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Attenuation Landfills – the Future in Landfilling

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1. Introduction

Landfilling is the simplest, cheapest and most cost-effective method of disposing of waste (Moore, 1994; Barrett & Lawler, 1995; Allen 1998). Despite waste reduction and recycling policies, and waste pretreatment programmes to lower the proportion of waste going to landfill, at the end of the day landfills will still be required to accommodate residual wastes (Allen et al. 1997). However, although the *proportion* of waste to landfill may be decreasing, the *total volumes* of municipal solid waste (MSW) being produced are still increasing significantly (Douglas, 1992), and from 1990-1995, there was an increase of 10% in total waste generated in the EU (EEA, 1998). Thus, in the EU overall, despite the trend towards incineration by some of the wealthier nations, dependence on landfills for disposal of waste is likely to continue for the foreseeable future.

Over the last decade, the most significant waste management trend throughout Europe has been the enormous increase in cost of disposal to landfill. This has stemmed from the introduction in most European countries of more stringent legislation governing landfill management, in order to protect the environment and minimise health hazards arising from landfills. More rigorous legislation governing landfills was long overdue, and must be welcomed, but has led to an alarming increase in waste management costs, which cannot but have negative economic repercussions for less wealthy nations. Some of the new legislation, although affording in many situations only minimally enhanced protection to the environment, is extremely expensive to implement, thus greatly inflating waste management costs.

The two most important trends in landfill management policy over the last decade have been the almost universal adoption of the containment approach to emission control, which is now mandatory in many countries, and the increasing legal requirement to install artificial membranes as bottom liners and caps to landfills, in order to contain emissions. The containment approach requires that all liquid and gaseous emissions produced within the landfill, are contained within the landfill and collected for treatment, so expensive leachate drainage systems, containment ponds and treatment facilities are essential additional components of modern landfills. Artificial lining systems, which represent the high technology engineering solution to containment of emissions within the landfill, are the single most costly feature of modern landfills, and are virtually mandatory for all landfills even in situations where they are unnecessary. For example, at one landfill site in Ireland, underlain by 21-30 m of red lateritic clay with a hydraulic conductivity of 10^{-9} ms^{-1}, and initially successfully operated unlined, an Irish EPA permitting requirement to install an artificial liner system, resulted in a tenfold increase in the operating costs of the site (Allen, 1999). Furthermore, artificial membranes have proved less than effective, having suffered such unremitting leakage problems, that it has been necessary to design composite two-, three- and four-layer multibarrier clay/membrane systems consisting of sheets of artificial membrane, most commonly high density polyethylene (HDPE), interlayered with bentonite-rich clay layers (Cossu, 1995). Leak detection, leachate collection and landfill gas collection systems are all essential components of containment landfills that have added to their overall management costs. Also, because such high technology landfills are only economical on a large scale, regional ‘superdumps’ have emerged, with attendant high waste transport costs, and the additional requirement of transfer stations. Commonly, bitter opposition to the siting of such landfills by the local communities affected, leads to delays in licensing procedures and frequently in expensive court actions. Thus the containment strategy, currently the only permissible leachate management option within the EU, together with the increasingly mandatory employment of artificial lining systems to contain emissions, is responsible for the dramatic increase in landfill management costs over the last two decades.

Purely engineering solutions to pollution control are invariably expensive and rarely completely successful, and are often beyond the technological and financial resources of less wealthy nations. Furthermore engineering solutions usually have negative impacts, and the tendency is that the more sophisticated the solution, the greater the care and maintenance that will be required (Mather 1995). A much more sensible and cost-effective approach should invoke some form of enhancement of natural processes by the integration of a cheap, simple technology. In this presentation, flaws in the containment landfill strategy are highlighted, which preclude the likelihood of sustainability ever being achieved by this approach. The alternative strategy of employing the natural geological characteristics of the subsurface to attenuate emissions is examined, and some relatively inexpensive engineering options, which can enhance the natural processes, are described.

2. Flaws in the Containment Strategy

The sustainability of the containment approach to leachate management has recently been questioned (Mather, 1995, Allen 1998; 1999; in press). The main flaws in the strategy are:

- leakage problems and major uncertainties as to the long-term durability of artificial lining systems,
- chemical interaction of landfill leachate with many clay liners, particularly bentonite liners, leading to an increase in hydraulic conductivity,
- total reliance placed on the lining system, with little account taken of geological/ hydrogeological characteristics of sites being selected, and commonly no secondary geological barrier to protect groundwater in the event of liner failure,
- encapsulation of the waste by the artificial lining/capping system, inhibiting degradation of the waste and thus prolonging the activity of the waste, possibly for several decades or even centuries, so increasing the potential for environmental pollution over the longer period and necessitating long term post-closure maintenance and monitoring of the landfill,
- excessive costs in development and operation of containment landfills, and the financial burden of long-term, post-closure maintenance and monitoring of landfills, making the whole strategy uneconomic and unsustainable,
- inappropriateness of such a high-technology, high-cost waste management strategy to less wealthy nations with more limited financial and technological resources,
- present generations waste problems left for future generations to deal with.

Although all of the above deficiencies detract from the suitability of containment as a strategy for protecting the environment, the most critical is the performance of the liner system.

2.1. Durability of Artificial Lining Systems

A fundamental flaw in the containment strategy is that the long-term durability of artificial landfill liners is as yet unproven. Landfill waste degradation is a long-term process, and even under wet conditions, stabilisation of waste to an inert state (‘final storage quality’) has not occurred in most landfills 20 years after completion and capping (Belevi & Baccini, 1989a). Furthermore, estimates of long-term compositional characteristics of leachates (Belevi & Baccini, 1989b; Krug & Ham, 1997; Kruempelbeck & Ehlrig, 1999), indicate that for some components, e.g. NH_4-N, concentrations will not have fallen to compliance thresholds of EU waste water regulations for at least 100 years subsequent to landfill closure (Kruempelbeck & Ehlrig, 1999). However, landfill liner systems have only been in use for about 30 years, so their long-term performance is uncertain.

The behaviour of synthetic materials in artificial liners subjected over long time-scales to the corrosive effects of leachate, and the elevated temperatures generated by the exothermic processes operating within landfills, is extremely uncertain. The polymer membranes (e.g. HDPE) are generally regarded as being the most chemically and biologically resistant of the synthetics (Cossu, 1995). However, HDPE membranes have been shown to be prone to stress cracking (Rollin et al., 1991) and are also known to crack under cold conditions (Thomas & Kolbasuk, 1995). Synthetic membranes are also highly prone to damage (Artieres & Delmas, 1995), particularly from stones in the protection layer and from heavy dumping equipment (Nosko & Touze-Foltz, 2000), or failure of the membranes near welded seams (Surmann et al., 1995). Furthermore, the quality of installation of these lining systems is critical to their performance, because they are susceptible to failure if installation is not subject to strict quality controls and favourable weather conditions (Averesch, 1995). Thus, apart from leakage problems, which have plagued them from the outset, the durability of synthetic membranes remains suspect.

Mineral layers within artificial lining systems, typically consist of bentonite clays, primarily composed of expansive smectite group minerals. They are usually situated below the synthetic membranes, and so are isolated from the landfill leachate. To be effective, these layers necessitate emplacement and compaction at optimum moisture contents (Mundell & Bailey, 1985; Daniel, 1987; Majeski & Shackleford, 1997), but regardless of this, clay layers will tend to desiccate rapidly under the elevated temperatures generated within landfills. Indeed bentonitic mineral layers have been shown to be susceptible to severe dessication cracking due to inaccessibility of moisture (Meggyes et al., 1995), and elevated temperatures (Holzlöhner, 1989). Furthermore, in the event of failure or leakage of the synthetic membrane, chemical interaction between both organic and inorganic pollutants and bentonite lead to cracking and an increase in permeability (Fernandez & Quigley, 1985; Alther, 1987; Wagner, 1988). Also, sorption of heavy metal ions within the intermediate layer of the smectite may result in the loss of swelling potential and plasticity as well as to significant volume changes in the smectite (Wagner, 1994). Thus, in the event of failure of the synthetic membrane, mineral layers in artificial lining systems may have significantly reduced potential to inhibit leachate migration.

Ultimately, the success of the containment strategy depends on the effectiveness of composite artificial liner systems in preventing leachate migration from the landfill. This will mainly depend on the performance of the synthetic membrane member(s). It is unlikely that any synthetic membrane is completely free of defects (Christensen et al., 1994), regardless of quality control and, whilst leakage may be minimal initially, it is the long-term durability of the membrane(s) over decades or possibly even hundreds of years, under conditions which are ultimately unpredictable, that leaves grounds for concern. In the light of the 'precautionary principle', the wisdom of placing such reliance on a technology as yet unproven over the long-term is short-sighted.

2.2. Problems with Clay Liners

Clay liners are in common use, particularly in North America, but have been employed solely with a containment function. Thus permeability has been the critical property, attenuation properties being of little significance. Various types of clay liner have been experimented with (Farquhar, 1994), including in-situ clay deposits; swelling clay (usually bentonite); sand-swelling clay mixtures (ranging up to 15% w/w bentonite); and remoulded and compacted clay. All are subject to a greater or lesser extent to three main problems:

- Chemical interaction with leachate and resulting increase in permeability,
- Necessity for strict quality controls during installation,
- Problems of determination of hydraulic conductivity.

Bentonite or bentonite-bearing mixtures have been primarily used as clay liners in the past. The problem of chemical interaction of leachate with bentonite has been discussed above, as has the necessity for optimum placement conditions. Bentonites are composed of the highly unstable smectite mineral montmorillonite, which has Na and Ca end-members, the former having the greater swelling potential and higher activity (Cancelli et al., 1994). Replacement of Na in the montmorillonite by Ca, also occurs due to reaction with MSW leachate, results in shrinkage of the clay, development of cracks, increased permeability and lower activity (Hoeks et al., 1987 Madsen & Mitchell, 1989). The extent to which this occurs, depends on the degree of incompatibility between the clay liner and the leachate (Farquhar & Parker, 1989), which will be a function of the leachate composition and the Na:Ca ratio of the montmorillonite. For instance, European bentonites with greater substitution of Ca and Mg as opposed to Na are less susceptible to Na replacement, and thus less prone to shrinkage and increase in permeability (Hoeks et al., 1987; Madsen & Mitchell, 1989). In general, however, bentonite and sand-bentonite liners appear not to perform a containment function well in the longer term.

Compacted clay liners consisting mainly of non-swelling clays do not suffer to a major extent from the problem of reaction with MSW landfill leachate, provided the swelling clay content is kept to a minimum (Gordon, 1987; Farquhar & Parker, 1989). In fact liner permeability often decreases with time due to sealing by precipitate formation, solids accumulation and biomass growth along the upper surface of the liner and into any pre-existing cracks and fissures (Quigley & Rowe, 1986; Daniel, 1987; Farquhar & Parker, 1989). So compacted liners are the most versatile type of clay liner as far as containment is concerned.

However, as indicated above, hydraulic conductivity of clay liners is critically dependent on moisture content and degree of compaction. The nature of this dependence is an increased density with compaction effort and also a non-linear dependence of density on moisture content resulting in an optimum moisture content to produce maximum density (Farquhar, 1994). This dependence is specific to the clay mixture being tested, and cannot be applied to other soils, so equivalent data sets must be generated for each liner material being considered. Thus, in order to comply with hydraulic conductivity specifications in landfill design regulations, each clay liner must be rigorously tested, with placement necessitating optimum weather conditions, standardised compaction effort, strictly controlled moisture content and very careful compaction techniques. Adverse weather conditions, which delay completion of the placement process can have serious ramifications in terms of liner performance. Overall, regardless of whether an in-situ or cheap local source of clay is available, the testing and correct installation of clay liners performing a containment function is costly.

Furthermore, the hydraulic conductivity of clay liners is notoriously difficult to determine in the field, and laboratory values do not correlate well with field values, often being several orders of magnitude lower than field measurements (Daniel, 1987; Williams, 1987). This primarily stems from the high hydraulic gradients of several hundred under which laboratory tests are performed, compared with normal field hydraulic gradients of less than 1.0. Such high gradients generate unnatural flow conditions, which adversely affect hydraulic conductivity leading to errors (Quigley et al., 1988). Other problems with laboratory tests are the size of the samples, which are insufficiently large to account for field heterogeneities such as cracks, or their insufficient duration to account for long term interactions between the liner and the leachate (Farquhar, 1994). The only correct hydraulic conductivity is that exhibited by the liner in place, determined by seepage measurements in the field using large-scale infiltrometers. However, these are expensive and take several months to complete.

More critically, the hydraulic conductivities of natural clay-rich materials differ markedly for leachate and water. For instance, hydraulic conductivities for the same sand-bentonite mixture have been shown to be two orders of magnitude higher for leachate than for water (Hoeks et al., 1987). Thus, field or laboratory determinations of the hydraulic conductivities of natural materials will have little bearing on their ability to contain landfill leachates.

Thus, natural clay liners, whilst probably more durable and certainly cheaper and more environmentally friendly than synthetic liners, may not perform a purely containment function as adequately as might be hoped over the longer term, due to problems of chemical interaction with leachate, difficulties in placement and in precise determination of hydraulic conductivity. However, in the event of failure of clay liners, attenuation properties of the clays can mediate, to a greater or lesser extent, groundwater contamination by the leachate.

Furthermore, it has now been recognised that the dominant mechanism of contaminant migration may be diffusion and not advection, (Rowe, 1994b). Consequently, and this applies both to synthetic and natural materials, even if the liner system performs to expectation, and leakage is minimal, migration of contaminants through the liner by diffusive processes, may still occur. Therefore, complete containment of all contaminants emitted by landfill waste may be a fallacy. However, migration of contaminants through natural clay liners may be mitigated by the attenuation properties of the clays.

3. Attenuation Landfills

Natural leachate management solutions that utilise the hydrogeological characteristics of the subsurface and the attenuation properties of subsurface materials, are totally ignored in current landfill management strategies. One such alternative approach – attenuation - which allows the liquid wastes to migrate from the landfill, employing the natural geological/hydrogeological characteristics of the subsurface to moderate and attenuate pollutants, is currently prohibited within the EU. However, numerous studies (DoE, 1978; Warith & Yong, 1991; Batchelder et al, 1998a, b), have shown that, in appropriate circumstances, such an approach is effective in preventing pollution of water resources. Attenuation takes advantage of the natural subsurface processes of filtration, sorption and ion exchange that are in continuous and effective operation in the purification of groundwater, which in normal circumstances requires no treatment for use as household water supply. Other advantages of using natural in situ geological/ hydrogeological barriers is that natural barriers do not encapsulate waste and inhibit its degradation, little or no maintenance costs are involved, and the natural infiltration and percolation characteristics of the subsurface are not disrupted. Such natural leachate management solutions could significantly reduce the cost of landfilling as much of the expensive engineering technology, particularly landfill lining systems, associated with the containment approach are unnecessary.

Attenuation landfills are based on the ‘dilute and disperse’ principle of leachate management, defined by Gray et al, (1974), which has been largely superseded by the containment strategy. This method of leachate management relies on natural low permeability and attenuation characteristics of geological barriers in the subsurface to prevent groundwater pollution by landfill leachate. It employs the natural confinement potential of primarily low permeability clay-rich overburden and to a lesser extent consolidated mudrocks to impede the migration of leachate from the landfill, whilst at the same time attenuating and purifying it by processes of filtration, sorption and ion exchange. Such natural processes operate continuously and effectively to purify groundwater, which under normal circumstances requires no treatment for use as household water supply.

The dilute and disperse’ principle of leachate control has been unfairly maligned, due to failures which occurred where it was employed without adequate geological/ hydrogeological investigations. Thus, many sites at which it was employed, were totally inappropriate for this method of leachate management, due to the absence of a suitable geological barrier to attenuate the leachate. The ‘dilute and disperse’ principle is now militated against in many countries by legislation that requires all leachate emanating from the landfill to be collected and treated (Mather, 1995).

3.1. Physical Characteristics of Natural Attenuation Barriers

Natural geological barriers, may be defined as *low permeability clay-rich geological units (hydraulic conductivity <10^{-7} ms^{-1}), which can perform the function of an attenuating layer, enabling leachate to percolate slowly downwards, simultaneously undergoing attenuation by filtration, sorption and exchange processes with the clays in the unit*. Extremely low permeability geological units (hydraulic conductivity <10^{-9} ms^{-1}) cannot fulfil an attenuation function, as they perform in a similar manner to artificial or natural lining systems, providing complete containment of all emissions. Similarly, geological units with higher permeability (hydraulic conductivity >10^{-7} ms^{-1}), do not provide sufficient confinement to leachate, so are also unsuitable for an attenuation role. The optimum permeability for attenuation is of the order of 10^{-7}-10^{-9} ms^{-1}.

Suitable geological barriers, mainly in the form of thick relatively impermeable overburden sequences, exist in many parts of the world. Bedrock has limited potential as a geological barrier, as although many rock types have extremely low primary permeabilities, rocks are usually fractured or jointed to a lesser or greater extent, particularly rocks that have undergone moderate burial prior to exposure at the Earth’s surface. Clay-rich Mesozoic or Cenozoic sediments, which have not undergone deformation and recrystallisation, may be locally suitable as geological barriers, such as in parts of the UK, Holland, Germany, Poland, the Baltic States, Belarus, Russia and the Ukraine. However, such rocks do not have sufficiently widespread development to be of major significance.

Overburden deposits have much greater potential as geological barriers, due to their ubiquitous development at the Earth's surface, and their common high attenuation potential. However, overburden is extremely variable both in lithology and thickness, the first controlling both their primary permeability and attenuation potential, the latter also being critical to their attenuation potential. In high latitude regions, which underwent Pleistocene glaciation, thick clay-rich tills are widespread and may provide excellent geological barriers. In tropical regions, thick clay-rich weathering profiles are also potentially suitable as geological barriers.

Overburden deposits just outside the acceptable range of hydraulic conductivity, could have their hydraulic conductivities modified by addition of fine sand in the case of extremely low permeability natural units, or clay in the case of higher permeability deposits. In-situ clay deposits may not require remoulding and compaction provided large scale permeability is not adversely affected by weathering, root penetration or continuous inclusions of coarser materials (Williams, 1987; Quigley et al., 1988). However, in many cases, it may be necessary to partially excavate the natural deposit in order to remove stones and homogenise it, and any modification of hydraulic conductivity by addition of sand or clay could be undertaken prior to re-emplacement.

The minimum thickness requirement for an attenuating layer should be dependent on its hydraulic conductivity and attenuation properties, so that provided the attenuation potential of the layer were sufficiently high, the limiting permeability could be related to layer thickness. In order to ensure that a geological barrier would, on its own, give sufficient protection to the environment, stringent geotechnical requirements regarding the nature, thickness, hydraulic conductivity and attenuation potential of the barrier would need to be specified. Furthermore, rigorous site investigation and field and laboratory testing of hydraulic conductivity and the attenuation properties of the geological unit would necessarily be a primary requirement of any application for a landfill licence.

The suitability of any individual barrier layer for attenuation is a function not only of its permeability, but also of its attenuation potential. The latter is dependent principally on the proportion of clay minerals and iron and manganese oxides, and also on the types of clay minerals present in the deposit, due to the variable sorption and cation exchange capacities (CEC) of the various clay mineral groups. The least activity (sorptive capacity) of the major clay mineral groups, and also the lowest CEC are possessed by the kandites. The illites have higher activities and CEC, then the sepiolite-palygorskites, followed by the vermiculites, whilst the smectites have the highest CEC and sorptive capacities due to their ability both to adsorb ions on to their external surfaces and also to absorb ions between their lattice sheets (van Olphen, 1977). Interactions between leachate and clay liners include ion exchange, adsorption-desorption, particle size reduction, mineral dissolution and clay mineral disordering and collapse (Batchelder et al, 1998a; Warith & Yong, 1991). High swelling clays such as the smectites are more prone to mineral transformations and collapse than mixed clay mineral assemblages and the low swelling illite and kaolinite clay groups (Batchelder et al, 1998a). Furthermore, clay-rich overburden and mudrock, can buffer acid leachates, leading to precipitation of heavy metals (Batchelder et al, 1998b), which displace Na^{+}, Ca^{2+} and Mg^{2+} on clay mineral surfaces by cation exchange mechanisms (Mohamed et al, 1994).

3.2. Design of Attenuation Landfills

Simple technologies can often be employed to enhance natural processes, and a number of potential engineering design options exist that may improve the effectiveness of attenuation landfills. In the main, these are relatively inexpensive and require minimal maintenance.

It may be possible to engineer a clay liner from natural *in situ* clay overburden deposits, to perform both attenuation and confining functions, by combining the special attenuation properties of the smectite group of clay minerals with the greater stability of the kandite and illite groups. The double mineral base layer (DMBL) concept (Wagner, 1994) involves the employment of two clay layers to line a landfill, an ‘active’ layer with a high content of highly active smectite clays (bentonite) and/or carbonate, situated above an ‘inactive’ layer composed predominantly of more stable clay minerals such as kaolinite. The ‘active’ layer performs an attenuation function through processes of sorption and ion exchange, whilst the ‘inactive’ layer performs a confinement role, but undergoes minimal reaction with the leachate. The presence of the ‘inactive’ layer beneath the attenuation layer impedes downward movement of leachate maximising the reaction time between the active layer and the leachate. As pointed out by Wagner (1994), this arrangement may represent a better option than a single attenuating layer, as the two functions of confinement and attenuation may be mutually exclusive, since the sorption and ion exchange processes in smectite clays lead to a gradual reduction in swelling capacity and consequent increase in permeability. The two layers could be produced simultaneously from natural in-situ clay deposits, by excavation of the natural material, separation of the excavated soil into two piles and treatment of them separately, adding kaolinite to one to create the ‘inactive’ confining layer, and smectite to the other to form the ‘active’ attenuation layer. Organic material, in the form of peat or compost, could also be added to the ‘active’ layer to enhance its sorption/ion exchange properties and improve its attenuation potential.

Although some care would be required in placement of the 'inactive' layer to ensure a suitably low hydraulic conductivity, because kaolinite has a limited swell potential, optimum moisture content is not essential. Also, because the required range in hydraulic conductivity is less extreme than the mandatory 10^{-9} ms^{-1} stipulated for containment landfills, compaction effort would be reduced. The hydraulic conductivity of the 'active' layer would be less critical, although a range in hydraulic conductivity of 10^{-7}-10^{-9} ms^{-1} would also probably be optimum, but it would not be necessary to emplace this layer with such extreme care at optimum moisture contents as for containment landfills.

More rapid stabilisation of waste in attenuation landfills may be achieved by allowing unrestricted ingress of rainwater into the waste, thus promoting biochemical and microbial degradation processes, i.e. the flushing bioreactor landfill (Campbell 1992, Blakey et al. 1995). In addition, a more dilute and therefore less toxic leachate will be produced. Therefore it would be highly advantageous if the capping consisted of a permeable material, whilst pretreatment of the waste by shredding could improve rainwater percolation and access to the waste. A major danger of uncontrolled rainfall ingress into a landfill is the build up of leachate head, particularly after periods of heavy rainfall. This could result in an increase in the rate of leachate migration through the 'active' attenuation layer below the landfill, and the build up of head against the 'inactive' confining layer, potentially leading to its hydraulic failure, with consequent groundwater pollution. It can also lead to side slope instability (Cossu et al, 2000). A solution to this problem is to install an efficient drainage and leachate collection system above the attenuating layer, which could control the leachate head in order to prevent shock loading of the receiving environment. The collected leachate could be stored in leachate ponds and recirculated by sprinklers to the landfill surface during periods when the leachate head is low. Thus, the leachate collection system would perform the function of controlling the rate of leachate migration from the landfill. The final mass release to the environment should be at a rate which does not cause any hazard or unacceptable damage to the environment (Knox, 1989).

Recirculation of leachate over the landfill surface can have its own impacts, particularly where the leachate has high chloride concentrations, which can precipitate out under evaporative conditions, salinising the landfill cover, and blocking the porous structure of the cover material, which is designed to enhance the recirculation process. This problem needs to be carefully assessed for each individual situation. The relatively dilute leachate produced in regions with moderately high precipitation may not be problematic, but in hot arid climates, where the quantity of leachate produced is minimal, high concentrations of chloride could be expected, and if evaporative demand is high, could be a serious problem. A relatively highly permeable capping could enhance rapid infiltration of the recirculate into the landfill, but could also lead to overload of the drainage system during periods of prolonged heavy rainfall. Recirculation of leachate when evaporative demand is low, such as at night, coupled with a moderately permeable capping could be another solution.

Fig. 1 depicts a simplified schematic diagram of the elements of an attenuation landfill. Although not shown on the diagram, continuation of the landfill above the ground surface, with the creation of bunds and extension of the DBML barrier could significantly increase landfilling space.

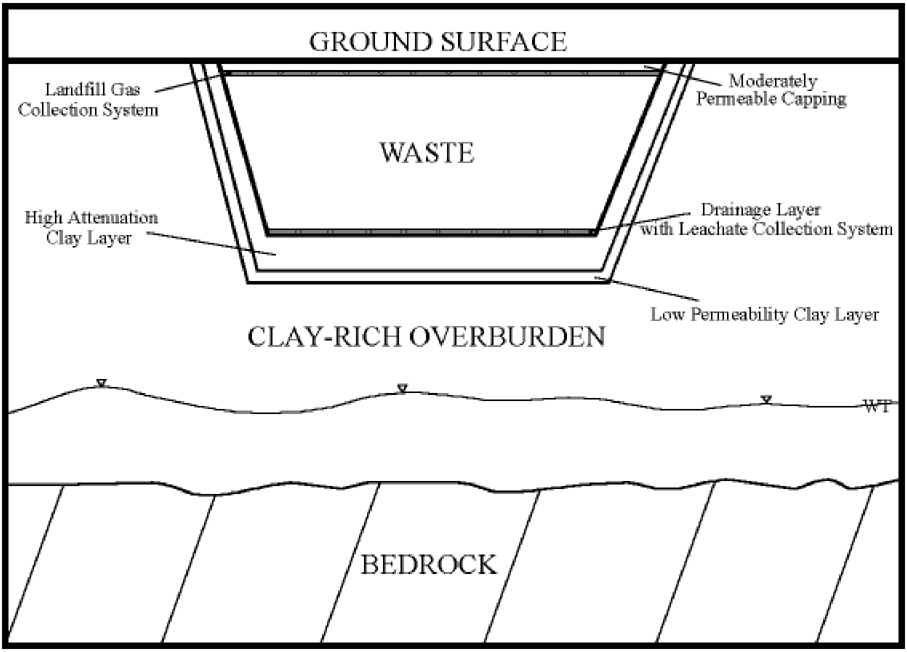

Fig. 1. Attenuation landfill with double mineral base layer (DMBL), consisting of a kaolinite-enriched ‘inactive’ clay layer overlain by a smectite-enriched ‘active’ clay layer. A drainage layer with a leachate collection system to control the rate of leachate migration overlies the DMBL, to prevent shock loading of the DMBL. A landfill gas collection layer overlies the waste and the capping consists of moderately permeable soil to allow ingress of rainwater

Rys. 1. Zabezpieczone wysypisko odpadów z podwójną mineralną warstwą denną, składającą się z warstwy „obojętnej” gliny wzbogaconej kaolinitem pokrytej warstwą aktywnej gliny wzbogaconej smektytem. Warstwa drenażowa wraz z systemem zbierania odcieków w celu kontroli ilości migrujących odcieków pokrywa podwójną warstwę mineralną, tak aby zapobiec szokowemu ładunkowi wpływającemu na podwójną warstwę mineralną. Warstwa zbierania gazu wysypiskowego pokrywa odpady a pokrycie składa się z średnio przepuszczalnej gleby, która pozwala na przejście wód deszczowych

The control of methane gas produced in attenuation landfills is another environmental problem, which needs to be addressed. Employment of a permeable capping system, as proposed above, presents no barrier to methane emission to the atmosphere. Methane forms by anaerobic degradation processes, which are promoted by compaction of the waste and its encapsulation in low permeability lining systems, so isolating it from oxygen. Thus, methane production is enhanced by the containment strategy. Shredding and the employment of a permeable capping system on attenuation landfills is intended to promote aerobic degradation processes, which operate more rapidly than anaerobic processes and produce carbon dioxide rather than methane. It is anticipated that this will significantly extend the timespan during which aerobic degradation processes operate within attenuation landfills, reducing the proportion of organic waste available for anaerobic degradation. Alternatively, air feed pipes may be built into the landfill during construction to pump air into the waste layers to maximise internal aerobic activity, the 'Fukuoka' method (Hanashima, 1999). However, despite shredding, and the employment of a permeable cap, it is likely that ultimately, settlement of waste will lead to the establishment of anaerobic processes and the production of methane. Since the base and sides of the landfill will have a relatively low hydraulic conductivity, particularly if a DBML barrier is established, migration of landfill gas produced will be mainly upwards, and this can be promoted by a landfill gas collection system. Alternatively, establishment upon the landfill cover, of certain tree species, such as populus species (poplars), with extensive root systems which harbour microbiological populations that convert methane to carbon dioxide, could achieve the same objective.

Attenuation landfills, as described above, take full advantage of the physical and geological/ hydrogeological properties of the subsurface, which moderate and purify groundwater, both in the unsaturated and saturated zones. In addition a number of simple inexpensive engineering solutions, also outlined above, can enhance the natural physicochemical and microbiological processes operating within a landfill. The object of these design options is to optimise the rate of degradation of the waste within the landfill, so that the stabilisation of the waste to an inert state can be expedited. Furthermore, the emphasis is on inexpensive technologies as the escalating costs of the containment strategy of landfill management have rendered this approach financially unsustainable (Allen, 1999, in press). The attenuation approach to landfilling with the design options proposed, conforms to the multibarrier concept of landfilling (Cossu, et al, 2000).

4. Conclusions

The escalating cost of landfill in the EU over the last two decades can be attributed to the adoption of the containment approach to landfill management and the mandatory legal requirement for artificial lining and capping systems to be installed at all landfills. Despite the confidence afforded the containment concept, the approach has been plagued by problems, and it has become increasingly apparent that the containment strategy is financially unsustainable. Of greater concern is the fact that waste in containment landfills with artificial lining systems will remain active for many decades and possibly even centuries, and long into the future will pose a pollution threat to the environment, in the event of degradation of the lining system.

Attenuation landfills have been militated against by the EU directive that all subsurface water must be protected, effectively requiring that all leachate produced in a landfill must be collected and treated on site, regardless of whether groundwater in the vicinity of the landfill is a resource that warrants protection. Attenuation landfills utilise the sorption, filtration and ion exchange properties possessed by subsurface mudrocks and clay-rich overburden, which are in continuous and effective operation in purifying groundwater. Several studies, (e.g. DoE, 1978), have confirmed that in appropriate circumstances, attenuation is an effective means of protection of groundwater resources against pollution. Attenuation landfills can benefit from design options that promote aerobic degradation processes, so expediting the stabilisation of waste to an inert state. Finally, a significant advantage of attenuation landfills is the relatively minor cost of construction, operation and maintenance compared to containment landfills. If technologies to hasten degradation of the waste in the landfill to its inert state are incorporated into the landfill design and operation, it is possible that attenuation landfills can achieve sustainability.

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Zabezpieczone wysypiska – przyszłość składowania odpadów

Streszczenie

Praca dotyczy zagadnienia zmniejszenia oddziaływania składowiska odpadów na środowisko naturalne oraz inżynierii zabezpieczenia przed przedostawaniem się odcieków do wód gruntowych w długim wieloletnim okresie eksploatacji. Koszty budowy i utrzymania wysypisk odpadów, w powiązaniu ze stałymi kosztami eksploatacji i monitorowania składowiska w czasie aktywności odpadów, są bardzo znaczące. Trwa to zwykle wiele dziesięcioleci zanim składowisko zostanie zamknięte i wiąże się z koniecznością doboru odpowiedniej strategii zarządzania.

Na wstępie autor podaje przykłady wad w strategii i procesie planowania i budowy składowisk odpadów. Przy budowie i eksploatacji składowiska odpadów, zmniejszenie niekorzystnego oddziaływania na środowisko naturalne powstających odcieków wymaga uwzględnienia sorpcji, filtracji oraz wymiany jonowej pokładów geologicznych bogatych w iły. Przy analizowaniu tych zagadnień, mając na względzie przede wszystkim zapobieganie skażeniu wód gruntowych, autor odwołuje się do uregulowań prawnych istniejących w Unii Europejskiej. Wskazując na inżynieryjne opcje budowy składowisk odpadów autor analizuje możliwe uszkodzenia hydrauliczne występujących pokładów iłów, wskazując rozwiązania optymalne. Uwzględnia przy tym słabości stosowanych obecnie zabezpieczeń wykładzinami z tworzyw sztucznych. Chociaż sztuczne systemy wykładzin stosowane powszechnie w budowanych składowiskach odpadów będą zabezpieczać przedostawaniu się odcieków przez kilka dziesięcioleci, to istnieje niebezpieczeństwo skażenia środowiska w przypadku degradacji lub przypadkowego uszkodzenia wykładzin. Autor optuje za naturalnymi warstwami nośnymi, które w długim okresie czasu będą przyczyniały się do stabilizacji i zobojętnienia powstających odcieków. Autor przedstawia koncepcję zabezpieczania wysypisk odpadów podwójną mineralną warstwą denną, składającą się z warstwy „obojętnej” gliny wzbogaconej kaolinitem pokrytej warstwą aktywnej gliny wzbogaconej smektytem. Warstwa drenażowa wraz z systemem zbierania odcieków w celu kontroli ilości migrujących odcieków pokrywa podwójną warstwę mineralną, tak aby zapobiec szokowemu ładunkowi wpływającemu na podwójną warstwę mineralną.

Duże znaczenie w takich rozwiązaniach mają, oprócz bezpieczeństwa, koszty budowy i eksploatacji składowisk odpadów.