Control of heat loss for heating the substrate of the biocomposting process

Evgeny Kuznetsov[1], *Anna* Khadzhidi[1], *Lyudmila* Kravchenko[2*], and *Jan* Poltorak[1]

[1]Kuban State Agrarian University named after I. T. Trubilina, 350044, Kalinina str, 13, Russia
[2]Don State Technical University, 344003, 1. Gagarin sq., Rostov-on-Don, Russia

Abstract. Soil biota (earthworms) plays an important role in the biocomposting of waste from agro-industrial enterprises. Maintaining the required humidity and temperature of the substrate determines the maximum yield of vermicompost (biocompost), which depends on the vital activity of worms. The article presents the results of preparation of the substrate by aerobic composting from the solid phase of pig manure and the liquid phase of alcohol waste with an admixture, crushed straw for biocomposting while controlling the temperature regime, humidity and maintaining a neutral environment. A dependence is obtained that determines the heating time of the vermicompost and provides control over heat loss when the substrate temperature drops below the critical temperatures in the bioreactor.

1 Introduction

Biocomposting is a process of biological processing of compost, in which compost is subjected to aerobic biodegradation by a mixed population of living organisms under conditions of elevated temperature and humidity. As a result of this process, the degradation of the substrate is carried out with the release of energy in the form of heat, which leads to the humification of the substrate [1,2]. The most effective biocomposting is animal husbandry waste – compost of farm animal manure. The process of biodegradation can be controlled by a set of living organisms, creating favorable thermal and water regimes in the compost [3,4].

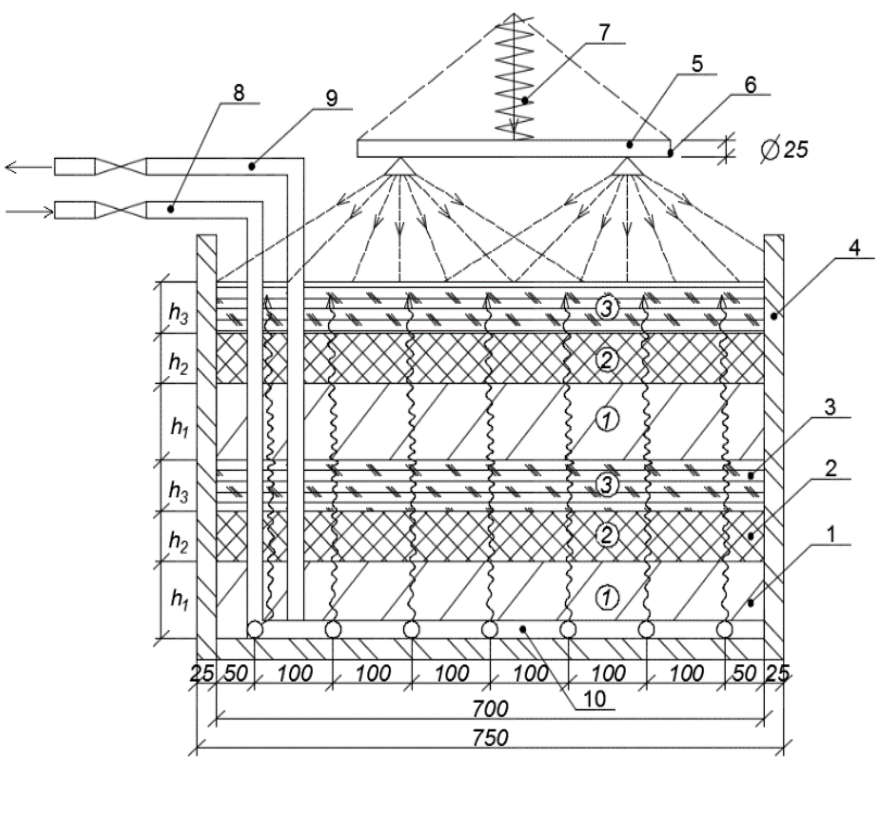
Biocomposting can be considered a continuation of the composting process, where compost obtained from animal manure acts as a substrate. Earthworms play a role in the final stages of the composting process and further processing of the organic matter of the compost. Maintaining the required humidity and temperature of the substrate determines the maximum yield of vermicompost (biocompost), which depends on the vital activity of worms. The work is devoted to the development of solutions for controlling the parameters of maintaining the necessary heat in a bioreactor for breeding worms.

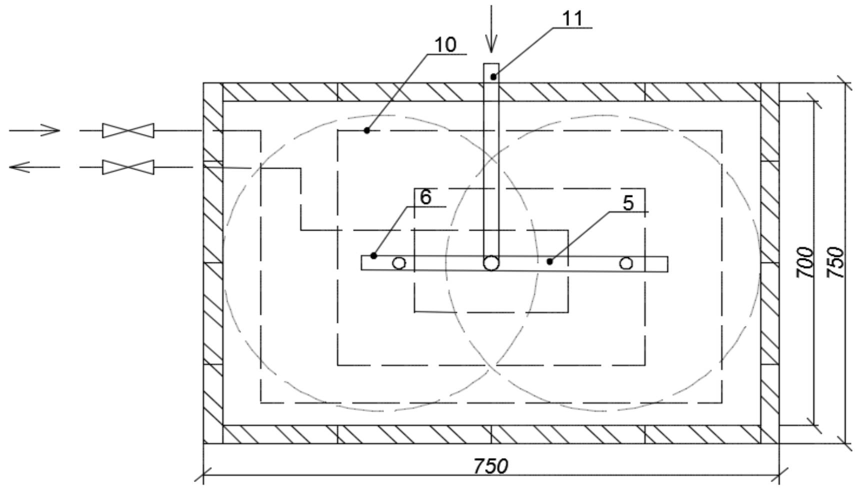
Analyzing the groups of microorganisms involved in composting, it can be concluded that soil biota plays a huge role in biocomposting [5]. The creation of the necessary conditions for the vital activity of biota by the control of environmental parameters is the subject of agrobiological reclamation: temperature, humidity, substrate nutrients, water-air and chemical regimes, etc. [6-8].

* Corresponding author: Lyudmila.Vl.Kravchenko@yandex.ru

2 Materials and methods

For the process of vermicomposting, an orderly arrangement of composting layers is adopted in the bioreactor: the first layer includes compost; the 2nd layer is a mixture of straw with soil; the 3rd is straw. The main process of biocomposting is the oxidation reaction of organic matter (aerobic fermentation) – compost [9, 10]. About 5.5 m^3 of oxygen is used to decompose 1 kg of compost [11]. In the process of biocomposting, in practice, the oxygen demand has not been established and about 40% of organic matter undergoes oxidation – biodegradation. The biotechnology of substrate processing in bioreactors includes technological operations: the entry of the substrate through quarantine into the bioreactor, maintenance of a given humidity and neutral substrate environment; cooling or heating of the substrate by air aeration through a perforated pipeline. Consequently, the main parameters of fermentation of the substrate of processing into biocompost are aeration, temperature and humidification of waste [12, 13]. The technological scheme of the physical model of the bioreactor is shown in the figure 1.





1,2,3 – layers of the substrate; 4 – square–shaped bioreactor; 5 – pipe for the supply of OW for irrigation of the substrate; 6 – nozzles for humidification; 7 – device for moving the humidifier; 8 – air supply from the compressor; 9 – air removal during perforation cleaning; 10 - perforated pipe; 11 – supply pipeline.

Fig. 1. Diagram of a bioreactor for the vermicomposting process

Bioreactor 4 has dimensions of 0.7 x 0.7 m, height of 1.0 m and is made of wooden pine boards. A perforated polyethylene pipe with a diameter of 0.025 m with an equal pitch of holes through 10 cm is laid on the bottom, a total of 100 pieces on the pipe. holes with a diameter of 2mm. The degree of perforation is 0.64, this ensures that air is supplied to the last hole under pressure. The air supply is carried out by the compressor through the dispenser through the pipeline 8. The air is discharged through the pipe 9. The pipeline 8 is connected to the collector, through which the air is evenly distributed to the supply pipes 11. The air from the holes 10 of the perforated pipe passes through the compost to the surface where the fermentation process is performed. The heated air escapes through the perforation and maintains the temperature of the substrate – 21-23oC.

Above the bioreactor there is a pipe 5 for supplying water to the nozzles 6, from where water is sprayed over the substrate under pressure, providing the necessary humidity. The pipe 5 can move down and up relative to the substrate surface using the mechanism 7. The compost is laid in layers and populated with worms to obtain vermicompost in a bioreactor. To increase the fermentation rate, the substrate is oxidized by air and moistened with irrigation water, which ensures the vital activity of worms and the necessary humidity. Layers of earth mixed with straw are arranged between the layers of compost.

3 Results and discussion

For a high-quality aerobic fermentation process, a uniform air supply is adopted throughout the compost volume, while controlling the temperature and humidity of the medium. Compost is a complex disordered substrate and, by the form of the moisture bond, refers to capillary-porous bodies. Taking into account the qualitative changes in the chemical composition of compost, its transformation into biocompost, depending on the increase in worm biomass (ΔG), the biocomposting function of the main parameters is adopted, which will have the form:

$$\Delta G = f\,(t,\ V_{в},\ \tau_{см},\ W,\ n,\ v_{в})\ ,\quad \Delta G \rightarrow G_{max}; \qquad (1)$$

where ΔG is the increase in worm biomass, g; G_{max} is the maximum biomass, g; V_b is the volume of the bioreactor, m^3; τ_{cm} is the time period of optimal conditions for the increase in worm biomass, s; n is the porosity coefficient; v_b is the air velocity in perforated pipes, providing a change in the heat capacity of the mixture, m/s.

Equation (1) is presented in parametric form, and considering each of its terms separately, in the form of separate functions:

$$W_{\min} \le W \le W_{\max},\ W \to W_{opt}; \quad (2)$$
$$v_в = f(x/l_{mp}); \quad (3)$$
$$t_{min} \le t \le t_{max},\ t \to t_{opt}; \quad (4)$$
$$V_в = f(n);\ n \to n_{opt};\ V_в \to V_{в\ opt}; \quad (5)$$
$$\tau_{cm} = f(\Delta Q), \quad (6)$$

where W is the humidity of the mixture, %; $W_{\min} \le W \le W_{\max}$ is the permissible range of the humidity parameter, % W_{opt} is the optimal humidity of the mixture, %; v_b is the air velocity in the perforated pipeline, m/s; x is the distance from the beginning of the pipe length l_{tr}, m; $t_{min} \le t \le t_{max}$ is the temperature range mixtures with respect to t_{opt}, ^{0},c; n is porosity of the substrate; τ_{cm} is heating time of the mixture, *s.*; ΔQ is heat balance of the substrate, J.

Solutions of equations (2-6) will be used to control the parameters of the substrate. Irrigation is used to moisten the compost. From the pipeline 5, water will be supplied to the surface of the substrate to create the necessary humidity of the capillary-porous mixture W_{opt}. The humidity parameter (2) is determined by the rate of irrigation water supply to the surface, which is found by the formula:

$$m = 0{,}1 \cdot n \cdot h\,(W_{opt} - W_i) \quad (7)$$

where m is the norm of irrigation water for moistening compost, mm; h is the thickness of the moistening layer, m; W_i is the permissible decrease in the humidity parameter in the moistened layer h, %.

It can be seen from formula (7) that for the biocomposting process, it is necessary to set the optimal humidity parameter, which depends on the porosity, initial humidity and depth of the ordered substrate layer. The parameter W is found experimentally by increasing the biomass of worms.

The temperature of the substrate is determined in the range $t_{min} \le t \le t_{max}$ (4). The range of the parameter t can be controlled by the loss of heat for heating the substrate in the bioreactor. The heated air is supplied through a pressure perforated gas pipeline through the substrate from the bottom to its surface. The heated air passes upwards through the thickness of the bioreactor mixture, losing heat. For uniform air supply to the compost on the gas pipeline, holes are arranged through the same distances. The movement of the air flow in the longitudinal direction occurs according to the law of aerodynamics of variable mass (3). The parameter of the air flow velocity of the gas pipeline is found by the formula:

$$v_x = v_в\,(1 - x/\,l_{mp}) \quad (8)$$

where v_x is the air flow velocity in the bioreactor at a distance x from the initial section, m/s.

The air velocity in the gas pipeline depends on the volume of supply, time for deoxidation and maintenance of the substrate temperature. The volume of air V_b required for deoxidation of the mixture in the aerobic process, taking into account formula (8) at $x = 0$, is determined by the formula:

$$V_в = s \cdot v_в \cdot \tau_{см} \ , \tag{9}$$

where s is the area of the bioreactor, m^2.

According to research data, it was found that about 5.5 m^3 per 1 kg of substrate is needed for aeration of capillary-porous media. It is assumed that the air flow is laminar, and the flow movement is considered as a continuum, then the heat loss due to friction against the walls in a perforated heating pipeline is determined from the Poiseuille equation taking into account (9):

$$dp = [(32 \text{ν} \rho_в / d^2)] \, v_в (1 - x/ l_{mp}) \, dx, \tag{10}$$

where dp is the friction loss when air moves through a perforated pipe Pa; ρ_b is the air density, kg/m^3; v is the kinematic viscosity, m^2/s.

Denoting by a constant coefficient $A = 32 \text{ ν} \rho_в /d^2$, and integrating from 0 to l_{tr}, a formula is obtained for determining the pressure loss at any point at a distance x of the perforated gas pipeline in the bioreactor:

$$p_x = A \ v_в \ (x - \frac{x^2}{2\text{ltr}}), \tag{11}$$

where $A = 32 \text{ ν} / g \, d^2$ is the specific coefficient of resistance which depends on the density and kinematic viscosity of the air in the laminar flow mode.

At $x = l_{tr}$, it turns out from (11) that heat losses without perforation are 2 times higher than in a perforated gas pipeline and this does not contradict the theory of thermodynamics of variable masses, heat losses are determined by the formula:

$$Q_{mp} = 0{,}5 \text{A} v_в \, l_{tr} \, V_b, \tag{12}$$

where Q_{tr} is the heat loss for heating the air in the perforated pipeline, J; τ_{cm} is the time for the process of heating the mixture, s; ω is the cross section of the air ducts, m2; V_b is the volume of air, m^3.

The movement of air in the substrate is considered as the movement of viscous air through capillary channels from the pipeline to the surface in a straight line (5). Applying Darcy's law for the laminar regime (Re=1-10), the volumetric average air flow is determined by the formula:

$$Q = (r^2 \, s /8 \, \mu) \, (\Delta P/ h) = k \, (s \, \Delta P \, / \, \mu \, h), \tag{13}$$

where r is the capillary size, m; μ is the dynamic viscosity coefficient, Pa s; ΔP is the pressure gradient, Pa; k is the permeability coefficient, m^2; h is the height of the ordered substrate layer, m.

To determine the heat loss in the substrate, $Q_{cap.}$ formula (13) is used, from which follows:

$$Q_{cap.} = k \, (s \cdot \Delta P \cdot \rho_в \cdot v_в \, / \, \mu), \tag{14}$$

where k is the coefficient of moisture conductivity (water permeability) is from the ratio for a porous medium, m^2:

$$k\,\gamma = k_{\phi} \cdot \mu \ , \tag{15}$$

where γ is the specific gravity, kg/m^3; k_f is the filtration coefficient of the substrate, m/s.

The Darcy setting is used to calculate the filtration coefficient of k_f. On the other hand, the air from the duct passes through the substrate, giving heat to the compost. The heat loss for heating the mixture with warm air from a perforated pipeline can be calculated from the well-known formula:

$$Q_b = v_b \cdot s \cdot C_b \cdot \rho_b \cdot \tau_{cm} \, (t_{opt} - \Delta t_i) \tag{16}$$

where C_b is the specific heat of the air, J/kg ^{0}C; t_{opt} is the temperature that is the best for growing worms in compost, ^{0}C; Δt_i is the deviation of the temperature at which the process of reproduction of worms in compost does not stop, ^{0}C.

Analysis of equations (12), (14) and (16) shows that for the process of vermicomposting, it is necessary to expend an amount of heat, which depends on the size of the bioreactor, temperature, time, and volume of air for fermentation of the substrate. In equation (16), the unknown quantities are the heating time (5), and the heat loss for heating the substrate with warm air from a perforated gas pipeline for the vermicomposting process.

The heating time of the substrate to the required temperature is determined by the balance method for maintaining the required temperature in the substrate:

$$Q_{tr} + Q_{cap.} = Q_b \ . \tag{17}$$

From the joint solution (12), (14) and (16), it follows:

$$\tau_{cm} = \frac{0{,}5\mathrm{Al}\text{т}\mathrm{pV_{B}} + k(s\Delta P \rho_{B}/\mu)}{\mathrm{sC_{B}}\rho_{B}(\mathrm{topt} - \mathrm{tmin})}. \tag{18}$$

The heating time of the vermicompost allows you to control the loss of heat when the substrate temperature drops below critical temperatures with the remaining specified sizes of the bioreactor.

Using the theoretical dependences of the parameters (1-6) and practical results, the requirements for the management of the biocomposting process of pig solid waste by the balance method (17) are established, which are given in the table.

Table 1. Requirements for managing the parameters of vermicomposting

№	Main indicators	Characteristics for vermicompost production processes
1	*pH*	6.5 – 7.5
2	Concentration of soluble salts	≤ 0.5%, at a salt concentration >0.5%, worms die
3	Substrate humidity	- 70-80%; at a humidity of 30-35%, the development of worms slows down, at a humidity of 22%, worms die
4	Temperature	- when feeding, the ambient temperature is 23^{o}C, when breeding – 21^{o}C; at a temperature of 32^{o}C, worms stop feeding, at > 36^{o}C, worms die
5	The content of ammonia in the substrate	- at an ammonia concentration > 0.9 mg in 1 kg of substrate, worms die

6	The maximum density of worms	- 0.3 kg/m^3 (1500 individuals), with an increase in the "sowing rate" leads to overwork of the population at the end of cultivation, to a decrease in biomass
7	Feeding quality	- the substrate prepared by aerobic composting from tf pig manure and ff alcohol waste with admixture, crushed straw is suitable for biocomposting
8	Type of earthworm	- technological strain, bred and adapted to the given area

Table 1 shows the results of preparation of the substrate by aerobic composting from the solid phase of pig manure and the liquid phase of alcohol waste with an admixture, crushed straw for biocomposting while controlling temperature, humidity and maintaining a neutral environment.

4 Conclusion

1. The dependence (18) is obtained, which determines the heating time of the vermicompost and provides control over the loss of heat when the substrate temperature drops below the critical temperatures in the bioreactor.

2. The balance method (17) was applied to solving the problem of heat management of vermicomposting (1-6).

3. The basic requirements for managing the process of biocomposting solid pig waste in a bioreactor were established (Table).

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