# FORMULATING ESSENTIAL MODELS FOR PREDICTING THE HYDRO-PHYSICAL PROPERTIES OF MUNICIPAL SOLID REFUSE FILLS

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**Abstract:** In this study, characteristic equations have been fitted to waste data obtained from small and large-scale tests on household refuse in an effort to describe the trends of the hydraulic and physical properties of municipal solid refuse fills. Whereas precise quantification of the waste properties may not be achieved with the formulated models, typical values that are useful for preliminary designs and operations of municipal refuse landfills can be obtained. These values would significantly enhance the understanding and the operation of solid waste facilities thereby minimising their pollution potentials. Owing to the necessity to formulate specific models for specific landfill sites due to the disparity in waste properties at various sites, the formulation process in this study is recommended for obtaining empirical models suitable for predicting the waste parameters often needed in the alternative analysis of solid refuse landfill systems. [Report and Opinion 2010;2(6):43-52]. (ISSN:1553-9873).

**Keywords:** hydro-physical properties, models, test data, curve fitting, municipal solid refuse.

## 1. Introduction

Any material that is unused or rejected as worthless or unwanted will intimately be disposed of to a refuse dump or an engineered landfill. The unabated and indiscriminately dumping of waste in refuse dumps in the developing countries has been responsible for various water-borne diseases as dumping sites are commonly located in areas susceptible to surface water flow, the streams of which often serve as the only supply of drinking water to the community ((Fenwick, 2006; Ejechi and Ejechi, 2008). Unfortunately, the affected people in these areas are usually very poor and therefore unable to afford basic medication, thereby resulting in deaths that can be prevented if there is adequate waste and water management in the respective countries (Fenwick, 2006). In recent years, the United Nations agencies and various charitable organisations have been involved in providing drinking water from deep wells and also providing basic medical needs to the poorest countries in the world. Many of these countries have also been promoting environmental awareness with the principal objective of educating its citizens of the dangers of polluted environment to human health and the need for sustainable development on Earth. In the developed countries, the current government policies to "reduce, reuse, and recycle" materials and the practice of engineered landfilling have significantly reduced the adverse effect of waste landfill on sustainable living. However, the pollution potential of the old landfills, which were operated prior to the engineering of landfills exist, and cannot be ignored, and may even jeopardise current efforts, if not dealt with using appropriate methods. For the overall global objective of sustainable development to be achieved, the origin and source of any environmental pollution ought to be identified and assessed so that adequate measures could be provided to prevent or limit its negative potential. Owing to the non-availability of comprehensive data on waste landfills and the difficulty in measuring the waste properties in situ, researchers often rely on modelling waste characteristics using models often derived from test data which appeared representative of the field data (Oni and Richards, 2004; Beaven and Powrie, 1996).

Waste is heterogeneous in formation and also in its emplacement within and in landfills therefore making it very difficult to predict its behaviour unlike soil which is mainly homogenous in nature. Waste streams deposited to municipal refuse fills often comprise materials that range from tiny perishable (putrescible) materials to large chunks of glass and stones, poly sheets and planks of wood. The complex nature of waste makes it difficult for the formulation of models that can adequately describe the bio-chemical processes within a waste fill (El-Fadel et al., 1997). In essence, the majority of the essential waste models formulated for waste have been for hydraulic and physical properties (Bleiker et al., 1995, Oni and Richards, 2004). Owing to the popular and public identification of waste fills with leachate, it is not surprising that the majority of the models on waste have been for the prediction of the volume of leachate produced from refuse landfills. (Holmes, 1980; Campbell, 1983; Farquhar, 1989; Blight et al., 1989; Bengtsson et al., 1994; Parsons, 1995; El Fadel et al., 1997; Oni, 2000; Oni and Okunade, 2009.). In this aspect, the Hydrologic Evaluation of Landfill Performance (HELP) computer model, developed by the U.S Army Engineer Waterways Experiment Station for the U.S. Environmental Protection Agency Risk Reduction Engineering Laboratory had been widely used (Schroeder et al., 1994). The model basically uses a quasi-two-dimensional hydrological model with underlying basis of the water balance method, which utilises weather, soil and design data to simulate the water movement across, into, through and out of waste landfills.

In order to enhance stabilisation methods such as leachate recycling in waste fills, investigations have also been undertaken on the modelling leachate solute transport in waste fills using physical and stochastic models (Rosqvist and Bendz, 1999; Rosqvist and Destouni 2000; Beaven and Hudson, 2003; Beaven et al., 2005; Rosqvist et al., 2005, Oni, 2009; Oni, 2010a; Oni, 2010b; Oni, 2010c; Oni, 2010d; Oni, 2010e). In all the cases, traditional soil models have been employed using the waste data obtained from tests in mainly large cells and pilot landfills. In general, the modelled and the measured data of waste have been found to be reasonably synonymous. Owing to the complex nature of waste, models that can exactly simulate field conditions have been not been formulated, and probably may never exist, therefore waste models have been commonly validated based on reasonable fitting often based on the characteristic trends of the pertinent waste properties. It is very important to recognise that the traditional soil models which have been typically used for waste properties have been initially formulated as empirical models derived from fitting trend equations to the measured soil data. The successful validation of such trend equations on different types of soils consequently resulted in world-wide acceptance and general formulation of these traditional models.

Owing to the heterogeneity of waste, it is unlikely to formulate universal characteristic models that can be used to simulate the properties of waste. Instead, formulated models on waste will be applicable only to the general waste type of the waste fill from which the test data utilised for the derivation is obtained from. In this study, trend equations have been fitted to the data obtained from hydro-physical tests on similar municipal solid refuse in small and large cells. The use of data from varied scales of tests was undertaken to enhance the modelling process through curve fitting over a wide spectrum of the the respective waste property.

## 2. Methodology

### 2.1 Data

The data used for the formulation of the trend equations were obtained from tests undertaken on municipal solid refuse in small scale cells (Oni, 2000) and large scale cells (Beaven, 2000; Beaven and Powrie, 1995; Beaven and Powrie, 1996). The test procedure for these tests have been well defined by various authors and therefore summarised herein.

The small test cell, shown in Figure 1 comprises a 12 mm thick Perspex cylinder, 240 mm internal diameter and 230 mm height, which was sealed with Perspex plate and firmly secured in a hollow wooden base plate fastened to a wooden support frame. The waste in the cell was compressed by a perforated 240 mm-diameter Perspex platen (8 mm-hole diameter), connected by steel rod to an upper wooden base platform on which various loads were applied. To enhance uniform water inflow, a 50 mm deep layer of 10mm washed gravel was located on the base plate. Other components such as galvanised steel screens, polystyrene cubes, Pyrex standpipes, flow ports, and a manifold of distributing plastic tubes were fixed appropriately to enhance accurate measurements of the properties of the waste fill in the cell. The fresh waste materials used in the tests were obtained from the working face of an active cell at White's Pit landfill, Magna Road, Wimborne, Dorset. The composition of the waste materials is summarised in Table 1. Owing to the small size of the cells, the waste particles were reduced to a particle size of 20 x 5 mm, which was deemed compatible with the size of the test cell. This complies with the report by Wall and Zeiss (1995) that waste samples used for conducting behavioural tests should be less than 20% of the diameter of the test cell in order to achieve pragmatic results. To replicate various landfill practices, three different types of waste samples were used in the tests. They are: (1) Sample 1, which comprises waste materials only; (2) Sample 2, which comprises waste materials with interbedded layer of a cover material whose thickness was 7.5% of the entire waste fill; and (3) Sample 3, which comprises waste materials with interbedded layer of a cover material whose thickness was 10% of the entire waste fill. The cover soil was obtained from the sand residue of the mineral excavation of the site and was classified as lightly clayey/silty gravely sand, with a density of 1850 $kg/m^3$ and saturated hydraulic conductivity of $6.35 \times 10^{-7}$ m/s (Oni, 2000). The various hydro-physical tests were undertaken using the experimental methods commonly used in the measurement of soil and waste properties.

The large-scale cell (Pitsea cell) is a compression cell which comprises a steel cylinder, 2m in diameter and 3m in height, into which refuse was placed for various types of tests. The cell was placed on load cells, which allowed continuous measurement of the weight of the waste fill in the cell. The base of the cylinder was sealed by a lower platen seated on an "O" ring to create a watertight seal, and the upper platen was connected to, and moved by two 200mm diameter hydraulic operated pistons. The maximum load application was 1900kN. Water was supplied to the cell via two 450l tanks and the water flows throughout the tests were measured with electromagnetic flow meters. The waste materials were obtained from the tipping face of a municipal landfill in the proximity of Pisea, Essex, UK (Beaven, 2000; Beaven and Powrie, 1995; Beaven and Powrie, 1996). The composition of the waste materials is shown in Figure 1. As in the small scale tests, the hydro-physical tests were undertaken using the typical experimental methods for the measurement of waste properties.

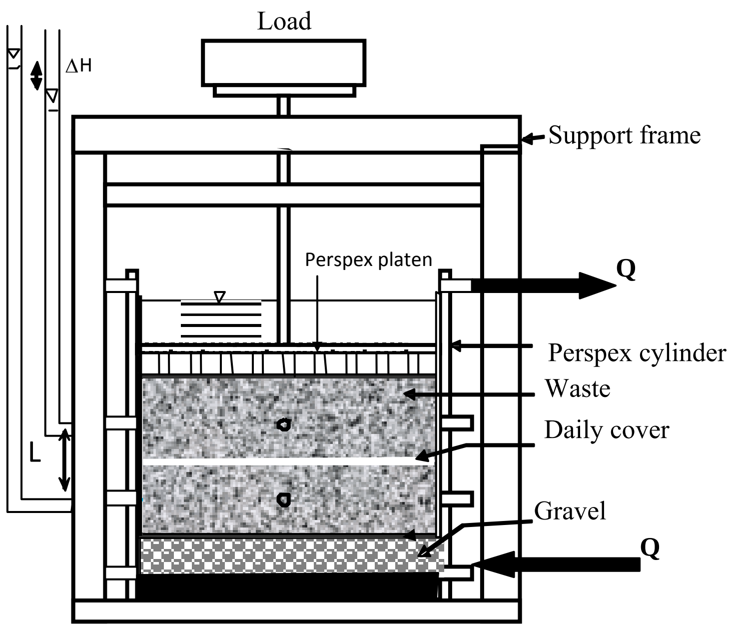


Figure 1: The small compression cell unit used for the hydro-physical tests on municipal solid refuse (Oni, 2000)

Figure 2: The large-scale Pisea compression cell unit used for the hydro-physical tests on municipal solid refuse (Beaven, 2000; Hudson, 2010)

Table 1: The composition of waste samples used in the test (Oni, 2000; Beaven, 2000)

| | Percent of dry mass (%) | | | | |
|---|---|---|---|---|---|
| Waste components | Waste 1 (No cover soil) | Waste 2 (7.5% cover soil) | Waste 3 (10% cover soil) | Beaven (No cover ) | Dry unit mass (kg/m$^3$) |
| Paper | 24.09 | 24.47 | 22.8 | 35.1 | 0.4[a] |
| Cardboard | 4.82 | 5.98 | 5.57 | | |
| Thick plastic | 4.6 | 3.57 | 3.33 | 5.7 | 1.1[a] |
| Thin plastic | 7.12 | 5.54 | 5.16 | 4.4 | 1.0[a] |
| Textile | 2.21 | 1.71 | 1.6 | 2.6 | 0.3[a] |
| Glass | 5.33 | 4.14 | 3.86 | 5.5 | 2.9[a] |
| Ferrous Metals | 5.66 | 3.42 | 3.19 | 7.0 | 6.0[a] |
| Non Ferrous metals | 1.85 | 1.44 | 1.34 | 1.5 | 6.0[b] |
| Combustible | 7.94 | 6.17 | 5.75 | 9.1 | 1.0[b] |
| Wood | 0.69 | 0.54 | 0.5 | | |
| Green/garden | 18.46 | 10.83 | 10.09 | 22.0 | |
| Food waste | 8.55 | 2.91 | 2.72 | | |
| Misc. non combustible | 0.96 | 7.33 | 6.83 | 1.0 | 1.8[a] |
| Fines<10mm | 7.71 | 21.95 | 27.27 | 6.2 | 1.8[b] |
| Total | 100 | 100 | 100 | 100 | - |

**2.2 Formulation of Characteristic Models**

Formulation of empirical models to soil and waste characteristics such as settlement of fills is often done by fitting curves and equation to the measured temporal spot heights (Buisman, 1936; Sowers, 1973; Charles and Burland, 1982; Wall and Zeiss, 1995). In this study, the formulation of characteristic models for typical hydro-physical properties of municipal solid refuse has been done in three stages as follows:

- Stage 1: Plot the measured data of waste properties for both large and small scale tests
- Stage 2: Fit curves that depict the trend of data. The curves have been chosen so that the same trend reasonably fit the data for both the large scale and small scale tests.
- Stage 3: Formulate equations for the fitted curve, showing the goodness of fit using the $R^2$- value of the data plot. R2 is the square of the correlation between the response values and the predicted response values.

**3. Results and Discussion**

The plots of the data of various hydro-physical properties of the municipal solid refuse described above are shown in Figures 3 – 8. All the plots have been depicted such that the visual comprehension of the behavioural trend of the pertinent waste parameters is simple and clear. The similarity in the waste composition of the small scale and large scale tests (Table 1) enables the two datasets to be combined and plotted as a single but larger dataset. A semi-log plot of saturated hydraulic conductivity against the dry density (Figure 3) shows a linear relationship; with the correlation value ($R^2$) for the plots of small scale and large scale tests more than 0.92. The use of the dry density as determinant parameter is often desired as it is easier to measure than the majority of waste parameters. The $R^2$ for the single plot for all the data is slightly more than 0.91, indicating that the unified trend equation (Table 2) that relates dry density to the saturated hydraulic conductivity of the municipal solid refuse is reasonable. This trend equation is a characteristic or empirical model that can be used to predict saturated hydraulic conductivity values for known or determined values of the dry density for any municipal solid refuse that is similar in composition to the waste materials used in tests summarised in this study.

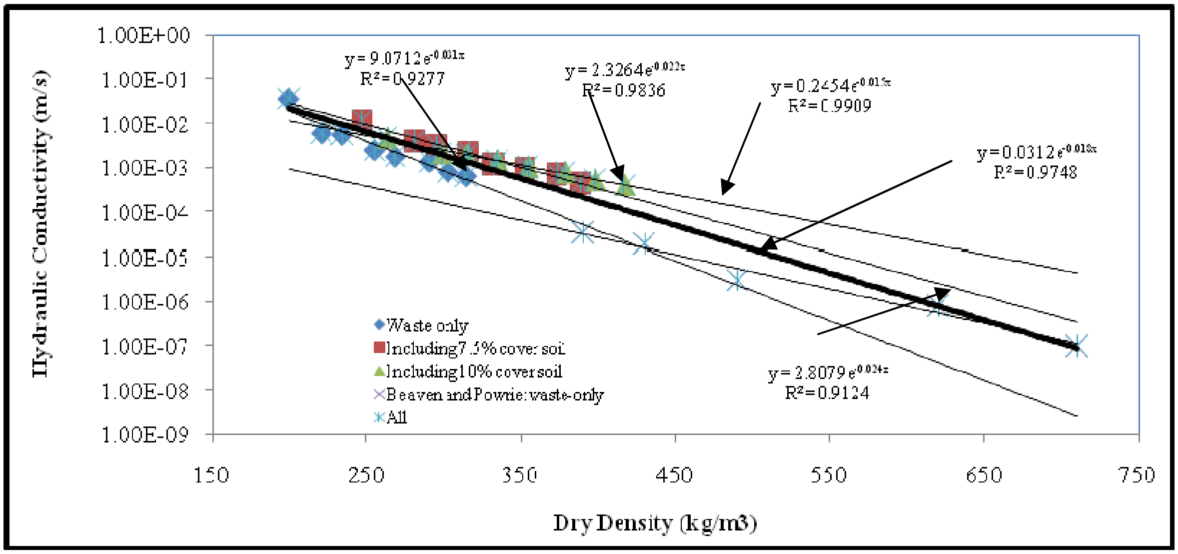


Figure 3: The plots and characteristic trends of saturated hydraulic conductivity versus dry density for the municipal solid refuse

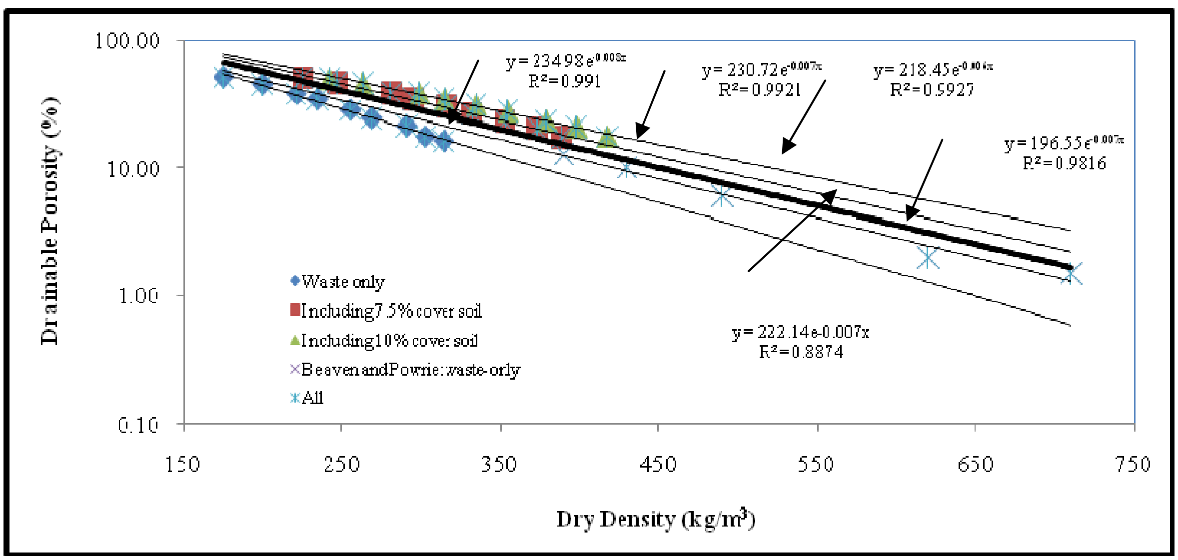


Figure 4: The plots and characteristic trends of drainable porosity versus dry density for the municipal solid refuse

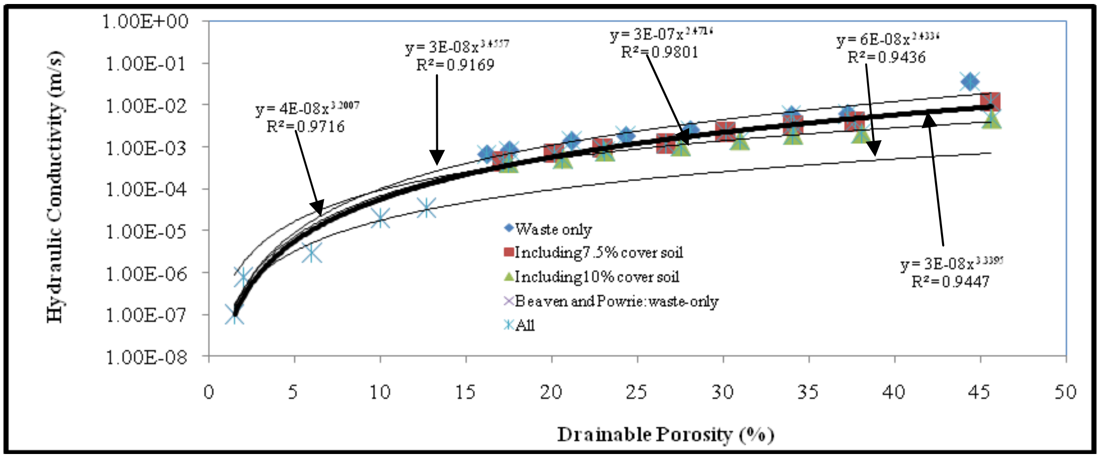


Figure 5: The plots and characteristic trends of saturated hydraulic conductivity versus porosity for the municipal solid refuse

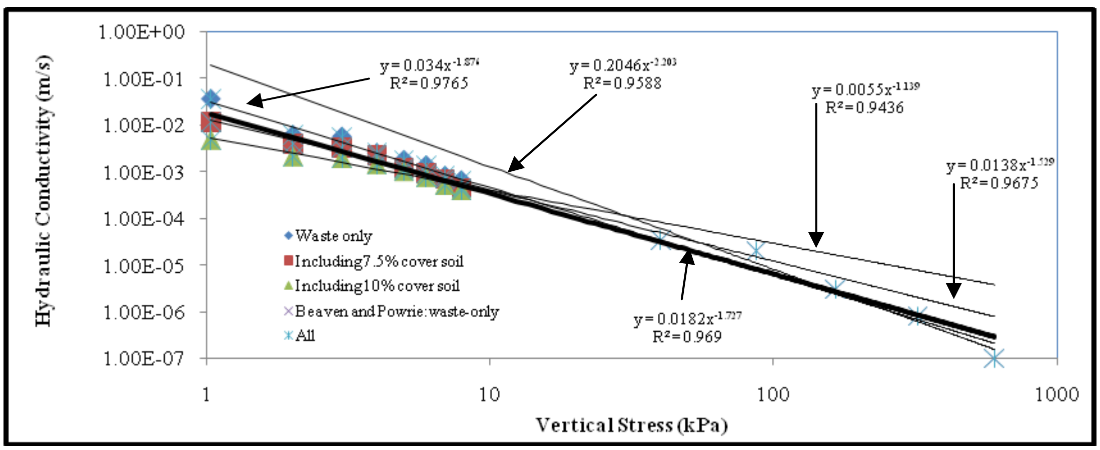


Figure 6: The plots and characteristic trends of saturated hydraulic conductivity versus vertical stress for the municipal solid refuse

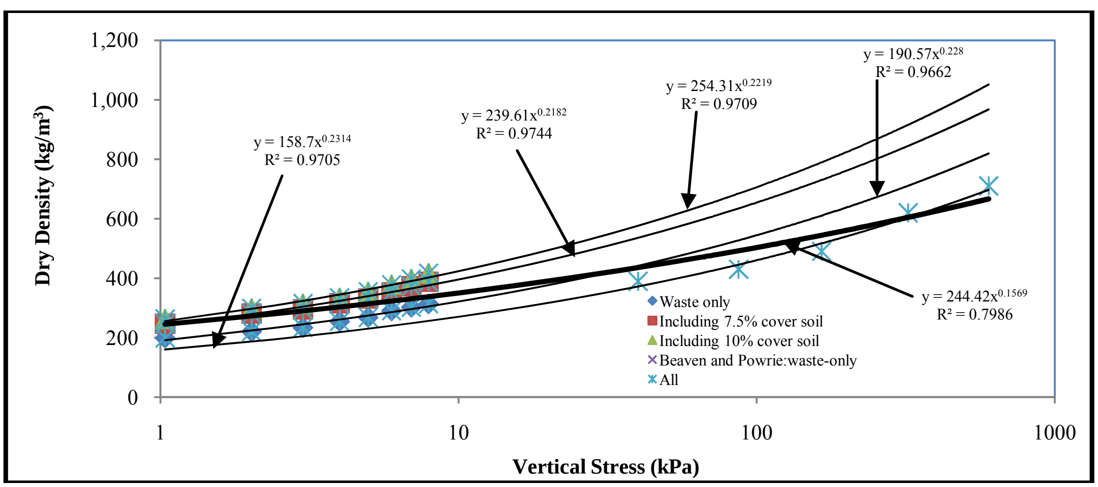


Figure 7: The plots and characteristic trends of vertical stress versus dry density for the municipal solid refuse

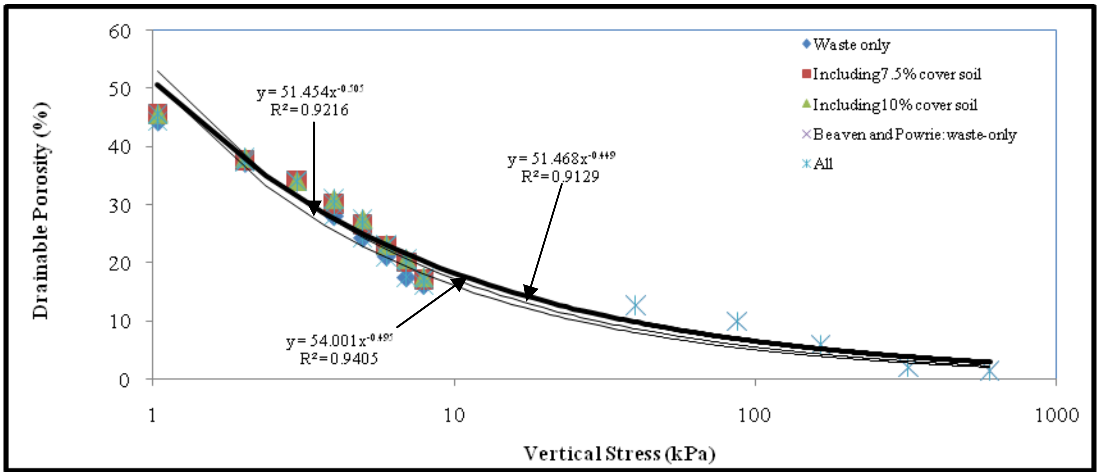


Figure 8: The plots and characteristic trends of drainable porosity versus vertical stress for the municipal solid refuse

Table 2: Derived characteristic models using the waste data for various hydro-physical tests

| Figure | | Small scale tests | | | Large scale tests | Combined |
|---|---|---|---|---|---|---|
| | | Waste only | Waste + 7.5% soil | Waste + 10% soil | Pitsea (Beaven &Powrie) | |
| 1 | Equation | $HC= 9.0712e^{-0.031DD}$ | $HC = 2.3264e^{-0.022DD}$ | $HC = 0.2454e^{-0.015DD}$ | $HC = 0.0312e^{-0.018DD}$ | $HC = 2.8079e^{-0.024DD}$ |
| | Correlation | $R^2 = 0.9277$ | $R^2 = 0.9836$ | $R^2 = 0.9909$ | $R^2 = 0.9748$ | $R^2 = 0.9124$ |
| 2 | Equation | $DP = 234.98e^{-0.008DD}$ | $DP = 230.72e^{-0.007DD}$ | $DP = 218.45e^{-0.006DD}$ | $DP = 196.55e^{-0.007DD}$ | $DP= 222.14e^{-0.007DD}$ |
| | Correlation | $R^2 = 0.991$ | $R^2 = 0.9921$ | $R^2 = 0.9927$ | $R^2 = 0.9816$ | $R^2 = 0.8874$ |
| 3 | Equation | $HC= 3E\text{-}08DP^{3.4557}$ | $HC = 4E\text{-}08DP^{3.2007}$ | $HC = 3E\text{-}07DP^{2.4716}$ | $HC = 6E\text{-}08DP^{2.4336}$ | $HC= 3E\text{-}08DP^{3.3395}$ |
| | Correlation | $R^2 = 0.9169$ | $R^2 = 0.9716$ | $R^2 = 0.9801$ | $R^2 = 0.9436$ | $R^2 = 0.9447$ |
| 4 | Equation | $HC = 0.034\sigma^{-1.876}$ | $HC = 0.0138\sigma^{-1.529}$ | $HC = 0.0055\sigma^{-1.139}$ | $HC = 0.2046\sigma^{-2.203}$ | $HC = 0.0182\sigma^{-1.727}$ |
| | Correlation | $R^2 = 0.9765$ | $R^2 = 0.9675$ | $R^2 = 0.9436$ | $R^2 = 0.9588$ | $R^2 = 0.969$ |
| 5 | Equation | $DD = 190.57\ \sigma^{0.228}$ | $DD = 239.61\ \sigma^{0.2182}$ | $DD = 254.31\ \sigma^{0.2219}$ | $DD = 158.7\ \sigma^{0.2314}$ | $DD = 244.42\ \sigma^{0.1569}$ |
| | Correlation | $R^2 = 0.9662$ | $R^2 = 0.9744$ | $R^2 = 0.9709$ | $R^2 = 0.9705$ | $R^2 = 0.7986$ |
| 6 | Equation | $DP = 51.454\ \sigma^{-0.505}$ | | $y = 51.468\ \sigma^{-0.449}$ | | $y = 54.001\ \sigma^{-0.495}$ |
| | Correlation | $R^2 = 0.9216$ | | $R^2 = 0.9129$ | | $R^2 = 0.9405$ |

Note: HC = saturated hydraulic conductivity; DD = Dry density; DP = Drainable Porosity; σ = Vertical stress

Similarly, the drainable porosity is plotted against the dry density in Figure 4. The drainable porosity is the void space of the saturated waste that can be drained under gravity. It is often expressed as the percentage of the ratio of this void space to the total volume of the waste. The semi-log plot shows the correlation value ($R^2$) for the different plots of the various tests to be greater than 0.98. The correlation value ($R^2$) for the common plot of the various data is however approximately 0.9, which is still reasonable based on heterogeneity of waste and the different scale of the test cells. The trend equation derived from this plot (Table 2) can thus be reasonably used to predict the drainable porosity from the determined values of the dry density.

The saturated hydraulic conductivity is plotted against the drainable porosity in Figure 5. The semi-log plot shows that the curves fit well the various datasets. The correlation value ($R^2$) is more than 0.91 for the various datasets and the common plot of data (Table 2). This further illustrates the correlation of the datasets of the different scale of the tests and a high degree of confidence in using the derived characteristic equations from the plots.

The relationship of the above waste parameters with the vertical stress in the waste owing to the applied vertical load (overburden) is depicted in Figures 6-8. A log-log plot of the saturated hydraulic conductivity against the vertical stress is shown in Figure 6. The fitting linear plot show that the correlation value ($R^2$) is greater than 0.94 for all the datasets. In fact, the correlation value ($R^2$) for the common plot of the combined data is approximately 0.97. The semi-log plot of the dry density against the vertical stress is depicted in Figure 7. Although the correlation value ($R^2$) for individual data sets is high – greater than 0.96, the correlation value for the common plot of the combined dataset is relatively less than this value. Nevertheless, the corresponding characteristic equation (Table 2) could also be used for waste parameter predictions, considering the complexity of the nature of waste. The semi-log plot of the drainable porosity against the vertical stress (Figure 8) shows a well correlated curve for all the datasets. The variability in the dataset for the waste including 7.5% cover soil and 10% cover is so small that the same trend curve virtually passes through their data set. As in other plots, the correlation of the datasets is high, thereby making the ensuing characteristic equations to be valid and adequate in predicting any waste parameter whose determinant waste parameter is known or determined.

## 4. Conclusion

Basic characteristic models can be derived from the trend equations of the fitted curves to the plot of a comprehensive test data of a municipal solid refuse. The high correlation values of the fitted curves as observed in this study indicates that the derived models can be used to reasonably predict the waste parameter whose determinant parameter is known or determined.

The findings in this study for a municipal solid refuse fill whose composition is analogous to that summarised in Table 1 is as follows:

- An exponential relationship exists between saturated hydraulic conductivity and dry density
- An exponential relationship exists between drainable porosity and dry density
- A power relationship exists between saturated hydraulic conductivity and drainable porosity
- A power relationship exists between saturated hydraulic conductivity and vertical stress
- A power relationship exists between dry density and vertical stress
- A power relationship exists between drainable porosity and vertical stress

The derived models in this study is not universally applicable to all municipal solid refuse fills, however the procedure used to derive the models can be applied to any waste data having wide range of values.

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## References

1 Fenwick, A. Waterborne infectious diseases--could they be consigned to history? Science 2006; 313(5790): 1077-1081.
2 Ejechi, EO, Ejechi, BO. Safe Drinking Water and Satisfaction with Environmental Quality of Life in Some Oil and Gas Industry Impacted Cities of Nigeria. Social Indicators Research 2008; 85(2): 211-222.
3 Oni, OA, Richards, DJ. Estimating moisture volume in a MSW landfill during refuse infill. Proc 19th Int. Conf on Solid Waste Technology and Management, Philadelphia, USA. The Journal of Solid Waste Technology & Management 2004; pp 446-455. Widener University Publication, USA.
4 Beaven, RP, Powrie, W. Determination of the hydrogeological and geotechnical properties of refuse in relation to sustainable landfilling. 19th International Madison Waste Conference, Department of Engineering Professional Development, University of Wisconsin, Madison1996; pp. 435-454.
5 El-Fadel, M, Findikakis, AN, Leckie, JO. Modeling leachate generation and transport in solid waste landfills. Environ. Technol. 1997; 18; 669–686.
6 Bleiker, DE, Farquhar, G, McBean, E. Landfill settlement and the impact on site capacity and refuse hydraulic conductivity. Waste Management and Research 1995; 13: pp. 533-534.
7 Holmes, R. The water balance method of estimating leachate production from landfill sites. Solid Wastes 1980; pp. 20 –33.

8 Campbell, DJV. Understanding water balance in landfill sites. Waste Management, November 1983; pp. 594-605.
9 Farquhar, GJ. Leachate: production and characterisation. Canadian Journal of Civil Engineering 1989; 16 (3): 317-325.
10 Blight, GE, Hojem, DJ, Ball, JM. Generation of leachate from landfills in water-deficient areas. Proceedings Sardinia 89, Second International Landfill Symposium, Cagliari, Italy, 1989; XXVI-1 – XXVI–15.
11 Bengtsson, L, Bendz, D, Hogland, W, Rosqvist, H, and Akesson, M. Water balance for landfills of different age. Journal of Hydrology 1994;158: pp. 203-217.
12 Parsons, R. Water balance method to predict leachate generation: Geohydrological experiences. Proceedings Sardinia 95, Fifth International Landfill Symposium, Cagliari, Italy 1995; pp. 275-284.
13 El-Fadel M, Findikakis, AN, Leckie, JO. Modeling Leachate Generation and Transport in Solid Waste Landfills. Environmental Technology 1997; 18(7): 669 – 686.
14 Oni, OA. An investigation into the impact of sequential filling on properties of emplaced waste lifts and moisture stored in a municipal solid waste landfill. PhD Thesis, University Of Southampton, Southampton 2000.
15 Oni, OA, Okunade E. A basic investigation into the hydro-physical properties of emplaced waste lifts in a MSW landfill. Australian Journal of Basic and Applied Science 2009; 3(2): 628-643.
16 Schroeder, PR, Dozier, TS, Zappi, PA, McEnroe, BM, Sjostrom, JW, Peyton, RL. The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3, EPA/600/9-94/xxx, U.S. Environmental Protection Agency Risk Reduction Engineering Laboratory, Cincinnati, OH 1994.
17 Rosqvist, H,.Bendz, D. An experimental evaluation of the solute transport volume in biodegraded municipal solid waste. HESS. 1999; 3, pp. 429–438.
18 Rosqvist, H, Destouni, G. Solute transport through preferential pathways in municipal solid waste. Journal of Contaminant Hydrology 2000; 46 (1-2), pp 39-60.
19 Beaven, RP, Hudson, AP. Description of a tracer test through waste and application of a dual porosity model. In Ninth International Waste Management Symposium, Sardinia 2003.
20 Beaven, RP, Dollar, L, Oni, OA, Woodman, ND. A laboratory scale saturated and unsaturated tracer test through waste. HPML International Workshop, University of Grenoble, France 2005; 4p.
21 Oni, OAG. Studying Pollutant Solute Transport in Saturated MSW using Multi-Tracer Tests. Australian Journal of Basic and Applied Sciences 2009; 2(4): 3727-3740.
22 Rosqvist, H, Dollar, LH., and Fourie, AB. Preferential flow in municipal solid waste and implications for long-term leachate quality: valuation of laboratory-scale experiments. Waste Management & Research 2005; 23 (4): 367-380.
23 Oni, OAG. Numerical Simulation of the Mass Flow of Leachate in a Municipal Waste Fill (Part 1) – Closed Recycling Flow Systems. Journal of Applied Sciences Research 2010a; 6(6): 742-750.
24 Oni, OAG. Numerical Simulation of the Mass Flow of Leachate in a Municipal Solid Waste Fill (Part 2) - Vertical Flow Systems. Journal of American Science 2010b; 6(7): 358-366.
25 Oni, OAG. Numerical Simulation of the Mass Flow of Leachate in a Municipal Solid Waste Fill (Part 3) – Leaked Vertical Flow Systems. Research Journal of Applied Sciences, Engineering and Technology 2010c; 2(5): 480-486.
26 Oni, OAG. Understanding solute transport in a solid waste fill using basic principles of soil mechanics and stochastic modelling. Research Journal of Applied Sciences, Engineering and Technology 2010d;2(4): 348-355.
27 Oni, OAG. Contaminant Solute Transport in MSW Fills: Reviewing Fundamental Theories, Methods, Results and Models. Australian Journal of Basic and Applied Sciences 2010e; 4(6): 1512-1517.
28 Beaven, RP. The hydrogeological and geotechnical properties of household waste in relation to sustainable landfilling. PhD Thesis, Queen Mary and Westfield College, University of London, London 2000.
29 Beaven, RP, Powrie, W. Hydrogeological and geotechnical properties of refuse using a large-scale compression cell. Proceedings Sardinia 95, Fifth International Landfill Symposium, Cagliari, Italy 1995; pp. 745–760.

30 Buisman, ASK. Results of long duration settlement tests. Proceedings, 1st International Conference on Soil Mechanics 1936; pp. 103-106.
31 Sowers, GF. Settlement of waste disposal fills. Proceedings, 8th International Conference on Soil Mechanics and Foundation Engineering, Moscow 1973; pp. 207-210.

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32 Charles, JA, Burland, JB. Geotechnical considerations in the design of foundations for buildings on deep deposits of waste materials. The Structural Engineer 1982; 60A (1): pp. 8-14.
33 Wall, DK, Zeiss, C. Municipal landfill biodegradation and settlement. Journal of Environmental Engineering 1995; ASCE, 121 (3): pp. 214-223