Int. J. Pure Appl. Sci. 1:9-15 (2015)

IJPAS
ijpas@tunceli.edu.tr
ISSN: 2149-0910

Research/Araştırma

Hydraulic Properties Estimation of an Experimental Urban Soil Column Constructed with Waste Brick and Compost

Deniz Yilmaz[1*], Murat Dal[2]
[1]*LUNAM Université, IFSTTAR, GER, Bouguenais, F-44341, France*
[2]*Tunceli University, Engineering Faculty, Civil Engineering Department, Tunceli, Turkey*
**Corresponding author: E-mail: dyilmaz@tunceli.edu.tr*

Abstract

For sustainable development, cities have to revalorize waste material produced by human activities. Urban soils could be constructed from waste material such as bricks or concrete waste and mixed with compost material for greening application in urban environment. This study proposes to study from hydraulically point of view an experimental urban soil constructed with waste brick and compost using an adapted evaporation laboratory method. The hydraulic properties are estimated using Hydrus 1D code inverse procedure and are compared with classical soils such as sand, loam and silt. Conclusions are promising but more investigation should be done to confirm the possibility of using this material as urban soil for greening application in cities.

Key words: Evaporation Experiment, Hydrus 1D, Hydraulic Properties, Urban Soil

Atık Tuğla ve Kompost ile İnşa Edilen Deneysel Bir Zeminin Hidrolik Karakteristiklerinin Buharlaşma Metodu ile Tespiti

Özet

Kentlerin sürdürülebilirliği için, kendi atıklarını yeniden değerlendirmesi ile mümkündür. Özellikle kentsel dönüşüm projelerinde inşaat atıklarının değerlendirmesi önem arz etmektedir. Kentsel zeminler atık tuğla, atık beton gibi malzemeler ile inşa edilebilir. Bunlara yeşillendirme fonksiyonu verilebilmesi içinde atık malzemelere kompost eklenebilinir. Bu çalışmada laboratuarda buharlaşma metodu yöntemini kullanarak atık tuğla ve kompost ile inşa edilmiş, deneysel bir zeminin hidrolik açıdan incelenmesi ve karakteristiklerinin tespiti amaçlanmıştır. Hidrolik özellikler; Hydrus 1D kodunun inverse prosedürü kullanılarak tespit edilmiştir. Kum, kil ve silt gibi klasik zeminlerin karakteristikleri ile karşılaştırılmıştır. Bu zeminler hem mekanik, hem hidrolik ve hem de biyolojik açıdan ele alınarak, şehir zeminlerinde uygulanması söz konusudur.

Anahtar kelimeler: Buharlaşma metodu, Hydrus 1D, Hidrolik özellikler, Şehir zemini

INTRODUCTION

Cities are renewing continuously by demolition of old construction. This process is producing wastes of demolition such as bricks, concrete, ballast of railway track, excavated soils. These wastes are consistently exported out of the city and are land filled or parts of them are recycled (Marshall and Farahbakhsh, 2013). For example, the amount of waste material stemming from civil engineering activities in France is 253 million tons for 2009 (ADEME, 2012). For Turkey, there is no net data regarding the amount of demolition waste (Esin and Cosgun, 2007). After the earthquake of 1999 in Marmara region 13 million of waste material occurred (Esin and Cosgun, 2007). The construction and demolition waste are estimated of 200 kg per person per year in Turkey (Arslan et al., 2012). Since one year, a big project of demolition of old construction in Turkey is planned for sustainable city retrofitting named as 'kentsel Dönüşüm' in Turkish. Thus the amount of demolition waste creates will increase in Turkey and will be a huge issue of waste management. In other part, cities are also producing compost material and green wastes from maintenance of gardens and parks which can provide nutriments for vegetation in an urban soil matrix. City practitioners are usually building urban soils from agricultural soil stripping and aggregates coming from quarries. One alternative idea is to reuse the waste material produced by the city as urban soils for parks, gardens and tree lines. SITERRE project was launched and funded by the French environmental agency (ADEME) to develop the knowledge on urban soils built with waste material. A part of the project is focusing on the feasibility to reuse waste brick mixed with organic matter (compost and green waste) for plant growth and trees in urban environment. These urban soils have to display adequate properties with respect to their bearing capacity in an urban environment, their agronomic properties for plant growth, their drainage capacity and the environmental restrictions enforced by the French regulation in order to prevent pollutant release in the underlying aquifer.

The knowledge of hydraulic properties of urban soils is very important to understand hydraulic functioning of urban areas. These are necessary for modeling hydrologic processes at the city scale for rainwater management purposes (Mitchell et al., 2001; Dussaillant et al., 2004; Lassabatere et al., 2010), for modeling the evapotranspiration of trees to assess their impact on urban climate (House-Peters and Chang, 2011) and its effect on the urban heat island phenomenon, and also for modeling the pollutant transfer where it is known that water flow is the main vector of transportation for pollutants (Lassabatere et al., 2007; Lamy et al., 2009, Yilmaz et al., 2010). These properties are also important to understand if the materials have ability for agronomic purposes. Hydrodynamic properties of urban soils built with waste material are rarely studied and not very well known. Only a few studies tried to focus on hydraulic properties (Sere et al., 2012; Ojeda et al., 2011) of urban soils built from waste material.

As means of hydraulic characterization at the laboratory scale, the evaporation method through analysis of experimental pressure heads at different heights in a vertical column has become widespread in obtaining hydraulic properties for soils (Wind, 1968; Tamari et al., 1993; Simunek et al., 1998; Yilmaz et al., 2010).

The aim of this work is the characterization of hydraulic parameters of urban soil built from brick waste and compost using an adapted wind laboratory method.

MATERIAL AND METHODS

Studied Materials

The studied material noted Br-Co (Br: Brick waste and Co: compost) was built from a mixture of 60 wt.% of brick (Br) fabrication waste and 40 wt.% of compost (Co) coming from waste management facilities and waste composting. Its specific density was estimated in laboratory using picnometer method to 2.18 g.cm^{-3}.

The Adapted Evaporation Method

The column configuration for the evaporation experiment used in this study is different than the conventional method known as Wind method (Wind, 1968). For this reason, the method used in this study is mentioned as adapted evaporation method. In laboratory, the studied material was packed into 40 cm high and 7 cm radius column, placed on a monitored balance (Figure 1). Three tensiometers (T5, Ums Gmbh, Münich, Germany), with cups of 7 cm long and 0.5 cm in diameter were horizontally inserted into drill holes in the material core at 8.5 cm, 10 and 11.5 cm from the sample surface.

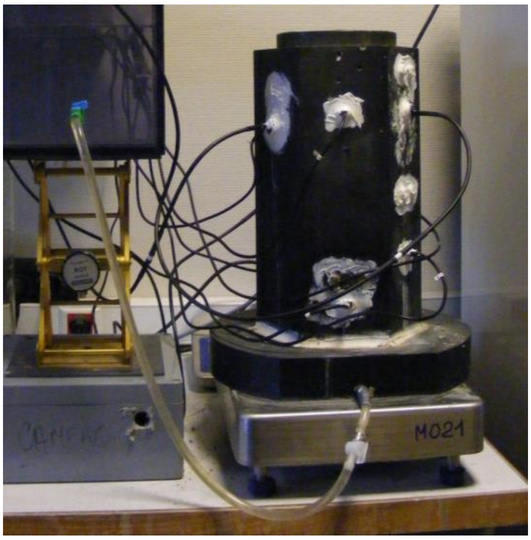

Figure 1. Adapted evaporation column experiment.

The system was saturated with water during a sufficient time to reach hydraulic equilibrium. The measurement of the mass was performed by weighing with mass balance every hour and the measurements of pressure heads each five minutes. The potential evaporation rate was measured every hour using a square tank filled with water, this system was placed on monitored balance and the weighting measurements were done every hour. Both balance system were connected to a computer for data collection. Tensiometers were connected to a data logger CR10X from Campbell scientific for data collection. Initial pressure head of -10 cm for the tensiometer at 8.5 cm was measured. The experiment was performed till the water pressure heads reach the pressure head of -800 cm. The experiment lasted 5 months. At the end, the material was extracted from the columns and dried to determinate the water content profile with 5 points.

Modeling was performed using HYDRUS 1D code (Simunek and al., 2008) that resolves the Richards' equation. The unsaturated soil hydraulic properties are described by the Van Genuchten (equation 1 and 3) model in junction with Mualem capillary model (equation 2).

The evaporation experiment setup was simulated through a 40 cm length mesh with 0.1 cm length elements. Observation points were introduced at the tensiometer depths. The initial condition corresponded to pressure equilibrium with 0 cm at the surface and 40 cm water pressure head at the bottom. The boundary conditions correspond to no flux at the bottom and daily measured potential evaporation rate. The hydraulic parameters were estimated through the HYDRUS 1D inverse procedure (Marquardt, 1963). The data to be fitted correspond to the evolution of the pressure heads at the observation points and the total water loss at the end of the experiment.

Hydraulic parameters

Van Genuchten-Mualem (Mualem, 1976; Van Genuchten, 1980) models are used to describe the hydrodynamic functions h(θ) and K(θ) in Hydrus.

$$\frac{\theta-\theta_r}{\theta_s-\theta_r}=\left(1+\left(\frac{h}{h_g}\right)^n\right)^{-m} \quad [1]$$

$$m=1-\frac{1}{n} \quad [2]$$

$$K(\theta)=K_s\left(\frac{\theta-\theta_r}{\theta_s-\theta_r}\right)^l\left[1-\left(1-\left(\frac{\theta-\theta_r}{\theta_s-\theta_r}\right)^{1/m}\right)^m\right]^2 \quad [3]$$

where n, m are the hydraulic shape parameters, θ_s and θ_r are the saturated and residual water contents respectively, h_g the scale parameter for water pressure head, and K_s the saturated hydraulic conductivity. The parameter l is the pore connectivity parameter and it's usually set to the value of 0.5 [-].

The saturated water content is supposed equal to the porosity and is estimated from both the dry bulk (ρ_d) and specific (ρ_s) densities through the following equation:

$$\theta_s=1-\frac{\rho_d}{\rho_s} \quad [6]$$

RESULTS AND DISCUSSIONS

Particle Size Distribution

The particle size distribution (PSD) analysis, involving manual sieving and complemented by a grain size analyzer, is illustrated in figure 2. The percentages according the U.S.D.A (U.S Department of Agriculture) above 2 mm fractions (gravel), between 0.05 and 2 mm (sand), between 0.05 and 0.002 mm (silt), and less than 0.05 mm (clay) are 58.3%, 31.3%, 10.2% and 0.2%. Br-Co material is composed with large pieces of bricks and this explains the high value of the percentage of gravel.

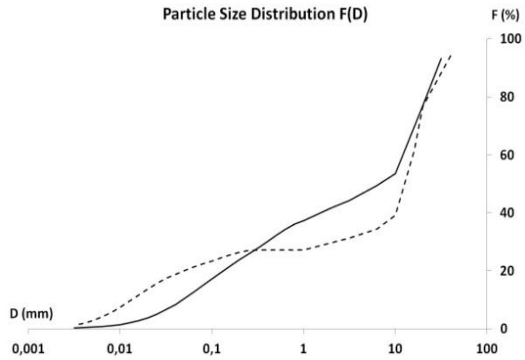

Figure 2. Particle size distribution of studied material.

Adapted Evaporation Column Experiment and Inversion Results

The experiment started the 25th November 2013 and was stopped the 11 April 2014 after the upper tensiometer has reached the value of -800 cm in pressure head. The figure 3 is showing the time evolution of pressure head at -8.5, 10.0 and 11.5 cm level for the surface of the evaporation column and the corresponding model estimation from Hydrus 1D software. For the inverse procedure, the saturated water content θs ($cm^3.cm^{-3}$) was fixed and calculated to 0.631 through equation n°6. At the end of the evaporation experiment, the material was dried and the dry bulk density was estimated to 0.80 $g.cm^{-3}$. The residual water content was fixed to 0.1 $cm^3.cm^{-3}$. The initial water content was supposed equal to the saturated water content. The inversion results are shown in table 1.

Research/Araştırma

Table 1. Br-Co material hydraulics parameters estimated from inversion of data collected from the adapted evaporation experiment

Hydraulics parameters	θr ($cm^3.cm^{-3}$)	θs ($cm^3.cm^{-3}$)	|hg| (cm)	n (-)	Ks ($cm.h^{-1}$)
Br-Co studied material	0.1	0.631	12.8	1.43	29.0

The model gives similar values of pressure head for the three heads up to pressure head of -300 cm. After that, the differences between the three heads are more distinct. The fit of the model on experimental data are reproducing the experimental tendency.

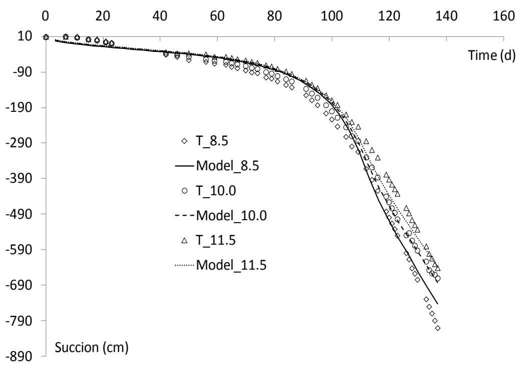

Figure 3. Evaporation experiment results of pressure head monitoring at level -8.5 cm. 10.0 cm and 11.5 cm from the top of the column and models corresponding to the inverse procedure.

Discussions

For purpose of discussion, hydrodynamic curves h(θ) and K(θ) of the studied Br-Co material are displayed respectively in figure 4 and 5. In order to compare this material with classical soils such as a sandy, loam and silt, their hydrodynamics curves are also reproduced. For that, we used the hydraulic parameters proposed in HYDRUS database for sand, loam and silt.

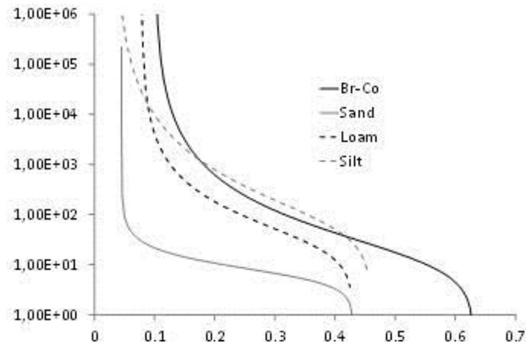

Figure 4. Water retention curves, Volumetric water content [$cm^3.cm^{-3}$] on horizontal axe and absolute pressure head [cm] for vertical axe displayed in logarithm scale.

The studied material Br-Co has his saturated volumetric water content θ_s higher than classical natural soil or cultivated soil. This could be explained by the high content of organic matter in the material. Organic matter is well known for its important total porosity ranging from 0.7 $cm^3.cm^{-3}$ for composts material to 0.9 $cm^3.cm^{-3}$ for peat material (Cannavo and Michel, 2013). Br-Co material absolute pressure head for volumetric water content in very dry condition (<0.15 $cm^3.cm^{-3}$) is lower than those of classical soil. For volumetric water content upper than 0.15 $cm^3.cm^{-3}$, absolute pressure head of Br-Co material are contained between thus of silt soil and loam soil.

For hydraulic conductivity curves, the same tendency of retention curves is observed. For dry condition, the hydraulic conductivity of the studied material is lower than thus of classic soils. For volumetric water content upper than 0.2 $cm^3.cm^{-3}$ hydraulic conductivity K is contained between the K of a silt and loam soil.

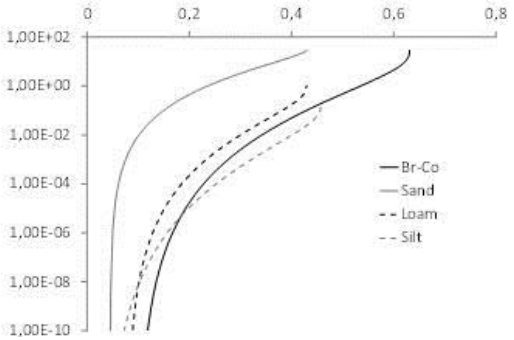

Figure 5. Hydraulic conductivity curves, Volumetric water content [-] on horizontal axe and water conductivity [$cm.h^{-1}$] for vertical axe in logarithm scale.

From hydraulic point of view, this material is functioning between a silt soil and loam soil. It could be used as an urban soil for greening purposes (for instance, for tree or grass growth) but this has to be studied by experimental application of greening.

CONCLUSION

The studied material Br-Co was constructed with a mixture of waste fabrication bricks and compost to be used as an urban soil for greening purpose such as grass or tree. The hydraulic properties of this material were obtained through an adapted evaporation experiment and experimental collected data were inversed using Hydrus 1D code. The estimated hydraulics properties permit to classify the studied material from hydraulics point of view between a loam and a silty soil. This experimental urban soil material have high porosity and high hydraulic conductivity value of K_s and it can achieve the role of urban soil for greening purpose like gardens, parks and trees lines, but more additional study has to be done like greening experimental plot in situ to verify the feasibility. Also, an environmental impact study has to been done before using this material as urban soil. For Turkey, demolition waste could be also valorized as urban soil. Further research on hydraulics properties of urban soil constructed with waste demolition material coming from Turkish market has to be done and feasibility of the reuse as urban soil as to be checked. Finally, the proposed hydraulics properties of this study can be used for the settings of urban soil hydraulic parameters in multiple applications as water modelling, evapotranspiration modelling or pollutant transfer study at the city scale.

REFERENCES

Ademe. 2012. Les déchets- Chiffres Clés (Edition 2012).

Arslan, H., Salgın, B., Coşgun, N., 2012. Construction and demolition waste management in Turkey. *INTECH Open Access Publisher*.

Cannavo, P., Michel. J.C., 2013. Peat particle size effects on spatial root distribution and changes on hydraulic and aeration properties. *Scientia Horticulturae,* 151:11-21

Dussaillant, A.R., Wu, C.H., Potter, K.W., 2004. Richards equation model of a rain garden. *Journal of Hydrologic Engineering*, *9*(3): 219-225.

Esin, T., Cosgun, N., 2007. A study conducted to reduce construction waste generation in Turkey. *Building and Environment*, 42(4), 1667-1674.

House-Peters, L.A., Chang, H., 2011. Modeling the impact of land use and climate change on neighborhood-scale evaporation and nighttime cooling: A surface energy balance approach. *Landscape and Urban Planning,* 103(2):139-155.

Lamy, E., Lassabatere, L., Bechet, B., Andrieu, H., 2009. Modeling the influence of an artificial macropore in sandy columns on flow and solute transfer. *Journal of hydrology*, 376(3) : 392-402.

Lassabatere, L., Spadini, L., Delolme, C., Février, L., Cloutier, R.G., Winiarski, T., 2007. Concomitant Zn–Cd and Pb retention in a carbonated fluvio-glacial deposit under both static and dynamic conditions. *Chemosphere*, 69(9) : 1499-1508.

Lassabatere, L., Angulo-Jaramillo, R., Goutaland, D., Letellier, L., Gaudet, J.P., Winiarski, T., Delolme, C., 2010. Effect of the settlement of sediments on water infiltration in two urban infiltration basins. *Geoderma,* 156:316–325. doi:10.1016/j.geoderma.2010.02.031

Marquardt, D.W., 1963. An algorithm for least-squares estimation of nonlinear parameters. *SIAM J. Appl. Math,* 11:431–441. doi:10.1137/0111030

Marshall, R.E., Farahbakhsh., K., 2013. Systems approaches to integrated solid waste management in developing countries. *Waste Management*. ISBN: 0470999675.

Mitchell, V.G., Mein, R.G., McMahon, T.A., 2001. Modelling the urban water cycle. *Environmental Modelling & Software*, 16(7): 615-629.

Mualem, Y., 1976. A new model for predicting the hydraulic conductivity of unsaturated porous media. *Water Resour. Res.* 12:513–522. doi:10.1029/WR012i003p00513

Ojeda, G., Mattana, S., Bonmati, M., Woche, S.K., Bachmann, J., 2011. Soil wetting-drying and water-retention properties in a mine-soil treated with composted and thermally-dried sludges. *European Journal of Soil Science*.. 62(5):696-708.

Sere, G., Ouvrard, S., Magnenet. V., Pey, B., Morel, J.L., Schwartz, C., 2012. Predictability of the evolution of the soil structure using water flow modeling for a constructed technosol.*Vadose Zone Journal*.. 11(1) : 0-0.

Simunek, J., Wendroth, O., van Genuchten, M.T., 1998. Parameter estimation analysis of the evaporation method for determining soil hydraulic properties. *Soil Science Society of American Journal*, 62: 894-905.

Simunek, J., Van Genuchten, M.T.H., Sejna, M., 2008. Development and applications of the HYDRUS and STANMOD software packages and related codes. *Vadose Zone J.* 7:587–600. doi:10.2136/vzj2007.0077

Tamari, S., Bruckler, L., Halbertsma, J., Chadoeuf, J., 1993. A simple method for determining soil properties inthe laboratory. *Soil Science Society of American Journal*, 57:642-651.

Van Genuchten, M.T., 1980. A closed form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of American Journal*, 44:892-898.

Wind, G.P., 1968. Capillary conductivity data estimated by a simple method. In 'Water in the saturated zone'. (eds PE Rijtema and H Wassink) pp.181-191. (*Proceeding.Wageningen Symposium* June 1966: Gent Brugge.. Belgium).

Yilmaz, D., Lassabatere, L., Angulo-Jaramillo, R., Deneele, D., Legret, M., 2010. Hydrodynamic characterization of basic oxygen furnace slag through an adapted BEST method. *Vadose Zone Journal*, 9(1) :107-116.

Yilmaz, D., Lassabatere, L., Angulo-Jarmillo, R., Legret, M., 2010. Hydrodynamic characterization of BOF slags through numerical inversion of an evaporation experiment and through water infiltration experiments: a comparison."*Proceedings of the 19th World Congress of Soil Science: Soil solutions for a changing world, Brisbane, Australia, 1-6 August 2010.* International Union of Soil Sciences (IUSS), Universität für Bodenkultur.