Variation of fluid conductivity with settlement of domestic waste

G. Stoltz[12], JP. Gourc[1]

[1] LTHE Laboratory, Grenoble University, BP 53 - 38041 Grenoble Cedex 9, France
[2] CRPE, Veolia Environnement, Limay, France

ABSTRACT: Domestic waste (MSW) can be considered as a gradually changing porous medium. This paper reports tests of a new type on a waste sample in order to get correlations between mechanical and hydraulic properties. Compression tests coupled with gas permeability tests have been made on waste sample taken from a hole drilled in a French landfill. The apparatus used for these tests is an oedo-permeameter developed in Lirigm-LTHE. In a second stage, the oedo-permeameter cell has been modified to carry out retention tests on a waste sample under compression. These tests allow to get water retention curve and to assess pores volumetric distribution of the waste.

INTRODUCTION

Land disposal of solid waste has changed dramatically because the “dry tomb” approach is not sustainable. Indeed optimal moisture is required for biological degradation. Municipal solid waste landfills can be operating as bioreactor which intends to accelerate waste degradation by circulating fluids through the waste in a controlled manner. One of the main uncertainties concerning the practicality of operating a landfill as a bioreactor is the control of fluids flows and of the water content of waste. The hydraulic permeability (leachate), the gas permeability (biogas) and the retention properties of the waste govern the ease with which fluids may be introduced into and extracted from the landfill. These hydrodynamics properties depend on the mechanical compression and the saturation degree of the fluids (liquid and gas) and also on the waste evolution upon the elapsed time characterized by biodegradation. Moreover these parameters depend on initial mechanical and biological pre-treatment of the waste (MBT).

In the context of bioreactor technique, these data could be specifically useful (Beaven 1995, Benson 2006, Durmusoglu 2006, Jain 2005 and 2006, Olivier 2007, Powrie, 1999)

PRESENTATION OF THE RESEARCH PROGRAM

Domestic waste is a complex porous medium. Its void structure is largely dependent of the components and the possible mechanical pre-treatment. Its evolution over time is dramatically conditioned by its settlement due to the surcharge of the column of waste in the landfill and by biodegradation.

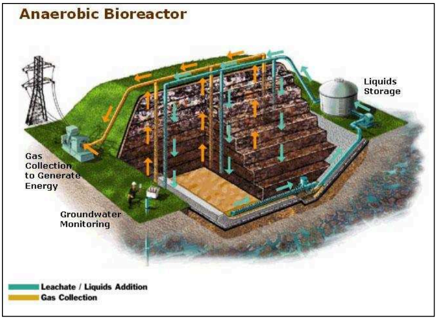

FIG 1. General schema of a bioreactor (Ademe source)

Characterization of the evolution of the void structure can be obtained through measurement of the fluid permeability and water retention. In addition, quantification of these properties is important for a better understanding of the bioreactor operation.

Following a large research programme about waste settlement and geomechanical properties of waste, a new programme is starting in Lirigm-LTHE about the correlation between mechanical and hydraulic properties. The programme attempts to use for waste, experimental tests previously used for soils.

Several specific prototype devices are used for coupling measurement of settlement of a refuse sample and measurement of the hydraulic or gas permeability.

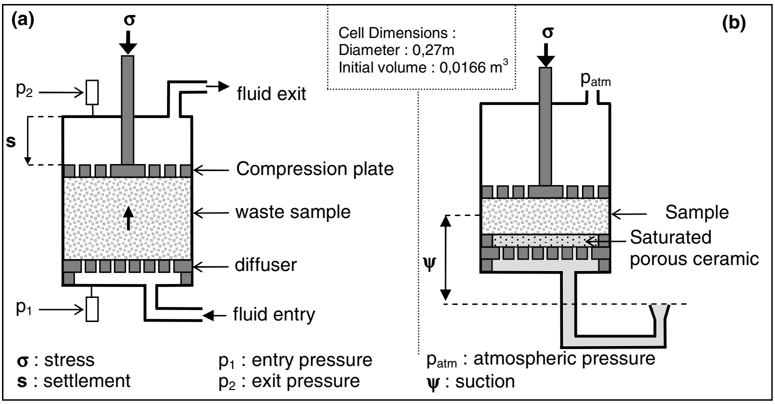

FIG 2. (a) Schematic section of the compression cell of the oedopermeameter equipped for the gas permeability test , (b) Schematic section of the modified oedopermeameter compression cell equipped for the suction test

GENERAL DESCRIPTION OF THE OEDOPERMEAMETER

The oedopermeameter (Figure 2a) consists of a rigid cylindrical cell (diameter 0,27m and height 0,29m) subject to vertical compression σ in oedometric conditions (lateral strains prevented) up to 200 kPa (equivalent to the self-weight of a 20 m waste column) by means of a load apparatus. The cell is equipped to perform gas permeability test. All electronic equipments are connected to an automatic data-acquisition system.

ORIGIN AND COMPOSITION OF THE TESTED WASTE

The studied waste was collected from a hole drilled (few meters under the surface) in a French landfill. This waste was stored one year ago. It was dumped in the landfill without any pre-treatment but the effect of drilling was to shred the waste particles.

Waste characterization of the material showed that it is composed of 20 % of organic waste (including kitchen and green waste, wood, paper and cardboard), 16 % of plastics, 8 % of glass, 3 % of textile, 7 % of metals, 29% of very small particles and 17 % of others. Its particle size distribution was also evaluated: The fraction < 50 mm is around 70% of the waste mass.

The waste was characterised first with regard to its initial water content (by oven-drying at 70°C during 72 h). The water content (w) expressed as the ratio of the mass of constitutive water to the mass of solid particles was hence evaluated to approximately 30%.

Only short duration tests are presently carried out, so the influence of the biodegradation is not taken in consideration.

COMPRESSION OF THE WASTE SAMPLES

The waste was prepared in the cell in thin layers and compacted with added water. After humidification for compaction in the cell, the water content (w) reached 56% and the corresponding volumetric water content (θ) (i.e. the ratio of the volume of water in the sample to the total volume of the sample) was around 27%.

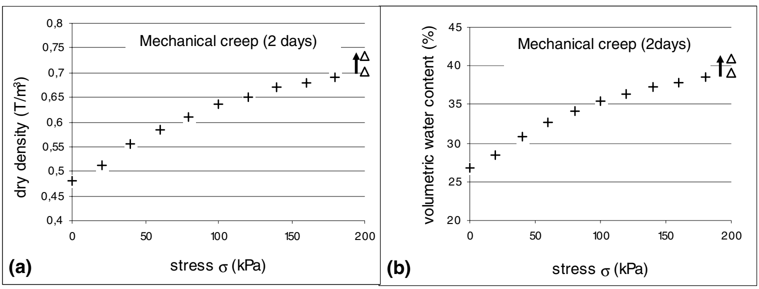

FIG 3. (a) Evolution of the dry density versus the compression vertical stress, (b) Evolution of the volumetric water content versus the compression vertical stress

The test procedure consisted of compressing the waste to 200 kPa (normal stress) in 20 kPa steps. Every step lasts 20 minutes. A diagram corresponding to the increase of the dry density due to the compression is presented Figure 3a and the increase of the volumetric water content is presented Figure 3b. At each compression step, a gas (nitrogen) permeability test was carried out.

At the last step, the load was held at 200 kPa for two days. During this phase at constant load, a mechanical creep is observed. A gas permeability test was done at the end of this phase.

EVOLUTION OF THE HYDRO-PHYSICAL CHARACTERISTICS OF THE WASTE VERSUS COMPRESSION STRESS

In order to perform the gas permeability tests, pressure sensors are installed at the entry and exit of the cell (Figure 2a). A mass flow meter is placed at the entry of the cell.

The gas permeability measures are realized in Darcy's conditions and the gas permeability coefficient k_g is given by the relation:

$$\frac{q_1}{A} = \frac{k_g}{\mu_g}\frac{1}{2L}\frac{p_1^2 - p_2^2}{p_1}$$

With A the section of the sample, L the height of the sample, μ_g the dynamic viscosity of gas (taken at 20°C, temperature of the permeability tests), q_1 the gas volumetric flow at the entry of the sample, p_1 the gas entry pressure and p_2 the gas exit pressure.

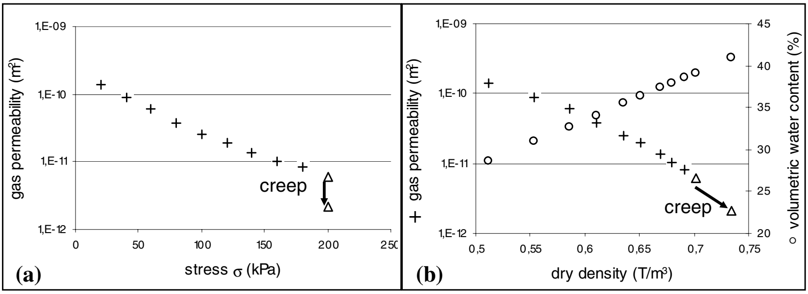

FIG 4. (a) Evolution of the gas permeability versus the compression vertical stress, (b) Evolution of the gas permeability versus the dry density

Figure 4a shows that the gas permeability decreases when compression stress and thus the dry density increases. The Figure 4b shows that the gas permeability is depending on the dry density and volumetric water content. The creep phase is identified on every diagram. It is worth noting on Figure 4b that the relationship between gas permeability and dry density seems independent of the method used to achieve settlement: increasing compression stress (points drawn with a cross on Figure 4b) or creep under constant compression stress (points drawn with a triangle on Figure 4b)

INFLUENCE OF THE SATURATION ON THE PERMEABILITY

A first characteristic of the porous structure is that intrinsic permeability is independent of the fluid. When the fluid saturation S of the porous media is 100%, the fluid permeability is marked $k_{g,wSat}$ and corresponds to the intrinsic permeability with $k_{gSat}= k_{wSat}$. At a constant density, the fluid (gas, water) permeability varies with the water saturation (Figure 5) and whether the system is wetting or drying (hysteresis). Fluid permeability ($k_{g,w}$ in m^2) is related to fluid conductivity ($K_{g,w}$ in m/s) as follows:

$$K_{g,w} = k_{g,w} \frac{\rho_{g,w} G}{\mu_{g,w}}$$

With $\mu_{g,w}$ the dynamic viscosity of fluid, $\rho_{g,w}$ the density of fluid and G the acceleration due to gravity.

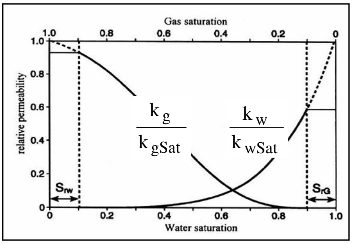

FIG 5.Schematic relative permeability with respect to fluid saturation (Warrick, 2002)

At the end of the compression process, the waste sample are initially fully saturated with water and subsequently drained to reach the field capacity. At field capacity, the volumetric water content is around 43,5%. A gas permeability test was done at this volumetric water content value (Figure 6a).

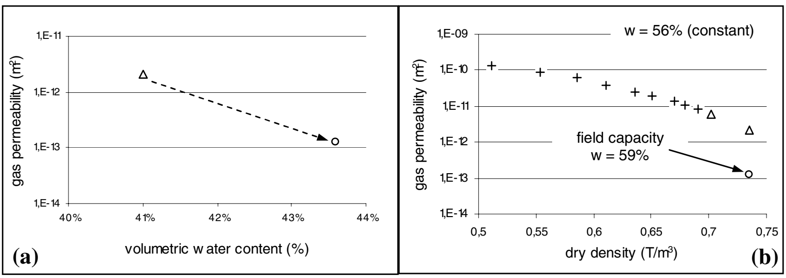

FIG 6. (a) Evolution of the gas permeability versus the volumetric water content after a saturation-desaturation cycle (field capacity state), (b) Evolution of the gas permeability during the phase of compression and after a saturation-desaturation cycle (field capacity state)

It is worth noting that for the same dry density, the gas permeability is decreasing with increasing volumetric water content in agreement with Figure 5. In the future, we intend to perform tests at a constant density and at different water content to obtain a diagram similar to Figure 5.

WATER RETENTION CURVE AND PORE VOLUMETRIC DISTRIBUTION

The oedopermeameter is modified so as to realize a retention test on a waste sample under compression. The waste sample is set above a porous ceramic plate which has an air entry pressure of 50kPa. The suction is given by the capillary pressure which is the difference between the pressure of the water and the atmospheric pressure (Figure 2b).

At suction equilibrium, the capillary pressure is plotted versus the corresponding volumetric water content. This is the conventional retention curve obtained from desaturation of the sample. The hysteresis effect is not studied. Results of Figure 7 correspond to two compression stresses and therefore to two dry densities.

The retention curve obtained shows that the porometric structure is modified by the compression.

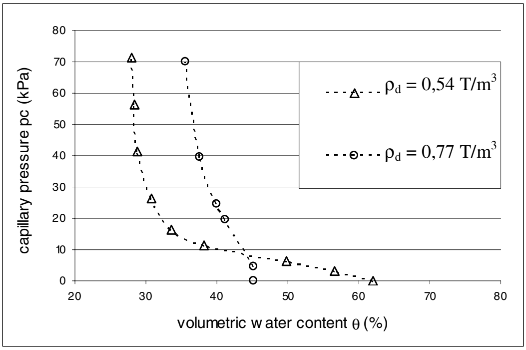

FIG 7. Water retention curve of the drilled domestic waste at two dry densities

The water retention curve can be interpreted in pores volumetric distribution. Indeed, the Laplace relationship gives a relation between the capillary pressure p_c and the equivalent pores diameter d_p:

$$p_c = 4\frac{T}{d_p}$$

With T the superficial tension of the fluid and given by the value of the water at 20°C ($T = 7,3.10^{-2}\,N.m^{-1}$). The solid surface is supposed perfectly wettable.

An increment of suction is correlated to a pore diameter d_p. This suction induces a drawdown of a porometric class corresponding to an increment of void volume.

Figure 8a and 8b show the pores volumetric distribution deduced from the Laplace relationship for the water retention curves presented on Figure 7.

The two suction tests at two dry densities are realized at constant solid dry mass (m_d=1970g). Figure 8a shows that for a given sample in the oedopermeameter the volume of void of each class decreases when the sample is compressed. The volume of void with pore diameter d_p < 40 µm is almost the same for the two tests when the largest pores are dramatically decreasing.

Figure 8b extrapolated from Figure 8a corresponds to two samples of the same overall volume: the total void volume (characterized by θ_{Sat}) is decreasing with increasing density, but the volume of smallest pores is increasing.

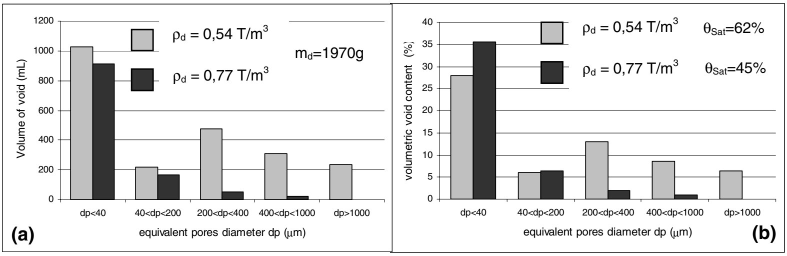

FIG 8. (a) Volume of void versus equivalent pores diameter of the drilled domestic waste at two dry densities, for a given mass of waste, (b) Volumetric void content versus equivalent pores diameter of the drilled domestic waste at two dry densities (corresponding to a given unit overall volume of waste)

CONCLUSION AND PERSPECTIVES

Bioreactor efficiency is depending on the optimal wetting of the waste body. As demonstrated, the porometric structure is dramatically changing with compression. Consequently the alteration of the hydraulic and gas conductivities will be taken into account in the management of a bioreactor. The use of the oedopermeameter to assess the hydro-mechanical properties of waste is promising.

AKNOWLEDGMENTS

This research programme is supported by the Environment French Agency (Ademe) and the Veolia Environment Research Center (Crpe).

REFERENCES

Beaven, R.P. et Powrie, W. (1995) Hydrogeological and geotechnical properties of refuse using a large scale compression cell. Proc. Sardinia 95, 5th International Landfill Symposium, Cagliari, Vol.II

Benson CH, Barlaz MA, Lane DT, et al. (2007) Practice review of five bioreactor/recirculation landfills Waste Management 27

Durmusoglu E, Sanchez IM, Corapcioglu MY (2006) Permeability and compression characteristics of municipal solid waste samples Environmental Geology

Jain P, Powell J, Townsend TG, et al. (2005) Air permeability of waste in a municipal solid waste landfill Journal of Environmental enginneering

Jain P, Powell J, Townsend TG, et al. (2006) Estimating the hydraulic conductivity of landfilled municipal solid waste using the borehole permeameter test Journal of Environmental enginneering

Olivier, F. and Gourc, J.P. (2007) Hydro-mechanics of Municipal Solid Waste subject to leachate recirculation in a large-scale compression reactor cell. Waste Management 27

Olivier, F. Gourc, J.P. Achour, F. Morais, J. Bayard, R. (2005) Evolution of bio-physical and mechanical characteristics of MSW after 2 years incubation in a laboratory-scale bioreactor Proc. Sardinia 2005, 10th International Landfill Symposium, Cagliari, Italy

Olivier, F. (2003) Tassement des déchets en CSD de classe II : du site au modèle. PhD dissertation, University of Grenoble, 325 p.

Powrie, W. et Beaven, R. P. (1999) Hydraulic properties of household waste and implications for landfills. Proc. of the Institution of Civil Engineering, Vol. 137

Warrick. A.W. (2002) Soil Physics Companion CRC Press LLC 389 p

Evaluating Cr(VI) Leaching from Recycled Waste Concrete Aggregate Using Acceleration Tests

Toru Inui[1], Masashi Kamon[2], Takeshi Katsumi[3], M. ASCE and Akiko Kida[4]

[1] Assistant Professor, Graduate School of Global Environmental Studies, Kyoto University, Yoshida-honmachi, Sakyo, Kyoto 606-8501, Japan, inui@mbox.kudpc.kyoto-u.ac.jp
[2] Professor, Graduate School of Global Environmental Studies, Kyoto University, Yoshida-honmachi, Sakyo, Kyoto 606-8501, Japan, kamon@mbox.kudpc.kyoto-u.ac.jp
[3] Associate Professor, Graduate School of Global Environmental Studies, Kyoto University, Yoshida-honmachi, Sakyo, Kyoto 606-8501, Japan, tkatsumi@mbox.kudpc.kyoto-u.ac.jp
[4] Head of Laboratory, Research Centre for Material Cycles and Waste Management, National Institute for Environmental Studies, 16-2, Onogawa, Tsukuba, 305-8506, Ibaraki, Japan, akida@nies.go.jp.

ABSTRACT: Cement based secondary materials, such as waste concrete aggregates and cement stabilized wastes, are often utilized as geo-materials. Their physical and chemical properties may change in field due to the loss of soluble chemicals and/or the surface wearing. Thus, the laboratory testing protocol for evaluating their in situ leaching behavior needs to be developed. In this study, three different acceleration tests, wetting-drying test, freezing-thawing test and abrasion test, are conducted for several waste concrete aggregates (WCAs) to evaluate the effects of the exposure to these conditions, which may actually occur in field conditions, on the leaching behavior of hexavalent chromium (Cr(VI)) contained in the mortar of WCA. Leaching amounts obtained are compared and correlated with those in the conventional batch leaching test. Exposure to these accelerated conditions, particularly the wetting-drying process, promotes the leaching of Cr(VI). Leaching amounts from granular WCA exposed to these conditions are no more than that in the conventional batch leaching test, which is conducted for WCA crushed with < 2 mm in grain size. This finding supports that the Cr(VI) leaching amount of WCA exposed under environmental conditions can be conservatively estimated by the conventional batch leaching test.

INTRODUCTION

Annual discharge of waste concrete from demolition works has reached 32 million ton in Japan. Most of waste concrete is processed into waste concrete aggregate (WCA) by crushing and grain-size control (Fig. 1) and recycled as geo-materials (Kamon et al. 2000). However, a certain amount of chromium is contained in both raw materials for cement and cement products (Kamon 2000). Accordingly, the leaching of hexavalent chromium (Cr (VI)) with considerable concentrations from the mortar fraction of WCA has been observed (Kamon et al. 2004). Thus, characterization of the Cr(VI) leaching behavior is necessary for assuring the environmental suitability of the WCA.

Physical and chemical properties of cement based secondary materials, such as WCA and cement stabilized wastes, may gradually change in field due to the loss of soluble chemicals and/or the surface wearing. Thus, developing the testing method to evaluate the effect of these property changes on the leaching behavior has been one of important issues (e.g. Gervais et al. 2004).

In this study, leaching behavior of Cr(VI) is evaluated for the WCA exposed to three types of acceleration tests, i) wetting-drying, ii) freezing-thawing and iii) abrasion, to which the WCA may be subjected in field conditions. Leaching amounts obtained are compared and correlated with those in the conventional batch leaching test to discuss a possibility to estimate the long term leaching performance with a simple evaluation test.

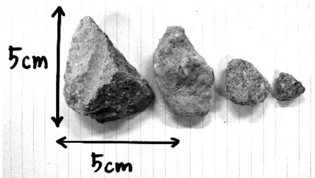

FIG. 1. Waste concrete aggregate used in the experiment.

LABORATORY EXPERIMENTS

Waste Concrete Aggregate

Three different WCA samples, which are referred to WCA-1, 2 and 3 were used. They were collected from demolition works of the concrete structure. Table 1 shows the basic properties including the grain size distribution of three WCA samples. Water content and water absorption tests are carried out according to JIS A1203 and JIS A1110, respectively. WCA-2 is considered to contain a larger amount of mortar since the water absorption, which is a good index of mortar content, is greater than others.

Table 1. Basic properties of WCA samples.

Sample	WCA-1	WCA-2	WCA-3
Site	Tokyo, Japan	Kanagawa, Japan	Tokyo, Japan
Age of original structure	Unknown	40 years	40 years
Natural water content (%)	3.3	5.5	4.2
Water absorption capacity (%)	5.4	7.0	5.2
Grain size distribution (%)			
19 mm –	14	0	0
9.5 mm – 19 mm	41	13	23
4.75 mm – 9.5 mm	22	50	55
– 4.75 mm	23	37	22