yabroudi et al. (2013) studied the landfill leachate biological treatment by nitritation/in an activated sludge sequencing batch reactor. The removal efficiencies of N–NO_2-at the end of the anoxic phase (1 h) ranged between 8% and 31% indicating low availability of easily biodegradable organic matter in the leachate. No imbalance was observed over the nitritation process at the end of the aerobic phase (48 h) of treatment cycles and the specific rates ranged from 0.043 to 0.154 kg. N-NH_3/kg.SSV day, demonstrating the applicability of the simplified nitritation/denitritation in the treatment of effluents with low C/N. Zhu et al. (2013) introduced a system which combined ASBR with pulsed SBR (PSBR) to enhance COD and nitrogen removal from the real landfill leachate. The results obtained from the joint operation period (157 days) show that the COD removal rate of ASBR was 83–88% under the specific loading rate of 0.43–0.62 gCOD $gVSS^{-1}$ day^{-1}. PSBR's operation can be divided into four phases according to the different influent NH_4^{+}–N which increased to 800–1000 mg L^{-1} finally, and total nitrogen (TN) removal rate of more than 90% with the effluent TN of less than 40 mg L^{-1} was obtained. Consequently, the system achieved COD and TN removal rate of 89.61–96.73% and 97.03–98.87%, respectively. Eldyasti et al. (2011) applied circulating fluidized bed bioreactor (CFBBR) to biological treatment of landfill leachate, at empty bed contact times (EBCTs) of 0.49, and 0.41 d and volumetric nutrient loading rates of 2.2–2.6 kg COD/(m^3 d), 0.7–0.8 kg N/(m^3 d), and 0.014–0.016 kg P/(m^3 d), were used to calibrate and compare developed process models in BioWin and AQUIFAS. BioWin and AQUIFAS were both capable of predicting most of the performance parameters such as effluent TKN, NH_4–N, NO_3–N, TP, PO_4–P, TSS, and VSS with an average percentage error (APE) of 0–20%. BioWin underpredicted the effluent BOD and SBOD values for various runs by 80% while AQUIFAS predicted effluent BOD and SBOD with an APE of 50%. Xu et al. (2010) developed a

Table 1 Classification of landfill leachate according to the composition changes (Alvarez-Vazquez et al., 2004; Chian and DeWalle, 1976).

Type of leachate	Young	Intermediate	Stabilized
Age (years)	< 5	5–10	> 10
pH	< 6.5	6.5–7.5	> 7.5
Biodegradability	Important	Medium	Low
Kjeldahl nitrogen (g/L)	0.1–0.2	–	–
Ammonia nitrogen (mg/L)	< 400	–	> 400
TOC/COD	< 0.3	0.3–0.5	> 0.5
Heavy metals (mg/L)	Low to medium	Low	Low
BOD_5/COD	0.5–1.0	0.1–0.5	< 0.1
COD (mg/L)	> 10,000	4,000–10,000	< 4000

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biological treatment with the integration of partial nitrification, anaerobic ammonium oxidation (Anammox) and heterotrophic denitrification in a SBR with periodical air supply to treat landfill leachate. An operating temperature of 30 ± 1 °C and a dissolved oxygen concentration within 1.0–1.5 mg/L were maintained in the SBR. First, the mixture of Anammox biomass and aerobic activated sludge (80% w/w) were inoculated, and inorganic synthetic wastewater with progressively increased N-loading was added. The activities of maximum aerobic ammonium oxidizing and anaerobic ammonium oxidizing reached 0.79 and 0.18 (kg $NH_4{}^+$–N/kgdw/day) after the inoculation lasting 86 days, respectively. Secondly, an unexpected group of heterotrophic denitrifying bacteria was inoculated into the reactor along with the feeding of raw landfill leachate, and the final maximum activities of aerobic ammonium oxidizing, anaerobic ammonium oxidizing and denitrification reached 2.83 (kg NH_4^+–N/kgdw/day), 0.65 (kg NH_4^+–N/kgdw/day) and 0.11 (kg NO_3^+–N/kgdw/day), respectively. Schematic representation of the 3L lab-scale SBR is shown in Fig. 1.

Yahmed et al. (2009) carried out Jebel Chekir landfill leachate (Tunisia) treatment using an aerobic pilot unit with three immersed and fixed biofilms reactors. A preliminary analysis indicates a high biodegradable fraction in the leachate (BOD_5/COD = 0.4), which implies that biological treatment process can be applied. Performance results obtained during this study indicate a significant organic matter reduction; between 60% and 90% of TOC reduction was obtained. However, a consortium containing a mixture of the bacterial isolates inoculated in the raw leachate, reaches TOC yield of about 84%. Trabelsi et al. (2009) studied anoxic digestion based on the endogenous biomass activities in batch reactor (V = 150 L) for the treatment of landfill leachate of Jebel Chekir landfill (Tunisia). With a retention time of 90 days, the anoxic digestion reactor has shown reductions in BOD_5, COD, TOC, NH_4–N and TKN respectively by 91%, 46%, 65%, 45% and 63%. Later, the effluent was further treated in down flow cascade in three aerated submerged biological reactors, with 7 days of total retention time. Further reductions in these

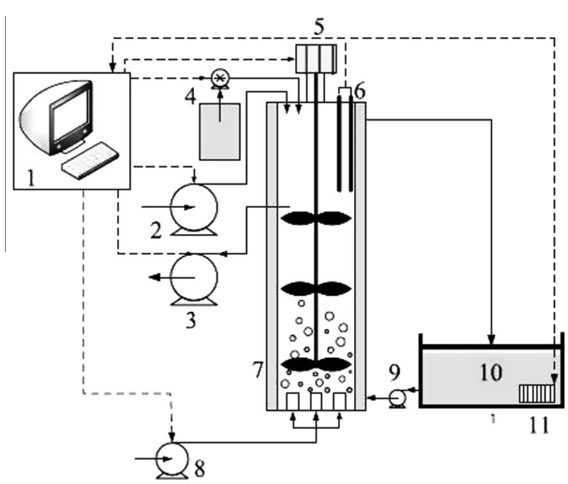

Figure 1 Schematic representation of the 3L lab-scale SBR (1; control system, 2;influent pump, 3; effluent pump, 4; pH controller, 5; stirrer, 6; probes (pH, DO, T), 7;jacketed SBR, 8; air compressor, 9; thermostatic pump, 10; thermostatic tank, 11; heater.

parameters were achieved in the aerobic reactors and the overall removal efficiencies achieved by the coupled system of anoxic and aerobic reactors were 95% for BOD_5, 94% for COD and 92% for NH_4^+–N. Moreover, post treatment aimed at the removal of heavy metals by adsorption on powdered activated carbon (PAC) was also studied in this work and was found effective to enhance the removal of COD up to a total reduction level of 99.7%.

Sun et al. (2009a,b) investigated the nitrite accumulation in the denitrification process with sequencing batch reactor (SBR) treating pre-treated landfill leachate in anoxic/anaerobic up-flow anaerobic sludge bed (UASB). Nitrite accumulates obviously at different initial nitrate concentrations (64.9, 54.8, 49.3 and 29.5 mg L^{-1}) and low temperatures, and the two break points on the oxidation–reduction potential (ORP) profile indicate the completion of nitrate and nitrite reduction. Usually, the nitrate reduction rate is used as the sole parameter to characterize the denitrification rate, and nitrite is not even measured. For accuracy, the total oxidized nitrogen (nitrate + nitrite) is used as a measure, though details characterizing the process may be overlooked. Additionally, batch tests are conducted to investigate the effects of C/N ratios and types of carbon sources on the nitrite accumulation during the denitrification. It is observed that carbon source is sufficient for the reduction of nitrate to nitrite, but for further reduction of nitrite to nitrogen gas, is deficient when C/N is below the theoretical critical level of 3.75 based on the stoichiometry of denitrification. Five carbon sources used in this work, except for glucose, may cause the nitrite accumulation. From experimental results and the cited literature, it is concluded that Alcaligene species may be contained in the SBR activated-sludge system. Yin and Qun (2006) applied an UASB/stripping tower/Orbal oxidation ditch (dosing PAC) process for refuse leachate treatment. More than one-year practical operation shows that COD and nitrogen removal efficiencies are high. The effluent quality is stable. All parameters of the effluent reach the national discharge standard. Wang et al. (2010) applied a two stage up-flow sludge blanket (UASB) and sequencing batch reactor (SBR) system to treat municipal landfill leachate and took high efficiency in the removal of nitrogen. The results demonstrated that COD removal is highly effective by anaerobic biodegradation. The effluent NH_4^+–N removal efficiency was maintained around 99%. Total nitrogen (TN) removal efficiency could reach 85% with the effluent TN lower than 15 mg/L. Sun et al. (2010) investigated treatment of real leachate from municipal landfill with high ammonia nitrogen content by using lab-scale anoxic/anaerobic UASB-A/O process. On the basis of achieving simultaneous COD and nitrogen removal, how to achieve and stabilize partial nitrification in the A/O reactor was studied. Denitrification and methanogenesis were conducted in UASB reactor, and the average removal rate of organics and NOx–N was 5.3 and 1.1 kg/(m^3 d), respectively. Partial nitrification was achieved (nitrite accumulation ratio was above 50%) after 54 days of operation, and after 70 days, nitrite accumulation ratio in A/O reactor reached above 90% at ambient temperature of 12–30.6 °C.

2.2. Membrane technology

2.2.1. Microfiltration (MF)

MF remains interesting each time that an effective method is required to eliminate colloids and the suspended matter like,

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for instance, in pre-treatment for another membrane process (UF, NF or RO) or in partnership with chemical treatments. But, it cannot be used alone. Only Piatkiewicz et al. (2001), in a polish study, reported the use of MF as prefiltration stage. No significant retention rate (COD reduction between 25% and 35%) was achieved. Schematic of the experimental RO circuit for the leachate treatment is shown in Fig. 2.

2.2.2. *Ultrafiltration (UF)*

UF is effective to eliminate the macromolecules and the particles, but it is strongly dependant on the type of material constituting the membrane. UF may be used as a tool to fractionate organic matter and so to evaluate the preponderant molecular mass of organic pollutants in a given leachate. Also, tests with membrane permeates may give information about recalcitrance and toxicity of the permeated fractions.

Syzdek and Ahlert (1984) suggested that UF might prove to be effective as a pre-treatment process for reverse osmosis (RO). UF can be used to remove the larger molecular weight components of leachate that tend to foul reverse osmosis membranes. Chen and Yang (2012) investigated the best running condition and the effluent quality of membrane system for the treatment of SBR leachate drainage by submerged ultrafiltration membrane process in pilot equipment. In the condition of EFM cleaning of hydrochaloric acid and the best running existing, the operation of membrane system was stable. The trans-membrane pressure (TMP) was less than 0.025 MPa. Membrane system for COD and NH_3–N removal was effective. And SDI was less than 1. All of that made the pollution of the next process reduced. Sun et al. (2010) applied two kinds of ultrafiltration membrane, PTFE and PVDF to conduct the experiment as well as to improve the treatment of landfill leachate. The result shows that the effectiveness of the two kinds in the leachate treatment process is almost the same, but PTFE performs better, powerful in contamination resistance and suitable for leachate treatment. Table 2 summarized studies including an UF step. The elimination of polluting substances is never complete (COD between 10% and 75%).

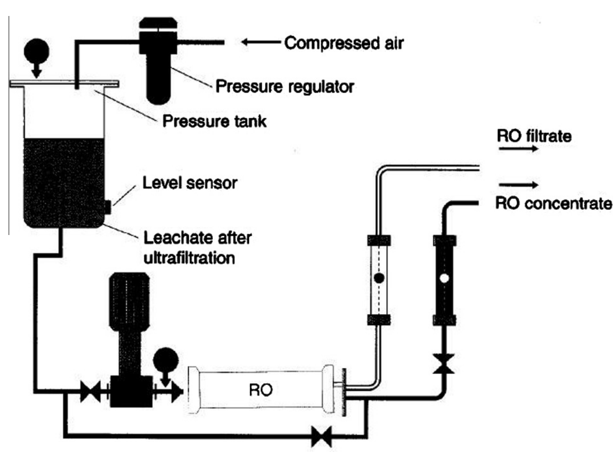

Figure 2 Schematic of the experimental RO circuit for the leachate treatment (Piatkiewicz et al. 2001).

2.2.3. *Nanofiltration (NF)*

NF technology offers a versatile approach to meet multiple water quality objectives, such as control of organic, inorganic, and microbial contaminants. NF studied membranes are usually made of polymeric films with a molecular cut-off between 200 and 2000 Da. The high rejection rate for sulfate ions and for dissolved organic matter together with very low rejection for chloride and sodium reduces the volume of concentrate. Schematic of the nanofiltration pilot plant is shown in Fig. 3.

(Linde and Jönsson (1995a,b)) NF was utilized to treat a landfill leachate with an extremely high salt content from a waste cell containing mainly ash because of the good separation of cations. Most of the heavy metals, which are multivalent cations, are rejected while the monovalent cations, which are rather harmless substances, pass through the membrane. The retention of, for example, cadmium, zinc, lead and chromium was found to be higher than 70%, while the retention of potassium and sodium was less than 10%. Since the trans-membrane osmotic pressure was low, due to the low retention of the monovalent ions, the flux was several times higher than for RO membranes. The flux of the leachate, with a conductivity of 6800 mS/m, was above 50 l/m^2 h at 3 MPa and 25 °C. Vogel et al. (2007)carried out bench-scale filtration experiments to study the fouling behaviour during the NF of a synthetic landfill leachate. The results indicate that calcium in combination with organic matter could play a major role in governing the fouling process. Membrane fouling depended on the calcium concentration in the feed solution. Moreover, the results also indicate a significant influence of membrane fouling on the retention of Bisphenol A (BPA). It was hypothesized that pore blocking and the presence of the fouling layer resulted in an enhanced sieving effect, which subsequently increased the retention of BPA. On the other hand, cake layer

Table 2 Treatment effectiveness of landfill leachate with the use of ultrafiltration.

Material/geometry	Performance		Reference
	Flux ($L\ h^{-1}\ m^{-2}$)	COD removal (%)	
Substituted olefin, aromatic, polymer, polyelectrolyte complex, cellulose acetate (Amicon)	30–80	–	Syzdek and Ahlert, 1984
Cellulosic/tubular (Memtek Corp.)	–	95–98	Pirbazari et al., 1996
PVC/flat	–	50	Bohdziewicz et al., 2001
Polysulfone/tubular (Membrana GmbH/UltraPES)	–	5–10	Piatkiewicz et al., 2001

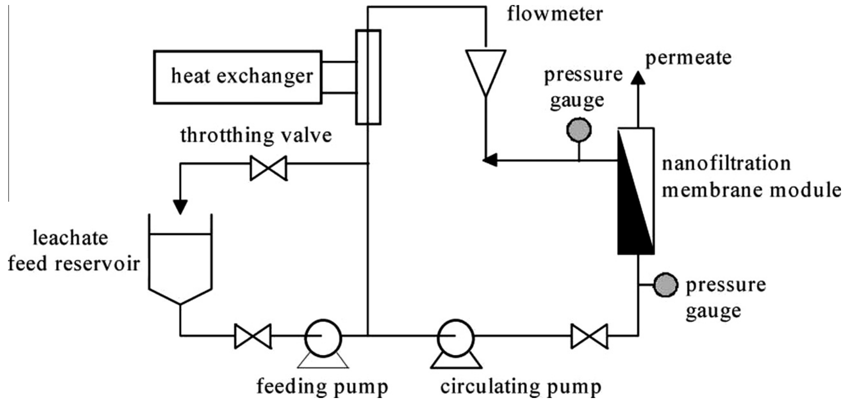

Figure 3 Schematic of the nanofiltration pilot plant.

enhanced concentration polarization could hinder BPA from back diffusing into the bulk solution, which would eventually result in a lower BPA retention. Mohammad et al. (2004) filtered leachate wastewater from a sanitary landfill site in Malaysia through a NF membrane in order to determine the rejection capability of the membrane towards pollutants such as chemical oxygen demand (COD), conductivity, nitrate, ammonia–nitrogen, and heavy metals such as Pb, Cd, Cu, Zn and Fe. The NF membrane used was HL membrane, which under the atomic force microscope (AFM) imaging, showed visible discrete pores. The overall rejections of the pollutants were more than 85% except for nitrate and ammonia nitrogen. NF can be considered an alternative for advanced filtration especially within a hybrid treatment system combining biological–physical treatment and membrane filtration.

2.2.4. Reverse osmosis (RO)

RO seems to be one of the most promising and efficient methods among the new processes for landfill leachate treatment. In the past, several studies performed both at lab and industrial scale, have already demonstrated RO performances on the separation of pollutants from landfill leachate. Values of the rejection coefficient referred to COD parameter and heavy metal concentrations higher than 98% and 99%, respectively, were reported.

Linde and Jönsson (1995a,b) studied the influence on membrane performance when treating new types of landfill leachate. The reduction of pollutants was high. The reduction of the chemical oxygen demand and NH_4^+–N was more than 98% for leachate from both the conventional landfill and the biodegradable waste, for example. The salt concentration, and thus the osmotic pressure, was very high in the leachate from the cell containing special waste. The flux was therefore too low for RO to be a suitable treatment process for this leachate. Šír et al. (2012) studied the treatment of hazardous waste landfill leachate with the help of reverse osmosis. The landfill is located in an abandoned brown coal pit in northern Bohemia. The leachate contained 7.2 g/L of dissolved inorganic salts. Among other contaminants were heavy metals, arsenic, ammonia nitrogen and associated organic pollutants, especially chlorinated compounds. A mobile membrane unit (LAB M30) equipped with a spiral wound element (FILMTEC SW30–4040), with a membrane area equalling 7.4 m^2 was used for the pilot plant experiments. All experiments were carried out in a batch mode. 94% conversion of the input stream into the permeate was achieved by use of a two-stage arrangement. Removal efficiencies of the monitored contaminants in the feed ranged from 94% for ammonia nitrogen to 99% for the two-valent ions. Removal efficiency for total dissolved solids was 99.3% on average. Fig. 4 is the scheme of the technological steps for pilot plant experiments.

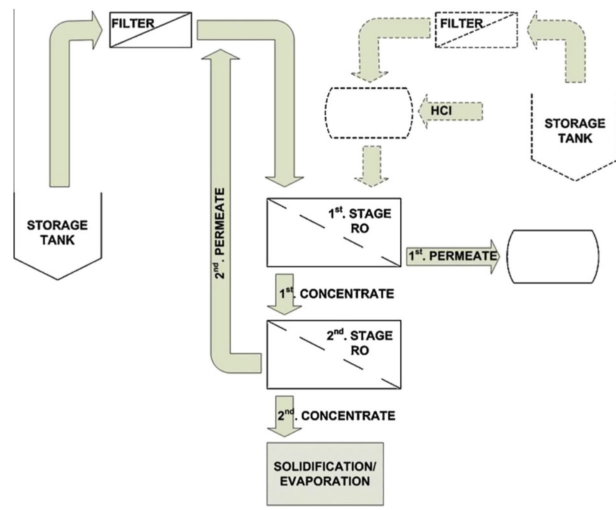

Figure 4 Scheme of the technological steps for pilot plant experiments. The solid line shows the basic two-stage arrangement of reverse osmosis (RO); the dashed line shows the supplemental experiment with the acidified leachate (Šír et al. 2012).

Li et al. (2009) studied a leachate purification system, equipped with the thin open channel spiral wound modules. In Phase I, the permeate flux dropped dramatically, from an average value of 6.5 l/m(^{2})/h–4.23 l/m(^{2})/h. In Phase II, an average flux of 7.8 l/m(^{2})/h was maintained at an initial trans-membrane pressure difference of 20 bar, an average recovery rate of 70% was achieved. The study shows that direct reverse osmosis membrane filtration with thin open channel spiral wound modules is able to achieve satisfactory results in terms of water quality, process stability and membrane flux. The obtained quality of the permeate quality in this study met the German standards for leachate discharge. At the end of each filtration cycle, the membrane was maintained through

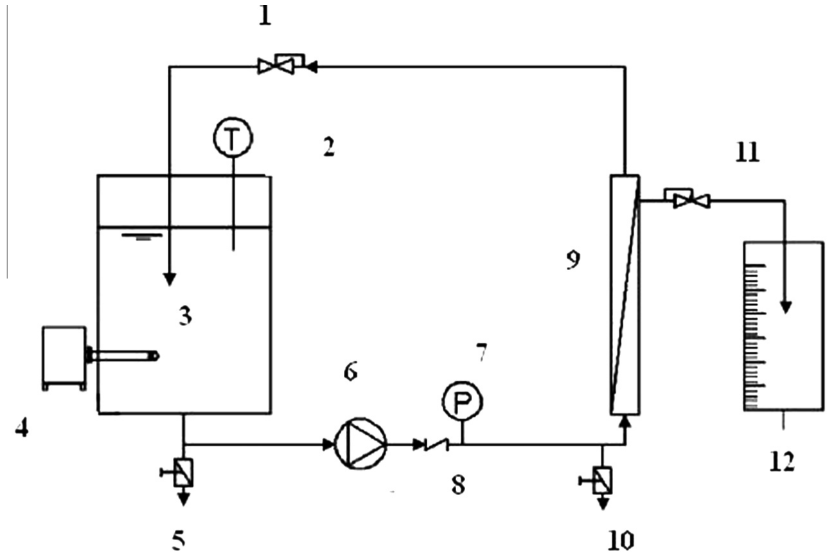

Figure 5 Experimental installation of ultra-low pressure reverses osmosis membrane system. 1 – Flow control valve; 2 –Thermometer; 3 – Leachate storage tank; 4 – Temperature Controller; 5 – Drain valve; 6 – Frequency circulating pump; 7 – Gauge; 8 – Check valve; 9 – Reverse osmosis membrane tube; 10 – Leachate sampling valve; 11 – Filtrate sampling valve; 12 – Filtrate measuring tank.

alkaline chemical cleaning in order to remove any irreversible membrane fouling. After the maintenance procedure, the membrane flux was found to recover to the initial value. Prevention and control of membrane fouling is a major factor influencing membrane performance.

Liu and Li (2007) investigated membrane fouling and chemical cleaning carried out by analysing Disc-tube RO membrane treating landfill leachate. The study results indicated that membrane fouling layer was a complex system, in which organic substances played a major role in membrane fouling, containing Al and Si colloid, as well as Ca and Fe compound. The optimum method of chemical cleaning is alkali agents followed by acid agent, because organic substances play an important role in fouling layer formation.

Guo et al. (2011) applied the ultra-low reverse osmosis membrane to process landfill leachate in order to test the variations of flux of membrane, desalination rate, the removal rate of COD and NH_3–N under different technical conditions. The research results indicate that a maximum flux is corresponding to a certain output frequency under various pressure conditions. The suitable pressure could be set to 018$\sim$019 MPa. Changing the pH value has smaller influence on the removal rate of COD and NH_3–N, but has greater impact on the desalination rate. When pH increases the flux of membrane reduces. The suitable scope of pH of landfill leachate should be ranged from 715 to 815. The flux of membrane and the desalination rate decrease along with the increment of the influent conductivity, and the influent conductivity should be no more than 18 mS/cm. Experimental installation of ultra-low pressure reverses osmosis membrane system shown in Fig. 5.

3. Major challenges and future prospects

3.1. For biological treatment

In recent years, a variety of biological leachate treatment technologies continues to emerge, and achieved good results, but there are certain problems. Such as aerobic activated sludge process and biological engineering turntable big investment, operation and management of the high cost of the treatment effect are influenced by temperature; while stabilization pond technology long residence time (10–30d), covers an area of large and purification capacity with large seasonal variation. Anaerobic treatment process developed rapidly in recent years, particularly suited to high concentrations of organic wastewater, its drawback is to stay a long time, and contaminant removal is relatively low, more sensitive to temperature changing. Anaerobic–aerobic biological treatment process leachate is better, but investment, operation and management of the construction of a dedicated leachate treatment plant are very high, and with the closure of the landfill, water treatment facilities eventually scrapped, it should be carefully selected. Before the closure of the landfill, leachate concentrations generally high and difficult to handle, even with anaerobic–aerobic biological treatment process is also difficult to achieve emission standards; addition, since the leachate effluent water quality and generally are quite different, and does not stable, so purely biological treatment technology is difficult to meet compliance requirements. But as technology development and social progress, leachate biotechnology will become increasingly mature, will have broad prospects for development and application (Yu et al. 2005).

But for the biological treatment of landfill leachate application prospect, many questions have yet to be studied in depth. As with the general sewage leachate water quality is quite different, and unstable, purely biological treatment technology is difficult to meet compliance requirements, it should strengthen the pre-or post-processing technology. In addition, explore technically and economically feasible process plan, process combination will be a trend in the various processes and coordination problems with research.

3.2. For membrane technology

The world is currently facing the worst environmental crisis in its entire history. Within the last few decades, the enthusiasm of huge waste production and environmental preservation has been one of the most challenging topics which has focused on the greatest public concern and critical considerations towards the recovery of contamination resources. In line with the growing anxiety of the environment-friendly technologies and achieving the status of green environmental policy, various research and development efforts have been advocated to utilize membrane separation technology contemplated mainly for landfill leachate treatment, in accruing worldwide environmental benefit and shaping the national economy. Although there have been some successful industrial-scale applications and implications, generally the industry is still facing various challenges, the availability of economically viable technology, sophisticated and sustainable natural resources management (cost-prohibitive membrane material and difficulties associated with membrane cleaning), and proper market strategies under competitive markets. Besides, membrane fouling and concentration polarization are important issues that we must pay more attention to.

Currently membrane experts are trying to use a variety of new techniques and dynamic experiments testing methods fouling phenomena observed and controlled, reducing the adverse effects of membrane fouling, and further improve the efficiency of membrane separation, therefore, appropriate measures pollution control membrane will be more validity and relevance. It can be expected, with specific membrane separation membrane fouling processes relevant basic and applied research will become film studies in one of the hotspots.

Since a variety of contaminants, the membrane cleaning is a complex subject, indicating the characteristics of the contaminated sediment membrane, for the selection of the most economical and most effective cleaning agents and cleaning solution is important. Analysis of membrane contaminants are a variety of techniques, advantages and disadvantages, pollution-specific membrane utilization of a variety of analytical techniques to be analysed in order to ensure the most accurate pollution information. Membrane fouling cleaning in many ways, there are many types of cleaning agents for different pollution membrane should continue to experiment to find the best cleaning agent and the best cleaning method can be combined with a variety of cleaning agents and methods, but should pay attention to a variety of agents batches should be used. The choice of membrane cleaning methods to extend the life and application promotion is essential.

4. Conclusions

Over the years, the world's giant factories and processing industries are gradually expanding, driving towards the overwhelming solid waste generation. Predictions for the next 20 years indicate an upward trend in waste production and, subsequently in leachate infiltration. Today, the growing discrepancy and limited success of remediation in field applications has raised apprehensions over the use of biological treatment and membrane technology or other integrated technologies as a measure to the environmental pollution control. Despite various drawbacks and challenges has been identified and clarified, a widespread and great progress of in this area can be expected in the future.

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