Constructed Wetlands - A Sustainable Solution for Landfill Leachate Treatment

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***Abstract* - The concentrated leachate from landfill sites is a major threat to aquatic ecosystems and public health. This paper presents an overview of the use of constructed wetlands for remediation of landfill leachate. The constructed wetland is a relatively novel technology with great potential for environmental remediation. This treatment technology has been extensively studied for treatment of diverse type of wastewaters. They have been found highly effective for the remediation of bio-refractory organic compounds, plant nutrients, as well as hazardous heavy metals. The treatment process mechanism, parameters, plant species, and performance for removal of pollutants from landfill leachate are to be evaluated. The constructed wetlands may provide sustainable solution for treatment and management of landfill leachate.**

***Keywords:* Landfill leachate, Constructed wetland, Wastewater Treatment, Sustainable**

I. INTRODUCTION

The growing economy, rapidly rising urban population, and shifting lifestyles have resulted in change in composition and increase in volume of municipal solid waste (MCW) in India. The MSW generation is expected to rise from 64-72 million tonnes (at present) to 125 million tonnes by 2031 [1]. The use of sanitary landfills for the disposal of MSW is a common technique all over the world due to easy and economical operation with technical feasibility. However, this practice generates leachate which poses risk of exposure of community to toxic pollutants by contamination of water resources and release of micro-pollutants in the environment, if not disposed safely. The developing world is particularly prone to environmental hazard owing to lack of resources for leachate treatment.

The leachate is produced by decomposition of waste in landfill when rainwater percolates through it and washes out degradation by-products. Its quality and quantity vary with waste composition, compaction method, landfill age, microbial community, leachate recirculation, and environmental conditions [2]. It may contain organic compounds e.g. benzene and toluene [3], and CN^-, Cr, Cu, Ag, As, Ni, Pb, Cd, Hg, and Zn [4], [5]. The metals persist in the environment and bio-magnify through food chains to affect ecosystems.

A constructed wetland (CW) is a cost effective engineered system designed as a novel alternative for treatment of the wastewaters from diverse sources i.e. domestic, agricultural, storm runoff, industrial, acid mine drainage, and landfill etc. CWs with low energy and maintenance requirement offer a sustainable alternative for leachate treatment as compared to the conventional processes e.g. activated sludge and membrane filtration etc. CWs are particularly useful for developing world and remote sites with small communities [6]. The CWs have significantly higher efficiency than usual biological processes for the treatment of low biodegradability wastewaters [7]. This paper is aimed to present an overview of application of constructed wetlands as a sustainable solution for landfill leachate treatment.

II. LEACHATE CHARACTERISTICS

The leachate is usually a dark colored liquid with strong odor containing four groups of pollutants: biorefractory organics (aromatic hydrocarbons, pesticides, and phenols, etc.), dissolved organics (humic substances and volatile fatty acid etc.), inorganics (Na^+, K^+, Ca^{2+}, Mg^{2+}, NH^{4+}, Mn^{2+}, Fe^{2+}, HCO_3^-), heavy metals (Pb^{2+}, Ni^{2+}, Cd^{2+}, Cr^{3+}, Zn^{2+}, Cu^{2+}) [8], and microorganisms [9]. It is generated by degradation of the organic matter in landfill involving three phases i.e. aerobic degradation (1-3 months), followed by anaerobic phase, and finally humic phase. The anaerobic phase is sub-divided into acidic and methanogenic phases. The metahanogenic phase, end phase of organics degradation, starts at about 10 years. It may take about 100 years of operation for landfill to attain humic phase which involve final stabilization of organic waste to form humic substances [10]. The composition of leachate changes throughout the aerobic, acetogenic, and methanogenic phases with the age of the landfill [11].

The leachate is potentially toxic with high Chemical Oxygen Demand (COD) (100–50,000 mg/L) and Biochemical Oxygen Demand (BOD) (3–25,000 mg/L) [12]. It is generally characterized by 13–5000 mg/L of suspended solids, 5–11 pH, and 10–13,000 mg/L of nitrates. The BOD, COD, and BOD/COD ratio decline with time while pH rises [11], [13]. The young leachate generally contains high organic load (BOD/COD < 0.6) with a pH <6.5. Whereas, the old (≥6 years) leachate is generally characterized by low BOD/COD ratio

(<0.1), >400 mg/L of ammonium content, and pH > 7.5 [14], [15].

III. CONSTRUCTED WETLANDS

The CWs have become an attractive technology for wastewater treatment due to economic installation, low energy need, easy operation, high efficiency for pollutants removal, and aesthetic value [16], [17]. CWs mimic natural processes for removal of pollutants from wastewater involving various physical, chemical, and biological processes. They comprise of vegetation, substrate, soil, microorganisms, and water [18]. The selection of plant species, substrate, depth of water, hydraulic retention time (HRT), hydraulic loading rate (HLR), and feeding mode are crucial factors for achieving optimum performance. The plants are main biological components in CWs. They improve various purification processes, directly uptake nutrients (i.e. nitrogen and phosphorus etc.), and can accumulate heavy metals and xenobiotics from wastewater [19], [20]. Plants extensive root system provides unique micro-environment with large surface area for the growth of microorganisms which promote pollutant removal from landfill leachate by filtration, cation exchange, absorption, and chemical transformation through root [21]. The commonly used plant species in CWs have been compiled in Table 1.

The substrate is important for plants growth and easy passage of wastewater through wetland. The clay, sand, gravel, marble, calcite, fly ash, bentonite, vermiculite, slag, limestone, dolomite, wollastonite, shell, zeolite, and activated carbon have been used as substrate in CWs. HLR and HRT are important factors for pollutant removal. The nitrogen removal requires a longer HRT as compared with removal of organics.

Table I Commonly Used Plants in CWs [20]

S. No.	Macrophytes	Examples
1.	Emergent plants	Typha spp. (Typhaceae), Phragmites spp. (Poaceae), Juncus spp. (Juncaceae), Scirpus spp. (Cyperaceae), Eleocharis spp. (Spikerush), and Iris spp. (Iridaceae)
2.	Submerged plants	Potamogeton crispus, Ceratophyllum demersum, Myriophyllum verticillatum, Vallisneria natans, and Hydrilla verticillata
3.	Floating leaved plants	Marsilea quadrifolia, Trapa bispinosa, Nymphoides peltata, and Nymphaea tetragona
4.	Free floating plants	Lemna minor, Hydrocharis dubia, Salvinia natans, and Eichhornia crassipes

The mode of feeding (i.e. continuous, batch or intermittent) of wastewater may affect the treatment efficiency by influencing oxygen transfer, redox conditions, and diffusion of pollutants in wetland system [20]. The surface flow (SF) (Fig. 1) or horizontal sub-surface flow (HSSF) (Fig. 2) wetlands have been mostly utilized for degradation of leachate. SF wetlands are reliable with high degradation efficiency but require large area and longer HRT (almost a year) [22]. While, SSF wetlands require less area and intensify the purification processes with few days HRT (e.g. 7 days) [23]. HSSF system has easy operation but suffer with low nitrogen reduction efficiency because of anaerobic conditions which limit nitrification. Vertical type of SSF (VSSF) wetland (Fig. 3) is useful for improvement of aeration and enhances nitrification.

SF system is replica of natural marshland characterized with surface flow of water. They are not affected via large change in volume and organic load. Mechanism of impurity degradation in CWs incorporate physical i.e. filtration through soil, adsorption on media surface, and sedimentation, chemical i.e. precipitation and oxidation-reduction, and bio-treatment i.e. plant uptake and bio-degradation [17], [24] (Table 2). The primary treatment is required previous to SSF CW to contain suspended matter which can clog the system [25].

VSSF systems have smaller HRT and are able to nitrify because of high aeration than SF and HSSF systems. They have high suspended matter, BOD, and pathogens degradation efficiency with less clogging problem as compared to HSSF system. They need less area as compared to SF wetlands. They have small operating cost but need expert design and construction with regular maintenance as compared to HSSF systems. VSSF systems involve vertically down passage of water through media. They can be combination with HSSF wetlands to provide aerobic conditions to ensure nitrification [26].

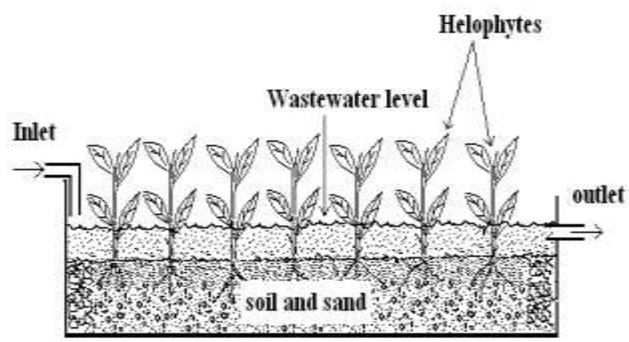

Fig. 1 Surface flow (SF) constructed wetland [17]

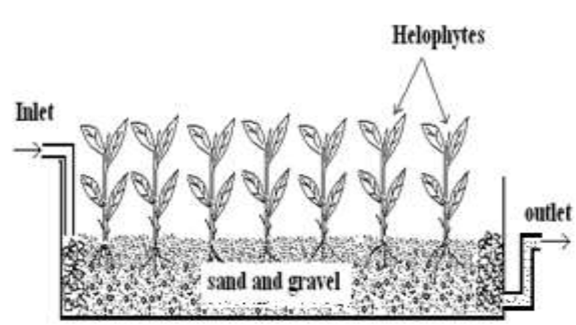

Fig. 2 Horizontal subsurface flow (HSSF) constructed wetland [17]

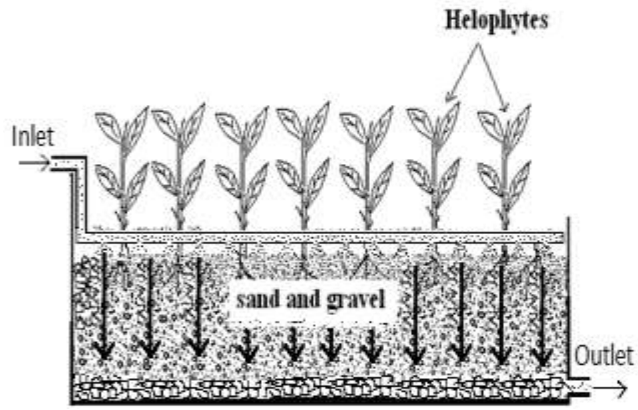

Fig. 3 Vertical subsurface flow (VSSF) constructed wetland

Table II Treatment Processes in Constructed Wetlands

Parameter	Removal mechanism
Suspended solids	Sedimentation and filtration
Dissolved Organics	Aerobic and anaerobic microbial degradation, phyto-degradation, phyto-volatilization, and plant uptake
Phosphorus	Plant uptake and matrix sorption
Nitrogen	Ammonification, microbial nitri-fication, plant uptake, denitrification, matrix adsorption
Metals	Sedimentation, filtration, adsorption, precipitation, and plant uptake

IV. LEACHATE TREATMENT

The leachate decontamination is a scientific challenge because of variability of pollutant nature with time. The various physico-chemical and biological processes have been tried to treat leachate. The biological processes are more effective for the degradation of biodegradable fraction but suffer by low efficiency due to increasing quantity of bio-refractory organics in leachate as decomposition of waste progress. However, they are either expensive and less effective for removal of bio-refractory organics, or not feasible for widespread rural application [14]. There is need of economical and efficient wastewater treatment technologies for rural areas and developing world. CW's offer an attractive and sustainable solution in this regard with low maintenance and operating cost.

The removal efficiencies for color, turbidity, total solids, BOD, COD, nutrients, and heavy metals are shown in Table 3 and 4. Analysis of the above results for leachate treatment shows that CW systems can effectively treat landfill leachate. The observed removal efficiencies varied from 30 to 95% for BOD, 34 to 96% for COD, 63 to 90% for color, 84% for turbidity, 91% for total solids, 35% for Cl^-, 49% for SO_4^{2-}, 59.8 to 99.7% for phosphorous, 50 to 98.5% for total nitrogen (TN), 26 to 99% for NO_3^{2-} , 26 to 99% for NH_4^+, 88-100% for phenol, 80 to 99% for heavy metals, and about 85% for bacterial population. A wide variation, in the removal of different contaminants has been observed among different studies. The removal of contaminants from landfill leachate usually depends on the concentration, type of compounds, toxicity and the process operation parameters of the treatment system.

Table III Efficiency of Constructed Wetlands for Landfill Leachate Treatment

Location	System Configuration	Removal Efficiency (%)					Reference
		Turbidity, Color, Solids, Cl^-,So_4^{2-}, Bacteria, Phenol	BOD	COD	Nutrients	Heavy Metals	
Isfahan (Iran)	HSSF, Plant: Vetiver, Flow rate: 27L/day, HRT: 5day	----	30	34	NH_4^+-N (26), NO_3^--N (40), TN (50)	----	[6]
Japan	VSSF, Plant: Phragmites australis	Phenol: 88-100	----	----	----	----	[27]
Chlewnica (Northern Poland)	Multistage SSF, Plant: Phragmites australis (Common reed), HRT: 1.1-3.5 day	----	88-95	47.8-86.6	Nitrogen: 68.9-98.5	----	[2]
San Pedro village (Southwest Colombia)	HSSF, Plant: Polyculture - Gynerium sagittatum (Gs), Colocasia esculenta (Ce) and Heliconia psittacorum (He), HRT: 7 day, Water inflow 0.5 m^3/day	----	----	50-67	----	Hg, Pb, Cd (10-80)	[28]
Vellore (Tamil Nadu, India)	HSSF, Plant: Cattail (Typha latifolia) and Bulrush (Scirpus californicus), HRT: 1-24 h	Turbidity: 84, TS: 91	----	82	NH_4^+-N: 65, Phosphate: 89	----	[29]
Malaysia	Adsorption and HSSF, Plant: Typha domingensis, Contact time: 50.2 h, Leachate-to-wastewater mixing ration (20%)	Color: 90.3	----	86.7	99.2	Ni: 86, Cd: 87.1	[5]

NW Bulgaria	VSSF, Plant: Phragmites australis, HLR: 0.38 cm^3 cm^{-2} min^{-1}	----	95.96	94.69	----	----	[30]
Hisar (Haryana, India)	VSSF (Up flow and down flow), Plant: Canna and Typha (Mixed culture), HRT: 4, 8, 12 days	----	----	55-87.2	NH_4^+-N: 72.2-63.1, TN: 67.7-74.3, Phosphate: 79.8- 85.9	----	[31]
Isfahan (Iran)	HSSF (Leachate, 20% and domestic wastewater, 80%), Plant: Typha domingensis, Optimum contact time: 48.7 h	Phenol: 90.5	----	----	----	Mn: 89.4	[32]
Bangkok (Thailand)	HSSF, Guinea grass (Panicum maximum TD 58), HRT: 10 day, HLR: 0.028 m/day	----	70.6	68.5	TKN: 73.5	----	[33]

TN: Total nitrogen, TKN: Total kjeldahl nitrogen

Table IV Efficiency of Constructed Wetlands for Landfill Leachate Treatment

Location	System Configuration	Removal Efficiency (%)					Reference
		Turbidity, Color, Solids, Cl^-,So_4^{2-}, Bacteria, Phenol	BOD	COD	Nutrients	Heavy Metals	
Pulau Burung Sanitary Landfill (Malaysia)	HSSF, Cyperus haspan, HRT: 3 week	Turbidity:39.3–86.6, Color: 63.5–86.6, TSS: 59.7–98.8	60.8–78.7	39.2–91.8	NH_4^+-N: 29.8–53.8, TN: 33.8–67, TP: 59.8–99.7	Fe: 34.9–59, Mg: 29–75, Mn: 51.2–70.5, Zn: 75.9–89.4	[16]
Kampung Padang Siding, Ulu Pauh, Perlis (Malaysia)	HSSF, Plant: Limnocharis flava and Scirpus atrovirens, Flow rate: 0.029 m^3/day, HRT: 24 h	----	----	----	NH_4^+-N: 38.7-61.3, PO_4^-P: 48-52	----	[34]
Kampung Padang Siding, Ulu Pauh, Perlis (Malaysia)	HSSF and VSSF, Plant: Limnocharis flava, Flow rate: 0.029 m^3/d, HRT: 24.1 h and 19.7 h for HSSF and VSSF CWs	----	----	----	----	Fe: 91.5 - 99.2, Mn: 94.7 - 99.8	[35]
Saginaw Township (Michigan, USA)	VSSF and SF, HRT: 60 days	----	----	----	NH_4^+-N: 99.5	----	[36]
Atleverket (Sweden)	SF, HRT: 180-365 days	----	----	68	----	----	[22]
Anamosa, Iowa (USA)	HSSF	----	88-97	35-60	TN>90	----	[37]
Ljubljana (Slovenia)	Combined VSSF and HSSF, Plant: Reeds and Cattails, Hydraulic load: 0.5 cm/day	Cl^-: 35, SO_4^{2-}: 49	59	50	NH_4^+-N: 51, PO_4^{3-}: 53	Fe: 84	[23]
Lafléche (Ontario, Canada)	HSSF and SF	----	93-99	----	TKN: 90-94, NH_4^+-N: 97-99	----	[38]
Germany	VSSF and HSSF, HRT: 5.5 days	----	----	20-40	TN: 82	----	[39]
Dragonja landfill site on the Adriatic coast	SF, Hydraulic load: 3 cm/day	Bacteria: 85	46	68	NH_4^+-N: 81	Fe: 80	[40]
Esval (Norway)	HSSF (HRT: 5 days) and SF (HRT: 40 days)	----	91	88	TN: 83	----	[41]
Perdido (Florida, USA)	SF, HRT: 20 days	----	----	90	NH_4^+-N: 99	----	[42]

TSS: Total suspended solids, TP: Total phosphorus

V. CONCLUSION

The constructed wetlands offer an attractive solution for leachate treatment particularly for developing world and rural areas. The literature results analysis shows that CW systems can efficiently treat leachate. There is observed wide variation in the contaminants removal efficiency among different studies. The contaminants degradation from leachate usually depends on the amount, nature of organics, toxicity, and the parameters of the treatment system.

The individual processes are not useful for degradation of contaminants from leachate owing to non-homogeneous nature and varying composition. Hence, the development of hybrid treatment processes is essential to meet wastewater discharge limits. The constructed wetlands can be easily combined with other treatment processes as an efficient and sustainable solution for leachate treatment.

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