**Designation: D 6003 – 96**

# Standard Test Method for Determining Weight Loss From Plastic Materials Exposed to Simulated Municipal Solid-Waste (MSW) Aerobic Compost Environment [1]

This standard is issued under the fixed designation D 6003; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method is used to determine the degree and rate of aerobic biodegradation of plastic materials exposed to a controlled composting environment. Aerobic composting takes place in an environment where temperature, aeration, and humidity are closely monitored and controlled.

1.2 The test is designed to determine the biodegradability of plastic materials, relative to that of a standard material, in an aerobic environment. Aeration of the test reactors is maintained at a constant rate throughout the test and reactor vessels of a size no greater than 4-L volume are used to ensure that the temperature of the vessels is approximately the same as that of the controlled environment chamber.

1.3 Biodegradability of the plastic is assessed by determining the amount of weight loss from samples exposed to a biologically active compost relative to the weight loss from samples exposed to a "poisoned" control.

1.4 The test is designed to be applicable to all plastic materials that are not inhibitory to the bacteria and fungi present in the simulated Municipal Solid Waste (MSW).

1.5 The values stated in SI units are to be regarded as the standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—There is no similar or equivalent ISO method.

## 2. Referenced Documents

2.1 *ASTM Standards:*

D 618 Practice for Conditioning of Plastics and Electrical Insulating Materials for Testing[2]
D 883 Terminology Relating to Plastics[2]
D 1193 Specification for Reagent Water[3]
D 1898 Practice for Sampling of Plastics[2]
D 2973 Test Method for Total Nitrogen in Peat Materials[4]
D 2974 Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils[4]
D 2976 Test Method for pH of Peat Materials[4]
D 2980 Test Method for Volume Weights, Water-Holding Capacity, and Air Capacity of Water-Saturated Peat Materials[4]
D 3593 Molecular Weight Averages and Molecular Weight Distribution of Certain Polymers by Liquid Size Exclusion Chromatography (Gel Permeation Chromatography)[5]
D 4129 Test Method for Total and Organic Carbon in Water by High-Temperature Oxidation and Coulometric Detection[6]
D 5338 Test Method for Determining Aerobic Biodegradation of Plastic Materials under Controlled Composting Conditions[7]
D 5509 Practice for Exposing Plastics to a Simulated Compost Environment[7]
D 5512 Practice for Exposing Plastics to a Simulated Compost Environment Using an Externally Heated Reactor[7]

2.2 *APHA-AWWA-WPCF Standards:*

2540 G Total, Fixed, and Volatile Solids in Solid and Semi-Solid Samples

## 3. Terminology

3.1 *Definitions*—Definitions of terms applying to this test method appear in Terminology D 883 and Practice D 5509.

## 4. Summary of Test Method

4.1 The test method consists of the following:

4.1.1 Selecting plastic materials for exposure in a controlled aerobic composting environment;

4.1.2 Preparing and characterizing a simulated compost with the proper C:N ratio, pH, water holding capacity, porosity, and inoculum to establish and maintain a high biological activity;

[1] This test method is under the jurisdiction of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D20.96 on Environmentally Degradable Plastics.

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[2] *Annual Book of ASTM Standards*, Vol 08.01.

[3] *Annual Book of ASTM Standards*, Vol 11.01.

[4] *Annual Book of ASTM Standards*, Vol 04.08.

[5] *Discontinued, 1993*. Replaced by Test Method D 5296.

[6] *Annual Book of ASTM Standards*, Vol 11.02.

[7] *Annual Book of ASTM Standards*, Vol 08.03.

4.1.3 Exposing the test materials to the compost under controlled, aerobic conditions;

4.1.4 Removing the test specimens for cleaning; and

4.1.5 Assessing the degradability of the plastics by measuring weight loss from the test specimens.

## 5. Significance and Use

5.1 Aerobic composting represents an attractive alternative to the disposal of solid wastes in landfills. Composting by biologically mediated oxidative decomposition produces highly stable organic matter that may be used for land applications or horticulture. However, the degradation of plastics within a compost can affect the decomposition of materials enclosed by the plastic, other non-plastic materials in the compost, and the resulting composition and appearance of the composted material. This test is intended to help assess the environmental degradability of plastics under standard composting conditions. Characterization of the ability of a plastic to degrade under controlled, environmentally relevant conditions is essential when developing products with a programmed lifetime.

5.2 Considering the diversity of materials that may be introduced into a particular compost, as well as the variety of designs of composting facilities, it is important to recognize that no single test can adequately simulate all the conditions which may occur during composting. Consequently, this test is intended to provide a uniform, standardized environment simulating a representative MSW compost operating at near-optimum conditions.

5.3 Because a specimen degrades to the point where it can not be distinguished from the other materials within the compost does not mean that it has become fully mineralized. Determination of a plastic's degradation products and their potential toxicity requires further testing. Mineralization of the plastic material (that is, conversion of polymer-C to $CO_2$) should be investigated using Test Method D 5338.

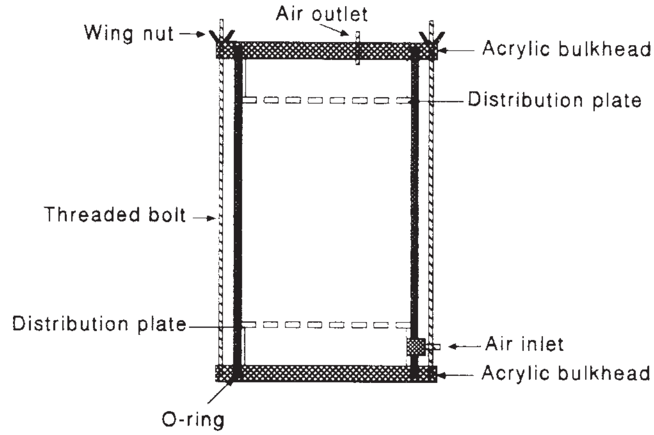
5.4 Predicting long-term environmental fate and effects of a plastic from the results of short-term exposure to a simulated waste disposal environment is difficult. Thus, caution should be exercised when extrapolating the results obtained from this or any other controlled-environment test to disposal in the natural environment.

## 6. Apparatus

6.1 *Composting Apparatus*:

6.1.1 A suitable bioreactor vessel (see Fig. 1) consists of a 127-mm (i.d.) by 300-mm long acrylic cylinder; two acrylic bulkhead plates (150 mm × 150 mm); two acrylic distribution plates, positioned 25 mm from the bulkhead plates; and four all-thread bolts with wing nuts. Air enters the bioreactor through an inlet (6.4-mm i.d.) positioned about 25 mm above the bottom bulkhead, and exits the bioreactor through an outlet (6.4-mm i.d.) in the top bulkhead.

NOTE 2—The size of the reactor may be changed as long as there is sufficient volume to allow for the even distribution of the MSW and test materials. However, the internal volume of the reaction vessel should not exceed 4 L; this will allow adequate control of the internal temperature of the compost via the exchange of heat between the contents of the reaction vessel and the environment chamber.




NOTE 1—Bioreactor = acrylic cylinder; 127-mm (ID) × 300 mm long.
Air exit port = 6.4 mm diameter.
Air inlet port = 6.4 mm diameter; 25 mm above the acrylic bulkhead.
Perforated distribution plate: positioned 50 mm above the acrylic bulkhead.

**FIG. 1 Schematic Drawing of the Aerobic Bioreactor**

6.1.2 The bioreactors are connected to a filtered air supply capable of providing water-saturated air at a rate of 100 to 200 mL $min^{-1}$. The air supply to each bioreactor is humidified by passing through a fritted-glass air dispersion tube immersed in distilled water (300 mL in a 500-mL Erlenmeyer flask) and regulated via a flow meter (see Fig. 2). Water in the humidifier flask must be maintained at the temperature of the environment chamber.

6.1.3 A controlled-environment chamber capable of maintaining a temperature of 30 (±2) to 70 (±2) °C.

6.2 *Analytical Equipment*:

6.2.1 *Analytical Balance*, to weigh test materials, (±0.1 mg).

6.2.2 *Top Loading Balance*, to weigh MSW samples for determining water content, (±0.01 g).

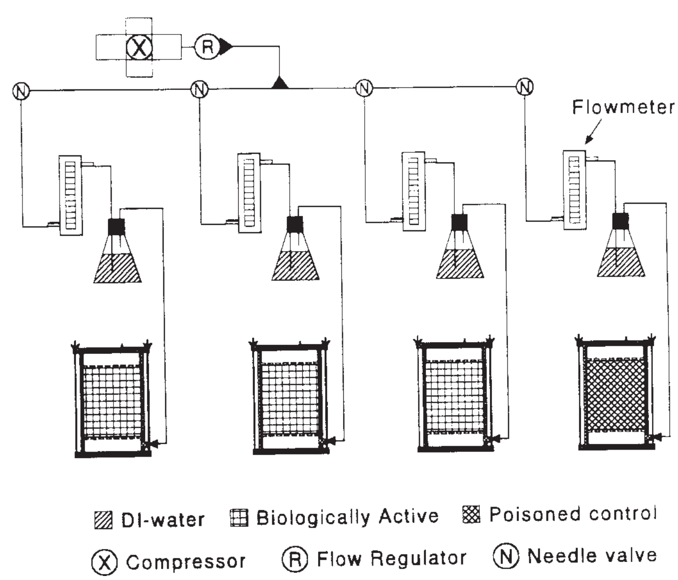



**FIG. 2 Schematic of the Film Weight-Loss Bioreactor System**

6.2.3 *Oven*, for determining the water content of the simulated MSW compost, set at 103 to 105°C.

6.2.4 *Muffle Furnace*, for determining the volatile solids and ash content of the simulated MSW compost, set to 550 (±50) °C.

6.2.5 *pH Meter*.

## 7. Reagents and Materials

7.1 All chemicals shall be of American Chemical Society (ACS) reagent-grade quality.

7.2 Distilled water should be prepared in accordance with Specification D 1193.

7.3 *Simulated Municipal Solid Waste (MSW) Compost*—Simulated MSW composts range from the relatively simple to the complex; the mixes listed in Tables 1 and 2 provide suitable environments for this test.

7.3.1 *Mix 2* **(1)**[8]—940 g shredded leaves (1:1, w/w, mix of oak and maple); 340 g shredded paper (1:1, w/w, mix of newspaper and computer paper); 140 g mixed, frozen vegetables; 120 g meat waste (added as a 1:1, w/w, mix of dried dog food and dried cat food); 360 g dehydrated cow manure; 40 g sawdust; 40 g urea; and 20 g commercial compost seed. Enough water is added to bring the mix to 60 % water holding capacity (Test Method D 2980). The C:N ratio of the starting mix is 14:1.

7.3.2 *Mix 4* **(3)**—3500 g dehydrated alfalfa meal; 1300 g cottonseed meal; 1400 g Poplar sawdust; 1000 g fresh cow manure; 1500 g black garden soil; 2500 g shredded newspaper; 480 g $CaCO_3$; 40 g $NaHCO_3$; and 13 L of water. The mix is blended in a Hobart Mixer until the average particle size is 3 to 4 mm. The C:N ratio of the starting mix is 30:1.

7.3.3 An alternative MSW compost, designed to simulate a particular waste stream, may be used.

7.4 A simulated yard-waste mix composed of dried grass and leaves (67 %, w/w) and twigs (33 %, w/w) may be used in place of the MSW. The ratio of grass (typically rich in nitrogen) to leaves (typically low in nitrogen) should be adjusted to provide a C:N ratio of about 25:1.

## 8. Hazards

8.1 This test method requires the use of hazardous chemicals. Avoid contact with chemicals and follow manufacturer's instructions and Material Safety Data Sheets.

[8] The boldface numbers in parentheses refer to a list of references at the end of this test method.

**TABLE 1 Mix 1**[A]

| Category | Wet Weight (%) | Wet Weight of Specific Component (%) |
|---|---|---|
| Food waste | 16.6 | Tomatoes (3.3), Lettuce (3.3), Meat (3.3), Cottage Cheese (3.3), Bread (3.4) |
| Garden waste | 13.9 | Leaves (6.9), Grass (7.0) |
| Paper | 58.5 | Bleached (19.5), Brown (19.5), Cardboard (19.5) |
| Plastics | 7.7 | Test material plus HDPE from shredded plastic milk bottles |
| Textiles | 0.8 | Cotton |
| Wood | 2.5 | Twigs |

[A] See Practice D 5509.

**TABLE 2 Mix 3 (2)**

| Component | Weight (g) | Carbon (g) | Nitrogen (g) | Water (g) |
|---|---|---|---|---|
| Water | 214.1 | ... | ... | 214.1 |
| Sand | 107.0 | ... | ... | ... |
| Rabbit chow (Purina HF 5326) | 72.1 | 30.9 | 1.7 | 7.2 |
| Newspaper[A] | 53.6 | 24.9 | 0.1 | 4.8 |
| Manure composted cow | 5.4 | 2.2 | 0.1 | ... |
| Total | 452.2 | 58.0 | 1.9 | 226.1 |

[A] Shredded; ca. 2 mm × 25 mm.

8.2 The MSW may contain sharp objects; thus, to avoid injury, extreme care should be taken when handling such mixtures.

8.3 The bioreactor vessel is not designed to withstand high pressures; it should be operated at close to ambient pressure.

## 9. Inoculum

9.1 *Suitable inocula include*:

9.1.1 Commercial compost seed (for example, Recycle Compost Maker®, Ringer Corp., Minneapolis, MN).

9.1.2 Material from a commercial composting process, or previous composting exposure.

9.1.3 Composted potting soil from a garden supply store or a horizon material from a native soil.

## 10. Test Specimen

10.1 Test specimens should conform to Practice D 618.

10.1.1 Plastic materials may be tested in the form of films (25 mm × 75 mm) prepared by casting from solution or by melt forming (compression molding or extrusion).

10.1.2 Fabricated parts, or sections cut from fabricated parts, may also be used as test specimen.

NOTE 3—Test and control specimens should have essentially the same dimensions. An important factor in the choice of specimen configuration is the ratio of surface area to internal volume. Specimens of the same type of material but with different dimensions may produce percent weight loss values (not normalized to the surface area) that differ significantly. It may be necessary to test a range of forms and sizes to determine how this affects the extent or rate of biodegradation.

10.2 The test should include both degradable and nondegradable reference materials to follow the activity of the compost and standardize between-run testing.

10.2.1 Suitable positive reference materials include: uncoated cellophane and cellulose acetate with an average degree of substitution of less than or equal to two acetate esters per glucose monomer.

10.2.2 High-density polyethylene that has not been exposed to toxic materials (for example, the HDPE used to make plastic milk bottles) is suitable as the negative reference material.

NOTE 4—In devising a test program to determine quantitative changes occurring during and after composting, it is essential that the number of replicate specimen be sufficient to establish a reliable value for the property in question. For a homogeneous material, three test specimen per sampling point are usually adequate for assessing the visual effects of exposure or for determining weight-loss; however, five replicate specimens are usually required for assessing changes in tensile-properties. Always sample and test the same number of specimens for each exposure interval. It is to be expected that the physical properties of the specimens will vary as a function of exposure in the compost environment; hence values indicating the greatest amount of biodegradation are the most significant. ASTM Manual STP 15D may be used as a guide.[9]

## 11. Procedure

11.1 Select test specimens from materials evaluated in accordance with Practice D 1898.

11.1.1 At least three replicates of the test specimens and controls should be used for each sampling point. Replicate samples may be tested in a single bioreactor or separately in bioreactors operated under identical conditions. More than one sample type can be placed in each bioreactor.

11.2 Choice of the simulated MSW mix may vary depending on the particular environment that the user is trying to simulate and, if necessary, mixtures other than those described in this test method (see 7.3 and 7.4) may be employed.

11.2.1 Weigh out and record the condition of each component. All components should be smaller than 2.5 cm in diameter; materials larger than this should be milled or shredded to <2.5 cm in diameter. (Do not shred the plastic test specimens.) The components of the simulated MSW should be mixed thoroughly, either mechanically or manually.

11.2.2 Add up to 10 % (w/w) of inoculum (see 9.1) to promote the composting process.

11.3 Determine the pH (see Test Method D 2976) and C:N ratio (see Test Methods D 4129 and D 2973) of the simulated MSW.

11.4 Determine the water content and water holding capacity (WHC) of the simulated MSW (see Test Methods D 2974 and D 2980, respectively).

11.5 Determine the porosity (air-filled pore space) of the simulated MSW.

11.5.1 Add a sufficient amount of the solid waste mix (at 60 % moisture) to a 100-mL beaker (pre-calibrated) so that the final volume is 100 mL after compaction (place a 300-g metal or ceramic weight on top of the MSW and let sit for 1 h).

11.5.2 Add hexane to the MSW until the liquid reaches the 100-mL mark on the beaker and record the volume of hexane added. The volume of free air in the compost mix is estimated as being equal to the volume of added hexane.

11.5.3 Optimal composting activity usually is obtained when 40 to 50 % of the MSW mix is occupied by air-filled pore space. Adjustments to the amount of air-filled pore space in the MSW mix can be achieved by altering the size of the mix components.

11.6 *Loading the Bioreactor*—Prepare the bioreactor by attaching the bottom bulkhead and distribution plates. Place the simulated MSW in the bioreactor vessel. (Using MSW mix no. 2, a reactor of the size described in 6.1.1 is loaded with about 300 g of raw material at a water content of 50 to 60 %.)

11.6.1 Mix in the plastic and control specimens, maintaining a random orientation and distribution. The total weight of the specimens (test and reference) should not exceed 7.7 % (w/w) of the MSW mix.

NOTE 5—If, due to orientation or location within the bioreactor, the replicate specimen degrade at significantly different rates or to significantly different extents, the test should be repeated with the replicate specimen placed in specific locations (top, middle, or bottom) and with specific orientations (vertical or horizontal).

11.6.2 Attach the top distribution and bulkhead plates, connect the air supply, and place the bioreactor in the controlled environment chamber.

11.7 *Aeration*—Sufficient aeration should be maintained to keep the contents of the bioreactors aerobic. A continuous supply of air is maintained throughout the composting process by passing filtered air through a diffusion stone at the bottom of a 500-mL Erlenmeyer flask containing 300 mL of distilled water and maintained at the temperature of the environment chamber. The water-saturated air (100 to 200 mL $min^{-1}$) enters the bioreactors at the bottom and exits through a port at the top (Fig. 2).

11.8 *System Maintenance*—The simulated MSW is mixed (mechanically or manually) every 3 to 5 days, at which time the pH, temperature, and water content of the compost are determined.

11.8.1 Water content of the compost is determined by weighing approximately 5 g of moist compost in a labeled aluminum weighing pan and drying at 103 to 105°C for 18 to 24 h. The water content is calculated as described in 12.1.1.

NOTE 6—If the water content drops below 50 %, add DI-water to the compost, mixing thoroughly; if the water content exceeds 65 %, pass dry-air through the compost until the desired water content is re-established. If necessary, increase or decrease the number of humidifier flasks in the air supply system.

11.8.2 The composting process is carried out for 30 days or until the test specimens disappear completely, whichever comes first.

11.8.3 Triplicate test specimens are removed from the bioreactors at 3 to 5 day intervals.

11.9 Wash each test specimen with DI-water and clean gently with a moist tissue. Ultrasonic cleaning may be required to remove particles adhering strongly to the surface. Dry each test specimen in a vacuum oven at 30°C (10-mm Hg) to a constant weight (±0.05 mg). Weight loss is then calculated and, for films, may be normalized with respect to surface area (that is, expressed as $\mu g\ mm^{-2}$).

11.9.1 *Optional*—Additional testing of the exposed samples can be performed in accordance with standard ASTM protocols (see Appendix X2). In this event, test specimens should be air-dried at room temperature and reconditioned under standard laboratory conditions (23 ± 2°C and 50 ± 2 % relative humidity; see Practice D 618).

11.10 *Optional*—The temperature of the bioreactors may be changed at specified time intervals (by changing the temperature of the environment chamber) to simulate the temperature profile of a self-heating and cooling composting process **(2-6)**.

11.10.1 For example, the temperature of the environment chamber and bioreactor vessels may be maintained at 40°C for 3 days, to simulate the mesophilic start-up phase; increased to 55°C and maintained for three days, to simulate the sanitizing period; increased to 62°C and maintained for eight days to simulate thermophilic composting; and reduced to 40°C and maintained for five days to simulate the mesophilic curing phase.

[9] Available from ASTM Headquarters, Customer Service, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

11.11 *Controls*—A "poisoned" (abiotic) control vessel must be included in each test run.

11.11.1 Sterilize the compost by heating the mix under pressure in an autoclave (121°C, 15 lb in.$^{-2}$ for 1 h). The compost mix should be autoclaved on three consecutive days.

11.11.2 To reduce the risk of re-introducing an active microbial population during sampling (see section 11.7.3), the compost is poisoned by the addition of KCN (2 g per 100 g dry compost). Alternatively, an anti-bacterial agent (for example, tetracycline at 5 to 10 µg g$^{-1}$ compost) and an anti-fungal agent (for example, cycloheximide at 5 to 10 µg g$^{-1}$ compost) may be added to the compost after the final autoclaving.

11.11.3 Periodically determine the populations of viable heterotrophs (CFU g$^{-1}$ compost) in the active and abiotic bioreactors.

11.11.4 Upon completion of the test, determine the pH and dry weight of the remaining compost.

## 12. Calculations

12.1 *Water Content*:

12.1.1 Determine the water content (%) of the simulated MSW by weighing a representative sample before and after it is dried to a constant weight in an oven at 103°C. The sample must be dried for at least 18 h. Calculate the percent water (on a dry-weight basis) as follows:

$$\% \, H_2O = \frac{(S_W + W_P) - (S_D + W_P)}{(S_W + W_P) - W_P} \times 100 \quad (1)$$

where:
$S_W$ = weight of the wet sample,
$S_D$ = weight of the oven-dry sample, and
$W_P$ = weight of the aluminum pan.

NOTE 7—It may be desirable to express the water content of the compost on a dry-weight basis. Water contents calculated on a wet-weight basis can be expressed on a dry-weight basis using the formula:

$$\theta_D = \frac{\left(\frac{\% \, H_2O}{100}\right)}{1 - \left(\frac{\% H_2O}{100}\right)} \quad (2)$$

where:
$\theta_D$ = water content (g $H_2O$ g$^{-1}$ compost) expressed on a dry-weight basis.

12.1.2 The total dry weight of compost to be added to the bioreactor(s) is calculated as:

$$C_D = C_W \times \left(1 - \frac{\% \, H_2O}{100}\right) \quad (3)$$

where:
$C_D$ = weight of the dry compost, and
$C_W$ = weight of the wet compost (for example, 300 g).

12.1.3 The amount of raw compost, at a known initial water content of $WC_R$, that is equivalent to $C_D$ is calculated as:

$$C_R = \frac{C_D}{1 + \frac{WC_R}{100}} \quad (4)$$

12.1.4 The amount of water needed to bring the compost to the desired final water content of 50 to 60 % is calculated as:

$$W_A = C_R \times \left(\frac{WC_F - WC_R}{100 - WC_F}\right) \quad (5)$$

where:
$W_A$ = amount of water to be added, and
$WC_F$ = the final water content (%).

12.1.5 *Example*—Assuming that a freshly prepared, unmoistened MSW compost has a water content of 11.9 %, calculate the amount of oven-dry material needed to fill one bioreactor (that is, 300 g of moistened compost), and the amount of water needed to adjust the original (raw) compost to a final water content of 60 %.

12.1.5.1 The amount of oven-dry compost needed to yield 300 g at a water content of 60 %:

$$C_D = 300 \times \left(1 - \frac{60}{100}\right) = 120 \text{ g} \quad (6)$$

(*1*) The amount of original (raw) compost that equals 120 g oven-dry compost is:

$$C_R = \frac{120}{1 + \frac{11.9}{100}} = 136.2 \, g \quad (7)$$

(*2*) The amount of water needed to bring the original (raw) compost to a final water content of 60 % is:

$$W_A = 136.2 \times \left(\frac{60 - 11.9}{100 - 60}\right) = 163.8 \text{ g } H_2O \quad (8)$$

NOTE 8—Calculations involving water contents expressed on a dry-weight basis are presented in Appendix X1.

## 13. Report

13.1 *Report the following information*:

13.1.1 Source of the inoculum and the components used to make the simulated MSW compost.

13.1.2 C:N ratio, water holding capacity, water content, ash content, and percentage of air-filled pore space in the initial MSW compost.

13.1.3 Amount and dimensions of the test specimens, and the form in which they were added.

13.1.4 Temperature of the bioreactor vessels and environment chamber; this parameter should be tracked throughout the composting process.

13.1.5 Initial and final pH of the MSW compost.

13.1.6 A valid test exposure requires that dry-weight loss from the compost matrix itself (after correction for removal of the test and reference specimens) exceed 20 % or some other value determined by experimentation for the system under use. Other criteria, such as percent loss of total carbon from the matrix, also may be used to determine a valid exposure.

13.1.7 Normalized weight loss (µg mm$^{-2}$) from the control and test specimens.

13.1.8 Condition of the control and test specimens indicating any visible signs of biodegradation or deterioration.

13.1.9 *Optional*—Initial and final molecular weight of the test and control specimens (see Test Method D 3593).

## 14. Precision and Bias

14.1 The precision and bias of this test will be determined for inclusion at the next revision.

14.2 Preliminary results from within-laboratory testing, using uncoated cellophane and cellulose acetate (degree of substitution = 1.7 and 2.5) as the reference materials are summarized in Table 3. Test runs were carried out at 53 ± 2°C, and were performed within a six-month period by the same operator.

TABLE 3 Aerobic Degradability of Cellophane and Cellulose Acetate (CA) with Degrees of Substitution of 1.7 and 2.5[A]

| Time (days) | Percent Biodegradation | | |
|---|---|---|---|
| | Cellophane | CA (ds 1.7) | CA (ds 2.5) |
| 2 | 13.5 ± 3.4 | 11.8 ± 1.7 | ... |
| 4 | 35.2 ± 1.2 | 35.1 ± 2.7 | ... |
| 5 | ... | 49.8 ± 3.4 | 8.3 ± 3.6 |
| 7 | 100 | 100 | ... |
| 10 | | | 22.5 ± 5.9 |
| 12 | | | 39.8 ± 4.0 |
| 15 | | | 46.8 ± 5.1 |
| 20 | | | 100 |

[A] Summarized from data reported in Ref **(1)** and **(7)**.

## 15. Keywords

15.1 abiotic; aerobic; biodegradation; compost

# APPENDIXES

**(Nonmandatory Information)**

## X1. WATER CONTENT CALCULATIONS—EXPRESSED ON A DRY-WEIGHT BASIS

X1.1 *Water Content*—Water contents determined on a dry-weight basis are expressed as g $H_2O$ $g^{-1}$ dry-compost.

X1.2 Weigh a representative sample of the MSW before and after it is dried to a constant weight in an oven at 103°C. The sample must be dried for at least 18 h. Calculate the percent water (on a dry-weight basis) as follows:

$$WC = \frac{(S_W + W_P) - (S_D + W_P)}{(S_D + W_P) - W_P} \quad \text{(X1.1)}$$

where:

$S_W$ = the weight of the wet sample,
$S_D$ = the weight of the oven-dry sample, and
$W_P$ = the weight of the aluminum pan.

NOTE X1.1—Water contents calculated on a dry-weight basis can be converted to a wet-weight basis using the formula:

$$\theta_W = \left(\frac{\theta_D}{1 + \theta_D}\right) \times 100 \quad \text{(X1.2)}$$

where:

$\theta_W$ = the water content expressed on a wet-weight basis (that is, as a percent of the total weight of the wet sample), and
$\theta_D$ = the water content expressed on a dry-weight basis (that is, g $H_2O$ $g^{-1}$ dry compost).

X1.3 Calculate the total dry weight of compost to be added to the bioreactor(s) as:

$$C_D = \frac{C_W}{1 + WC_F} \quad \text{(X1.3)}$$

where:

$C_D$ = the weight of the dry compost,
$C_W$ = the weight of the wet compost (for example, 300 g), and
$WC_F$ = the final (desired) water content (in g $H_2O$ $g^{-1}$ compost) of the compost at 60 to 70 % of the compost's water-holding capacity (WHC).

X1.4 Calculate the amount of raw compost, at a known initial water content of $WC_R$, that is equivalent to $C_D$:

$$C_R = C_D \times (1 + WC_R) \quad \text{(X1.4)}$$

X1.5 Calculate the amount of water needed to bring the compost to the desired final water content (for example, 60 % WHC):

$$W_A = C_D \times (WC_F - WC_R) \quad \text{(X1.5)}$$

where:

$W_A$ = the amount of water to be added, and
$WC_F$ = the final water content (%).

X1.6 *Example*—Assuming that a freshly prepared, unmoistened MSW compost has a water content of 0.15 g $H_2O$ $g^{-1}$ dry-compost and a water holding capacity of 1.35 g $H_2O$ $g^{-1}$ dry-compost, calculate the amount of oven-dry material needed to fill one bioreactor (that is, 300 g of compost at 60 % WHC), and the amount of water needed to adjust the original (air-dry) compost to final $H_2O$ content of 60 % *WHC*:

X1.6.1 60 % *WHC* = 0.60 × 1.35 g $H_2O$ $g^{-1}$ dry-compost

$$= 0.81 \text{ g } H_2O \text{ g}^{-1} \text{ dry-compost}$$

X1.6.2 The amount of oven-dry compost needed to yield 300 g at 60 % *WHC* is:

$$\frac{300}{(1 + 0.81)} = \frac{300}{1.81} = 165.7 \text{ g} \quad \text{(X1.6)}$$

X1.6.3 The amount of original (raw) compost that equals 165.7 g oven-dry compost is:

$$165.7 \times (1 + 0.15) = (165.7)(1.15) = 190.6 \text{ g} \quad \text{(X1.7)}$$

X1.6.4 The amount of water needed to bring the original compost to a final $H_2O$ content of 60 % *WHC* is:

$$165.7 \times (0.81 - 0.15) = (165.7)(0.66) = 109.4 \text{ g } H_2O \quad \text{(X1.8)}$$

## X2. EVALUATING THE LEVEL OF DEGRADATION OF PLASTICS EXPOSED TO A BIOLOGICALLY ACTIVE COMPOST ENVIRONMENT

X2.1 *Visible Effects of Biodegradation*—If the test is for visual effects only, remove the specimens from the test vessel(s) and rate degradation as shown in Table X2.1.

X2.2 *Effect of Exposure on Physical, Optical, or Mechanical Properties*—Wash the specimens free of any residue, be sure to use a solvent-free, neutral pH cleaning agent. Ultrasonic cleaning may be used to remove strongly adhering contamination or microbial growth.

X2.2.1 It may be desirable to test specimens in the unwashed, water-saturated condition. Test values will be influenced by the moisture and surface adherents; thus, values for unwashed, water-saturated specimens may be more indicative of how the plastic degrades/disintegrates under environmental conditions of exposure.

X2.3 Test methods for evaluating the mechanical and optical properties of plastics exposed to an aerobic composting environment are shown in Table X2.2.

**TABLE X2.1 Visible Effects of Biodegradation**

| Observed Change in the Specimen | Rating |
|---|---|
| None | 0 |
| Slight change in color or dimensions | 1 |
| Moderate change in color or dimensions | 2 |
| Major changes or flaws, or both; sample nearly unrecognizable | 3 |
| Sample unretrievable (dissolved or disintegrated completely) | 4 |

**TABLE X2.2 Test Methods for Evaluating the Mechanical and Optical Properties of Plastics Exposed to an Aerobic Composting Environment**

| ASTM Designation | Title | ASTM Volume[A] |
|---|---|---|
| | **Tensile Strength** | |
| D 638 | Test Method for Tensile Properties of Plastics | 08.01 |
| D 882 | Test Methods for Tensile Properties of Thin Plastic Sheeting | 08.01 |
| D 1708 | Test Method for Tensile Properties by Use of Microtensile Specimens | 08.01 |
| | **Hardness** | |
| D 785 | Test Method for Rockwell Hardness of Plastics and Electrical Insulating Materials | 08.01 |
| | **Optical Properties** | |
| E 1164 | Standard Practice for Obtaining Spectrophotometric Data for Object-Color Evaluation | 06.01 |
| E 1347 | Test Method for Color and Color-Difference by Tristimulus (Filter) Colorimetry | 06.01 |
| D 1003 | Test Method for Haze and Luminous Transmittance of Transparent Plastics | 08.01 |
| | **Water Vapor Transmission** | |
| E 96 | Test Methods for Water Vapor Transmission of Materials | 08.01 |
| | **Impact Resistance** | |
| D 256 | Test Methods for Impact Resistance of Plastics and Electrical Insulating Materials | 08.01 |
| D 1709 | Test Methods for Impact Resistance of Polyethylene Film by the Free Falling Dart Method | 08.01 |
| D 3419 | Practice for In-line Screw-Injection Molding Test Specimens from Thermosetting Compounds | 08.02 |
| D 3420 | Test Method for Dynamic Ball Burst (Pendulum) Impact Resistance of Plastic Film | 08.02 |
| D 4272 | Test Method for Total Energy Impact of Plastic Film by Dart Drop | 08.02 |
| D 4508 | Test Method for Chip Impact Strength of Plastics | 08.03 |
| D 4812 | Test Method for Unnotched Cantilever Beam Impact Strength of Plastics | 08.03 |
| | **Tear Strength** | |
| D 1922 | Test Method for Propagation Tear Resistance of Plastic Film and Thin Sheeting by Pendulum Method | 08.01 |

[A] *Annual Book of ASTM Standards.*

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