The Generation, Composition and Fate of Landfill Leachate: A Review

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ABSTRACT

The quantity of waste generated each year is in increase. Landfilling is one of the predominant methods for municipal waste disposal. Unfortunately, leachate is formed during the landfill operations. Therefore, proper management of leachate is essential to avoid unwanted impacts on the environment. In order to do that, the composition in relation to stage of generation should be studied. In this review, the generation and composition of leachate are highlighted.

Keywords: landfill, leachate, waste.

I. INTRODUCTION

Municipal solid wastes are waste which can come from houses, schools, offices, etc. Different methods are used for the disposal of this kind of waste in order to reduce and minimize its hazardous effect on the environment. Waste disposal methods include landfilling, incineration, recycling and composting, but prior to disposal of any kind of waste, reduction and re-use should be implemented for best management results and resource recovery [1].

II. WASTE DISPOSAL METHODS

A. Landfills

There are three different kinds of landfills:

- Open dump or open landfill: It is the most common disposal method in the developing countries where the waste is simply dumped in low areas on open land and the waste is tipped randomly.
- Sanitary landfills: These are used in the developed countries with facilities for the management of leachate and control of gases.
- Semi-controlled or operated landfills: The dumped waste is compacted and daily covered by soil at a designated site. Different types of waste are dumped without segregation. It is un-engineered and thus there is no proper management of leachate and landfill gases [1].

B. Incineration

Is used to handle waste high in organic content or chemicals. It destroys gases, solids, liquids and sludges at high temperature ranging from 1000 to 14000 °C resulting into solid ash and gases. Incineration requires high capital, operation and maintenance costs [1].

C. Recycling

Is the recovery of some materials like plastic metals, glass and paper which were collected from the waste in urban areas by scrap and waste dealers [1].

D. Composting

Is the collection of organic solid waste and storing under conditions that favor their breakdown naturally? The resulting compost is later used as a natural fertilizer [2].

III. LANDFILL SITING AND SUITABILITY

Assessment of the suitability of existing and potential landfill sites requires assessment of site conditions and potential impacts on the environment. Landfills should be appropriately separated from sensitive land uses and environmentally sensitive areas by means of buffer zones [3]. For example, surface water contamination is less likely at sites away from lakes and rivers. Furthermore, proximity of a landfill to a groundwater well is an important environmental criterion in the landfill site selection in order to protect wells from the runoff and leaching of the landfill [4]. Some important criteria that should be considered during landfill siting are hydrology, topography and road access [3], [5], [6]. Moreover, faults, surface water, groundwater, and permeability of soil should be highly considered as criteria for landfill site selection [7], [8]. Therefore, based on the availability of data, many criteria should be considered for proper landfill siting to minimize the negative impacts of landfill on the environment [9].

IV. THE FORMATION OF LEACHATE

Different physical, chemical, and biological mediated processes occur within a landfill. As a consequence, waste is degraded and transformed. As water percolates through the landfill, contaminants are leached from the solid waste giving
rise to landfill leachate [10]. Leachate is a contaminated liquid that results from the percolation of water through a landfill. The sources of leachate are rainfall, groundwater intrusion, moisture and other liquids contained in the wastes deposited in the landfill and by-products of decomposition [11], [12]. But much of it may come from runoff or surface water that percolates downward through the waste material [11].

The rate of generation of leachate in a landfill depends on a number of variables, including waste characteristics, moisture content, temperature, pH and the availability of nutrients and microbes [13]. When the amount of rainfall is more than the evaporation rate, the leachate quantity in the landfill increases [14]. The quality of leachate is variable; it may contain high quantities of organic and inorganic compounds [15].

V. STAGES OF WASTE DECOMPOSITION IN LANDFILLS

The organic wastes in a landfill decompose by aerobic and anaerobic processes. The decomposition of landfilled wastes is characterized by five decomposition stages: Initial adjustment, transition, acid formation, methane fermentation and final maturation.

A. Phase I: Initial Adjustment

It is an adjustment phase which starts with placement of waste and lasts when enough moisture has accumulated to develop microbial community [16]. Here, the organic waste decomposes aerobically with the production of carbon dioxide (CO₂), water, nitrates, and other organics [17], [18]. This kind of aerobic degradation is very limited since very low concentration of oxygen is trapped within the waste [19] [18].

B. Phase II: Transition

This phase starts when field capacity is exceeded causing a considerable formation of leachate [13]. With the depletion of Oxygen, anaerobic microorganisms dominate producing volatile organic fatty acids and CO₂ lowering the pH and thus increasing the solubility of inorganic salts leading to higher conductivity [16], [17].

C. Phase III: Acid Formation

With the continuous hydrolysis and fermentation of waste and leachate, intermediary volatile organic fatty acids become predominant [16]. Ammonia, hydrogen and CO₂ persist at high concentrations throughout this phase [19]. At this stage, the pH decreases. Low pH suppresses methane production by toxifying the methane producing organisms [17] and causing the mobilization of metals [16]. This phase is characterized by high biochemical oxygen demand (BOD), chemical oxygen demand (COD) and conductivity [18]. Nutrients like nitrogen and phosphorus are released and utilized by biomass [16].

D. Phase IV: Methane Fermentation

After a period of time, methane producing microorganisms predominate degrading the organic acids and giving rise to methane and CO₂ [18]. This raises the pH allowing precipitation of metal to proceed [17]. Leachate organic strength decreases due to the increases in gas production [16]. COD and BOD concentrations decrease while sulfate and nitrate are reduced to sulfides and ammonia [18].
E. Phase V: Final Maturation

It is a stage of relative dormancy where nutrients may become limiting, gas production decreases and natural environmental conditions restore to their former conditions. Oxygen and oxidized species may slowly reappear, and microbial resistant organic compounds may be slowly converted and possibly produce humic-like compounds which might re-mobilize heavy metals [16].

VI. FACTORS AFFECTING LEACHATE COMPOSITION

The composition of the leachate is highly variable because of the various physical, chemical, and biological processes that occur within the landfill compartments. It is dependent on many factors such as type of waste deposited in the landfill, degree of decomposition (degradation phase), precipitation rates, temperature, humidity, surface runoff, hydrology, age of landfill and landfill design and operation [20], [17]. For example, high rainfall and highly porous soils give rise to large quantities of leachates, but the concentrations of pollutants leached will be lower than in low rainfall areas. Finely textured soil will reduce the rates of leachate movement, whereas, coarse soil or fractured bedrock will increase the rate of leachate movement [16].

The chemical composition of leachate has been related to the phase or stage of decomposition of refuse [12]. Moreover, waste composition determines the extent of biological activity within the landfill. Rubbish, food, garden wastes and animal wastes contribute to the organic portion in leachate, while construction and demolition waste contribute to the inorganic components of leachate [16].

It has been proven that there is an influence of municipal landfill age on municipal leachate quality [21]. Generally, leachate from new landfills is high in BOD and COD. It then steadily declines to reach the minimum after about 10 years [22]. It was found that leachate concentrations in general decrease with the age of the landfill [23]. Most leachate components are present in high concentrations at an early age, about 12 months and decrease with landfill age [23], [24]. While McBean and his colleagues (1995) stated that leachate quality reaches a peak after about two to three years followed by a gradual decrease. The pH tends to increase gradually with time from slightly acidic towards alkaline values in leachate which is older, and therefore more stabilized. On the other hand, toxic metal concentrations decrease in aged landfills [25]. Moreover, the aeration process has a considerable effect on reducing the concentration of several pollutants [26].

As mentioned earlier, the composition of leachate is variable because of the heterogeneity of waste and other factors relating to the landfill [10]. Municipal solid waste (MSW) contains hazardous components like paints, batteries, pharmaceuticals, vehicle maintenance products, mercury-containing waste, and many other products [27]. Household hazardous wastes are disposed of to landfill along with general household waste. The quantities are not well known but generally, it is assumed that they are small and thus risks of disposal are negligible [27]. In contrast, some studies have found that leachates from municipal landfills have similar composition to mixed or hazardous landfills [24]. Thus, the kind of waste differs from site to site. Table II shows the difference in leachate composition from similar age landfills in different countries.

### Table II: Concentration of Leachate Parameters in Different Countries

| Leachate constituent            | Kuwait [28] | Palestine, Gaza [29] | India [30] |
|---------------------------------|-------------|----------------------|------------|
| pH                             | 7.82-8.06   | 8.40                 | 6.90       |
| Total Dissolved Solids (TDS)    | 1100-9910   | NA*                  | 25514      |
| Electrical Conductivity (EC)    | 6210-2190   | 52000                | NA         |
| Total Suspended Solids (TSS)    | 188.0-2550  | NA                   | NA         |
| Volatile Suspended Solids (VSS) | 62.00-1596  | NA                   | NA         |
| Chemical Oxygen Demand (COD)    | 6400-8800   | 45500                | 25102      |
| Sulfate                        | 55.00-345.0 | 1337                 | NA         |
| Zinc (Zn)                      | 0.200-4.800 | 5.600                | 2.100      |
| Nickel (Ni)                    | 0.400-6.000 | NA                   | 0.380      |
| Iron (Fe)                      | 1.400-54.60 | NA                   | 63.41      |
| Magnesium(Mg)                  | 86.00-268.0 | NA                   | NA         |
| Calcium (Ca)                   | 52.00-122.0 | NA                   | NA         |
| Copper (Cu)                    | 0.00-0.200  | 6.000                | NA         |
| Aluminium (Al)                 | 1.200-12.40 | NA                   | 0.800      |
| Ammoniacal Nitrogen (NH3-N)     | NA          | 2045                 | NA         |
| Nitrate                        | NA          | 325.0                | 361        |
| Chloride (Cl)                  | NA          | 12200                | NA         |
| Total Organic Carbon (TOC)     | NA          | 1352                 | NA         |
| Lead (Pb)                      | NA          | BDL*                 | 1.100      |
| Cadmium (Cd)                   | NA          | BDL                  | 0.050      |
| Phenol                         | NA          | BDL                  | 0.020      |
| Chromium (Cr)                  | NA          | BDL                  | 0.230      |

All values are in mg/l except pH and EC (µS/cm). NA*, Not Available. BDL*, Below Detection Levels.

VII. THE FATE OF LEACHATE IN THE ENVIRONMENT

Landfills may generate several environmental problems like air emissions, dust, odor, explosion hazards and others, but groundwater contamination by leachate is considered to be the most important problem [31]. It can pollute the surrounding soil and eventually the groundwater in the area [12]. Not only that, leachate from a landfill can continue to be groundwater pollution problem even after the closure of the landfill [12].

Leachate moves through the landfill to the bottom, sides, and through the soil by the force of gravity until it reaches the groundwater zone. As it moves down, it mixes with the groundwater captured in the soil spaces between soil particles in the unsaturated zone. This mixture moves along the groundwater path as a plume of contaminated groundwater. The leachate pollutants first enter the unsaturated zone and eventually are transported to the groundwater table (saturated zone) [32].

The chemicals in leachate that leave the landfill may go through a variety of reactions as they pass through the soil and into the formations underneath through a process called attenuation [33]. The slow movement of leachates in the unsaturated zone causes attenuation of certain leachate chemicals. Positively charged cations like lead, zinc, cadmium and mercury are readily attenuated. As leachate
contaminating these metals percolates through the soil, the metals leave the leachate and adsorb to the soil. Other leachate pollutants, such as VOCs and acids, are not readily attenuated, and they move through the soil [33]. Obviously, the attenuation capability is governed by the composition and texture of the soil. Different soils have different capabilities to attenuate and exchange chemicals. Once all the binding sites of the soil particles become occupied, they can’t hold any more chemicals and hence, pollutants will move through the soil towards the groundwater. As the binding sites become full, they become more selective. Only those which form tight bonds with soil, will become attenuated, while chemicals which bind loosely to soil will be replaced and leave the soil and re-enter the leachate, posing a continued threat to groundwater [32].

The plume normally has concentrations of various chemical constituents which are much higher than the pristine groundwater values [12]. In this context, groundwater contamination is the most significant problem associated with leachate production. Incidents of groundwater pollution by leachate have been considerably reported since early 1970s [13]. The contamination of groundwater by leachate has been recorded in a number of research studies e.g., [34] [24]. Although leachate contamination of groundwater is less likely to occur in engineered landfills due to liners and leachate collection systems, the risk still exists. Knowledge of leachate composition is needed for site remediation [27].

Leachate has negative effects on groundwater quality and the environment surrounding it. In a study evaluating the environmental quality in and around Mathkal dumping ground in Kolkata, India, high concentrations of heavy metals in groundwater were recorded indicating that the groundwater quality has been significantly affected by leachate percolation [35]. It has been also revealed that landfills were sources of groundwater contamination in Illinois in USA [36]. Analysis of samples taken from downstream groundwater wells in vicinity to Gaza landfill showed that most of boreholes were contaminated [29]. Another study investigating leachate effect from a landfill located in vicinity to coastal water in Taiwan has revealed that leachate could result in pollution of coastal water and subsequently expose aquatic life to toxicity [37]. Moreover, serious groundwater contamination was reported in and around Ampar Tenang un-engineered landfill site in Malaysia [38] and Ibb landfill in the Republic of Yemen [39]. Further studies have verified that landfills are sources of soil and groundwater contamination in Bousher and Barka (Oman) in which elevated metallic contamination and high counts of faecal coliforms have been observed [40]. Moreover, incidents of heavy metals contamination in soil around waste disposal sites were reported in India and Antarctica [41], [42].

The vicinity of landfills to residential areas poses a serious health risk through the contamination of groundwater, air pollution, litter, animals, scavenging birds and vermin [43]. Contaminated groundwater contains a variety of toxic and carcinogenic chemicals, which may cause harm to both human health and environment. Furthermore, leachate-contaminated groundwater has an adverse impact on industrial and agricultural activities that depend on groundwater. The use of contaminated water for irrigation can decrease soil productivity and contaminate crops. The contaminants tend to bioaccumulate in organisms that consume crops irrigated with contaminated water leading to health problems [32].

VIII. Conclusion

The generation of leachate is one of the environmental issues that needs to be managed well. Therefore, the generation stages and complex composition of leachate need to be known for proper management and minimization of any unwanted effects on health and environment.

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