Compost Engineering
and
an ACE Oriented Systems Analysis

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

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

Input: Municipal Solid Wastes, Food Wastes, Sewage Sludge , Agricultural Crops, Food Wastes, Industrial Wastes, Logging and Wood-Manufacturing Residues, Miscellaneous Organic Wastes, etc.

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%, **適中**： 50 to 70%)
- aqueous environment
- soluble compounds
- on available FAS
- on the mass transport of oxygen

Temperature (**下限**：40；**適中**：45 – 70, 75；**上限**：80 ^{o}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. <u>References</u>

1. Haug, R.T. 1980. Compost engineering principles and practice . Technomic Publishing Company, Inc., Lancaster, PA.655p.
2. Poincelot, R.P. 1975. The biochemistry and methodology of composting. Bulletin 754, The Connecticut Agricultural Experiment Station, New Haven, Connecticut.
3. Singley, M.E., A.J. Higgins and M. Frumkin-Rosengaus. 1982. Sludge composting and utilization: a design and operating manual. Bioresource Engineering Department , Rutgers University , New Brunswick, NJ.
4. Kania, S. et al. 1993. Report on the rotary drum composter facility in Tennessee. Bioresource Engineering Department , Rutgers University , New Brunswick, NJ.

MODEL gico

Governing Equations for a Modular Compartment

$d(BVS)/dt = -k_d (BVS)$

where, BVS = Biodegradable Volatile Solid, kg

t = time, day

k_d = 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 = temperature , °C

$F1 = 1.0 - 17.3\,(SM)^{6.94}$ if $(1.0 - SM) >= 0.4$

$20.6614(1.0 - SM)^{4.06}$ if $(1.0 - SM) < 0.4$

where, SM = Solid Mass content, decimal

F2 = function(Free Air Space); approximately 0.95 for FAS > 0.3

FO2 = (VOLPO2) / [(VOLPO2) + 1.0]

where, VOLPO2 = volumetric percentage of O_2 in free air, %

C1 = first calibration factor for model gico

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

$a_1 = [2.0\,x1 + (x2 - 3.0) / 2.0 - x3] / 2.0$

$a_2 = x1$

$a_3 = (x2 - 3.0) / 2.0$

$Q_h = 395.253\,a_2 + 286.391\,a_3 + 45.638$

where, Q_h = heat generation, kJ/mol of $C_{x1}H_{x2}O_{x3}N$

VSMW = 12 x1 + x2 + 16 x3 + 14

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

therefore, $Q_h = (1000)\,[(395.253\,a_2 + 286.391\,a_3 + 45.638) / VSMW]$

in kJ/kg $C_{x1}H_{x2}O_{x3}N$

Mass Consumption

from	air	O_2	:	32 a_1 / VSMW	kg/kg
	VS	C	:	12x1 / VSMW	kg/kg
		H	:	x2 / VSMW	kg/kg
		O	:	16x3 / VSMW	kg/kg
		N	:	14 / VSMW	kg/kg
		H_2O	:	Drying	

Mass Generation

in	air	CO_2 :	$44a_2$ / VSMW	kg/kg	
		H_2O :	$18a_3$ / VSMW	kg/kg	and from VS drying
	VS	H_2O :	condensation	kg/kg	
		NH_3 :	17/VSMW	kg/kg	

Psychrometric Equations

[ASAE Data: ASAE D271.2, 1983-84 Agricultural Engineers Yearbook of Standards, p.314-316.]

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

Energy Balance

MASSAIR * ENTHALPY]$_{in}$ - [MASSAIR * ENTHALPY]$_{out}$
+ [MASSSW * CPSW * TSW]$_{in}$ - [MASSSW * CPSW * TSW]$_{out}$
+Q_h * DBVS + HFG * MASSCOND – AUS * (TSW – TAMB) * (C2)
- AUE1 * (TSW – TE1) * C3 – AUE2 * (TSW – TE2) * C4 = 0

where, MASSAIR = mass flow rate of air, kg/day
ENTHALPY = enthalpy of air, kJ/kg
MASSSW = mass flow rate of solid waste including added water, kg/day
CPSW = specific heat of solid waste, kJ/kg ^oC
TSW = temperature of solid waste, ^oC
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/^oC day
TAMB = side ambient temperature, ^oC
AUE1 = end 1 heat conductance of drum, kJ/^oC day
TE1 = end 1 ambient temperature, ^oC
AUE2 = end 2 heat conductance of drum, kJ/kg day
TE2 = end 2 ambient temperature, ^oC
C2 = second calibration factor for model gico
C3 = third calibration factor for model gico
C4 = fourth calibration factor for model gico

<u>Governing Equations for a Multi-compartment Composter</u>

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