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Determination of specific gravity of municipal solid waste

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This investigation was conducted to evaluate experimental determination of specific gravity (G_s) of municipal solid waste (MSW). Water pycnometry, typically used for testing soils was adapted for testing MSW using a large flask with 2000 mL capacity and specimens with 100–350 g masses. Tests were conducted on manufactured waste samples prepared using US waste constituent components; fresh wastes obtained prior and subsequent to compaction at an MSW landfill; and wastes obtained from various depths at the same landfill. Factors that influence specific gravity were investigated including waste particle size, compaction, and combined decomposition and stress history. The measured average specific gravities were 1.377 and 1.530 for as-prepared/uncompacted and compacted manufactured wastes, respectively; 1.072 and 1.258 for uncompacted and compacted fresh wastes, respectively; and 2.201 for old wastes. The average organic content and degree of decomposition were 77.2% and 0%, respectively for fresh wastes and 22.8% and 88.3%, respectively for old wastes. The G_s increased with decreasing particle size, compaction, and increasing waste age. For fresh wastes, reductions in particle size and compaction caused occluded intraparticle pores to be exposed and waste particles to be deformed resulting in increases in specific gravity. For old wastes, the high G_s resulted from loss of biodegradable components that have low G_s as well as potential access to previously occluded pores and deformation of particles due to both degradation processes and applied mechanical stresses. The G_s was correlated to the degree of decomposition with a linear relationship. Unlike soils, the G_s for MSW was not unique, but varied in a landfill environment due both to physical/mechanical processes and biochemical processes. Specific gravity testing is recommended to be conducted not only using representative waste composition, but also using representative compaction, stress, and degradation states.

1. Introduction

Specific gravity is broadly defined as the ratio of the density (mass of a unit volume) of a substance to the density of a standard reference substance. The definition used in geotechnical engineering is "the ratio of the mass of a unit volume of soil solids to the mass of the same volume of gas-free distilled water at 20 °C" (ASTM D854), where the specific gravity is expressed as:

$$G_s = \frac{\rho_s}{\rho_w} \quad (1)$$

where G_s is the specific gravity of soil solids, ρ_s is the density of soil solids, and ρ_w is the density of water at 20 °C. The same units are used for the densities resulting in the dimensionless parameter G_s.

Specific gravity is used in geotechnical and geoenvironmental engineering in calculation of basic phase (i.e., weight–volume) relations including void ratio, porosity, volumetric water content, degree of saturation, and unit weight of soil. The parameter G_s can be applied to other geomaterials such as MSW. If G_s is known, particle (i.e., dry solid) density can be calculated readily using Eq. (1). Geotechnical engineering provides a general framework for determination of engineering properties and behavior of municipal solid waste (MSW). Geotechnical engineering approaches commonly have been adapted to determine compaction, hydraulic conductivity, shear strength, and compressibility/settlement characteristics of MSW (e.g., Hudson et al., 2004; Qian et al., 2005; Hanson et al., 2010a). These approaches require estimation of basic weight–volume relations including specific gravity of waste solids for MSW analyses. In addition, specific gravity is a fundamental

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material property used in design calculations as well as modeling for predicting behavior of landfill systems (e.g., McDougall, 2007; Gourc et al., 2010; Bareither et al., 2012).

Specific gravity of soils typically is determined using water pycnometry (e.g., ASTM D854). Testing for waste specific gravity is complicated by several factors including: large particle sizes; heterogeneous mixture of particles (size, shape, and material composition); relative specific gravity of individual particles with respect to water; complex particle microstructure; and potential interaction with water. Particles with specific gravity less than water may float in the test setup. Waste constituents with occluded intraparticle voids may bias specific gravity measurements. These voids may be dry or partially or fully saturated. Compressible particles also may influence measurements. Furthermore, absorption or dissolution reactions with waste constituents may influence determination of specific gravity. Use of liquids other than water or gas pycnometry may resolve some of the testing issues. However, prescience of the wide variety and complex nature of constituent components of MSW is not possible for selecting a test fluid that could be used for all potential waste materials without any physical or chemical interactions.

Water pycnometry was adopted by Hettiarachchi (2005), Entenmann and Wendt (2007), Reddy et al. (2009a, 2011), Breitmeyer (2011), and Wu et al. (2012) to determine specific gravity of MSW (Table 1). The ASTM standard method for determination of G_s of soils, D854, was used directly in some studies. This test method requires testing on solids smaller than 4.75 mm diameter (No. 4 sieve size) and a pycnometer with a minimum capacity of 250 mL. Use of a 500-mL pycnometer is common in geotechnical engineering practice with a recommended test specimen mass between 50 and 100 g for fine- to coarse-grained soils, respectively. Tests were conducted on 100-g specimens of a manufactured MSW sample with particle sizes less than 5 mm and the G_s was determined to be 1.6 by Hettiarachchi (2005). G_s was determined on shredded fresh (from active face) and old (1.5 years) wastes from an MSW landfill in the US. The measured specific gravities were 0.85 and 0.97 for fresh and old wastes, respectively (Reddy et al., 2009a). Tests were conducted on fresh and degraded manufactured wastes by Reddy et al. (2011). The G_s was determined to be 1.09 for the fresh wastes, whereas the G_s varied from 2.05 to 2.47 for specimens that underwent low to high degradation, respectively. Tests were conducted on waste samples obtained from shallow, middle, and deep layers of an MSW landfill in China by Wu et al. (2012). The particle size distributions of the waste samples from the three layers in the landfill indicated that 50–65% of the particle sizes were larger than 4.75 mm. Details were not presented, but tests may have been conducted on only a fraction of the waste samples. The G_s was reported to be 1.51, 1.88, and 2.14 for shallow, middle, and deep layers, respectively (Wu et al., 2012). Water pycnometry also was used to test mechanically and biologically pre-treated waste by Entenmann and Wendt (2007), who reported results in terms of density of solid particles with values between 1.58 and 1.98 g/cm^3.

A modified version of ASTM D854 was used by Breitmeyer (2011) on MSW specimens with particle sizes less than 25 mm. Tests were conducted using a two-chambered vessel (75-mm diameter by 300-mm height) separated by a perforated disk, which prevented floating of low specific gravity particles. The G_s was determined to be 1.34 for shredded and recombined relatively fresh (3–4 month old) wastes obtained from an MSW landfill. The G_s was determined to be 1.65, 1.80, and 1.90 for shredded and recombined relatively fresh wastes obtained from the same MSW landfill that had undergone low, medium, and high levels of degradation, respectively in laboratory reactors (Breitmeyer, 2011).

Limited data is available on factors that influence waste specific gravity. G_s has only been related to degradation. G_s was reported to increase with decreasing organic content for samples obtained from an MSW landfill in the US (Reddy et al., 2009a) and for manufactured wastes that were subjected to degradation in the laboratory (Reddy et al., 2011). The specific gravities were 0.85 and 0.97 and

Table 1
Summary of previous specific gravity investigations.

Material	Test	Details	G_s	References
Manufactured waste	ASTM D854	US representative waste stream 100 g specimens Particle sizes less than 5 mm	1.6	Hettiarachchi (2005)
Mechanically and biologically pre-treated waste	Water Pycnometry	Waste samples obtained prior to disposal from a German landfill	1.58–1.98[a]	Entenmann and Wendt (2007)
Fresh shredded waste	ASTM D854	Samples obtained from active face of a landfill in US Sample collection prior or post compaction not reported Max. particle size was 40 mm	0.85	Reddy et al. (2009a)
Old shredded waste	ASTM D854	Samples obtained from 20 m depth at a landfill in US Waste age was 1.5 years Max. particle size was 40 mm	0.97	Reddy et al. (2009a)
Manufactured waste	ASTM D854	US representative waste stream Max. particle size was 40 mm Undegraded	1.09	Reddy et al. (2011)
Manufactured waste	ASTM D854	US representative waste stream Max. particle size was 40 mm Degraded	2.05–2.47	Reddy et al. (2011)
Relatively fresh waste	Modified ASTM D854	Shredded and recombined relatively fresh (3–4 month old) wastes obtained from a landfill in US Max. particle size was 25 mm	1.34	Breitmeyer (2011)
Laboratory degraded waste	Modified ASTM D854	Same waste as above after low (L), medium (M), and high (H) degradation in the laboratory Max. particle size was 25 mm	1.65 (L), 1.80 (M), 1.90 (H)	Breitmeyer (2011)
Old waste	ASTM D854	Wastes obtained from shallow (S), middle (M), and deep (D) layers from a landfill in China	1.51 (S), 1.88 (M), 2.14 (D)	Wu et al. (2012)

[a] Converted to G_s.