MULTIDISCIPLINARY STUDY OF CLOGGING OF LEACHATE DRAINS

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ABSTRACT: The study had four key components: (1) A laboratory study of the effects of the mass loading, temperature, size and shape of particles in the granular media, and filter media between the waste and the granular material on clogging; (2) A field investigation of portions of the leachate collection system at the Keele Valley Landfill that was carried out alongside an examination of the suitability of dolomitic limestone for use in leachate collection systems; (3) The development of a model for interpreting the results of the laboratory tests; and (4) The integration of concepts and data from these investigations to develop a practical engineering technique for estimating the service life of leachate collection systems. The findings are summarised.

1. INTRODUCTION

In the 1970s it was recognised that in order to provide ground and surface water protection it was necessary for municipal solid waste landfills to have some form of "barrier system" involving a leachate collection system and liner. The liner provides resistance to the outward flow of leachate. However, for the liner to be effective, it is also essential to control the driving force causing potential migration of contaminants through the liner. Thus the primary function of the leachate collection system is to control the leachate head (i.e. the height of leachate) above the liner. Early leachate collection systems (involving toe or perimeter drains only) were useful for controlling leachate seeps out through the landfill sideslopes or cover, but were ineffective in controlling the leachate mound within the landfill, and hence ineffective at controlling contaminant escape to underlying aquifers. The next generation of leachate collection systems involved drains (typically granular material placed around perforated leachate collection pipes) at spacings of between 50 and 200 meters (e.g. at the City of Toronto's Brock West Landfill and in Stages 1 and 2 of Toronto's Keele Valley Landfill). The third stage in the evolution of leachate collection systems was a continuous granular blanket with perforated leachate collection pipes at spacings of up to 200 meters (e.g. Stages 3 and 4 of the Keele Valley Landfill). Field observations in Canada and other countries suggested that these collection systems have a finite service life and can fail due to a build-up of biofilm, chemical precipitates and small (e.g. silt and sand-sized) particles that are deposited in pipes and the granular material (e.g. sand or gravel) used to drain and collect the leachate generated by a landfill (Brune et al., 1994; Rowe et al. 1995a,c; Rowe 1998a,b). This build-up reduces the ability to drain the leachate and is called "clogging". Thus although they might continue to collect leachate for a long period of time, in as little as a decade some systems had clogged to the point that they no longer satisfy their primary
design function of controlling the leachate head on the underlying liners.

The Ontario Ministry of the Environment was one of the world leaders in recognising that to provide adequate environmental protection over the long term it was important to design a facility where the effective service life of each engineered system exceeds the projected contaminating lifespan of the landfill. Thus policies such as the "Engineered Facilities Policy" (MOE 1993) identified the need for landfill designers to establish the service life of the barrier system. However, although designers were required to establish the service life of leachate collection systems (LCSs), there was, at that time, at best only a very rudimentary understanding of the nature of the clogging of LCSs (mostly based on work in Germany). There was no quantitative data or technique that could be used to explain why some systems performed better than others or that could be used to allow engineers to estimate the service life of LCSs or compare one system with another. This study was initiated to address that need.

The experimental component of the research involved three different scales of study. The first two consisted of flask (VanGulck 1998; Fleming 1999) and column tests (Armstrong 1998; Rowe et al. 2000a,b; Cooke et al. 2000b) that were used to examine the influence of variables such as leachate characteristics, mass loading, particle size and roughness, and temperature. The third involved a series of laboratory mesocosm tests (Rowe et al. 1995a; Fleming 1999; McIsaac et al. 2000) in which laboratory test cells represented full scale sections of a granular drainage blanket leachate collection system. These were studied using actual Keele Valley landfill leachate percolating horizontally and vertically through the system at the rates expected near the collection pipes in the Keele Valley landfill.

The field study component involved (a) an examination of Keele Valley landfill leachate characteristics with time (Armstrong & Rowe 1999); (b) a field investigation of portions of the leachate collection system at the Keele Valley Landfill after one to four years exposure to municipal solid waste leachate (Fleming et al. 1999) and a related examination of the suitability of dolomitic limestone, as used at the Keele Valley landfill (and many other landfills in Southern Ontario) for use in LCSs (Bennett et al. 2000a); and (c) an examination of the stable isotope characteristics of landfill gas and leachate at several Ontario landfills (Bennett 1998; Bennett et al. 2000b,c). The theoretical study has involved development of a model that can be used to simulate the biologically induced clogging of porous media (Rowe et al. 1997a; Cooke & Rowe 1999; Cooke et al. 1999, 2000a,b). Finally, the concepts and data from the laboratory and field investigations have been integrated to develop a practical engineering technique for estimating the service life of LCSs (Rowe & Fleming 1998).

Given the very large body of research, theses and papers arising from this research, the objective of the present paper is to provide an overview of the entire "clogging" portion of the project, to summarise some of the findings, and to provide references where more information can be found. In addition to the "clogging" work, related aspects of this study included a detailed examination of (a) the structural behaviour of leachate collection pipes (see Brachman et al. 2000 for a summary), (b) diffusion through barriers systems (Lake et al. 1998; Lake & Rowe 1999, 2000; Krol 2000; Millward 2000; Rowe et al. 1995b, 1996a, 1997b, 2000c), and (c) modelling of landfill processes (Demirekler et al. 1999, 2000). These will not be discussed herein.

2. LABORATORY FLASK AND COLUMN TESTS

The work by Brune et al. (1994) and Rittmann et al. (1996) outline a process for the accumulation of clog material in the drainage layer. In particular, based on analyses of landfill leachate, flask (see below) and mesocosm (see Section 3) experiments performed in the early stages of this study (Rowe et al. 1995a), Rittmann et al. (1996) identified the potential link between the consumption of chemical oxygen demand (COD) and carbonate deposition in porous media permeated by leachate.

The laboratory flask experiments (Rowe et al. 1995a; VanGulck 1998; Fleming 1999) were conducted to evaluate the effect of temperature, pressure, granular media, and particle size on the removal of COD and CaCO₃ with time in municipal solid waste leachate. The results of this study were used to calculate a CaCO₃ yield coefficient. The experimental apparatus consists of flasks filled with leachate and partially filled with different granular media. The flasks are essentially a batch reactor that simulates conditions in a leachate collection system and allows for leachate to be removed for chemical analysis. Flask tests were performed at three different pressures of the gas-phase head space in the flasks (1.5, 30.5 and 61 cm of water), and three temperatures (10, 20 and 27°C). The results indicated that there is significantly more biological activity (and deposition of solids in a given time period) at elevated temperatures and that
increasing surface area of porous media available for biofilm growth resulted in increased deposition of clog material. However they also showed that the value of the CaCO₃ yield coefficient is independent of pressure and temperature.

The findings from the flask experiments prompted the initiation a series of Anaerobic Fixed Film Reactor (AFFR) column tests to evaluate the effect of flow-rate, leachate characteristics, temperature and nominal grain size, and particle shape on the rate and extent of clogging (Millward 1997; Armstrong 1998; Rowe & Armstrong 2000a,b; Cooke et al. 2000b). The tests conducted are summarised in Table 1. Although a number of investigators have performed column experiments (e.g. Brune et al. 1994; Pasky et al. 1998; Peeling et al. 1999), none have systematically examined these factors in a way that could be used for establishing parameters needed to predict the rate of clogging. Furthermore, none of these other studies were reported in sufficient detail to allow them to be used for evaluation of a numerical "clogging" model (see Section 6).

Column tests were performed using both actual and synthetic Keele Valley landfill leachate. The synthetic leachate was formulated to mimic the average Keele Valley chemical composition but without the suspended solid content of the real leachate. This was done so that the extent of clogging due to biological and chemical precipitation could be evaluated. This approach allowed the role of suspended solids to be isolated.

The results from the column testing indicated that the "real" leachate columns tend to have a greater rate of clogging due to the increased suspended solids loading and the continuous microbial addition from the real leachate. The rate and extent of clogging is dependent on the temperature, flow-rate, particle size, and the substrate and microorganism content of the leachate. At higher temperatures, the rate of clogging is greater due to the accumulation of more biomass within the same period of time. It was found that higher flow-rates gave rise to "less efficient" bioreactors (i.e. a smaller reduction in organic and inorganic loading per unit volume of leachate in a given time). From the clogging perspective, this effect was more than compensated by the increase in mass loading associated with the higher flow-rates. In other words, increasing the flow-rate and mass loading on the columns increases the rate of clogging. Finally, the observed rate of clogging for smaller particles was greater than for larger particles due to the smaller pore size and larger surface area per unit volume. An empirical relationship between hydraulic conductivity and drainable porosity as clog material accumulated was obtained (Rowe & Armstrong 2000a,b).

Autopsies of AFFR columns were performed to obtain the density of the active and inactive portions of the biomass, identify the type of bacteria present, and estimate the biofilm thickness. The columns were found to be colonised by a diverse consortia of bacteria, including methanogens and sulphate reducing and denitrifying bacteria that are typically found in landfill waste and leachate. The very high aggressivity (hence large population) of methanogens in the lower half of the column indicates that the bacteria are not only colonising the columns, but developing niches to allow specialised bacteria to grow and thrive. The saturated columns showed a very clear variation in drained porosity with distance along the column, indicating the clogging will be greater where the organic loading is greatest. These test results provided ideal data for testing the numerical clogging model in the saturated portion of the landfill.

The results of this study lead to several conclusions of practical significance relating to the design and operation of a LCSs. Firstly, since the rate of clogging has been shown to be related to mass loading, reducing the distance between the leachate collection pipes would decrease the total volume of leachate collected for one individual pipe and hence reduce the mass loading and rate of clogging around the pipe. Secondly, increasing the diameter of the granular media (D<sub>10</sub>) used in a leachate collection system may increase the LCSs operational life span, with all other factors being equal. Thirdly, this study has found bulk densities of clog material, ρ<sub>c</sub>, between 1.5 and 2.0 Mg/m<sup>3</sup>. This, combined with the observed total calcium fraction of 26% of total clog material (f<sub>Ca</sub> = 0.26) can be used in simple engineering calculations such as those proposed by Rowe & Fleming (1998) to estimate the rate of clogging of different collection system designs. The simplicity of this method stems, in part, from the observation that the yield coefficient Y<sub>0</sub>, (i.e. mg/L of CaCO₃ removed from solution per mg/L of COD stabilized anaerobically) is independent of particle diameter, flow-rate and temperature over the ranges considered. Finally, this study has provided experimental data that can be used by researchers developing more sophisticated clogging models (see Section 6) to test for accuracy under relatively controlled conditions.
Table 1: Summary of Laboratory Column Tests

<table>
<thead>
<tr>
<th>Series</th>
<th>System Type</th>
<th>Leachate Type</th>
<th>Porous Media Type</th>
<th>Media Diameter (mm)</th>
<th>Temp. (°C)</th>
<th>Flow Rate (m²/m²/d)</th>
<th>Sample Points</th>
<th>VFA Samples²</th>
<th>Multiple Autopsies³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Saturated, column</td>
<td>Synthetic</td>
<td>Beads</td>
<td>6</td>
<td>21</td>
<td>0.5</td>
<td>Yes</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Saturated, column</td>
<td>Synthetic</td>
<td>Beads</td>
<td>6</td>
<td>21</td>
<td>0.5</td>
<td>2</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>3</td>
<td>Saturated, column</td>
<td>KVL</td>
<td>Beads</td>
<td>6</td>
<td>21</td>
<td>0.5</td>
<td>7</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>4</td>
<td>Saturated, column</td>
<td>KVL</td>
<td>Beads</td>
<td>6</td>
<td>27</td>
<td>0.5/1.0/2.0</td>
<td>2</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>5</td>
<td>Saturated, column</td>
<td>KVL</td>
<td>Beads</td>
<td>4/6/15</td>
<td>27</td>
<td>1.0</td>
<td>2</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>6</td>
<td>Saturated, column</td>
<td>KVL</td>
<td>Beads</td>
<td>6</td>
<td>10/21/27</td>
<td>1.0</td>
<td>2</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>7</td>
<td>Saturated, column</td>
<td>KVL</td>
<td>Pea/Graded Gravel</td>
<td>Variable</td>
<td>21</td>
<td>0.5</td>
<td>2/3/7</td>
<td>yes</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>Saturated, column</td>
<td>KVL</td>
<td>GT Filter</td>
<td>N/A</td>
<td>27</td>
<td>0.5</td>
<td>2</td>
<td>yes</td>
<td>No</td>
</tr>
<tr>
<td>9</td>
<td>Unsaturated, column</td>
<td>KVL</td>
<td>50 mm Gravel</td>
<td>50</td>
<td>27</td>
<td>0.0055</td>
<td>2</td>
<td>yes</td>
<td>No</td>
</tr>
</tbody>
</table>

¹ The number of sample ports along flow path.
² "yes" implies VFA concentrations were determined frequently. COD concentration was measured in all experiments.
³ Identically operated columns were terminated at different times allowing progressive analysis of clog material.

3. MESOCOSM TESTS

Eighteen (18) Primary Leachate Collection System mesocosms operating a laboratory at 27°C were set up to simulate conditions representative of a section of a continuous granular blanket adjacent to a leachate collection pipe. Details regarding the set up of these mesocosms are given in Rowe et al. (1995a) and Fleming (1999). A summary of some of the tests and the findings related to the unsaturated portion of the mesocosms on termination of the tests is given in McIsaac et al. (2000). The mesocosms were built at true (full) scale so that they could be filled with a drainage blanket, 0.3 m thick, comprised of clean crushed dolomitic limestone of either nominal 19mm or 38 mm size. Refuse covers the stone to simulate field conditions.

Different design variables were incorporated into the mesocosms. Two designs used geotextile filters between the waste and the stone. In one pair of mesocosms a nonwoven needle punched polypropylene geotextile was used between the waste and stone. In another pair of mesocosms a woven silt-film geotextile was used between the waste and stone. One pair of mesocosms utilised a graded granular filter consisting of 4 cm each of well graded concrete sand and pea gravel (6 mm) between the waste and underlying 38 mm stone. One pair of mesocosms had an additional "sacrificial" layer of stone placed between the upper nonwoven geotextile and the waste. As a control, 10 mesocosms were designed with no filter between the waste layer and the drainage stone layer (typical of the Keele Valley Landfill).

Leachate from the Metro Toronto Keele Valley Landfill (see McIsaac et al. 2000 for the average concentration of key leachate constituents) was passed through the mesocosms at rates that mimic real time field conditions with lateral flow-rates corresponding to the expected average horizontal flow in the drainage layer near the collection pipe (for 50m spacing of leachate collection pipes) and a vertical percolation rate of 0.2 m³/a/m². When the tests were terminated after six years, clogging was observed in all mesocosms with the greatest clogging observed in the saturated stone where the porosity has reduced from 0.48 to about 0.15 with a void volume occupancy (VVO) of about 70%. This is consistent with the 50-80% VVO noted in the exhumation of the 4 year old system at Keele Valley. For the unsaturated systems, the greatest clogging was for the 19 mm stone where the maximum VVO was observed to be 20% and where the average VVO of about 7% corresponded to an average decrease in drainable porosity from 0.42
to about 0.39. Different filters between the waste and the stone (woven and nonwoven geotextiles, graded granular and no filter) were examined and it was found that the nonwoven geotextile and graded granular filter both have a beneficial effect.

Eleven Secondary Leachate Collection System (SLCS) mesocosms were also established (at 27°C) and showed no significant clogging in the SLCSs due to MSW leachate permeation through a clayey till liner after six years of operation, indicating that the clay has a very beneficial effect in reducing the potential for clogging in the secondary system. These results suggest a very long effective service life for SLCS.

A key component of these clogging tests is the monitoring of the change in leachate characteristics between influent and effluent. Correlations between the change in COD, Ca²⁺ and CO₃²⁻ concentrations with the rate of clogging have been developed that are consistent with "theoretical" predictions based on the leachate chemistry (Rittmann et al. 1996). This correlation is a key component of the clogging model.

An additional series of column tests involving 50 mm stone in downward flow unsaturated columns was conducted to better understand biological growth, leachate flow and clogging in this region, and to provide data to check the model in the unsaturated zone.

4. FIELD OBSERVATIONS

An exhumation of the leachate collection system at the Keele Valley Landfill was performed as reported by Fleming et al. (1999). The clog material was very similar to that obtained in the mesocosms and column tests. The inorganic clog material was predominantly CaCO₃. The VVO in the lower (saturated) zone in the 4 year old section exhumed is consistent with that observed after 4 years in the saturated mesocosm cell. The hydraulic conductivity of the stone was measured to have dropped by at least three orders of magnitude in the saturated zone.

The 8 mm diameter perforations in the pipe were mostly blocked by clog material, especially the lower rows of holes. Within the perforated pipes, significant accumulation of solid material had occurred in the form of large, loosely cemented pieces. Many of the clog samples removed from inside pipes (that had not been cleaned) were actually larger than the opening size of the perforated piping. It is therefore evident that many of these particles must have grown inside the pipe by precipitation of leachate minerals. The composition of the clog material is similar to that developed in the AFFR columns (Section 2) and mesocosms (Section 3). Since the leachate flow is focused to a large degree within the leachate collection pipes, the rate of clogging appears to be strongly influenced by the leachate loading rate. This is consistent with the findings of the AFFR columns (Section 2). This exhumation indicates the need for regular cleaning of leachate collection pipes and also suggests the desirability of larger holes.

The field investigation (Fleming et al. 1999) provided an opportunity to compare clogging where the waste was in direct contact with the underlying drainage blanket (as is the case beneath most of the Keele Valley Landfill) with the clogging where the geotextile filter had been placed between the waste and the underlying drainage blanket. A significant difference in the degree of clogging was observed in the upper unsaturated portion of the collection system (i.e. the portion influenced by the presence of the geotextile filter) with between 0 and 20% of the pore space being filled with clog material below the geotextile as compared to 30-60% loss of void space in a comparable area where no geotextile was used. This highlighted the advantages of having a suitable filter between the waste and any underlying coarse gravel drainage blanket.

5. STABLE ISOTOPIC STUDIES

The stable carbon and hydrogen isotopic compositions of methane and the stable carbon and oxygen isotopic compositions of carbon dioxide were monitored for biogas arising from the microbial degradation of Keele Valley Landfill (KVL) and synthetic leachate in several mesocosm and AFFR columns. Landfill gases extracted from the gas collection systems of three landfills of different ages (KVL, Brock-West and Beare Road) were also characterised isotopically (Bennett 1998; Bennett et al. 2000b,c).

The stable carbon and hydrogen isotopic compositions of both the mesocosm gases and the landfill gases suggested that the dominant methane-forming process in these systems was acetate fermentation. This process added inorganic carbon (DIC) (dissolved carbonate) to leachate, which may result in carbonate supersaturation and crystallisation of calcite in the LCSs. A second methane forming process, CO₂ reduction, seems to increase in importance as the landfill matures. This is significant, because CO₂ reduction removes DIC from leachate. Eventually, a steady-state is reached with respect to the input and output of leachate DIC. This behaviour
suggested that the input of DIC to leachate by acetate fermentation may be matched by an outward flux resulting from CO₂ reduction and calcite crystallisation. As a result, the rate of clogging may be higher in the early life of the landfill, and may stabilise to a more predictable steady-state level after a few years.

The stable isotopic characterisation of AFFR column gases suggests that acetate fermentation is by far the dominant methane forming process. The CO₂ reduction pathway was less prominent in these laboratory experiments than in actual landfills. The CH₄/CO₂ ratio (vol%, by GC FID) is much higher for AFFR column gases than it is for landfill gas extracted from the gas collection systems. In landfills, methane is formed largely in regions where the water content is below 100%. It appears that these laboratory experiments are more representative of early waste degradation, when acetate fermentation completely swamps the CO₂ reduction signal. This implies that the early stages of waste degradation produce the highest rate of clogging and that the AFFR experiments would provide a conservative estimate of the rate of LCSs failure if applied to the entire active life of a landfill.

The study (Bennett et al. 2000a) of leachate chemistry at the Keele Valley, Brock West, Beare Road and Halton landfills, and the exhumed leachate collection stone from the Keele Valley landfill suggested that the dolomitic stone commonly used for LCSs in Southern Ontario is quite suitable for use (contrary to claims made by some German authors). This is the first time that this issue has ever been examined scientifically and it provided good news for Ontario since the results suggest that the relatively cheap local material can continue to be used without negatively impacting the environment.

6. MODELLING OF CLOGGING AND ITS IMPACTS

A clogging model (BIOCLOG) was developed for the purpose of predicting the rate of clogging of LCSs. The model utilises transient anaerobic, fixed-film wastewater treatment processes combined with geotechnical engineering concepts within a time marching algorithm. This algorithm is used to model the evolution of the influent and effluent organic and calcium concentrations, biofilm thickness, inert biofilm plus mineral film thickness, and porosity at any position or time as summarised in more detail by Cooke et al. (2000a). It has been developed to model column tests, mesocosms, and landfill LCSs.

Using published biofilm growth kinetic parameters for the methanogenesis of acetate and the acetogenesis of propionate, and an experimentally determined calcium carbonate yield coefficient, a good fit of predicted effluent organic and calcium concentration, and porosity profiles for laboratory column tests conducted under saturated conditions have been obtained (Cooke et al. 2000b).

The results indicate that the processes simulated in the model are largely responsible for the biologically induced clogging of landfill LCSs and that these processes may be accurately represented. The model is also being refined and tested against column tests conducted under unsaturated conditions and against the mesocosm data (that incorporates both saturated and unsaturated components). The ultimate objective is that this model will be used to predict the rate of clogging for landfills and to optimise collection system design.

A contaminant transport model (Rowe and Booker 1997, 1998) was also developed to allow the modelling of transport through liners and into the secondary leachate collection system for conditions both before and after clogging of a primary leachate collection system. This model can be used to evaluate the level of engineering required to protect groundwater while allowing for the finite service life of the primary leachate collection system and geomembrane liner.

7. PREDICTING SERVICE LIVES

The concepts and data from the laboratory and field investigations were integrated to develop a practical engineering technique for estimating the service life of LCSs as described by Rowe and Fleming (1998). This technique provides a means of calculating the service life of LCSs in municipal solid waste (MSW) landfills and can be used in engineering practice for comparing the potential performance of different proposed designs.

8. CONCLUSIONS

This project has involved the integrated examination of the mechanisms associated with the clogging of municipal solid waste LCSs and the development of a quantitative technique that can be used for calculating the service life of these systems and comparing the potential performance of different proposed designs.

The laboratory (see Section 2 & Section 3), field (see Section 4 & Section 5), and theoretical (see Section
studies showed that although substrate utilisation by active micro-organisms drives the processes occurring in LCSs, clogging of these systems is largely the result of biologically induced precipitation, especially of calcium carbonate, CaCO$_3$ of inorganic constituents contained in leachate. Clogging appeared to be initiated by a diverse consortium of bacteria including methanogens, and sulphate reducing and denitrifying bacteria. Methanogens were dominant in areas where clogging was most severe. Analyses of clog material both in the laboratory and the field provided very consistent results with 65% (or more) of mature clog material being calcium carbonate (CaCO$_3$) (i.e. approximately 26% of the dry mass of clog material was calcium). The bulk density of the clog material was found to vary between 1.5 and 2 Mg/m$^3$. These parameters represent important, experimentally derived, input to the quantitative model that was developed for predicting the rate of clogging in LCSs. An examination of the yield of calcium carbonate (CaCO$_3$) relative to chemical oxygen demand (COD) indicated that the carbon in CaCO$_3$ represents less than 4% of the organic carbon represented by a drop in COD. Hence the clogging is controlled by the availability of calcium rather than the availability of the bicarbonate ion (the latter being generated as a result of biological processes) in the landfill. This finding was reflected in the quantitative model developed for predicting service life.

It was found that the porous medium may be regarded as being effectively clogged (i.e. no longer able to perform its primary design function) when the unclogged (drainable) porosity decreased to approximately 10%. An empirical relationship was established between hydraulic conductivity (i.e. the ability to transmit leachate to the collection pipes) and drainable porosity (the unclogged space through which leachate can readily flow). Laboratory studies demonstrated that even though clogged systems could still transmit leachate, the hydraulic conductivity dropped to a point where a build-up of leachate would be expected at the base of a landfill. The findings from the laboratory study were supported by the observations from the field exhumation that was conducted at the Keele Valley Landfill. It was shown that a portion of the 50 mm gravel drainage blanket near the leachate collection pipe experienced a 100-1000 fold decrease in hydraulic conductivity during four years exposure to leachate. This rate of clogging was consistent with the development of a leachate mound that is now being observed in Stages 1 and 2 of the Keele Valley Landfill (Barone et al. 1997). Furthermore, the findings from the laboratory study conducted using particles with a grain size similar to that used around the leachate collection pipes in the Brock West Landfill readily explain the relatively rapid development of a leachate mound that was observed at the Brock West Landfill. This could be predicted using the Rowe & Fleming (1998) model.

The examination of the suitability of dolomitic limestone for use in LCSs (e.g. at the Keele Valley landfill and many other landfills in Southern Ontario) showed that the clogging was not a result of dissolution (by acidic leachate) of the crushed dolomitic limestone. Thus there is no reason to discontinue to use this readily available material in municipal solid waste landfill LCSs.

The laboratory and field studies demonstrated that the gravel drainage blanket which forms part of the LCS behaves like an anaerobic fixed film reactor used in waste water treatment. Thus, the processes that induce clogging result in a decrease in organic strength and dissolved solids in the leachate and hence provide some level of leachate pre-treatment. Since the leachate that is collected at the end of the drainage pipe has been subject to passive pre-treatment within the drainage system, it is not fully representative of the original leachate. This suggests that there may be means of improving leachate quality (i.e. reducing the amount of treatment required after extraction from the landfill) by designing systems to take advantage of the biological processes taking place in the landfill while minimising the potential effects of clogging and consequent development of a leachate mound.

Based on the clogging mechanisms and parameters established from the laboratory and field studies, a technique (Rowe & Fleming 1998) was developed for calculating the time for clogging of different LCSs and establishing the effect of parameters such as thickness of the drainage blanket and spacing of the leachate collection pipes on the likely performance of different systems. A more sophisticated model (Biologic) that could be used for serving a similar, but more detailed, analysis is in the final stages of development.

The field and laboratory observations provided a rationally supportable basis for recommendations regarding various design details for landfill LCSs including issues related to filter placement, particle size, pipe spacing, perforation size, and inspection and maintenance. These findings are reflected in Ontario’s new landfill standards (MoE 1998, Schedules 1 and 2).
9. ACKNOWLEDGEMENTS

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10. REFERENCES


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