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Hazardous Components of Landfill Leachates and Its Bioremediation

Menaka Salam and Namdol Nilza

Abstract

Landfill leachates contain both dissolved and suspended material and may pose a threat to the environment because of the toxic substances that it carries and contaminates surface water and groundwater. They are composed of several different categories of components out of which many of them are recalcitrant and highly toxic. Major components of landfill leachates are dissolved organic compounds, inorganic macro compounds, heavy metals such as copper, lead, cadmium, chromium, nickel etc. and xenobiotic compounds such as polychlorinated biphenyls. Complex organic compounds which are released from industrial effluents like perfluorooctanoic acid and benzothiazole are also common in many of the landfill leachates. Biological treatment is a low cost effective method for the treatment of landfill leachates which can act as an accelerator for further treatment by either chemical or physical method. Improved strategies have been developed in the biological treatment of leachates which shows the efficiency of the system. But, as leachate characteristics vary depending on the rainfall and other environmental factors, it is important to first thoroughly analyze the physical and chemical properties of the landfill under study. A combined effort involving proper analysis of the leachate components, monitoring leachate flow, risk assessment, and treatment of the leachate before its release is required to efficiently control its impact to the environment.

Keywords: landfill leachates, xenobiotic, bioremediation, microorganisms, bioreactor

1. Introduction

Landfill leachate is a liquid composed of absorbed components which may be soluble solids or any other undesirable components present in the landfill. It is formed when water passes through the landfill waste in the form of rain and seeps through the stockpile consisting of waste materials from different sources such as municipal and industrial wastes. Since the waste material can comprise of various chemicals, organic and inorganic compounds in large volume which also gets decomposed, the leachate that is formed is generally high in toxicity.

Due to generation of huge amount of solid wastes, many of which contain toxic and recalcitrant substances, its control and management has become the utmost need in recent years. Segregation of waste materials and recycling are two major ways of reducing the pollution in a solid waste dumpsite or a landfill. Among the

hazardous components of landfill leachates, microplastics in the size range of 100 to 1000 μm is also found in many of the municipal solid waste landfill leachates. This has been developed after a long time period of time, and the major types are polyethylene and polypropylene which are increasingly used throughout the years because of its convenience to use. Other hazardous components which have been of major concern since long time are toxic heavy metals like lead, arsenic, cadmium, mercury etc. and xenobiotic compounds like halogenated organic compounds. Proper and timely monitoring of the landfill and its leachate is required to control the pollution that can occur to the groundwater, soil and air. Gases that get released due to decomposition and microbial activity have caused severe accidental bursts in many landfill areas due to improper management and lack of monitoring. Therefore, risk assessment is an important criterion for the management of landfill areas. A number of treatment methods comprising of physical, chemical and biological methods have been developed, but none of these methods alone can be declared as having the highest efficiency as the landfill leachates also vary in their composition, volume and migration. However, bioremediation or treatment using biological processes is of major interest because of its low-cost, high efficiency and environment friendly. Physical and chemical methods, although very efficient, have high cost and some of the chemical methods pose environmental concerns in the long run. Regarding biological processes, a number of microorganisms are yet to be explored which can be used as a bioremediating agent. Many bacteria and fungi are already proved to have high removal capacity of leachate parameters like BOD, COD, nitrate and sulphate. In recent years, microorganisms able to remediate heavy metals, xenobiotic compounds and even plastics have been discovered. This shows that there is huge potential of microorganisms to help in the treatment of landfill leachates.

2. Components of landfill leachates

Leachates contain both organic and inorganic pollutants, out of which some constituents are highly toxic and pose a threat to the environment. The actual composition of landfill leachate varies according to the type of waste which has been dumped and accumulated. In developing countries waste segregation is not practiced, waste management and treatment system are not well established and landfill systems are also not properly designed to prevent leachate flow. Because of lack of waste segregation, landfill dumpsites may have mixed waste materials. For example, in a municipal solid waste (MSW), food waste, household discards, plastics, paints, mercury containing waste, batteries and other products made up of toxic compounds and heavy metals may be present. However, in general, the dissolved organic matter comprises of acids, alcohols, aldehydes and sugars, and the inorganic components such as calcium, magnesium, sulphate, chloride and ammonia. These constituents are present in much higher concentrations than normal aquifers. Inorganic pollutants found in leachates are ammonium, phosphorous, sulphate and heavy metals. Volatile fatty acids are majorly present in young leachates and tend to decrease gradually in aged landfills. Humic acids and fulvic acids are also commonly present in old landfills and leachate plumes. Among the heavy metals, the common ones are Fe, Pb, Ni, Cd, As, Cr, Cu and Hg. Other toxic pollutants which are present in landfill leachates are the aromatic hydrocarbons (Benzene, Toluene, Ethylbenzene, and Xylene), phenols, pesticides, polyethylene, plasticizers, and halogenated organic compounds like PCBs and dioxins. Landfills are also a shelter for pathogenic microorganisms, mostly coliform bacteria and a few viruses. The pH and temperature changes may, however, inactivate these microorganisms.

Landfill site	TDS (mg/l)	Electrical Conductivity (mS/cm)	pH	Chloride (mg/l)	Nitrate (mg/l)	Sulphates (mg/l)	BOD (mg/l)	COD (mg/l)	Heavy metals	References
Ghazipur Landfill site, Delhi, India	34,560	23,221	8.4	1598	449	ND	9250	20,992	Fe, Zn, Cu, Pb, Ni, Cr, Cd	[1]
Mavallipura landfill site, Bangaluru, India	2027	4120	7.4	660	22.36	ND	1500	10,400	Fe, Ni, Pb, Cu, Cd, Cr	[2]
Borg El-Arab landfill site, Egypt	27,452	40,921	7.8	11,387	1.4	596	11,700	15,629	Fe, Zn, Ni, Cd, Cr	[3]
Sukawinatan landfill, Indonesia	4640	ND	7.45	162.5	93.6	199	145.7	900	Fe, Cu	[4]
Alhend'in landfill site, Spain	34,470	ND	7.96	7298	ND	166.7	5750	30,994	Fe, Cd, Cu, Ni, Pb, Zn	[5]
Landfill at Bizerte, North Eastern Tunisia	1770	19.6	7.4	3300	1628	ND	5200	26,200	Fe, Cu	[6]

(ND: Not defined)

Table 1.
 Comparison of some important parameters of various landfill sites.

A variety of microorganisms degrades the various components present in the landfill waste and produces their metabolic products and other decaying organic matters. Through decomposition of organic constituents by microorganisms dwelling in the landfill site and also through chemical reactions between the components of waste, landfill gases are released in the form of methane and carbon dioxide which are greenhouse gases. The gases release increases gradually over time and poses environmental threat and security issues to the people residing near the landfill sites. **Table 1** shows a comparison of some important pollution parameters of landfill sites at various places. It is observed that the pHs of these landfill sites are mostly in the alkaline range, there is increased level of electrical conductivity, COD, chloride and nitrate concentrations, and the common heavy metals which are present are Fe, Ni, Cu and Cr.

3. Effect of leachates on the soil environment

Landfill leachates cause serious environmental issues mostly in developing countries polluting the groundwater, soil and air. Even in an engineered landfill site with landfill liners, the barriers tend to get damaged or deteriorate with time, therefore, leachate may get leaked and pass through the soil. The consequence is harmful effects to human health and also causes hindrance to economic health and development. Heavy metals such as Pb, As, Cd, Cr and Hg leach out from uncontrolled landfill sites and cause a major threat to human health. Due to rapid urbanization, areas near the landfill sites in many cases are gradually transformed into residential areas and also covered by agricultural fields. Inorganic cations and anions like sodium, calcium, chloride, sulphate etc. seep through the leachate and contaminate groundwater and soil. These inorganic substances are not altered by the soil type and remain a pollutant of the water and soil [7]. This ultimately gives rise to changes in soil composition and fertility. Studies have shown that iron and zinc are the major pollutants of the soil samples in the vicinity of landfill sites. Zinc is present mostly in the upper soil layer and iron has highest dispersion rate [2]. Leachate percolation in soil reduces the hydraulic conductivity resulting in clogging of the soil and these changes the properties of the soil such as water retention, field capacity etc. The soil microbial community gets changed and formation of biofilms with metal precipitation may arise.

4. Role of microorganisms in remediation of landfill leachates

Remediation of landfill leachate using microorganisms is a cost effective approach as compared to conventional treatment processes. However, a lot need to be explored and studied regarding this area. The conventional methods of treatment are chemical and physical methods such as coagulation/flocculation, chemical oxidation, air stripping and membrane filtration [8]. These methods can remove COD and other toxicity levels ranging from 40–90%. However, in many cases, cost of the whole process and also production of non-degradable sludge remains a disadvantage. Use of microorganisms does not have these disadvantages and are also effective in the treatment process as there are a number of microorganisms which produce various extracellular enzymes through which they can degrade toxic compounds to less toxic or non-toxic products. Landfill leachate samples have been studied to investigate the microorganisms dwelling in them and which have the capability of degrading the main pollutants of leachate such as nitrate, phosphate and ammonia. It has been found that certain fungi, actinomycetes, and bacteria

Organism	Source of isolation	Substance degraded	Percent removal	Heavy metal resistance	Reference
<i>Lysinibacillus</i> sp., <i>Bruvundimonas</i> sp., <i>Brevibacterium</i> sp., <i>Thermococcus</i> sp.	Powerstown Landfill, Co. Carlow, Ireland	Nitrate, Phosphate, ammonia	35%, 55%, 88%	As, Cd, Fe, Ni, Cu	[9]
Not characterized, wastewater effluent as microbial source	Weltevreden Sanitary landfill site, Brakpan, South Africa	Ammonia COD	99% 36%	—	[10]
<i>Chlorella vulgaris</i> and <i>Chlamydomonas</i> <i>reinhardii</i>	Municipal landfill management, Istanbul	Nitrogen Phosphorous	69.03% 100%	—	[11]
<i>Actinomycetes</i> , <i>Bacillus</i> , <i>Pseudomonas</i> and <i>Burkholderia</i>	Jebel Chekir landfill leachate, Tunisia	TOC	70–80%	As, Fe, Pb	[12]
<i>Trametes versicolor</i>	Nonthaburi landfill site, Thailand	Color, BOD, COD	78%, 68%, 57%	—	[13]
Immobilized microorganisms	—	COD and Ammoniacal Nitrogen	98.3%, 99.9%	—	[14]

Table 2.
Removal efficiency of leachate pollutants by some organisms.

belonging to *Firmicutes* and *Proteobacteria* have efficient degrading potential. Many of these microorganisms are also tolerant to heavy metals like Arsenic, iron, nickel, cadmium and copper. **Table 2** shows the removal efficiency of some microorganisms as well as microalgae isolated from landfill leachates.

5. Effectiveness of bioremediation

Bioremediation using microorganisms is a method of choice due to its low cost and simplicity in operation mechanism. The various types of biological treatment processes are upflow anaerobic sludge blanket (UASB), activated sludge reactor, membrane bioreactor, rotating biological contactor, batch reactor and moving bed biofilm reactor. All of them are efficient in treatment of young leachates. The UASB and batch reactor processes are also efficient in treatment of middle aged and mature leachates. Anaerobic reactor using seed sludge as inoculants has been found to tolerate high levels of COD and also precipitate heavy metals such as Fe, Zn, Ni, Cd, Pb, Cu and Cr [15]. Phytoremediation is one efficient and inexpensive process for remediation of mature leachates. However, phytoremediation has many limitations like remediation only limited to the surface and depth where the roots can reach, slow growth, and inadequacy in preventing the contaminant from leaching into the groundwater.

Various bioremediation processes have been experimented and their efficiency studied so far, but it has been observed that bioremediation when combined with physical and chemical processes in a monitored manner shows much promise and efficacy in removal of pollutants of leachate plumes.

6. Management of soil contamination caused by leachates

Landfill is the preferred method for solid waste disposal all over the world due to its ease and low-cost operations. However, landfilling requires proper designing of its structure and planning of disposal in order to avoid its pollution effects to the environment. Landfill leachates if not properly controlled can give rise to serious consequences like soil contamination and ultimately damage to crops and vegetation. In some cases, there may be accumulation of heavy metals in vegetation and consequently in fishes dwelling in contaminated water bodies like lakes and streams. The ultimate effect is biomagnification and serious health issues to people inhabiting the nearby areas of the landfill. Most of the components are carcinogenic and genotoxic in the long run. Therefore, the landfill leachates need to be properly monitored and controlled. Due to lack of engineered systems in most of the landfills all over the world, and also due to the practice of merely dumping wastes in the landfill sites of developing countries, underlying soil and groundwater pollution by the toxic leachates have become a major concern in the recent years [16].

Management of leachate has posed a challenging task as it requires various stages such as (i) monitoring of its formation and flow or migration, (ii) assessment of the various parameters of leachates, (iii) investigation of its hazardous components, and (iv) its treatment before finally releasing to the environment.

6.1 Monitoring of leachate formation and flow or migration

Leachate formation and its duration may depend on the components of a particular landfill site and its microbial community composition. The flow rate and the leachate volume may also vary depending on the season and rainfall. Therefore, proper investigation of the leachate formation is required in order to control the flow rate and migration of leachate plume. Various techniques used for monitoring leachate plume migration are hydro-geological techniques, electromagnetic methods, fluorescence methods, stable isotopes labelling, microbial analysis etc. [16]. Microbes play important role in characterizing the important parameters of leachates. Present day advancement in molecular biology techniques shows great promise to delineate the microbial community composition in a short time period. Metagenomics and next generation sequencing technology would greatly help in finding out novel microorganisms with novel pathways of complex compounds degradation. This information would further help in managing the landfill sites through natural attenuation.

6.2 Assessment of various parameters of leachates

The important parameters like pH, alkalinity, BOD, COD, TDS, nitrate, sulphate, chloride, electrical conductivity etc. should be assessed regularly and check whether their values are according to the permissible limits set by various regulators. Multi parameter analyzer can be used to measure different parameters such as pH, electrical conductivity, oxidation reduction potential, salinity, temperature etc. Spectrophotometers are used to check many of the parameters which involve color development [17]. Procedure for measurement of parameters should be according to the standard procedures adopted by United States Environment Protection Agency (USEPA) or similar professional organizations which have set the standard protocols. The values obtained can be compared with the standards of various regulatory limits so as to assess the risk of the leachate to the environment.

6.3 Investigation of hazardous components

Hazardous components of landfill leachates such as toxic heavy metals, halogenated compounds, aromatic compounds, pesticides and other recalcitrant organic compounds, if present even in minute quantities can eventually give rise to contamination of soil and the groundwater. Therefore, the hazardous components need to be analyzed and proper treatment methods such as physico-chemical and biological treatments can be recommended. Assessment of heavy metals in landfill leachate is often an arduous task as we have to understand the metal speciation and its flow [18]. Heavy metals tend to get oxidized and this fact has to be considered in the assessment studies. Most of the heavy metals are present in the form of complexes and the metal speciation is also influenced by biological activities. Risk assessment i.e. the effect of hazardous components to the environment needs a systematic approach because of the uncertainty of the soil environment and groundwater flow. Various predication models and softwares are available for risk assessment of landfill leachates [19]. The implication of biological toxicity tests of leachate samples is also commonly applied by many investigators. Phytotoxicity tests of leachate samples have been reported using *Sinapis alba*, *Lemna minor*, *Vicia faba*, *Zea mays*, *Hordeum vulgare*, *Lepidium sativum*, *Lycopersicon esculentum*, *Helianthus annuus*, *Medicago sativa* etc. and seed germination and root elongation have been mostly studied [20, 21].

6.4 Treatment of landfill leachate before its disposal

The various reliable treatment methods of landfill leachates are (i) Biological reactors, (ii) Physico-chemical treatment, and (iii) natural attenuation. Biological treatment methods have been found to be more efficient in case of young leachates which are easily biodegradable whereas in case of old leachates, physico-chemical treatment methods are more suitable. Combined treatment methods where biological, physical and chemical treatment methods are applied have been shown to have highest efficiency [16]. Natural attenuation, which involves the merging of physical chemical and biological processes occurring in nature, has been found to be very useful for remediation of leachate plume. Natural processes in constructed wetlands and aerated lagoons have shown high efficiency (60–99%) in removing BOD, COD, ammoniacal nitrogen, Chloride, phosphate, iron and phenols [22–24]. Biological reactors with aerobic and anaerobic digestion processes have shown high removal capacity of BOD and COD as well as heavy metals in some cases. Among the advanced oxidation processes, ozonation has potential in removing color and organic acids i.e. humic acid and fulvic acid [25]. Coagulation using Ferric chloride followed by filtration and reverse osmosis has been shown to completely remove organic pollutants like Di-(2-ethylhexyl) phthalate (DEHP) and Bisphenol A [26]. Among the latest treatment technologies, leachate treatment using magnetic adsorbents and nanomaterials are of special interests as they have high efficiency in removal of organic acids and heavy metals [27, 28]. But the use of these techniques has environmental impacts and further research need to be done with green and environmental friendly processes.

7. Conclusions

Landfill leachates pose serious threats to the environment. In many cases, groundwater contamination has occurred due to lack of monitoring and efficient treatment system. The general parameters which are measured in a landfill site

are pH, alkalinity, electrical conductivity, TDS, BOD, COD, chloride, ammoniacal nitrogen, nitrate, sulphate etc. Analysis of hazardous components like toxic heavy metals, halogenated compounds, polymers etc. are also necessary. Treatment methods using microorganisms is an attractive way for removing or remediating the pollutants in the leachates as it is cost effective and environment friendly. There is a great potential in studying the efficiency of microorganisms in leachate treatment, but a lot need to be explored in this field. Novel microorganisms having potential use in leachate treatment can be explored using modern techniques like metagenomics. Biological treatment of leachates from young landfill sites has already been proved efficient. The treatment efficiency for leachates from old landfill sites can be improved by integrating biological method with physical and chemical methods. Natural attenuation through aerated lagoons and phytoremediation is also a means for eliminating pollutants in the vicinity of landfill sites. In the present scenario, reducing solid waste and hazardous waste components by reuse and recycling should be strictly considered. The landfill sites should be properly designed to avoid leachate contaminants to soil and groundwater. Proper monitoring, risk assessment, and leachate treatment with advanced technologies are very much necessary to avoid any kind of serious environmental impact.

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