APPLIED TECHNOLOGIES IN MUNICIPAL SOLID WASTE LANDFILL LEACHATE TREATMENT

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Contents

Summary

This chapter illustrates the municipal solid waste landfill’s characteristics and discharge standard, its pollution problems and environmental impacts, and its typical applied solution technologies. The applied treatment technologies are discussed based on two main catalogues of conventional and advanced technologies. The conventional technologies include: (i) physico-chemical (coagulation-flocculation, chemical

precipitation, activated carbon adsorption, ion exchange, membrane filtration, chemical oxidation etc.); (ii) biological (aerobic or anaerobic conditions, suspended-growth or attached-growth conditions, and fixed-bed or moving-bed conditions). The advanced technologies are introduced to three integration groups of (i) physicochemical, (ii) multi-biological, and (iii) physicochemical-biological processes.

1. Introduction

One of the major pollution problems caused by the municipal solid waste (MSW) landfill is landfill leachate, which is generated as a consequence of precipitation, surface run-off, and infiltration or intrusion of groundwater percolating through a landfill, biochemical processes in waste's cells and the inherent water content of wastes themselves. After a landfill site is closed, a landfill will continue to produce contaminated leachate and this process could last for 30-50 years. Generally, leachate may contain large amounts of organic matter (biodegradable, but also refractory to biodegradation), as well as ammonia-nitrogen, heavy metals (e.g. copper, iron, zinc, lead, manganese etc.), chlorinated organic and inorganic salts (e.g. chloride, sulfate, sodium etc.), which are a great threat to the surrounding soil, groundwater and even surface water (Renou et al., 2008; Robinson, 2005). The composition of landfill leachate is not ubiquitous and varies with different sites and environmental conditions, depending on the nature of the deposited wastes, on soil characteristics, rainfall patterns and on the "age" of the landfill (Iaconi et al., 2006; Park et al., 2001).

The landfill leachate creates the potential to contaminate ground water and surface water supply, and threaten human health when migrating from the landfill and contaminates the surrounding lands and water. With the growth of population and development of the industry, the landfill leachate problem becomes increasingly serious. According to the survey of United States Environmental Protection Agency (USEPA), there are about 55,000 landfills in the USA, approximately 75 percent of which are polluting groundwater (USEPA, 2004). The cases of water polluted by landfill leachate have also been found globally, especially in European countries, Australia and China.

Generally, the best way of controlling the pollution of environment by the landfill leachate is treating leachate to remove the hazardous components before it enters the water systems. The reason is that once the leachate enters the water bodies, it is very expensive and difficult to clean up the contaminated water. There are two leachate management strategies used by modern municipal landfills. These two processes are leachate recirculation and single pass leaching (Scott et al., 1994). The recirculation of leachate (including leachate containment, collection, and recirculation) is appropriate for landfill located in warm areas with low rainfall, and the benefits of this method are simplicity of operation and low operation costs. On the other hand, the single pass leaching strategy is applied to most landfills where the generated leachate is collected and treated to remove most of the contaminants before it is discharged.

Characterization and treatment of landfill leachate has only taken place within the last 40 years. The main applicable methods are physical, chemical and biological. Since it is difficult to obtain satisfactory effluent quality by using anyone of those methods alone, a combination of physical, chemical and biological methods are employed for efficacious treatment of landfill leachate (Kargi and Pamukoglu, 2004a; Uygur et al., 2004). In the physical treatment technologies used for landfill leachate treatment, air-stripping, adsorption and membrane filtration are the major ones. Coagulation-flocculation, chemical precipitation and oxidation are the common chemical leachate treatment methods. Meanwhile, biological treatment technologies consist of aerobic, anoxic and anaerobic processes, which are widely employed for biodegradable contaminants removal from landfill leachate.

2. Leachate Characteristics and its Discharge Standards

2.1 Leachate Characteristics

Landfill leachate consists of a number of complex factors, including solid waste composition, age of the waste, operation of the landfill, hydrogeological conditions in vicinity of the landfill site, rate of the water movement through the waste, landfill temperature, moisture content, pH, landfill chemical and biological activities and seasonal weather variations (Westlake, 1995; McArdle et al., 1988). The production of leachate also varies widely through the successive aerobic, acetogenic, methanogenic and stabilization stages. Table 1 gives the definition of three types of leachates according to landfill age (Renou et al., 2008). The typical chemical concentrations in young and old landfill leachates comparing with sewage and groundwater are also shown in Table 2 (McBean et al., 1995).

Parameter	**Young**	**Intermediate**	**Old**
Age (years)	< 5	5–10	>10
pH	6.5	6.5–7.5	>7.5
COD (mg/L)	>10,000	4,000–10,000	<4,000
BOD5/COD	>0.3	0.1–0.3	<0.1
Organic compounds	80% volatile fat acids (VFA)	5–30% VFA + humic and fulvic acids	Humic and fulvic acids
Heavy metals	Low–medium	Low	Low
Biodegradability	Important	Medium	Low

Table 1 Landfill leachate classification vs. age

Parameter	**Young leachate concentration (mg/L)**	**Old leachate concentration (mg/L)**	**Typical sewage concentration (mg/L)**	**Typical groundwater concentration (mg/L)**
COD	20,000–40,000	500–3,000	350	20
BOD5	10,000–20,000	50–100	250	0
TOC	9,000–15,000	100–1,000	100	5

Volatile fatty acids (as acetic acid)	9,000–25,000	50–100	50	0

Table 2 Typical chemical concentrations in landfill leachate comparing with sewage and groundwater

Landfill / Parameter(mg/L)	LHWMC (NSW)	Olympic Park (NSW)*	Russell Vale (NSW)	Lyndhurst (VIC)	Summary
Age (year)	2-12	6	4	—	—
pH	6.2-8.9	6.59-6.98	8.4	5.3-7.9	5.3-8.9
COD	270-14000	—	218	50-730	50-14000
BOD_5	12-11400	—	46	30-200	6.8-11400
DO	0-4	—	9.9	—	0-9.9
Conductivity(μS/cm)	6000-22000	17700-23100	—	270-22000	240-23100
Temperature (^oC)	15-34	—	—	36-38	15-38
SS	25-605	—	8.6	24-2600	8.6-2600
TDS	—	10400-13900	—	270-14000	270-14000
TOC	135-6200	—	—	59-2700	59-6200
TKN	—	—	42.7		0.14-42.7
NO_3^-	—	—	1	<0.05-2.3	<0.05-2.3
NO_2^-	—	—	0.14	<0.05-0.21	<0.05-0.21
N(organic)	—	—		2-70	2-70
NH_3	255-2600	109-242	32.4	1.1-390	1.1-1600
Inorganic PO_4(μg/L)		—	31.5		31.5
P(total)(μg/L)		—	80.6		80.6
Cl^-	40-1190	7200-19800	296	610-6400	40-19800
SO_3^{2-}		—	1.03	0.2-0.75	0.2-1.03
SO_4^{2-}	<5-295	—	195	1.4-130	1.4-295
Alkalinity($CaCO_3$)	—	—	1605	490-4500	490-4500
Ca	—	—	71.7	70-350	70-350
Mg	—	—	30.9	0.74-540	0.74-540
K	400-1200	—	62.3	99-380	62.3-1200
Na	200-1500	—	228	71-3900	71-3900
As	<0.05	0.00001-0.00151	—	0.008-0.07	0.00001-0.07
Ba	<1-22.5	—	—	—	<1-22.5
B	1.3-2.2	—	—	—	1.3-2.2
Cu	<1	0.001-0.005	<0.1	0-0.17	<1
Cd	<0.01-0.02	0.00005-0.0005	<0.05	<0.02	<0.05
Cr	<0.02-1	0-0.01	<0.05	0-0.13	0-0.13
Fe	8.1-235	0.31-9.1	13	0.56-130	0.56-235
Pb	0-0.05	0.0002-0.01	<0.1	0-0.05	<0.1
Mn	<0.05-0.95	—	0.59	0.33-0.51	0.05-1.6
Hg	<0.002	0	—	—	<0.002
Ni	—	—	—	0.07-0.08	0.07-0.08
Se	<0.01	—	—	—	<0.01
Ag	<0.05	—	—	—	<0.05
Zn	0-12	0.037-0.388	0.8	0.34-0.35	0-12
Phenols (total)	0-24	—	—	—	0-24
Toluene	0-1	0.039-3.54	—	—	0-3.54
Xylenes	0-0.5	0.025-1.01	—	—	0-1.01
Benzene	0-0.04	—	—	—	0-0.04
Ethylbenzene	0-0.12	0.014-1.92	—	—	0-1.92

* Data from Sydney Olympic Park landfill, NSW, Australia

Table3. The characteristics of some typical landfill leachate in Australia

Normally, young landfill leachates (the acid-phase landfill, <5 years) contain large amounts of biodegradable organic matter. More than 95% of the dissolved organic carbon (DOC) content of 20,000 mg/L consists of volatile fatty acids, and as little as 1.3% of high molecular weight compounds. In a landfill matures (the methanogenic-phase landfill), the organic fraction in the leachate becomes dominated by refractory (non-biodegradable or humic-like) compounds, and 32% of the DOC content of 2100 mg/L consists of high molecular weight compounds (Wang et al., 2003; Welander et al., 1997; Harsem, 1983). According to the study of Diamadopoulos (1994), the concentration of the organic substances and the ratio of BOD to COD are generally higher during the active stage of decomposition and decrease gradually to less than 0.1 because of the leachate stabilized. Ammonia nitrogen represents the high strength and heavy metals such as copper, iron, zinc, lead, manganese have relatively low concentration. Dissolved solids such as chloride, sulfate, and sodium also present the high level in landfill leachate.

It is known that no two municipal landfills produce the same quality of leachate. Australian landfill leachate contains high strength of ammonia nitrogen (1.1-1600 mg/L), chemical oxygen demand (50-14,000 mg/L), biological oxygen demand (96.8-11,400 mg/L), total dissolved solids (270-14,000 mg/L) and refractory organic matter, which have potentially detrimental to the environment (Scott et al., 2005). Table 3 shows the characteristics of some typical landfill leachates in Australia.

2.2 Leachate Discharge Standards

Currently, the quality of landfill leachate effluent has to comply with increasingly stringent discharge standard. Since there has no legislated landfill leachate discharge standards in Australia, Tables 4 lists the discharge standards of treated wastewater into the aquatic ecosystem (EPA, 2005). Table 5 indicates that several countries and regions have their own leachate discharge standard (Cao et al., 2001; Qzturk et al., 2003; Kurniawan et al., 2006a; Fan et al., 2007; Bohdziewicz et al, 2008a). The removal of organic substances based on total organic carbon (TOC), chemical oxygen demand (COD), biological oxygen demand (BOD) and ammonium from leachate is the usual prerequisite before discharging the leachates into natural waters. Toxicity analysis has confirmed the potential dangers of landfill leachates and the necessity to treat it so as to meet the standards for discharge in receiving waters (Silva et al., 2004; Clément et al., 1997).

Pollutants (mg/L)	Discharge Limits	
	Aquatic ecosystem	
	Fresh water	Marine

pH	6.5-9	—
TOC	15	10
BOD_5	10	10
DO	>6	>6
Turbidity (NTU)	20	10
SS	20	10
TN	5	5
NH_4-N	0.5	0.2
PO_4-P	0.1	0.1
TP	0.5	0.5
As	0.05	0.05
Cu	0.01	0.01
Cd	0.002	0.002
Cr^{5+}	0.001	0.0044
Fe	1	—
Pb	0.005	0.005
Hg	0.0001	0.0001
Ni	0.15	0.015
Se	0.005	0.07
Ag	0.0001	0.01
Zn	0.05	0.05
Phenols (total)	0.05	0.05
Toluene	0.3	—
Benzene	0.3	0.3
PCBs	0.000001	0.00004
PAHs	0.003	0.003

Table 4 Australian treated wastewater discharge standards

Country Parameter	**UK**	**Hong Kong**	**Vietnam**	**Germany**	**France**	**South Korea**	**Turkey**	**Taiwan**	**Poland**
COD (mg/L)	—	200	100	200	120	50	100	200	125
BOD_5 (mg/L)	60	800	50	20	30	—	50	—	30
SS (mg/L)	—	—	—	—	—	—	100	50	—

NH_4-N (mg/L)	—	5	—	—	5	50	—	—	10
PO_4-P (mg/L)	—	25	6	3	25	—	1.0 (TP)	—	—
Total nitrogen	—	100	60 (TKN)	70	30	150	—	—	—

Table 5 Maximum overseas treated leachate discharge limits

3. Problems and Environmental Impacts of Landfill Leachate

3.1 Organic Matter

Organic matter is one of major pollutants present in landfill leachate. When the leachate with high concentration of organic pollutants enters underground or surface water, organic matter is degraded by respiration of aerobic microorganisms which consume dissolved oxygen (DO). When the water is not able to sustain certain level of DO, the life in the water not can survive. The organic matter can also be degraded by anaerobic microorganisms into some hazardous gas such as CH_4, CO_2 and NH_3, which influence the quality of water severely (Zhang et al., 1999). Organic compounds can be divided into two groups: volatile organic compounds (VOCs) and nonvolatile organic compounds (Scott et al., 2005). Both of them contain carbon-based compounds that are often toxic or carcinogenic. Considering environmental and health effects, dichloromethane, 1,2-dichloroethane and trichloroethene in leachate are the most important organic toxicants in terms of drinking water standard. Dichloromethane, trichloroethene, tetrachloroethene, toluene and PCBs may increase the risk of cancer and may cause some skin problems such as chloracne, rashes and irritation. The health effects of organic toxicants are listed in Table 6. It is difficult to degrade these toxicants using chemical and biological processes within landfill where there is no access for oxygen and sunlight. Moreover, these contaminants cannot be absorbed by soil particles and easily migrate to groundwater beyond the landfill boundaries from leachate.

Organic Compounds	**Health Effect**	**References**
Dichloromethane (DCM)	Short-term exposure – headaches, fatigue, and feeling of drunkenness Exposure to high concentrations – unconsciousness and death Long-term exposure – damage to liver and brain Cancer – lungs, liver and pancreas.	Richardson，1992
1,2-dichloroethane (12-DCE_a)	Short-term exposure-may cause eye problems, headache, feeling of drunkenness, fatigue, central nervous system depression, convulsions, pulmonary oedema, unconsciousness and death. Long-term exposure – damage to the liver, kidneys, lungs and	ATSDR, 1997

	adrenal glands.	
Trichloroethene (TCE_e)	Short-term exposure – beginning with headache, dizziness, and confusion and progressing with increasing exposure to unconsciousness and death. Long-term exposure – damage liver and kidney to leukemia Skin – rushes and liver cancer	Sittig, 1991
Tetrachloroethene (T_eCE_e)	Inhalation – dizziness, headache, sleepiness, confusion, nausea, difficulty in speaking and walking, unconsciousness, and death Skin – irritation	Sittig, 1991
Toluene	Inhalation – fatigue, confusion, headache, dizziness and drowsiness. Ingestion – abdominal spasms Skin – irritation Long-term exposure – liver and kidney damage	Furnell et al., 1989
Hexachlorobenzene	Ingestion – liver disease with associated skin lesions called porphyria cutanea tarda Children – abnormal physical development	ADSTR, 2002
Pentachlorophenol (PeCP)	Short-term exposure – increases in temperature, profuse sweating, and difficulty breathing, even death. Long-term exposure – damage to liver and immune system, damage to the thyroid and reproductive system.	ADSTR, 2001
Aldrin/Dieldrin	Ingestion – convulsions and some died. Long-term exposure – headaches, dizziness, irritability, vomiting, and uncontrolled muscle movements	ADSTR, 2002
Lindane	Short-term exposure – central nervous system stimulation (usually developing within 1 hour), mental/motor impairment, excitation, clonic (intermittent) and tonic (continuous) convulsions, increased respiratory rate and/or failure, pulmonary edema, and dermatitis Long-term exposure – kidney, pancreas, testes, and nasal mucous membrane damage	Ware, 1986
PCBs	Long-term exposure – anemia, damage to liver, stomach, thyroid gland and immune system Skin – chloracne and rashes Cancer – liver and biliary tract	Sittig, 1991

Table 6 Health effects of organic toxicants in landfill leachate

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Huu Hao Ngo is an academic and senior environmental research engineer with more than twenty five years' professional experience in Australia and in Asian countries. He is now working as Associate Professor of Environmental Engineering and Manager, in-charge of Environmental Engineering R & D Laboratory, School of Civil and Environmental Engineering at University of Technology, Sydney (UTS). He is also serving as a core member (Team Leader of advanced water and wastewater treatment materials based technology group and Project Investigation of membrane based technology in the theme of Urban Water Management) of the Institute of Water and Environmental Resource Management at UTS. Assoc. Prof. Ngo is internationally known for his activities in the development of innovative water, wastewater treatment and recycling technologies, and is a recognized authority on the flocculation and filtration process, biofiltration and membrane hybrid technology. He has been involved in more than 50 research projects and published more than 200 technical papers including two books and several book chapters. He is also a reviewer for more than 20 international journals.

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