Compost Engineering
and
an ACE Oriented Systems Analysis

K.C. Ting and Wei Fang

I. Composting Process - microorganisms consuming (oxidizing) substrates (volatile solids) to support their activities (reproduction):

\[ [C_{x_1}H_{x_2}O_{x_3}N] + a_2 [O_2] \rightarrow a_2 [CO_2] + a_3 [H_2O] + NH_3 + Q_h \]


Output: Earth Odor, Dark Color, Fluffy Structure, Low Specific Gravity, Cool, C/N = 10 to 12, May Contain 25% of Dead and Living Microorganisms (Question of Stability ?)

II. Factors Affecting the Process (Rate Limitations)
Available Substrate (Biodegradable Volatile Solids)
- solubilization of solid substrate
- mass transport of solubilized substrate to the cell
C/N Ratio (30 to 50 ideal)
- C for growth and N for protein synthesis
O_2 Supply
- Mass transport of oxygen to the cell
Moisture Content (下限：20%，中值：50 to 70%)
- aqueous environment
- soluble compounds
- on available FAS
- on the mass transport of oxygen
Temperature (下限：40；中值：45 – 70, 75；上限：80 °C)
- mesophilic
- thermophilic
Free Air Space (FAS)
- Oxygen transport and supply
pH (hydrogen ion $H^+$ and hydroxide ion $OH^-$)

enzymatic activity

III. Composting Systems

1. Enclosure-
   Non-reactor (Open)
   Reactor (Enclosed or Within-Vessel)

2. Bed Condition –
   Static Solids Bed
   Agitated Solids Bed
   Moving Agitated Bed
   Moving Packed Bed
   Tumbling Solids Bed

3. Aeration –
   Natural
   Forced

4. Material Flow –
   Stationary
   Vertical Flow
   Horizontal and Inclined Flow

5. Compartmentization
   Single Compartment
   Multiple Compartment

IV. Scientific Research vs. Engineering Challenge

   Bench Top Experiment vs. Large Scale Operations
   Laboratory Findings vs. Engineering Design
   Narrowly Focused Knowledge Base vs. Systems Integration
   Incorporation of Quantitative Date and Qualitative Knowledge
   Methods for Dealing with Non-Uniformity and Uncertainty
   The Issue of Engineering Economics

V. Eweson Composter

1. Classification
   Multiple Compartment (normally three)
   Inclined Flow
   Forced Aeration
   Tumbling Solids Bed
Reactor

2. Schematic Diagram

3. Numerical Modeling and ACE Oriented Analysis
   i. A Modular Compartment
      Automation: Monitoring, Control, Material Handling
      Culture: Kinetics of Microbial Activity (BVS Conversion Rate)
      Environment: Mass (Air, Water, Solid) Balance
      Energy Balance
      Chemical Balance (Stoichiometric Balance)
   ii. The Whole Composter – The Issue Of Connectivity
   iii. The Entire Composting Facility – Plant Layout and Materials Flow

VI. References
**MODEL gico**

**Governing Equations for a Modular Compartment**

\[
\frac{d(BVS)}{dt} = -k_d (BVS)
\]

where, BVS = Biodegradable Volatile Solid, kg

\[ t = \text{time, day} \]

\[ k_d = \text{rate constant, day}^{-1} \]

\[ k_d = (F1)(F2)(FO2)(k_{dm})(C1) \]

\[ k_{dm} = 0.0126[1.066^{(T-20)} - 1.21^{(T-60)}] \]

where, \( T = \text{temperature, } ^\circ\text{C} \)

\[ F1 = 1.0 - 17.3 (\text{SM})^{0.94} \text{ if } (1.0 - \text{SM}) \geq 0.4 \]

\[ 20.6614(1.0 - \text{SM})^{4.06} \text{ if } (1.0 - \text{SM}) < 0.4 \]

where, SM = Solid Mass content, decimal

\[ F2 = \text{function(Free Air Space); approximately 0.95 for FAS > 0.3} \]

\[ FO2 = \frac{\text{VOLPO2}}{[\text{VOLPO2} + 1.0]} \]

where, VOLPO2 = volumetric percentage of \( \text{O}_2 \) in free air, %

\[ C1 = \text{first calibration factor for model gico} \]

\[ [C_{x1}H_{x2}O_{x3}N] + a_2[O_2] \rightarrow a_2[CO_2] + a_3[H_2O] + NH_3 + Q_h \]

\[ a_1 = [2.0 \times 1 + (x_2 - 3.0) / 2.0 - x_3] / 2.0 \]

\[ a_2 = x_1 \]

\[ a_3 = (x_2 - 3.0) / 2.0 \]

\[ Q_h = 395.253 a_2 + 286.391 a_3 + 45.638 \]

where, \( Q_h = \text{heat generation, kJ/mol of } C_{x1}H_{x2}O_{x3}N \)

\[ \text{VSMW} = 12 x_1 + x_2 + 16 x_3 + 14 \]

where, VSMW = Volatile Solid Molecular Weight, g/mol

therefore, \( Q_h = (1000) \left[ (395.253 a_2 + 286.391 a_3 + 45.638) / \text{VSMW} \right] \)

in kJ/kg \( C_{x1}H_{x2}O_{x3}N \)

**Mass Consumption**

<table>
<thead>
<tr>
<th>from</th>
<th>air</th>
<th>( O_2 ) :</th>
<th>32 a_1 / VSMW</th>
<th>kg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>VS</td>
<td>C</td>
<td>12x1 / VSMW</td>
<td>kg/kg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>x2 / VSMW</td>
<td>kg/kg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>16x3 / VSMW</td>
<td>kg/kg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>14 / VSMW</td>
<td>kg/kg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H_2O</td>
<td>Drying</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Mass Generation

\[
\begin{align*}
\text{CO}_2 & : \quad 44a_2 / \text{VSMW} \quad \text{kg/kg} \\
\text{H}_2\text{O} & : \quad 18a_3 / \text{VSMW} \quad \text{kg/kg} \quad \text{and from VS drying} \\
\text{VS} & : \quad \text{H}_2\text{O} \quad \text{condensation} \quad \text{kg/kg} \\
\text{NH}_3 & : \quad 17/\text{VSMW} \quad \text{kg/kg}
\end{align*}
\]

Psychrometric Equations


dry bulb temperature, relative humidity, humidity ratio,
specific volume, dew point, enthalpy, wet bulb temperature,
latent heat of vaporization (condensation)

Energy Balance

\[
\begin{align*}
\text{MMASSAIR} \times \text{ENTHALPY}_\text{in} - \text{MMASSAIR} \times \text{ENTHALPY}_\text{out} \\
+ \text{[MMASSW} \times \text{CPSW} \times \text{TSW}]_\text{in} - \text{[MMASSW} \times \text{CPSW} \times \text{TSW}]_\text{out} \\
+ Q_h \times \text{DBVS} + \text{HFG} \times \text{MASSCOND} - \text{AUS} \times (\text{TSW} - \text{TAMB}) \times \text{(C2)} \\
- \text{AUE1} \times (\text{TSW} - \text{TE1}) \times \text{C3} - \text{AUE2} \times (\text{TSW} - \text{TE2}) \times \text{C4} = 0
\end{align*}
\]

where, MMASSAIR = mass flow rate of air, kg/day
ENTHALPY = enthalpy of air, kJ/kg
MMASSW = mass flow rate of solid waste including added water, kg/day
CPSW = specific heat of solid waste, kJ/kg °C
TSW = temperature of solid waste, °C
DBVS = consumed portion of biodegradable volatile solid, kg/day
HFG = latent heat of condensation, kJ/kg
MASSCOND = mass of condensate, kg/day
AUS = side heat conductance of drum, kJ/°C day
TAMB = side ambient temperature, °C
AUE1 = end 1 heat conductance of drum, kJ/°C day
TE1 = end 1 ambient temperature, °C
AUE2 = end 2 heat conductance of drum, kJ/kg day
TE2 = end 2 ambient temperature, °C
C2 = second calibration factor for model gico
C3 = third calibration factor for model gico
C4 = fourth calibration factor for model gico

Governing Equations for a Multi-compartment Composter
Integrate the equations for a number of modular compartments.

**User Interface and pre- and Post- Data Processing**
- Menu-driven data entry
- Initial conditions, information flow, and process control of simulation
- Presentation of results