KEYNOTE ADDRESS

RECENT DEVELOPMENT IN LANDFILL LEACHATE TREATMENT

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ABSTRACT

Existing solid waste landfill sites in developing countries mostly involve either open dumping or unsanitary landfilling, but landfilling is limited by leachate generation. Leachate is formed when water from rain and degraded matter passes through waste in a landfill cell. Leachate is composed of high amounts of organic compounds, ammonia, heavy metals, and other hazardous chemicals and is characterized by COD, color, and NH_3-N, which are among the problematic parameters that are difficult to be completely removed. As such, leachate should be processed in appropriate treatment facilities before it can be discharged into the environment. Treatments depend on leachate characteristics, operation and capital costs, and regulations. Thus far, the development of holistic solutions to leachate-related problems has been widely promoted. As an example of these solutions, multiple-stage treatments require the use of physical, biological, chemical, and combination methods. In this paper, recent techniques for the treatment of landfill leachate with low biodegradability and high COD, color, and NH_3-N content, especially leachate treatment applications for semi-aerobic landfills in developing countries, are described. Some of the challenging issues in overall leachate treatment processes are also elucidated.

Keywords: Ammonia, color, COD, landfill, leachate, treatment.

INTRODUCTION

Malaysia generates about 6.2 million tons of solid waste per year or approximately 17,000 tons per day. This amount is expected to increase to more than 30,000 tons per day by 2020 because of increasing population and per capita waste generation. In general, organic waste constitutes 40%–60% of the overall weight of waste in most developing countries. Despite several advantages of landfilling, the resulting highly polluted leachate has caused urgent concerns because landfilling is a widely used solid waste disposal technique. Leachate is formed when water from rain infiltrates the deposited waste. As water passes through a landfill, many organic and inorganic compounds, such as ammonia and heavy metals, are transported into leachate. Leachate then moves to the surface or base of a landfill cell and may create surface and groundwater pollution, which may negatively affect human health and aquatic environments. Numerous factors, such as seasonal weather variation, landfilling technique, waste type and composition, and landfill structure, influence the quality and quantity of leachate. As such, environmental specialists are determined to develop efficient treatments for large quantities of polluted leachate. A number of leachate treatment techniques, which involve biological, physical, and chemical processes and a combination of these processes, have also been applied.

LANDFILLING

Despite the implementation of waste reduction, recycling, and transformation technologies, solid waste disposal in landfills remains an important component of an integrated solid waste management strategy. Most of the existing solid waste landfill sites in developing countries practice either open dumping or controlled dumping. For example, landfilling is the primary method of municipal solid waste disposal in Malaysia and will be the preferred method for the next 10–15 years. However, appropriate sanitary landfill concepts are yet to be fully implemented because of technological and financial constraints.

Landfill types can be broadly classified into anaerobic, anaerobic sanitary, semi-aerobic, and aerobic landfills. Among these types, anaerobic and semi-aerobic landfills are the most common. However, anaerobic landfills are limited by high concentrations of leachate, which is difficult to be treated and to be in compliance with standard discharge limits. The use of anaerobic landfills is also restricted by greenhouse gas emissions mainly containing methane and CO_2 and fire accidents. Conversely, the Fukuoka method or a semi-aerobic system, which was developed more than 20 years ago at the Fukuoka University, is a proven technology practically tested in many places in Japan and in few developing countries, such as Malaysia, Iran, and China, but this method has yet to be introduced to many countries. In Malaysia, semi-aerobic landfilling was initially applied in 1988, and remarkable improvements in leachate quality have been observed. The Fukuoka method can also be implemented in developing countries under many circumstances for different purposes, including developing a new landfill site, upgrading an existing landfill site, or properly closing a completed landfill site.

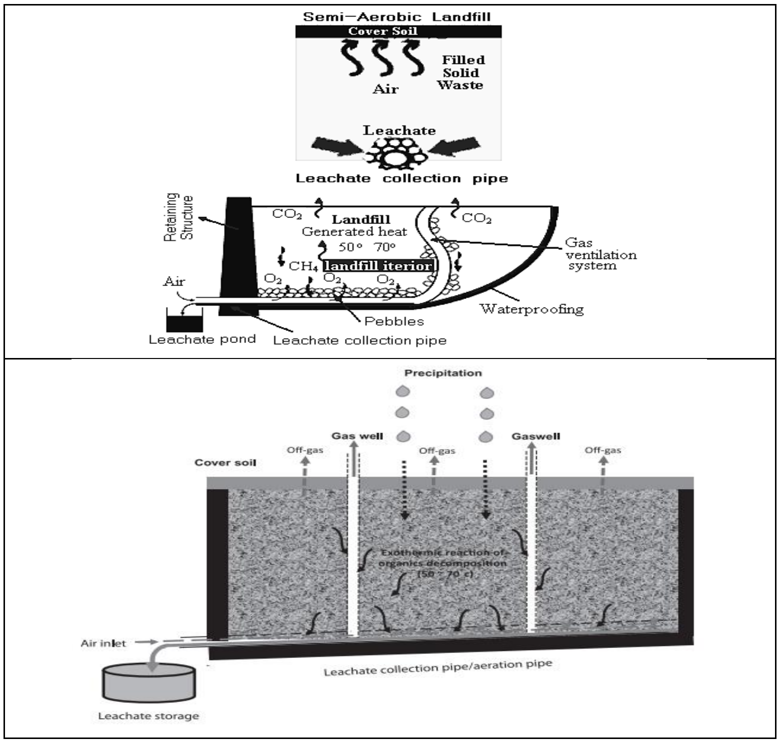

Figure 1. Concept of semi-aerobic landfill [1]

Fig. 1 illustrates a semi-aerobic landfill designed with a leachate collecting pipe set up underneath. This pipe eliminates leachate from a site where waste is deposited. Natural air from an open pit enters the leachate collecting pipe and moves to a landfill layer. This process promotes aerobic waste decomposition and enables early waste stabilization to prevent the production of methane and greenhouse gases [2]. Another conceptual diagram of a semi-aerobic landfill applied on site is shown in Fig. 2.

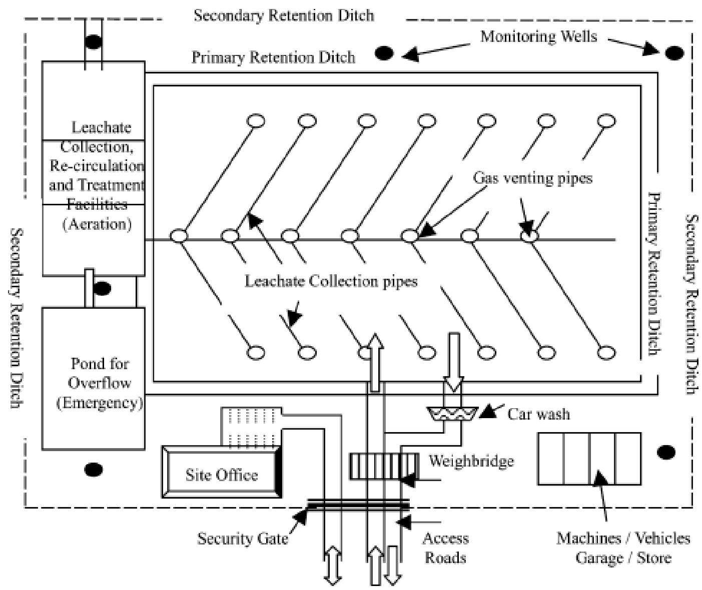

Figure 2. Conceptual diagram of a semi-aerobic landfill site [3]

Leachate collecting and gas venting pipes play an important role in a semi-aerobic landfill system. Fig. 3 presents the concept of a semi-aerobic landfill leachate collection pipe. Similar to human blood vessels, leachate collection pipes supply oxygen and discharge leachates from a body of waste layers [4]. These pipes also provide various advantages. For example, leachate is drained at a faster rate than leachate in landfills without these pipes. Thus, fouling of leachate in waste materials is prevented and fresh air can easily enter landfills. Microbial activity is enhanced under aerobic conditions and waste decomposition is improved. Collection pipes are protected not only from clogging because of their position in rocks but also from damage during operation. The risk of leachate seepage is reduced because the pressure caused by water on the bottom ground is decreased by rapidly draining leachate [5].

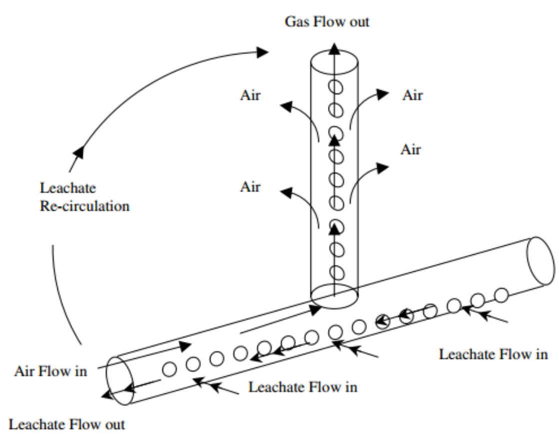

Figure 3. Concept of semi-aerobic landfill leachate collection pipes [3]

Semi-aerobic landfills are preferred because they offer more benefits than other systems do. For example, leachate is discharged as quickly as it is collected in pipes in these landfills, thereby reducing water pressure and preventing possible seepage. Waste stabilization and leachate purification require a short period because fresh air naturally penetrates through waste. The concentration of emitted methane is reduced even though the concentration of carbon dioxide is increased. Furthermore, semi-aerobic landfills require a simple technology, employ easy installation and operation with a low degree of technical requirements, machines, and devices, involve convenient operation and maintenance, and entail low initial investments. Semi-aerobic landfills also help mitigate global warming by reducing the amount of methane [4].

LANDFILL LEACHATE

Landfill leachate is formed when water percolates through waste and carries organic and inorganic matter, impurities, heavy metals, and other polluted and harmful substances. Biochemical processes involved in landfill treatment can be determined on the basis of the qualitative composition of leachate. More than 200 substances are characterized as leachate pollutants, and most of them are harmful to the environment. Leachate sources include precipitation, wet material storage, groundwater and surface water inflow, transpiration, water losses through evaporation, surface flow, and organic compound hydrolysis and biodegradation [6].

Many factors, including seasonal weather variation, landfilling type, waste type and composition, and landfill structure, affect the quality and quantity of leachate. Unfortunately, landfill leachate is rapidly generated in tropical countries, such as Malaysia, because rainfall generally exceeds the evaporation rate during the rainy season.

CHARACTERISTICS OF LANDFILL LEACHATE

Landfill leachate usually contains various materials and organic compounds, such as humic substances, fatty acids, heavy metals, and other hazardous chemicals. The typical characteristics of landfill leachate are summarized in Table 1. Organic loading in leachate is usually determined by measuring COD, BOD_5, and total organic carbon (TOC). Color is also an important indicator of organic loading; for example, a high color intensity indicates a high organic content in leachate [7]. High levels of COD, color, and ammonia are detected in landfill leachate over a long period of time, and these high levels are considered urgent problems routinely faced by landfill operators.

LANDFILL LEACHATE TREATMENT

One of the main problems in landfill management is the development of efficient treatments for large amounts of leachate. Different physicochemical, biological, chemical, and physical methods have been used to treat leachate, but these methods generally require various processes, which are expensive and complicated. Difficulties in applying leachate treatments are due to their high loading, complex chemical composition, and seasonally variable volume [8]. A combination of different methods consisting of biological, chemical, and physicochemical processes is necessary to implement an effective leachate treatment. This combination maximizes the advantages of each process and thus increases the efficiency of leachate treatment [9, 10]. As a consequence, affordable technologies combining various methods have been developed [11]. For instance, [12] combined agitation, coagulation, sequencing batch reactor technique, and filtration to treat landfill leachate. They applied an ammonia stripping method to remove ammonia, used poly ferric sulfate in coagulation, and prepared it to treat SBR and eliminate COD. As a result, they eradicated 99.2% NH_3-N and 97.4% COD. This finding confirms that integrating different methods yields remarkable outcomes in leachate treatment.

Table 1: Typical landfill leachate characteristics

No.	Parameter	Unit	Type of landfill leachate		
			Young (< 5 years)	**Intermediate (5 –10years)**	**Stabilized (> 10 years)**
1	pH		<6.5	6.5–7.5	>7.5
2	COD	mg/L	>10000	4000–10000	<4000
3	BOD_5/COD		0.5–1.0	0.1–0.5	<0.1
4	Organic compound		80% VFA[a]	5–30% VFA[a] + HFA[b] HFA[b]	HFA[b]
5	NH_3-N	mg/L	<400	NA[c]	>400
6	TOC/COD		<0.3	0.3 –0.5	>0.5
7	Kjeldahl nitrogen	g/L	0.1–0.2	NA[c]	NA[c]
8	Heavy metals	mg/L	Low to medium	Low	Low
9	Biodegradability		Important	Medium	Low

a= Volatile fatty acids, b=Humic and fulvic acids, and c= Not available
Source: [13, 14]

Appropriate methods and actual leachate treatment systems are determined on the basis of the characteristics of leachate, but these treatments involve complex processes and entail high costs. Some of the commonly applied methods for landfill leachate treatment are illustrated in Fig. 4.

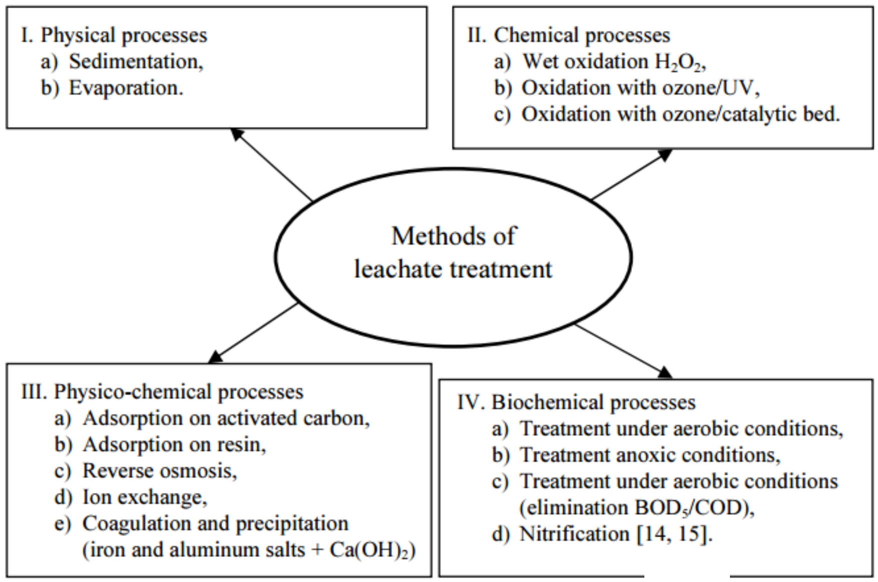

Figure 4. Commonly used leachate treatment methods in municipal landfills [6].

Tables 2 to 6 summarize the performances of treatment processes and their efficiencies for the past few years.

Table 2. Summary of the performance of treatment processes for different leachate types

Treatment process	Target removal	Performance – Type of leachate – Young	Medium	Old
Combined treatment with domestic sewage	Suspended solid	Good	Fair	Poor
Recirculation	Improve leachate quality	Good	Fair	Poor
Activated sludge process	Organics	Good	Fair	Poor
Sequencing batch reactor (SBR)	Organics	Good	Fair	Poor
Aerated lagoon	Organics	Good	Fair	Poor
Reed bed	Organics	Fair	Fair	Good
Trickling filter	Organics	Good	Fair	Fair
Rotating biological contactor	Organics	Good	Fair	Poor
Moving bed biofilm reactor (MBBR)	Organics	Good	Fair	Poor
Anaerobic sequencing batch reactor (ASBR)	Organics	Good	Fair	Fair
Upflow anaerobic sludge blanket reactor (UASB)	Organics	Good	Fair	Fair
Anaerobic filter	Organics	Good	Fair	Fair
Hybrid filter	Organics	Good	Fair	Fair
Anaerobic fluidised bed filter	Organics	Good	Fair	Fair
Anaerobic lagoon	Organics	Good	Fair	Poor
Coagulation-flocculation	Heavy metals and suspended solids	Poor	Fair	Fair
Flotation	Suspended matter	Poor	Fair	Fair
Ammonia/Air stripping	Ammonia or volatile organics	Poor	Fair	Fair

Chemical precipitation	Heavy metals, NH_3 -N and some anions	Poor	Fair	Poor
Adsorption	Organic compounds	Poor	Fair	Good
Chemical oxidation	Organics; detoxification of some inorganic species	Poor	Fair	Fair
Electro-chemical process	Suspended solids and some inorganics	Poor	Fair	Fair
Micro-filtration	Suspended solids	Poor	Poor	Poor
Ultrafiltration	Bacteria and high molecular weight organics	Poor	Fair	Fair
Nano-filtration	Sulphate salts and hardness ions, like Ca (II) and Mg(II)	Good	Good	Good
Reverse osmosis	Dilute solutions of organic and inorganic compounds	Good	Good	Good
Sand filtration	Suspended matter	Poor	Poor	Poor
Ion exchange	Dissolved inorganics, anions/cations	Poor	Fair	Fair

Source: [9, 15, 16]

Table 3. Summary of the efficiencies of different treatment processes for landfill leachate

Process	**Initial Concentration**	**Removal (%)**		
		COD	**Color**	**NH_3-N**
Electro-coagulation	COD: 12860 (mg/L), NH_3-N: 2240 (mg/L), pH: 8.2	56	–	–
Electro-Fenton	COD: 2350 (mg/L), NH_3-N: 310 (mg/L), Color: 1143(Abs.), pH: 8.36	72	90	28
Fenton	COD: 34920 (mg/L), pH: 5.1	50.79	–	–
Fenton	COD: 2340 (mg/L), NH_3-N: 1055 (mg/L), pH: 8.26	63	76	–
Coagulation/flocculation+ PAC*	COD: 2817 (mg/L), NH_3-N: 2000 (mg/L), pH: 8.6	70 - 86	–	–
Photo-Fenton	COD: 3823 (mg/L), NH_3-N: 2016 (mg/L), pH: 7.94	86	100	–
Photo-Fenton	COD: 1320 (mg/L), NH_3-N: 260 (mg/L), pH: 8.36	80	–	–
Photo-Fenton	COD: 1960 - 2880 (mg/L), Color: 2160 - 2560 (Pt-Co.), NH_3-N: 730 – 980 (mg/L), pH: 8.4 – 8.7	70	80	80
Persulfate ($Na_2S_2O_8$)	COD: 1270 (mg/L), NH_3-N: 2000 (mg/L), pH: 8.3	91	–	100
Persulfate ($Na_2S_2O_8$)	COD: 2451(mg/L), pH: 7.9	TOC 39	79	–
Persulfate/AC ($K_2S_2O_8$/AC)	COD: 275(mg/L)	77.8	–	–
Ozonation	COD: 560, (mg/L), pH: 10	40		
Ozonation	COD: 5230 (mg/L),	27	87	–
Ozonation	COD: 3945 (mg/L), NH_3-N: 800 (mg/L), pH: 4.5	48	–	–
Ozonation	COD: 1090 (mg/L), Colour: 1130 (TCU), NH_3-N: 455 (mg/L), pH: 8.5	73	90	67
Ozonation	COD: 2422 – 3954 (mg/L), (mg/L), NH_3-N: 750 - 800 (mg/L), pH: 8 – 8.5	40	–	–
Ozonation	COD: 7800 - 8200 (mg/L), NH_3-N: 1690 - 1810 (mg/L),	49	–	–

	pH: 8.4 – 8.6			
Ozone + Hydrogen Peroxide (O_3/H_2O_2)	COD: 1740 (mg/L)	93		
Ozone + Hydrogen Peroxide (O_3/H_2O_2)	COD: 5678 (mg/L), pH: 8.7	60 - 90		
Ozone + Ultraviolet radiation (O_3/UV)	COD: 7800 - 8200 (mg/L), pH: 8.4 – 8.6	78		
Adsorption via composite adsorbent (activated carbon, zeolite, limestone and rice husk ash)	COD: 1,478–3,540 (mg/L), Color: 3773–5100 (Pt-Co.), NH_3-N: 1,010–2,740 (mg/L), pH: 8.1–8.7	65	98	70
Adsorption (carbon-zeolite composite adsorbent)	COD: 2033 (mg/L), NH_3-N: 1920 (mg/L),	57.5		37
Adsorption (durian peel-based activated carbon)	COD: 3100 (mg/L), NH_3-N: 3286 (mg/L),	41.9	39.9	
Powdered Activated Carbon-Sequential Bach Reactor (SBR)	COD: 1396 (mg/L), Color: 3262 (Pt-Co.), NH_3-N: 579 (mg/L), pH: 8	27.3	65.4	89.9
Powdered ZELIAC-Sequential Bach Reactor (SBR)	COD: 1301 (mg/L), Color: 1690 (Pt-Co.), NH_3-N: 532 (mg/L), pH: 8.25	72.84	84.1	99.0

Source: [17]

Table 4. Summary of the treatment efficiencies of different treatment processes for semi-aerobic landfill leachate

process	**Initial Concentration**	**Removal (%)**		
		COD	**Color**	**NH_3-N**
Coagulation/ flocculation	COD: 1925 (mg/L), NH_3-N: 1184 (mg/L), Color: 3869 (Pt-Co.), pH: 8.4	43.1	94	–
Anionic resin	COD: 2380 – 2850 (mg/L),), NH_3-N: 1820 - 2200 (mg/L), pH: 8.3 – 9.10	70.3	91.5	–
Flotation+ coagulation ($FeCl_3$)	COD: 2610 (mg/L), Color: 4000 (Pt-Co.),	75	93	41
Fenton	COD: 2950 (mg/L), Color: 3850 (Pt-Co.), pH: 8.5	58	78	–
Electro-Fenton	COD: 2950 (mg/L), Color: 3850 (Pt-Co.), pH: 8.5	94.07	95.83	–
PAC-SBR*	COD: 1655 (mg/L), Color: 3672 (Pt-Co.), NH_3-N: 600 (mg/L), pH: 7.87	64	71	81
Ion exchange process	COD: 2667 (mg/L), Color: 4059 (Pt-Co.), NH_3-N: 1760 (mg/L), pH: 8.2	87.9	96.8	93.8
Flotation + coagulation alum ($Al_2(SO^4)_3$)	COD: 2610 (mg/L), Color: 4000 (Pt-Co.), NH_3-N: 1975 (mg/L), pH: 8.13	79	70	-
O_3/H_2O_2/Fe	COD: 2180 (mg/L), color: 4100 (TCU), NH_3-N: 1065 (mg/L), pH: 8.5	65	98	22
O_3/H_2O_2/Fe	COD: 1780 (mg/L), color: 3450 (TCU), NH_3-N: 780 (mg/L), pH: 8.5	78	98	22
$O_3/S_2O_8^{2-}$	COD: 2480 (mg/L), color: 3450 (TCU), NH_3-N: 810(mg/L), pH: 8.5	72	96	55

$O_3/S_2O_8^{2}$	COD: 2025 (mg/L), color: 3550 (TCU), NH_3-N: 810 (mg/L), pH: 8.5	72	96	76

Source: [17]

Table 5. Performance of leachate parameter removal by different applications [18]

Treatment Method	Leachate parameters					
	BOD	COD	SS	NH_3-N	Colour	Heavy metals
Activated Sludge Process	▲	●	Ø	Ø	Ø	Ø
Contact Aeration Process	▲	●	Ø	Ø	Ø	Ø
Rotary Biodisk Conductor Process	▲	●	Ø	Ø	Ø	Ø
Biological Trickling Process	▲	●	▲	Ø	Ø	Ø
Biological Nitrogen	▲	●	Ø	▲	Ø	Ø
Flocculation -Sedimentation	●	▲	▲	Ø	▲	●
Sand filtration	Ø	Ø	▲	×	●	×
Activated Carbon (Adsorption)	▲	▲	●	Ø	▲	●
Chemical Oxidation	×	●	×	×	▲	×

High (▲) Medium (●) Low (Ø)

Table 6. Summary of ozone in AOPs on leachate treatment

Initial Concentration	**Removal (%) after**				
	O_3	**O_3/H_2O_2**	**O_3/UV**	**O_3/H_2O_2/Fe**	**$O_3/S_2O_8^{2-}$**
COD: 5230 (mg/L), colour: dark brown	COD: 27%	COD: 50%	-	-	-
COD: 743 (mg/L), NH_3-N: 714 (mg/L), pH: 3.5	COD: 23% - 40%	COD: 63%	-	-	-
COD: 1090 (mg/L), color: 1130 (TCU), NH_3-N: 455 (mg/L), pH: 8.5	COD: 73%, color: 90%, NH_3-N: 67%	COD: 80%, color: 96%,, NH_3-N: 78%	-	-	-
COD: 5678 (mg/L), NH_3-N: 339 (mg/L), pH: 8.7	-	COD: 60% - 90%	-	-	-
COD: 1740 (mg/L)	-	COD: 93%	-	-	-
COD: 760 (mg/L)	-	COD: 97%	-	-	-
COD: 5020 (mg/L)	COD: 30%	-	COD: 37%	-	-
COD: 7800 - 8200 (mg/L), NH_3-N: 1690 - 1810 (mg/L), pH: 8.4 – 8.6	COD: 49%	COD: 57%	COD: 78%	-	-
COD: 560, (mg/L), pH: 10	COD: 40%	COD: 50%	-	-	-
COD: 1090 (mg/L), NH_3-N: 455 (mg/L), pH: 3-4	-	COD: 28%	-	-	-
COD: 1280 (mg/L), pH: 2	-	-	COD: 54%	-	-
COD: 2180 (mg/L), color: 4100 (TCU), NH_3-N: 1065 (mg/L), pH: 8.5	COD: 15%, color:27%,			COD: 65%, color:98%, NH_3-N: 22%	-
COD: 1780 (mg/L), color: 3450 (TCU), NH_3-N: 780 (mg/L), pH: 8.5	-			COD: 78%, color:98%, NH_3-N: 22%	-
COD: 2480 (mg/L), color: 3450 (TCU), NH_3-N: 810(mg/L), pH: 8.5	COD: 39%, color:55%, NH_3-N: 20%	-	-	-	COD: 72%, color: 96%, NH_3-N: 55%
COD: 2025 (mg/L), color: 3550 (TCU), NH_3-N: 810 (mg/L), pH: 8.5	-	-	-	-	COD: 72%, color:96%, NH_3-N: 76%

Source: [17]

Note: Data in bold describe a semi-aerobic leachate

Malaysia practices different processes to treat leachate. An example of a successful leachate treatment system in Malaysia is illustrated in Fig. 5.

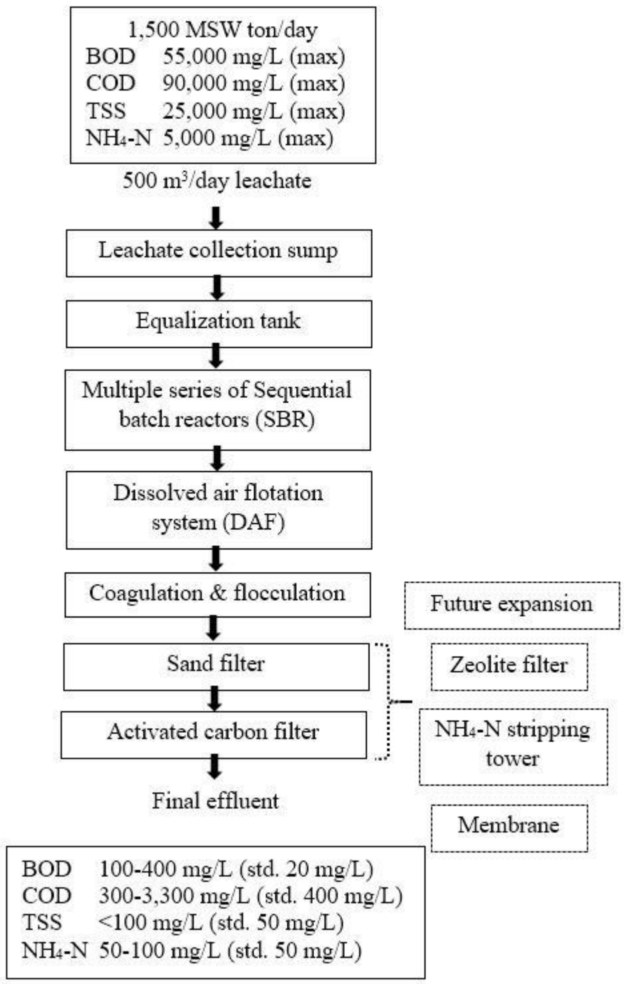

Figure 5. An example of a successful landfill leachate treatment system in Malaysia

CHALLENGES

1. Leachate treatment is composition dependent. For example, a good system for leachate A may not be applicable for leachate B because their compositions differ. Theoretical outcomes may differ from practical or actual results. Therefore, treatability studies should be conducted.
2. Difficulties in installing and maintaining a good treatment system are encountered in developing countries because of budget constraints.
3. Removing ammoniacal nitrogen remains a great challenge. Current treatment systems normally require a nitrification–denitrification mechanism or an ammonia stripping facility, but these requirements are costly. Nevertheless, zeolite filters have emerged as well-known devices used to remove ammoniacal nitrogen.
4. Technical information regarding management and operation of treatment facilities is limited in developing countries.

CONCLUSION

Current trends in leachate treatment involve a combination of biological, chemical, and physicochemical processes in multiple-stage treatment systems. Preferred methods depend on various technical considerations, which should be adequately evaluated because one method cannot be generally used for common applications. Studies have been conducted to develop treatment systems that can improve performance and reduce cost. With enhanced systems, landfill management strategies, especially those in developing countries, can be improved.

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