Influence Factors in Clogging of Landfill Leachate Collection System

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**Abstract:** A common failure mode for landfills is clogging of the leachate collection system. Based on the studies of clogging about landfill leachate collection system, the influence factors about clog were comprehensively and systematically analyzed. The results show that calcium is the dominant mineral of the dry mass of clog material, and CaCO\(_3\) is the main component of the clog. The growth of biomass, minerals precipitation and deposition of suspend inorganic particles are the three major mechanisms for the clogging of LCSs. However, the clogging rate and extend of LCSs is affected by particle size of the granular media, pipe spacing and pipe diameter, filter-separator layer, mass loading, saturated or unsaturated conditions and temperature. These conclusions have profound guiding significance for the design and operation of landfill leachate collection system.

**Introduction**

Leachate collection system (LCS) is a critical component of barrier systems in today’s landfills, which is shown schematically in Fig.1. Modern LCS typically involves a continuous blanket of granular material covering the landfill base liner and a regular pattern of leachate collection pipes. These systems can control the leachate head acting on the underlying liner and remove leachate for either recirculation or treatment and disposal. However, field evidence has shown that the LCS can clog in the granular media, in geotextiles, and in the leachate collection pipe perforations or the pipes themselves [1-10]. The accumulation of clog material decreases the pore space available to transmit leachate and reduces the hydraulic conductivity, consequently reduces the efficiency of the leachate collection system, ultimately cause the leachate level to build up within a landfill. This can increase the potential for groundwater contamination, reduce the stability of landfill side slopes and impact on the effectiveness of landfill gas collection systems. So it is necessary to understand the influence factors of LCS clogging, which can guide the design of LCSs to minimize the clogging process and prolong the service life of these systems.

Because of the potential adverse impact on the surrounding environment and human health, a number of studies on clogging of LCSs have been conducted, but more is to consider the single factor. However, the clogging of LCS is affected by a lot of parameters, including design details, waste characteristics and mode of operation, so it is necessary to give a systematic analysis of the influence factors of LCS clogging.

The objective of this study is therefore to comprehensively and systematically analyze the influence factors based on previous researches, which can guide the design of LCSs to minimize the clogging process and prolong the service life of these systems.
A number of studies have been performed to investigate clog material composition of landfill LCSs (Table 1). Although the waste characteristics was differ, but the mineral composition of the clog solids obtained in field studies, laboratory column tests and numerical studies were consistent, it can be concluded that calcium was the dominant mineral of the dry mass of clog material, and CaCO3 was the main component of the clog.

### Table 1 Summary of clog composition from studies

<table>
<thead>
<tr>
<th>Case</th>
<th>Method</th>
<th>Clog composition</th>
<th>Source and comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Field studies (German landfills)</td>
<td>The clog material (dry mass) averaged about 21% calcium, 34% carbonate, 16% silica, 8% iron, and 1% magnesium.</td>
<td>Brune (1991)[2]</td>
</tr>
<tr>
<td>2</td>
<td>Field studies (Keele Valley Landfill (KVL) in Maple, Ontario)</td>
<td>The clog material (dry mass) averaged about 20% calcium, 30% carbonate, 21% silica, 2% iron, and 5% magnesium.</td>
<td>Fleming (1999)[7]</td>
</tr>
<tr>
<td>3</td>
<td>Field studies (Florida Landfill in USA)</td>
<td>The dominant clog mineral was low-magnesium calcite.</td>
<td>Maliva (2000)[8] The landfill receives incinerator ash and municipal solid waste.</td>
</tr>
<tr>
<td>4</td>
<td>Field studies</td>
<td>The dominant clog mineral was calcite, together with gypsum and iron mineral.</td>
<td>Manning (2000)[12]</td>
</tr>
<tr>
<td>5</td>
<td>Field studies (Keele Valley Landfill (KVL), in Maple, Canada)</td>
<td>The clog material comprised over 50% calcite (CaCO3), 16–21% silica where there is no filter, and iron and manganese representing up to 8% and 5% respectively. The clog material contained on average 40 and 45% of volatile and inorganic solids, respectively, and Hydromagnesite (Mg5(CO3)4(OH)24H2O) was the mineral component of the inorganic solids.</td>
<td>Rowe (2005)[13]</td>
</tr>
<tr>
<td>6</td>
<td>Laboratory study (column experiment)</td>
<td>Leachate was obtained from Brady Road landfill in Winnipeg, Man.</td>
<td>Lozecznik (2009)[14]</td>
</tr>
</tbody>
</table>
Clog mechanisms

Clogging is a build-up of biofilm, chemical precipitates and small (e.g. silt and sand) particles that are deposited in pipes, granular material (e.g. sand or gravel), and geotextiles that are used in leachate collection systems [13]. Clogging mechanisms involve growth of active and inert biomass, minerals precipitation and inorganic particles originally suspended in the leachate. The contribution of one of the clogging processes influences the other two, and therefore, the rate of clogging [20].

**Growth of active and inert biomass.** Biological clogging of leachate collection systems is a common phenomenon. The anaerobic bacteria in the leachate easily remove volatile fatty acids (VFAs) from the leachate, colonize the surfaces of leachate collection systems materials and form a thick biofilm [2, 16-17, 20, 22-26]. The growth of these bacteria results in a decrease in pore volume of the leachate collection system [22]. The bacteria included methanogens, denitrifying bacteria, and sulfate-reducing bacteria [16-17].

**Accumulation of minerals precipitation (predominantly as CaCO3).** The primary cause of clogging is calcium carbonate (CaCO3(s)) precipitation from leachate and its accumulation within the pore space of the leachate collection systems. When the VFAs in landfill leachate (primarily acetic acid) are degraded by microbes, some of the resultant carbon dioxide dissolves to become carbonic acid. This results in an increase in pH and total carbonates, causing or accelerating the precipitation of CaCO3 [15, 27-28]. Additionally, other noncalcium cations (e.g., iron and magnesium) precipitated with carbonate (CO3^2-) when present in the leachate [15, 29]. The amount of carbonate is related to the conversion of propionate to acetate, butyrate to acetate, and acetate to methane, and can be represented in terms of microbiologically catalysed reactions [19, 30].

**Deposition of inorganic particles originally suspended in the leachate.** Suspected inorganic particles are a significant component of clog matter in leachate collection system, with silica representing 16%–21% of the clog material, but have been less significant (2%–4%) in the clog matter formed in laboratory column experiments with real leachate (because soil particles may settle out before testing) and negligible in synthetic leachate-produced clog matter (0%) [7, 25, 31-32].
readily attaches to the porous media and provides nucleation sites for further growth [16].

**Influence factors**

**Effect of particle size.** For a given leachate and flow rate, the particle size of the granular media is a critical factor affecting the rate of clogging. Other conditions being equal, the larger the particle size of the granular material the more slowly it clogged, and hence prolonged the service life of leachate collection system. Brune [2] reported the results from the column tests on granular material with different grain size distributions (2-4 mm, 2-8 mm, 1-32 mm, 8-16 mm, 16-32 mm). They showed that the rate of clogging was least for 16-32 mm and increased as the particle size became smaller or the material became much more graded. Rowe [16] reported similar findings for columns filled with uniformly graded glass beads of different sizes (4 mm, 6 mm, and 15 mm). Clogging of the finer (4 mm) beads was faster and focused near the influent end of the column. As the particle size increased, the rate of clogging was slower and more uniformly distributed throughout the column. McIsaac [33] reported the results from mesocosm tests to investigate the effect of different gravel sizes (38 and 19 mm). They showed that the 38 mm gravel performed much better than the 19 mm gravel. Fleming [18] reported that less clogging was associated with a larger particle size of “clear” (washed or screened) crushed dolomitic limestone by mesocosm tests analysis. The numerical model analysis also showed that for the same drainage material, the rate of clogging in leachate collection systems is increased with an increase in the grain size of the drainage material [34-35].

**Effect of leachate collection pipe.** Rowe [36] reported that the rate of clogging of the drain will also be reduced with smaller pipe spacing since the mass loading of organics and inorganics entering a single collection pipe decreases. Rowe [34] also found that the larger the pipe spacing the higher the clogging rate and hence both the sooner the leachate mound began to increase and the higher the mound by numerical model analysis. Lozecznik [14] reported that smaller diameter pipes accumulated more clog mass than larger pipes for all other conditions being equal by laboratory pipe experiments.

**Effect of filter-separator layer.** The use of a filter–separator between the gravel and waste material can help reduce the amount and rate of clogging in the underlying gravel drainage material [37]. Ming Xiao [38] reported that comparison between soil and geotextile filters shows the geotextile provides a better filtration function without excessive clogging for the same types and sizes of particle concentrations by modeling work and experimental investigations. Fleming [18] reported that the presence of an appropriate filter–separator between the top surface of the drainage layer and the overlying waste improves the performance of the drainage layer against clogging, and a graded granular filter or nonwoven geotextile filter–separator performed better than a woven geotextile with physical properties and strength similar to those of the nonwoven geotextile by mesocosm tests analysis. It is also consistent with the findings of Rowe [39] who found that the filter–separator layer played a crucial role in improving the service life of the underlying drainage layer, and a sand filter layer was more effective at extending the service life of the drainage layer than a nonwoven geotextile.

**Effect of mass loading.** Mass loading has a significant impact on the rate and extent of clogging in a leachate collection system. Brune [2] founded that there was little clogging when the “lightly-loaded” permeating leachate had low concentrations of organic acids and cations (such as calcium) but the significant clogging occurred when the concentration of organic acids and cations was high (“highly-loaded” leachate). Cardoso [40] also found that the MSW monofill generated leachates with high levels of biological activity, lower concentrations of calcium, and a rich carbonate system. Co-disposal of MSW, combustion and treatment process residues generated leachates that were not limited in either calcium or carbonate, creating ideal conditions for formation of precipitates by lysimeter comparison of the role of waste characteristics. Hajra [41] reported an increase in the maximum specific growth rate, led to a faster reduction in permeability. For the media with higher initial masses of microorganisms, the reduction in permeability of the soil system is more rapid, but the ultimate reduction is still limited by the substrate concentrations. Rowe [16] founded that clogging is greatest where there is the greatest mass loading (near the inlet in this case, but likely near the
collection pipes in a field situation), and the columns with high flow experience greater rates of clogging than those with low flow by laboratory column tests. Rowe [42] summarized that the flow rate and the composition of the leachate (organic acids, inorganic cations, suspend solids concentrations et. al.) entering the leachate collection system have a critical effect on the rate of clogging.

**Effect of saturated or unsaturated conditions.** Fleming [7] reported that the amount of clog observed in the upper unsaturated portion of the drainage layer was considerably less than that in the lower saturated zone by observations from a field exhumation of a granular LCS at a large municipal landfill site. McIsaac [43] also found that the clogging in the fully saturated gravel was substantially more than in the partially saturated gravel by mesocosms tests.

**Effect of temperature.** Laboratory column tests of using Keele Valley leachate and synthetic leachate by Rowe [44-45] demonstrated that the columns which was noted over 1 year at temperatures of 22 and 27°C had a high flow rate and significant clogging. Armstrong [46] found that the higher the temperature the greater the rate of clogging (other things being equal) over the range of temperatures examined. The practical implication of this study is that anything that reduces the temperature in the LCS (and hence on the liner) below that optimal for biological growth (often 30-40°C and 50-60°C) will extend the service of the LCS as the clogging rate of porous medium is decreased. It will also enhance the service life of the liner systems [19].

**Conclusions**

Based on the results and discussions from field, laboratory and numerical studies, calcium is the dominant mineral of the dry mass of clog material, and CaCO$_3$ is the main component of the clog. The growth of active and invert biomass, minerals precipitation and inorganic particles originally suspended in the leachate are the three major mechanisms for the clogging of LCSs. The clogging rate and extend of LCSs is affected by particle size of the granular media, pipe spacing and pipe diameter, filter-separator layer, mass loading, saturated or unsaturated conditions and temperature. The clog rate of LCSs can be reduced by:
1. increasing the particle size of granular media.
2. decreasing the pipe spacing and increasing the pipe diameter.
3. using a filter-separator layer between the waste material and coarse gravel.
4. reducing the mass loading (decreasing leachate strength, reducing flow rate, or both).
5. ensuring water-unsaturated conditions in the leachate collection system.
6. reducing the temperature in the LCS below that optimal for biological growth (often 30-40°C and 50-60°C).

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**References**


