Liquid and gas permeability of Waste materials

For the liquid and gas phases the interstitial velocity \( \nu_{em} \) can be estimated using Darcy’s equation,

\[
\nu_{em} = -k_{em} \left( \frac{\partial h}{\partial x} \right)_{em}
\]  

where \( \frac{\partial h}{\partial x} \) are the head gradients and \( k_{em} \) are the permeabilities of the waste in the \( em \) direction, for the relevant liquid or gas components. The permeabilities may be expressed as,

\[
k_{em} = k_{REL} \left( \zeta_e^E \right) K_{em}^P \quad \zeta_e^E = \frac{\zeta_e - \zeta_e^R}{\zeta_e^{MAX} - \zeta_e^R}
\]

\( \zeta_e^E \) is the effective degree of saturation which falls to zero when the actual degree of saturation, \( \zeta_e \), reaches the residual degree of saturation, \( \zeta_e^R \), for the material. \( \zeta_e^{MAX} \) is the maximum degree of saturation that the material can reach, \( 1 - \zeta_e^{MAX} \) being related to the residual amount of trapped gas that will be retained by the material.

\( K_{em}^P \) are the fully saturated hydraulic conductivity, and the permeability to gas in the absence of liquid, respectively. \( k_{REL} \left( \zeta_e^E \right) \) are functions of effective leachate saturation, \( \zeta_e^E \), with values that lie between 0 and 1, and thus modify the values of \( K_{em}^P \) to allow for the impact on permeability of partially saturated conditions.

The hydraulic conductivity of the waste in a saturated condition may be estimated using the empirical relationship between hydraulic conductivity and effective stress \( \sigma' \) (kN/m\(^2\)) proposed by (Powrie and Beaven 1999).

\[
K_{em}^L = k_{vh} K_{REF}^L \left( \frac{\sigma'}{\sigma_{REF}'} \right)^\eta
\]

\( K_{REF}^L, \sigma_{REF}' \) and \( \eta \) are empirical coefficients which will be sensitive to the condition and nature of the particular waste being modelled. Examples of evaluations of equation (3) are shown in Figure 1. \( k_{vh} \) is the ratio of vertical to horizontal permeability.

In LDAT the effective stress, \( \sigma' \) (kPa), is calculated using,

\[
\sigma' = \sigma - \rho g L - (1 - \zeta) p^G
\]
where $\sigma$ is the total stress applied by the load due to overburden and any applied surface load per unit area, $\sigma_0$, or surface stress (kPa).

The value of $K_{em}^L$ may be adjusted for temperature through viscosity and density using the following approach, (Das 1983). If $\rho^L_{R_{E,F,T_0}}$ and $\mu^L_{R_{E,F,T_0}}$ are the reference density and viscosity at the temperature $T_0$ at which the reference permeability $K_{R_{E,F,T_0}}^L$ in equation (3) has been measured, then the permeability to a liquid with density $\rho^L_T$ and viscosity $\mu^L_T$ is given by replacing $K_{R_{E,F}}^L$ in equation (3) by,

$$K_{R_{E,F,T}}^L = K_{R_{E,F,T_0}}^L \frac{\mu^L_{R_{E,F,T_0}} \rho^L_T}{\rho^L_{R_{E,F,T_0}} \mu^L_T}$$  (4)

Equation (4) may also be used to estimate the gas permeability under conditions of gas saturation thus,

$$K_{em}^G = K_{em}^L \frac{\mu^L}{\rho^L \mu^G}$$  (5)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Notation</th>
<th>Units</th>
<th>LMC2 data¹</th>
<th>Example data²</th>
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</thead>
<tbody>
<tr>
<td>Hydraulic conductivity</td>
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<td>Power law index</td>
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<tr>
<td>Surface stress</td>
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<td>kPa</td>
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<td>50</td>
</tr>
</tbody>
</table>

1. Values used in (White and Beaven 2013)
2. Values used for the modelling example described in Section 3(White et al. 2014)

Figure 1 Parameters for saturated hydraulic conductivity, equation (3).