

Application of a Maturity-accelerating Reagent (MAR) to Food Wastes Composting Processes

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In order to increase the degradation rate of organic materials and reduce ammonia emissions simultaneously during the aerobic composting period, a commercial maturity-accelerating reagent (MAR) was employed. Comparative composting experiments were conducted: Run A with the addition of MAR in the composting mixture, and Run B without the addition of MAR, while some parameters such as organic carbon, ammonia, and pH were measured under controlled air flow rate in the composting process. After 26 days of composting, the experimental results revealed that the degradation rate in Run A ($21 \text{ g kg}^{-1} \text{ d}^{-1} \text{ DM}$ (dry mass)) was higher than that in Run B ($18 \text{ g kg}^{-1} \text{ d}^{-1} \text{ DM}$) by 16.7 %, while ammoniacal N (NH_3 and NH_4^+) retained in Run A was $13.6 \text{ g kg}^{-1} \text{ DM}$, which was more than that in Run B ($8.3 \text{ g kg}^{-1} \text{ DM}$), possibly because struvite crystal was formed. Apparently, the application of MAR had a positive effect on composting wastes, not only promoting organic degradation and nitrogen conversion, but also improving the quality of the compost, to be used as soil amendment in agriculture.

Key words:

Ammonia emissions, degradation rate, struvite crystal, ammoniacal nitrogen, oxygen uptake rate

Introduction

Food wastes (FWs) are generated from households, educational eateries, institutions and the food industry,¹ amounting to various percentages of municipal solid wastes (MSWs) for various local conditions, e.g. household waste accounts for 40 % of MSW in Allahabad, India,² and 48.9 % in Spain.³ In general, MSWs are usually disposed by incineration, landfill, and composting.⁴ However, it is unsuitable to generate electricity by incineration for high moisture contents of MSWs, even worse, some carcinogen compounds are formed in incineration process simultaneously.⁵ Landfill gases affect the environment, human health and quality of life, and landfill sites are known to create leachate containing organic and inorganic pollutants as well,⁶ which poses a threat to ground water.⁷ Composting has proved to be a sustainable and environmentally friendly alternative as a resource or for the reuse of organic wastes, known as soil amendment in agriculture. However, composting is likely to impact the ambient atmosphere for the odorous gas especially ammonia emissions which is given great attention in waste management scopes.⁸

Many technologies have been developed for recycling of FWs as new resources, such as compost,^{9,10} anaerobic digestion,¹¹ biotechnology with earthworm,¹² fermentative production of lactic acid,¹³ and biological hydrogen production.^{14,15} It is difficult to remove harmful materials from FWs for animal feed and keep the useful ingredients from decomposing during transportation or storage.¹⁰ The FWs containing high carbohydrate materials are always used as raw materials for methane or hydrogen production.¹⁶ Biotechnology with earthworm employs earthworms to degrade organic materials and stabilize wastes. Besides, there are also several advantages for FWs to be composed, e.g. recycling elements such as phosphorus and nitrogen with agronomic interest, reduction of the initial volume of waste, elimination of toxic organic substances¹⁷ and decrease in contamination generated by heavy metals and some toxic substances.¹⁸ Hence, compost products are extensively applied as fertilizers or soil amendments. However, traditional composting causes major loss of nitrogen mainly in NH_3 form, and NO_x and N_2 form as well,¹⁹ which leads to the reduction of the agronomic value of the compost.²⁰

Ammonia (NH_3) is the main factor responsible for offensive odors, atmospheric contamination and

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nitrogen nutrient loss, particularly composting FWs alone. Many investigations conducted on ammonia emissions have indicated that initial C/N ratio, temperature, and pH are the main parameters influencing ammonia emissions. It is commonly considered that more nitrogen loss with lower C/N ratio, however, a higher initial C/N ratio can not prevent nitrogen loss effectively.¹⁹ The data of ammonia emitted in the composting of five wastes with mixing of bulking agent implies that the ammonia emission pattern significantly depends on process temperature, an exponential increase when process temperature increases in thermophilic stage of composting, and a linear correlation was found between ammonia emissions and temperature in mesophilic stage of the composting process.²¹ With increasing pH, more NH₃ will be emitted to the compost free air space. Some inorganic chemicals have been employed to increase the acidity of compost wastes²² such as alum Al₂(SO₄)₃, used in composting poultry litter.²³ In many other studies, the means of using intermittent aeration have proved effective in reducing ammonia emissions.²⁴

However, most of the relevant literature only involves mature compost or nitrogen loss. In the present paper, a commercial maturity-accelerating reagent (MAR), which was invented by Yu²⁵ *et al.* and justly used in the corn stem disposal field, was applied to the composting of simulated FWs in order to shorten the degradation process and improve the quality of the compost. Therefore, this study aimed to investigate (1) the effects of the MAR on the FWs mainly on organic decomposition rate, and (2) the ammonia emissions under controlled experimental conditions.

Materials and methods

Experimental apparatus and raw materials

In this study, a composting reactor with 30 L of working volume was employed. Fig. 1 displays a schematic diagram of the experimental apparatus. The cylindrical composting reactor was constructed using an acrylic column 300 mm in diameter, 450 mm in height, with a wall thickness of 6 mm, and a working volume of 30 L. Three layers of heat-insulating materials were employed to prevent loss of conductible heat. A heavy-duty aluminum foil was put on the inner layer for reflecting heat. Foam insulation material was used to fill the spaces between the reactor's surface and pillars. An insulator filled with fiberglass of 3.5 mm in thickness was used as the outer layer around the reactor.

Two thermometers (Traceable 15-077-9E; Control Company, Friendswood, TX, USA) were

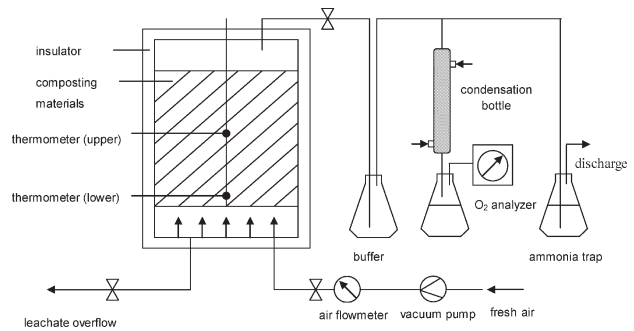


Fig. 1 – Schematic diagram of the composting system

placed at the center (lower and upper levels) of the reactor to monitor temperatures. The lower one was set at 1 inch from the segmentation plate and fixed.

The MAR consisted of ferrous chloride, magnesium phosphate, potassium nitrate, calcium cyanamide, and sodium bisulfite with $w = 60\%–80\%$, $6\%–10\%$, $2\%–4\%$, $10\%–22\%$ and $2\%–4\%$, respectively,²⁵ and most components of the reagent were necessary and favorable to bacterial growth.²⁶ The simulated FWs mixture including potatoes, rice, carrot, leaves, pork, soybean, and seed soil was used as the composting substrate in this study. The composting substrate was minced into pieces of less than 5 mm in diameter using a food processor (Philips International, The Netherlands) and mixed well before the composting process. Approximately 125 g of the MAR was dissolved in 700 g water, and then mixed with approximately 10 kg wet simulated FWs mixture. Finally, the simulated FWs mixture was loaded in the composting reactor. The detailed composition of the simulated FWs for the composting process is presented in Table 1. The initial characteristics of the simulated FWs are given in Table 2.

Table 1 – Composition of food wastes (FWs)

Components	Run A	Run B
potatoes (kg)	1.27	1.27
carrots (kg)	1.96	1.96
meat (kg)	0.35	0.35
rice (kg)	2.01	2.01
soybean (kg)	1.96	1.96
leaves (kg)	0.46	0.46
seed soil (kg)	2.00	2.00
MAR (g)	125	0
water added (g)	700	700

Table 2 – Characteristics of experimental food wastes (FWs)

Parameters	FWs
moisture (w/%)	66 ± 2
dry matter (w/%)	35 ± 1.5
organic matter (w/% DM)	18.9 ± 0.1
NH ₄ ⁺ -N (w/% DM)	11.2 ± 0.1
C/N ratio	17 ± 0.3
pH	5.8 ± 0.2
ash content (w/%)	7.2 ± 0.2

Experimental design

In order to clearly compare and analyze the effects of the MAR on the degradation rate of organic materials and ammonia loss during the FWs composting processes, two sets of experiments were carried out using in-vessel composting reactors. In Run A, the MAR was added to the turning composting mixture. Run B was conducted as a control treatment without the MAR and duplicate of Run A and B were carried out.

The composting reactors were run in a laboratory where the ambient temperature was $\theta = 20 \pm 1$ °C. Air was driven to the bottom of each reactor by a vacuum pump (MOA-P101-AA; GAST Manufacturing Inc., Benton Harbor, MI, USA) and evenly distributed to the FWs mixture through a perforated plate at a flow rate of 0.4–6.0 L min⁻¹. The exhaust gas from the reactor passed through a condensate trap (with a buffer flask) and 100 mL of 1 mol L⁻¹ H₂SO₄ solution in series to capture moisture condensate and ammonia, respectively. Finally, the gas was discharged to the laboratory ventilation system. When the simulated FWs mixture was loaded into the reactor, the original sample was taken immediately and the composting reaction was started, and the reaction time was marked as zero simultaneously. The reactor was opened once every two days for weighing, turning, observation, and sampling. The materials in the reactor were stirred well with a shovel to homogenize the mixture, expose new surfaces, and keep the material permeable to airflow.²⁷ Then samples were taken from different levels of the reactor. After mixing, sub-samples (about 5 g) of each 50 g were drawn randomly for analysis of moisture content, pH, organic carbon, and ammoniacal nitrogen.

Analytical methods

Oxygen in the exhaust gas was tested using an M40 multi-gas monitor (Industrial Scientific Corp., Oakdale, PA, USA). The pH of the compost (5 g

fresh mass) was diluted with 10 mL deionized water and measured using a benchtop pH/temperature meter (410Plus; Thermo Orion, Waltham, MA, USA) after shaking for 30 min.²⁸ Moisture content in the compost was determined after drying at 105 °C overnight. Volatile matter was measured by heating samples at 550 °C for 4 h.²⁰ A solid sample was acidified by pouring 3 mL of 0.1 mol L⁻¹ H₂SO₄ over the entire sample before drying to avoid NH₄⁺-N loss, and the dry sample was then ground to homogeneous powder for analysis. Ammonium nitrogen in solid samples was analyzed using the FIAstar 5000 Analyzer (Foss Analytic AB, Hoega-naes, Sweden). A LECO TruSpec CN determinator (LECO Corporation, St. Joseph, MI, USA) was employed to measure the total amount of carbon and nitrogen in the compost. The thermometers were adjusted every day with the decrease of material height using the reading of the upper one as the temperature of the compost. The population of microorganisms was measured using the spread plate counting method. Ashby's mannitol agar was used as incubation media for isolation of nitrogen-fixing bacteria.²⁹ The extent of the simulated FWs degradation was expressed as follow:

$$\eta = (\gamma_0 - \gamma_t) / \gamma_0 \quad (1)$$

Where η is the degree of degradation, γ_0 is expressed as initial dry mass of compost matter at composting time of 0, and γ_t as dry mass of compost matter at composting time of t day.

Results and discussion

Effects of the MAR on degradation degree of the simulated FWs

The degradation variation of the organic material is shown in Fig. 2. Until day 6, the degree of degradation in Run A reached 15.5 %, and 9.5 % in Run B, possibly because the biochemical, physical and chemical reactions occurred earlier in Run A. MAR was provided with many elements which were required to microorganisms. In the following 10 days, the degradation degree was similar. With the development of composting, the large molecular substances transformed into small molecular materials that could be digested directly by microorganisms in Run B, while in Run A, the available materials were insufficient during this period. At day 20, the degree of degradation stabilized: 45.9 % in Run B, and 54.5 % in Run A, which suggested that both runs had matured, almost all compost materials had converted into stable organic matter and the carbohydrates had transformed into H₂O and gases.³⁰

The average degradation rates were calculated: 21 g kg⁻¹ d⁻¹ DM and 18 g kg⁻¹ d⁻¹ DM for Run A

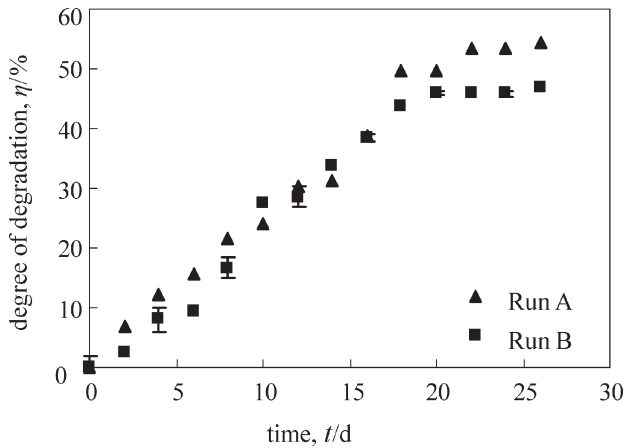


Fig. 2 – Degradation degree in the aerobic composting process

and Run B, respectively, during the composting process, the dry material from 3.8 to 1.75 kg and 3.4 to 1.79 kg in Run A and B, respectively, both of which show the organic degradation process. Bustamante *et al.* report that organic matter losses correspond to temperature variation.³⁰ The results of this study seem to contradict such a report in the period up to 10 composting days. The cumulative oxygen uptake of Run A (634 m³) is more than that of Run B (450 m³), indicating higher microbial activity in Run A. Therefore, it would be correct to conclude that the MAR promotes the activity of microbes, and consumes the organic matter quickly before the temperature change in the early compost period.

Change of pH in the aerobic composting process

The change in pH during the composting process is shown in Fig. 3. For the first 4 days, the pattern of pH is similar for both runs, and the pH drops from 5.8 initially to the lowest value 4.4 at day 4. After that period, the pH of Run B increases slowly until day 8, when it increases notably from acidic range to basic range and tends to maintain a constant value of approximately 8.4; the pH of Run A also increases slowly until day 14, and then a fast increase of pH from 4.9 at day 14 to 8.6 at day 18 is observed and remains constant. For the last several days, the pH value of Run A is slightly higher than that of Run B. The decline in pH value during the first 4 days of the composting process can probably be attributed to the generation of a large amount of short-chain organic acids such as lactic acid, acetic acid produced in the reactor.³¹ Slow increment of pH indicated that more ammonia was being produced than organic acids, and lots of ammonia reacted with the generated organic acids. It was assumed that in the fast increment phase, organic acids reduced fast because the activity of bacteria and

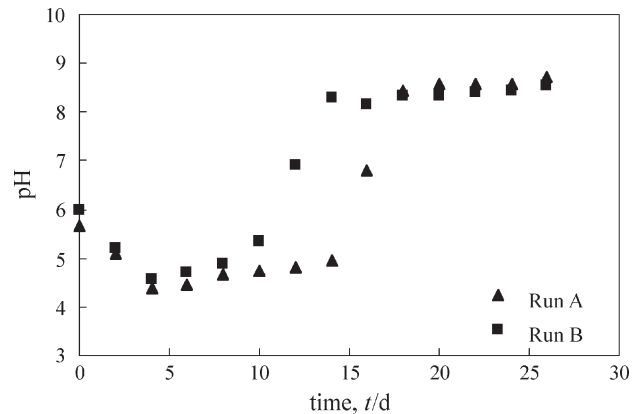


Fig. 3 – pH in the aerobic composting process

quantity of ammonia formed simultaneously.¹⁰ In the phase of constant pH, the composting system stabilized and the compost products matured.³²

Changes in O₂ uptake rate and temperature in the aerobic composting process

In addition to using temperature to monitor the composting process, monitoring respiration using oxygen uptake rate (OUR) is a very useful technique. OUR has been widely adopted for the evaluation of microbial activity and composting efficiency in composting researches.^{33,34} Fig. 4 shows the time dependence of OUR, while the temperature variation is shown in Fig. 5. These two figures clearly indicate that the OUR follows the temperature closely. For each run, the increases in OUR corresponded to temperature rises, and decreases in OUR corresponded to temperature drops. At the end of the composting process, the OUR had decreased to a very low, relatively stable value in both runs, indicating the completion of the composting. Run B showed a typical composting temperature profile, and continued its temperature rise up to 66 °C as mesophilic microorganisms had been overcome by thermophilic bacteria³⁵ and kept high

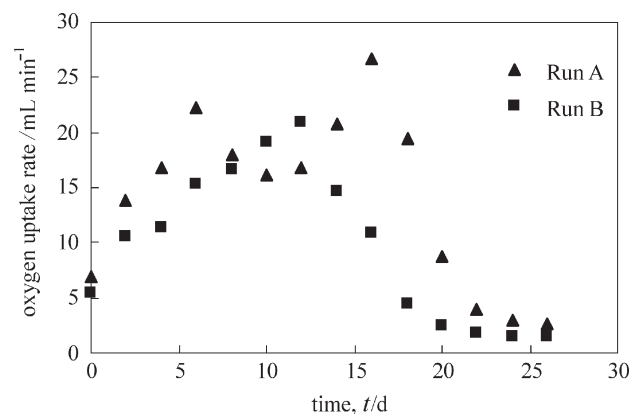


Fig. 4 – Changes in O₂ uptake rate in the aerobic composting process

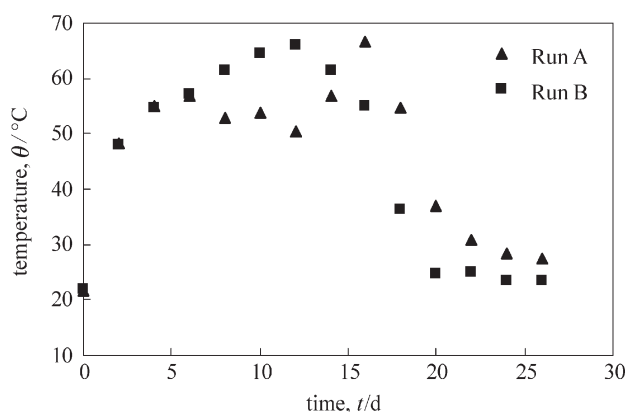


Fig. 5 – Temperature variation in the aerobic composting process

temperature ($> 55\text{ }^{\circ}\text{C}$) for more than 10 days. Temperatures higher than $55\text{ }^{\circ}\text{C}$ have been attributed to the elimination of pathogenic microorganisms.³⁶ However, Run A had an early drop around day 6 after they reached the first peak temperature. Similarly, OUR in Run A reached the first peak of 22.2 L min^{-1} at day 6, implying that the initial microbe was activated more quickly and was more active. The aerobic biodegradation and oxidation reactions are attributed to the abundance of available organic materials, and the large amount of organic acids were generated during the initial phase, which was assumed to explain the reason for this initial temperature drop. From day 8 to day 14, the OUR in Run A decreased subsequently, probably because the bacteria adapted to thermophilic phase and their activity became weaker for a while.³⁵ In the last few days, the O_2 uptake rates in both runs decreased extensively and leveled off, because of the weak microbial activity due to few available organic substances, low temperature, and almost ceasing variety of reactions.³⁷ Two major temperature peaks (about $57\text{ }^{\circ}\text{C}$ and $67\text{ }^{\circ}\text{C}$) along with OURs were observed at day 6 and day 16, respectively. This fact implies that the two major stages of the composting process were caused by two groups of bacteria. The decline in bacterial activity at $60\text{ }^{\circ}\text{C}$ and higher is in accordance with reported research.³⁷

Effects on loss of nitrogen in the aerobic composting process

Temporal variation in $\text{NH}_4^+\text{-N}$ in the solid phase is shown in Fig. 6. The variation tendency and concentration of the two runs were almost the same during the first 8 days, indicating that a small quantity of $\text{NH}_4^+\text{-N}$ was generated in this phase. In Run B, the $\text{NH}_4^+\text{-N}$ concentration abruptly increased from $2.1\text{ g kg}^{-1}\text{ DM}$ at day 8 to maximum value of $10.9\text{ g kg}^{-1}\text{ DM}$ at day 14, and then decreased to $8.3\text{ g kg}^{-1}\text{ DM}$. While in Run A, the $\text{NH}_4^+\text{-N}$ concentration showed an obvious in-

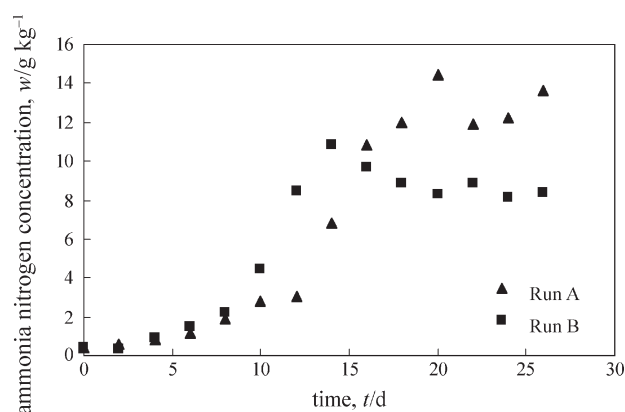


Fig. 6 – Changes in $\text{NH}_4^+\text{-N}$ concentration in the aerobic composting process

creasing trend, the maximum concentration was $14.5\text{ g kg}^{-1}\text{ DM}$ observed at day 20, and during the following days, the $\text{NH}_4^+\text{-N}$ concentration had not leveled off and attained $13.6\text{ g kg}^{-1}\text{ DM}$. It can be obtained that the $\text{NH}_4^+\text{-N}$ concentration retained in Run A is higher than that in Run B by 63.9%. $\text{NH}_4^+\text{-N}$ in the compost reactor had been conserved in the microbial biomass, stable molecules and struvite crystal.³⁸ Comparing the concentration of $\text{NH}_4^+\text{-N}$ in Run A with the added MAR, and Run B without the MAR, it can be concluded that MAR effectively increases the concentration of $\text{NH}_4^+\text{-N}$ in the compost product and its agronomic value.

Several factors (C/N ratio, temperature, mixing and turning, aeration rate) were controlled to increase the ammonia in the compost product.¹⁹ In this experiment, the neutralization reaction occurred during the early stage of the composting reaction, much of the ammonia transformed into salt, while some ammonia could be converted into biomass; the struvite crystals had probably formed during the aerobic composting reaction in Run A with the addition of MAR, retaining an amount of ammonia.²⁰ The population of mesophilic microorganisms was calculated as $2.4 \cdot 10^8$ colony nitrogen-fixing bacteria/(g WM) in Run A and only $1.0 \cdot 10^8$ colony nitrogen-fixing bacteria/(g WM) in Run B at day 26. It is obvious that with the addition of the MAR, the number of nitrogen-fixing bacteria increases. Nitrogen retained in compost products owing to the mesophilic bacteria (mainly the nitrogen-fixing bacteria), and the amount of cumulative ammonia emitted from Run A into the condensate trap was 8.3 g and 10.8 g from Run B, respectively, and more than 21% of ammonia remained in the compost product of Run A, compared to Run B. Jeong and Kim³⁸ reported that the high level of ammonia conserved in compost products was $10.8\text{--}14.3\text{ g kg}^{-1}\text{ DM}$, while the result of the present experiment showed a level in the range of $11.9\text{--}14.5\text{ g kg}^{-1}\text{ DM}$.

Conclusions

In this paper, the effect of MAR on the simulated FWs composting processes was investigated under well-controlled experimental conditions. The conclusions are summarized as follow:

(1) Compared to the control Run, the organic material degradation degree with MAR increased by about 10 %. The MAR has a positive effect on bacterial activity and promotes organic matter to decompose small molecular organic acids which can be directly used by microorganism.

(2) Accumulative ammonia loss is obviously reduced in Run A, while the ammonia retained in the compost with the MAR is 1.67 times higher than that without addition of the MAR. Due to the difference in nitrogen-fixing bacteria, many acids formed during the initial phase of Run A. Additionally, the struvite crystal recognized as fixed nitrogen material could be considered one potential reason.

(3) The MAR not only promotes the degradation degree, but also improves the quality of compost, and its application was thought to be beneficial for both agriculture and the environment.

(4) Further study should be conducted to confirm the existence of the struvite crystal and the function of the struvite and the nitrogen-fixing bacteria on the conservation of nitrogen in the aerobic composting process. Additionally, a pilot-scale research will be warranted to determine the effect of the ratio of the MAR to the FWs on the degradation rate and nitrogen conservation.

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List of symbols and abbreviations

DM	– dry mass
FWs	– food wastes
MAR	– maturity-accelerating reagent
MSWs	– municipal solid wastes
OUR	– oxygen uptake rate
t	– time, day
w	– mass fraction, %
WM	– wet mass
γ_0	– initial dry mass of compost materials at time 0, kg

γ_t	– dry mass of compost materials at time t , kg
η	– degree of degradation, %
θ	– temperature, °C

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