REVIEW OF SOME CURRENT UK LANDFILL DESIGN ISSUES.

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SUMMARY

The aim of this Paper is to highlight some landfill design issues that are currently under discussion within the UK waste industry. These include the specification of the lowest acceptable compaction moisture content for the placement of mineral liners, and the recent Environment Agency Guidance on the reduction in leachate drainage blanket thickness from 500mm to 300mm.

1.0 INTRODUCTION

The main function of a mineral liner within the landfill is to prevent the contamination of groundwater. To effectively function as a mineral liner it has to be able to (Brandl.1992):-

- Minimise pollutant migration due to flow or diffusion
- Adsorb and retard pollutants
- Be resistant to erosion and chemical degradation
- Have autogenous healing properties
- Be flexible and ductile to accommodate differential movement
- Have appropriate swelling and shrinkage characteristics

The function of a mineral liner is expressed in terms of permeability and is a result of its micro and macro characteristics and its environment in terms of overburden stress, foundation stability and liner thickness. The success of a mineral liner depends on the careful evaluation of the engineering properties of selected materials and adequate quality assurance and quality control during construction. In the UK high quality clays are not typically used to construct landfill liners; instead a variety of materials are used depending on the local availability. These include glacial and sedimentary clays, weathered mudstones and colliery spoil. Currently there is no formal guidance on the selection of the moisture content placement window for these materials. Within the landfill industry there is a difference in opinion on the selection of this window, in-particular with regards to the specified lower moisture content. The Environment Agency is currently seeking to achieve harmonization on the placement specification for mineral liners and ultimately produce a guidance documents for use throughout the UK. This paper aims to review current practice and identify the misconceptions made in adopting this method in comparison with the currently proposed alternative methods.

Whereas mineral liners are used to prevent the migration of contaminates, typically in the form of leachate, leachate collection systems are intended to control the leachate head on any underlying liner to reduce the potential of leachate migration. In the UK these generally take the form of a continuous granular drainage blanket with perforated leachate collection pipes falling to a leachate collection sump. The thickness of the drainage blanket has, until recently, been specified as 500mm unless a thinner drainage blanket can be justified by risk assessment. In addition the paper reviews the specification of tyres as a leachate drainage blanket in terms of hydraulic conductivity, compressibility and installation.

2.0 UK Landfill Regulations

On the 16th of July 2002 the co-disposal of hazardous and non-hazardous waste in the same landfill was banned in the UK. This requirement of the European Union (EU) Landfill Directive was brought into force with the introduction of the Landfill (England & Wales) Regulations 2002 (Landfill Regulations). These Regulations are enforced by the Environment Agency.

All landfill operators were required to submit a Site Conditioning Plan to the Environment Agency prior to 16th July 2002, effectively requiring all existing sites to be classified as: Hazardous; Non-Hazardous, and; Inert. Based on the information provided in the Site Conditioning Plan the existing landfills were assessed on potential environmental risk. This allowed the permitting process to be brought in phases based on site priority in terms of low, medium or high. The final stage in the classification process was the submission of the Pollution Prevention and Control (PPC) Permit Application. The PPC permit application under the Landfill Regulations requires risk assessments to be carried out which adresses hydrogeology, site stability, landfill gas and habitats. In applying the Landfill Regulations the Groundwater Regulations must also be applied. The Groundwater Regulations require that there should be no unacceptable discharge to water.

The assessments, required as part of the PPC application, ensure that appropriate levels of engineering and site management are put in place according to the nature of waste to be disposed of. In assessing the engineering requirements of the landfill there are two basic rules which must be applied in all cases:

- There must be no likelihood of unacceptable discharge/emission over the entire lifecycle of the landfill (i.e. Landfill Regulations and Groundwater Regulations compliant);
- There must be structural/physical stability over the entire lifecycle of the landfill (Environment Agency 2004)

3.0 Mineral Liner Requirements

Schedule 2 of the Landfill Regulations outlines the minimum requirements for the geological barrier. The landfill base and sides shall consist of a mineral layer which provides protection to soil, groundwater and surface water at least equivalent to that resulting from the following permeability and thickness requirements:

(a) in a landfill for hazardous waste, $k \leq 1.0 \times 10^{-9}$ metre/second: thickness ≥ 5 metres;
(b) in a landfill for non-hazardous waste, $k \leq 1.0 \times 10^{-9}$ metre/second: thickness ≥ 1 metres;

(c) in a landfill for inert waste, k <= 1.0 × 10^{-7} metre/second: thickness ≥ 1 metres.

Where the geological barrier does not meet the requirements naturally, it may be completed artificially and reinforced by other means providing equivalent protection; in any such case a geological barrier established by artificial means must be at least 0.5 metres thick (Landfill Regulations 2002).

3.1 Hydraulic Conductivity

One of the most contentious issues in quality assurance testing is the degree to which hydraulic conductivity obtained from laboratory tests carried out on undisturbed 75mm diameter specimens provides an accurate indication of the field hydraulic conductivity. Benson (1999) studied eighty five compacted mineral liners, and has shown that for poorly built mineral liners the laboratory hydraulic conductivities can be several orders of magnitude lower than the field hydraulic conductivities (carried out using lysimeters and sealed double-ring infiltometers) when compared with well built liners where the two values can be very similar. Similar values of field and laboratory hydraulic conductivities occur when evaluated at similar effective stress and when the mineral liner in the field is devoid of macroscopic features e.g. macropores, cracks and fissures.

To ensure that compacted mineral liners will have low hydraulic conductivity, construction specifications typically in the UK require that the moisture content falls within a specified range and that the percentage of compaction is equal to or less than the 5% air voids. The upper moisture content has typically been set at the point at which the shear strength of the mineral liner meets the minimum strength requirements for the liner design, typically 50 kPa, although higher values may be required where slope stability requirements dictate. The specification of the lower moisture content limit is currently being debated.

3.2 Moisture Content Placement Criteria: Plastic Limit

Historically Plastic Limit (PL) has been set by the Environment Agency as the lowest acceptable compaction moisture content. It has been considered that this is the lowest moisture content at which the soil behaves in a truly plastic manner, and that a liner which exhibits plastic behaviour is able to absorb and 'self heal' any fissures which might develop as a result of stresses and strains imposed on the liner. In fact plasticity is the ability of a material to undergo permanent deformation under load. For a material to exhibit 'self healing' the material would have to be ductile i.e. a material which can deform without rupture.

The PL test is a measure of water content when an unconfined sample of soil ruptures and is not the limit of plastic behaviour. The laboratory test (BS 1377-2, ASTM D427 and DIN 18122-1) for determining the PL is universally accepted. The PL is defined as the water content where soil starts to exhibit rupture. To determine the PL a thread of soil is said to be at its plastic limit when it is rolled at low pressure between fingers to a diameter of 3 mm and crumbles. The PL test relies heavily on the skill of the operator and is entirely subjective despite attempts to define the procedure.

The test was subjected to a comparative testing programme carried out in the UK and reported by Sherwood (1970). The repeatability of the test undertaken by over 40 laboratories in the UK was tested and gave the results presented in Table 1 for PL.

Table 1. Results of comparative PL testing programme. (Sherwood 1970)

	Soil B	**Soil G**	**Soil W**
Plastic Limit %			
Mean	18	25	25
Range	13 - 24	18 – 36	20 - 39
S.D	2.4	3.2	3.1
Coefficient of Variation	13.1	12.8	12.7

The range of results is alarming but not surprising considering the test is highly dependant on the operator. Due to the low level of repeatability of the plastic limit it is considered that the results of the PL should be viewed with caution especially when trying to imply a relationship between Plastic Limit and field permeability.

Benson's (1999) study of compacted mineral liners concluded that the relationship between field permeability and soil properties, e.g. Atterberg limits, are not statistically significant. The data set showed that clay liners can be constructed with a broad range of clayey soils, and that values currently being used to define acceptable ranges for the Atterberg Limits and particle size characteristics yield liners with sufficiently lower hydraulic conductivity than the required design. Therefore the selection of materials based on classification parameters are purely guidelines and does not give any guarantee that the design criteria will be met.

3.3 Moisture Content Placement Criteria: Wet of Optimum Moisture Content

Soil compaction is an effective method to ensure suitable soil properties are achieved in creating a mineral, for example permeability. The extent of compaction depends on the moisture content of the soil and the compactive effort used. In a compaction test the object is to determine the optimum moisture content and maximum dry density achievable with a given compactive effort. A plot of dry density versus moisture content (Figure 1) indicates that compaction becomes more efficient up to a certain moisture content, after which the efficiency decreases. The maximum dry density is obtained at this optimum moisture content.

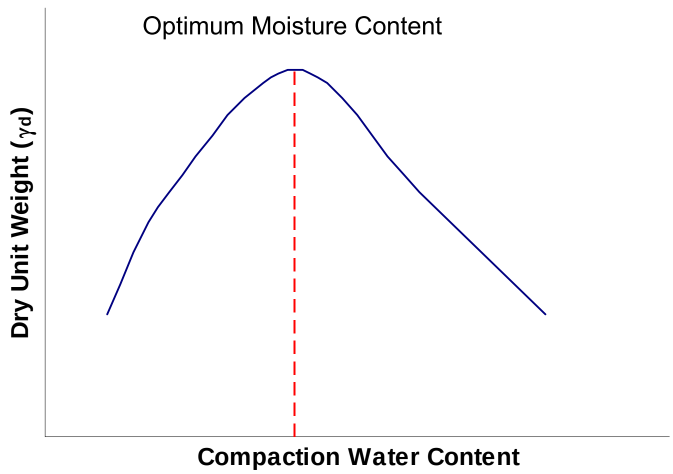

Figure 1 Dry density to moisture content relationship

Laboratory compaction methods are limited in simulating field compaction as the compactive effort in the field is impossible to determine in advance and will undoubtedly vary from point to point. On the basis of this it is difficult to justify a single arbitrary compactive effort for use in laboratory testing. Many UK designers currently specify either the 2.5 kg or 4.5 kg compactive effort. Instead it would be logical to select several compactive efforts in the laboratory that span the range of compactive efforts anticipated in the field. If laboratory testing is completed in this manner an appropriate approach would be to use the water content and dry unit weight of any intermediate compactive effort.

Many consider the mineral liner should be placed wet of the optimum moisture content. Materials wet of the optimum generally exhibit ductile behaviour, with materials placed dry of the optimum exhibiting brittle behaviour. Materials placed wet of the optimum are devoid of macroscopic features which increases the mass permeability of the mineral layer. This is particularly important when maintaining the required hydraulic conductivity in the long term. Whilst this practice of placing wet of the optimum moisture content is effective in terms of meeting the required hydraulic conductivity it may also cause problems with near surface desiccation or shrinkage cracking occurring within the compacted mineral liner. Boynton & Daniel (1985) demonstrated that desiccated clay swells when rewetted, but it does not regain the original low hydraulic conductivity if compressive stress from overburden is low. Therefore, it is very important to find a way to compact a mineral liner to achieve both low hydraulic conductivity and low shrinkage potential. In many cases the problem of shrinkage cracking is reduced by placing a geomembrane or a soil protection layer over the mineral liner.

Another factor that influences compaction is clod size. Benson and Daniel (1990) reported that clod size had a significant influence on hydraulic conductivity of soils compacted dry of the optimum moisture content. They observed that the driest specimen compacted appeared more like a granular material than a clay soil with the compactive effort not sufficient to reconstitute and remould the dry, hard clods together and eliminate large interclod voids. The resulting hydraulic conductivities were high. Increasing the compactive effort only resulted in greater deformation of clods, reduction of large voids, and a lower hydraulic conductivity. When the clay soil was compacted wet of optimum moisture content the clods were soft and remoulded with relative ease, resulting in smaller interclod voids and lower hydraulic conductivity.

Benson and Daniel (1990) suggest that clods may be destroyed in one of two ways:

i) The soil can be wetted with a high water content to produce soft, weak clods that can easily be remoulded into a mass that is free of large interclod pores (provided that the soil is reasonably workable at high water content, i.e. adequate shear strength)

ii) The soil can be compacted at a lower water content, but with an extremely heavy roller that crushes the clods and thereby eliminates large interclod pores.

The other aim of the compaction process is to achieve reduce the air voids in the mineral liner to a minimum, and therefore in addition to moisture content the other controlling factor is the dry density. The upper limit of the dry density is often referred to as the 5% air voids line or the line of optimum.

As part of Benson et al (1999) study of eighty five compacted mineral liners large-scale field hydraulic conductivity tests (lysimeters and sealed double-ring infiltrometers) were conducted. The database indicated that 1 in 4 of the mineral liners exceeded the required hydraulic conductivity. In most cases the primary cause for failure was that compaction was achieved dry of the line of optimum. The liners compacted with points falling on or above the line of optimum had permeability which met the required hydraulic conductivity. Often conventional compaction specifications are based on a minimum percent compaction and minimum water content, as shown on Figure 2 which leads to difficulties when trying to achieve compaction above the line of optimum.

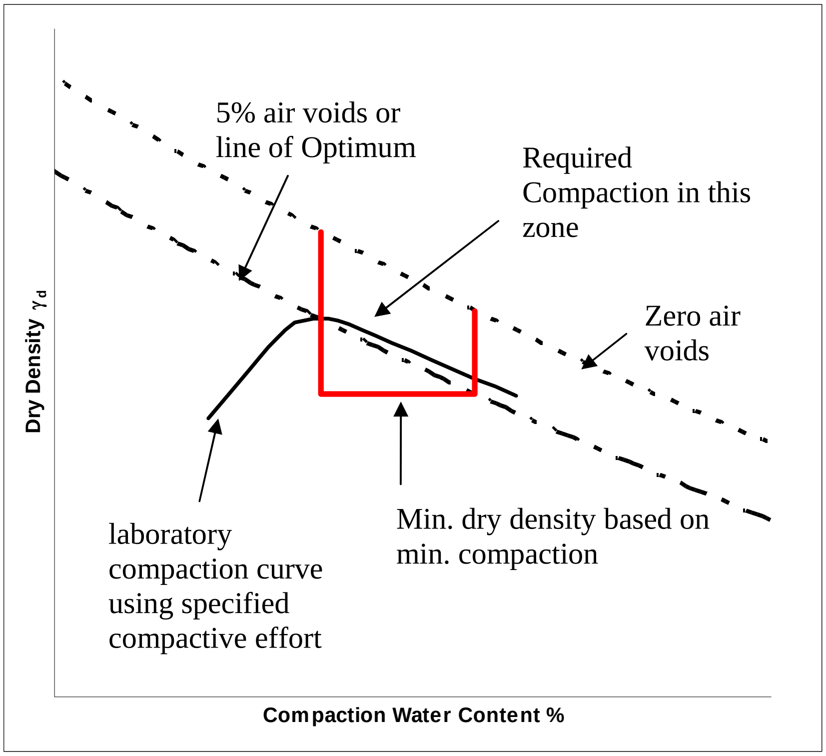

Figure 2 Percent Compaction Specification

In order to determine the compaction specification in terms of establishing water content and dry unit weights a comprehensive preconstruction laboratory testing is required. This shall include compaction tests at a range of compactive efforts to develop compaction curves. The compacted specimens should be permeated to determine their hydraulic conductivity at a variety of moisture contents it is important that this is carried out at stresses specific to the site conditions. The laboratory testing should be followed by the construction and hydraulic conductivity testing of a test pad to demonstrate that the required design hydraulic conductivity are achieved within the field.

4.0 Leachate drainage blanket

As part of the Landfill Regulations it is required that a leachate collection and sealing system is provided to ensure that leachate accumulation at the base of the landfill is kept to a minimum. This is a requirement for all non-hazardous and hazardous landfills. Inert landfills do not require a leachate collection system as it is expected that there will be no generation of leachate from inert waste.

In the UK the requirement has been for a 500mm thick layer, unless justified otherwise by risk assessment. The Environment Agency and Waste Industry are working together towards developing a model to assess the efficiency of different thicknesses of leachate drainage blanket and particle size grading of aggregate for leachate drainage blanket. In the interim the Environment Agency have issued guidance which allows the drainage blanket to be reduced to a 300mm thick granular leachate drainage blanket in combination with a robust and well engineered slotted/perforated pipework system (Environment Agency 2007a).

The leachate collection system has two primary functions; firstly to reduce leachate head acting on the liner; and to remove contaminant from the landfill. To reduce the leachate head acting on the liner all cell bases within the UK are required to have a minimum gradient cell of between 1% and 2%. Secondly the leachate drainage blanket must have a sufficient hydraulic conductivity to ensure that the leachate generated can be removed effectively for the required design life. Hydraulic conductivity values required for the drainage medium are typically between 1×10^{-3} m/s and 1×10^{-4} m/s.

4.1 Aggregate Leachate drainage blankets

Originally leachate collection system designs in the UK consisted of perforated pipes surrounded by granular material. In order to reduce the likelihood of leachate mounding or head between pipe spacing a full drainage blanket of 500mm was introduced by the Environment Agency. The design of this 500mm drainage blanket was dependant on the liner details for the site. Typically where geosynthetic liner systems were installed the drainage blanket was specified as a 100mm thick layer of BS 13242:2002 10/20 size aggregate and an overlying 400mm thick layer of 20/40 size aggregate. For sites with only mineral liners the leachate drainage blanket was specified as 500mm thick 20/40 aggregate placed on a separator geotextile overlying the mineral liner. For aggregate placed on a geosynthetic liner system the aggregate is required to comprise of rounded particles. The rounded particles are to prevent perforation or excessive straining of the geomembrane liner by the individual sharp particles due to high waste loading. To protect the impact of aggregate loading on the geomembrane liner a protector geotextile is placed above the geomembrane. Cylinder tests (Environment Agency 2006) are required to assess the performance of the proposed protector geotextile under site specific conditions. In order to reduce the grade of the required protector geotextile the 100mm thick finer graded aggregate is specified to be placed in direct contact with the protector geotextile. The remaining 400mm layer thickness is comprised of 20/40 aggregate.

4.2 Biological and Chemical Clogging

Biological and chemical clogging requires consideration when designing leachate drainage blanket. Clogging of the drainage layer becomes significant when the hydraulic conductivity of the blanket drops to, or below, the hydraulic conductivity of the overlying waste. Research has demonstrated a clear relationship between the grain size distribution and biological/chemical clogging. The work of Rowe et al. (2002) confirmed that increased pore size associated with larger particle size increases the time required for occlusion of pore spaces. Brune et al. (1999) showed that pore spaces of the drainage medium become clogged with aggregates of bacteria and deposits of inorganic material. The major component of clogging appears to be microbiology related. The anaerobic conditions that exist in a leachate drainage blanket lend to the formation of biofilming and encrustation. The clogging rate has been shown to be governed by leachate strength and the volume of leachate passing through the drainage medium and therefore not strictly time dependant.

The Environment Agency's (2007a) interim guidance has reduced the thickness of the drainage blanket to 300mm. However, to take in to account the affects of the clogging in the long term, and a requirement to maintain hydraulic conductivity, the aggregate is required to be 20/40 throughout its full thickness. A reduction in aggregate grading to 10/20 is permitted provided that a filter geotextile is placed over the drainage blanket. In general the 10/20 aggregate is applicable where it is to be placed over a geosynthetic liner.

Studies by Flemming et al. (1999) compared clogging of the drainage blanket in direct contact with the overlying waste with that where a non-woven geotextile filter had been placed between the waste and the underlying drainage blanket. The study showed a significant difference in the upper portion of the collection system. Where the geotextile filter had been used 0 and 20% of the pore space was filled with clog material whereas there was a 30-60% loss of pore space in a comparable area where no geotextile was used.

The advent of the aggregate tax on virgin aggregates in the UK, together with environmental pressures has led to an increase in the use of secondary aggregates as leachate drainage. Suitable secondary aggregates can consist of crushed concrete, waste bricks, glass and tiles. Consideration of the suitability of these materials as a drainage aggregate is dependant on hydraulic conductivity, physical strength, chemical compatibility, protection to the liner system, and the uniformity of this material. Currently there is no guidance on use of this material and the responsibility lies with the designer proposing the material to demonstrate that their performance as a leachate drainage blanket is satisfactory. Equally important is the design of the filter geotextile in terms of its ability to filter (pore opening size) and its long term durability (resistance to chemical and microbiological degradation.

4.3 Tyres as Leachate drainage blankets

From 16th July 2003 the Landfill Regulations required that tyres were no longer allowed to be placed in landfills but could be used for engineering applications. As a result the use of whole and shredded tyres as a leachate drainage blanket was permitted on sites. Currently the Environment Agency are reviewing the design and performance of 'Used Tyre Derived Aggregate Replacements' (UTDAR) and have issued an interim guidance note on their use (Environment Agency 2007b). Due to the uncertainty regarding performance of the UTDAR the Environment Agency has specified that they should not be used on sensitive landfill sites, e.g. major aquifers or high source protection zone/areas, unless proven by risk assessment that the protection of the environment is insensitive to the control of leachate heads within the waste.

When specifying tyres as the leachate drainage blanket consideration needs to be given to the suitability of UTDAR in particular with regard to the following: hydraulic permeability; tyre compressibility, and; installation.

Hudson, Bevan, Powrie and Parkes (2007) suggest that hydraulic conductivity of UTDAR will be higher than that achievable by primary aggregates under clean conditions. McIsaac and Rowe (2003) conducted a series of laboratory experiments which suggested that clogging rates using shredded tyres was higher than aggregates, than that of an aggregate drainage layer lasting 3 times longer than a layer of compressed tyre shreds. The difference in clogging rates is primarily due to the difference in void structure in the tyre shred compared with the aggregate and its effect on the exposed surface area available for clog growth. In particular the compressibility of the shreds allows the void space between the shreds to decrease as the waste load is applied resulting in shred to shred contacts, low initial void volumes and small constrictions between open void space. As a result it is recognised that a greater compressed thickness of material will be required to achieve the same service life as a conventional aggregate drainage layer. Therefore the recent Environment Agency guidance calls for a minimum compressed thickness of 500mm of shredded tyres as opposed to the current 300mm thick layer for aggregate drainage layers. In addition a filter geotextile is recommended to be placed over the shredded tyres to reduce the clogging rate of the drainage blanket.

Shredded, whole and baled tyres compress at different rates depending on the waste loading. Bevan et al (2006) provides recommendations based on the data presented in their paper on the initial thickness of an uncompressed layer of different forms of tyre drainage layers that will compress to a thickness of 500mm under increasing depths of waste with an average density of 1t/m^3, see Figure 3.

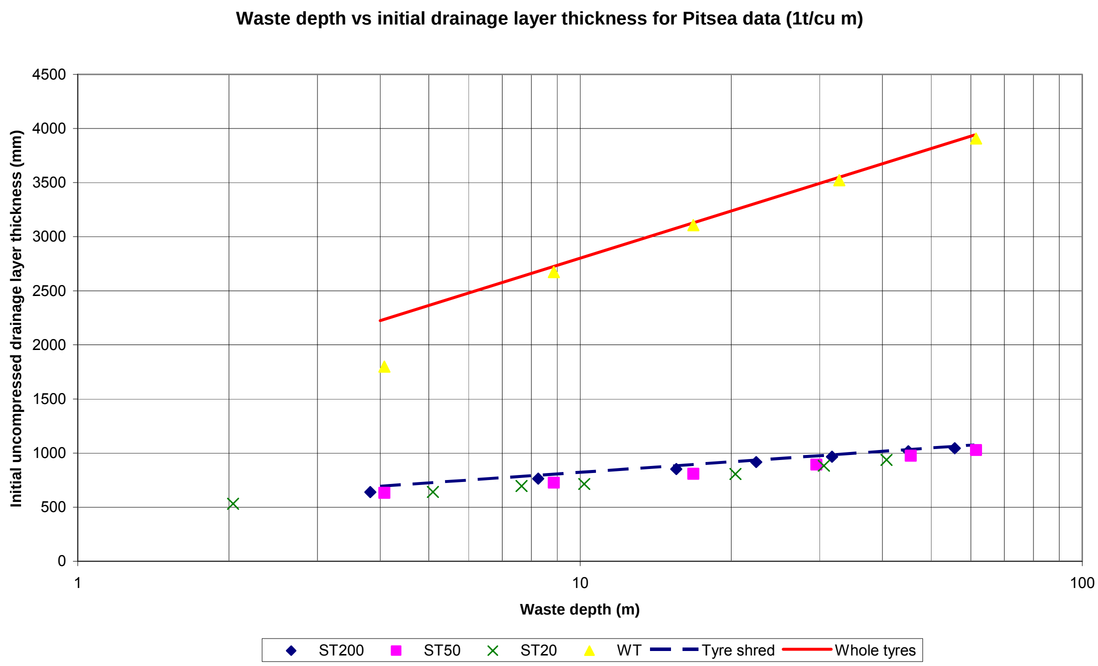

Figure 3 Compressibility of different forms of tyre drainage layers with waste depth

In general waste operators prefer shredded tyres as opposed to whole tyres as the initial volume of tyres required is less. This is particularly important considering the storage of tyres on site and the risk of fire, and the placement method being less tedious

A major concern for the installation of shredded tyres as a leachate drainage system over geosynthetic liner is the possibility of exposed metal wires protruding from the shreds and puncturing the liner. To prevent this happening, tyre shreds containing bead wire should not be placed in contact with the underlying geosynthetic liner. GeoSyntec (1998) suggested a 150mm layer of soil with a hydraulic conductivity equivalent to coarse gravel would provide suitable protection to the underlying liner. In comparison, whole tyres can be placed in a random manner or in a regular herringbone 'laced' pattern directly on to the liner system. Random placement has the advantage of producing a more homogenous hydraulic performance but is subjected to tyre displacement, whereas regular placement has the advantage of producing a uniform thickness of drainage blanket and therefore is the preferred option. Whichever placement method is adopted, it is important that every effort is made to limit the "floatation" of tyres up through the waste. In order to prevent this a geogrid or geotextile is recommended to be placed over the mass of tyres and overlapped and tied in at the edges to reduce dislocation during waste placement. Due to concerns regarding installation and protection of the underlying liner system UTDAR are generally specified where the liner is mineral only as oppose to geosynthetic where the risk of puncturing and damage is higher.

5.0 Conclusions

Over recent years in the UK, the philosophy behind many aspects of landfill design has changed as a result of research development and experience. This has in brought with it some changes in the engineering requirements of landfills. In order to bring consistency within the industry the UK's Environment Agency has produced guidance notes on many aspects of landfill design, in particular with regards to mineral liners and leachate drainage blankets. However, it is stressed that these are 'guidance' notes and ultimately the responsibility lies with the designer to specify the particular engineering requirements for a site on a site-specific basis. The design should be undertaken with full knowledge of the site's risk assessments. Details of the availability and type of materials should be obtained at the earliest opportunity to allow a carefully planned regime of laboratory testing, and where required field trial testing, to be carried out prior to the start of engineering works, allowing appropriate specification of materials avoiding costly delays. It is important to appreciate that the design of landfills will evolve with time as the behaviour, durability and efficiency of materials are better understood as a result of long term research and experience.

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