Biodegradation of lipidic compounds in synthetic food wastes during composting

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Lemus, G.R. and Lau, A.K. 2002. **Biodegradation of lipidic compounds in synthetic food wastes during composting**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **44**: 6.33-6.39. Changes in food production, consumption patterns, and more restrictive regulations, result in larger quantities and higher diversity of waste materials that need to be treated and disposed. Organic wastes rich in lipidic compounds are not typically composted. However, fats, oils, and grease (FOGs) residues have a high-energy content that makes them ideal candidates for aerobic composting. The aim of this project was to evaluate the treatability and process performance of FOGs residues during composting. A series of preliminary tests was performed using canola oil as lipidic compound. The main substrate used was synthetic food waste (dry dog food). Thermophilic temperatures were readily achieved without any external heat addition with peak temperatures approximately 70°C. Results indicated that the thermophilic runs had an average lipid reduction of 70% with a maximum of 79%. However, change in volatile solids content was only 20% for the 10-day composting period. Cumulative heat generation ranged from 1.7 to 3.4 MJ for the thermophilic runs, which is one order of magnitude greater than the mesophilic runs (0.07 to 0.17 MJ). The contribution of lipids to heat was higher for the runs where canola oil was added. **Keywords**: Compostability, oil-rich wastes, canola oil, FOG residues.

Des changements dans la production des aliments, les habitudes de consommation et l'introduction de réglementations plus restrictives ont pour conséquence une augmentation des quantités et de la diversité des déchets alimentaires qui doivent être traités et rejetés. Les déchets organiques riches en composés lipidiques ne sont généralement pas compostés. Toutefois, les résidus de gras, huiles et graisses (GHGs) ont un contenu en énergie élevé qui font d'eux de parfaits candidats pour le compostage aérobique. Le but de ce projet a été d'évaluer les performances des GHGs à être traités et transformés durant le compostage. Une série de tests préliminaires a été réalisée en utilisant de l'huile de canola comme source de lipide. Le substrat principal était des déchets de nourriture de synthèse (nourriture à chien sèche). Des niveaux de température thermophilique ont été obtenus sans l'ajout extérieur de chaleur avec des températures maximales d'environ 70°C. Les résultats indiquent que les essais thermophiliques ont résulté en une réduction moyenne des lipides de 70% avec un maximum de 79%. Cependant. les variations au niveau du contenu en solides volatiles n'ont été que de 20% après une période de 10 jours de compostage. La quantité de chaleur cumulative générée a varié de 1,7 à 3,4 MJ pour les essais thermophiliques, ce qui est d'un ordre de magnitude supérieur à ceux des essais mésophiliques (0,07 à 0.17 MJ). La contribution des lipides à la production de chaleur a été plus élevée lorsque de l'huile de canola était ajoutée au substrat. **Mots clés:** Capacité à composter, déchets riches en huile, huile de canola, résidus gras huile graisse

INTRODUCTION

Fats, oils and grease (FOGs) residues are considered problematic substances in both liquid and solid waste treatment systems. In wastewater collection systems, FOGs tend to clog drainpipes and sewer lines, producing an odor nuisance and sewage back-ups into residential and commercial facilities (GVRD 2000). FOGs presence under anaerobic conditions often leads to the corrosion of sewer pipes (Becker et al. 1999; Stoll and Gupta 1997). Due to the biodegradable nature of FOGs, some countries (like France), have already banned their disposal in sanitary landfills (Lefebvre et al. 1998). Composting has proven to be a very successful treatment process for mineral oils (hydrocarbons) and residues from oil extraction processes (e.g. olive oil) (Filippi et al. 2002; Wan et al. 2002), though composting of food residuals rich in oil and grease is not a common practice.

The main constituents of FOGs are animal fats and vegetable oils used in restaurants and industrial operations. Chemically, FOGs are triglycerides consisting of straight-chain fatty acids attached, as esters, to glycerol. FOGs also comprise a combination of free fatty acids and glycerol whenever hydrolysis has taken place (Jakobsen 1994). FOGs residues include a broad variety of substances that share the common property of being soluble in various organic solvents (e.g. hexane). These lipids include relatively simple, C-even or odd long chain in the C_{16} - C_{32} range compounds, such as fatty acids, n-alcohols, n-alkenes, sterols, terpenes, fats, waxes, and resins (Fernandes et al. 1988; Wakelin and Forster 1997; Lefebvre et al. 1998).

Lipids contain twice the energy of other organic materials, like sugars and starch (Fernandes et al. 1988; Wiley 1957). This high-energy content represents a clear advantage for processes where thermophilic temperatures are desirable to achieve pathogen content reduction. In addition, at high temperatures the reaction rates are faster, thus resulting in shorter residence times. Thermophilic conditions promote changes in most of FOG's physical properties, such as melting point, diffusivity, and solubility, which are temperature dependent (LaPara and Alleman 1997; Becker et al. 1999).

The aim of this study was to evaluate the treatability of organic wastes loaded with lipidic compounds under aerobic composting conditions. In particular, composting process performance was investigated in terms of temperature profiles, fulfillment of pathogen reduction requirement, lipids compostability, and organic matter biodegradation. Furthermore, the effect of different types and concentrations of inocula were studied.

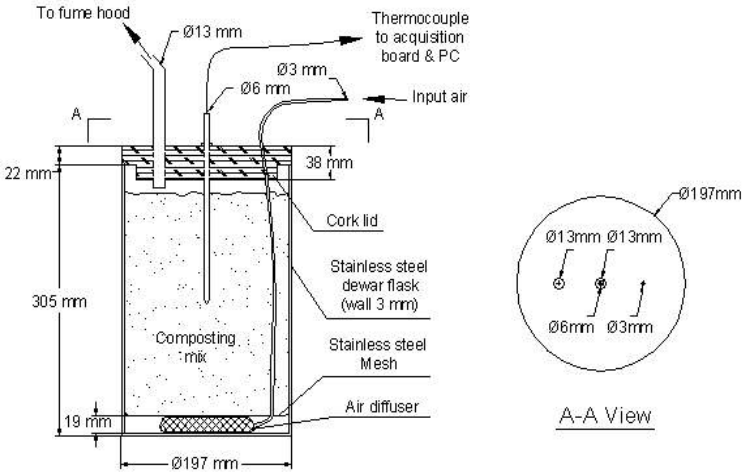

Fig. 1. Composting reactor (Dewar flask) details.

BACKGROUND

There are few studies about the aerobic degradation of organic wastes loaded with lipid-rich wastes of vegetable and animal origin. Researchers have studied the feasibility of lipid-rich wastes such as wool scouring wastewater, olive oil mill wastewater, food processing residuals, bakery wastes, and fast food restaurant wastewater.

Viel et al. (1987a) studied the aerobic composting of agricultural and industrial wastes. Lipid-rich wastes used were fats and slaughterhouse waste. After composting for 7 to 9 days, fats degradation was 80% and peak temperature was 75°C. The lipid concentration after 120 days was further reduced achieving an overall reduction of 95%.

With temperature controlled conditions (60-76°C), Viel et al. (1987b) further researched the solid substrate composting of mixtures containing 8% wet weight of flotation foams (scum). The highest microbial activity took place at 60 - 70°C. Fat degradation was 85% and the energy released, mostly by fats, was estimated as 4180 kJ/kg dry matter per week.

Fernandes et al. (1988) studied the feasibility of fatty wastes disposal through in-vessel composting. Solid substrate composting of lipid rich materials (flotation foams and slaughterhouse wastes), was carried out in a 100-liter stainless steel reactor. This study found that process temperature (60-70°C) fulfilled pathogen reduction requirements, and that a relatively low decomposition of organic matter can be associated with a high degree of lipid degradation.

Joshua et al. (1994) successfully composted grease trap sludge using an environmentally controlled composting system. The temperature of the composting mix (grease trap sludge, wheat straw and wood shavings) peaked at 65°C and remained constant for the next 48 hours. After composting for 5 to 11 days, the composting mix had no oxygen demand or reheating potential. The researchers concluded that a curing phase was not necessary.

The information of lipid-rich waste composting reported in previous studies is very brief, and none of the studies gave information on the comparison between adding or not adding lipid-rich wastes to composting mixes, particularly in terms of composting process performance.

MATERIALS and METHODS

Experimental configuration

Composting reactors were stainless steel Dewar flasks of 6 L total volume. The composting vessel was placed in an insulation (adiabatic) box to simulate a typical in-vessel composting process, or the core part of a compost pile. Temperature inside the composter and ambient temperature were monitored hourly using copper-constantan thermocouples (see Fig. 1 for more details). The temperature data were collected by a data acquisition board and a PC. Verification of the fulfillment of the pathogen reduction requirement and heat production were derived from the temperature profiles.

Process control

Labtech Control™ Software (Labtech, Adover, MA) was used for the composting process control. The strategy used was the Rutger's temperature-feedback method (Finstein et al.), where aeration is intermittent (33% duty cycle) below the setpoint of 70°C and continuous above the setpoint.

Aeration (upflow direction) was provided using a series of pumps. The metallic mesh at the bottom of the reactor provided support for the composting mass. An aquarium air diffuser located below the mesh distributed the incoming air. The active phase of the composting process lasted 10 days, since the temperature inside the composter had dropped back to ambient temperature within 10 days.

Composting recipe formulation

The main composting substrate was synthetic food waste (dry dog food, according to VanderGheynst et al. 1997) with wood shavings and wood chips as bulking agents. The dry dog food used was No Name®, Special Dinner-Packet Club (Sunfresh Limited, Toronto, ON), with composition, according to the label, of 21 % protein, 7% fat, 5% fiber, 7.5% ash, and 12% moisture.

Generic brand canola oil (No Name®, Canola Oil, Sunfresh Limited, Toronto, ON) was added as the lipid fraction. Moisture content was adjusted to achieve 55 to 65%. As inoculum, either activated sludge (from the University of British Columbia pilot wastewater treatment plant) or bagged chicken litter (weathered manure and bedding, retail quality) was used. See Table 1 for details on the proportion of feedstock used for the composting mixes.

Analytical measurements

Volatile solids and moisture content were measured before and after composting, using standard analytical methods (APHA 1995). Lipid content (n-hexane extractable materials, HEM) was measured by Soxhlet extraction method using n-hexane as organic solvent (USEPA 1998).

Experimental runs

Five manipulated variables were chosen based on the values suggested in the literature: (1) initial Carbon-to-Nitrogen ratio, (2) presence or absence of canola oil, (3) initial oil concentration, (4) inoculum type, and (5) inoculum concentration.

Table 1. Proportion (percentage wet basis) of feedstock used for all composting mixes. Remaining percentage was tap water.

Run #	DDF*	CO	BA	CM	AS
1	14	4	29	5	0
2	15	0	30	5	0
3 - control	0	0	37	5	0
4	18	4	28	1	0
5	18	0	29	1	0
6 - control	0	0	35	1	0
7	20	4	27	0	1
8	19	4	27	0	5

* DDF = dry dog food; CO = canola oil; BA = bulking agents; CM = chicken manure; AS = activated sludge

RESULTS and DISCUSSION

Temperature profiles

Except for the control runs (Run 3 and Run 6) that performed in the mesophilic range with temperature peaks between 28-38ºC, the temperature profiles were similar for all other experimental runs, illustrating the temperature regimes typical of composting. They were in the thermophilic range with peak temperature values between 68 to 72ºC. As seen in Figs. 2 to 5, temperature peaks occurred in the first 20 to 50 hours after composting started.

Pathogen reduction requirement

The requirement for pathogen reduction for in-vessel composting is three consecutive days (72 h) at 55ºC or above (CCME 1996). Based on the temperature profiles, all but the control runs satisfied this criterion, though Runs 2 and 5 (dry dog food with no canola oil added) barely fulfilled the requirement since there was a break between two temperature peaks.

Table 2. Composition and characteristics of composting mixes used in the experiment.

Run #	Main substrate*	Canola oil added*	Initial FOG concentration (% ds)	Initial moisture content (%)	Initial C:N	Inoculum*	Inoculum concentration (% w.b.)
1	DDF	Y	10	55	40	CM	5
2	DDF	N	3**	60	40	CM	5
3 - control	BA	N	1**	65	90	CM	5
4	DDF	Y	10	55	40	CM	1
5	DDF	N	3**	60	40	CM	1
6 - control	BA	N	1**	65	130	CM	1
7	DDF	Y	10	55	40	AS	1
8	DDF	Y	10	55	40	AS	5

* DDF = dry dog food; BA = bulking agents; CM = chicken manure; AS = activated sludge; Y = yes; N = no
** Naturally occurring lipids from the feedstock used

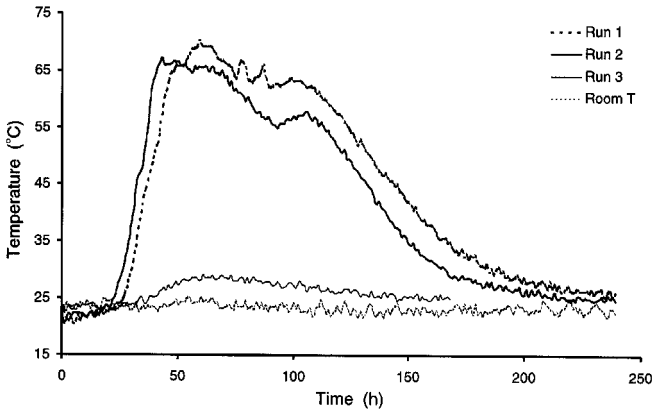

Fig. 2. Temperature profiles of experimental Runs 1, 2, and 3. Synthetic food waste (dry dog food) with 5% (w.b.) chicken manure as inoculum.

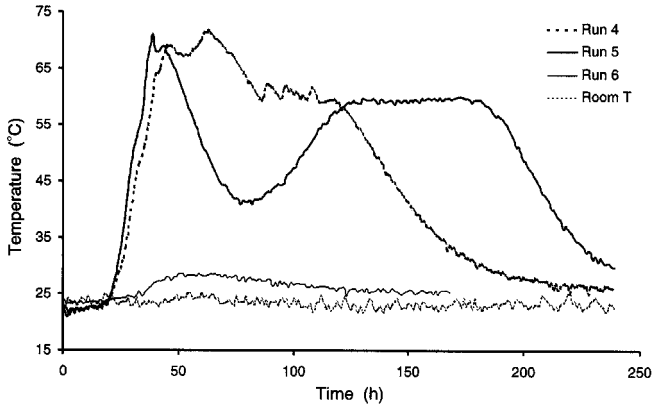

Fig. 3. Temperature profiles of experimental Runs 4, 5, and 6. Synthetic food waste (dry dog food) with 1% (w.b.) chicken manure as inoculum.

The main response variables were: (1) temperature profile, (2) heat generation, (3) pathogen reduction requirement fulfillment, (4) reduction in oil content, (5) reduction in volatile solids, and (6) reduction in total mass and water content. A total of eight experimental runs were performed (see Table 2).

Change in total mass and moisture content

As shown in Table 3, wet mass reductions were on average 3.0% and 36.3%, for the control runs and other experimental

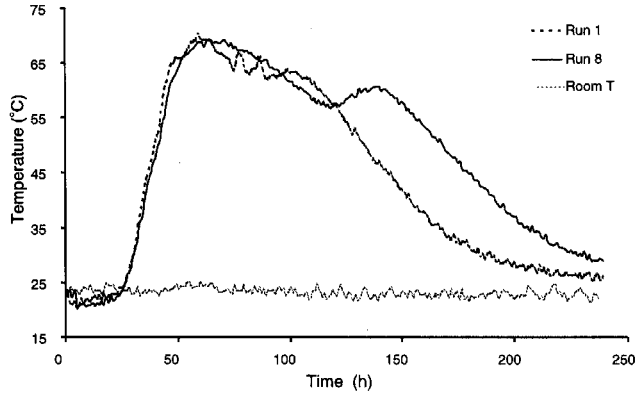

Fig. 4. Temperature profiles of experimental Runs 1 and 8. Synthetic food waste (dry dog food) with 5% (w.b.) of chicken manure and activated sludge as inoculum, respectively.

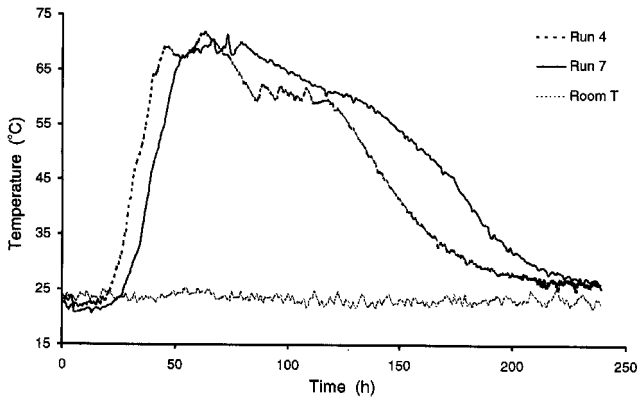

Fig. 5. Temperature profiles of experimental Runs 4 and 7. Synthetic food waste (dry dog food) with 5% (w.b.) of chicken manure and activated sludge as inoculum, respectively.

Table 3. Changes in total mass and moisture content for runs 1 to 8.

Run #	Reduction in total mass (% of initial wet mass)	Reduction in water content (% of initial water content)
1	33.1	49.9
2	36.8	50.0
3 - control	3.8	8.2
4	39.8	59.9
5	41.4	58.4
6 - control	2.2	3.5
7	34.1	48.7
8	32.5	42.8

Table 4. Initial content and changes in volatile solids and FOG after composting.

Run #	Initial volatile solids (kg ds)	VS change (kg ds)	Initial FOG content (kg ds)	FOG change (kg ds)
1	0.697	0.114	0.075	0.0550
2	0.634	0.147	0.016	0.0110
3 - control	0.419	0.008	0.004	0.0015
4	0.678	0.120	0.074	0.0480
5	0.618	0.134	0.019	0.0115
6 - control	0.417	0.004	0.005	0.0010
7	0.618	0.113	0.067	0.0475
8	0.614	0.145	0.065	0.0515

runs, respectively. The lower wet mass reductions (2.2-3.8%) for the control runs coincided with mesophilic temperatures which were not high enough to drive off the excessive moisture. In contrast, thermophilic runs had higher wet mass reductions (32.5-41.4%). Reductions in water content being 5.9% for the control runs and 51.6% for the thermophilic runs further supported this argument.

Volatile solids reduction and FOG biodegradation

Table 4 summarizes the data on volatile solids reduction and lipids degradation. Volatile solids reductions for the mesophilic runs (control) were minimal, ranging from 1 to 2%. In contrast, the thermophilic runs had an average volatile solids reduction of 20%. These findings coincide with the observations of Viel et al. (1987b) who found that only 20% of the organic matter (as volatile solids) was degraded when composting flotation foams. In addition, Fernandes et al. (1988) found organic matter reductions of 15 to 44% (of initial dry weight).

Lipids concentration was reduced by 21 to 79% in all runs. It was observed that mesophilic runs attained lower FOG biodegradation values (29% on average). The thermophilic runs had an average reduction of 70%, with a maximum of 79%. As reported by Haug (1993), oil and grease wastes were readily degradable under aerobic composting conditions. The highest FOG biodegradation value is closer to the 85-95% FOG biodegradation range reported in the literature (Fernandes et al. 1988; Viel et al. 1987b). Figures 6 and 7 give a more detailed comparison between the runs in terms of volatile solids and FOG reductions.

Heat production

The value of cumulative heat produced during the entire composting period was calculated by two methods. The first method was based on Calorimetry (Empirical Method, discussed in detail by Haug 1993 and Ndegwa et al. 2000) and made use of the actual temperature data and operational parameters in the heat balance, which includes heat loss (sensible and latent, Q_{lost}), heat accumulation ($Q_{accumulated}$), and heat production ($Q_{produced}$), as represented by:

$$Q_{produced} = Q_{accumulated} + Q_{lost} \quad (1)$$

$$Q_{lost} = UA\left(T - T_{ambient}\right) + m_{air}\left(h_{exhaust\ gas} - h_{inlet\ air}\right) \quad (2)$$

$$Q_{accumulated} = MC_p \frac{dT}{dt} \quad (3)$$

where:

U = overall heat transfer coefficient (0.03 W m^{-2} $°C^{-1}$),
A = surface area (1.65 m^2),
T = temperature of the composting materials (°C),
m_{air} = mass flowrate of air passing through the composting materials (kg/s),
h = enthalpy of air (J/kg),
M = compost mass (kg w.b.), and
C_p = specific heat of the composting mix (0.65, 4.18, and 1.9 kJ kg^{-1} $°C^{-1}$, for compost, water, and oil, respectively).

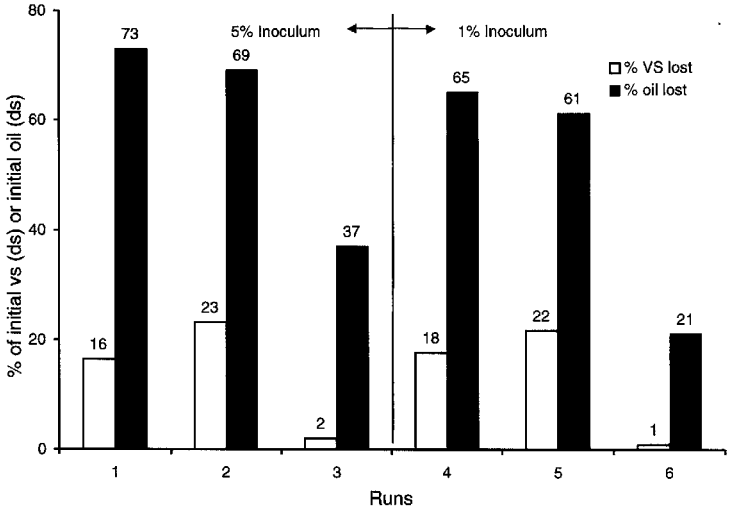

Fig. 6. Volatile solids and oil content reductions for experimental Runs 1 to 6.

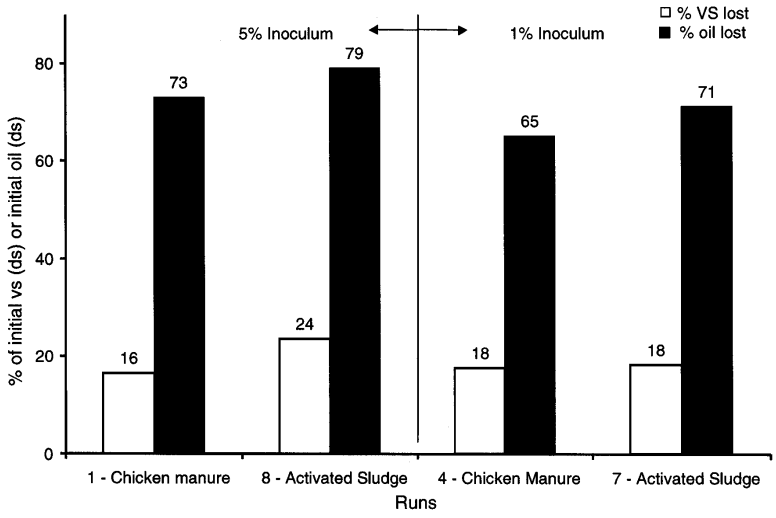

Fig. 7. Volatile solids and soil content reductions for experimental Runs 1 vs 8 and 4 vs 7.

Cumulative (whole composting period) heat values derived from actual data were from 1.7 to 3.4 MJ for the thermophilic runs, which is one order of magnitude greater than the mesophilic runs (Control) that generated 0.07 to 0.17 MJ of heat.

The second method (stoichiometric method, as discussed by Tchobanoglous et al. 1993) estimated heat production based on the amounts of volatile solids and oil degraded and their respective heats of combustion. See Eq. 4 for details. Figure 8 shows the cumulative heat production values estimated by these two methods.

$$Q_{produced} = m_{solids\ consumed} Q_{combustion\ solids} + m_{oil\ consumed} Q_{combustion\ oil} \quad (4)$$

where:

$Q_{combustion\ solids}$ = 13.9 MJ/kg and
$Q_{combustion\ oil}$ = 38.5 MJ/kg.

On average, the cumulative heat production calculated on the basis of temperature data (Method 1) and heat of combustion (Method 2) differs by 16%. Figure 9 depicts the contribution from oil to the total heat generated, which is on average 60%. This value agrees with the "2/3 contribution" reported by Viel et al. (1987b). The contribution of lipids to heat was higher for the runs where canola oil was added.

Effect of inoculum type and concentration

Runs 1 to 3 had chicken litter at 5% w.b. as inoculum, while Runs 4 to 6 had only 1% w.b. of the same inoculum. For comparison purposes, Run 7 used 1% activated sludge and Run 8 had 5% activated sludge as inoculum. The temperature profiles for runs with the same concentration of inoculum but different inoculum type were almost the same, as illustrated in Figs. 4 and 5. This suggests that both types of inoculum, chicken litter and activated sludge, had the microbial diversity needed for aerobic degradation. The lipid contribution to heat generation was independent of the type of inoculum added. Again, this was evident in Fig. 9, showing Run 1 vs Run 8 results (inoculum concentration of 5% w.b.), as well as Run 4 vs Run 7 results (inoculum concentration of 1% w.b.).

The difference between using a 1 or 5% inoculum concentration was not significant. However, from the temperature profiles, a higher initial concentration of inoculum tended to achieve more uniform temperature profiles. Schloss and Walker (2001) stated that the addition of inoculum (in this study 'more' inoculum) reduced the variability in the temperature data.

CONCLUSIONS

Aerobic biodegradation of synthetic food waste (dry dog food) loaded with lipidic compounds under thermophilic conditions produced acceptable results in terms of wet mass reduction and moisture removal. The pathogen reduction requirement, according to the CCME (1996) regulation, was achieved during thermophilic composting. Lipid content was substantially reduced (by 70%) for the short processing period of 10 days, whereas volatile solids content reductions were in the 20% range. Either activated sludge or chicken litter worked very well as inocula for lipid-rich wastes composting.

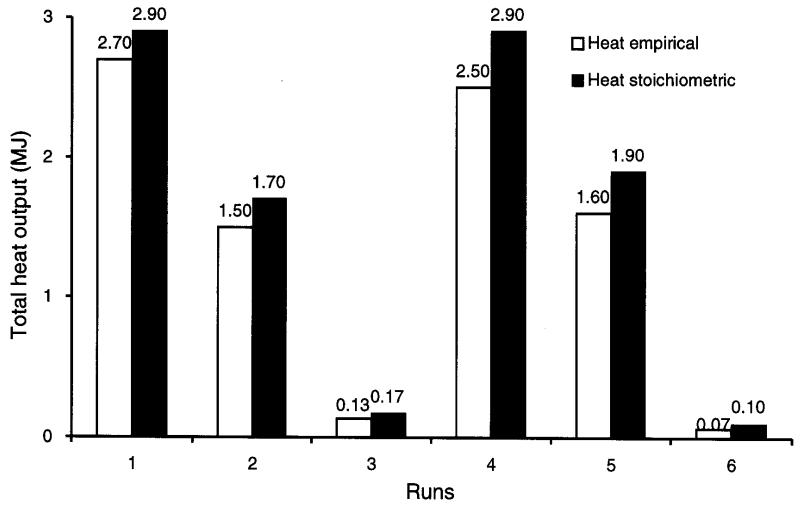

Fig. 8. Cumulative heat stoichiometric and empirical methods for experimental Runs 1 to 6. Substrate: synthetic food waste (dry dog food).

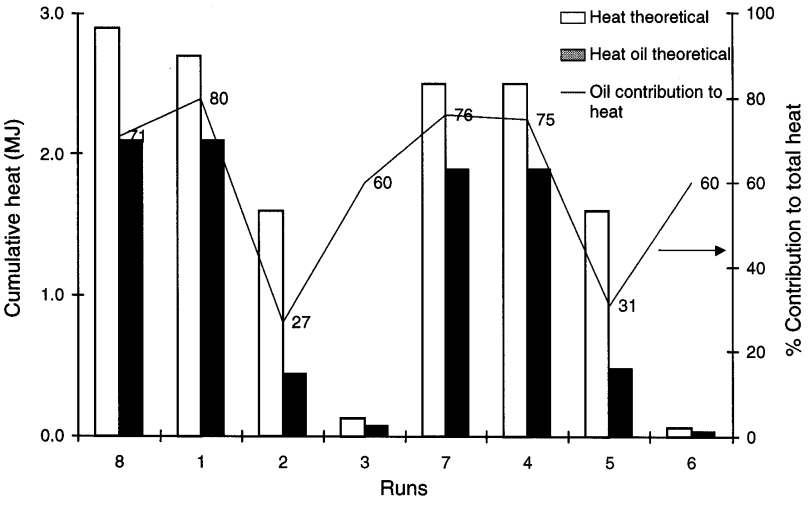

Fig. 9. Cumulative heat generation total (stoichiometric method), total and percent contribution of oil to total heat, for experimental Runs 1 to 8. Substrate: synthetic food waste (dry dog food).

Heat production was calculated based on an energy balance (empirical method) taking into account heat losses and heat storage, and by using the heat of reactions (stoichiometric method) of the degraded fractions (volatile solids and oil). Both methods prove to be suitable to calculate the cumulative heat generated.

The aim of this study was to evaluate the feasibility of an environmentally friendly treatment option for organic wastes and FOGs residues, thereby helping in reducing the environmental impact due to FOG residues current disposal practices.

ACKNOWLEDGEMENTS

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