New Kinetic Modeling Parameters for Composting Process Applied to Composting of Chicken Manure

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Abstract

This study aimed to evaluate the applicability of the area lying below the process temperature as a function of time (ALT) and an area lying between ambient and process temperature as a function of time (ALAT) as kinetic parameters to determine optimum mixture ratio of chicken manure, sawdust and wheat straw for composting. Therefore, materials were mixed at different ratios and composted in 64 L - experimental composting reactors. Results showed that optimum mixture ratio was found as 60% chicken manure, 30% sawdust and 10% wheat straw on dry weight.

The three different kinetic models were applied for modeling decomposition rate to the experimental values. Three different kinetic parameters, which were average of daily process temperature (T), ALT and ALAT, were used in these models as temperature function. Performance of kinetic models was analyzed with Chi-square (χ^2), root mean square error (RMSE) and modeling efficiency terms (EF). Statistical analysis revealed that all models were found to be applicable to this study but when ALAT used as temperature function, all models yielded more correct model results.

Key words: Composting, chicken manure, optimum mixture ratio, modelling of composting process, kinetic models, new kinetic parameters.

Introduction

Recently, composting and biogas production from wastes are very important disposal processes in TURKEY due to environmental pollution from wastes and rising fertilizer prices (Kulcu and Yaldiz 2005, Sönmez 2012).

Composting has been defined as a controlled microbial aerobic decomposition process with the formation of stabilized organic materials that may be used as soil conditioners and/or organic fertilizer and growing media (Garcia et al. 1992, Schlegel 1992, Tateda et al. 2005, Hoyos et al. 2002, Xi et al. 2005, Olle et al. 2012).

The number of chicken stocks in Turkey was 237 873 469 in 2011 (TurkStat 2012).

Chicken manure can be used as nitrogen source since it is rich in nitrogen content. On the other side, sawdust is rich in carbon content, it can be used as a carbon source as well as bulking agent.

Kinetic model can be used as a tool to study composting process on an industrial scale for the optimization of the process. The degradation rate of waste can be predicted using kinetic models of the process indicators (temperature, organic matter content, moisture content, O_2/CO_2 concentration, pH, C/N ratio, particle size, etc.) (Petric et al. 2012). Modeling of composting kinetics is necessary to design and operate composting facilities that comply with strict market demands and tight environmental legislation (Hamelers 2004).

There have been many studies on kinetic modeling composting, which the first-order equation is the most common form to model kinetic of composting process (Baptista , 2009). Various models were developed by researcher (Haug 1993, Ekinci et al. 2001, Hamoda et al. 1998, Bari et al. 2000, Paredes et al. 2000, Kulcu and Yaldiz 2004, Baptista et al. 2010). All models used process temperature as base process parameter.

This study aimed to increase the predictivity of kinetic models for modeling of decomposition rate. The three different kinetic models were applied for modeling decomposition rate to the experimental values. Three different kinetic parameters, which were average of daily process temperature (T), ALT and ALAT, were used in these models as temperature function.

Materials and Methods

Chicken manure, wheat straw and sawdust were used as experimental materials. The nitrogen content of chicken manure, wheat straw, and sawdust was 2.01, 0.51, and 0.24 %, respectively (Table 1).

Table 1. Chemical properties of raw materials

	Moisture Content (%w.b.)	Organic Material (OM)(%)	N (%)	C (%)	C/N
Sawdust	3.81	76.06	0.24	42.25	176.04
Wheat Straw	16.11	84.11	0.51	46.72	91.60
Chicken Manure	60.24	51.13	2.01	28.40	14.13

Chicken manure, wheat straw, and sawdust were mixed at four different ratios to determine optimum mixture ratio. C/N ratios and Free Air Spaces (FAS) of each mixtures were different due to their physical and chemical properties (Table 2).

Table 2. Chicken manure, wheat straw, and sawdust mixture ratio in composting reactors (dry basis)

Reactor	Chicken Manure (%)	Wheat Straw (%)	Sawdust (%)	C/N	Free Air Space (FAS)(%)
Reactor 1	50	10	40	33.72	32.12
Reactor 2	70	10	20	25.14	28.21
Reactor 3	55	20	25	32.24	39.06
Reactor 4	60	10	30	27.11	30.13

The heat generated in composting process is a result of microbial metabolism and the accumulation of the heat energy retained within the composting mass. There were three temperature probes inside of each reactor fixed at 27 cm from plenum with equally spaced horizontally measured data with 30 minute intervals (Figure1). CO_2 and O_2 concentration levels were measured by a digital waste gas analyzer once a day. Organic material content (OM) and moisture content were measured daily. Moisture content of the experimental material was analyzed by drying oven method at 105 ˚C (APHA 1995). Organic matter contents of the materials were measured by burning in oven at 550 ˚C for 5h (APHA 1995). The organic matter (OM) contents were calculated according to the following equation (Navarro et al. 1993);

$$OM(\%) = ((W_{105} - W_{550}) / W_{105}) \qquad (1)$$

Losses of organic matter (OML) were calculated from the initial and final volatile solid contents, according to the following equation (Haug 1993):

$$OML = \frac{\lfloor OM_m(\%) - OM_p(\%) \rfloor 100}{OM_m(\%).[100 - OM_p(\%)]} \qquad (2)$$

Four cylindrical reactors, each of which has effective volume of 64 L, were built with plastic material and isolated with 50 mm glass wool. Air was supplied with radial fan (Figure 1). The aeration period was adjusted by timers to 15 min in one hour. Composting study was performed in greenhouse and process lasted for 21 days.

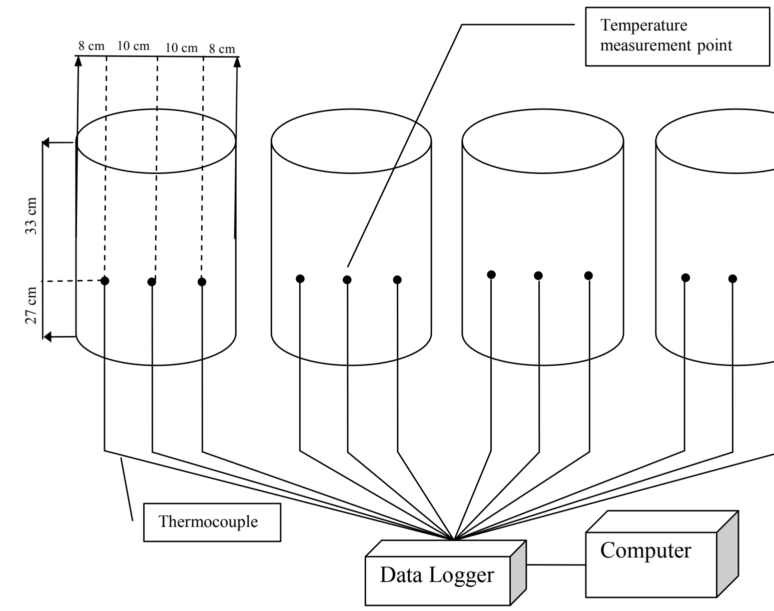

Figure 1. Experimental composting reactors.

Kinetics of Composting

To determine biodegradability of waste and generate a useful measure for the loss of organic matter during composting, it is necessary to determine process kinetics using data obtained by experimental study under controlled conditions. The degradation of organic matter as a function of time follows first-order kinetics were calculated according to the following equation (Haug 1993, Hamoda et al. 1998)

$$\frac{d(OM)}{dt} = -k(OM) \quad (3)$$

where OM is the quantity of biodegradable volatile solids at any time of the composting process in kg, t is time in days, k is the reaction rate constant.

Three different kinetic models were used for decomposition rate. The description of the decomposition rate and other process characteristics which was in relation with kinetic models, was verified by applying models given in Table 3. Model 1 was modified by changing reference temperature point of Haug's model (Haug 1993). While the original model employed k_{20} (k values at 20˚C) and T-20 function, Model 1 used k_{min} (k values at minimum temperature). Model 2 was developed by Ekinci (Ekinci et al. 2001), which was function of initial moisture (M_i) of material and temperature values (T). Model 3 was developed by Kulcu and Yaldiz (2004), which was a function of process temperature (T) and moisture content of material (M_c).

Table 3. Kinetic Models used in the study

Model No	Kinetic Models
Model 1	$k = k_{\min} . a^{(T - \min)}$
Model 2	$k = a . e^{b . \left[\left(\frac{M_i - c}{d} \right) + \left(\frac{T - f}{g} \right) \right]}$
Model 3	$k = \frac{\frac{a}{M_C}}{T - (C.b)} . e^{\left[(T.c) - (\ldots \right.}$

In this study, process temperature (T), ALT, which is the area lying below the temperature as a function of time, (ºC.days), and ALAP, which is area lying between ambient and process temperature as a function of time (ºC.days) were used as temperature parameters in models. ALT and ALAP were calculated with Mathlab 6.5 software using Trapezodial Numerical Integration function.

The suitability of the models was compared and evaluated using Chi-square (χ^2), root mean square error (RMSE) and modeling efficiency (EF);

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \left(k_{pre,i} - k_{\exp,i} \right)^2}{N}} \tag{4}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(k_{\exp,i} - k_{pre,i}\right)^2}{N - n} \tag{5}$$

$$EF = \frac{\sum_{i=1}^{n}\left(k_{\exp,i} - k_{\exp,mean}\right)^2 - \sum_{i=1}^{n}\left(k_{pre,i} - k_{\exp,i}\right)^2}{\sum_{i=1}^{n}\left(k_{\exp,i} - k_{\exp,mean,i}\right)^2} \tag{6}$$

Reduced Chi-square is the mean square of the deviations between the experimental and calculated values for the models and, is used to determine the goodness of the fit. The RMSE shows the deviations between the calculated and experimental values and it requires reaching zero. The modeling efficiency also shows the ability of the model and its highest values is 1 (Yaldiz et al. 2001).

Results and Discussion

The average of three temperature of each reactor during the active composting is presented in Figure 2. Generally, temperature ranging from 52 to 60 ˚C are considered to maintain the highest thermophilic activity in composting systems (MacGregor et al. 1981), temperature of 55 ˚C for 3 days is necessary to destroy the pathogens in piles (Rynk et al. 1992) and temperature exceeding 60-65 ˚C would kill almost all microorganisms and cause the process to cease (Golueke and Diaz, 1996; Huang et al. 2005).

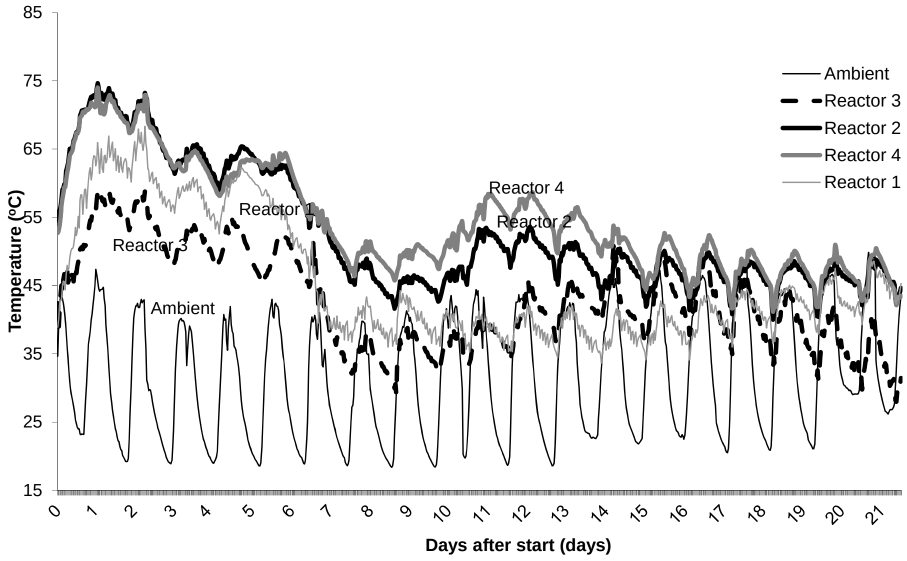

Figure 2. Temperature changes in all reactors during composting process.

In the first 3 days, compost temperature in each reactor rose quickly to their peaks, especially that of R4 and R2. R1 and R3 compost reactors yielded lower temperature than the others during the composting process. Compost temperature in R3 reactor reached to 56˚C in the first 3 days, afterwards decreasing gradually to 30-38˚C. The highest temperature values were in R4 reactor during the process. Except R3, all the other reactors provided thermophilic temperatures more than 3 days for destroying of pathogens. Ambient temperature fluctuated very rapidly during composting since reactor systems were located in greenhouse during the study (Figure 2).

The moisture contents of the samples decreased continuously during composting. Initial moisture content of the mixtures was around 65-75% (wet basis, wb.), because of the different water holding capacity of mixtures. Water loss was the similar for all the composting reactors during the process (Figure 3).

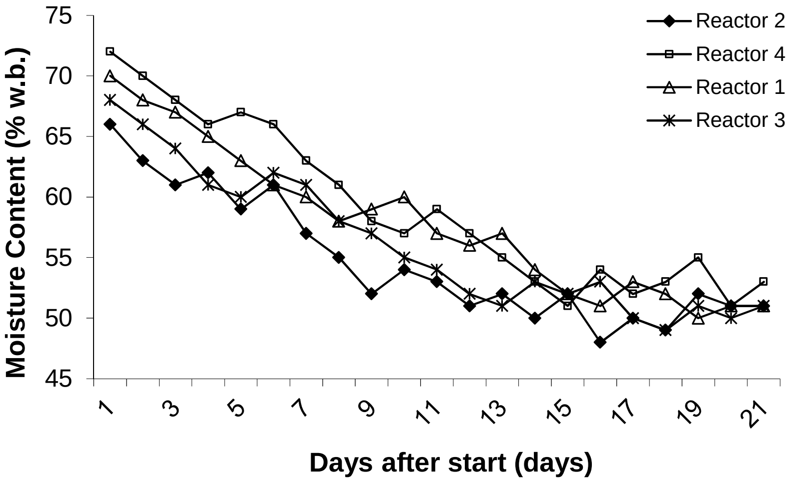

Figure 3. Moisture content changes in mixtures during composting.

As shown in Figure 4, organic material content of mixtures decreased gradually during the process, this decrement was faster in R4 than the others. Final organic matter content was calculated as 52.11, 53.05, 51.13, and 48.22% for R1, R2, R3, and R4, respectively.

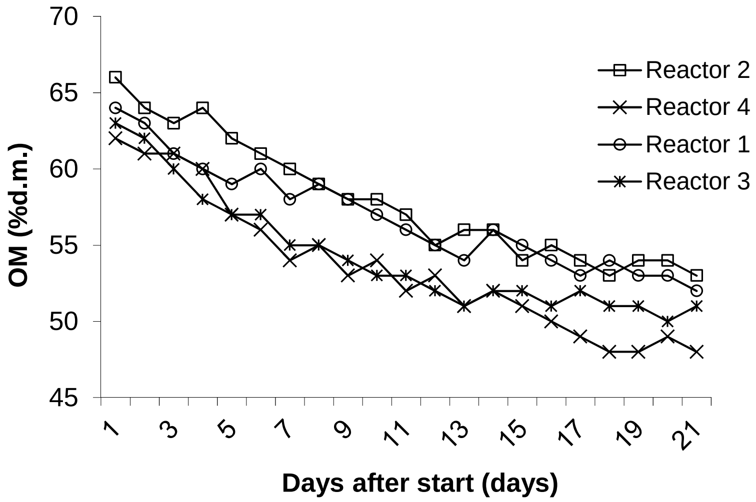

Figure 4. Organic matter content changes in mixtures during composting.

Organic material loss (OML) values were given in Table 4. The organic matter loss was calculated as 39.18, 41.21, 38.23, and 43.67 % for R1, R2, R3, and R4, respectively.

Table 4. OM loss (OML) of mixtures at the end of composting process

	Reactor 1	Reactor 2	Reactor 3	Reactor 4
OML	39.18	41.21	38.23	43.67

CO_2 is produced as results of mineralization of organic matter in the substrate. Figure 5 shows the results of the mean CO_2 changes inside each reactor. CO_2 concentration level increased in all the reactors in proportion to microorganism activity during the process. CO_2 concentration was higher in R4 and R2 than the others.

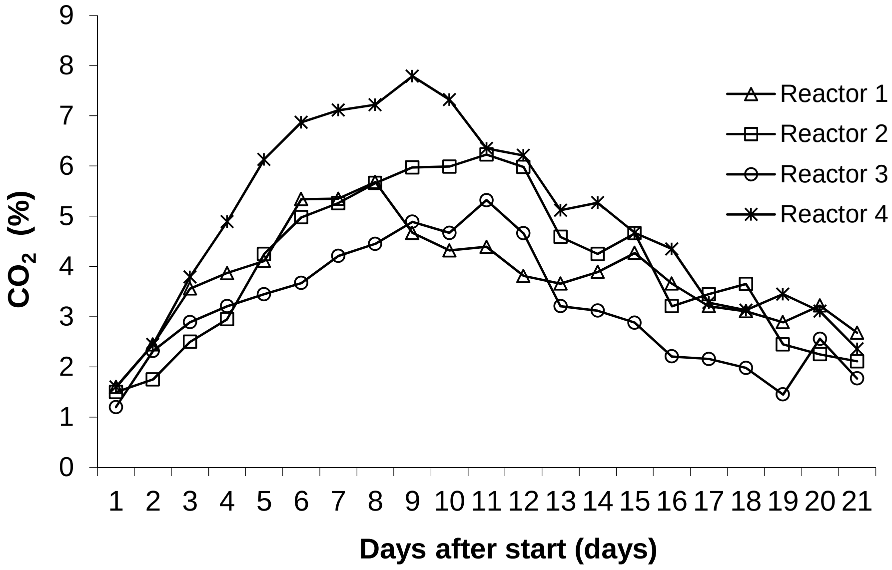

Figure 5. CO_2 rate changes in the reactors during composting.

O_2 concentration level decreased in all the reactors in proportion to microorganism activity during the process. O_2 concentration level of reactors decreased but these values were not below 8% in all reactors during the composting process. O_2 concentration of R2 and R4 were lower than others. Since the bottom limit value of O_2 for aerobic microorganism is 5%, all the reactors provided aerobic conditions (Figure 6).

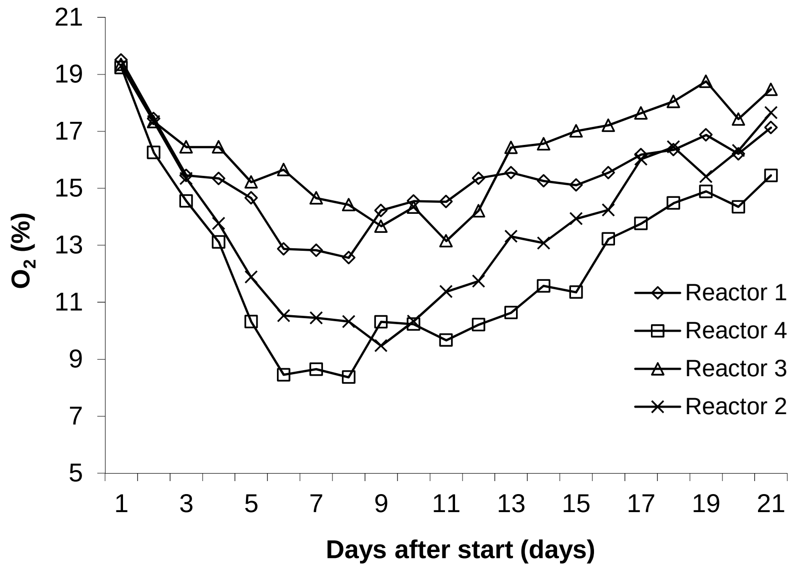

Figure 6. O_2 rate changes in the reactors during composting.

Results of statistical analysis (RMSE, χ^2,and EF) of models were given in Table 5. Statistical analyses showed that; when ALAP used as temperature parameters, RMSE and χ^2 of all the model values decreased and EF values increased. Model 1 showed lower EF and higher RMSE and χ^2 values than the others since it uses only temperature functions. RMSE and EF values of Model 2 and Model 3 calculated were closed to each other. However, χ^2 value of Model 3 was lower than Model 2 since it employs fewer constants.

Table 5. Results of statistical analysis

Parameter		RMSE	χ^2	EF	a	b	c	d	f	g
ALAT	Model 1	0.0112629	0.0001335	0.5667	0.9998	-	-	-	-	-
	Model 2	0.0090109	0.0000855	0.6900	-53687091.19	-14694024.83	5.3430	3846.28	5.3519	142687.39
	Model 3	0.0084559	0.0000753	0.8690	68.7383	0.0274	0.0015	-0.1093		
ALT	Model 1	0.0115309	0.0001509	0.5376	0.9999	-	-	-	-	-
	Model 2	0.0151102	0.0001399	0.6587	0.0057	0.0009	1.0000	1.0005	1.00000	1.0079
	Model 3	0.0096908	0.0000988	0.7838	127.6732	6.9020	0.0020	3.5846	-	-
T	Model 1	0.0119730	0.0002403	0.5236	0.9920	-	-	-	-	-
	Model 2	0.0163148	0.0002802	0.5771	0.0298	-12.7932	46.595	21.7649	61.7676	21.4462
	Model 3	0.0096977	0.0000989	0.6295	1.3272	0.1353	0.0632	-0.1193	-	-

Conclusions

Results showed that the highest organic matter degradation and temperature value were obtained in the R4. Thus, chicken manure of 60%, sawdust of 30% and wheat straw of 10% on dry basis mixture ratio could be applied for composting process.

Based on results of the statistical analysis, it can be said that all kinetic models were found to be applicable to this study but when ALAP and ALT used as temperature functions, all kinetic models yielded more accurate results when comparing with the experimental values.

Acknowledgments

This paper was made possible by funding from the Research Fund of Suleyman Demirel University, Isparta, TURKEY.

Nomenclature

W_{105}- Oven dry weigh of mass at 105 ˚C

W_{550}- Furnance dry weight of mass at 550 ˚C

OML : Loss of organic material

OM_m- Organic material content at the beginning of the process

OM_p - Organic material content at the end of the process

OM- the quantity of biodegradable volatile solids at any time of the composting process

t- Time in days

T- Process temperature (°C)

M_c- Materials daily moisture content (%wb)

M_i- Materials initial moisture content (%wb)

C- Daily CO_2 rate in composting reactor (%)

k- the reaction rate constant

k_{exp}- experimental reaction rate (g om/g om day)

$k_{exp,mean}$- mean value of experimental reaction rate (g om/g om day)

k_{pre}- Predicted experimental reaction rate

N- Number of observations

n- Number of constants in the model

RMSE- Root mean square error

χ^2 – Chi-square

EF- Modeling efficiency

a,b,c,d,f,g-Constans of kinetic models

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