

**MATERIAL AND ENERGY BALANCES IN A LARGE-SCALE  
AEROBIC BIOCONVERSION CELL**

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**On the basis of several experimental studies of the aerobic bioconversion of organic wastes, the preferred values of operating parameters and of the biochemical rate constants of oxidation to CO<sub>2</sub> and H<sub>2</sub>O were identified. Energy and material balances were then constructed for a large, 3-m deep aerobic cell holding 1,440 tons of the ‘wet’ component of organic wastes (major organic constituent: [C<sub>6</sub>H<sub>10</sub>O<sub>4</sub>]<sub>n</sub>). It was found that conduction/ convection and radiation losses to the surroundings amount to a relatively small fraction of the chemical heat released by oxidation. The excess heat must be removed by means of an upward water-saturated airflow that is several-fold the stoichiometric requirement for biodegradation. This study has quantified a basic process difference between anaerobic and aerobic bioconversion of organic matter: In the former, most of the chemical energy in the converted organic matter is stored chemically in the generated methane gas. In the latter, this energy is released in the cell and must be carried out in a relatively large air/water vapor flow through the cell.**

*Key words: aerobic, anaerobic, bioreactor, cell, bioconversion, solids, organic, composting, waste, process design, heat and material balances*

**INTRODUCTION**

Dennison (1996) has estimated that the municipal solid wastes (MSW) collected in the U.S. amount to 190 million tons (209 million short tons) per year. Excluding high-density materials like metals and glass, MSW consist of food and plant wastes, paper, plastics, wood, leather and various fabrics. The unpleasant odors and liquids associated with ”garbage” are due to the decomposition, in the absence of an adequate supply of oxygen, of the

putrescible organic components of food and plant wastes. These organic materials contain 50-70% water, an essential element for bacterial action; when they are stored for days in containers, transfer stations and transport trucks they decompose emitting unpleasant gaseous and liquid emissions. In warm weather, the rates of bioconversion increase.

About 60% of the U.S. MSW, i.e. an estimated 127 million tons (140 million short tons) per year (Franklin Associates, 1995), is disposed in landfills that are effectively sealed so that bioconversion reactions catalyzed by bacterial organisms are carried out in the absence of oxygen and produce principally methane (natural gas) and carbon dioxide. In contrast, most of the bioconversion of organic matter in nature, e.g. in fields and forests, occurs in the presence of oxygen, i.e. aerobically, and the products are water and carbon dioxide.

As available sites for conventional landfilling become scarce, as is already the case for New York City, it makes sense to separate the “wet” fraction (plant and animal organic matter) from the “dry” fraction of the MSW (paper, plastics, metal, glass, etc.) at the source, i.e. at the household, and treat each fraction separately. This is already done in at least two Canadian communities, Halifax, Nova Scotia, and Guelph, Ontario. A current study by Columbia University of integrated waste management in NYC is examining, amongst other options, the pros and cons of separating the MSW into a “wet” and a “dry” stream that can be processed to usable materials and energy most effectively. The “wet” fraction, that in NYC constitutes less than 30% of the total MSW (i.e. about one million tons per year), decomposes quickly and complicates the transport and processing of the dry materials; this fraction can be bioconverted or combusted.

This paper examines the material and thermal energy balances for a projected large size cell where food and plant wastes are composted aerobically by means of forced air injection.

## **AEROBIC BIOCONVERSION IN LANDFILLS**

The concept of aerobic bioconversion by injecting air in a landfill was examined in a relatively large scale in California (Merz and Stone, 1962). However, the results were inconclusive due to the fact that the rate of airflow was too low and, therefore, both aerobic and anaerobic reactions were encountered. Haug (1993) discusses the injection of air in enclosed static piles in Maryland. The raw material was sludge from a wastewater treatment plant, admixed with wood chips. Reported average aeration rates were of the order of

2,000 ft<sup>3</sup>/h per ton of dry solids treated and the mean temperature was about 70°C over the 24-day campaign. Haug describes several other aerated static cells.

Aerobic bioconversion of MSW is carried out in a section of the Columbia County landfill near Augusta, Georgia (Hudgins and March, 1998). Air blowers inject air through a network of PVC pipes at the bottom of the landfill and a recirculation system collects leachate at the bottom of the landfill and injects it through the clay cap on top of the waste mass; the leachate percolates downward, countercurrently to the airflow. The results have shown a 50% increase of bioconversion rate and an 86% reduction in leachate flow, in comparison to the anaerobic section of the landfill; also, metal and VOC concentrations in the leachate were decreased by 75-99%. The air injection in the cell is maintained so that the oxygen concentration in the exit gas is less than 2%. In the aerated zone of the landfill, observed temperatures were between 40 and 60°C and moisture levels over 50%.

A U.S. patent by Markels (1996) proposed that the moisture level in an aerobic landfill be maintained between 50-70% and the temperature between 60 and 80°C. The desirable airflow is not mentioned, apart from the need to keep the oxygen content in the gas through the landfill “from about 5% to 15% oxygen”. In contrast, another patent by Green (1999) states that “levels of 1-2% oxygen are preferred”.

## **COMPOSITION OF MSW**

Tchobanoglous et al (1993) estimated that the U.S. MSW contains from 6-18% food wastes and 5-20% yard wastes. The “typical U.S.” MSW was estimated to contain 9% of food wastes and 18.5% yard wastes; these numbers are not much different from a New York City study (SCS Engineers, 1992) that estimated that the food wastes represented 12 % of the city’s MSW and the total organic wastes less than 30%.

The U.S. average composition of MSW is shown in Table 1 (Tchobanoglous, 1993). It can be seen that food wastes contain about 70% moisture.

**Table 1. Proximate analysis of various components of the MSW**  
(Tchobanoglous, Theisen, and Vigil, 1993)

	Moisture	Volatile matter	Fixed carbon	Non-combustible	kJ/kg* as collected
Mixed food wastes	70	21.4	3.6	5	4180
Fruit wastes	78.7	16.6	4	0.7	3970
Meat wastes	38.8	56.4	1.8	3.1	17730
Mixed paper	10.2	75.9	8.4	5.4	15600
Yard wastes	60	30	9.5	0.5	6050
<b>Commingled Residential MSW</b>	<b>21</b>	<b>52</b>	<b>7</b>	<b>20</b>	<b>11630</b>

The ultimate (atomic) analysis of the various types of wastes is shown in Table 2 (Tchobanoglous et al, 1993).

**Table 2. % Ultimate analysis of various components of the MSW**  
(Tchobanoglous, Theisen, and Vigil, 1993)

	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur
Mixed food wastes	48	6.4	37.6	2.6	0.4
Fruit wastes	48.5	6.2	39.5	1.4	0.2
Meat wastes	59.6	9.4	24.7	1.2	0.2
Mixed paper	43.4	5.8	44.3	0.3	0.2
Yard wastes	50.1	6.4	42.3	0.1	0.1

On the basis of the composition data of Table 2 and the atomic weights of the respective elements, the composite molecular formula corresponding to each material component of MSW is calculated to be as follows:

Mixed food wastes:  $C_6H_{9.6}O_{3.5}N_{0.28}S_{0.2}$

Mixed paper:  $C_6H_{9.6}O_{4.6}N_{0.036}S_{0.01}$

The above formulae are useful in determining the principal reactions that occur during bioconversion, the reaction products, and the expected heats of reaction. It can be seen that sulfur and nitrogen are relatively minor components and occur principally in mixed food wastes. Also, if one excludes nitrogen and sulfur, the molecular structure of mixed paper is very close to

cellulose,  $(C_6H_{10}O_5)_x$ . On the other hand, the structure of mixed food and plant wastes can be approximated by the molecular composition  $(C_6H_{10}O_4)_x$ , which, for  $x=1$  corresponds to that of at least ten organic compounds, such as ethyl butanedioic acid, succinic acid, adipic acid, ethylene glycol diacetate, and others (Table 3, after Roinen, 1999). The most common value for the heat of formation of these compounds is near -230 kcal/mol. All thermodynamic calculations in this study utilized the commercially available chemical thermodynamics program HSC Chemistry 4.0 (Roinen, 1999).

**Table 3. Identified organic compounds with formula  $C_6H_{10}O_4$**   
(mol. weight: 146.143 g/mol; after Roinen, 1999)

Chemical formula Structural formula	Chemical name (common name)	Heat of formation cal/(mol*K)
$C_6H_{10}O_4$ HOCC(CH <sub>3</sub> ) <sub>2</sub> CH <sub>2</sub> COOH	2,2-Dimethylbutanedioic acid (2,2-Dimethylsuccinic acid)	-232.316
$C_6H_{10}O_4$ (COOCH <sub>2</sub> CH <sub>3</sub> ) <sub>2</sub>	Diethyl oxalate (Ethanedioic acid diethyl ester)	-176.774
$C_6H_{10}O_4$ HOOCCH <sub>2</sub> CH(CH <sub>2</sub> CH <sub>3</sub> )COOH	Ethylbutanedioic acid (Ethylsuccinic acid)	-232.168
$C_6H_{10}O_4$ CH <sub>3</sub> COOCH <sub>2</sub> CH <sub>2</sub> OOCCH <sub>3</sub>	1,2-Ethanediol diacetate (Ethylene glycol diacetate)	-192.832
$C_6H_{10}O_4$ (CH <sub>3</sub> COO) <sub>2</sub> CHCH <sub>3</sub>	1,1-Ethanediol diacetate (Ethylidene diacetate)	-194.027
$C_6H_{10}O_4$ HOOC(CH <sub>2</sub> ) <sub>4</sub> COOH	Hexanedioic acid (Adipic acid)	-231.778
$C_6H_{10}O_4$ HOOCCH(CH <sub>3</sub> )CH(CH <sub>3</sub> )COOH	meso-2,3-Dimethylbutanedioic acid (meso-2,3-Dimethylsuccinic acid)	-233.599
$C_6H_{10}O_4$ HOOCCH(CH <sub>3</sub> )CH(CH <sub>3</sub> )COOH	Racemic-2,3-Dimethylbutanoic acid (Rasemic-2,3-Dimethylsuccinic acid)	-233.599

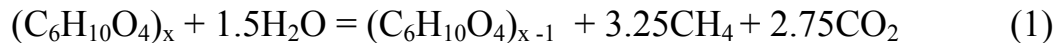
## BIOCONVERSION OF ORGANIC WASTES

### Anaerobic bioconversion of MSW

The principal products of anaerobic decomposition are methane and carbon dioxide; ammonia, hydrogen sulfide and mercaptans (sulfonated

hydrocarbons) are also generated. In the absence of adequate moisture content throughout the reactive landfill, the rate of bioconversion of wastes is very slow or can cease altogether. Old landfills have been opened after several decades and little decomposition of the entombed material has been observed at locations where there was no ingress of moisture. On the other hand, if a large amount of precipitation water is allowed to permeate through the landfill, the leachate solutions formed within it must be collected and treated continuously so they do not contaminate the groundwater and adjacent bodies of water.

The quantity of natural gas generated during anaerobic decomposition can be determined by considering the simplified molecular formula of organic waste derived earlier and assuming that the decomposition reaction proceeds as follows:



Depending on the assumed heat of formation of the complex organic compound (Table 3), this reaction ranges from slightly endothermic to slightly exothermic; generally, in landfills there is some ingress of oxygen that generates heat by means of partial aerobic reaction. According to Equation (1), the product gas contains about 54% methane and 46% carbon dioxide. It also contains water vapor at the saturation pressure corresponding to the landfill temperature, plus small amounts of ammonia, hydrogen sulfide and other minor constituents. If it is assumed that the  $(C_6H_{10}O_4)_x$  component is 25% by weight of the MSW stream, the maximum amount of natural gas that can be produced from MSW is calculated from Equation (1) to be 134 standard  $m^3$ /metric ton (4,300 standard cubic feet (scf) per short ton). However, as the hydrocarbon chains become shorter, the organic molecules become more stable and the rate of bioconversion decreases substantially. The reported (DOE/SRI study: see Franklin, 1995) maximum capacity of MSW in landfills to produce methane is 62 standard  $m^3$ /t (2,200 scf/short ton) of  $CH_4$ , i.e. 50% of the total amount projected by Equation 1.

The capture of methane gas produced in landfills in the U.S. has been estimated at about 66% (Dennison, 1996). On the basis that the total U.S. MSW is 190 million tons (209 million short tons), 61% of it is landfilled, and 66% of the generated methane is recovered, the carbon loss to the atmosphere in the form of  $CH_4$  is calculated to be 1.45 million tons C/year. Since methane is 25 times more potent as a greenhouse gas than  $CO_2$  (Graedel and Allenby,

1995), the methane losses from landfills may correspond to 36.4 million tons of carbon, or about 2% of the total U.S. contribution to global warming.

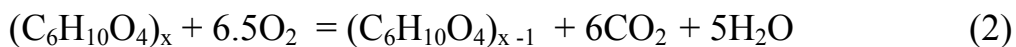
### **Aerobic bioconversion of organic wastes**

In the presence of an adequate supply of oxygen, moisture, and aerobic bacteria, the hydrocarbons contained in organic wastes undergo partial oxidation to smaller molecules. This results in the destruction of odor-forming compounds and the formation of carbon dioxide, water vapor and a compost product that can be used as soil conditioner. In its natural form, aerobic bioconversion of organic matter occurs naturally beneath the surface in fields and forests.

In order to divert organic wastes from landfills, many communities and private companies operate aerobic composting plants. These range from “windrow” composting, to sophisticated “in-vessel” bioreactors, such as the Bedminster (1994) bioreactor, a rotating cylindrical vessel through which the raw organic material flows countercurrently to an air flow. Haug (1993) describes several other types of operating aerated bioreactors.

Aerobic bioconversion is presently used in various forms to produce compost product from a reported 7.5 million tons per year of biosolids and organic wastes in Europe vs. only 1.3 million tons per year that are subjected to anaerobic decomposition (Jewell, 1999). These numbers do not include MSW landfills. In the U.S., aerobic composting amounts to about 6.3 million short tons/year, i.e. 3.5% of total MSW.

By representing organic wastes by the simplified chemical formula presented earlier, the aerobic bioconversion reaction can be expressed as follows:



In contrast to anaerobic bioconversion, this reaction is strongly exothermic; for an assumed heat of formation of the organic matter of 230 kcal/mol, as discussed earlier, Equation 2 generates -616 kcal of heat per mole of organic matters reacted. For comparison, the heat of biodegradation of glucose ( $C_6H_{12}O_6$ ) to carbon dioxide and water is -673 kcal/mol.

## **PREFERRED OPERATING PARAMETERS IN AEROBIC BIOCONVERSION CELL (ABC)**

### **Geometry and loading of packed-bed ABC**

An objective of this study was to compare the thermodynamic heat

generated by aerobic bioconversion in a cell with the capacity of the system to dissipate this heat, a) as latent heat of evaporation of water, b) as sensible heat in the air flow through the cell, and c) as heat loss by convection and radiation from the surface of the cell exposed to the atmosphere.

The cell in this study is assumed to be 6-meter (20-feet) wide and, initially, 3-meter (10-ft) deep; the length would depend on the tonnage of material to be processed, and for the purposes of this study has been assumed to be 100 meters (330 ft). Cells of similar geometry are presently used for aerobic composting (e.g., the Paygro or the Longwood cells) but, in contrast to the static cell examined in this study, the waste material is turned over at frequent intervals by mechanical means, in order to expose the wastes to air and water and dissipate the heat generated by the bioconversion reaction; the composting process usually lasts three weeks and is followed by a “curing” period of three to four weeks.

In the hypothetical cell of this study, it is assumed that the packed bed of wastes is not disturbed mechanically during the composting period. Air is injected through a grid floor by means of a ventilation plenum that forces air through the bed of wastes; such a device is presently used in over 24 installations of the static “tunnel” composting system (Haug, 1993); however, a network of perforated pipes at the bottom of the cell (Hudgins and March, 1998) can also be used. During operation, adding water at the top of the bed controls the moisture level. At the end of the bioconversion period, a front loader or other device moves the composted material to the curing area.

From the analysis of mixed food wastes (Table 2), the C/N ratio is calculated to be 18. It is assumed that the organic material feed contains about 10% of paper waste (C/N=143), resulting in a C/N ratio of 30.

Tchobanoglous (1993) reports the typical density of food wastes to be  $890 \text{ kg/m}^3$ . However, the admixed paper (10% of total) in the assumed NYC “wet stream” brings the expected bulk specific gravity of the material loaded in the ABC to 0.8 ( $800 \text{ kg/m}^3$ ). Therefore, the capacity of our hypothetical cell ( $1800\text{m}^3$ ) is 1,440 metric tons per composting period. By mixing food waste with 10% paper waste, the initial moisture content of bulk waste stream is estimated at 65%.

On the basis of the molecular composition of food wastes,  $\text{C}_6\text{H}_{9.6}\text{O}_{3.5}\text{N}_{0.3}$ , and the assumption that they consist mainly of carbohydrates, protein and fat, the dry base weight ratio, mole fraction and density can be approximated as shown in Table 4. It can be seen that the computed heat of combustion of the mix is very close to that calculated on the basis of Equation 2.

**Table 4. Estimation of composition of mixed food and 10% paper waste (dry basis)**

	M.W.	wt%	mol. fraction	specific gravity	Heat of * combustion
Carbohydrates( $C_6H_{10}O_5$ )	162.142	75.7	0.68	1.27-1.61	-603.0
Protein ( $C_2H_5O_2N$ )	75.067	11.7	0.25	1.14	-163.8
Fat and oil( $C_{16}H_{32}O_2$ )	256.428	12.6	0.07	0.85	-2387.0
Average of mixture				1.34	-614.6

### **Water flow into the cell**

Once the exothermic biodegradation starts, sufficient water flow is provided over the surface of the cell so as to saturate the air flow and also maintain a 50% moisture content throughout the bed until the end of composting. On the basis of these approximations, the average Free Air Space (FAS) and the porosity of the packed bed are calculated to be 34% and 76.5%, respectively.

### **Cell airflow, moisture level, and temperature**

Keener (1997, 1998) summarized the operating conditions and experimental results of a large number of pilot aerobic bioconversion studies. The preferred aeration rate was expressed in terms of volumetric airflow rate per unit mass of waste and ranged from 0.35 to 0.97 liters/min/kg. Several authors (Bernreuter and Stessel, 2000) have recommended an aeration rate of 0.5 liters/min/kg of waste. It is interesting to note that this rate is nearly the same as the average flow rate of 2,100 cfh/dt(cu.feet per hour per dry ton), reported by Haug (1993). Vander Gheynst (1997) reported aeration rates of 0.06-0.94 liters/min/kg, desirable moisture content of 45%, and temperature of 55°C. Temperatures much higher than 60°C are considered to be undesirable because they may kill all but the most thermophilic bacteria; also, in the absence of local moisture, high temperatures may result in spontaneous ignition in the bed; in fact, this occurred at times in the 15-m x 150-m x 7-m deep aerobic landfill in California (Merz and Stone, 1962).

The preferred moisture content in the ABC of this study ranges from 45-60% and the cell temperature is maintained below 60°C.

### **Overall rate of bioconverting - Specific rate constant**

One measure of the rate of bioconversion mentioned in the literature is the Specific Oxygen Uptake Rate (SOUR), also called “respiration activity”. For example, aerated composting piles were found (Sesay et al, 1998) to have an initial SOUR value of about 19mg O<sub>2</sub>/g material per hour; this value dropped to 1.81 after 51 days of aeration. By considering that it takes about 1.425g of oxygen to decompose 1g of organic matter (Equation 2), the SOUR value of 1.81mg O<sub>2</sub>/g/h can be converted readily to a more useful measure of the bioconversion rate: The fraction of initially present organic matter that is decomposed per day. Accordingly, the 1.81 mg O<sub>2</sub>/g/h reported by Sesay after 51 days corresponds to a fractional degree of reaction of 0.0305/day. Muller et. al. reported similar values (1995; 0.0205/day after 150 days).

On the other hand, Murphy et al (1995) reported lower bioconversion values. In their tests, the fractional rate of decomposition of a MSW/sewage sludge mixture after ninety days, as measured by analyzing for cellulose content, was only 0.0025/day.

An analysis of numerous pilot studies by Keener et al (1998) considers bioconversion to be a first order reaction. The present study also assumes that under controlled moisture, air and temperature conditions, the composting reaction will proceed as a quasi-first order reaction:

$$dc/dt = -k_r c \quad (3)$$

The  $k_r$  values presented by Keener (1998) range from 0.024 to 0.083/day. A study by Hamoda et al (1998) reports higher values ranging from 0.053 to 0.180/day.

After examination of the Schulze and Wiley’s experimental results, Haug and Ellsworth (1993) suggested the following equation for the biodegradation of ground MSW mixed with de-watered, digested sludge:

$$k_r = 0.00632(1.066)^{T-20} \text{ g BOM oxidized/g OM/day} \quad (4)$$

where BOM: biodegradable organic matter  
OM: organic matter

Because thermal inactivation occurs above 65°C, the above equation is only valid below 65°C. Moreover, moisture content and available free airspace and oxygen contents will affect the reaction rate also. By counting all these factors,

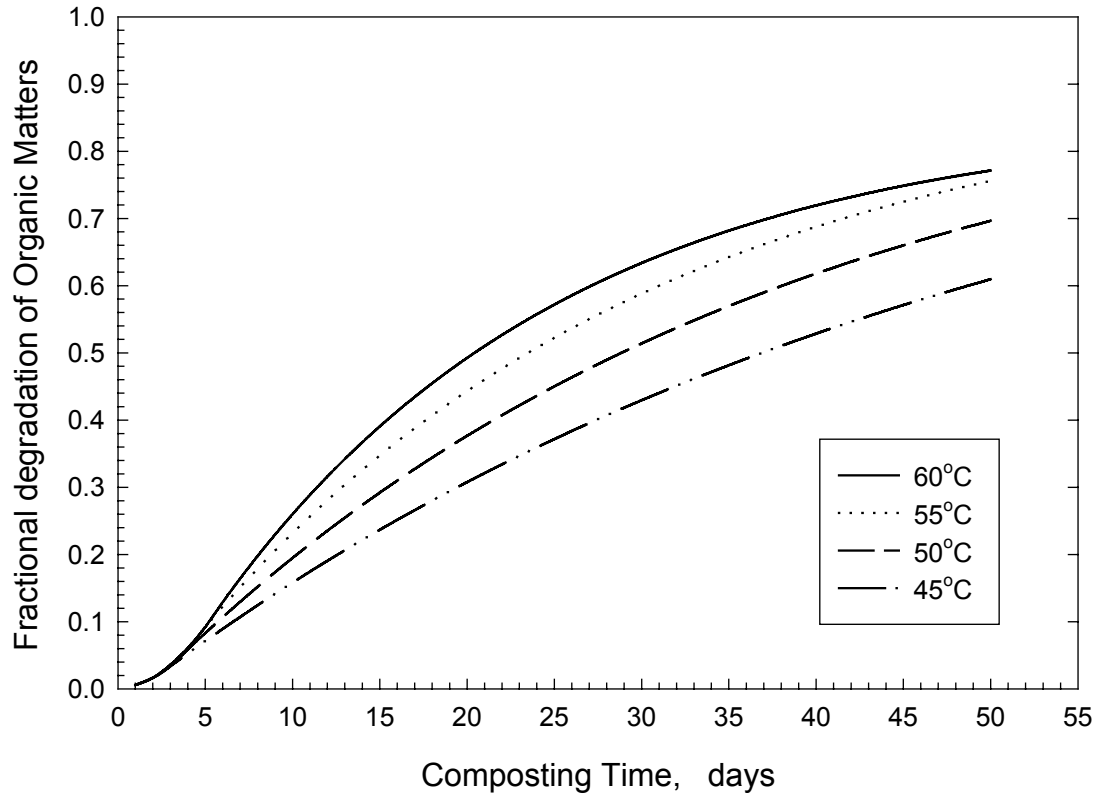


Figure1. Fractional bioconversion of OM with composting temperatures

Figure 1 shows how decomposition is expected to proceed with days of operation with time. The results show that, at 50°C, 28 days are required to finish the 50% degradation of organic matters, which is in fair agreement with the values reported by Sesay (1998), Muller (1998), and Murphy (1995). However, the initial very high values of decomposition reported by Sesay do not fit the first order reaction profile. Also, Figure 1 shows that increasing the composting temperature can shorten the required composting period. The projected relatively short bioconversion periods are in agreement with the reported results of aerated in-vessel systems, such as the agitated bins of Longwood Manufacturing Corporation (King, 1999), where the composting stage of biosolids mixed with leaves, paper fiber and wood shavings lasts 21 days, followed by a 24-day period of aerated curing of the compost product. Nearly the same composting and curing periods were reported for the treatment of biosolids mixed with wood chips and sawdust in aerated, static piles (Block, 1999) and are used in the aerobic composting facilities of Halifax, Nova Scotia (Wendt, 2000).

## **HEAT GENERATION AND DISSIPATION IN AN AEROBIC BIOCONVERTING CELL**

The aerobic decomposition of organic waste, as represented by Equation (2) is a strongly exothermic reaction. The calculated heat of biodegradation is  $-614.6$  kcal/mol ( $4,192$  kcal/kg dry OM) which is nearly the same as that obtained from Equation 2 (Roinen, 1999). The air is assumed to enter the cell at 20°C and 50% humidity, and to leave at 50°C - 60°C and 100% humidity. Therefore, the net moisture removed with the exhaust gases is  $0.079(50^{\circ}\text{C}) - 0.153(60^{\circ}\text{C})$  g water/g inlet air. Furthermore, it is assumed that each ton of mixed food waste contains 640 kg of moisture and 360 kg of organic matter. The total heat generated by 50% biodegradation during the composting period is calculated to be 893 Gcal.

The corresponding daily heat generation pattern by biodegradation is shown in Figure 2. It can be seen that the maximum generation of heat occurs within 4-5 days after composting is started.

Kayhanian and Tchobanoglous (1992) reported that the typical bio-degradabilities of mixed food waste and mixed paper are 81.9% and 66.7%, respectively. For 50% bioconversion of the organic materials fed to the cell, 148 kg of biodegradable organic matters (BOM), i.e.  $1.01$  kmol must be reacted

per ton of feed material, over the composting period. In order for the cell to remain at steady state during the campaign, the amount of heat generated by reaction must be removed continuously. This can be accomplished by a) the upward air flow, b) the evaporation of the downward water flow into the ascending air stream, and c) the convection and radiation heat losses from the cell to the environment.

An approximate calculation showed that the principal heat loss is by natural convection/radiation from the surface of the bed and the outer surface of the walls of the cell (both assumed to be at 40°C) to the atmosphere (20°C). The overall heat transfer coefficient was estimated at 10 W/(m<sup>2</sup> K) (Themelis,

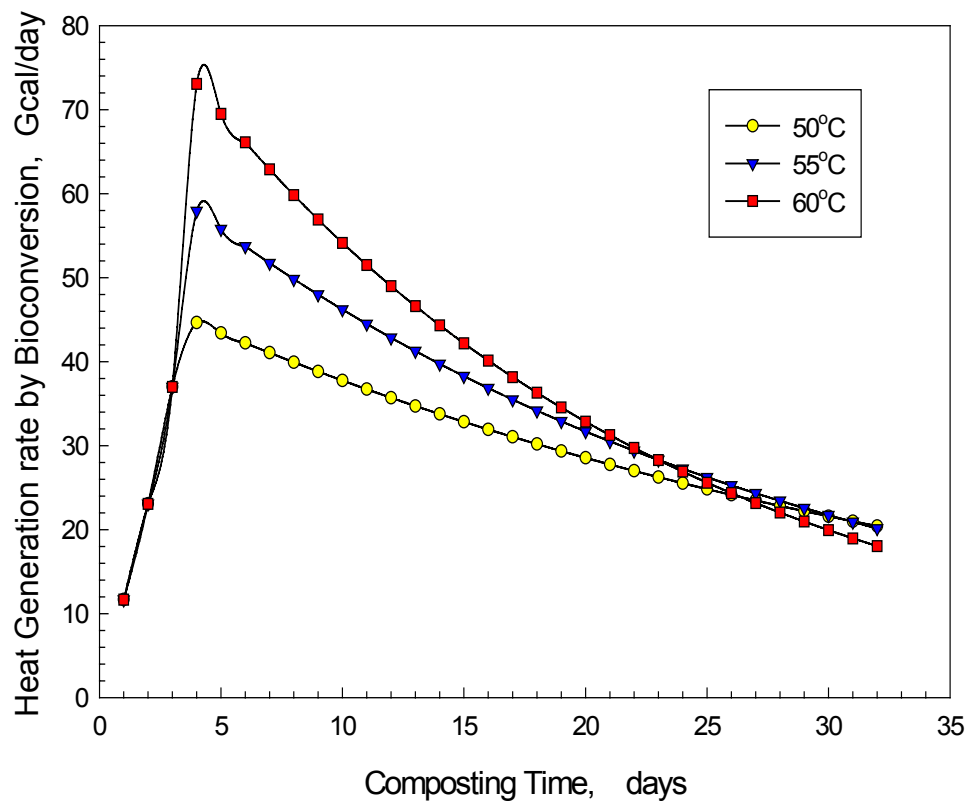


Figure 2. Heat Generation Rate of proposed ABC cell (capacity 1,440 ton; 36%OM)

1995). The calculated overall heat loss during the entire composting period ranges from 227Gcal (60°C) to 252Gcal (50°C). This result indicates that only

about one fourth of the heat generated by bioconversion will be removed through heat loss to surroundings. Therefore, it is necessary to cool the cell by means of air flow through it and the evaporation of water added to the bed during operation.

The air flow through the cell was dictated by the requirements for thermal balance. Figure 3 shows how the required air supply through the bed, expressed as superficial velocity, varies during the composting period. As the operating temperature of bed increases, both average and peak air supply rates decrease primarily due to the higher heat of vaporization. Within the operating temperatures considered, the average superficial velocity of air varies from 0.55cm/s (1,980cfh/ton of OM reacted; 60°C) to 0.67cm/s (2,400cfh/ton of OM reacted; 50°C) and the peak air velocities are 1.1 cm/s (3,950cfh/ton of OM reacted). The amounts of air supplied to keep the bed temperature 50°C and 60°C are calculated to be 55 and 30kg air/kg OM reacted, respectively, which is about 9 – 5 times higher than the stoichiometric air requirements.

The excess air introduced to keep the temperature of the bed eventually causes drying of solid waste. To assure the proper rate of biodegradation

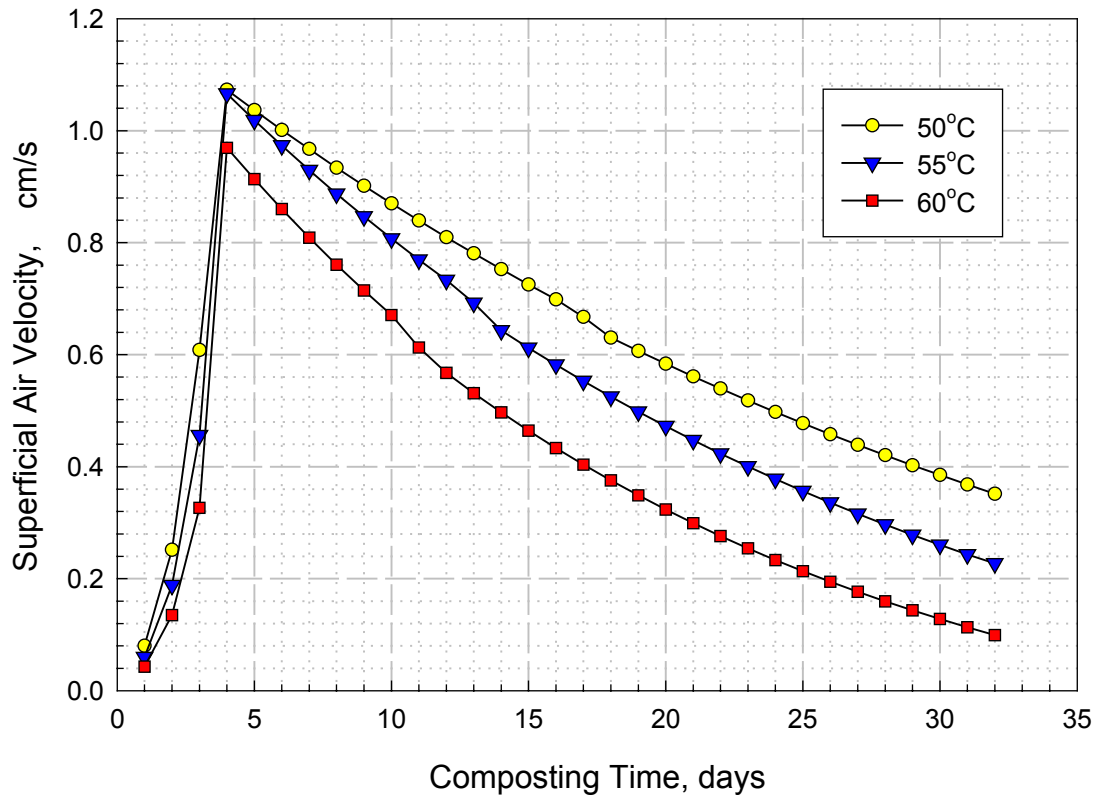


Figure 3. Aeration Requirement for proposed Cell  
 [Size:100mx6mx3m; Capacity:1,440 ton MFW(36% OM)]

reaction, moisture contents should be maintained over 50%. Continuous spraying of water is therefore necessary at about one or two weeks after composting has started, depending on the temperature of exit air and the desired moisture level. The cumulative water balances at 55°C is presented in Figure 4.

Per each ton of organic matters, the initial amount of water is 1.78 tons and another 0.25 tons are produced by bioconversion and the amount of water removed from mixed food waste to keep the moisture contents 50% is 1.19 tons for all operation temperatures. On the other hand, the amount of water removed by aeration mainly relies upon the desired composting temperature. By increasing the composting temperature from 50°C to 60°C, the water addition required to keep the 50% moisture level throughout the composting period increases from 0.3 tons/ton of OM, to 2.5 tons/ton of OM. This result implies that the amount of water carried out by the saturated exit air is the most important factor to determine the amount of additional water required during the composting period.

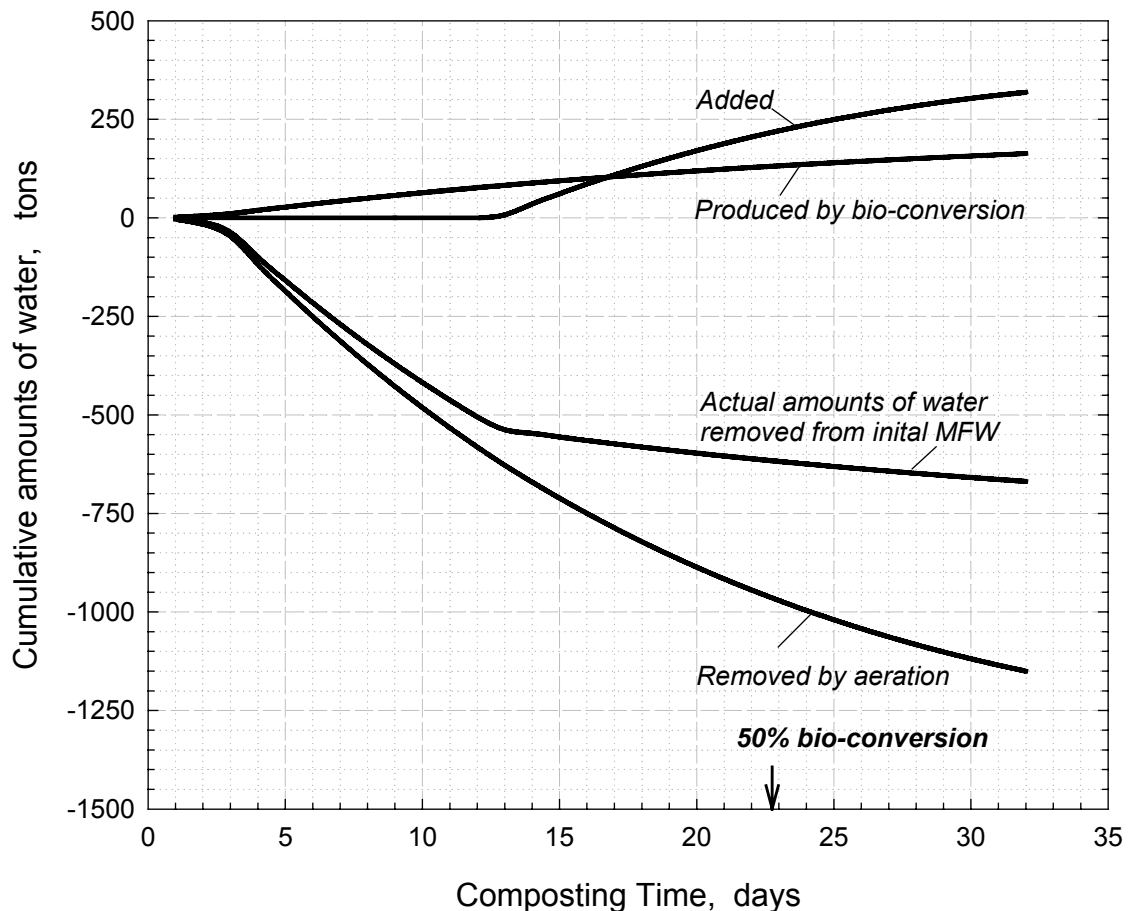


Figure 4. Water balance of ABC Cell [ Temp. 55°C; Moisture level 50%; Capacity 1440 ton(36%OM)]

## CONCLUSIONS

This study used operating conditions recommended in a number of experimental studies to develop the process design of a 600 m<sup>2</sup> by 3-m deep aerobic bioconversion cell that can compost 1,440 metric tons of mixed food and wastes in 19-28 days period. The bioconversion plant envisaged would consist of a number of such cells, some in operation and some being loaded or unloaded. The re-use of the cells is predicated on the assumption that the compost product will be used in large-scale soil conditioning projects. It is assumed that the forced airflow through the bed will be sufficiently uniform to prevent the formation of anaerobic pockets where methane and noxious gases are produced.

The results of the study showed that, for a cell of this design, the heat losses to the surroundings over the composting periods would amount to 227-252Gcal, about 25% of the chemical heat released by aerobic bioconversion. The rest of this heat must be removed by means of an upward airflow through the cell that corresponds to 500 - 900% of the stoichiometric requirements for oxidation. The principal cooling is provided not by the sensible heat in the air but by the evaporation of the water percolating through the cell and saturation of the airflow. The average superficial velocities of the air are 0.67, 0.63 and 0.55 cm/s for the bed temperatures of 50°C, 55°C and 60°C, respectively. The conversion of these velocity to specific aeration rate, G, ranges from 2,000 – 2,400 cfh/ton OM, which is within the typical aeration rate of static pile systems.

This study has quantified the principal difference between anaerobic and aerobic biodegradation in a static cell, from a process design point of view. In anaerobic reaction, most of the chemical energy of the organic matter is transferred to the generated methane gas; this gas can be captured and then used as a fuel. In aerobic bioconversion in a static cell, this energy must be carried out in a continuous and relatively large air/water vapor flow through the cell. For the 600 m<sup>2</sup> x 3m cell of this study, the air to be injected for 50% bioconversion amounts to 4.5 - 8.0 tons/ton of feed materials, or 3.3–4.0 standard m<sup>3</sup>/s for the entire cell. The air blower to deliver this flow at 1/3 atm (5 psig) would be rated at about 200-240kW. The corresponding power consumption over the entire period is calculated at 63kWh(60°C, 19days)-112kWh(50°C, 28 days) per ton of waste material to be treated; at present power rates this would amount to \$6-\$11/ton of mixed food waste and would represent the major operating cost. The water input required per ton of

dry OM to maintaining the desirable moisture level in the bed and saturate the airflow would increase from 0.3 tons to 2.5 tons as the composting temperature increases from 50°C to 60°C.

The method of analysis presented above can be applied to any cell geometry.

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