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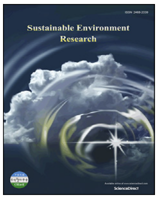

Original Research Article

An experimental study on the impact of two dimensional materials in waste disposal sites: What are the implications for engineered landfills?

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ABSTRACT

It is generally accepted that landfilled municipal solid waste develops a heterogeneous and anisotropic structure during placement, degradation and settlement. Flow and transport processes, in traditional and alternative landfills, are strongly influenced by the type of structure developed. The presence of preferential flow has gained research interest, given its impact on landfill processes. This paper describes an experimental investigation carried out on a specimen of degraded municipal solid waste.

Preferential flow was detected and caused by the specimen layered structure composed of two dimensional particles derived from less easily degradable materials such as plastics, textiles and paper which made up more than 50% of the specimen dry mass. The results suggest that two dimensional particles play a role in promoting preferential flow because they modify flow paths and increase the tortuosity. A high content of less easily degradable two dimensional materials suggests incompatibility with better management practices, seeking a more even distribution of fluids to enhance degradation and faster stabilisation rates within engineered landfills. Consequently, there is a need to re-think the types and quantities of materials that are restricted under current landfill policies.

1. Introduction

In total 1.3 billion tonnes of municipal solid waste (MSW) are produced globally, at an average daily rate of 1.2 kg per capita. By 2025 this amount will increase to 2.3 billion tonnes per year [1].

Although final disposal of MSW is considered the least desirable option it remains the predominant solution worldwide [2]. Approximately, 80% of global urban MSW is placed in waste disposal sites, of which only 20% is contained in engineered and controlled landfill sites [3]. This is despite the fact that pollution originating from active and closed landfill sites and open dumps, is likely to persist for centuries, rather than decades [4]. MSW has a heterogeneous composition. Its properties are influenced by the materials that constitute the waste body. The nature of MSW varies within and among countries, although some general tendencies can be drawn [5,6]. In higher income countries, paper and plastics, account for 31 and 11% of the waste matrix, respectively. Under current MSW practices, the entry of paper, plastics and textiles into controlled waste disposal sites is not likely to experience a significant reduction in the short to medium term because their generation is linked to economic growth [1]. Such waste entries are incompatible with waste management practices focused on recycling and recovery [7,8].

The effect of preferential flow (PF) on modern landfill operation is not yet certain, although the effectiveness of leachate and gas collection systems in engineering landfills and the operation of modern landfills, that seeks to improve biodegradation and stabilisation processes, do rely on the fluid flow characteristics of the waste body [2]. Research evidence suggests that certain materials such as paper, plastics and textiles have the potential to affect fluid flow patterns and therefore influence some characteristics within a waste body. The experiments discussed in this paper add further empirical evidence to support this hypothesis.

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To use the United Kingdom as an example, approximately 48 Mt of MSW were generated in 2006. This was reduced to 28 Mt by 2012, due to the implementation of the 1999 Landfill Directive. This European directive was introduced in an attempt to reduce the amount of biodegradable waste sent to landfill. It was successful. The proportion of such waste was 79% in 2006, a percentage which dropped to 46% by 2010 [9]. The disposal of plastics however, has not seen such a reduction. In fact, the amount of plastic sent to UK landfills increased slightly from 3.5 to 3.9 million from 2006 to 2010 [10].

Any increase of non-easily and not rapidly biodegradable materials such as, but not limited to, plastics, textiles and paper may be of concern for controlled waste disposal site operations and management, as two dimensional particles (as defined in Section 2.3) are thought to divert or impede flow paths, alter flow patterns and reinforce the waste structure [11–15]. This likelihood is thought to increase with particle size and higher overall proportions in the waste body. If the materials are horizontally oriented, this will also have an effect. Two dimensional particles are said to reduce permeability in porous medium, whilst increasing its heterogeneity [11,16–18]. The combination of these effects increases tortuosity [19,20], which may influence the transport and distribution of liquids and gases within a waste matrix. Such conditions could favour PF, a mechanism which causes the transport of contaminants to be associated primarily with a small fraction of the total pore space [21].

The transport of water and solutes is essential for the degradation of biodegradable fractions within the waste matrix, as this leads to the stabilisation of landfilled waste. The distribution and eventual flushing of non-biodegradable substances, are also dependent on the movement and distribution of liquid through waste which are, in turn, strongly influenced by the MSW structure. Studies by Dixon and Langer, Hudson, Ivanova and Rees-White at laboratory and field scale [14,22–24] indicate that landfilled MSW develops a strong, layered and anisotropic structure, resulting from its heterogeneity and deposition in progressive layers and compaction. Experimental laboratory work on waste columns has revealed the presence of non-uniform flow and stagnant zones [25–27] whilst tracer test field studies indicate PF in landfills [28–30].

Scaling up results from laboratory to field scale is a challenge for scientists. Some of the difficulties include the number and size of the samples used, and the representation of field conditions in the laboratory. A study by Rosqvist and Destouni [30] compared experimental results from tracer tests at both laboratory and field scales. Their results showed that not only the waste body but also, the local fluctuations of the surrounding environment, can influence the hydraulic characteristics and flow patterns and by extension, favour PF in landfills. To better understand the nature of different phenomena in landfills (e.g. hydraulic properties, flow patterns, waste mechanics and degradation rates), controlled experiments are generally first conducted at laboratory scale and, at later stages are scaled up to pilot or landfill scales, in order to properly account for site specific conditions.

Plastics, textiles and paper are of particular interest when it comes to enhancing engineered landfill performance, via an improved understanding of how such materials can create PF conditions. PF could, for example, lead to a partial leaching of the bulk waste fill, giving a false indication as to the degradation state of a waste disposal site. This may result in an underestimation of pollution potential and the premature and erroneous decision to change a site's status from closure to post-closure [30].

In this paper, the extent of which plastics, textiles and paper, influence MSW structure and PF is investigated using flow visualisation techniques. Changes in the mass fractions during degradation and how they may affect landfill processes are also discussed.

2. Materials and methods

PF mechanisms are widely studied within soil science and related disciplines. Flow visualisation studies have become increasingly popular because they permit the optical recognition of flow paths and make it possible to infer flow regimes from both a qualitative and quantitative perspective [31,32]. Flow visualisation techniques can range from the qualitative observation of structures [33,34] to the use of tracers, particularly dyes such as Brilliant Blue [21,34]. The latter is used in this paper.

2.1. Sample and previous testing

An experimental study was undertaken using a compressed and aged waste sample, collected in 2007 from a MSW landfill site in the UK. Both the waste structure and the flow paths were analysed through visual methods, using Brilliant Blue dye. The study of the structure involved the cutting of the sample into sections to evaluate its content and layout. Special attention was paid to the orientation of those two dimensional materials that have the potential to modify flow patterns.

The waste specimen was previously used in waste settlement studies by Ivanova [23]. A pre-treatment of the waste specimen included the removal of metals and the characterisation of waste constituents. The specimen was used as a control sample placed in a consolidating anaerobic reactor (CAR), where microbial processes were inhibited during the first 345 days, in acidic conditions. The sample was saturated using a prepared mineral media containing 10% of anaerobically digested sewage sludge. Following the 345 days, the sample was kept for a further 574 days in a perspex cylinder of 480 mm diameter, under a 50 kPa compression load, achieving a final dry density of 0.48 t m^{-3} and a total porosity of 31.4%.

2.2. Hydraulic conductivity measurements

The sample's hydraulic characteristics were obtained via hydraulic conductivity measurements. It was re-saturated by pumping water through the base of the CAR cell. Constant head (CH) hydraulic conductivity tests were performed with the methodology typically used for compressed soil and MSW samples [35–37]. The CH tests were run in upward and downward flow conditions to assess any significant differences produced by localized pore water pressures or air bubbles under both flow directions. The test were run under three different hydraulic gradients (i.e., 0.5, 1.5 and 2.5). The inlet and outlet head conditions were set by installing pipes connected to the top platen holes, which in turn discharged through a 'T' joint with a breather pipe open to atmosphere as described by Sandoval [38].

2.3. Structural and material characterisation

Following the hydraulic conductivity tests, the core sample was drained and extracted from the cell using a piston and then wrapped in cling film. It was 483 (±4) mm in diameter, suggesting that the original structure had been reasonably well preserved.

The core's top portion (230 mm height) was cut into six 80 mm wide sections (denoted a, b, c, d, e and f in Fig. 1) so as to enable a detailed structural examination; the bottom core section (120 mm height) was used in dye tracer tests (see Fig. 1b). The remnants from the cutting process, 2000 g of the original sample, were thoroughly mixed together to provide five representative waste sub-samples, in preparation for the particle size distribution (PSD) analysis and subsequent material characterisation. The five samples were sieved using meshes of 20, 12, 7, 5, and <5 mm, according to the British

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