Conseil canadien du
COMPOST
Council of Canada

BEST PRACTICES FOR OPERATING AN AERATED WINDROW COMPOSTING FACILITY

Prepared by

The Compost Council of Canada

for the

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Conservation and Water Stewardship

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ACKNOWLEDGEMENTS

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Compost Council of Canada

Founded in 1991, The Compost Council of Canada serves as the central resource and knowledge network for organics recycling and compost use. In partnership with its members and soil health advocates, it has helped establish the organics recycling industry, developing training, advancing regulations & guidelines, supporting research, education & communication and building markets.

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PREFACE

This document provides the operational procedures for processing up to 2,500 tonnes per year of source-separated-organic (SSO) waste and amendment. This is equivalent to the organic waste produced from a population base of about 5,000 persons.

In planning a windrow composting facility to process a waste mix that includes more than 15% food waste or other odorous materials, the technology should include forced aeration and periodic turning. This document was prepared specifically with this technology in mind and it is to be used as a reference for operating new, expanding, or updating compost facilities in Manitoba. It is also useful in determining the feasibility of expanding a leaf & yard waste composting site to include other organic waste fractions, including SSO.

The fundamentals of composting are discussed in detail to provide understanding and emphasize adherence to the basics of composting to negate a vast majority of problems with compost facilities.

While some design information is provided for illustration purpose, the document is not to be used as a design manual because detailed facility design depends on the amount of waste processed, site location, composting process and local building codes. Instead, an engineering company, with proven experience in composting, should be considered for specific site and process design.

1. INTRODUCTION

It is sometimes said that composting is a natural decay process; however, while this may be true at some fundamental level, composting of the organic fraction of municipal solid wastes involves a high-rate degradation phase that is rarely encountered in nature. The high-rate phase produces large amounts of heat resulting in temperatures well above ambient and rapid depletion of oxygen and moisture required by the microorganisms. Furthermore, commercial composting is a controlled process designed to optimize the microbial environment to provide maximum efficiency for decomposition of organic waste materials.

The organic waste materials to be composted are residential and Industrial, Commercial and Institutional (ICI) SSO. Due to their high moisture content and chemical composition, such as high nitrogen content, these materials are highly putrescible and become readily odorous.

To successfully manage SSO, it is necessary to use a forced aeration, turned windrow process. Adequate oxygen supply is essential to the welfare of the aerobic microorganisms and the oxidation of organic molecules and, hence, a crucial factor in the success of the composting process. Aeration allows better process control (oxygen, temperature) and odour control. At the start of the microbial activity, oxygen concentration in the voids of the biomass varies from 15 to 20% (by volume) and the carbon dioxide concentration is between 0.5 and 5% (by volume). As the process continues, oxygen is consumed and carbon dioxide produced. As the oxygen concentration decreases below 15%, anaerobic microorganisms begin to proliferate at the expense of the aerobic microbial population, resulting in production of anaerobic respiration and fermentation products. The accompanying obnoxious odours are the primary reasons for complaints and, if allowed to persist, for process failures and plant closures. Therefore, all high-rate composting processes have mechanical systems to introduce air uniformly into the biomass.

To ensure uniform distribution of the air, it is also necessary to add a bulking agent, such as woodchips, to waste consisting only of small particles or that tends to consolidate during the process (e.g. fruit and vegetable or produce waste).

Since microbial activity is concentrated at the surface and in pores of particulate matter, size reduction of waste will increase the available surface area. However, if the particles are too small, exchange of oxygen and carbon dioxide between the surface of the particles and the interstitial air is restricted as the resistance to airflow increases and the voids become filled with condensed water vapour. For practical purposes, the optimum particle size for SSO is less than 75 mm (3 inches).

Microorganisms also grow in colonies on the biomass. It is beneficial, if not essential, to include mechanical mixing or agitation to redistribute the microbes to prevent exhausting local nutrient supply. Although several commercial processes provide mixing of the biomass on a weekly basis, the fact that most microbial populations tend to peak in approximately 24-hour cycles seems to indicate that the process would benefit from more frequent mixing. Other benefits of mixing include size reduction of lumps and improved structure for air distribution.

High-rate decomposition generally occurs at a process temperature of 45 to 60^{0}C. Airflow in excess of the basic biological demand is used to maintain the desired temperature. A temperature feedback control system, in which the biomass temperature is monitored and compared with the set point, is normally used to operate the air moving equipment for cooling. Since it takes approximately nine (9) times more air to remove excess heat than to supply oxygen for microbial activity, one of the problems with aeration cooling is the excessive removal of moisture from the biomass. Therefore, moisture content monitoring is another important process requirement and normally water must be added at some point in the process to maintain optimum conditions. The best time to add water is during mixing or agitation so that it will be uniformly distributed.

Use of a forced-aerated, turned windrow to compost organic waste requires an understanding of the fundamentals of the composting process. The system is a hybrid of the traditional aerated static pile and the turned windrow with aeration offering better process and odour control and turning providing important moisture and porosity control. On the other hand, turning, especially during the most active composting phase, allows release of odours trapped in the matrix of the substrate. Given the fact that the vast majority of problems with composting facilities can be traced to either a lack of understanding or a failure to adhere to the basics of composting, the fundamentals of composting are presented in some detail in Appendix A for reference.

The remainder of the manual was written to assist composting facility operators to manage the process and the facility to ensure minimum impact on the environment and human health while producing high quality compost that meets or exceeds the CCME *Guidelines for Compost Quality* Category A compost for unrestricted use.

2. REGULATIONS AND CONSIDERATIONS

2.1 Municipal Sites

A compost facility at a permitted Class 2 or Class 3 waste disposal ground (WDG) or waste transfer station (WTS) may require an alteration to the operating permit. For definitions on WDG and WTS "classes", see the *Waste Disposal Ground Regulation 150/91* under the *Environment Act* found at http://web2.gov.mb.ca/laws/regs/index.php.

A permit application may require an engineering proposal/study that must include

- proposed volumes
- receiving area
- processing cell(s)
- geotechnical report, monitoring well locations
- operation and maintenance proposal
- material end use.

All compost facility site and operation requirements for a permit are site-specific; but basic facility guidelines for WDS or WTS include:

- 100 meters from public right-of-way;
- 400 meters from any dwelling, cemetery, or potable water well;
- 30 meters buffer between active site and property line;
- All-weather access road;
- Controlled accessible entrances;
- Staffed entrances when accessible to the public;
- Annual reporting.

The single most important site selection criterion is separation distance from receptors. While guidelines include minimum separation distances, experience has shown that greater distances are recommended to minimize the effect of odour and bioaerosol emissions on neighbours. It is known that the characteristics of some odorants allow detection one kilometer or more from the site even when emitted at very low concentrations.

When constructing or expanding a Class 1 waste disposal ground (serving > 5000 people), an Environmental Act License is required from MB Conservation. Compost facility site and operation requirements for a license are site-specific.

For information on the licensing process publications and forms, issued licenses and online public registries, visit the Manitoba Conservation and Water Stewardship Environmental Approvals Branch web site found at http://www.gov.mb.ca/conservation/eal/.

Regulations are subject to change. For updates, contact applicable Manitoba government department and local authorities.

Additional municipal by-laws and Conditional Land Use Orders may also apply to an operation.

2.2 Commercial Sites

Commercial compost facilities are classified as Class 1 developments under the *Classes of Development Regulation 164/88* in the *Environment Act* (found at http://web2.gov.mb.ca/laws/regs/index.php), typically as a manufacturing and industrial plant facility or a bulk materials handling facility. They are required to have an Environmental Act License administered by MB Conservation. Compost facility site and operation requirements for a license are site-specific.

For information on the licensing process publications and forms, issued licenses, and online public registries. visit the Environmental Approvals Branch web site found at http://www.gov.mb.ca/conservation/eal/.

ICI sectors that are composting on-site may not require an Environmental Act License for their composting site but are encouraged to contact their regional MB Conservation and Water Stewardship office before composting.

Contact your local municipality for additional conditional land use requirements.

3. SITE DESCRIPTION

The facility covered in this manual is designed to compost a mix of less than 2,500 tonnes per year of source-separated-organic waste (SSO) and sufficient leaf & yard waste, woodchips or other amendment to obtain the proper moisture and nutrient content. The composting system is an aerated windrow with periodic turning of the substrate to maintain an optimal, aerobic environment for the microbial population.

The following diagram is an illustration of a site layout. The actual dimensions depend on the current and future waste quantities to be processed. As mentioned above, minimum separation distances must be in accordance with the guidelines for WDS or WTS: 100 meters from public right-of-way; 400 meters from any dwelling, cemetery, or potable water well; and, 30 meters required between active site and property line.

The site surface must be designed to allow proper drainage and vehicle traffic without creating tracks in which leachate and surface runoff is collected. Ideally the site should be covered with asphalt or similar impervious surface but the cost may be prohibitive for a small operation. As a minimum requirement, site design must include

- *0.5 m of clay with a hydraulic conductivity of less than $1x10^{-7}$cm/s or equivalent, and*
- *be at least 0.5 m above the seasonal high water table*

to prevent groundwater contamination.

As incoming feedstock is often a major source of odours, it should be received in a covered building with an impervious, sloped floor to capture leachate of incoming wastes. The building is located away from the composting operations so that the trucks delivering the waste do not come in contact with active substrate, curing or stored compost. Also, to prevent contamination of access roads by organics adhering to truck tires, the tipping floor is scraped after every delivery and cleaned daily.

The number of windrows is determined by the amount of waste processed and the residence time. For example, in the case of a 2,500 t/y facility[1], five (5) triangular windrows (35 m long x 7 m wide x 2.5 m high) are required if a residence time of eight weeks is assumed.

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[1] 1,250 t/y of organic waste plus 1,250 t/y of amendment using a volume mix of 1:3 at an assumed density of 600 kg/m^3.

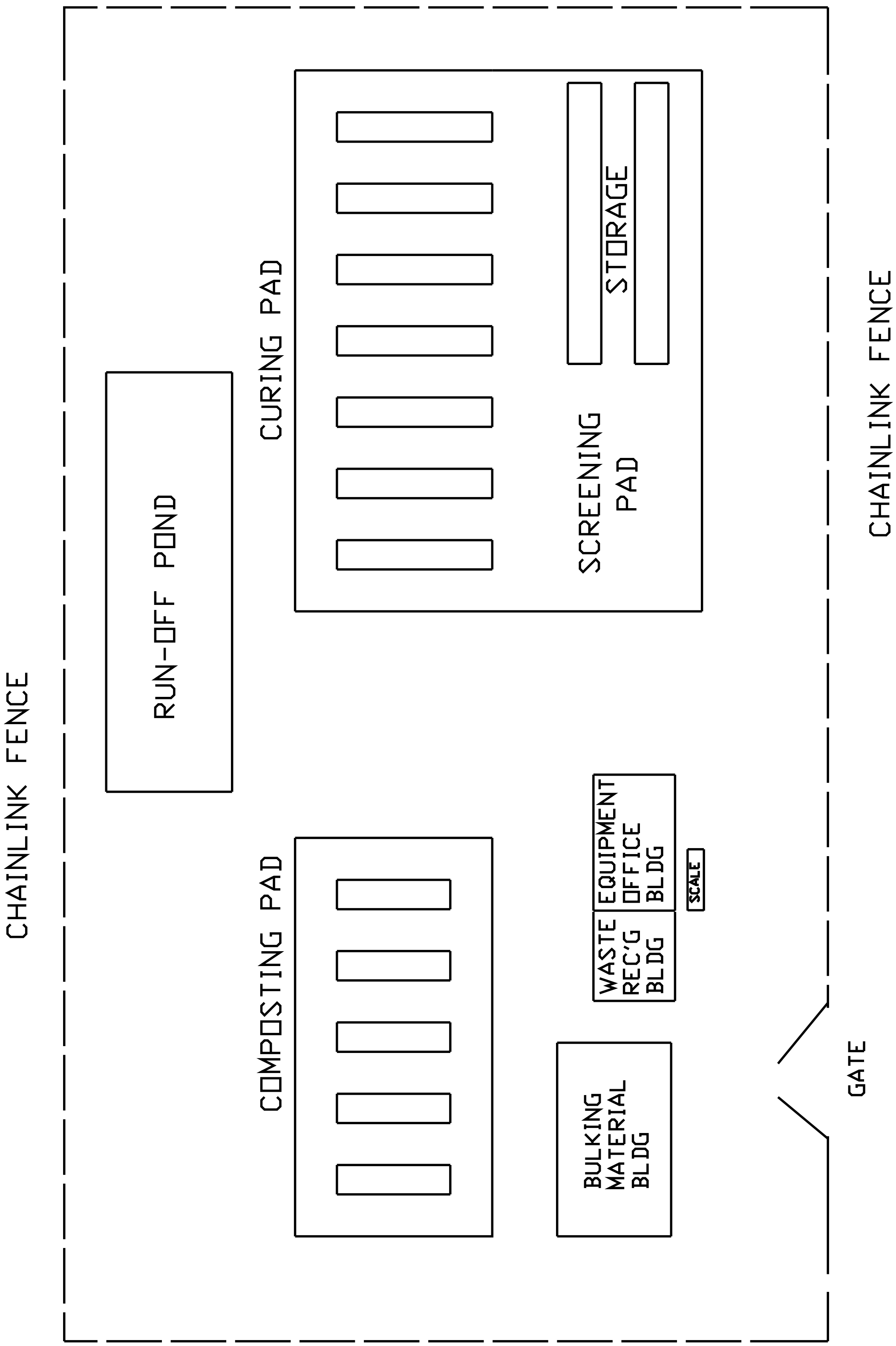

Figure 1. Example of Site to Compost 2,500 t/yr of SSO mix.

Each windrow will hold two weeks of incoming waste. Thus, the waste of the first two weeks of a cycle is put in the far left hand row and then moved to the next row before the waste of Week 3 arrives. After passing through 4 moves, the waste is moved to the curing pad. With each move, the substrate is mixed and the moisture content adjusted.

The windrows are placed on a sloped (about 2 to 4^{o}) pad (approximately 40 m x 70 m) with the distance between the windrows determined by the equipment used to turn the substrate. For a front-end loader, the distance should be about 7 m; while for a windrow turner, it depends on the design of the turner. Two air channels below the windrow, spaced 1.2 m apart, provide air and allow drainage of excess leachate and water to the retention pond.

Composted material from 2 composting windrows is placed in one of seven (7) curing windrows, each (50 m long x 7 m wide x 2.5 m high) and cured for about four (4) months to produce high quality compost that meets or exceeds the CCME Standards of Type A compost. The curing pad (55 m x 100 m) is designed to contain surface runoff from rainfall and snowmelt together with leachate generated in the process.

The mature compost storage area is large enough to store at least six months of compost production in piles no higher than 6 m or in 4 m high windrows. The temperature of stored mature compost should be monitored and recorded on a weekly basis to prevent fires. The combined storage and screening area shown in the diagram is about 40 m x 100 m.

Equipment at the site should include two front-end loaders (one for use during the composting process and one for use in curing, screening, and shipping in order to prevent reinfection with pathogens). However, given the small size of the operation, only one front-end loader is sufficient but care must be taken to clean the loader before handling material that has passed through the pathogen reduction phase. Additionally, a grinder/mixer to prepare the substrate, windrow turner and screening equipment would be needed. Some of the equipment may be leased when required. In particular, screening of matured compost can be subcontracted. A truck scale should be installed to properly track and weigh inbound waste, amendment, shipped compost, and overs and contaminants sent to landfill.

The site must be fenced to avoid unauthorized access as well as illegal dumping and entry of nuisance animals. Access to the fenced facility is through a gate that is closed outside operating hours. In addition, access to the various operations is restricted to operating personnel.

Signs should be posted and maintained at the facility in a manner that are clear, legible and visible and shall include the following information:

- Name of the Facility and Owner;
- Permit Number;
- Name of the Operator;
- Hours of Operation;
- Allowable and Prohibited Waste;
- Telephone Number to Register Complaints;
- 24-hour Emergency Telephone Number;
- Warning against Dumping Outside the Facility.

4. SITE MANAGEMENT

A diagram showing the organization of the operation and management of the composting facility should be posted at the site to reinforce the structure and clarify all roles for a smooth operation and high quality products. Staff will be encouraged to attend courses, seminars and annual conferences of organizations such as The Compost Council of Canada.

Two employees will be assigned to the operation of the facility. Current municipal staff from the administrative, engineering, operating and maintenance sections will support the operators. The facility operators must maintain detailed records of all materials entering and leaving the site and detailed daily records of all technical data regarding the operations at the site.

Operators should be required to complete in-class and on-site compost facility management courses and training, such as the course offered by The Compost Council of Canada. They should also be familiar with the procedures outlined in this manual.

5. OPERATION PLAN

The Plan covers operation of an aerated windrow plant that processes SSO and similar high-moisture, putrescible feedstock blended with one or more bulking agents.

The following diagram outlines the main process operations of a facility. The green boxes represent the feedstock preparation steps, the two blue boxes the active composting steps and the two buff boxes the post-processing steps. The red box designates control process.

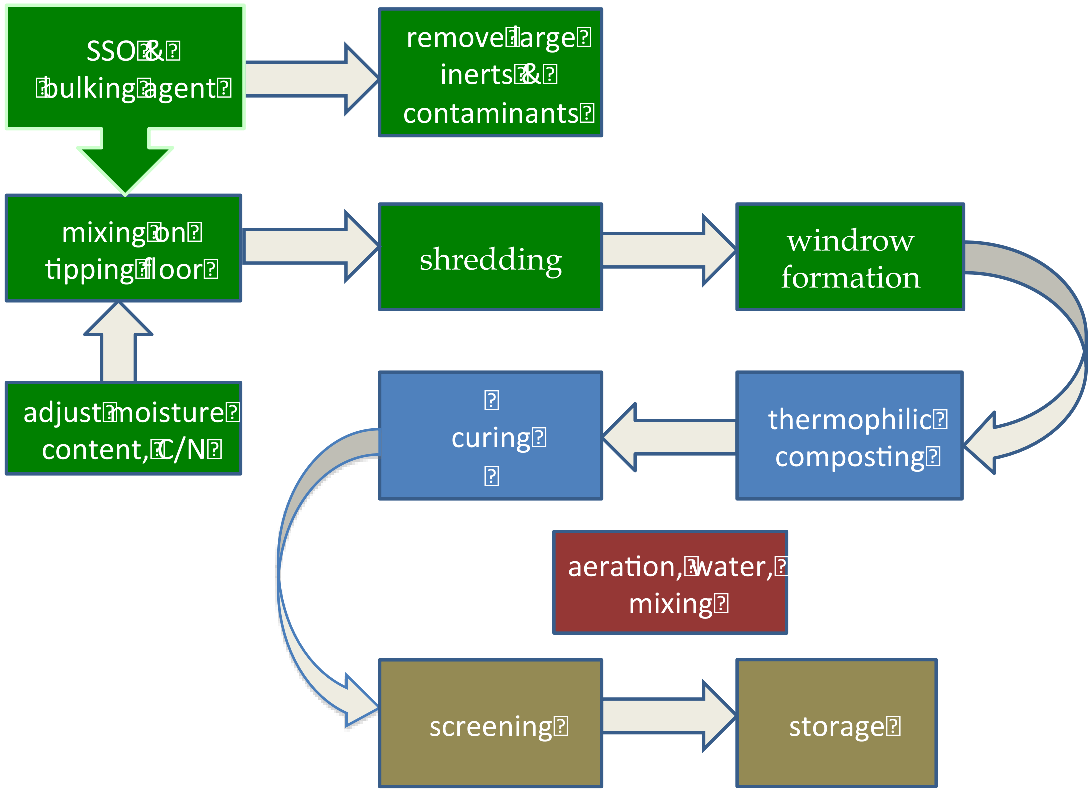

Figure 2. Schematic of Composting Operations

5.1 Receiving Primary Feedstock

The compost facility can receive up to 2,500 tonnes of SSO and required amendment per year. Appendix B contains a list of acceptable components in the primary feedstock, as well as unacceptable components. In general, materials that may be hazardous to the operators, damage equipment or cause production of compost that cannot meet the CCME Standards of Type A[2] compost are not acceptable.

Despite careful planning, public education and curbside enforcement, SSO contains unwanted materials that should be removed prior to composting. Kitchen and bathroom waste often contains small pieces of plastics, bottles caps, ties, empty makeup containers, and sometimes cutlery and batteries. The screening process can help to remove most of these items from the finished compost; however, batteries are of

[2] Canadian Council of Ministers of the Environment, 2005. *Guidelines for Compost Quality*. ISBN 1-896997-60-0

greater concern because they may disintegrate during the process, contaminating the compost with heavy metals. Including a magnetic separator in the feedstock processing or screening system can help recover batteries that otherwise would not be possible to remove.

Yard waste often contains stones, demolition debris, nails, screws, bolts, discarded motor oil, plastic cups and flowerpots, garden hose, plastic fertilizer bags, spray cans, soft drink cans, glass bottles and jars, toys, gardening tools, tennis and golf balls, string and rope, metal parts, etc. Aside from the risk of contaminating the compost, some of the contaminants may damage equipment or present a serious risk to the operators. For example, stones and similar objects easily become dangerous projectiles as they pass through a shredder or windrow turner.

5.2 Feedstock Preparation

Feedstock (substrate) preparation is probably the most important part in successfully composting putrescible organic waste. It deserves careful attention to ensure the desired initial porosity, C/N ratio, moisture content and homogeneity of the substrate. Errors in preparing the substrate usually result in operational problems during the process, including odour generation and emissions.

The key objectives of feedstock preparation are:

- to obtain a thorough mixture of primary feedstock and bulking agents[3] with porosity that promotes aerobic conditions within the windrow;
- to establish an acceptable particle size distribution of the feedstock to provide greater surface area for higher decomposition rates while retaining structural support in the windrow;
- to thoroughly mix the feedstock components and bulking agents to produce optimal moisture content and carbon-to-nitrogen ratio; and
- to remove harmful substances such as glass, plastic and metals that may be found in the bulking agent or feedstock.

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[3] Suitable bulking agents are discussed in Appendix C.

STEP 1. Debagging Feedstock

Organic waste collected in large plastic bags is readily recovered by opening the bags using bag-breaking equipment. However, kitchen waste placed in small plastic bags is more difficult to recover because bag-breaking equipment is normally not designed to handle small bags. Slow speed shear shredders have been found helpful to open both large and small bags. Subsequent handling and turning expose the organic materials to the composting environment.

SSO and other highly putrescible waste have often started to degrade in an anaerobic environment before collection and are, therefore, odorous upon arrival. To prevent the receiving area from becoming a major source of fugitive odours, it is essential that the inbound material be processed as quickly as possible, usually within 4 hours, and under no circumstances later than 24 hours.

STEP 2. Removing Contaminants and Non-compostables

Remove all large objects that can damage equipment or present a hazard to the operators.
Remove all hazardous chemical contaminants.

STEP 3. Adjusting Carbon-to-Nitrogen Ratio (C/N)

Determine or estimate the C/N and moisture content of primary feedstock and bulking agent, including unprocessed organic overs from the screening operation.

Calculate the amount of bulking agent needed to obtain a C/N ratio of 25/1 to 35/1. (See Appendix D for the method to calculate the amount).

STEP 4. Pre-mixing Feedstock and Bulking Agent

Since mixing of organic waste and ground bulking agent must be done thoroughly to form a uniform substrate, the streams are pre-mixed in proper proportions on the tipping floor using a frontend loader. This also helps to identify additional contaminants.

As an *approximation*, the ratio of food waste to bulking agent (yard waste or woodchips) is 1:1 on a weight basis or 1:2 or 3 on a volume basis (assuming that the bulk density of the final mix is about 600 kg/m^3). If there is a large amount of L&Y waste in the collected material, a volume ratio of 1:2 may suffice.

STEP 5. Shredding and Blending Substrate

Shred and blend the mix of waste and bulking agent to give a porosity of at least 45%. Maximum particle size should not exceed 75 mm.

STEP 6. Moisture Control

The moisture content of the mix can be determined from samples taken prior to shredding and then adjust the water content to be 55 to 65%. Subsequent shredding and blending will provide a good method to distribute the moisture.

a) If moisture content is < 55%, water can be added at any point in the substrate preparation process.

b) If moisture content is > 65%, add more dry amendment[4]

Given the importance of moisture content, it is recommended that the moisture content be verified after shredding when the substrate is more homogeneous.

5.3 Windrow Formation

STEP 1. Windrow Preparation.

After previously composted material has been removed from the windrow position to the curing area, the aeration floor needs to be cleaned to ensure that the aeration holes in the aeration trench covers are open.[5]

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[4] In this case, the final C/N ratio may be outside the recommended range; however, due to the risk of developing anaerobic conditions in the wet substrate, the moisture content criterion trumps the C/N ratio one. The alternatives are to use a drier form of the amendment, use a different amendment or add a third component that is dry (e.g. sawdust or straw).

[5] A hydraulically driven power-broom mounted on a frontend loader is a useful tool in cleaning the aeration floor and other areas of the composting facility.

Figure 3. Cleaning with tractor-mounted broom.

After cleaning. a visual inspection is made of the aeration holes to ensure that they are open. Openings that remain closed after brushing can be opened with a screwdriver or similar pointed device.

STEP 2. Windrow Construction

During the windrow construction, the fan is put in the "ON" position to prevent settling of small particles in the holes and to aerate the substrate as it is deposited in the windrow.

Before adding a daily batch to the windrow, place a 15 cm or deeper layer of screening overs or coarsely ground bulking agent on the aeration floor to provide better air distribution.

The substrate is transferred with a frontend loader from the shredder to the composting pad to construct the windrow. Normally a windrow is triangular in shape to allow shedding of rain but, during dry weather, a trapezoidal shape may be advantageous in trapping rainwater. The windrow cannot be compressed because it reduces the free air space.

The maximum width and height of the windrow are determined by the size of the windrow turning equipment. If turning is done with a frontend loader, the width should be 6.0 to 8.0 m and the height 2.5 to 3.5 m. Care must be taken to have a uniformly constructed windrow along the entire length.

Figure 4. Layer of coarse bulking agent

For example, a food intake of 50 t/week and 50 t of bulking agent requires a windrow 7 m wide x 2.5 m high x 20 m long if the bulk density of the mix is about 600 kg/m^3.

Spacing between windrows must be sufficient to allow access to any section along the windrow with a frontend loader, either to mix the substrate or to free a dedicated windrow turner should it stop along the way.

The space between the windrows must be kept clean to prevent accumulation of debris and leachate, which are significant sources of odours. Cover the windrow with layer of 15 cm (6") to 30 cm (12") of mature compost or overs[6] from the screening operation, This will act as a biofilter to capture fugitive odours.

STEP 3. Windrow/Batch Identification

Each windrow is assigned a number to track the substrate during the composting process. For example, the following pile identification method gives the necessary information:

(Windrow Number) - *(Year)* - *(Date started)*

For example: 150 - *2012 – 09/12*

Windrow processed at the facility: 150

[6] Instead of mature compost or overs, windrows can also be covered with a fabric cover available from several manufacturers; however, the capital and maintenance cost of the covers are high. Covers also tend to freeze to the ground and are easily damaged during winter operations.

Year produced: 2012
Month and day when pile started: September 12

If desired, daily batches can also be identified with the overall windrow number by adding a number and the date when the batch was added to the windrow.

For example: 150 - 2012 – 09/12 – 3 - 09/14

A sign with the number is placed in front of the windrow for reference.

Windrows are tracked on a board located in the office by noting when the windrow was turned, water was added, and transferred to the curing pad.

5.4 Thermophilic Composting Process Control

Composting involves rapid decomposition of the primary waste by thermophilic microorganisms in an aerobic environment. Therefore, the objective of operating a composting process is to optimize and control the conditions that favour aerobic microorganisms in each step of the process. It is generally accepted that this requires temperature, oxygen, moisture and porosity control.

5.4.1 Temperature

As temperature and rate of temperature change are the best indicators of the health of the composting process, temperature measurements and records are essential in managing the process.

STEP 1. Temperature Measurements and Records

Use a dial thermometer or portable digital temperature probe with a 1 m stem to take measurements at 10 m intervals along the weekly windrow, making sure that at least three (3) readings are taken to give a representative average.

Measurements should be made at about 0.3, 0.6 and 0.9 m depths from the top and sides of the windrow with the probe inserted perpendicular to the surface and left for at least five minutes to stabilize.

Temperature readings at the three depths are done on a daily basis during the first week of composting or until the process is established. After that, a daily reading at the 0.9 m depth is sufficient.

Report all readings on a datasheet or spreadsheet similar to the sample in Appendix E.

Review the temperature profile daily to determine the stage of the process and to detect the development of any problems.

STEP 2. Temperature Control

Under normal circumstances, the temperature of fresh substrate is expected to increase rapidly during the first two or three days to the thermophilic control temperature. The rate of temperature change depends on the type of substrate and ambient conditions.

Forced aeration is used to provide oxygen required by the aerobic microorganisms and to remove excess heat from the substrate. Aeration is normally intermittent with control provided by a timer or a temperature-feedback control system.

Temperature-feedback control uses temperature measurements to turn the fan ON or OFF during the most active composting phase. However, because temperature control may not supply sufficient oxygen during start-up and the mesophilic phase, timer control is used to supply the oxygen demand. Alternatively, the earlier phases can be controlled with an oxygen-feedback control system but oxygen probes are expensive and subject to plugging.

Control Action:

1. *Start-up and mesophilic phases:*

   For timer-controlled aeration, set the fan cycle between 1/3 to ½ ON, with an OFF time of less than 30 minutes, to provide sufficient oxygen for biological oxygen demand while allowing the substrate temperature to rise to the 55 to 65^{o}C range. During extremely cold weather when waste comes in cold, the timer control needs to be altered to allow heating of the substrate.

   With oxygen control, set the oxygen concentration set point to 10% so that the fan will supply sufficient air for biological oxygen demand.

2. *Thermophilic phase:*

When T>65°C, set the timer to run the aeration system continuously until the temperature drops to about 60°C. Once the temperature has dropped, return the system to the normal schedule.

With temperature feedback control, the upper setpoint should be 63°C and lower setpoint 58°C.

3. *Pathogen reduction:*

Regulatory requirements to reduce human pathogen in windrow composting specify that the substrate must be at least 55°C for at least 15 days[7] plus at least 5 turnings of the windrow during the entire thermophilic phase. Daily temperature records must be available to verify the prescribed temperature requirement.

5.4.2 Oxygen content

Determine the oxygen concentration in the substrate using a long probe to draw a gas sample into the instrument, read and record the output.

Use the same locations as the temperature measurements to allow a correlation between the oxygen content and temperature.

Control Action:

If oxygen readings are consistently below 10% and aeration system is working correctly:

1. *increase aeration rate by increasing the relative amount of ON time that the fan runs, and/or*

2. *turn the windrow to increase porosity[8].*

[7] 15 days do not need to be consecutive.

[8] Supplying oxygen by turning only is not sufficient to maintain aerobic conditions. Research has shown that, without forced aeration. the oxygen level in the substrate is used up in less than one hour, and in very active compost, in less than 30 minutes.

5.4.3 Moisture content

It is difficult to determine a representative moisture content of a windrow as, within the substrate, there are regions of dry and wet material. Frequently the top is much wetter than the centre due to condensation while the base tends to be drier at the ventilation channels. Elsewhere in the windrow, ventilation dries the substrate because about 90% of the heat removed is by evaporative cooling.

A minimum of three (3) substrate samples are collected from each windrow, taking care that the samples are from at least 0.6 m below the surface. Each sample is tested for moisture content using the oven test.

Oven Test:

- Standardized test for accurate moisture determination.
- Uses a dedicated facility microwave or laboratory convection oven.
- To ensure that the moisture content is valid for the whole windrow, a composite sample must be obtained using the procedure outlined in Appendix G.
- The oven test is used to verify the moisture content after water addition and/or turning.

Aside from the oven test, it is often useful to determine a quick estimate of the moisture content during daily operations. In this instance, the squeeze test is a useful method.

Squeeze Test:

- A rough indicator of the moisture content.
- Performed quickly.
- Used to determine if more moisture should be added while turning a windrow
- Take a handful of substrate sample, remove large pieces and squeeze it tightly.
  - If moisture drips freely from the fist, the moisture content is too high (>65%);
  - If, upon opening the hand, the material crumbles, the moisture content is too low (<50%);
  - Anything in between indicates an acceptable moisture content.
  - With sufficient experience, an operator becomes quite adept at estimating the moisture content in this manner.

5.4.4 pH

pH is another operating parameter that could be readily monitored but it is rarely necessary because microorganisms involved in composting are capable of working over a wide range of pH. However, pH measurements can useful to indicate problems with the process.

Litmus Test:

- The simplest pH measurement is done by saturating a compost sample with distilled water, stir the mixture, let the compost settle, and take the pH with a litmus paper.

pH Meter:

- Accurate pH measurement
- Make a saturated paste of the composite sample by thoroughly mixing 50 g of sample and 50 g of distilled water and allow it to sit for 4 hours in a covered beaker.
- Take a reading using a laboratory pH probe that was calibrated using pH 7 and pH 10 buffer solutions.

Control Action:

If pH>8.5, blend small amounts of sulphur until the pH is below 8. Note that the buffering capacity of compost may prevent large pH changes.

If pH<5.0, blend small amounts of wood ash, kiln dust or liming products (e.g. gypsum) to increase the pH in the substrate to 6.5 or higher.

5.4.5 Frequency of monitoring composting parameters

Temperature and oxygen concentrations are the prime indicators of the microbial activity of the composting process. In the case of food waste and other highly putrescible feedstock, both parameters need to be measured on a daily basis during the high-rate phase of the process. As the reaction rate decreases, oxygen measurements can be made less frequently, dropping to once a week later in the process. On the other hand, temperature measurements must be recorded daily throughout the process for process control.

Moisture content should be taken weekly during the composting process and less frequently during curing. Regular monitoring of pH is not required in processing residential food waste but can be used to determine the status of decomposition.

5.5 Windrow Turning

5.5.1 Turning objectives

Turning substrate during each of the phases is an important operation to maintain optimum composting conditions throughout the windrow. Turning is known to

- provide more uniform mix of substrate;
- restore free airspace for improved air movement;
- reduce odour production by eliminating anaerobic pockets;
- redistribute moisture, nutrients, microorganisms, and free enzymes;
- allow moisture control through addition and redistribution of water;
- shred clumped substrate;
- reduce hot spots;
- move cooler outer layers to the inside for exposure to pathogen reduction temperatures; and
- allow short-term temperature control by releasing trapped water vapour and heat.

It is important to realize that, as turning reduces the moisture content of the substrate, turning can be used to lower the moisture content if the substrate is too wet.

Figure 4. Clumps of hard, dried-out substrate.

5.5.2 Turning equipment

A *bucket loader* or *skid loader* can be used to turn windrows. The loader lifts and turns the substrate as it is placed in a new windrow. The main disadvantages of bucket loaders are

- incomplete mixing, resulting in non-uniform free air space, inefficient pathogen kill;
- difficulties in adding water uniformly;
- inability to break up clumps (unless the bucket is equipped with a shredder);
- high labour costs; and
- extra space requirement between rows.

Use of a specially designed *windrow turner* reduces or eliminates those disadvantages and requires much less time but at a higher capital cost. The better windrow turners move substrate from the outside of the windrow to the centre while shredding clumps of material. Compost turners should be equipped to add water during the process. The best results are obtained with nozzles that provide a large number of fine droplets that are blended uniformly with the substrate particles during mixing.

5.5.3 Turning frequency

The frequency of turning is governed by the rate of decomposition and thus varies for the different phases, becoming less often as the process progresses. It also depends on the type of aeration (natural or forced), feedstock, weather conditions and season.

Control Action:

1. *Start-up and mesophilic phases:*

   The objective during this period is to reach and maintain thermophilic temperatures for rapid decomposition of the most putrescible feedstock.

   Normally there is no need to turn the windrow during the start-up and mesophilic phases if the substrate was properly prepared and placed in the windrow. With the exception of cold winter conditions, the start-up and mesophilic period is relatively short ($\leq$ 3 days) so that the porosity and moisture content remain in the accepted range.

2. *Thermophilic phase:*

Operators must develop a turning schedule as they gain experience with the system and substrates. The frequency can vary from daily to weekly during the first two or three weeks of high-rate decomposition.

As a guideline, the first turning should be done after the second week of thermophilic composting but no later than the end of the third week. Subsequent turnings are on a weekly or bi-weekly basis until the process has slowed as indicated by the temperature history, which will probably occur after 6 to 8 weeks of thermophilic composting.

In addition to regularly scheduled turning, it may be necessary to turn sooner as indicated by the temperature history or moisture content. For example, when

- *temperature exceeds 70^{o}C;*
- *temperature drops for three (3) or four (4) consecutive days (depletion of nutrients; compost too dry; anaerobic substrate); or*
- *temperature varies along the windrow (non-uniform mixing or moisture distribution).*

If moisture content becomes an issue, the following turning schedule has been shown to be helpful for SSO or similar organic type substrate.

MOISTURE CONTENT (%)	TURNING ACTION
>70	Turn daily until the moisture content is <70%
60-70	Turn at 2-day intervals
45-60	Use normal turning schedule or temperature data
>45	Turn while adding moisture

3. Regulatory Requirements:

Regulatory requirements must be taken into account in developing a turning schedule. Thus, pathogen reduction criteria for windrows state that the substrate must be maintained at a minimum of 55^{o} C for at least 15 days (need not be consecutive) and that the windrow must be turned at least five times during this period.

After each turning, the windrow needs to be covered again with a layer of mature compost or overs, at least until the substrate has been composting for 6 weeks.

5.6 Winter Operation

All of the above operational procedures require suitable ambient conditions but the feasibility of operating a windrow system in a windy, wet or cold climate is more challenging. In particular, freezing temperatures have a significant impact on the composting process. While active windrows will continue to degrade substrate in the interior, the surface material is degraded at a much lower rate, if at all. The layer near the surface is likely to become saturated due to condensation of water vapour, which negatively affects the airflow rate and the airflow distribution.

Aeration of active windrows needs to be carefully controlled because cold air may result in too much cooling of the substrate near the air ducts.

The most problematic aspect of freezing temperatures is that inbound SSO and bulking agents are cold or frozen. This represents two major problems. One is that the food waste does not drain during collection and transport and, hence, has higher moisture content than during warmer weather. The second one is that the cold (frozen) mix is placed on frozen ground and will be exposed to freezing air temperatures when aerated.

Some windrow facilities, usually large-scale ones, deal with the problem by heating the aeration air or by heating the pad with heat recovered from an active windrow using a glycol-filled piping system embedded in the surface of the pad. However, even in these instances, it may take a week or more for the temperature of the substrate to start to increase to thermophilic levels.

Little information is available regarding windrow composting without heating frozen food waste or similarly highly putrescible substrates.

It is possible to process the substrate and place it in windrows using the normal procedure and wait until the ambient temperature is above freezing. This will impact the size of pad because it may take weeks before the material has completed the composting process.

Climatic conditions also impact the curing process as cold winter temperatures reduce the biological activity in the windrow. In this case, reduced aeration and turning frequency is used to maintain the core temperature.

5.7 Curing Process

While curing is essential to producing mature compost, it is often the most neglected, least managed phase of composting. This is probably because curing is a much slower, mesophilic process that requires more than 3 months. The rate of oxygen consumption, heat generation and moisture evaporation are lower than in the active phases. Nevertheless, curing is a microbial process that requires moisture and oxygen. It is therefore essential that the moisture content of curing compost is checked and adjusted on a regularly basis. Similarly, the material must be turned at regular intervals, albeit less frequently than during active composting.

Most curing is done in windrows or static piles without forced aeration. Due to the shrinkage resulting from the composting process, two (2) windrows of compost may be combined to form one windrow, about 3 m high x 7 m wide, for curing. Larger windrows tend to restrict oxygen infiltration by natural convection, causing compost in the pile to become anaerobic and a significant source of odours.

The position of the substrate on the *curing pad* is recorded and a record kept of temperature and oxygen measurements, turning events, moisture additions and other observations made during the curing process.

Ready to Cure:

> *The substrate is ready for curing when the windrow temperature does not increase after turning (assuming that the moisture content is correct). At this point, the microbial activity has slowed and decomposition of resistant compounds, the production of nitrate-nitrogen for plant use and humus for the soil is starting.*

Substrate is also considered ready for curing[9] when

a) *carbon dioxide production is < 12mg CO_2/g VS/day, or*
b) *Solvita® Index is $\geq$5*

Process Control

- *Aeration: must maintain aerobic conditions ($O_2 \geq 10\%$)[10]*
    - *Natural convection: small piles or windrows < 3 m x 7 m*
    - *Forced convection: cycle fans to maintain oxygen level*

[9] Samples used for maturity testing must come from at least one metre inside the pile to be valid.
[10] 10% instead of 16% used in active composting is acceptable because the rate of oxygen consumption is lower.

- *Moisture content: ideally 45%*
    - *<35% creates large amounts of dust*
    - *<40% too low for sufficient microbial activity*
    - *>50% increased chance of anaerobic pockets and odours*

- *Temperature: <50^{o}C to prevent inhibition of mesophiles; weekly temperature measurements*

- *Turning is required to maintain uniform moisture and airflow but at reduced frequency – monthly for the first couple of months or when required to correct porosity or moisture.*

- *Reduce turning later on in the process to preserve the growth of mycelium of actinomycetes which is important in maturing compost.*

Curing Period

- *Curing is a slow process and may require 3 months or more to complete depending on ambient conditions.*

- *During the first month of curing, it may be advisable to cover the windrow with moist woodchips, mature compost or overs as a precaution to odour emissions. The layer would also provide insulation during cold weather and reduce the impact of rain.*

Curing is complete when

- *temperature has decreased to near ambient without reheating after the material is turned at a moisture content of about 40% and the compost is not anaerobic;*

- *carbon dioxide production is ≤ 4 milligram of carbon/gram of organic matter (dry basis); or*

- *Solvita® Index is >7.*

At this point, compost[11] is ready for screening.

5.8 Screening

Screening removes oversized material from the compost. It can be done prior to curing or after curing; however, it is better to keep the bulking agent in the substrate during curing to maintain more free airspace for air movement, especially if natural convection is used to aerate the windrow. Also, if a cover layer of

[11] *Mature* compost is not necessarily the same as *stable* compost. Compost is stable when there is no significant microbial activity at a given temperature (low) or moisture content (low). It becomes unstable and reheats when one or both conditions change. Mature compost is stable at all temperature and moisture conditions and does not reheat.

woodchips or overs was used during curing these materials must be screened out before marketing the compost.

The moisture content of the material to be screened affects the effectiveness of the equipment and must be in the range of the equipment manufacturer's specification. Typically, a moisture content of between 40 and 45% is suitable for screening. Higher moisture content leads to screen binding and lower moisture content to excessive dust.

Usually screening is done to produce three fractions of different particle size; namely,

1. *>75 mm - to remove large contaminants (e.g. plastic bags);*
2. *<75 mm and > market size - to recover uncomposted bulking agent and substrate; and*
3. *market size (e.g. residential use: < 12 mm; agricultural market < 25 mm)*

The largest fraction often contains useful bulking agent but it is difficult to recover due to the large amount of plastics and other contaminants. The market fraction still contains some contaminants and some of these can be removed using a vacuum system installed on the conveyor. The recovered bulking agents can be used again for blending with the food waste or as windrow cover.

5.9 Storing Overs

Overs are a valuable source of carbon, useful as a structural amendment or windrow cover but can also become a source of odours or start on fire if not stored properly. Overs are often stored in large piles prior to use; however, if the moisture content exceeds 40%, microbial activity of the partly decomposed material may be sufficient to start heating. It is, therefore, necessary to monitor the temperature of the pile of overs on at least a weekly basis. Any indication of a consistent increase in temperature, especially after a rainfall, requires immediate deconstruction of the pile and cooling of the material.

5.10 Storing Mature Compost

Mature compost from the curing pad is stockpiled by combining two (2) curing windrows to form a Lot. The number assigned to a Lot consists of the four original windrow numbers. Stockpiles are monitored to ensure that the temperature does not increase, indicating higher than desired microbial activity. It is also necessary to prevent excessive dust, contamination with weeds, and reinfection with human pathogen due to wildlife and birds.

Despite all the precautions to ensure that only mature compost is stored, it is possible that some immature compost finds its way into the windrow. In this case, the material will become anaerobic and could cause an odour problem during shipping or even start on fire.

Due to the long processing periods, compost sold in one year is produced from food waste processed in the previous year. For example, compost sold in early April must start the curing process no later than October of the previous year.

It should be noted that the agricultural industry often accepts immature compost that has not been cured or completed the curing process. However, this material is **not deemed to be compost** and does not meet regulatory standards for unrestricted use.

6. HOUSEKEEPING

A well-managed composting facility places considerable emphasis on keeping the buildings, pads, access roads and equipment clean to minimize environmental and adverse health impact. A lack of proper housekeeping leads to excessive dust, litter, odour and bioaerosols. Furthermore, it enforces the public misconception that composting is a dirty process.

An example of the sheet used by the staff to carry out weekly maintenance of the site and its infrastructure is given in Appendix E.

6.1 Noise Control

Noise caused by frontend loaders, trucks, screening equipment, windrow turner, etc., including the backup alarms, is unavoidable at a composting facility. However, some measures can be taken to ensure that the noise level is kept at a minimum. For example,

- use properly functioning mufflers on all equipment; and
- confine operating hours to Monday through Friday between 7:00 am and 5:30 pm.

6.2 Dust Control

It is inevitable that dust is created at the facility. Therefore, dust control is an important part of housekeeping operations.

- Take measures to control dust at the facility and access roads by spraying small amounts of water on the dust-producing areas.
- Keep the space around the windrows clean using a sweeper.
- Do not turn the windrows or screen compost during periods of high wind.
- Do not screen compost with moisture content below 37% wet basis (add moisture by turning).

6.3 Litter Control

Litter is a common problem at composting facilities processing municipal source-separated organics. Aside from the receiving and preprocessing operations, most of the blowing litter is generated during windrow turning and screening. Litter control involves

- collection of loose litter at the receiving and mixing stages with suitable disposal;
- installation of fences, screens, or suitable vegetation barriers;
- suspension of turning and screening during periods of high wind; and
- collection of material captured by the barriers and off-site litter.

6.4 Vector and Vermin Control

Given the high temperatures of active window rows, it is not expected that vectors or vermin will burrow into them. However, if vectors and vermin are found in the curing windrows, mature compost piles, or bulking agents storage, appropriate extermination methods need to be implemented.

For the rest of the facility, conditions will be maintained that are sanitary and therefore unfavourable for harbouring, feeding and breeding of vectors. Nevertheless, composting facilities should have commercial rodent control stations around the site.

The operator will inspect the facility daily to detect any vectors and promptly take corrective action.

6.5 Odour Control

A significant source of odours related to housekeeping is the result of spills and tracking of organic waste by operating equipment and trucks. Often a frontend loader is used to clean up the debris but it leaves a thin layer of odour-producing organics on the surface. A tractor-mounted broom is better in keeping surfaces clean. As cleanup activities release volatile organic compounds, timing of the cleanup should coincide with ambient conditions that provide dispersion and a wind direction that is away from the nearest receptors.

6.6 Leachate and Runoff Control

Leachate and runoff must not be allowed to pond on the site and become a source of odours. Therefore, obstructions that prevent proper drainage of leachate and runoff must be removed. Similarly, damage to the pads by equipment or otherwise must be repaired as quickly as possible.

6.7 Maintenance

In view of the importance of the aeration system in maintaining an aerobic environment, the housekeeping plan must include

- monthly inspection of the aeration blowers and ducts,
- cleaning of the aeration floor and openings after each batch,
- bi-monthly inspection of the leachate collection system of the aeration system, and
- annual flushing of the piping system and leachate collection system.

7. PROCESS MONITORING, RECORDS & REPORTS

Accurate record keeping and regular reporting are not only important responsibilities of the facility operator but are also useful management tools. The records that need to be kept include daily operating information, mass flows (inbound waste, amendment material, compost shipped, overs shipped for disposal), odour complaint reports, and a daily logbook.

7.1 Operating Information

It is important to maintain records of daily temperature measurements to monitor the health of the composting process and to meet regulatory requirements for pathogen reduction. Other operating data to be recorded are oxygen readings, moisture contents, turning events, moisture additions, and retention time of substrate in each phase of the process.

By storing the data as an electronic spreadsheet, the trends are readily shown in graphical form. The table in Appendix E is an example of a datasheet for monitoring a windrow. A similar spreadsheet should also be used to track the curing process and storage piles. A turning event or other observation can be noted in the table, either in an additional ‘comment’ column or as a line item.

A copy of all data must be kept at the facility for five (5) years.

Once a windrow is moved to the curing pad, a detailed spreadsheet and graph should be printed and filed for future reference. Material sampling and laboratory testing results are also filed with the process data.

7.2 Complaint Reports

All complaints received pertaining to the operation of the facility shall be logged and kept on file for at least five (5) years.

7.3 Site Activity Log

The Site Activity Log is used to keep track of operating and other activities, equipment hours, staff hours, etc. The following information is to be included in the weekly log sheet with entries made daily.

- date and time of arrival of personnel;
- weather conditions (temperature, wind direction and precipitation)
- quantity and source of waste received;
- quantity of waste at the site at the end of the operating day;

- quantities and destination of each type of waste (contaminants and excess overs) shipped from the site;
- record of site inspections, including daily odour patrols;
- record of substrate sampling events;
- laboratory reports of analysis of stored mature compost ready for shipping;
- record of spills or process upsets at the site, the nature of the spill or process upset and the action taken for the clean-up of the spill or correction of the process upset, the time and date of the spill or process upset, and for spills, the time that the Ministry and other persons were notified in fulfillment of the reporting requirements; and
- record of any waste refusals which shall include: amounts, reasons for refusal and action taken.

8. HEALTH AND SAFETY

8.1 Bioaerosols

The specific health and safety concern related to composting is the exposure of staff and public to bioaerosols released during the process. Research has shown that high concentrations of bacteria, actinomycetes and fungi, and, to a lesser extent, endotoxin and dust are released close to the source of composting operations with the highest concentrations observed during windrow turning.

Some people may be sensitive to some bioaerosols and experience acute or chronic respiratory health effects, mucosal membrane irritation or dermatitis. The two bioaerosols that have received most attention are *Aspergillis fumigatus* and endotoxins. *Aspergillis fumigatus* is a ubiquitous fungus found in all decaying organic matter and soils. It is an opportunistic pathogen that can cause respiratory infections (aspergillosis, aspergilloma), especially in persons with a compromised immune system. *Aspergillus fumigatus* is also an allergen that may cause immunoallergic reactions, such as broncho-pulmonary aspergillosis and allergic alveolitis.

Endotoxins are microbial cell byproducts that can cause inflammatory responses, such as fever, cough, headache and respiratory impairment.

Constant exposure to dust may cause irritations of the mucous membranes of the respiratory system, which can result in chronic bronchitis.

Despite the fact that most compost workers experience no significant problems from exposure to bioaerosols, it is recommended that particulate respirators or half-mask respirators with disposable cartridges be used by all workers, especially in areas where substrate and compost are handled, such as during grinding, windrow formation, windrow turning, screening and moving of compost. Similarly, handling equipment should have sealed, ventilated cabs equipped with proper particulate filters.

Finally, workers should wear protective clothing and equipment. All cuts should be treated and disinfected. Other normal sanitary procedures such as washing hands before eating should be followed.

If a worker does develop a respiratory infection or allergic reaction, it is important to seek medical treatment and to suspect bioaerosols as the causing agent.

As far as off-site exposure to bioaerosols is concerned, research has demonstrated that bioaerosol concentrations decrease rapidly with distance from the source. For example, at 100 m downwind of the source, bioaerosol concentrations were substantially reduced by comparison with levels at the source. In several studies involving *Aspergillis fumigatus,* the concentration at 100 m was comparable to background concentrations.

Nevertheless, good management practice should include precautions to minimize bioaerosol emissions from the operation. For example, minimizing substrate handling, application of water to reduce dust, and monitoring wind to avoid blowing emissions towards neighbours can help minimize impacts. Fortunately the best practices recommended for control of bioaerosols are the same as those for odour control.

8.2 Safety

Safety concerns are mostly related to equipment operations and truck traffic so that the normal safety procedures must be followed.

Use of windrow turners requires special precautions. Some windrow turners use flails rotating at a high speed to mix the compost. It is not uncommon that flails eject stones and other solid objects as high speed projectiles. It is imperative that all workers keep a safe distance from windrow turners when in use.

Shredding/grinding equipment used to reduce the size of inbound waste and to mix the various substrate streams must be operated as directed by the manufacturer. In particular, tub grinders need to be run fully loaded to prevent ejection of materials.

9. ODOUR MANAGEMENT PROGRAM

As mentioned earlier, odorous compounds are generated during the breakdown of organic waste, even when the microbial environment is aerobic. The emphasis of odour management is to follow best process management practice aimed at reducing the amount of odorous compounds produced and emitted from the facility.

9.1 Odour Control Technology

The odour control technology used at the facility is limited to covering active windrows and windrows in the early curing stage with a layer of mature compost, moist woodchips or overs recovered from the screening operation. The layer contains aerobic microorganisms and acts as a biofilter by decomposing odorous compounds into carbon dioxide and water vapour.

9.2 Application of Best Management Practice

The control of potentially objectionable or offensive odours is a fundamental consideration in the processing and composting of organic materials. A continual and conscientious effort toward odour control is essential. Composting is inherently an odorous process due to the production of intermediate decomposition compounds. Intensity and characteristics of the odours depend on the type of waste, C/N ratio of mix, amount of material composted, and operational activity such as turning. In addition, highly putrescible waste arriving at the facility is most likely to be in a partial state of anaerobic decomposition and, hence, has an offensive smell. All of these factors are difficult to control; however, sources of preventable odours are spills, biodegradable bulking agent storage, tracking of waste onto roads, parking areas, and composting pads. Only prompt action and application of best management practices will prevent the odours from becoming a nuisance.

SOURCE	**CONTROL**
Receiving area	Do not store waste on site. (Plan must include an alternate site for disposal) Do not accept waste near end of day or before weekends. Process waste within 24 hrs. Clean area at end of day. Place contaminated bags, etc. in closed waste container.
Bulking agent storage	Do not store large amounts of *moist* bulking agents on site.

Mixing	Mix quickly. Transfer mix to windrows without delay. Clean equipment daily.
Windrow	Build windrow and immediately cover with biofilter layer. Keep space between windrows and pads clean.
Process	Manage moisture, temperature and oxygen.
Turning	Turn on schedule or when indicated by process parameters. Turn only when wind direction is away from nearest receptors. Turn only when weather conditions provide sufficient dispersion.
Screening	Screening should be restricted to times when there is minimal off-site impact of odours and dust.
Equipment and trucks	Keep from tracking waste onto the pads and access roads.
Leachate and surface water	Do not allow leachate and/or surface water to pond on site.
Sweeping	Only sweep site when weather conditions provide sufficient dispersion. Only sweep when wind direction is away from receptors.

It is not unusual that composting plants run long periods without odour complaints and then start to receive complaints. In all cases, this can be traced to a change in feedstock, complacency in managing the process, or attempts to increase the capacity without regard to the fundamental requirements of the composting process. In all instances, a return to the basics of composting usually resolves the problem; however, it may not reverse public opinion. Once there has been a significant odour problem, the public has become sensitized and will react quicker in the future.

An important tool in determining the local weather conditions is to have a recording, on-site weather station. In addition to temperature and humidity, the station must record wind speed and direction and provide 5-minute average. The information is used to determine ambient conditions suitable for on-site activities and to note wind direction and speed when odour complaints are received.

9.3 Odour Monitoring

Personnel who have been certified as odour monitors shall perform a daily patrol survey of the site and property line to determine if there are fugitive odours. The time of the survey should coincide or immediately following site operations that are most likely to allow odour emissions, such as turning. A record of the observations will be kept along with the prevailing weather conditions and weather station readings.

If elevated odours are detected during the survey, the patrol should be extended to include the nearest off-site receptors.

9.4 Complaint Response

All complaints received regarding the operation of the facility will be addressed as follows.

The Manager shall record and number each complaint using the spreadsheet form found in Appendix E and note

- the nature of the complaint;
- if the complaint is odour- or nuisance-related, the weather conditions and wind direction at the time of the complaint;
- the name, address and telephone number of the complainant (if provided); and
- the time and date of the complaint;

The Manager, upon notification of the complaint, shall initiate appropriate steps to determine possible causes of the complaint, and will proceed to take the necessary steps to eliminate the cause and forward a formal reply to the complainant.

The Manager shall complete and retain on-site a report written within one week of the complaint date, listing the action taken to resolve the complaint and make recommendations for remedial measures, and managerial or operational changes to avoid the recurrence of similar incidents.

If the complaint is less than two hours old, contact the complainant and try to confirm the odour event at the complainant's location. Also,

- obtain readings from the wind monitoring station (both current and at the time that the complaint was made) and determine whether the odour may have originated from the facility by evaluating the location of the complainant relative to the wind direction; and

- make a note of the on-site activities at the time of the complaint; e.g. turning substrate, delivery of food waste etc.

9.5 Emergency Measures

9.5.1 Excessive odour emissions

In the event that significant odours are emitted during a turning or other site operation and the wind is in the direction of sensitive receptors, the operation shall be stopped and the exposed surface covered with a biofilter layer. The operation will only be resumed when the weather conditions are suitable.

If a windrow has become anaerobic, it is necessary to take immediate measures to return the substrate to aerobic conditions. In this case, the windrow needs to be turned as soon as the weather conditions allow. It is also necessary to determine why the substrate became anaerobic (too wet, insufficient aeration or low pH) and to take corrective action. If the weather is not suitable for turning and the windrow emits significant amounts of odour, adding more cover material may provide temporary relief but it will not solve the problem.

If the substrate has become too wet, additional dry bulking agent must be added. If the pH is < 5.5, lime or wood ash can be added to increase the pH by neutralizing the organic acids formed during the anaerobic process.

9.5.2 Power failure

Given the importance of maintaining aerobic conditions at all times, a generator will be obtained to supply power to the blowers in case of power failure.

9.5.3 Equipment breakdown

In the case of equipment breakdown, such as the shredder/mixer or frontend loaders, obtaining temporary replacements will prevent accumulation of primary waste. However, if a replacement cannot be found within 24 hours, inbound primary waste must be directed to a landfill or other suitable destination for disposal.

10. TROUBLESHOOTING

10.1 Troubleshooting Guide

All composting facilities sooner or later experience process problems and odour emissions. As an aid to the operator, the following table lists the most common problems, possible causes, tests and observations recommended to identify the cause and the solution to the problem. It will be seen that the problems are almost always the result of deviation from the basic science of composting; that is, incorrect moisture content, loss of aerobic environment, lack of nutrients or improper nutrient balance for microbial growth. As shown in the following table[12], the solution to the problem is always to correct the aerobic microbial environment.

Problem	**Possible Cause**	**Observations & Tests**	**Solution**
Substrate does not heat.	Too dry	Squeeze test does not produce water. Moisture content <45%	Add water or wet ingredients and turn.
	Too wet	Substrate feels wet. Windrow slumps. Moisture content >60%	Add dry bulking agent and turn.
	Poor nutrient balance: insufficient nitrogen	C/N ratio > 50/1 Large amount of woody material.	Add high nitrogen source (manure, fresh grass, fertilizer) and turn. Revise substrate recipe.
	Poor structure	Windrow settled quickly. Few large particles. Not excessively wet.	Add bulking agent and turn.
	Cold weather	Cold or frozen ingredients.	Increase insulation layer. Add highly degradable, unfrozen ingredient. Mix new, cold substrate with thermophilic substrate.
	Low pH	Substrate smells like garbage. pH < 5.5	Add lime or wood ash and turn thoroughly.

[12] With some exceptions, the contents of the table were taken, by permission, from "Field Guide On-Farm Composting". Mark Dougherty, Editor. Natural Resource, Agriculture, and Engineering Service. Ithaca, NY 14853-5701. NRAES-114. June 1992.

Temperature decreases consistently over several days.	Too dry. Insufficient oxygen.	Squeeze test does not produce water. Moisture content <45%. Gradual temperature decrease instead of rapid drop.	Add sufficient water and turn. Increase aeration rate.
Temperature continues to decrease and does not increase after turning or aeration	Composting nearing completion	Approaching expected composting time. Adequate moisture. C/N < 20:1.	None required.
Temperature >65ºC	Insufficient aeration to remove heat. Moderate to low moisture content; limited evaporative cooling. Windrow too big for prevailing ambient conditions.	Substrate is moist. Substrate feels damp but not excessively wet or dry. Height > 3 m.	Increase aeration rate. Add water, turn, aerate continuously until temperature returns to target value. Decrease windrow size.
Rapid temperature increase to >80ºC in composting, curing or storage piles.	Chemical oxidation (See section 8.2)	Low moisture content. Interior of windrow or pile looks or smells charred.	Decrease pile size. Increase moisture content and turn. Open charred or smothering sections of windrow or pile, add water and mix with composting material.
Temperature is not uniform or varying odours emitted along windrow.	Poorly mixed substrate. Uneven airflow or short-circuiting. Material at different stages of maturity.	Visible difference in the moisture content and materials. Visible difference in the moisture content and materials. Temperature varies along the windrow length.	Turn and mix. Turn and mix. Check aeration system. None required.
Ammonia odour	High nitrogen level High pH Low availability of carbon in amendment	C/N ratio < 20:1 pH > 8.0 Large wood particles; C/N < 30:1	Add high carbon amendment. Lower pH with acidic ingredients and/or avoid alkaline ingredients. Use another carbon amendment or increase the carbon portion.
Sulphurous (e.g. rotten-egg smell) or putrid odours coming continually from the windrow	Anaerobic condition: Substrate too wet Poor structure Insufficient aeration Windrow compacted Anaerobic condition: Windrow too big	Low temperatures.	Add dry material. Add bulking agent. Turn windrow and increase aeration. Turn, add bulking agent if required. Decrease size of windrow.

	Airflow uneven or short circuiting	High temperatures.	Turn and mix.
Odours generated only after turning.	Odorous raw materials. Insufficient aeration; anaerobic interior	High temperatures. Falling temperatures	Increase turning frequency; increase porosity; add odour absorbing amendments. Increase aeration rate; increase turning frequency; increase porosity
High temperature or odours in curing windrows and storage piles.	Compost not stable. Piles too high.	Active composting phase was short; temperature and odour change after turning. Height > 3 m and width > 7 m	Manage windrow or pile for temperature and odour control; turn windrow as necessary; decrease windrow or pile size. Decrease windrow or pile size.
Site-related odours (windrows not odorous).	Raw materials. Poor drainage. Holding pond overloaded with nutrients or sediment.	Odour characteristic of raw material. Puddles of leachate/runoff. Heavy algae and weed growth; gas bubbles on pond surface.	Process raw materials quicker. Cleanup & improve drainage. Install sediment trap. Treat pond water.
Fly and mosquito problems.	Flies breeding in compost piles. Mosquitoes breeding in stagnant water.	Fresh waste accessible at surface; flies hover around windrow. Standing puddles of water; nutrient rich pond.	Turn windrow every 4 to 7 days; cover windrow with layer of mature compost. Grade site properly; maintain pad surface; maintain pond in aerobic conditions.

The only problem in windrow composting that does not have a simple solution is very low winter temperatures because the primary substrate arrives very cold or frozen and the ventilation air is also cold.

10.2 Spontaneous Combustion

Spontaneous combustion of organic matter becomes possible when the rate of heat production exceeds the rate of heat loss. It is sometimes encountered in the storage of grain, hay, beans and other agricultural products at higher than acceptable storage moisture contents.

The normal process leading to spontaneous combustion is started with aerobic biological activity (as in composting) followed by a rise in temperature above the thermal death point of the microorganisms. At 80^{o}C or higher, short chain hydrocarbons are chemically oxidized and, with insufficient heat loss from the pile, the temperature will continue to increase rapidly to 150°C or higher and the material will self-ignite.

Due to the availability of moisture in an active composting system fires are uncommon; however, if the substrate at thermophilic temperatures is allowed to dry out to a moisture content between 30 and 45%, spontaneous combustion is possible. This condition is more likely to develop during curing and storage, especially if the substrate did not decompose sufficiently in the active phases. Furthermore, the risk increases as curing or storage piles are made larger (e.g. 4 m or higher). On the other hand, if equilibrium is established between heat gain and loss, the pile comes to an equilibrium temperature and will not reach the spontaneous combustion point. For example, compost temperatures of 90°C have been observed in large piles without further temperature increase or ignition.

One of the complications of spontaneous combustion is that it may start in a small part of the pile where the local conditions are suitable for heating. For example, when a batch of immature compost is put adjacent to a dry batch in a curing or storage pile, the active batch continues to produce heat and the surrounding dry material prevents the heat from leaving the pile.

Spontaneous ignition inside a large pile produces heat, smoke and other combustion gases but does not have a flame because oxygen in the pile is quickly consumed. The result is a smouldering fire that usually bursts into flames when oxygen is added to the pile by aeration, turning, or opening the pile. Addition of water to a smouldering pile can also cause a flaming fire or, if the material is contained in a vessel, an explosion [13].

Unfortunately, fires at composting facilities are more common than is thought to be the case. However, they are sufficiently infrequent and not severe enough to attract public attention. In most instances, they are contained with little damage other than to the compost. There have been a few major fires with considerable damage and even destruction of the facility but these are rare.

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[13] There are many instances of explosion of grain silos due to spontaneous combustion and the addition of water to fight the fire. For this reason, rural fire departments normally do not use water.

10.2.1 Preventing fires in bulking materials

Fire prevention involves understanding the causes of spontaneous combustion and the elimination of the conditions leading to spontaneous combustion within large piles of feedstock, amendment, curing and stored compost; namely,

- relatively dry materials (moisture content between 30 and 45%)
- insufficient airflow to remove heat
- non-uniform mix of materials (non-uniform airflow)
- poor moisture distribution (adjacent dry and wet pockets)
- large well-insulated piles (greater than 4 m)
- time for heat build-up (infrequent or insufficient temperature monitoring)

Aside from preventing the above conditions from occurring, one or more of the following observations point to the potential development of spontaneous combustion in piles and windrows.

- Temperatures of 80°C or higher.
- Rapid increase in temperature above 65°C.
- Development of vents exhausting steam.
- Exhaust with a burnt smell.

10.2.2 Fighting spontaneous combustion fires

An Emergency Response Plan must be developed in consultation with the local Fire Department at the time of planning the facility. It should include guidance as when the Fire Department should be called to fight the fire and the type of equipment needed to fight the fire. The Emergency Response Plan must be part of the training of all site personnel and be clearly posted at the site.

The Emergency Response Plan must include a method to handle the runoff resulting from fighting a fire.

Depending on the size or potential size of the fire, local Fire Department policy, location of buildings and neighbours, smoldering fires can be extinguished with care by the facility’s staff.

- Never climb onto the pile because the surface may only be a dome that could collapse allowing an inrush of oxygen with catastrophic results.

- Do not start to aerate the pile because oxygen increases the intensity of the fire.

- Carefully remove layers of material from the pile with a loader until the burning sections are located and isolated.

- Material removed from the pile should be spread on the ground or placed in windrows for cooling. It may be necessary to put water on hot material in danger of igniting.

- Apply water or other chemicals to the burning material (visible flames) to extinguish the fire.

11. COMPOST QUALITY ASSURANCE

11.1 Feedstock Quality

The objective of composting is to turn valuable organic waste into a high quality product that meets or exceeds the CCME Standards of Type A compost. Obviously the type and quality of the primary feedstock and amendments, as well as proper management of the process, determine the quality of the product.

The quality of SSO waste depends mostly on how well the public separates the acceptable organic components from other waste components. Aside from the waste collectors, it is the responsibility of the facility operators to identify and report persistent contaminants to the Solid Waste Management Department. The operators are also required to remove large contaminants from SSO before composting.

The bulking agent or amendment must be inspected prior to purchase to ensure that the material is acceptable for composting and free of contaminants, such as pressure treated and painted lumber or construction debris. Delivery slips must be used for each load and the site operator must sign off on delivery. Contaminated loads are either not accepted or reloaded for disposal at the area landfill site.

Primary feedstock, overs and new amendment must be tested twice a year to determine acceptance in terms of heavy metals and nutrients.

11.2 Process Control

Substrate preparation, active composting, curing and storing must be managed as described earlier in this manual to ensure that the material is processed properly. Temperature, oxygen and moisture content of each windrow will be recorded and filed, as well as, turning events, process upsets, and odour complaints. Temperature data are used to confirm that pathogen reduction criteria were met for each windrow.

Once moved to the curing pad, compost is allowed to cure until it is mature which make take three (3) months or longer. The process must be monitored and managed to ensure that aerobic microbial activity is present.

11.3 Screening

Mature compost from the curing pad is screened to meet user demand and stored as a Lot in a windrow or windrows or plies sufficient in size to hold six months of inbound feedstock.

11.4 Quality Analysis

Each Lot is sampled using the sampling methodology described in the *CCME Guidelines for Compost Quality* and sent to an accredited laboratory. The Lot number is used for sample identification.

Only compost that meets all of the standards is sold. Compost that fails anyone of the standards will be processed again, allowed a longer curing period, used as Type A or B compost, or sent to the landfill depending on the reasons for failing to meet the CCME Guidelines.

11.5 Compost Quality Alliance

The Compost Quality Alliance (CQA) is a voluntary program established by the Compost Council of Canada and the compost producers utilizing standardized testing methodologies and uniform operating protocols to improve customer confidence in compost selection and utilization. Compost facilities that are members of the CQA must submit compost samples to a CQA-laboratory for analysis. Participating CQA-laboratories across Canada and the United States are involved in the CAP (Compost Analysis Proficiency) program, a laboratory quality assurance program to calibrate procedures and evaluate inter-lab method performance. Product testing involves the CCME Guidelines for Compost Quality regulatory requirements as well as agronomic parameters and usage guidelines. Compost facilities will have an annual licensing agreement to use the CQA logo on packaging and product promotion.

APPENDIX A

NOTES ON THE SCIENCE OF COMPOSTING

A1. Basic Process

Composting is a *self-heating, thermophilic, aerobic, biological process in which complex organic compounds are partially oxidized while releasing heat, water vapour, carbon dioxide, ammonia, and trace quantities of other gases. The non-mineralized component is humified to form a stable end product.*

This description contains all of the components that are crucial to understanding the process and, hence, to managing the process effectively and efficiently with a minimum of complications, such as the emission of odours.

A1.1 Microbiological Aspects of Composting

First and foremost, composting is a biological process in that the active agents are microorganisms (bacteria, actinomycetes, and fungi). As a wide spectrum of microorganisms is indigenous to the waste, the main objective in successful composting becomes the provision of conditions conducive to microbial activity and rapid growth. The conditions include proper nutrition balance and optimum physical and chemical environments.

The organic waste fraction of MSW contains a large number of simple and complex chemical compounds, such as lipids, carbohydrates, proteins, amino acids, lignin, cellulose, and ash. One of the interesting aspects of the decomposition of this mixture is that different groups of nutritional and metabolic interacting microorganisms are required. Thus, the metabolic end products of one group of organisms become the nutrients of another group so that different microorganisms are required to decompose complex waste into a stable product.

The exact chemical and biochemical reactions resulting in the breakdown of organic wastes are complex, and the details are not fully known. In a general sense, the breakdown of proteins and carbohydrates includes the following pathways:

proteins + peptides + amino acids + ammonium compounds = bacterial protoplasm + nitrogen or ammonia

carbohydrates + simple sugars + organic acids = bacterial protoplasm + CO_2

The ability of a microbe to assimilate a nutrient source depends upon its capacity to synthesize the enzymes required to break down complex compounds into intermediate metabolites or into elements. Very complex compounds require an extensive enzyme system that may be supplied collectively by several groups of organisms. However, some complex compounds have molecular structures that can only be assimilated by a few groups of microorganisms, thus limiting the rate of decomposition of the waste. For example, materials consisting mainly of aromatic hydrocarbons, lignin, or cellulose are structurally more complex than highly proteinaceous materials, such as vegetables, meat scraps, etc., and therefore break down more slowly. As a result, the overall rate of composting is controlled to a significant extent by the nature and structure of the waste.

From an elemental chemical perspective, living organisms require large amounts of hydrogen, oxygen, carbon and nitrogen. Both hydrogen and oxygen represent a large percentage of cellular mass as water and as part of the cellular material. About 50% of the cellular mass consists of carbon and some 2 to 8% is nitrogen so that these two elements are known as macronutrients. Carbon is also the major energy source for microorganisms and must be available to the microbes in large quantities; however, not all of the carbon contained in a waste is immediately available because some of it is bound in compounds that are resistant to biological attack. An example is the carbon in cellulose of newspaper where individual cellulose fibres are partially sheathed in lignin.

Nitrogen is also an essential macronutrient for growth and production of microbial cells. The amount of nitrogen needed per unit of carbon varies with the type and concentration of organism. Moulds, which are most active in the very early and last stages of composting, require approximately one part of nitrogen to thirty parts of carbon.

In addition, phosphorous, sulphur, calcium and potassium are also required, albeit in much smaller quantities. Finally, several elements, mainly metals (cobalt, magnesium, manganese, iron, copper, molybdenum, zinc, etc.) are needed in trace amounts and are called micronutrients.

A1.2 Moisture Content

Microbial activity takes place only in a liquid film on the exterior and pore surfaces of waste particles. Moisture provides the means of transporting soluble nutrients and effecting the biochemical reactions of the process. A moisture content of 50 to 65% will produce an appropriate environment for high-rate composting. Lower moisture content results generally in cessation of microbial activity, while excess moisture may increase compaction and reduce the porosity of the waste to the point of excluding air.

A1.3 Self-Heating

In a typical commercial composting process, there are three distinct phases: high-rate decomposition, low-rate decomposition and maturing. As shown in Figure 1, the temperature of the substrate rises rapidly during the first composting phase. Energy produced by biological oxidation of part of the carbon content is partially used in metabolism but most of the energy is given off as heat. Since biomass is a poor conductor of heat, the temperature of the biomass continues to increase until it reaches levels at which certain microorganisms are killed or become inactive by forming spores. There are two temperature threshold levels of interest; the first one occurs around 45^0C, causing destruction of mesophilic organisms and the proliferation of thermophilic ones. The upper threshold level is about 70^0C where growth becomes severely inhibited. Only a few species of thermophilic bacteria show metabolic activity above 70^0C.

The second phase starts when most of the soluble substrates have been used. As the microbial activity decreases, the rate of heat generation is also reduced. As the substrates cools, the various microbial species repopulate the biomass at the appropriate temperatures. During this period, the more difficult to decompose materials, such as lignin and cellulose, are consumed.

The curing (maturing)[14] phase can be started when the substrate temperature approaches ambient values and no longer increases after turning with the moisture content in the correct range.

It should be noted that the two active phases can take days or weeks but the curing phase takes several months depending on the type of substrate and the process management.

[14] Curing and maturing are often used for the same process but curing is the better phrase.

A1.4 Aerobic Process

Composting is an aerobic process because the microorganisms require oxygen to live and grow. Therefore, there must be sufficient oxygen in the biofilm to ensure the wellbeing of the microbes. Failure to provide sufficient oxygen results in a decrease in the number or in the activity of the aerobes and a proliferation of anaerobes. Anaerobic processes produce intermediate compounds with strong odours that are the main reason for the failure of composting operations.

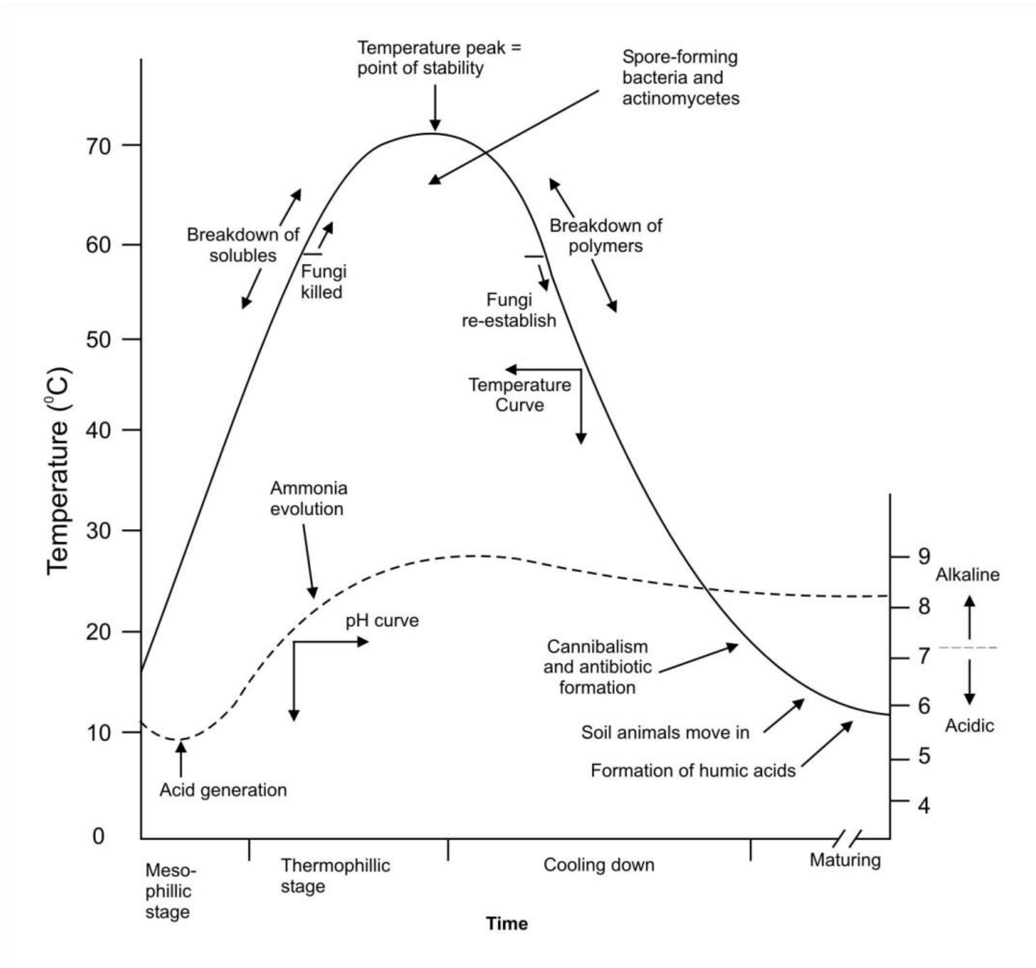

Figure A1. Temperature-time model of the composting process.

A2 Process Parameters

Given the basic nature of composting, there are several process parameters that are used to develop, manage and monitor the commercial composting process; namely,

- Carbon to nitrogen (C/N) ratio
- Oxygen concentration
- FAS (Free Airspace), particle size, surface area, and structure
- Moisture content
- Temperature
- pH level

A2.1 Carbon/Nitrogen Ratio – Range of 25:1 to 35:1

As mentioned, microorganisms require carbon and nitrogen as macronutrients. Therefore, the carbon-to-nitrogen ratio (C/N) of organic waste is an important indicator of its compostability and the practicality of composting as a means of treating the waste. It is generally agreed that a C/N ratio of between 25:1 and 35:1 is the optimum range for high-rate, aerobic decomposition. At a ratio less than 25:1, nitrogen is lost to the atmosphere in the form of ammonia; especially at high temperatures and pH. Under those conditions, there is not enough carbon to provide the energy to convert all available nitrogen into protoplasm. On the other hand, excessively high C/N ratios cause a decline in the reproduction and growth of the microorganisms in proportion to the decrease of nitrogen in the substrate. This reduces the overall composting rate.

A2.2 Oxygen Content – Range of 10 to 21%

At the start of the microbial activity, the oxygen concentration in the voids of the biomass varies from 15 to 21% (by volume) and the carbon dioxide concentration is between 0.5 and 5%. As the process continues, oxygen is used and carbon dioxide liberated. If the oxygen concentration decreases below 10%, anaerobic microorganisms begin to proliferate at the expense of the aerobic microbial population. The result is the production of undesirable anaerobic respiration and fermentation products.

There is a difference of opinion as to what the lowest allowable oxygen content in the voids can be before there is a significant risk of anaerobic conditions but, for all practical purposes, when the oxygen concentration falls below 10%, the risk becomes too high[15]. Moreover, at high activity rates, oxygen in

[15] An oxygen content of 5% in the airspace is the minimum value for aerobic conditions in the biofilm.

the biofilm can be consumed as fast as it is transferred from the air in the voids. It is therefore recommended that the oxygen concentration should not fall below 10% anywhere in substrate and that the target should be 16%. Maintaining the required oxygen content throughout the substrate depends largely on the preparation and management of the substrate and the aeration method.

In order to maintain optimum oxygen concentrations, air is blown or sucked through the substrate. There is no general agreement on which method is best but suction allows treatment of the exhaust from windrows with a biofilter. On the other hand, suction results in an increased pressure drop because of greater settling of fines and hence, requires larger blowers.

A2.3 Porosity and Free Airspace (FAS).

Two terms are used in the composting literature to denote the relative amount of space in a bulk material that is not occupied by the solids. The first one is *porosity* and it is defined as the ratio of void volume to the total volume of the material. The second one is known as *free airspace* (FAS) and it takes into account that some of the void space is occupied by water. Free airspace is therefore defined as the ratio of gas volume to total volume. Thus,

porosity = free airspace + fractional volume of water[16]

Since the amount and continuity of airspace in bulk material influences the resistance to airflow, FAS is the more important term in composting. A uniform porosity and moisture distribution are needed to ensure an optimum supply of oxygen throughout the substrate at all times. Unfortunately this requirement is difficult to obtain and to maintain in a composting system so that the local airflow in the substrate often varies considerable during the process.

As a rule-of-thumb, the porosity of the composting mix should range between about 45 to 60% with a target of 50%, while the FAS target is about 30% for optimum moisture content.

The values of both terms depend on the physical properties of the particles, such as size, size distribution, shape, and texture and also on forces applied to the bulk material, such as in compaction.

[16] Unfortunately the term porosity is sometimes used when the correct term is free airspace.

Compaction of moist substrate (moisture content of 60% or higher) by its own weight in windrows exceeding 2.5 m may result in a sufficient decrease in free air space and, hence, an increase in the resistance to airflow. At lower moisture contents, the compaction is much less so that higher windrows can be used later in the composting process and in curing.

A2.4 Particle Size, Texture, and Structure

Particle size plays an important role in determining the rate of decomposition because smaller particles have a greater specific surface area[17] than larger ones, allowing more space for the microorganisms to live and grow.

Sometimes it is said that smaller particles reduce the porosity; however, that is not necessarily correct. Instead, the range of particle sizes (particle size distribution) has a much greater effect on the effective porosity because smaller particles tend to fill the voids between larger ones. During the decomposition process, the particle size is reduced and the range of particle size is increased as different materials decompose at different rates.

Not surprisingly it is possible to find different recommendations of initial particle size in the composting literature. Some authors recommend 3 to 50 mm, others 25 to 75 mm or 50 to 75 mm. In part, this apparent confusion is due to the types and mixes of substrate to be composted. For example, digested sewage sludge has a small particle size but the bulking agent would have the larger particle sizes. The size recommendation also depends on the composting technology, including the method of supplying air and mixing process. For example, in-vessel systems with forced aeration can handle smaller particles than windrow processes with passive aeration.

Another parameter that influences the available surface area is texture. Smooth surfaces have less available area than rough ones or those that have a large number of internal pores. For this reason wood that has been shredded has a greater available surface area than chipped wood.

Structure determines the resistance of particles to deformation caused by compaction or settling. A compost mixture requires good structure to ensure sufficient free airspace for air movement throughout the entire process.

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[17] specific surface area = area per unit mass of material (m^2/kg of material)

A2.5 Temperature

Monitoring of the substrate temperature is essential as it is a reliable indicator of microbial activity and the predominant type of microorganisms (mesophilic or thermophilic). Although composting can be done at mesophilic temperatures, commercial composting is normally done at thermophilic temperatures. For high-rate composting, the upper threshold temperature is often taken to be 70^0C and the best overall performance is obtained when the process temperature is controlled between 50 and 60^0C [18]. However, regulatory requirements require that the process must exceed 55^0C for a specified time to destroy thermosensitive human and plant pathogens.

To prevent the temperature from exceeding the thermal death point of thermophilic microorganisms, the amount of heat loss from the substrate must be greater than or equal to the amount of heat generated by microbial respiration. Forced aeration is the most effective temperature control because it increases the amount of evaporative cooling. Since evaporative cooling removes large amounts of water needed by the microorganism, it is also necessary to monitor the moisture content to ensure that it does not fall below 40%.

A second method to reduce the temperature of windrows is to turn the substrate with a frontend loader or windrow turner. Although turning enhances heat loss, including evaporative heat loss, its effect is relative short lived, especially at high ambient temperatures.

A third approach is to use smaller windrows so that the ratio of surface area-to-volume is increased. As the smaller volume results in a reduced amount of decomposing substrate and, hence heat generation, the relatively larger surface area allows greater cooling. Of course smaller windrows reduce the capacity of the site.

Monitoring temperatures of curing compost is also important because not only does it provide information on the curing progress but it also provides an indication of the potential of spontaneous combustion. A

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[18] Bacteria of the genus *Thermus* grow in numbers as high as 10^8 to 10^{10} per gram of dry compost at temperatures from 50-80ºC, with optimum growth between 65 and 75ºC.

rapid rise in temperature to 80^{0}C or higher coupled with low moisture content is indicative of moving from biological oxidation[19] to chemical oxidation (burning) and possibly combustion.

As mentioned above, aside from a short sanitation period, the high-rate decomposition process requires a process temperature of 50 to 60^{0}C. Airflow in excess of the basic biological demand may be used to maintain the desired temperature. A temperature feedback control system, in which the biomass temperature is monitored and compared with the set point, is normally used to operate the air moving equipment for cooling. Since it takes approximately nine times more air to remove excess heat than to supply oxygen for microbial activity, one of the problems with aeration cooling is the excessive removal of moisture from the biomass. Therefore, moisture content monitoring is one of the process requirements and normally water must be added at some point in the process to maintain optimum conditions. The best time to add moisture is during mixing or turning so that the moisture will be uniformly distributed.

A2.6 pH

pH is a measure of acidity or alkalinity of a material. All microorganisms have species that can tolerate a low or high pH; however, most of the composting process occurs in the range of 5.5 to 8.0. In general, fungi are more tolerant of acidic conditions than bacteria and actinomycetes, which prefer a pH of 6.0 to 7.5

In a naturally ventilated system where oxygen concentrations tend to be low, the pH may show a decrease in value during the early period of composting. This is due to the formation of organic acids at a rate greater than their decomposition. As proteins are decomposed with the production of ammonia, the pH increases. In forced aeration, the initial decrease in pH is usually not seen.

Unless the substrate is predominantly anaerobic so that organic acids accumulate, it is rarely necessary to adjust the pH in composting most substrates. If the substrate pH drops below 6.0, it is advisable to aerate or mix the substrate in order to increase the pH to less acidic levels.

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[19] The absolute maximum temperature achievable in composts due to biological activity is said to be 82°C, at which point biological activity and metabolic heat evolution cease.

APPENDIX B

ACCEPTABLE PRIMARY FEEDSTOCK AND UNACCEPTABLE WASTE

The primary feedstock to be processed is an *organic* waste material discarded by homeowners, food producers/manufacturers/retailers, landscapers, and others. Normally the primary material does not have the physical and chemical characteristics required for composting. In particular, it does not have the carbon-to-nitrogen ratio and moisture content to supply the conditions for rapid microbial decomposition.

Therefore in order to provide the conditions summarized below other materials, called amendments or bulking agents[20], must be blended with the waste. For example, grass, which is generally high in nitrogen, can be co-composted with high carbon content waste. On the other hand, crop residues, wood shavings, wood chips, sawdust, or tree barks are excellent sources of carbon for blending with high nitrogen waste, such as SSO.

PARAMETER	RANGE	TARGET
C/N ratio	25/1 - 35/1	30/1
Moisture content (%)	45 - 60	55

B3.1 Characteristics

Since the chemical characteristics of the feedstock determines the nutrient balance and the quality of the compost, it is essential to have an analysis done of the primary waste and amendments. Furthermore, most regulatory requirements state that each of the material streams in a mix must meet the heavy metal and other contaminant restrictions.

B3.2 Primary feedstock

The following table shows the various sectors that produce wastes suitable as primary feedstock. The type of feedstock that can be processed with an acceptable risk of odour emission depends on whether natural

[20] Strictly speaking, amendments change the C/N ratio and moisture of the waste while bulking agents provide structure for free airspace in the mix. For the purpose of the manual, the term amendment is used for both types of material because bulking agents used with SSO need to supply carbon.

or forced ventilation is used. In general, only leaves, branches, brush, grass clippings, wood waste, vegetables and fruit are suitable feedstock for *naturally ventilated* windrows and piles.

SECTOR	WASTE
Municipal	Source-separated organics Sewage sludge
Industrial, Commercial, and Institutional	Source-separated organics Fruit & vegetables waste Spoiled grains & pulses Fats & oils Processing sludge Slaughterhouse waste Fish plant waste Off-spec products
Forestry	Woodchips, sawdust, bark Paper mill sludge
Agriculture	Manures Crop residues Spoiled hay, silage, grain

Feedstock acceptable for *forced ventilated* windrows with *active management* are listed in the following table. The list includes the components normally found in municipal and ICI source-separated organics (SSO). Processing of SSO or other types of food waste in naturally ventilated windrows invariably leads to serious odour problems.

Since the main driving force for composting is the recovery of organic waste, the broadest range of items should be included in the SSO programs without endangering the quality of the final product and in accordance with the market demand. In some municipalities, there has been opposition to the inclusion of disposable diapers, sanitary napkins and pet feces because it is assumed that these will increase the pathogen content or cause operational problems. Research has shown that neither assumption is valid provided that, in the case of disposable diapers, the feedstock preparation stage involves equipment capable of opening the diapers.

ORGANIC WASTE ACCEPTABLE FOR FORCED AERATED WINDROWS		
FOOD WASTE	PAPER PRODUCTS	OTHER
Baked goods Bones Cereals Coffee grounds & filters Dairy products Flour and grains Food processing waste Fruit Grease and fat Meat and fish Nuts Pasta and rice Sauces Tea bags and loose tea Vegetables	Baby wipes Cotton balls Disposable diapers Facial tissues Greasy pizza boxes Microwave popcorn bags Paper towels, napkins and plates Sanitary napkins Shredded paper (loose) Soiled newspapers, magazines, cardboard	Ashes Cigarette butts Digested Biosolids Dryer lint Floor sweepings Hair House plants & flowers Pet feces Pet fur Sawdust Vacuum cleanings Wood chips/shavings

B3.3 Unacceptable feedstock

In general, materials that may be hazardous to the operators, damage equipment or cause production of compost that will not meet the CCME Standards are unacceptable. Examples of feedstock that are not acceptable include:

- materials that contain contaminants or foreign mater in sufficient concentration that the compost will not meet the CCME Quality Standards

- materials that contain metal concentrations that exceed the allowable feedstock concentrations of the Standards

- predominantly inorganic materials such as construction debris

- hazardous or liquid industrial waste, including biomedical, PCB and radioactive waste

B3.4 Feedstock storage

Primary feedstock with high moisture content cannot be stored without becoming anaerobic. Therefore, best operating practice requires those materials to be processed within 24 hours or by the next business day in case of long weekends.

Leaf & yard waste and forestry waste can be stored in piles but are susceptible to the development of spontaneous combustion. This is particularly true if the yard waste includes grass clippings or the waste is wet.

APPENDIX C

SUITABLE BULKING AGENTS/AMENDMENTS

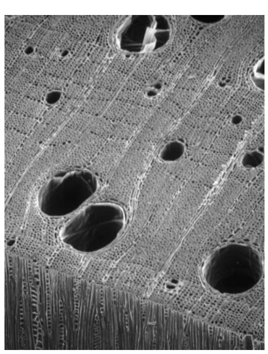
Bulking agents are an essential component of the compost substrate when primary feedstock has little or no structure and is wet. Thus, bulking agents are thoroughly blended with the wet feedstock

- to provide structural support throughout the process;
- to increase the size of pore spaces;
- to provide free airspace between particles;
- to allow uniform and easier airflow through the mixture; and
- to provide carbon

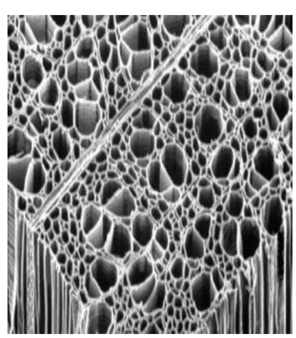
Clearly, the particles of the bulking agent must not be embedded in the wet substrate because they will not provide a self-supporting matrix. In this instance, there is too little bulking agent and there is no increase in fee airspace. On the other hand, too much bulking agent does not improve the free airspace but does increase the handling costs (blending and screening), increase the storage requirement, increase consumption and purchase costs.

If the bulking agent itself is porous and those pores are not saturated, the bulking agent will absorb water from the wet substrate like a sponge. In this instance, a smaller amount of bulking agent will provide sufficient free air space. The difference can be significant so that, in the case of dry woodchips, the absorbed moisture may be similar in volume as the volume of the voids, leaving sufficient FAS for airflow.

The difference in the absorption capacity of softwood and hardwood is also important. As shown in the following scanning electron micrographs, the structure of basswood (softwood) is much more open than



basswood



hickory

hickory (hardwood) and, hence, absorbs more moisture per unit volume of wood.

The following table contains examples of suitable bulking agents that are also a good source of carbon. The values are either typical values or range of values reported in the literature and are suitable for planning; however, before acquiring bulking agents, a sample should be tested for nutrients and metal contents.

MATERIAL	NITROGEN (% dry matter)	C/N RATIO	MOISTURE (% wet basis)	BULK DENSITY (kg/m^3)
Leaf & Yard Waste	1.22	40	40	410
Sawdust	0.06 - 0.80	200 – 750	20 – 65	200 – 25
Woodchips				
Hardwood	0.06 - 0.11	450 – 820		260 – 360
Softwood	0.04 - 0.23	210 – 1310		260 – 360
Lumber Mill Waste	0.13	170		
Cardboard	0.10	560	8	150
Newsprint	0.06 - 0.14	600	3 - 8	115 – 145
Straw	0.3 - 1.1	48 – 150	4 – 7	35 – 220

One of the best bulking agents or amendments is the overs of the final screening process. This stream contains the old, partially decomposed bulking agent covered with large populations of microorganisms for seeding the new waste. In general, woody materials lose about 20% of their mass during a process cycle, leaving the rest for subsequent cycles until the particles become part of the compost.

APPENDIX D

RECIPE CALCULATIONS

To develop a substrate recipe that consists of a primary feedstock and one or more amendments involves getting both the C/N ratio and moisture content in the recommended ranges.

The moisture content of a mixture of materials is calculated by determining the weighted average of the moisture contents of the components. Thus,

$$MC_m = \frac{(m_1 \, x \, MC_1) + (m_2 \, x \, MC_2) + (m_3 \, x \, MC_3) + \cdots}{m_1 + m_2 + m_3 + \cdots} \quad [1]$$

Similarly for the C/N ratio of the mix,

$$\frac{C}{N_m} = \frac{[C_1 \, x \, m_1 \, x \, (1 - MC_1)] + [C_2 \, x \, m_2 \, x \, (1 - MC_2)] + [C_3 \, x \, m_3 \, x \, (1 - MC_3)] + \cdots}{[N_1 \, x \, m_1 \, x \, (1 - MC_1)] + [N_2 \, x \, m_2 \, x \, (1 - MC_2)] + [N_3 \, x \, m_3 \, x \, (1 - MC_3)] + \cdots} \quad [2]$$

Where

$m_1, m_2, m_3, \ldots$ = total mass of components 1, 2, 3, …. (kg)

$MC_1, MC_2, MC_3, \ldots$ = moisture content of components 1, 2, 3, …. (fraction)

$C_1, C_2, C_3, \ldots$ = carbon in components 1, 2, 3, …. (% dry mass basis)

$N_1, N_2, N_3, \ldots$ = nitrogen components 1, 2, 3, …. (% dry mass basis)

If only SSO (component 2) and one amendment (component 1) are mixed to obtain the desired C/N ratio and moisture content, it is possible to treat the SSO stream as a single component for which the chemical analysis was done. In this case *the amount of amendment required per unit kilogram of SSO* to get the target C/N ratio is determined from equation [2] to be

$$m_1 = \frac{N_2}{N_1} \times \frac{\left(\frac{C}{N_m} - \frac{C}{N_2}\right)}{\left(\frac{C}{N_1} - \frac{C}{N_m}\right)} \times \frac{(1 - MC_2)}{(1 - MC_1)} \quad [3]$$

The next step is to check the corresponding moisture content using equation [1]. If the moisture content is between 50 and 60%, the calculated amount of amendment is correct. If the moisture content is below 50%, water must added and mixed with the substrate.

On the other hand, if the moisture content exceeds 65%, additional amendment must be added. In this case, the final C/N ratio may well be outside the recommended range; however, due to the risk of developing anaerobic conditions in the wet substrate, the moisture content criterion trumps the C/N ratio one. The alternatives are to use a drier form of the amendment, use a different amendment or add a third component that is dry (e.g. sawdust or straw).

APPENDIX E

REPORTING FORMS

E1. Record of Operational Parameters

The following table is an example of a record sheet used to record temperatures, oxygen readings, etc. and is readily put into spreadsheet form. There are several software packages on the market that can be bought with the probes and control systems that allow manual and automatic recording of probes readings. It is necessary to record moisture content, turning times, and water additions as well.

WINDROW IDENTIFICATION: 150 - 2012 – 09/12										**CURING PAD IDENTIFICATION:**							
DATE	DAY	TEMPERATURE (°C)					OXYGEN (% vol)				MC (%)				TURNING		COMMENT
		ambient	T_1	T_2	T_3	T_{ave}	O_1	O_2	O_3	O_{ave}	MC_1	MC_2	MC_3	MC_{ave}	Y/N	water	
	1																
	2																
	3																
	4																
	5																
	6																
	7																
	…..																

E2. Site Activity Log

The Daily Site Activity log sheet is used to keep track of activities, equipment hours, staff hours, etc.

DAILY SITE ACTIVITY LOG						
Week Starting:						
Days	Staff	Contracted Staff	Activities	Time in	Time out	Hours
Monday						
Tuesday						
Wednesday						
Thursday						
Friday						
Saturday						
Sunday						

E.3 Site Maintenance

Operational staff performing weekly site and infrastructure maintenance use the following or similar sheet.

SITE MAINTENANCE					**Week Starting:**			
Road and Site					Pad and Process			
Items	Remarks & Action	Completed	By		Items	Remarks & Action	Completed	By
Roads					Aeration System			
Perimeter Fence					Fans			
Gate					Sweeping Compost Pad			
Site Drainage					Sweeping Curing Pad			
Lagoon Level					Sweeping Roads			
Scales					Temperature Sensors			
Loader								
Receiving Building								
Shredder/Mixer								
Garbage Pickup								
Office								

Comments for current week		Comments for current week	
Priorities for next week		Priorities for next week	

E4. Nuisance Complaint Form

Contact Information			
Date (YYYY/MM/DD)	First Name	Last Name	
Address			
City		Postal Code	
Country		Phone	

Complaint			
Date of Nuisance (YYYY/MM/DD)	Address		
City			Postal Code
Weather Conditions at Nuisance Location			
Temperature		Precipitation	
Wind Direction		Other	
Describe Facility Activities at Time the Nuisance Occurred			
Describe Nuisance			
Describe Action Taken			

E5. Material Flow Reports

The following tracking spreadsheet can be modified and used to track Inbound Waste Tonnage and Amendment/Bulking Agent Tonnage.

Daily Log of Operations
Finished Compost Distribution Database

Date	Truck Number	Time of Departure	Amount of Compost (tonnes)	Name of Receiver	CQA Batch No.	Market	Size	Revenue	Daily Totals

APPENDIX F
COMPOST TOOL KIT

The composting facility should have some basic in-house equipment to obtain compost samples, to determine moisture content and maturity, and to monitor manually the temperature of the curing and storage windrows.

1. *Sampling Equipment* – the sampling procedure described in Appendix G requires the following equipment:

   shovel (stainless steel) for sampling
   25 L plastic or stainless steel pail
   plastic sheet or tarp (2 m x 3 m)
   garden trowel (stainless steel) for quartering
   soft broom
   large ziplock bags and marker
   plastic gloves

2. Moisture Content Determination

   Equipment –

   Laboratory scale (500 gram minimum capacity; accuracy ± 0.01 or better)
   Aluminum plates (4" dia for compost samples and 12" dia for feedstock mix)
   Forced convection laboratory oven (large enough to hold at least three large plates)

   Moisture Content Test – several standard moisture content tests[21] have been developed but all of them require drying a known amount of sample at a given temperature (e.g., 70±5ºC) for 18 to 24 hrs in preheated, convection drying oven until no further mass loss is observed. The difference in mass between the wet sample and dry sample is the amount of water removed.

   The moisture content is then calculated using

   moisture content (wet basis) = mass of water removed/mass of wet sample.

[21] TMECC 03.09-A *Total Solids and Moisture*. Test Methods for the Examination of Composting and Compost - USDA. Ed. Wayne H. Thompson. 2001.

3. Maturity Test

A commercial maturity test used by a number of operators to determine the degree of maturity of compost and to monitor progress of the process is the Solvita™ test. The Solvita™ Index was developed by Woods End Laboratories, Inc.[22] to measure production of carbon dioxide and volatile ammonia of active compost. It uses two different gas-trapping gels that react rapidly with carbon dioxide or ammonia, resulting in a colour changes in proportions to the gas concentration.

The corresponding sample maturity is obtained by comparing the colour changes with a colour chart provided with the test kits. Instead of using a visual comparison, Woods End Laboratories Inc. sells a Solvita™ Digital Color Reader that gives a more reliable colour analysis.

4. Temperature Monitoring

Temperature monitoring can be as simple as inserting a long stem thermometer (see illustration) at various locations in the windrow and reading the temperature from the dial. A record must be kept showing the windrow identification, measuring location, date/time and reading.

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[22] Mt. Vernon ME 04352; www.solvita.com

APPENDIX G.
ON-SITE SAMPLING

The following sampling procedure was developed to obtain representative composite samples of large piles and windrows of compost. It has been used extensively in research projects and proven to give reliable results.

The procedure is based on collecting ten incremental samples from a batch of compost to form a composite sample from which a 2 L subsample is produced for analysis. To ensure that the incremental samples are taken at random locations of the compost pile or windrow, the procedure uses a random number generator. For convenience, it is acceptable to ask someone to give you a number between 0 and 100 and then divide the number by 100 to get the required random multiplier.

STEP 1 Collecting increments

Horizontal co-ordinates

Establish an arbitrary reference point at the edge of the windrow.
Measure the perimeter of the windrow.
Divide the perimeter by ten to determine equal sampling intervals.
Generate a two digit random multiplier <1; e.g. 0.74
Multiply the interval length by the random number to establish the first sampling location.

Vertical co-ordinates

Measure the length of the face of the windrow.
Divide the length of the windrow face by four to determine sampling heights 1/4, 1/2 and 3/4 up the windrow face from the edge.

Depth of sample

Collect an incremental sample from 25 cm to 50 cm below the surface using the shovel. (There is no evidence to suggest that going deeper produces better results).
Care must be taken that the surface of the pile above the sample location does not slide down and become part of the sample!

Increment volume

Increment volumes should be as large as possible and still be thoroughly mixed. About 3 to 4 L is a manageable volume for the 'cone and quarter' method described below.
Map out sampling locations in terms of perimeter and height on the windrow face.
Start at random perimeter and alternate between heights.
Put the increments in the pail.

STEP 2. Mix and subsample

Empty the pail of compost onto the clean tarp.
Mix the compost by lifting a corner of the tarp and rolling the compost to the opposite corner.
Roll the compost back to the centre of the tarp.
Roll the compost at right angles to the first direction and then back to the centre.
Repeat for a total of five rolls in each direction.
Lift all four corners, forming a cone of compost in the centre of the tarp.
Flatten the top of the cone so that it is approximately three times as wide as it is tall.
Bisect the flattened cone into four equal quadrants.
Randomly select one of the quadrants and use a clean broom to remove it from the tarp, taking care to remove the fines.
Repeat the coning and quartering until the composite has been reduced to about 2 L.
Remove oversize particles using a 4.3 mm screen.
Put the sample in the appropriate clean, dry and labeled containers, including the fines. Place the containers in a box for shipping.
Samples for microbial analysis must be put in a polystyrene container with ice packs to maintain a temperature of 0 – 5^{o}C. The microbial samples must be in the laboratory for testing within 24 hours.

STEP 3. Clean equipment

Wash all equipment with a bleach solution and rinse thoroughly after each sample collection to prevent contamination of subsequent samples.
Store equipment in a dry place where it will not come in contact with feedstock of compost.

APPENDIX H

GLOSSARY OF TERMS/DEFINITIONS

Active Composting Area	The area where windrows or piles of feedstock are placed for active composting.
Aerated Static Pile (ASP)	A method of composting that involves mechanically moving air through the compost pile, either through suction or blowing air through the pile. Little or no agitation or turning is performed.
Aeration	The process by which the oxygen-deficient air in compost is replaced by atmospheric air. Turning compost, passive airflow, or forced airflow using blowers can enhance aeration.
Aerobic Conditions	An environment that is conducive to the microbial degradation of organic solid waste in the presence of oxygen.
Amendment	A supplemental material mixed with compostable feedstock in preparation for composting to create a favourable condition for composting, either by adjusting the moisture content or the carbon to nitrogen ratio.
Anaerobic Conditions	An environment in which microbial degradation of organic solid waste occurs in the absence of oxygen.
Anaerobic Digestion (AD)	A controlled and managed biological process that uses microorganisms to break down organic material in the absence of oxygen.
Aspergillus fumigatus	Bioaerosol released during composting but is also ubiquitous in nature and indoors (especially with pets). Opportunistic pathogen.
Bioaerosols	Particles of microbial, plant or animal origin and is also known organic dust.
Biodegradation	Process by which organic materials are degraded by microorganisms.
Biofilter	A bed of material that uses aerobic microorganisms to remove of a wide spectrum of odorous compounds from composting gases.
Biological Oxygen Demand	Amount of oxygen required by microorganisms to decompose biomass.
Biomass	Organic material that can be decomposed biologically.
Buffer Zone	The area between the active composting area and the property boundary.

Bulking Agent	An ingredient in a mixture of composting raw materials included to improve the structure and porosity of the mix. Bulking agents are usually rigid and dry, and often have large particles (e.g., straw or woodchips).
Carbon-to-Nitrogen Ratio	The ratio of the quantity of carbon (C) in a material (on a dry weight basis) to the amount of nitrogen (N) in the material (on a dry weight basis).
Co-composting	Composting two or more distinctly different materials together, generally as a strategy for achieving a better balance of carbon and nitrogen or a more favourable moisture content. Usually refers to the composting of solid wastes, which are relatively dry and carbon-rich, with wet sewage sludge, which is rich in nitrogen.
Compost	A stable, humus-like material that results from the biological decomposition and stabilization of organic materials under aerobic and thermophilic conditions. Compost is potentially beneficial to plant growth, and is sanitized to a degree that protects human and plant health.
Composting	A managed, biological process through which organic matter is degraded under aerobic conditions to a relatively stable, humus-like material called compost.
Contaminant	An element, compound, substance, or organism which, through its presence or concentration, causes an adverse effect on the nature of an environment or impairs human use of the environment.
Contamination	Any introduction into the environment (water, air, or soil) of microorganisms, chemicals, wastes, or wastewater in a concentration that makes the environment unfit for its intended use.
Curing	Final stage of composting in which stabilization of the compost continues, but the rate of decomposition has slowed to a point where turning or forced aeration is no longer necessary. Curing generally occurs at lower, mesophilic temperatures. This term is used synonymously with maturing.
Curing Area	The area where composting materials are placed to stabilize to reach maturity.
Empty Bed Residence Time	Time for air to travel through the bed. Usually calculated by dividing the volumetric flow rate by the volume of the bed without media.
Feedstock	All materials that are accepted at the composting facility and used in the composting process, including amendments and bulking agents.
Feedstock Preparation Area	The area where feedstock is temporarily placed for processing prior to active composting.

Food Waste	Discarded animal and vegetable matter from food and food preparation sources, including residences and commercial establishments, such as grocery stores, restaurants, produce stands, institutional cafeterias and kitchens, and industrial sources, like employee lunchrooms.
Forced Aeration	The practice of using fans to move air through the composting material.
Foreign Matter	Any matter resulting from human intervention that includes organic or inorganic components, such as metal, glass, and synthetic polymers (e.g., plastic and rubber) that may be present in the compost.
Free Air Space	A measure of the space between individual particles in the compost pile that are filled with air. Free air space is fundamental to active composting and curing, as there must be enough void space in the compost pile for oxygen. It is also critical that the spaces between the particles are interconnected so that air can move through the compost pile passively, or be forced through with aeration fans.
Groundwater	All water below the surface of the ground whether in liquid or solid state.
Humus	The dark or black, carbon-rich, relatively stable residue resulting from the decomposition of organic matter.
Inoculum	Feedstock that has already gone through the composting or digestion processes, or effluent from these processes that is mixed with fresh feedstock during preprocessing steps to initiate microbial activity.
In-vessel Composting	A method of composting where the materials processed are completely enclosed.
Leachate	The liquid that results when water comes in contact with a solid and extracts material, either dissolved or suspended from the solid.
Leaf and Yard Waste	Vegetative matter resulting from gardening, horticulture, agriculture, landscaping, or land-clearing operations, including materials such as tree and shrub trimmings, plant remains, grass clippings, leaves, trees, and stumps.
Liner	A continuous layer constructed of natural or synthetic materials, beneath or on the sides of a structure or facility, which restricts the downward or lateral migration of the contents of the structure or facility.
Mature Compost	Stable compost that has little or no organic phytotoxic substances that can cause delayed seed germination when used as a soil amendment, and meets maturity compost quality requirements, as set out in the *Guidelines for Compost Quality*, published by Canadian Council of Ministers of the Environment, as amended.
Mesophilic	The temperature range most conducive to the maintenance of mesophilic microorganisms, generally accepted as between 20 and 45 degrees Celsius (°C).

Micronutrient	A nutrient that the organism cannot produce itself but is required at low concentrations for various physiological functions.
Microorganism	A living organism so small that it requires magnification to be seen.
Moisture Content	The fraction or percentage of moisture in a material.
Municipal Solid Waste	The non-hazardous solid waste discarded from residential, industrial, commercial, institutional, construction, and demolition sources.
Odour	Property of a substance that affects or stimulates the sense of smell.
Odour Emission Rate	Volumetric sampling rate times the threshold odour concentration.
Odour Panel	Group of trained odour assessors who analyze odour samples using olfactometry.
Odour Sampling	Collection of samples of gaseous emissions from a composting process or other odour sources
Odour Units	Ratio of volume of odorous sample diluted to threshold to the original volume of sample.
Olfactometry	Measurement and characterization of odours in air using human olfactory response.
Overs	Fraction of screened compost that exceeds a desired size. Consists mostly of partially decomposed amendment and can be reused as bulking agent.
Passive Aeration	Air movement through compost windrows and piles caused by natural convection.
Pathogen	An organism, including some bacteria, viruses, fungi, and parasites, that is capable of producing an infection or disease in a susceptible human, animal, or plant host.
Pathogen Reduction	A set of criteria used to define the time and temperature requirements needed to reduce pathogen levels in a material. For in-vessel and ASP (Aerated Static Pile) composting, PFRP (Process to Further Reduce Pathogens) requires that materials be maintained at operating conditions of 55°C or greater for 3 consecutive days. For windrow composting, materials must be maintained at a temperature of 55°C or greater for at least 15 consecutive days, during which time, the windrow must be turned at least five times.

pH	A measure of the concentration of hydrogen ions in a solution. pH is expressed as a negative exponent. Thus, something that has a pH of 8 has 10 times fewer hydrogen ions than something with a pH of 7. The lower the pH, the more hydrogen ions present, and the more acidic the material is. The higher the pH, the fewer hydrogen ions present, and the more basic it is. A pH of 7 is neutral.
Phytotoxic	An adjective describing a substance that has a toxic effect on plants. Immature or anaerobic compost may contain acids or alcohols that can harm seedlings or sensitive plants.
Plug-flow	Term used to describe the movement of materials through a vessel as a discrete mass.
Porosity	A measure of the pore space around individual compost particles. Calculated as the total volume of the pores in a sample divided by the total volume of the sample.
Positive Slope	A slope that encourages positive drainage of water and minimizes ponding.
Pressure Swing	Adsorption Technology used to refine biogas in preparation for high-grade uses such as vehicle fuel or injection into natural-gas distribution systems.
Processing Area	The combination of the feedstock processing and the active composting area.
Putrescible	Subject to rapidly biodegradable.
Receiving Area	The area used to receive incoming feedstock.
Receptor	Person impacted by odour emissions.
Residence Time	The amount of time materials are retained in a composting or AD system (e.g., vessel, windrow, or pile).
Retention Pond	A pond that is designed to store process water and runoff from storm events.
Retention Time	See Residence Time.
Runoff	Any rainwater or melt water that drains as surface flow from the receiving, processing, curing, and associated storage areas of a compost facility.
Screening	The process of mechanically separating particles based on size. Typically used to remove large particles or contaminants from compost to improve consistency and quality of the end product.

Sharp Foreign Matter (sharps)	Foreign matter over 3 millimetres in dimension that may cause damage or injury to humans and animals during or resulting from its intended use. Sharps may consist of, but are not limited to, the following: metallic objects, glass, or porcelain, or pieces thereof.
Source Separation	Separation of the waste materials into two or more distinct components prior to collection to limit the possible contamination of one material stream by the other.
Source-Separated Organics	The organic fraction of MSW that has been accumulated and presorted by the generator, and collected separately from household hazardous material and non-compostable material.
Stability (of Compost)	Stability refers to the lack of change or resistance to change. A stable compost continues to decompose at a very slow rate but has a low oxygen demand.
Stable Compost	Compost that has a reduced rate of respiration and heat rise but may still contain organic phytotoxins.
Stackable	A term used to describes materials that have a low moisture content (e.g., less than 60%) and can be placed in piles.
Static Pile	A method of composting that does not involve turning the composting pile or otherwise using mechanical devices to introduce oxygen into the pile.
Substrate	Organic material mix that is composted or digested.
Thermophilic	Temperature range most conducive to the maintenance of thermophilic microorganisms; generally accepted as being greater than 45°C.
Threshold Odour Concentration	Minimum concentration of an odour that results in a sensation.
Trace Element	A chemical element present in compost at a very low concentration.
Turning	The action of mixing and agitating material in a windrow, pile, or vessel. Turning increases porosity, introduces oxygen, redistributes moisture, reduces particle size, breaks up lumps and makes the material more homogeneous.
Volatile Organic Compound	A naturally occurring or synthetic chemical compound that has a high vapour pressure during ordinary conditions, causing large amounts of molecules to evaporate and enter the surrounding air, resulting in odours.
Volatile Solid	An organic compound (plant or animal origin) that is removed or reduced through biological processes, has a calorific value, and can create odours and other nuisances.
Water Content	The amount of water in a material; usually expressed as a mass percent or fraction.

Wet (Low-Solids) Digester	A type of digester used to process feedstock that are in liquid form (i.e., with a moisture content greater 80%). Water or effluents are generally added to solid feedstock to reform them into liquids prior to digestion.
Windrow	A long, relatively narrow and low pile. Windrows have a large, exposed surface area that encourages passive aeration and drying.
Working Surface	An outdoor surface on which processing activities (e.g., grinding, mixing, composting, and screening) or material storage occurs. Typically designed to withstand the weight and wear of composting equipment

APPENDIX I

ACRONYMS OF FREQUENTLY USED TERMS

AD	Anaerobic digestion
CCME	Canadian Council of Ministers of the Environment
CQA	Compost Quality Alliance
EBRT	Empty bed residence time
FAS	Free air space
ICI	Industrial, Commercial, Institutional
L&YW	Leaf and yard waste
MSW	Municipal solid waste
OU	Odour unit
SSO	Source-separated organics
TOC	Threshold odour concentration
VS	Volatile solids