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Determination of the apparent specific gravity of a biodried municipal solid waste by "gas pycnometry"

Igor Petrovic[a], Nikola Kaniski[a], Nikola Hrncic[a], Ivan Hip[a]

[a] *Faculty of Geotechnical Engineering, University of Zagreb, Varazdin, Croatia*

ABSTRACT

This paper describes how to use standard geotechnical equipment as a "gas pycnometer." The presented "gas pycnometer" is used to determine the solid particle density (SPD) of mechanically and biologically treated (MBT) municipal solid waste (MSW). The measurements were made on waste samples obtained from Marišćina, a Croatian waste management plant. The average SPD value, obtained from 23 fresh samples, was 1.89 g/cm^3. In addition, 10 compacted and 3 shredded samples were also tested. Both compacting and shredding caused increases in the average SPD value to 1.91 and 1.93 g/cm^3, respectively. The obtained results show good agreement with the average SPD value for waste material based on results collected from the literature. The presented "gas pycnometer" has been proven to be a reliable, cost-effective, and quick solution for the determination of the SPD of MBT waste material.

KEYWORDS

Biodried waste; Solid particle density of waste material; Gas pycnometry; Landfill design

1. INTRODUCTION

Standard geotechnical practice defines the solid particle density as the ratio between the mass of solid particles and the volume of solid particles (Eqn. 1).

$$\rho_s = \frac{m_s}{V_s} \tag{1}$$

The solid particle density is commonly used to determine base phase relationships, such as, for example, the void ratio, porosity, volumetric water content, degree of saturation, and unit weight.

Several researchers have reported the solid particle density obtained for MBT waste. Table 1 presents the densities of the MBT waste solid particles, ρ_s, collected from the literature. The published values lie in a wide range: from 0.876 g/cm^3 up to 2.214 g/cm^3.

Table 1. Densities of solid particles, ρ_s, collected from the literature.

Ref.	ρ_s [g/cm^3]	Additional information
Heiss-Ziegler and Fehrer, 2003	2.214	Particle size ≤ 25 mm; waste was treated together with sewage sludge in a two-step process over a period of > 20 weeks
Hudson et al., 2004	0.876–1.303	The waste was processed using the DANO technique prior to testing. Evolution of solid particle density with vertical load. The vertical stress range went from 34 to 463 kPa.
Entenmann and Wendt, 2007	1.58–1.98	Various waste mixtures

Rose et al., 2009	1.902	MSW compost, test method NBR 7181/1984 (ABNT (a), 1984)
Sudarshana, 2011	1.69	0–10 mm fraction size, average value
	1.929	0–20 mm fraction size, average value
Velkushanova, 2011	1.63	BS1377-2, gas jar method
Petrovic et al., 2014	2.147	ASTM D 854-02, maximum particle size was 4.75 mm
Sivakumar Babu et al., 2015	1.26	Mechanically and biologically treated compost reject collected from the Mavallipura landfill site. Bottle and pycnometer method.

This paper will demonstrate how to utilize a simple gas pycnometer set-up, consisting only of one advanced pressure/volume controller and one hermetically sealed cell, devices that are currently fairly common in geotechnical laboratories.

For the purposes of this paper, the waste samples were taken from the waste management center (WMC) Marišćina, in Istria, Croatia. Although during measurement some possible sources of errors were disregarded, the obtained SPD values prove that the developed "gas pycnometer" can produce reliable and repeatable results within acceptable limits and with a small scattering of data. For the 23 tested waste samples, the obtained average SPD was 1.89 g/cm^3 with a standard deviation of ±0.13. The measured average value for intact specimens shows good agreement with the range of values obtained from the published data.

In addition to the intact specimens, 10 compacted and 3 shredded samples were also tested. The average SPD of the compacted samples was 1.91 g/cm^3 and the standard deviation was ±0.12, while the average SPD of the shredded samples was 1.93 g/cm^3.

The presented "gas pycnometer" has been proven to be a successful alternative solution to the commercially available gas pycnometers with respect to MBT waste material. It has been shown that the presented "gas pycnometer" method is a reliable, cost-effective, and fast solution for the determination of the SPD of MBT waste materials.

2. MATERIALS AND METHODS

2.1. Basic geotechnical properties of tested waste material

Fresh samples of the specified waste material (<25 mm) were obtained from the waste management center (WMC) Marišćina in Istria, Croatia (Figure 1).

Figure 1. Fine-grained fraction of MBT MSW from WMC Marišćina.

From Figure 2 it can be noticed that more than 92% of the tested sample have particles smaller than 31.5 mm. The mass percentages of each individual constituent of the sampled MBT MSW were as follows: plastics 6.43%, textiles 0.22%, glass 10.62%, metals 0.94%, paper/cardboard 4.71%, wood 1.18%, bones/skin 0.20%, stones 2.76%, ceramics 0.46%, rubber 0.13%, and kitchen waste 2.15%. From the obtained results it can be noticed that the main components of the examined material were plastics, paper/cardboard, and glass. Due to an intensive treatment process, more that 70% of the tested material could not be identified. The unidentified particles are classified into a miscellaneous category and divided into particles larger than 2 mm (42.48%) and smaller than 2 mm (27.71%). The high percentage of unidentified particles larger than 2 mm suggests that the examined material might show a reinforcing effect during the shearing process.

The in-situ moisture content was determined in accordance with the ASTM D 2216 standard. The average moisture content was 9.60%.

The organic content was determined in accordance with the ASTM D 2974 standard. The organic portion of the sampled MBT MSW was 51.6%.

The particle size analysis is conducted in accordance with the ASTM D 422 standard. Figure 2 shows the averaged granulometric curve obtained for 25 MBT MSW samples. For comparison purposes, Figure 2 also presents two granulometric curves of biostabilized MBT waste samples obtained by Petrovic et al. (2014) and a granulometric curve of MBT waste obtained by Borgatto et al. (2014). The comparison reveals that both treatment methods—biodrying vs. biostabilization—produce similar coarse-grained materials. The coefficient of curvature and uniformity coefficient of the biodried samples were $C_c = 0.86$ and $C_u = 15.8$, respectively. Thus, the examined MBT MSW can be classified as a coarse-grained material.

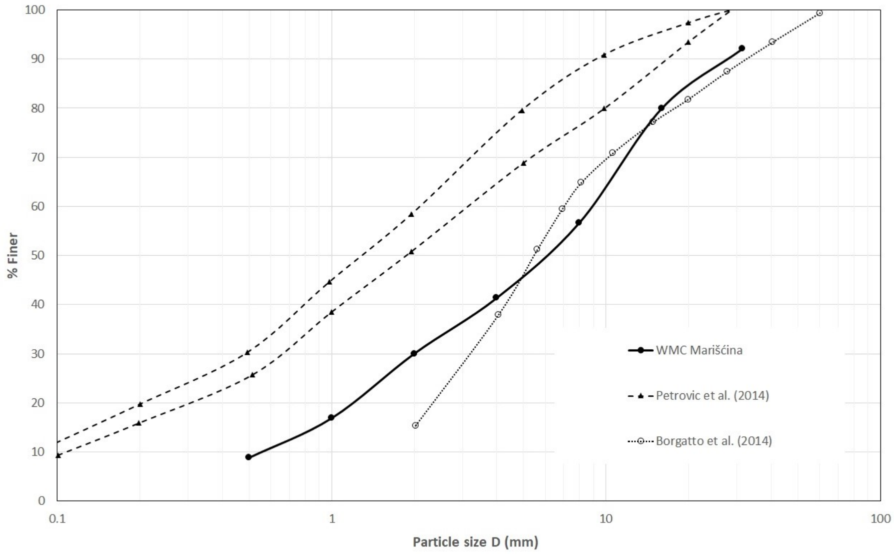

Figure 2. Particle size distribution curves for pre-treated MBT waste material.

The minimum and maximum dry densities of tested material under atmospheric pressure were determined in accordance with the ASTM D 4253 and D 4254 standards. In its loosest state, the dry density of the tested MBT MSW was 0.174 g/cm^3, while in its densest state it was 0.383 g/cm^3.

2.2. Geotechnical equipment used as a constant-volume gas pycnometer

A constant-volume gas pycnometer consists of two chambers. Both chambers are connected with tubes and a coupling valve as presented in Figure 3. One chamber is connected to a pressure source, while the second (sample) chamber has a relief valve.

The basic operation principle of a constant-volume gas pycnometer is as follows:

- gas is introduced into the pressure chamber; the coupling valve is closed;
- the relief valve of the sample chamber is open; the sample chamber is under atmospheric pressure;
- the initial pressure within the pressure chamber is measured;
- the relief valve on the sample chamber is closed;
- the coupling valve is opened, allowing the gas to expand between the two chambers;
- the equilibrated gas pressure is measured;
- based on the ideal gas law, the known volume of the pressure chamber, and the measured data, it is possible to calculate the volume of solid particles;
- based on the calculated volume of solid particles, the solid particle density (ρ_s) can be calculated using Eqn. 1.

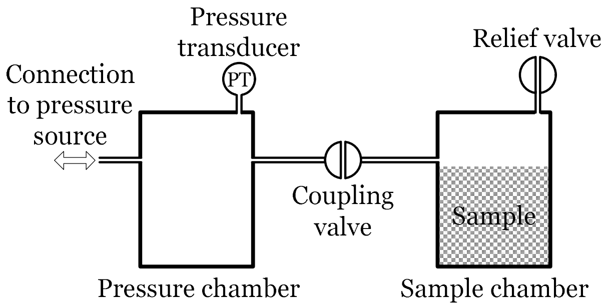

Figure 3. Schematic of a constant-volume gas pycnometer.

For the pressure chamber, an advanced pressure/volume controller is used. The controller used has a pressure accuracy of 0.1% FRO, a pressure resolution of 0.1 kPa, and a volumetric accuracy of 0.1%.

For the sample chamber, a so-called GDS toxic cell was used (a free flowing Bellofram rolling diaphragm has to be removed).

A photograph of the set-up is presented in Figure 4.

Figure 4. The advanced pressure/volume controller piston—pressure chamber; the GDS toxic-cell—sample chamber.

2.3. Verification

The gas-pycnometer's accuracy was checked by measuring the solid particle density for two sand samples. One sample had a fraction size ranging from 0 to 1 mm (Figure 5) while the second sample had a fraction size ranging from 0 to 4 mm.

Figure 5. Tested sand sample with fraction size in a range from 0 to 1 mm.

The solid particle density of the finer sand obtained using the standard water pycnometry method was 2.66 g/cm^3. The mean value based on five measurements in a range from 2.59 to 2.73 g/cm^3 obtained with “gas-pycnometry” was also 2.66 g/cm^3.

For the coarser sample the solid particle density obtained with the standard water pycnometry method was 2.72 g/cm^3. The mean value based on five measurements in a range from 2.70 to 2.77 g/cm^3 obtained with “gas-pycnometry” was 2.73 g/cm^3.

Thus, it was concluded that the specified “gas-pycnometer” set-up is sufficiently accurate.

3. RESULTS

Based on the procedure described in Section 2, three sets of measurements were made: the measurement of “as-it-is” samples, the measurement of samples compacted with a vibratory plate, and the measurement of shredded samples.

While the first set of measurements was made as a reference point, the subsequent two sets of measurements were made with the aim of investigating the influence of compaction and shredding on the SPD of waste material. The obtained results are presented in Table 2.

Table 2. SPD of pre-treated waste from WMC Marišćina obtained with constant-volume “gas pycnometer.”

SPD value	Arithmetic mean	Standard deviation	Sample condition
g/cm^3	g/cm^3	g/cm^3	
1.965	1.89	±0.13	Uncompacted
1.820			
1.736			
1.905			
1.873			
2.188			
2.132			
1.691			
1.899			
1.938			
1.695			
1.785			
1.784			
1.865			
2.026			
1.883			
1.765			

1.877			
1.862			
1.811			
1.974			
1.824			
1.998			
1.887			
1.979	1.93	/	Shredded
1.910			
1.989			
1.840			
1.929			
1.933			
2.024	1.91	±0.12	Compacted
2.041			
1.880			
1.654			
1.851			
1.999			

As can be seen from Table 2, the SPD values of "as-it-is" samples are in a range from 1.691 g/cm^3 to 2.188 g/cm^3. Clearly, the SPD of biodried MBT waste material is not a constant value. The obtained value strongly depends on the percentage of each individual component within the tested sample. Nevertheless, it is worth noting that the majority of the SPD values obtained for treated MBT waste materials (Table 1) lie above 1.58 g/cm^3, and the values go up to 2.214 g/cm^3. Therefore, the measured SPD value of biodried MBT waste fits reasonably well within the specified range of SPD values for MBT waste materials obtained from the literature.

Furthermore, the influence of shredding and compaction on the SPD value was also examined. Through shredding, the largest particle size of the examined MBT waste material was reduced to 6 mm. The compaction of samples was conducted in accordance with ASTM D 4253—test method 1A (Figure 6). The vibration time was 12 min at a frequency of 50 Hz, while the surcharge load was 14 kPa. During compaction, the amplitude was monitored with an accelerometer and velocimeter.

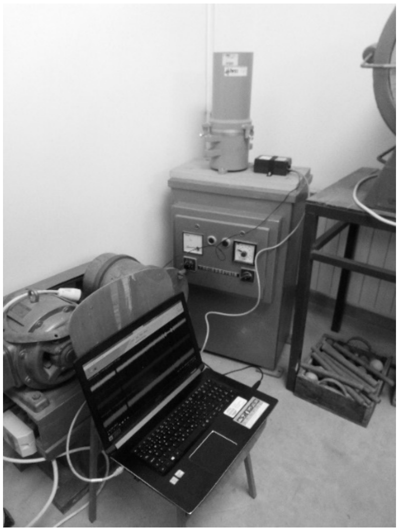

Figure 6. Compaction of MBT waste sample with vibratory table.

The obtained results (Table 2) reveal that both shredding and compaction influence SPD values. In both cases, the measured SPD values slightly increased, which was most likely caused by the removal of closed pores within the larger, more porous particles. A similar effect of compaction efforts on SPD values was also confirmed by Yesiller et al. (2014).

4. CONCLUSIONS

This paper shows how one can utilize a pressure/volume controller and a hermetically sealed cell in order to mimic a “gas pycnometer” of sufficient accuracy.

For the examined (biodried) MBT waste material, obtained SPD values were in a range from 1.61 g/cm^3 to 2.19 g/cm^3. The obtained average value was 1.89 g/cm^3. The established average SPD value corresponds well with results for MBT waste materials obtained from the published literature.

Furthermore, in order to examine the influence of particle size reduction on SPD value, 10 compacted and 3 shredded samples were additionally tested. The average SPD of the compacted samples was 1.91 g/cm^3, while the average SPD of the shredded samples was 1.93 g/cm^3. Therefore, it is confirmed that particle size reduction, regardless of the applied method, increases the SPD value of biodried MBT waste material by about 3%.

To increase the measurement accuracy, it is advisable to replace air with, for example, helium, since it can be considered an ideal and non-adsorbing gas at room temperature and low pressures.

The main advantage of the suggested “gas pycnometer” is that tests can be performed with equipment that is commonly present in geotechnical testing laboratories.

In summary, the presented “gas pycnometer” is a fast and efficient method. It takes only about 30 minutes to conduct one test, while at the same time the unpleasant odours and health hazards are minimised.

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