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Process Control of a Compost-Reactor Turning Operation Based on a Composting Kinetics Model

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Abstract: Composting is a biochemical as well as a heterogeneous process, and the turning operation is important to maintain aerobic conditions and improve the efficiency of the composting process. Therefore, the turning frequency is an important factor for the precise control of the composting reactor. It is necessary to determine the changes in the physical and chemical parameters of the composting process and to simulate them. Pretreated vinegar residue and wool washing sludge were mixed at a mass ratio of 6:4 for the composting process. The composting reactor's temperature, CO_2, CH_4, and organic matter content were collected during the composting process. According to the principles of composting, a kinetic model of composting based on the change in CO_2 gas concentration and heat balance in the composting reactor is developed, which provides a theoretical basis for the subsequent control of the composting reactor. The comparison of the model predictions to the measured results of the composting reactor shows that the SSE, R^2, and RMSE for the organic matter content simulation are 8.122, 0.943, and 1.274 g/kg, respectively, and the SSE, R^2, and RMSE for the temperature simulation are 29.54, 0.959, and 2.71 °C, respectively. Based on the prediction of the temperature in the reactor based on the composting kinetics model, the process control for the turning operation is proposed to achieve precise control of the composting process. The results show that the duration of high temperature in a composting reactor is prolonged for 2 days, the degradation rate of organic matter occurs at a more rapid speed, and the operation efficiency of the production line can be improved by more than 10%. This indicates that the decision-making method based on the composting kinetics model can improve the composting efficiency.

Keywords: composting; kinetics model; control; turning operation; organic matter degradation; heat balance

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1. Introduction

Composting is a biochemical as well as a heterogeneous process involving the mineralization of organic matter to CO_2, NH_3, and H_2O, and incomplete humification [1–4]. In order to realize the objectives of composting, it would be beneficial to optimize the composting process [5,6]. This can be achieved through effectively designing and controlling the various composting processes. In recent years, models representing the interactions between biochemical and physical characteristics have been developed in the composting process [7]. The models include matter balance and heat balance models [8,9].

Matter balance models are used for the simulation of organic matter degradation, including the first-order kinetic and Monod models [5]. For the first-order kinetic model, Huang (2008) developed a multi-component modeling system to simulate the organic matter degradation and oxygen consumption in composting processes. The model includes three conversion reactions: the growth of aerobic biomass, decay of aerobic biomass, and solubilization of insoluble substrate [10]. Saldarriaga (2018) used the first-order dynamic model to simulate the composting process of the organic fraction of municipal solid waste in two independent composting facilities, and the kinetic parameters were determined with the experimental data under different environmental conditions [11]. Xiao (2021) modeled the biodegradation in waste by integrating factors such as the temperature, moisture content, and C/N ratio with the first-order kinetic model. The experiment showed that the model could accurately estimate the degradation of the composting process [12]. For the Monod model, Sole-Mauri (2007) developed a dynamic model for the composting process, which integrated several biochemical and physical processes. Different microbial populations (mesophilic and thermophilic bacteria, actinomycetes, and fungi) have been considered, and the types of polymeric substrates (carbohydrates, proteins, lipids, hemicellulose, cellulose, and lignin) and their hydrolysis products have been specialized [13]. Kulcu (2004) used seven different organic matter degradation kinetic models to simulate the degradation process of the agricultural-waste-forced aeration composting process. The optimal aeration composting rate of the composting pile was obtained using the analysis results, and the highest organic matter degradation rate was obtained according to the aeration composting rate [14]. Xi (2006) used the Monod model to simulate the temperature, water content, and organic matter content in the process of garbage composting [15]. Seng (2015) developed a mathematical model of organic substrate degradation and its performance evaluation in a solid-waste windrow-composting system. The model was divided into slowly and rapidly degradable substrates [16]. Ge (2015, 2016) established the particle-scale modeling of the oxygen uptake rate model during pig manure–wheat straw composting. The model provides a theoretical basis for the design of an economical operation strategy for aerobic composting [17,18]. As the machine-learning model can explore the relationship between different parameters and draw universal conclusions, it was used to predict composting parameters and the optimal composting process. Ding (2022) determined the key parameters of the composting process using the SHAP (Shapley additive explanations) model and quantified the optimal range of processing parameters using the PDA (partial dependence analysis) model [19]. Dogan (2023) predicted the composting process parameters using a deep cascade forward neural network model and determined the optimal conditions for composting using the genetic algorithm model [20].

The degradation of organic matter is a biological and chemical reaction in the composting process, which is accompanied by heat generation occurring in the composting process, and the heat change is eventually reflected in the temperature. Therefore, research on the composting processes has been conducted to examine the composting heat balance [8]. Tremier (2005) researched the phase change of water occurring in a composting stack by modeling the heat balance of the composting process [21]. Petric (2015) created a heat model for the composting process through comprehensive modeling of the dynamic model, composting process quality, and heat balance model [22]. Ajmal (2022) produced the heat balance of the composting process in a container through the composting mechanism model and the heat balance model [8]. Ivakhnyuk (2020) studied the energy movement of organic waste and established a heat balance model, including the heat capacity and biological growth, which could closely predict the composting temperature of organic waste composting methods [23]. Golbaz (2020) developed a comprehensive mathematical model for the preparation of optimal initial mixtures for sewage sludge composting. The models include the terms of water and energy contents, air-filled porosity, and C/N ratio [24].

Therefore, the mass and heat balance simulation for the composting reactor mainly focuses on container or aeration composting methods. However, in the actual composting process, in order to realize commercial production, the composting reactor is a trough type composting pile and utilized with a machine that mixes the material, incorporating oxygen to achieve aerobic fermentation. Therefore, the turning frequency is an important factor for the precise control of performing the composting of waste products [25,26]. During the composting process, the oxygen distribution in the reactor is changed [27,28], and it is difficult to deploy the oxygen sensor in the reactor with different scales and materials of the composting reactor. In this study, in order to establish the control model for the turning operation of the composting process, according to the principles of aerobic and anaerobic composting, a discrete composting kinetic model for composting based on the changes in CO_2 gas concentration and heat balance in the composting reactor is constructed, which provides a theoretical basis for the decision-making process for the composting. Based on the composting kinetics model, the process control for the compost-reactor turning operation is proposed to achieve precise control of the composting process.

2. Materials and Methods

2.1. Materials

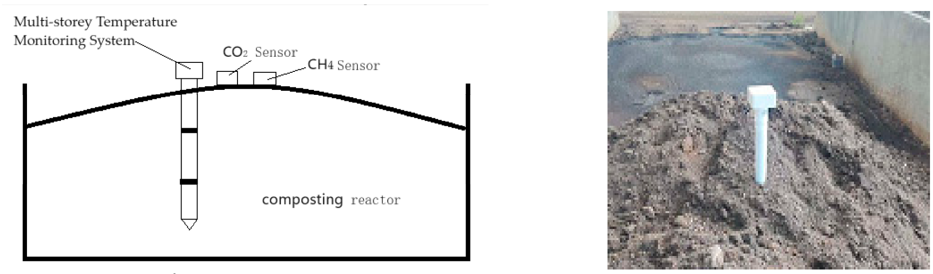
The experiment was conducted in the composting plant of Jiangsu Peilei Subtract Technology Development Co., Ltd., Zhenjiang, China, The composting is in a composting pile. Pretreated vinegar residue (the waste residue from the production of edible vinegar) and wool washing sludge (sludge from wool washing) were mixed at a mass ratio of 6:4 for the composting process. The property parameters of the composting materials are shown in Table 1. The carbon–nitrogen ratio of the composting reactor was adjusted to 25:1 by adding ammonium sulfate nitrate, and the water content was 57.2%. To analyze the effect of the turning operation, the turning frequency was set as 4d, with CK being without turning.

Table 1. Basic property parameters of composting materials.

Material	pH	C/N Ratio	Organic Matter Content/g/kg
Wool mud	5.2	20	476.2
Vinegar lees	5.7	33	670.7
Mixed	6.1	25	584.5

2.2. Composting Parameter Collection

The developed monitoring system was used to collect the compositing reactor parameters, including the temperature, CO_2 concentration, and CH_4 concentration, show as Figure 1, and the collection interval was set as 10 min [29]. The physical and chemical parameters of the composting materials, including the organic matter content, are presented. We obtained 3 groups of samples from around the sampling points of the online monitoring system every 3 days through the soil sampler for the experimental analysis. The organic matter content was detected using the potassium dichromate volumetric method.



(**a**) (**b**)

Figure 1. The online monitoring system for the compositing reactor parameters. (**a**) Schematic of the temperature and CO_2 concentration; (**b**) multi-story temperature monitoring system for the composting reactor.

2.3. Kinetic model of the Composting Process

2.3.1. Kinetic Model of Organic Matter Degradation

The fundamental of composting comes from microorganisms' degradation of organic matter in the composting process. When the degradation activity of microorganisms ceases, it indicates the end of the composting phase. As a chemical parameter of the composting reactor, the content of organic matter usually needs to be analyzed to model the degradation process through the kinetic model. However, the model is only related to time and is not applicable when the composting time is decreased or extended. Therefore, it is necessary to establish a correlation model between organic matter degradation and the emissions from composting [7].

During microorganisms' degradation of organic matter in the composting process, CO_2 is emitted from the composting reactor. Therefore, the correlation between CO_2 emission concentration and organic matter content can be established to provide a theoretical basis for the pre-simulation and prediction of the composting process. Since the composting reactor is an open space, the CO_2 in the composting reactor is emitted into the air outside the reactor, while the microorganisms produce CO_2; therefore, the balance model for CO_2 production (C_{prod}), accumulation (C_{acc}), and emissions (C_{emit}) can be described as [30]

$$C_{\text{acc}} = C_{\text{prod}} - C_{emit} \tag{1}$$

where the CO_2 production in the reactor can be described as the degradation of the organic matter as

$$C_{\text{prod}} = K\frac{dM_d}{dt} \tag{2}$$

where M_d is the organic matter content in the composting reactor, g/kg; and K is the organic matter degradation conversion coefficient.

With the monitoring system, the CO_2 concentration in the composting reactor can be collected; therefore, by introducing the internal and external air-exchange model in a non-closed environment, the exchange kinetic model for CO_2 can be described as follows:

$$\frac{dC}{dt} = K\frac{dM_d}{dt} + \frac{\gamma E_0 A}{V} - \mu(C - C_{emit}) \tag{3}$$

where C is the CO_2 concentration in the composting reactor, %; γ is the diffusion coefficient; E_0 is the precipitation rate, %/h; V is the reactor volume, m^3; A is the surface area of the reactor, m^2; and μ is the air-exchange rate, times/h.

The diffusion coefficient γ and precipitation rate E_0 are used to describe the loss caused by gas diffusion from the solid boundary in a closed environment. In this study, the solid boundary of the composting reactor was the wall, and the density of the wall was much higher than the density of CO_2, so CO_2 encounters difficulty in diffusing through the wall; therefore, this part can be ignored. Thus, the model can be described as follows:

$$\frac{dC}{dt} = K\frac{dM_d}{dt} - \mu(C - C_{emitt}) \tag{4}$$

2.3.2. Heat Balance of the Composting Reactor

According to the heat balance of the internal and external air of the composting reactor, the accumulation Q_{acc}, the heat production Q_{prod} by the degradation of organic matter, and the heat emitting by the heat exchange occurring between the inside of the reactor and the external environment Q_{emit} can be described as:

$$Q_{acc} = Q_{prod} - Q_{emit} \tag{5}$$

According to Khater (2014) [31], the temperature change occurring in the reactor and the heat accumulation of the composting reactor can be described as follows:

$$Q_{\text{acc}} = mc\frac{dT}{dt} \tag{6}$$

where m is the mass of the reactor, kg; c is the heat capacity of the composting reactor, J/(kgK); and T is the temperature in the reactor, °C.

The heat produced by organic matter degradation can be expressed as:

$$Q_{\text{prod}} = H_c\frac{dM_d}{dt} \tag{7}$$

where H_c is the heat production capacity of organic matter degradation, kJ/g·kg.

The heat lost by the composting reactor includes the heat transfer occurring between the composting reactor and ambient air, the heat radiation generated by the composting reactor, and the heat loss caused by convection and diffusion with airflow. In this study, the heat loss caused by thermal radiation was considerably less than that caused by heat transfer; therefore, the thermal radiation that occurred in this instance can be ignored. Moreover, the composting system was mainly used in a semi-closed plant shed, and the airflow was low; therefore, the heat loss that occurred in this study could be ignored, too. Thus, the heat emitted from the composting reactor can be simplified as follows:

$$Q_{emit} = UA(T - T_0) \tag{8}$$

where U is the heat transfer coefficient, W/(m^{2}K); A is the total heat transfer area, m^2; and T_0 is the environment temperature, °C.

Therefore, the heat balance of the composting reactor can be described as follows:

$$mc\frac{dT}{dt} = H_c\frac{dM_d}{dt} - UA(T - T_0) \tag{9}$$

The discretization of Equation (9) can be described as follows:

$$mc\frac{T_k - T_{k-1}}{\mathrm{T_t}} = H_c\frac{M_{d\mathrm{k}} - M_{d\mathrm{k}-1}}{\mathrm{T_t}} - UA(T_k - T_0) \tag{10}$$

where k is the sampling interval, *d*.

Using an iterative calculation, Equation (9) can be expressed as follows:

$$T_k = \frac{H_c(M_{d\mathrm{k}} - M_{d0}) - T_t UA\sum_{\mathrm{i}=0}^{k-1}(T_i - T_0)}{mc + T_t UA} + T_0 \tag{11}$$

Similarly, the discrete mathematical model of organic matter degradation kinetics presented in Equation (4) can be obtained:

$$M_{d\mathrm{k}} - M_{d0} = \frac{(1 + T_t\,\mu)(C_k - C_{emit}) + T_t\mu\sum_{\mathrm{i}=0}^{k-1}(C_i - C_{emit})}{K} \tag{12}$$

Equations (11) and (12) can be combined to obtain the temperature simulation model in the composting reactor:

$$T_k = \frac{H_c\left(\frac{(1 + T_t\,\mu)(C_k - C_{emit}) + \mathrm{T_t}\mu\sum_{\mathrm{i}=0}^{k-1}(C_i - C_{emit})}{\mathrm{K}}\right) - T_t UA\sum_{\mathrm{i}=0}^{k-1}(T_i - T_0)}{mc + T_t UA} + T_0 \tag{13}$$

Equation (13) can be used to simulate and calculate the internal temperature of the composting reactor by using the CO_2 concentration present in the composting reactor. Therefore, the model can be used to predict and control the temperature in the composting reactor to achieve more accurate control of the composting process.

2.4. Turning Decision-Making of the Composting Reactor Based on the Composting Kinetic Model

According to the analysis of the changes occurring in the composting process parameters, it can be concluded that if the composting reactor is not turning for a long time, anaerobic degradation will be generated in the composting reactor, which will inhibit the activity of the microorganisms. When the activity of aerobic microorganisms decreases, the heat production capacity of the composting reactor decreases, and the temperature of the composting reactor decreases, respectively.

In order to maintain the composting reactor in an aerobic state during the composting process, the composting kinetics model can be used to predict the temperature of the composting reactor. When the predicted temperature is lower than the actual temperature of the composting reactor, this indicates that the turning system of the composting reactor needs to be operated. With the historical temperature data and CO_2 concentration data collected by the monitoring system, and by using the least squares parameter estimation method, the parameters of the composting kinetic model can be fitted.

$$T_{k+1} = \frac{\frac{H_c T_t \mu}{K}(C_k - C_{emit}) + mcT_k + T_t UAT_0}{mc + T_t UA} \tag{14}$$

With the prediction temperature using Equation (14), when the prediction temperature is higher than the composting reactor's temperature, the turning operation needs to be conducted. The process of the control strategy used for the turning operation for the composting reactor is presented in Figure 2.

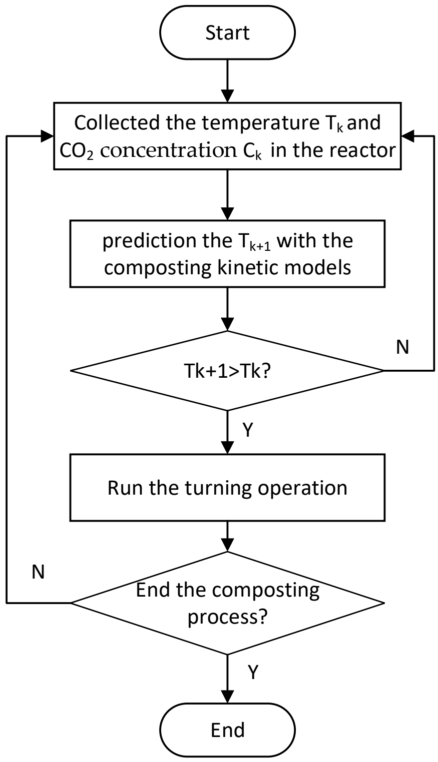


Figure 2. The process of the control strategy used for the turning operation for the composting reactor.

2.5. Models Fitting and Statistical Analyses

By using the data collected during composting, the organic matter degradation kinetic model and the heat balance model were fitted using the Curve fitting toolbox in MATLAB. Statistics methods such as the *SSE* (error sum of squares), the R^2 (determination coefficient), and the *RMSE* (root mean square error) were used in model performance comparisons and evaluations:

$$SSE = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \tag{15}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{\sum_{i=1}^{n} (y_i - \overline{y}_i)^2} \tag{16}$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{y}_i)^2} \tag{17}$$

3. Results

3.1. Simulation of the Composting Kinetic Model

With the turning frequency set as 4d and without a turning operation, the variations in the temperature, CO_2 concentration, CH_4 concentration, and organic matter content in the composting reactor are presented in Figure 3. The temperature, CO_2, and CH_4 concentration increased in the initial stage of the composting process. After 4 days, the temperature and CO_2 concentration were reduced, and the CH_4 concentration increased, respectively. Compared to without turning the reactor, after each turning operation, the temperature and CO_2 concentration increased again, and the CH_4 concentration decreased, respectively. The duration of the high-temperature periods exceeding 50 °C with and without turning were 9d and 2d, respectively. The degradation rate of the organic matter was rapid during the initial stage of the composting process, presenting a reduction in organic matter content.

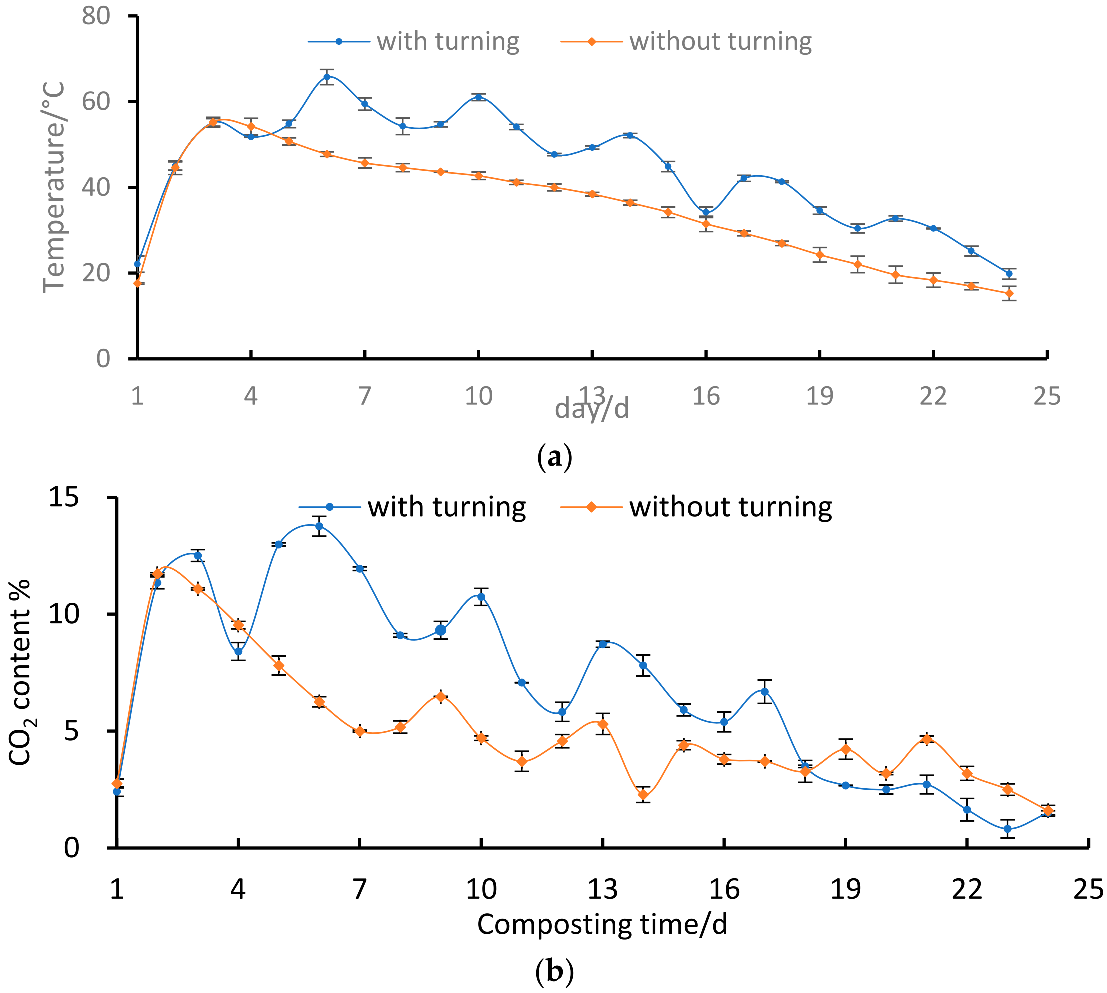
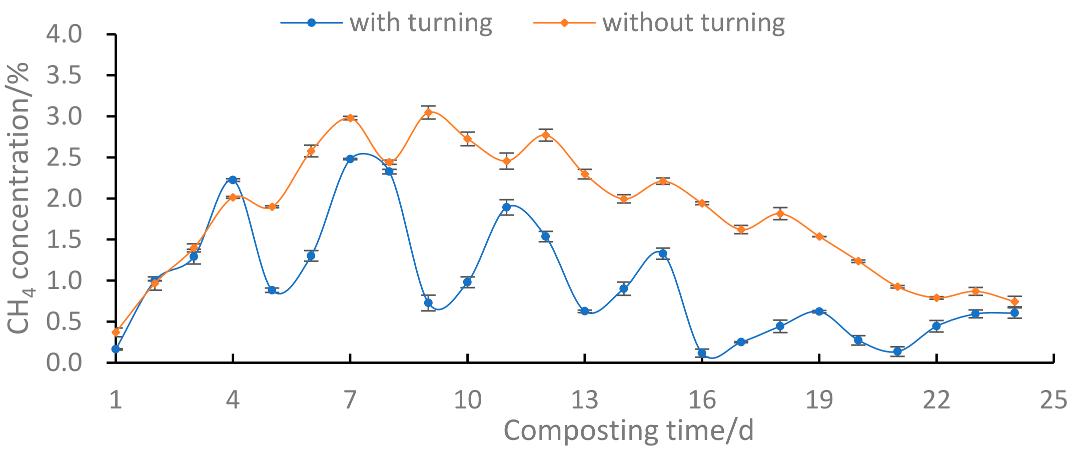
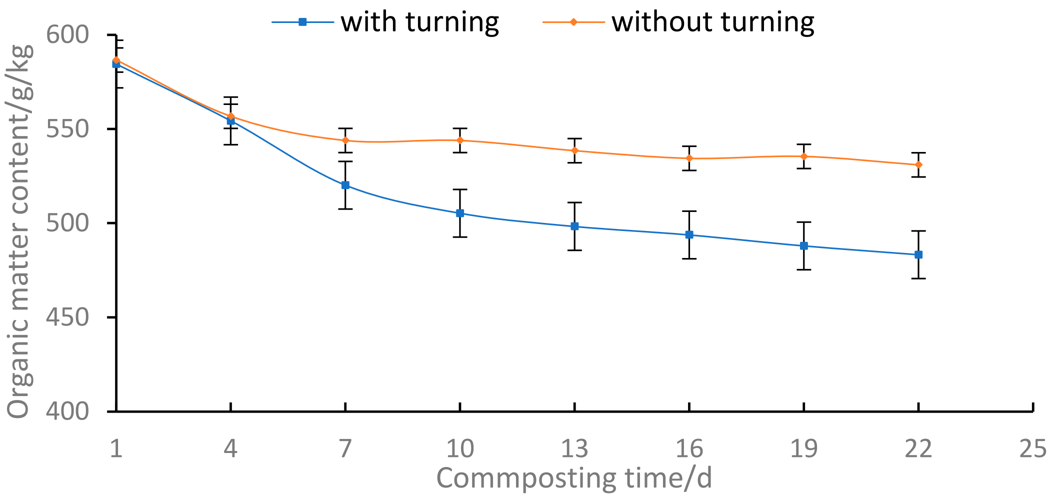


Figure 3. *Cont.*



(**c**)



(**d**)

Figure 3. The variations in temperature, CO_2 concentration, and CH_4 concentration in the composting process with a turning frequency of 4d and without turning. (**a**) The variations in temperature, (**b**) variations in CO_2 concentration, (**c**) variations in CH_4 concentration, and (**d**) variations in organic matter content.

The organic matter degradation kinetic model is as follows:

$$M_{d\mathrm{k}} = M_{d0}+0.896(C_k - C_{emit}) + 1.696\sum\nolimits_{\mathrm{i}=0}^{\mathrm{k}-1}(C_i - C_{emit}) \tag{18}$$

The heat balance model is

$$\mathrm{T_k} = \frac{2.638(M_{d\mathrm{k}} - M_{d0}) - 1.049\sum_{\mathrm{i}=0}^{\mathrm{k}-1}(\mathrm{T_i} - \mathrm{T_0})}{2.049} + \mathrm{T_0} \tag{19}$$

The temperature simulation model is

$$\mathrm{T_k}= 1.1535(C_k - C_{emit}) + 2.183\sum\nolimits_{\mathrm{i}=0}^{\mathrm{k}-1}(C_i - C_{emit}) - 0.512\sum\nolimits_{\mathrm{i}=0}^{\mathrm{k}-1}(\mathrm{T_i} - \mathrm{T_0}) + \mathrm{T_0} \tag{20}$$

Figure 4 presents the simulation results for the organic matter content; the results show that the predicted value of organic matter content is in good agreement with the measured value, the SSE (error sum of squares) is 8.122, the determination coefficient R^2 is 0.943, and the RMSE (root mean square error) is 1.274 g/kg. During the entire composting process, the maximum error is 6.35 g/kg, and the average difference is 3.37 g/kg, which is relatively small compared with the total amount of organic matter degradation that occurred during the entire composting process. Therefore, the model could successfully simulate the process of organic matter degradation.

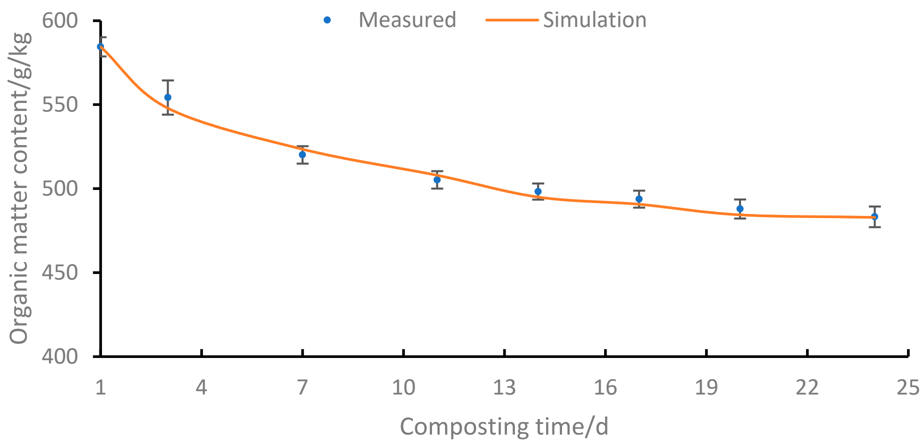


Figure 4. The simulation results of organic matter content in the composting reactor.

Figure 5 presents the simulation results for the temperature in the composting reactor; the results show that the predicted value of temperature is in good agreement with the measured value, the SSE is 29.54, the determination coefficient R^2 is 0.959, and the RMSE is 2.71 °C. The maximum error during the early stage is 3.5 °C, while the deviation during the late stage is considerable, with a maximum value of 6 °C. The results show that the simulation model for the temperature can be used to predict the temperature levels during the composting process.

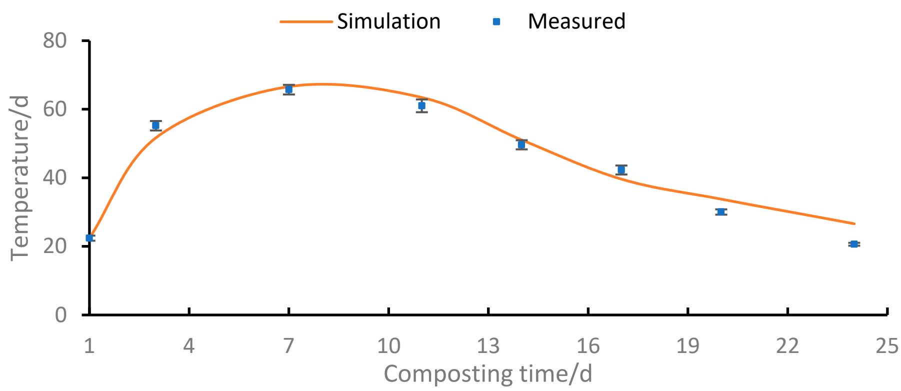


Figure 5. The simulation results for the temperature in the composting reactor.

3.2. Results of the Process Control of the Turning Operation Involved in the Decision-Making Process

In order to verify the effect of the control strategy for the turning operation of the composting reactor, two composting reactors were used to conduct the control strategy; the turning frequency was set to 4d for the CK group, and the turning operation of the other reactor was controlled by a control strategy based on the composting model. The composting materials are presented in Table 1. The experiments were conducted from 17 December 2021 to 10 January 2022 at Jiangsu Peilei Substract Technology Development Co., Ltd., Zhenjiang, China.

Figure 6 presents the temperature changes using different control methods; the temperature in the two reactors changed within a range of 20~60 °C, and the turning operation using the decision-making process occurred earlier than the 4d-frequency operation. During the high-temperature period (above 50 °C), the decision-making reactor reached 6 and

4d of the 4d-frequency operation. Therefore, the decision-making method can improve the composting temperature, including the average temperature, high-temperature keeping period, and high-temperature arrival time.

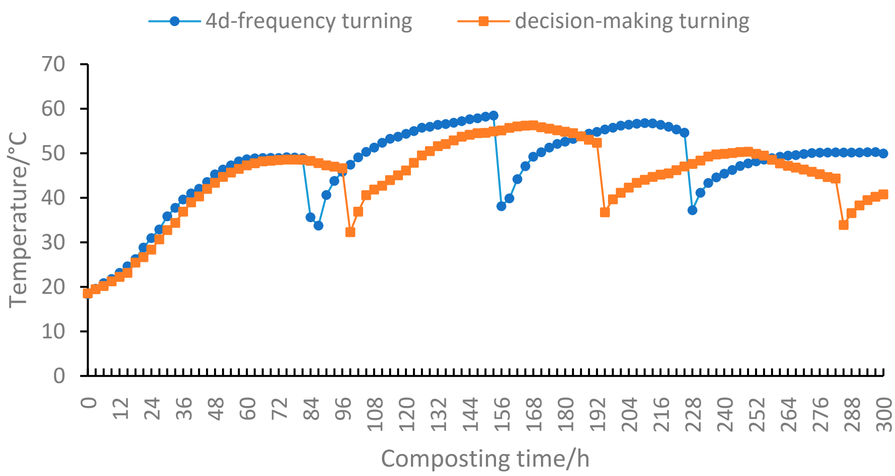


Figure 6. The temperature changes for 4d turning frequency and turning using the decision-making method.

Table 2 presents the results of the physical and chemical parameters of the composting reactor with the two turning methods. The mass of organic matter degradation using the decision-making method is 15.7 g/kg higher than that of the 4d turning frequency, indicating that the degradation rate in the composting reactor is greater when using the decision-making method. The pH when using the decision-making method is 7.13; it is closer to neutral than the 4d turning-frequency method. The EC is 3.53 mS/cm, less than the control group, and for the composted subtract, the low EC is more suitable for plant growth. The water content with the decision-making method is less than the CK. Although the number of turnings is less than the CK, the water is dissipated more quickly, indicating a higher fermentation efficiency.

Table 2. The physical and chemical parameters of composting reactors.

	Organic Matter Content/g/kg	pH	EC	Water Content/%
4d-frequency turning (CK)	505.5 ± 5.3	7.76 ± 0.13	3.92 ± 0.07	44.9 ± 1.7
decision-making turning	489.8 ± 4.6	7.13 ± 0.10	3.53 ± 0.05	41.7 ± 1.3

4. Discussion

According to the principle of composting, composting includes aerobic composting and anaerobic composting during the whole composting process [18].

When the composting reactor was not turned for a long time, the oxygen consumed inside the reactor could not be fully supplemented, and the oxygen required by the aerobic microorganisms in the degradation process was insufficient [17,26], which meant that the aerobic microorganisms could not rapidly convert the organic matter into CO_2 (Figure 3b), and the amount of heat released reduced, respectively (Figure 3a). Meanwhile, the anaerobic microorganisms converted the organic matter in the reactor into CO_2 and CH_4, so the emission of the CH_4 increased (Figure 3c). Compared to the composting reactor without the turning operation, the turned reactor made it easier for the external oxygen to enter the reactor. The aerobic microorganisms could also absorb oxygen more efficiently for the degradation of the organic matter and could release more heat and CO_2. The degradation rate with the turning operation was higher than without the turning operation (Figure 3d). The results show that the turning operation provided more sufficient oxygen for aerobic microorganisms, and the higher aerobic microorganism activity could maintain a better degradation capacity [32–34]. The results indicate that the turning operation is a critical method to improve composting production efficiency.

According to statistical analyses by Walling (2020), the focus subjects for the kinetics model for the composting process are temperature (64%), oxygen concentration (55%), and emissions from composting (13%) (e.g., CO_2, NH_3, water, and leaching) [5]. The O_2 concentration has been monitored since O_2 is the driving force for aerobic composting. Although the oxygen-drive method for the turning operation for the composting process is the most effective and direct method, during the composting process, the oxygen distribution in the reactor is changed [27,28], and it is difficult to deploy the oxygen sensor in the reactor with different scales and materials of the composting reactor. Meanwhile, the O_2 sensor needs to be inserted into the reactor, which will affect the operation of the turning machine. According to the principle of composting, aerobic composting and anaerobic composting lead to changes in emissions of CO_2. Thus, we use the CO_2 balance model to indicate the composting status for the turning operation. The CO_2 on the surface was measured instead of using the oxygen sensor in the reactor, which is more reasonable for the turning operation.

In order to realize the simulation of the composting process with the turning operation, the mass and heat balance model was constructed. The heat in the reactor was produced by the degradation of the organic matter [30,35–37]. During the turning process, the heat was lost, and after the turning process, the temperature increased again (Figure 4a); during this process, the continuous kinetic model could not simulate this process. In this study, considering the organic matter present in the reactor did not change during the composting process, we produced a heat balance model combined with an organic matter degradation model based on the CO_2 balance [38–40] by using the discrete model to solve the effect of the turning operation. Moreover, the discrete mathematical model results in a simulation curve that is not smooth, and the heat loss by the turning operation causes the discrepancy between the model and measured temperatures in the late stage. These abnormal issues in model simulation can be allowed for the decision-making of the turning operation. Thus, the model can simulate the composting process with the turning operation. The physical and chemical characterizations being dynamically changing during composting leads to uncertainty in the parameters of the model [41], so we used the least squares regression fitting methods instead of specifically determining parameters for the model.

The turning operation in a composting reactor is an important management method to reduce the occurrence of anaerobic degradation during the process of organic matter degradation. By using the heat balance model combined with the organic matter degradation model based on the CO_2 balance, the temperature in the reactor was simulated, and the turning decision of the composting reactor was based on the composting kinetic model. The results show that compared with the fixed turning frequency of 4d, the duration of the high temperature in the composting reactor is prolonged for 2 days (Figure 6), the degradation rate of organic matter is quicker, and the operation efficiency of the production line can be improved by more than 10% (Table 2). This indicates that the decision-making method can improve the composting efficiency [26,42,43].

5. Conclusions

The turning operation is an important process for improving the efficiency of composting methods. Therefore, the turning frequency is an important factor for the precise control of the composting process. In this study, by collecting the physical and chemical parameters created in the composting reactor with and without the turning process, based on the matter and heat balance, a discrete composting kinetic model was established to simulate the composting process. With the temperature prediction based on the composting kinetic model, the decision model was proposed to realize the decision-making process for the turning operation. The results show that the decision-making method can improve the composting efficiency.

In the future, since the composting process is a hysteresis process, it is necessary to include a hysteresis function and an intelligent control method to determine the turning decision [44]. Moreover, the water content reduced during the composting process; this caused the load of the turning machine to change, and it is necessary to carry out load-feedback-based turning control to save the energy of the composting turning operation [45].

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