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Landfill Leachate Technologies: A Review

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Abstract

Land filling of hazardous industrial solid waste is a major issue of the waste management system in India. The generated Leachate from landfills must be appropriately treated before being discharged into the environment. Technologies used for Leachate treatment can be classified as follows (1) biological methods, (2) chemical and physical methods and (3) emerging technologies. Here is a review of the main processes currently used for the landfill Leachate treatments.
Keyword- Landfill Leachate, Physicochemical Methods

I. INTRODUCTION

Wastewater is the liquid waste removed from residential area, institutions, commercial and industrial area together with groundwater, storm water and surface water may present. Wastewater has physical properties such as odour, colour and chemical constituents which can be organic or inorganic and biological constituents such as microbes and also dissolved gases such as oxygen, methane etc. Organic matter content is measured in terms of COD and BOD which can be used to categorize wastewater as low, medium and high strength wastewater. High strength wastewaters such as landfill leachate, tannery wastewater and diary wastewater etc., is considered as somewhat difficult to treat to achieve discharge limits.

An official study of the destination of collected wastes shows that land filling is the option chosen for 62% of municipal wastes and 57% of industrial wastes, in contrast to reuse by recycling, incineration or composting, which applies to a mere 35% of municipal wastes and 36% of industrial wastes. Keeping pace with both regulatory and technical trends, landfill centres and the more recent storage sites, must allow wastes to be managed rationally in terms of environmental impact and operating costs. In France, landfill sites are classified as Class I for ultimate and stabilised toxic industrial wastes or Class II for domestic and non-toxic industrial wastes. Wastes cause two types of pollution, which correspond to the migration into the natural environment of:

- leachates, defined as water that has percolated through the wastes (rainwater or groundwater seepage), a source of soil and groundwater contamination,
- biogas produced by the fermentation of organic matter, a source of air pollution. ith regard to leachates, controlling the pollutant loading means reducing its quantity y containing or treating the waste to comply with certain discharge characteristics hich are compatible with the receptor medium (river, sea, municipal treatment plant).

A. Leachate Characterization

The interaction of waste with water that percolates through the landfill produce highly polluted waste water termed as leachate. The constitution of landfill leachates may vary depending on the landfill's characteristics, such as:

- Type of waste received at the disposal site and its degree of decomposition.
- Variation in the weather during the waste disposal.
- The landfill environment: waste degradation phase, humidity, precipitation, temperature, etc.

Characteristics of Landfill leachate depends on type the waste, moisture content of the waste deposited, composition of the waste, site hydrogeology, seasonal weather variations, age of the landfill, dilution with rainfall and degree of decomposition within landfill depending on age. Landfill leachate varies widely in composition depending on the age of the landfill and the type of waste it contains. According to the age, the landfill can be classified as young (less than 5 years), medium age (5-10 years) and old (more than 10 years) [5]. The highly toxic leachate consists of high number of organic compounds like, Chemical Oxygen Demand (COD), Total Organic Carbon etc., and inorganic compounds like Calcium, Magnesium, Sodium, Iron etc., Heavy metals like, Chromium, Iron, Nickel, Zinc, Copper etc., Pathogens as well as Suspended particles.

Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD 5) concentration decreases, as time passed and leachate organic waste degradation goes through the successive aerobic, acetogenic, methanogenic, and stabilization stages. In fact, most of the biodegradable organic matter, which can be evaluated by BOD 5 value, is decomposed in the stabilization process and so BOD 5 /COD ratio decreases with time, because the non-biodegradable organic matter that contributes to the portion of COD will largely stay unchanged in this process. On the contrary, pH increases with age. In sum, young leachates are characterized by high COD concentrations (> 10000 mg L-1) and BOD 5 /COD ratios (0.5 – 1), whereas old leachates present COD concentrations below 4000 mg L-1 and BOD 5 /COD ratios below 0.1.

In addition to the type of waste involved (industrial, municipal), landfill leachate characteristics are depend on age of landfill, seasonal variation, the design and the mode of operation of the landfill, and also depend on its evolution through time. Due to successive biological, chemical and physical processes some oranic and inorganic contaminants of landfill leachate are released from the waste. Basically, three phases of decomposition are distinguished for domestic landfills ocurring within twenty years (2-4). In the first stage following waste deposit, initial arobic phase rapidly consumes the confined oxygen and water infiltration enhances acetogenic fermentation producing leachate characterised by high BOD, COD and ammoniacal nitrogen contents. Volatile fatty acids (VFA) are the main components of the organic matter released, besides the lower pH solubilises metals. Gradually, the methanogenic phase of decomposition starts and consumes the simple organic compounds resulting from acetogenic process to produce biogas. In that stage, the leachate composition represents the dynamic equilibrium between the two microbiological mechanisms with lower BOD and COD values while the ammonia concentration remains high. Dissolved inorganic materials are continuously released. With landfill ageing, waste stabilisation takes place. As the volatile fatty acids leachate content decreases parallel to the BOD/COD ratio, the leachate organic matter is made up of high molecular weight humic and fulvic- like material (HMW).

II. PHYSICOCHEMICAL TREATMENT OF LEACHATE

When leachate contains a large amount of nonbiodegradable organics and high concentration of bio-toxic materials biological treatments cannot give satisfactory reduction of nonbiodegradable organics. In such situations, physicochemical methods should be used along with biological treatment. It is known that none of physicochemical method alone can achieve universally effective or ideal for complete removal of all contaminants from stabilized leachate. Old leachate or biologically treated young leachate which characteristic with high COD, low BOD, relatively high NH4-N, and alkalinity high oxidation-reduction potential, can be treated using physicochemical methods such as coagulation- flocculation, chemical precipitation, activated carbon, evaporation, and ammonia stripping.

A. Coagulation-Flocculation

It is the process of removing non-biodegradable compounds and heavy metal from leachate by adding coagulant. Some of aliminium and Iron based common coagulants are $Al_2(SO_4)_3$, $FeSO_4$, $FeCl_3$, $FeClSO_4$ and $Fe_2(SO_4)_3$. Also Magnesium carbonate and hydrated lime are the other chemicals that used as coagulants. In coagulation, particles are aggregated with themselves. For an example, by changing pH and polymers used to aggregate particles and bind them together making flocs settle more easily this is called flocculation. Combination of these two processes removes colloidal and suspended particles in the solution. According to the study done by, the efficiency of precipitation is very much dependent on pH. Ion salts are more efficient than aluminium slats, resulting comparatively high COD removal, 56% and 39% respectively.

They accomplished with better results of ferric chloride than aluminium sulphate, which COD removal of 55% on 42% and turbidity removal 95% on 87% respectively. It has proven a better method of pre-treatment of leachate prior to reverse osmosis which has the major drawback of membrane fouling. Furthermore, coagulation flocculation has desirable to treat stabilized leachate or biologically pre-treated leachates than fresh leachate. Maximum 80% COD removal obtained from stabilized (old) leachate with optimal ferric concentration 2 g/L at pH 10. In general coagulation-flocculation is effective pre-treatment method in terms of COD and heavy metals removal. High chemical consumption increases the operational cost, high pH dependence makes difficulties in maintenance and excess sludge production are the disadvantages associated.

B. Air Stripping

Air stripping is a successful method that used to reduce the NH_3 content in leachate. When pH is reaching 11, all NH_3 forms will turn into gas which dissolved in wastewater. Maintaining pH around 11 in the stripper by adding NaOH, dissolved NH_3 can be released from wastewater. Ammonia loss was mainly due to desorption through the water surface. This suggests that temperature has an effect on the removal of ammonia. Leachate quality and configuration of the treatment reactor are important factors affecting the efficiency of ammonia removal by stripping processes. Higher ammonia removal can obtain by increasing air flow rate (which is air to waste flow rate) and using finer bubble diffusers.

The main drawback of air stripping is environmental pollution due to NH_3 releasing into the atmosphere. Hence further treatment to exhaust gas is needed. Further, though air stripping is effective in NH_3 removal, low efficiency of organic matter removal is a major setback in this process. In spite of 90% ammonia removal at 20^0C, air stripping individually cannot achieve effluent discharge limits. Thus subsequent nitrification/denitrification process with air stripping can probably can meet effluent discharge standards. Also some laboratory studies have shown that air stripping increased the toxicity despite of removing COD and ammonia. Yet, air stripping was found as most cost effective cheapest alternative method high removal of ammonia compared to other methods such as membrane filtration.

C. Activated Carbon Adsorption

Adsorption is a common method, in water and wastewater treatment where contaminants transport from aqueous media to a solid surface. When liquid in contact with a highly porous surface, contaminants bound to surface by liquid-surface intermolecular forces and deposited in the solid surface. Due to the high area to volume ratio, characteristic physical properties such as microporous structure and surface reactivity, activated carbon is most commonly used adsorption material recently.

It is proven that the chemical nature of the surface such as the amount of oxygen-containing functional groups is also accounted in determining the adsorption capacity of AC. Granular activated carbon (GAC) and powdered activated carbon (PAC) are two types of activated carbon, considerably used in leachate treatment. Free chlorine, color, non-biodegradable compounds, and organic compounds such as dichlorophenol can effectively remove using activated carbon adsorption. Work done by was evident that low molecular weight organics are highly preferable to adsorb on activated carbon than high molecular weight organics.

III. BIOLOGICAL TREATMENT

Biological treatment of leachate is the most widely used treatment method in the world. Compared to physicochemical methods, biological methods are environmentally friendly. Biological treatment can be aerobic, anaerobic or natural systems. With proper analysis and environmental control, almost all contaminants can remove biologically. Suspended growth and attached growth systems are the two basic biological processes. In suspended growth, microorganisms involved in the treatment of wastewater are kept in liquid suspension with mixing. Activated sludge process (ASP) is the most widely applied suspended growth method. Microorganisms involved in degradation of organic matter in wastewater are attached to an inner packing material. The trickling filter is an example of attached growth. ASP, sequencing batch reactors (SBR), oxidation lagoons, extended aerated systems, rotating biological contactors; biological aerated filters are several aerobic treatment methods.

A. Activated Sludge Process

ASP is a biological treatment process that involves the conversion of organic matter and other constituents of wastewater to gases and cell tissue of microbes by a large mass of microbes maintained in suspension by mixing and aeration. ASP is suspended growth process, containing three basic components. A reactor in which microorganisms responsible for treatment kept in suspension & aerated, liquid-solid separation unit which may be a sedimentation tank and a recycle system for returning solids removed by separation unit back to the reactor. ASP has been proven that it is a promising method of leachate treatment. Leachates from old landfills always associated with high ammonia concentration which may cause difficulties in biological treatment. This problem can overcome by very high ratio up to 300%-400% of effluent recirculation. But it also results in a very high treatment cost.

Sludge bulking and foaming are the main problems associated with ASP. Nutrient deficiency also affects the biological activity in the reactor and Phosphorous addition might be necessary. Sludge should be disposed of as special refuse because it can contain many hazardous materials. ASP involve relatively high cost and high energy consumption.

B. Sequencing Batch Reactors

There are number of studies done on a landfill leachate treatment using SBR. It is a process that all biological treatment phases, primary sedimentation, biodegradation, secondary sedimentation as well as nitrogen and phosphorous removal done in a single reactor. It is a system based on fill and draw mechanism. Unlike a conventional ASP, which has separate units for each stage of treatment, SBR uses only one reactor for the entire treatment. SBR has five phases in one treatment cycle. They are, fill phase, recent phase, settle phase, draw phase and idle phase. The most favourable conditions to remove organics and ammonia were a long sludge age (>20 days), longer HRT (>3 days), mixing and aeration in a cycle. Some other comparative results obtained by used SBR to investigate the effectiveness of enzyme application in leachate treatment.

The reason for low efficiency at initially may be insufficient aeration time to allow complete nitrification to take place and also the high organic loading rate can lower the nitrification due to insufficient time to the growth of nitrifying bacteria. But later 75% of average ammonia removal could be achieved. Enzyme treatment was used as chemical treatment and it has proven to be effective in COD and nitrogen removal.

Combined chemical and biological treatment is proven to be efficient in treatment of leachate. A study done by used SBR followed by electro-Fenton method assisted by chemical coagulation for landfill leachate treatment. Initial COD was 1940 mg L^{-1} and over 90% of removal efficiency was achieved using this combined treatment with SBR. Powdered activated carbon pre-treated leachate of Harmandali landfill, Turkey, was treated using five-step SBR (Anaerobic, Anoxic, Oxic, Anoxic, Oxic) resulted in 75% of COD, 44% of NH_4-N and 44% of PO-3-P removals after 21 hr operation. Initial concentrations of COD, NH_4- N and PO-3-P were 5750 mg L-1, 183 mg L^{-1}, and 65 mg L^{-1} respectively. This study has proven that PAC pre-treatment helps to improve effluent quality of the treatment process. Mixing domestic wastewater with leachate increases the biological activities of wastewater and enhance biological treatment. Anaerobic treatment anaerobic treatment is known as a more suitable method for high concentrated wastewaters such as leachate. Less energy requirement, less biological sludge production, less nutrient requirement, lower operation costs, and methane production are the main advantages of anaerobic treatment. Anaerobic pretreatment can increase the biodegradability of wastewater hence; it is very effective in treatment of the old leachate. Longer start- up time, the requirement of alkalinity addition, incapable of biological nutrient removal, highly sensitive to low temperatures on reaction rates and the need for further aerobic treatment are the disadvantages of anaerobic treatment.

IV. EMERGING TECHNOLOGIES

Emerging technologies includes Reverse Osmosis, Advance oxidation, Evaporation, Ion-Exchange etc.

A. Chemical Oxidation and Advance Oxidation Process (AOP)

Chemical oxidation is required for the treatment of wastewater containing soluble organic non-biodegradable and/or toxic substance. As reviewed, commonly used oxidants such as chlorine, ozone, potassium permanganate and calcium hydrochloride for landfill leach ate treatment resulted in COD removal of around 20-50%. The most processes based on direct reaction of oxidant (O_3 selective) with contaminates or via generated hydroxyl radicals (OH).

The Advance Oxidation Process enhances the chemical oxidation potentials as it increases the generation of the hydroxyl radicals. In the Fenton process the organic content, odour, colour and biodegradability of recalcitrant organic compounds was greatly improved. COD removal efficiencies range from 45% to 85%.

B. Membrane Technology

Membrane technology in leachate treatment is the application of membrane materials for the physicochemical treatment process. The principle of the membrane process is the separation of two solutions with different concentrations by asemi permeable membrane. Pressure is induced to the more concentrated solution (leachate) to force water to the one of lower concentration while most of the leachate compounds are well retained. However, the degree of retention of the leachate compounds varies depending on the membrane. The microfiltration (MF), ultrafiltration (UF), Nano filtration (NF) and the reverse osmosis (RO) are some examples of membrane technology.

C. Electrochemical Oxidation

Among the electrochemical technologies, the most studied in landfill leachate treatment are electrocoagulation, electro-Fenton and electrochemical oxidation. The electrochemical technologies are based on electron transfer. An electrochemical cell is required, where electrodes are in contact with the polluted solution and connected by an external circuit. The main advantage of these technologies is their environmental compatibility, since its main reagent, the electron, is a clean reagent. Other advantages are related to its versatility and amenability of automation.

Electrochemical Oxidation has attracted a great attention within last two decades and it is most promising process for Organic pollutants removal. In recent years, electrochemical treatment having features like relatively more economic and higher treatment efficiency has been a promising method. EC is one of the simple and efficient electrochemical methods for the purification of many types of water and wastewaters. The application of Electrochemical techniques to the treatment of colored effluent of industries and effective in removal of organic contaminants and for reducing the BOD and COD of the effluent these methods have been studied in situations where traditional methods have been unable to achieve the satisfactory concentration limits or where they offer economic advantages. Electrochemical technology offers ideal tools for addressing environmental problems.

The main reagent used here is electron and therefore no need for adding extra reagent. In addition, the high selectivity of the electrochemical process prevents the production of unwanted by-products. It is operated in room temperature and pressure and power is supplied by a D.C supply, When wastewaters are treated by action of direct current a number of physical chemical processes take place. Anodic oxidation and cathodic reduction of impurities present in wastewater, electrophoresis which is the passage of ions through semi permeable membranes, precipitation of metallic ions on cathode and desalination of water. There are three main directions in the development of electrochemical treatment process applied to wastewaters containing various impurities.

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