# Pollution in Peats

## La Pollution de la Tourbe

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SYNOPSIS

Peat-lands are one of the earth's major soil sorts and are becoming increasingly utilised. They are of great environmental importance and the impact of geotechnical activities such as waste disposal or unintentional pollution is a major cause for concern. In assessing the pollution risk, simulation studies of contaminant mobility in peats are of central importance and in this paper the transport parameters are related to the specific properties of peats. Starting with the convection dispersion equation, the importance of heterogenity, mechanical dispersion and adsorption phenomena is examined against a background of the structure of the pore space geometry. Finally case studies are used to illustrate the uses of simulation.

INTRODUCTION

Peat-lands are one of the earth's major soil types and occur wherever the mean annual litter-fall exceeds its mineralisation. These conditions are met in temperate, sub-arctic or elevated zones such as in Canada, Russia, and Northern Europe. Up to relatively recent times these somewhat inhospitable wetlands were of minor importance but this isolation has changed rapidly in the last few decades. The peatlands are now subject to extensive exploration, development and utilisation. Well known examples include oil and mineral winning and transport but the steady encroachment of permanent settlement cannot be underestimated. [Radforth and Brawner 1973].
One result of these developments is that geotechnical engineers are increasingly confronted with the need to successfully utilise peat lands with their unique properties. Settlement calculations, permafrost problems and drainage consolidation are common examples. Furthermore peatlands are often, and correctly, considered as zones of high ecological and environmental value and the impact of any proposed utilisation on this has to be correctly taken into account. Specific and critical examples of this are waste disposal and the risk analysis of possible pollution incidents. Pre-simulation of the impact of such activities on the peat environment has assumed central importance in the planning phase and in the setting up of relevant contaminant management strategies. In this paper some of the problems encountered in such simulations for peat soils will be explored.

THE PROPERTIES AND PORE STRUCTURE OF PEAT

There are several characteristics of the specificly peat soils that have to be taken into account when considering the migration of pollutants. These include:

1. The large porosity and invariably high saturation level even when located considerably above the formal water table.
2. The combination of extensive physio-chemical reactivity of the peat with a wide range of contaminants and the significant permeability giving the possibility of wide convective dispersion.
3. The low (acid) pH and negative (reducing) redox potential of the pore fluid in all except the very top horizons, which in turn results in quite different solution-precipitation equilibria than found in other soils.
4. The physical weakness and poor oxidative stability of the solid matrix.

To these factors should be added typical climatological factors associated with most peat-lands such as high precipitation rates, low evapo-transparation and low temperatures.

The migration of contaminants takes place through the pore-space and the interactions occur at the pore-solid interface and much understanding of the processes involved can be gained by studying the pore structure. Typically the pore space volume of peat is 90% of the sample volume. However, not all of this volume is equally available to convective water flow and further subdivision is possible. Peat arises from the humification (anerobic decomposition) of plant litter and the resulting structures reflect both the original plant associations and the extent of the humification. The more advanced the humification, the more amorphous the resulting pore structure. However, in most peats a mixture of the remains of cells, stems, roots and leaves can be identified. A typical photomicrograph of (North German) peat is shown in fig. 1.
The study of many such photomicrographs has lead to [Loxham 1980] the identification of 6 archetypes of pore space:

a) large multiply connected open pores

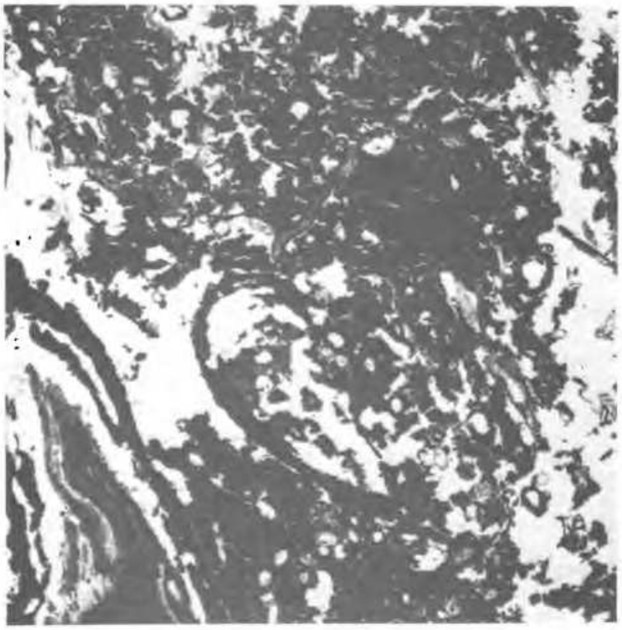

Fig. 1

- b) simply connected smaller pores
- c) closed ended pores
- d) completely isolated pores
- e) cell remains with walls intact
- f) spaces in massive woody structures such as roots and stems.

Type b) pores are typical porous medium pores allowing convective transport in much the same way as sand or loam. Type a) pores are large enough and extend far enough to cause by-pass flow as though tubes were inserted through the peat. The remaining types of pore space take no part in the convective transport process and can only be reached by the contaminant by the process of diffusion. These three classes a), b) and (c,d,e,f) will be referred to as large, active and dead pores respectively. (Soil mechanics will recognise here the underlaying cause of the abnormally long secondary consolidation period for peats. [Edil and Dhowian 1979]). This division of the pore space can be quantified by interpretation of $p^F$ curves or by computer image analysis and typical results are given in table I.

| | Pore Space Type - % | | | |
|---|---|---|---|---|
| Peat Type | Total | large | active | dead |
| High moor (bog) | 90 | 4 | 59 | 27 |
| Low moor (fen) | 87 | 5 | 42 | 40 |
| Low moor (drained) | 80 | 5 | 40 | 35 |

Table I  Typical pore type distributions [adapted from Loxham 1980].

Each of the three main sorts of pore space has a characteristic part to play in the spread of contaminants and this will now be examined.

## THE SPREAD OF POLLUTION IN PEATS

The spread of contaminants in peats involves several phenomena:

- a) Convective transport with the pore fluid flow.
- b) Mechanical dispersion arising from the multiple flow paths.
- c) The molecular diffusion of the contaminant from the active zone into the dead pore space.
- d) Adsorption - desorption of the contaminant into the organic matrix, including possible complex forming.
- e) Interactions between the contaminants themselves in the pore fluid that can lead to precipitation reactions.

These effects can be formulated together in the so-called convection dispersion equation [Fried 1975][Kirkham and Powers 1972].

$$\partial s/\partial t + \partial c/\partial t = \nabla(|D+\mathbf{D}|\cdot\nabla c_i) - v\cdot\nabla c_i + \phi_i \qquad (1)$$

where $s_i$ is the concentration of contaminant associated with the solid phase expressed as a concentration in the liquid phase, $c_i$ the concentration in the liquid phase, t the time, $(D+\mathbf{D})$ the dispersion, diffusion coefficient, v the in-pore velocity and $\phi_i$ a sink/source term to account for in-pore reactions, biological effects etc. Various solutions for simplified versions of equation ① by analytical techniques are available [Carslaw and Jaeger 1959] and an extensive literature on numerical techniques exists [see for a recent review v. Genuchten 1978]. For most practical problems successful solutions of equation ① can usually be obtained. The problem is then reduced to that of estimating the various parameters in equation ① for peats. That this is sometimes complicated will be seen below when each of the parameters is taken for evaluation. Considering firstly the convective mechanism for contaminant dispersion. This is the $(v\cdot\nabla c_i)$ term in equation ①. The velocity field can be calculated from the hydrological boundary conditions from the Laplace equation:

$$\nabla(\kappa\cdot\nabla\psi) = 0 \qquad (2)$$

where $\psi$ is the potential field and $\kappa$ the permeability. Here then

$$\tilde{v}_i = \kappa_i\, \partial\psi/\partial x_i \qquad (3)$$

where $\tilde{v}$ is the Darcy velocity and is related to the in-pore velocity of equation ① by:

$$v = \tilde{v}/(\eta) \qquad (4)$$

where $\eta$ is the porosity and following the discussion above has to be taken as the sum of the large and active pore volumes, and is not the total pore volume, i.e.

$$v = \tilde{v}/(\eta_a + \eta_i) \qquad (5)$$

One of the most important factors to be taken into consideration in setting up the velocity field is the possible occurence of heterogeneities that have the same scale as the lengths in the problem simulated. Permeability contrasts of 100 : 1 are not uncommon in peats and the $\kappa$ in equation ② can only rarely be factored outside the bracket. Attempts to allow for field scale heterogenity by increasing the dispersion coefficient are usually unsuccesful. The dispersion coefficient was origionally introduced into equation ① to account for micro-scale dispersion [Fried 1975], and for profiles of glass-beads and sands it seems experimentally justified [see for example Nielsen and Bigger 1962]. However, the unique properties of the peat pore space can give rise to other phenomena at the micro-flow level. These can be examined by constructing an equivalent pore space geometry consisting of tortuous capillary tubes whose volume, diameter distribution is forced to fit that found from the pF curves [see Loxham and Burghardt 1980]. The equivalent micro dispersion can then be calculated from the pore space model. In particular if the dispersion is seen as a distribution of travel times, then the cumulative volume fraction ($\nu$) with travel times less than the given time ($\tau$) (expressed as a fraction of the volume mean travel time) is given by:

$$\nu = 1 - \int_0^{\delta_c} \dot{M}\delta^2 d\delta \Big/ \int_0^{\infty} \dot{M}\delta^2 d\delta \qquad (6)$$

where $\dot{M}$ is the volume fraction of the profile associated with pore sizes of between $\delta$ and $\delta + \Delta\delta$ and the constant $\delta_c$ is given by:

$$\delta_c = \surd \int_0^{\infty} \dot{M}\delta^2 d\delta \cdot \surd \ ^1/\tau \qquad (7)$$

The distribution of travel times obtained in this way is compared to that from the constant dispersion coefficient formulation in fig. 2.

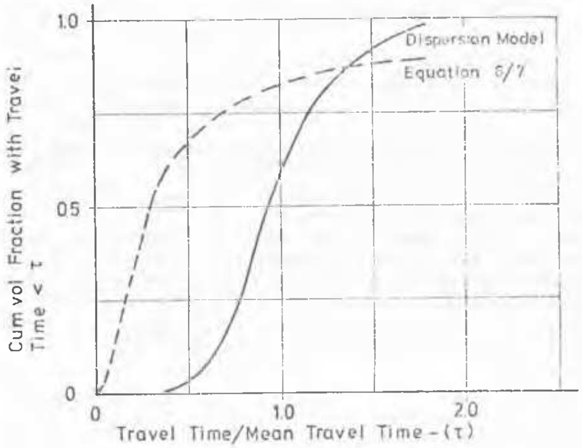

Fig. 2

The effect of the pore space can be seen in fig. 2. The large pores are responsible for the significant volume which discharges much earlier than otherwise expected. If the pore space model results are formally forced to give a dispersion constant by the method of Kirkham and Powers, 1972, then values much higher than those normally expected are found, typically a factor 10 to 100 greater than from correlations as in Fried, 1975 (p.30), depending upon the details of the pore space model chosen. For peats the dispersion coefficient formulation is a poor representation of the micro-mechanical dispersion and the inadequacies will be especially serious in problems where an accurate simulate of the first traces of contaminant build up is required.

If it is the large pores that complicate the microdispersion simulation then it is the other extreme, the dead pores, that have to be considered in adsorption phenomena. Adsorption is where the contaminant is immobilised on the surface of the organic matrix and is the main factor restricting the penetration through the profile. Peats have exceptional capacity for adsorption of a wide range of cations and in particular toxic heavy metals such as mercury, cadmium and copper. In the absence of other results it is usually assumed that adsorption is proportional to the surface area and the greatest proportion of the surface is found in the dead pore space and can only be reached by diffusion. There are thus two starting points for the adsorption simulation model. The adsorption can be controlled by the equilibrium between the contaminant and the adsorption site or by the speed of diffusion to that site compared to the speed of the dispersion process as a whole. Data from adsorption kinetic studies [Bunzl et al 1976] shows that the equilibrium controled mechanism can be assumed in most cases. The use of equations ① and ② in simulation studies will be briefly illustrated.

CASE STUDIES

One of the few advantages of waste disposal in peat-lands is that the peat can act as a barrier to the penetration of leachate into the deep-profile or the surrounding environment. In this section two examples of this will be studied. Firstly the efficiency of the peat barrier will be simulated. Consider the situation illustrated in fig. 3.

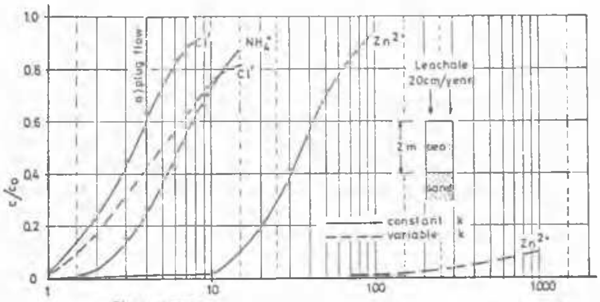

Fig. 3

Here a waste disposal tip is sited on a 2m thick peat layer overlaying sand. The objective of the simulation is to follow the build up of contaminant in the pore fluid and the break through into the sand aquafer. The leachate from a sanitary landfill has a very complicated composition [see Zanoni, 1973] but for the purposes here can be simplified by following the mobility of three characteristic components, ammonium, chloride and zinc. The concentrations of these ions in the leachate can be taken as 1800 ppm, 4000 ppm and 30 ppm. Chloride is not adsorbed in peat, ammonium to a limited extent and zinc strongly, but not as strongly as other heavy metals such as copper, cadmium or nickel. In fig. 3 the concentrations entering the sand layer are given, as a function of the time, and normalised as a fraction of the input concentrations. It is well known that the permeability of peats through which nutrients are flowing falls with time due to biological activity causing pore blockage by gas bubbles and flocs. This has to be added to the expected reduction in permeability as the highly compressible peat consolidates. Assuming that the overall process is exponential with a half life constant of 5 years the second set of break through curves shown in fig. 3 is obtained. Ammonium would be broken down by bacterial activity and has not been included in the second set. The simulation indicates that for chloride ion the peat constitutes no significant barrier neither with nor without taking credit for the reducing permeability. Furthermore there is a considerable toe of chloride ahead of the mean residence time in the active zone of four years. A similar but less severe result is obtained for ammonia. For zinc on the other hand the break-through is delayed by a factor of 10 to 25 in the constant permeability case and effectively prevented when the reduction in permeability is taken into account. This is an important conclusion when it is considered that zinc is one of the more mobile components in the peat environment. A calculation based only on the mean residence time would have given total break through at 10 years.

As A second and final example is illustrated in fig. 4.

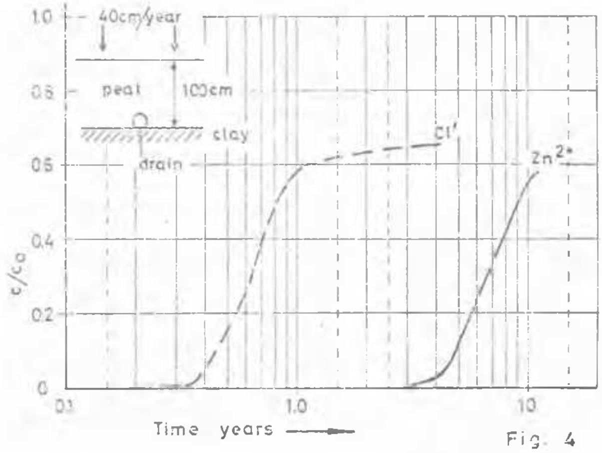

Fig. 4

In this case the peat deposit is above an impermeable clay layer and in order to avoid horizontal pollution spreading from a landfill site, a series of mole drains have been set under the tip. The objective of the simulation is to assess the need for heavy metal control in the discharge of the drains in their expected 50 years operating lifetime. In this case no credit will be taken for permeability reduction with time but an adjusted average permeability is used. The adsorption coefficients are taken from Bunzl (1976). In fig. 4 the concentration breakthrough of chloride and zinc are shown. If the criterion of maximum breakthrough of 1% of the input load is assumed, then the expected travel times to the drain are 0.3 years for $Cl'$, 3 years for $Zn^{2+}$, and ± 17000 years for $Cu^{2+}$ and $Pb^{2+}$. Cadmium will be absent from the drain for at least 4000 years at the concentration inputs expected in the raw leachale (± 0.25 mg/lt) and this concentration would have to be increased to 13 mg/lt before serious problems within the assumed time span. It should be emphasised that only convection, dispersion and adsorption have been considered here. Other effects such as mobility in the form of organic complexes, precipitation and redissolution can play an important rôle although little is known of these effects in peats. It can be concluded that in this case there will only be a significant problem from zinc in the drain effluent.

## CONCLUSIONS

The use of the dispersion-convection equation in the simulation of contaminant dispersion in peat lands can help the geo-technical engineer to assess and avoid potential pollution problems associated with his activities.
However, the determination of the parameters to be used can cause difficulties and an understanding of the structure of the peat pore space and physio-chemistry is of great importance.
Finally these is a serious need for large field trials to provide a sound basis for simulations such as here illustrated.

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