Settlement characteristics of saturated Mechanical Biological treated waste from Croatia

Nikola Kaniški, Nikola Hrnčić, Igor Petrović

Department of Environmental Engineering, University of Zagreb, Faculty of Geotechnical Engineering, Varazdin, Croatia

Abstract

Mechanical biological treatment (MBT) technology was developed in Germany with the aim of reducing the amount of biodegradable waste before landfilling and has several types of output products. Apart from useful and recyclable products, one part of waste from MBT process cannot be used as waste fuel or recyclable material but is still quite rich in organic matter. This type of waste (called methanogenic fraction) goes to a bioreactor landfill where water is added and recirculated, to accelerate and increase the biodegradation of methanogenic fraction, after which biogas is extracted. In this paper, the focus is placed on determining the settlement characteristics on single wet specimen of methanogenic fraction (particle size <25 mm) from a Croatian MBT plant. In order to conduct the experiment, oedometer cell with 150 mm diameter was used. Continuous settlement measurements were performed in three points using two callipers, and one calibrated linear transducer (LVDT). The obtained results have shown that as the load of the specimen increases, coefficient of consolidation and coefficient of permeability values decrease, making the material denser, and therefore more challenging for water recirculation and biogas extraction.

Keywords

Biodried waste, settlement characteristics, methanogenic fraction, oedometer test, consolidation coefficient, permeability

1 Introduction

Very common waste treatment technology used to reduce the amount of biodegradable waste before landfilling is the so-called Mechanical and Biological treatment or MBT. In Republic of Croatia so far, two Waste Management Centers (WMC) are in operation which use MBT as waste treatment technology and are public property (WMC Kaštijun and WMC Marišćina). Given that many MBT technology variations have been developed so far, this term includes plants with large differences in technical equipment and operating conditions. Mentioned Croatian plants use biodrying as their biological treatment technology.

The MBT process can be designed to have one or more primary output products as output. In addition to the primary products that can be created by the MBT process, in all MBT processes, secondary output products are created, such as recoverable materials (paper, metals, plastics), waste material that must be disposed of in a landfill, wastewater and air emissions. (WASTE MANAGEMENT PLAN OF THE REPUBLIC OF CROATIA FOR THE PERIOD 2007-2015, NN 85/2007) Waste material that must be disposed of in a landfill is still quite rich in organic matter and is called methanogenic fraction. This type of waste can go to a Bioreactor Landfill (BL) where after the material is installed and landfill body is closed, water is added and recirculated to accelerate or increase the biodegradation of waste material after which biogas is extracted. In contrast to conventional dry landfills, BL experience faster settlements due to increased waste decomposition rate and increased pressure due to higher specific weights. Therefore, determination of settlement characteristics is very important to a quality design process (PETROVIC, 2016). Although many of the researchers studied MBT waste (VELKUSHANOVA, 2011; CARRUBBA AND COSSU, 2003; BAUER ET AL., 2007; KUEHLE-WEIDEMEIER ET AL., 2000; BIDLINGMAIER ET AL., 1999; DUELLMANN, 2002; BAUER ET AL., 2006; HEISS-ZIEGLER AND FEHRER, 2003; SIDDIQUI ET AL., 2012; BORTOLUZZI, 2014), all the studies involved biostabilised and not biodryed waste material.

In this paper, authors presented results of single wet specimen of methanogenic fraction (particle size <25 mm) from WMC Marišćina, located in Croatia. The results are presented as basic geotechnical parameters of studied waste material (composition, specific gravity, particle size distribution, organic matter content) and as consolidation and hydraulic parameters (coefficient of consolidation and permeability) determined with a specially designed oedometer device. Furthermore, the obtained results related to the permeability coefficient were compared to the permeability coefficient for various wastes presented in PETROVIC, 2016.

2 Components of the Oedometer device

For purpose of this research, an oedometer device with 150 mm internal diameter and an 80 mm maximum height was used. The device consists of a rigid cell, rigid top plate, top plate sliding rail, Archimedes pulley, a rigid flat board with a hole in the middle, and displacement transducer together with two digital callipers. Figure 1 shows the oedometer assembly and measuring system installed on a platform with hoist originally developed for a Large Oedometer device (PETROVIC ET AL., 2014).

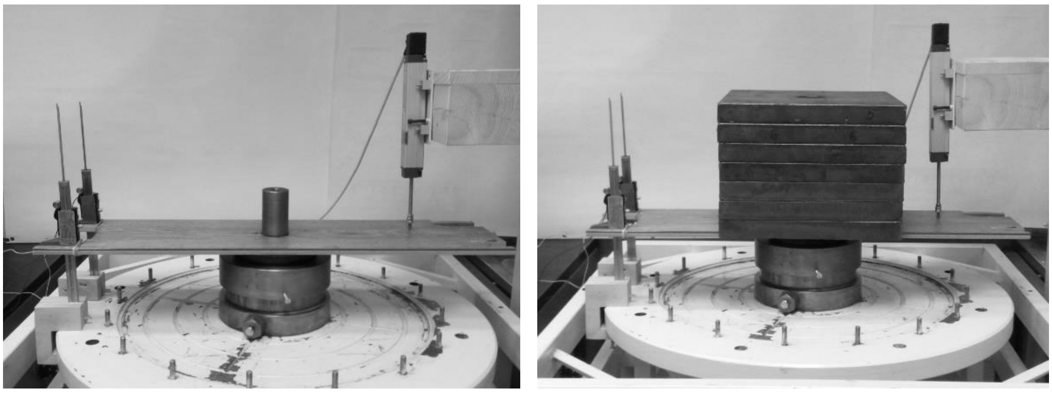

Figure 1 Oedometer assembly with and without weights

The applied dead load is a square metal plate, with a 50 mm diameter hole in the middle. The hole serves as a guide, so that round metal rod attached to the top plate can be placed precisely in the center of mass. The total applied load are 10 metal plates, each 20 kg (± 0.2-0.3 kg) in weight producing total sitting pressure of 119.5 kPa on waste specimen. The load is applied to the specimen with help of a rope, power tape, crane, and an Archimedes pulley.

The oedometer cell consists of upper ring connected with three steel bolts in horizontal direction to the specimen ring. A sliding rail (top plate) passes through the upper ring and goes all the way to the sample. Initial sitting pressure of the top plate is 5.39 kPa. Top plate has a threaded hole on the top, so that a round, four-piece metal rod can be screwed into it. Platform has a drainage channel which provides a clear drainage path for the excess pore water. On top of the specimen, below the top plate, a geomembrane is placed, to prevent any excess porewater to seep out of the cell through the top. To prevent clogging of the drainage holes a geotextile is placed at the bottom of the cell. To reduce friction between the top plate and the specimen ring, top plate was sprinkled with talc powder before installing the specimen (RUDENKO AND BANDYOPA, 2013).

On top of the top plate, a rigid wooden plate was installed, with a hole in the middle so that a metal rod can be attached through it. As can be seen from Figure 1, on the right side of the specimen, Vishay 155 L calibrated displacement transducer (LVDT) was used for measuring the settlements. The data logger used, recorded every 10 seconds the change of the height of the specimen under dead load. On the left side of the specimen, two callipers with a maximum measurement capacity of 150 mm were used. Each was placed on one edge of the rigid wooden plate so that three measurement points (2 callipers and a LVDT formed a triangle) provide differential settlement measurements. Callipers were both connected to a computer with an Arduino system where the change in settlement was logged every second.

3 Arduino working principle

Arduino is an easily programmed open-source microcontroller. It was designed and brought to public in 2005 to interact with environment using sensors and actuators. (LEO, 2016) In order to program the code (known as a sketch) for this research a board was used. Arduino board consists of a hardware and a software. The hardware designs are available online for free from official website https://www.arduino.cc/. For Arduino hardware to work properly a series of components must be used such as: microcontroller, external power supply, USB plug, internal programmer, reset button, analog pins, digital input/output pins, power and GND (ground) pins. A software is used to develop a program code (sketch). Commonly used Arduino software is Arduino IDE. The IDE contains following parts:

- text editor,
- message area,
- text,
- console toolbar. (LEO, 2016)

In this work, two Arduino Uno boards were used to read the data from digital callipers (Figure 2). The digital callipers have a digital output connector located under a small plastic cover which is used to connect Arduino Uno board and the readings on the callipers (Figure 3) with an USB cable. New development code can be uploaded to the board very easy and fast via a USB cable and if necessary, the code can be changed and uploaded again in very short time. The code used for the purpose of this work was compiled by THALHEIMER, M. and downloaded from his web page (see the reference list).

Figure 2 Two callipers connected with Arduino Uno

The output which appears on the serial monitor on personal computer is exactly the same as can be read on the callipers LCD. YAT was used as a serial terminal to write the measured values from callipers to a file on a personal computer (Available at: https://sourceforge.net/projects/y-a-terminal/). After end of the experiment, the values recorded every second throughout the test were averaged for every ten seconds in order to compare the recorded data to the results obtained with Vishay 155 L displacement transducer.

Figure 3 Digital calliper and output connectors

4 Tested material

In WMC Marišćina, mixed municipal solid waste is collected from households and brought with garbage trucks to a receiving pit. The waste material is first subjected to mechanical treatment with crushing into a fraction <200 mm, and then sent with the conveyors for further processing. Fraction >200 mm is sent back to crushing step. After first mechanical treatment step, the waste is sent to concrete chambers where the moisture content in the material is minimized by forced aeration for seven to ten days. To obtain as much recovery material as possible, the dried material is sieved again and subjected to various mechanical refining procedures to get as much separated recyclable material (plastics, metals, non-ferrous metals). In this stage of processing, the so-called methanogenic fraction is separated, which is not suitable for waste fuel, with a maximum particle size of about 25 mm. This type of material is disposed of in its dry state, in a BL located within the WMC Marišćina, from which biogas should be produced after BL closure and recirculation of the leachate. For this reason, it is very important to study how the installed waste material will react after the water is introduced in the BL body.

4.1 Testing procedure

In this paper, the settlement characteristics (coefficient of consolidation and permeability) on single wet specimen of methanogenic fraction were obtained. For that purpose, oedometer cell with 150 mm diameter was used, with dead load being ten metal plates with total of 119.5 kPa pressure. To prevent tilting of the top plate, a sliding rail was used, and the remained tilting was measured with three displacement transducers positioned in a triangular shape. Continuous settlement measurements were performed in three points using two callipers with 0.01 mm resolution and 150 mm maximum travel distance and one calibrated Vishay 115 L linear transducer with maximum travel distance of 100 mm and 0.1 mm resolution. The aim of this test was to examine the compressibility of methanogenic fraction in wet conditions.

The specimen of dry methanogenic fraction was installed into an oedometer cell in three layers. Installed dry specimen density was 380 kg/m^3 because that kind of density was reported by the WMC Marišćina operators. At the bottom of the oedometer cell, a geotextile was placed to prevent clogging of the bottom drainage path. The specimen was installed 1 cm lower than maximum height of the oedometer cell. Geomembrane was placed on top to prevent fines of the installed material to enter the gap between the container and the top plate and to prevent the moisture to seep out of the container. A total of 0.4224 kg specimen mass was installed in 63 mm height in its dry state. Each layer was compressed with a 2 kg weight by hand. After the specimen was installed, a solution of deaerated water and acetic and propionic acid was introduced into the specimen from bottom of the cell. Solution of acids prevented biodegradation of installed waste material (SIDDIQUI ET AL., 2012). A total of 535 973.451 mm^3 solution was added with GDS Enterprise Level Pressure Volume Controller slowly enough to prevent any disturbances of the initial height of the installed specimen (63 mm). No loads were on top of the specimen during saturation procedure. Initial bulk density after saturation procedure was 0.859 g/cm^3. Initial parameters of installed specimen are presented in Table 1.

Table 1 Initial parameters of installed methanogenic fraction

Condition	ρ (g/cm^3)	w (%) (WM*)	ρ_d (g/cm^3) (DM*)	ρ_s (g/cm^3) (DM)	e_0	S_r (%)
Wet	0.859	55.93	0.380	1.894	3.984	60.32

*DM-dry matter; **WM-wet matter

ρ denotes bulk density, w moisture content, ρ_d dry density, ρ_s average solid particle density, e_0 void ratio in dry state of the specimen, and S_r degree of saturation.

Initial sitting pressure as a first step in consolidation procedure was obtained with use of the top plate which produced 5.39 kPa of pressure to the specimen. Immediate settlement was recorded by hand after the top plate was placed on top of the specimen with use of calliper. After the immediate settlement was recorded, rigid plate was placed on top of the top plate together with first metal rod and the sample was submitted to additional load of 11.78 kPa. Total cumulative sitting pressure on the specimen is as follows: 5.39, 17.17, 28.38, 51.32, 74.2, 96.68 and 119.5 kPa, respectively. Each loading step except top plate lasted for about 24 hours before next step was applied.

5 Experimental results and discussions

After the waste samples were delivered to the Faculty of Geotechnical Engineering (University of Zagreb), Laboratory for Environmental Engineering, a series of tests were performed. Table 2 shows individual constituent components of methanogenic fraction which were manually separated and weighed to determine the average composition of studied waste material.

Table 2 Average composition of biodried waste components

Component	**Mass percentage [%]**
	Marišćina
Plastics	6.43
Textile	0.22
Glass	10.62
Metal	0.94
Paper/Cardboard	4.71
Wood	1.18
Bones/Skin	0.20
Stones	2.76
Ceramics	0.46
Rubber	0.13
Kitchen waste	2.15
Unidentified >2 mm	42.48
Unidentified <2 mm	27.72
Total	100

Figure 4 shows averaged particle size distribution curve for studied methanogenic fraction. Averaged distribution curve was obtained on a series of 25 sieved samples on a series of sieves as follows: 31.5, 16, 8, 4, 2, 1 and 0.5 mm.

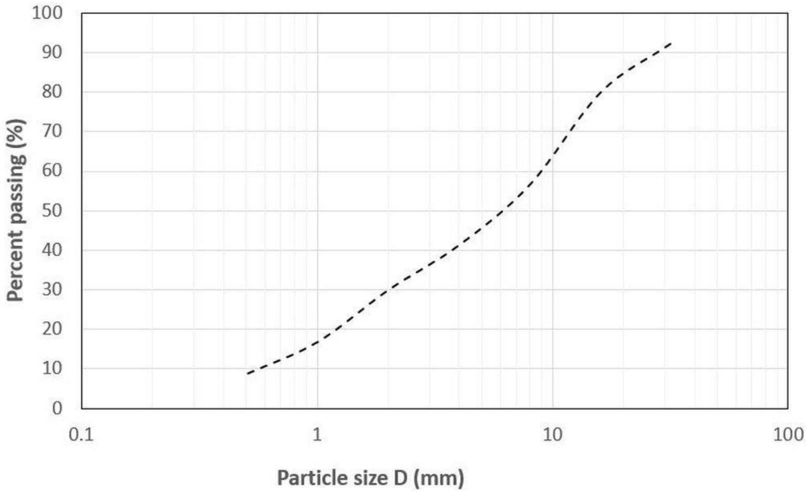

Figure 4 Averaged particle size distribution curve for studied biodried material

Organic matter content was obtained with a 50 g representative sample. The sample was subjected to a muffle furnace at 440 °C until no further changes in mass were observed. With respect to the mass before and after ignition, calculated organic matter content of studied methanogenic fraction was 51.6%.

The solid particle density of waste sample was determined with gas pycnometer method. The results vary from 1.69 g/cm^3 to 2.19 g/cm^3. On series of 23 samples, the average solid particle density of methanogenic fraction was 1.88 g/cm^3 with standard deviation of ±0.13 g/cm^3. The wide range of solid particle density can be attributed to the heterogeneity of the material.

5.1 Settlement curve

Time settlement curve is presented in Figure 5. Immediate settlement caused by pressure of top plate was measured by hand and it was 10.85 mm. Immediate settlement value is not included in Figure 5. According to settlement measurements obtained with LVDT and two callipers, maximum difference between LVDT measurement and calculated settlement value in the center of specimen gave maximum difference of 0.27 mm. Hence, the differential settlements can be disregarded.

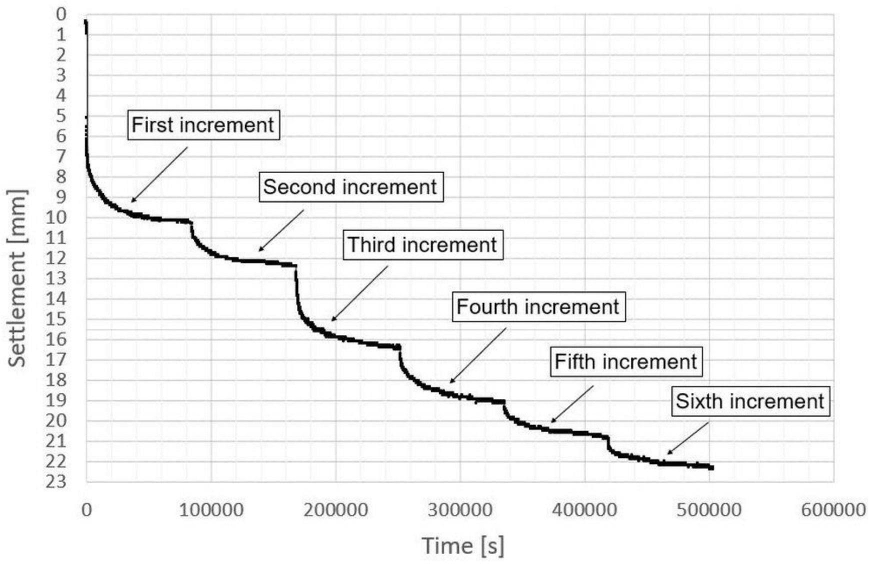

Figure 5 Time-settlement curve for wet specimen of methanogenic fraction from WMC Marišćina

In order to determine consolidation coefficient, Taylor method was used, which has been confirmed as a valid method for determination of c_v of saturated MBT waste material by SIDDIQUI ET AL., 2013, (Equation 1).

$$c_v = \frac{0.848*d^2}{t_{90}} \quad (1)$$

where d is drainage path in mm, and t_{90} is the time in seconds required to achieve 90% of the primary consolidation. Plotting settlement (mm) against $\sqrt{t}$ (min) obtained consolidation coefficient for every increment is presented in Table 3.

From the theory of one-dimensional consolidation, it follows that from results of the oedometer experiment, it is possible to calculate the coefficient of permeability of the testing specimen using following expression (2):

$$k = \frac{\gamma_w * c_v}{M_v} \quad (2)$$

where k is coefficient of permeability, γ_w is unit weight of water (9810 N/m^3), c_v is consolidation coefficient (m^2/s) and M_v is oedometric moduli (Pa). Calculated results of coefficient of permeability are shown in Table 3. Oedometric moduli was obtained using equation (3):

$$M_v = \frac{\Delta\sigma_v}{\Delta\varepsilon} \quad (3)$$

where $\Delta\sigma_v$ is increment of vertical total stress (kPa), $\Delta\varepsilon$ is the strain increment.

The vertical strains were calculated by equation (4).

$$\varepsilon = \frac{\Delta h}{h} \quad (4)$$

where Δh is the change in total specimen height, and h is the initial specimen height.

For more detailed discussion about vertical (true and engineering) strains in waste materials please take a look at POWRIE ET AL. (2019).

Table 3 Consolidation coefficient c_v, time to achieve 90% of the primary consolidation, permeability k, and oedometric moduli for every increment of present research

Increment No./stress (kPa)	First/ 5.39-17.17	Second/ 17.17-28.38	Third/ 28.38-51.32	Fourth/ 51.32-74.2	Fifth/ 74.2-96.68	Sixth/ 96.68-119.5
M_v (Pa)	72,430	335,500	363,990	527,330	802,040	1,091,040
t_{90} (s)	392.04	705.43	5,166.73	8,663.89	10,000.00	8,663.89
c_v (m²/s)	$4.813 * 10^{-6}$	$2.019 * 10^{-6}$	$2.361 * 10^{-7}$	$1.170 * 10^{-7}$	$8.858 * 10^{-8}$	$9.267 * 10^{-8}$
k (m/s)	$6.519 * 10^{-7}$	$5.903 * 10^{-8}$	$6.364 * 10^{-9}$	$2.176 * 10^{-9}$	$1.083 * 10^{-9}$	$8.332 * 10^{-10}$

For consolidation coefficient shown in Table 3, equation (1) -Taylor method was used, whereas for coefficient of permeability equation (2) was used. The data of permeability coefficients were compared to the permeability coefficients for various wastes presented in PETROVIC, 2016. The author made a comprehensive literature review, and the results show, that for pre-treated MSW with the same particle size range of 0-25 mm, the values of coefficient of permeability range from $7.8 * 10^{-8}$ (m/s) to $8.2 * 10^{-11}$ (m/s). However, it should be noted that for tested waste material the settlement vs. $\sqrt{t}$ curves did not show strong distinction between primary and secondary compression as is the case for soil materials. Therefore, the determination of the linear portion of the settlement vs. $\sqrt{t}$ curve is not strait forward and consequently the results are very much dependent on the personal judgement of the person who interprets the data.

5.2 Basic geotechnical parameters

Table 4 presents basic geotechnical parameters at the end of the testing procedure. Comparing Table 1 and 4, it can be concluded that the values of ρ and ρ_d have increased at the end of the testing procedure which was to be expected.

Table 4 *Basic parameters of tested specimens at the end of the oedometer test*

Condition	**ρ (g/cm³)**	**w (%) (WM**)**	**ρ_d (g/cm³) (DM*)**	**ρ_s (g/cm³) (DM*)**	**e_1**	**S_r (%)**
Wet	1.083	36.1	0.80	1.894	1.38	77.68

*DM-dry matter

**WM-wet matter

6 Conclusions

This paper provides an overview of the consolidation parameters and basic geotechnical parameters of single wet specimen of biodried mixed municipal solid waste, so called methanogenic fraction from the plant for mechanical-biological waste treatment in Marišćina, Croatia. For that purpose, a specially designed oedometer device was used.

The conducted test on saturated material mimicked the conditions that will occur at the plant during the operation of the BL. The obtained test results show that attention should be paid to the amount of water recirculated in the landfill body to allow uninterrupted operation. The results have shown that as the load of the specimen increases, stiffness modulus also increases while permeability coefficients simultaneously decreas, making the material denser, and therefore more challenging for water recirculation and bio-gas extraction.

The obtained permeability coefficients fit reasonably well within the range of permeability coefficients obtained on the various waste materials with similar particle size range presented in PETROVIC, 2016.

Given that waste samples were taken in the winter (February 2019), new tests should focus on material produced during the summer period to compare the impact of the tourist season on the settlement parameters and basic geotechnical parameters of waste.

Acknowledgments

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Author’s addresses

Nikola Kaniski, mag.ing.amb.
University of Zagreb, Faculty of Geotechnical Engineering
Department of Environmental Engineering
Hallerova aleja 7, HR-42000 Varazdin
Phone: +385 42 408 925
nikola.kaniski@gfv.unizg.hr

Nikola Hrncic, mag.ing.aedif., mag.ing.geoing.
University of Zagreb, Faculty of Geotechnical Engineering
Department of Environmental Engineering

Hallerova aleja 7, HR-42000 Varazdin
Phone: +385 42 408 925
nikola.hrncic@gfv.unizg.hr

Assoc. Prof. Igor Petrovic
University of Zagreb, Faculty of Geotechnical Engineering
Department of Environmental Engineering
Hallerova aleja 7, HR-42000 Varazdin
Phone: +385 42 408 919
igor.petrovic@gfv.unizg.hr