Strojnícky časopis – *Journal of* MECHANICAL ENGINEERING,
VOL 73 (2023), NO 2, 151 - 162

# PROCESS PARAMETERS AND CONDITIONS OF INTENSIFIED COMPOSTING OF KITCHEN BIOWASTE

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**Abstract:** Composting is one of the efficient and effective methods of disposal and recovery of biodegradable waste. A favorable and intensified course of the composting process can be achieved by optimal composition of the composted material (moisture, content of organic substances and nutrients, C:N ratio, etc.), and also by optimizing the conditions under which composting takes place (temperature, pH, structure and aeration of the material, etc.). The paper contains a methodology for calculating the composition of composted material and also a methodology for solving the forced aeration process of composted material. More specifically, some process parameters of the intensified composting of a defined amount of kitchen biowaste, taking place in closed composting reactors, are presented and analyzed. Using the material balance of the composting process, the connections between the desired composition of the matured compost, the composition of the composted material and the conditions under which the composting takes place are pointed out. The specified connections enable the composting process to be optimized appropriately.

**KEYWORDS**: composting, composted material composition, kitchen biowaste, process parameters, material balance, composting reactor

## 1 Introduction

Composting is a biochemical process characterized by controlled aerobic microbiological decomposition of organic matters in the composted material – organic substrate (biodegradable waste or biowaste). The composting process aims to stabilize organic materials – biodegradable waste, and obtain a stable product – compost, which contains humus substances and nutrients. Compost is used for soil improvement if its parameters meet the relevant specifications [3, 8, 11].

Biowaste composting can be carried out in various ways and in various technological devices [8, 10, 19]. Some methods of composting can be suitably combined, for example, standard thermocomposting with low-temperature vermicomposting [12, 20]. Composting can also be effectively combined with anaerobic digestion [11]. The chosen method and the used technology affect the course and result of the composting process. The processing of some biowaste by composting, characterized by a certain material composition and certain specific properties (e.g., kitchen and food biowaste), can be problematic [18].

By regulating and optimizing the conditions, the composting process can be intensifying, which standardly takes place in several phases – the decomposition phase, the conversion phase, the maturation and stabilization phases [8, 10, 11]. The decomposition phase, usually lasting three to six weeks, is characterized by the high activity of aerobic microorganisms decomposing the organic substrate, whereby the temperature rises to 70 °C (biowaste is hygienized), due to the formation of organic acids, the pH value decreases, the respiration of aerobic microorganisms produces carbon dioxide, and the most significant weight loss occurs. In the following stages of the composting process, the temperature gradually decreases, the

DOI: 10.2478/scjme-2023-0030, Print ISSN 0039-2472, On-line ISSN 2450-5471

pH returns to a neutral value, and humus substances are formed into which mineralized nutrients are gradually incorporated. Finally, the formed compost of dark brown color is gradually stabilized by maturation and acquires a uniform structure.

The overall decrease in weight of the composted material during the composting process due to the removal of the produced gaseous substances ($H_2O$, $CO_2$, $NH_3$, and others) depends on its composition and the composting technology [8, 10, 19]. It ranges from 20 to 50 % of its original weight, with one-quarter to one-third loss of organic matters and two-thirds to three-quarters loss of water. Weight losses of nitrogen and phosphorus can mostly be neglected. A schematic diagram expressing the overall weight loss of the composted material during the composting process is shown in Fig. 1.

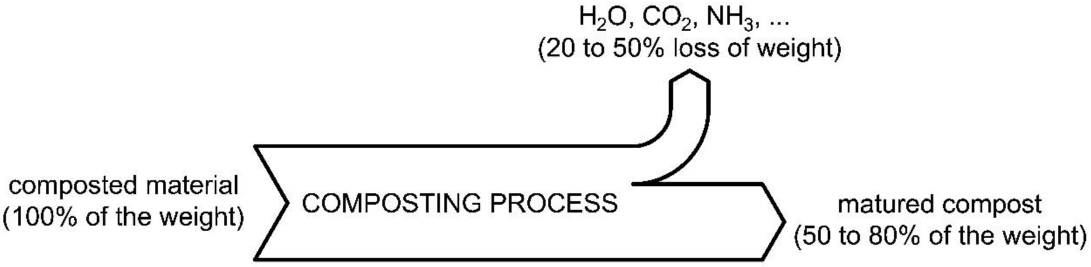


Fig. 1 Scheme of weight loss of composted material during the composting process.

## 2 Optimizing the conditions and intensification of the composting process

The composting process of biodegradable organic material (biowaste) can be positively influenced and intensified by ensuring the optimal composition of the composted material (moisture, organic matters content, sufficient nutrients – mainly nitrogen and phosphorus, C:N ratio, etc.) and by optimizing the conditions under which composting takes place (temperature, pH, aeration of the material, material structure – porosity, total volume of material and its homogeneity, etc.) [15, 17].

For the proper course of the composting process, the material (biowaste) must first be mechanically treated (chopping, crushing, chipping, etc.) to a suitable size (the optimal size of wood chips is 20 to 50 mm) [10].

A relevant condition for successful composting is the optimal composition of the composted material, which is determined by the optimal value of its moisture, optimal concentrations of organic matters, nitrogen, and phosphorus in its dry matter, as well as the optimal C: N ratio (mass ratio of organic carbon and nitrogen in the composted material). The composition of the composted material shall be optimized in terms of a favorable course of the composting process so that the compost obtained ensures the best possible soil fertilization (sufficient humus substances and nutrients in the compost) [5, 8, 10, 19]. Several publications also deal with optimizing the composition of composted material containing a significant proportion of kitchen and food biowaste [1, 4, 9, 14]. The methodology for calculating the composition of the composted material, including the C:N ratio, is presented in Chapter 3. Standard values of the main parameters characterizing the optimal composition of the composted material and the optimal composting conditions are listed in Tab. 1 [8, 10].

Since composting is an aerobic process of biological decomposition of organic matters, it is necessary to ensure a sufficient supply of oxygen (air oxygen is commonly used) to the entire volume of composted material [2, 7]. Therefore, the structure of the composted material must be porous. Sufficient oxygenation of the composted material can be ensured either by its periodic digging or by forced aeration. The process of forced aeration of composted material is briefly described from an aeromechanical point of view in Chapter 4.

For some types of biodegradable waste (e.g., kitchen biowaste), it is necessary to ensure their hygienization, the aim of which is the elimination of pathogenic microorganisms. Sufficient hygienization of biowaste intended for composting can be achieved by the effect of elevated temperature (above 70 °C) for at least 60 minutes. Biowaste must be mechanically treated (chopped) to a particle size of up to 12 mm [11].

Tab. 1 The main parameters characterizing the optimal composition of the composted material and the optimal composting conditions.

| **Parameter** | **Unit** | **Value** |
|---|---|---|
| mass ratio C:N | ( – ) | 30:1 to 35:1 |
| moisture content | (%) | 50 to 70 |
| temperature | (°C) | max 70 |
| phosphorus $P_2O_5$ content in dry matter | ( % ) | min 0.2 |
| pH value | ( – ) | 6 to 8 |
| particles size | (mm) | 20 to 50 |
| oxygen concentration | (%) | min 4 |
| concentration of carbon dioxide | (%) | max 17 |

Tab. 2 The main parameters characterizing the physical and chemical properties of compost intended for soil fertilization.

| **Parameter** | **Unit** | **Value** |
|---|---|---|
| pH value | ( – ) | 6.5 to 8.5 |
| bulk density | ($kg.m^{-3}$) | max 1000 |
| mass ratio C:N | ( – ) | max 30:1 |
| moisture content | (%) | 40 to 60 |
| content of combustible substances in dry matter | (%) | min 25.0 |
| nitrogen N content in dry matter | (%) | min 1.0 |
| phosphorus $P_2O_5$ content in dry matter | (%) | min 0.5 |
| potassium $K_2O$ content in dry matter | (%) | min 0.5 |
| calcium Ca content in dry matter | (%) | min 1.2 |
| magnesium Mg content in dry matter | (%) | min 0.5 |
| content of particles with a size below 20 mm | (%) | 100 |

The quality of the produced compost as a fertilizer intended for soil fertilization is assessed based on the values of several quality indicators of the compost (physical and chemical properties, content of hazardous elements and substances, content of pathogenic organisms, etc.). The required values of the main parameters characterizing the physical and chemical properties of compost intended for soil fertilization are listed in Tab. 2 [8, 11].

## 3 Methodology for calculating the composition of composted material and produced compost

If the quantities and compositions of the individual components of the composted material are known, the amount and the resulting composition of the composted material can be calculated using a mass balance based on the law of conservation of mass [6]. If the composting process is characterized by a defined biochemical transformation of the composted material, it is also possible to calculate the quantity and composition of the obtained compost using the mass balance [8, 10, 19].

Within the calculation of the composition of the composted material, the mass fraction of water in the material is primarily determined – moisture $x_w$ expressed by the relation

$$x_w = \frac{m_w}{m}\ 100\ \% \tag{1}$$

where $m$ represents the total weight of the material, and $m_w$ is the total weight of water contained in that material. It follows from equation (1) that the mass fraction of total dry matter $x_{DM}$ in the composted material is

$$x_{DM} = 100 - x_w \tag{2}$$

Subsequently, the mass composition of dry matter expressed by mass fractions of the individual dry matter components $x_j$ is specified using a general relationship

$$x_j = \frac{m_j}{m_{DM}}\ 100\ \% \tag{3}$$

in which $m_j$ is the weight of the respective dry matter component and $m_{DM}$ is the total dry matter weight. The relative loss of total weight can be expressed by equation

$$x_{ML} = \frac{m_{ML}}{m}\ 100\ \% \tag{4}$$

where $m_{ML}$ represents the absolute loss of total weight of the composted material. The calculation of the ratio of the masses of organic carbon to nitrogen C:N in the composted material can be done using the relation

$$C:N = \frac{\sum_{i=1}^{n} m_i x_{Ci}\left(100 - x_{wi}\right)}{\sum_{i=1}^{n} m_i x_{Ni}\left(100 - x_{wi}\right)} \tag{5}$$

in which $n$ is the number of components forming a mixture of composted material, $m_i$ are the weights of individual components and $x_{wi}$ represent their moisture content, $x_{Ci}$ and $x_{Ni}$ are the mass fractions of organic carbon and nitrogen in these components.

The specific compositions of the individual components of the composted material (composted mixture) are determined by their chemical analysis, or approximately using tabulated compositions that can be found for individual organic materials (biowaste) in the specialized literature [8, 10, 19]. If the exact values of the proportions of organic carbon in the dry matter of the individual components of the composted material (composted mixture) are not available, it can be assumed with sufficient accuracy that organic carbon represents approximately half of the weight of organic matters in the dry matter of the given components of the composted material.

## 4 Forced aeration process of composted material

Forced aeration of composted material, which can be defined from a process point of view as a single-phase flow of gas through a porous layer, is a technological process primarily intended for the sufficient supply of oxygen, necessary for the aerobic decomposition of organic material (biowaste) by microorganisms. However, forced aeration can also partially regulate the temperature and humidity of the composted material.

For a suitable technological solution for forced aeration of composted material, it is also important to know the connection between the magnitude of the airflow through the composted material and the loss of mechanical energy of the flowing air (pressure drop $\Delta p_z$). Based on the theory of single-phase fluid flow through a porous layer [13], the pressure drop of the flowing fluid depends on the properties of the porous layer (the porosity of the layer $\varepsilon$, the specific surface of the particles $a_v$, the size and shape of the particles, etc.), on the thickness of the porous layer $h$, on the properties of the flowing fluid (density $\rho$, dynamic viscosity $\mu$), and on the characteristic velocity of the fluid flow $u_0$ (so-called extra-layer velocity). The pressure drop of the fluid $\Delta p_z$ flowing through the porous layer can be expressed by the equation

$$\Delta p_z = \lambda' \frac{1-\varepsilon}{\varepsilon^3} \frac{h}{D_p} u_0^2 \rho \tag{6}$$

in which $D_p$ is the equivalent diameter of the particles according to the specific surface and $\lambda'$ is the modified friction factor. The equivalent diameter of the particles according to the specific surface $D_p$ depends on the specific surface of the particles $a_v$ according to the relation

$$D_p = \frac{6}{a_v} \tag{7}$$

The modified friction factor $\lambda'$ is a function of the modified Reynolds number Re', which is defined by the equation

$$\mathrm{Re}' = \frac{u_0 D_p \rho}{(1-\varepsilon)\mu}. \tag{8}$$

The Ergun equation can be used to express the function $\lambda' = f(\mathrm{Re}')$

$$\lambda' = \frac{150}{\mathrm{Re}'} + 1.75, \tag{9}$$

which is suitable for porous layers consisting of coarse particles [13].

## 5 Material balance and process conditions of the intensified composting of kitchen biowaste

This section presents a possible way to deal with intensified composting of kitchen biowaste [16]. Composting is carried out in closed batch composting boxes, in which optimal process conditions can be ensured. The scheme of the technology of the discontinuous process of intensified composting in closed batch composting reactors is shown in Fig. 2.

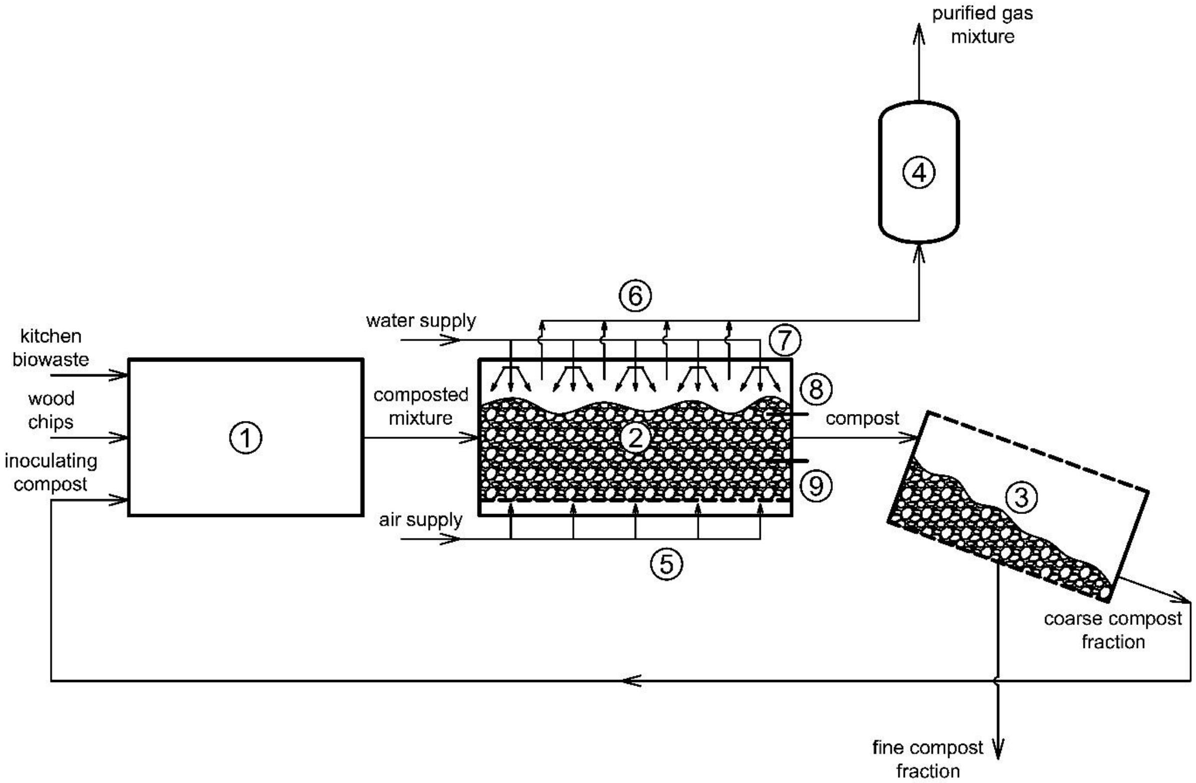


Fig. 2 Technological scheme of the discontinuous process of intensified composting in closed batch composting reactors.
1 – preparation and storage of composted mixture, 2 – composting reactor,
3 – rotary drum classifier of compost, 4 – biofilter, 5 – aeration system,
6 – degassing system, 7 – moisturizer of composted material, 8 – oxygen sensor,
9 – temperature and moisture sensors

Within the material balance of the composting process, the processing of kitchen biowaste in the amount of 5760 tons is primarily assumed. Based on statistical data, the given amount of kitchen biowaste roughly corresponds to its annual production in a town with 80,000 inhabitants (source: Statistical Office of the Slovak Republic). Kitchen biowaste is mixed with other components before composting in order to optimize the initial composition of the composted material. The composition of the composted material is defined by the types and amounts of components forming a mixture of substances (organic waste) intended for composting. In this case, the composted material consists of three components – kitchen biowaste as the main composted waste material, wood chips as auxiliary waste material, and matured compost used for inoculation. An example of the composition of a composted mixture, consisting of kitchen biowaste with a mass fraction of $x_{KB}$ = 65 %, of wood chips with a mass fraction of $x_{WC}$ = 30 %, and of inoculating matured compost with a mass fraction of $x_{RMC}$ = 5 %, is listed in Tab. 3. Tab. 3 also contains the values of the assumed weight losses of substances during the composting process (the assumed total weight loss of the composted material is $x_{ML}$ = 25 %), as well as the amount and composition of the obtained matured compost. The values listed in Tab. 3 were obtained by the material balance of the composting process, assuming a material transformation that can be achieved by composting (see the introduction of the article). The balance diagram of the composting process is shown in Fig. 3.

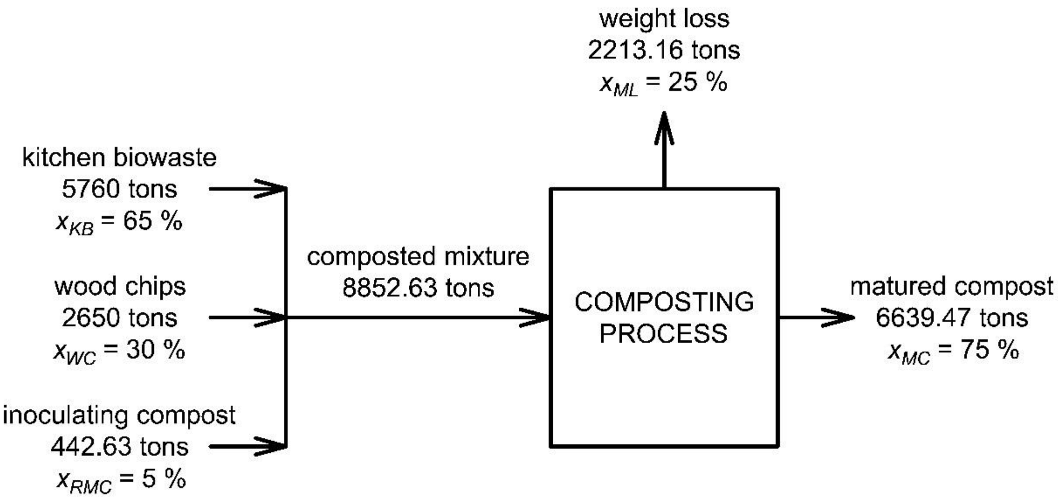


Fig. 3 The balance diagram of the composting process.

The graphs in Fig. 4 and Fig. 5 show how the mass ratio of the components of the composted material affects its material composition and also the material composition of the produced compost, if the assumed total weight loss of the composted material during composting is $x_{ML}$ = 25 %. The mass ratio of the components of the composted material is expressed by the mass fraction of kitchen biowaste in the composted material $x_{KB}$. The mass fraction of inoculating matured compost in the composted material $x_{RMC}$ is always 5 %.

Fig. 6 and Fig. 7 document the influence of the degree of substance conversion of the composted material (relative weight loss of composted material $x_{ML}$) on the material composition of the produced compost, while a constant mass ratio of the components of the composted material is assumed ($x_{KB}$ = 65 %, $x_{WC}$ = 30 %, $x_{RMC}$ = 5 %).

The process solution of intensified composting also includes process calculation and design of a suitable aeration system. The calculation of the energy demand of the process of forced aeration of composted material in closed composting reactors was carried out according to the methodology presented in Chapter 4. The assumed conditions under which the forced aeration of the composted material takes place are summarized in Tab. 4. Fig. 8 shows the calculated dependences of the pressure drop $\Delta p_{z1}$ of air flowing during aeration through a layer of composted material with a thickness of 1 m on the specific surface of the particles in the layer $a_v$ at two air temperatures 20 and 70 °C, at two values of the characteristic air flow velocity 0.001 and 0.002 $m.s^{-1}$, and at three assumed layer porosities 0.3, 0.4, and 0.5.

## CONCLUSION

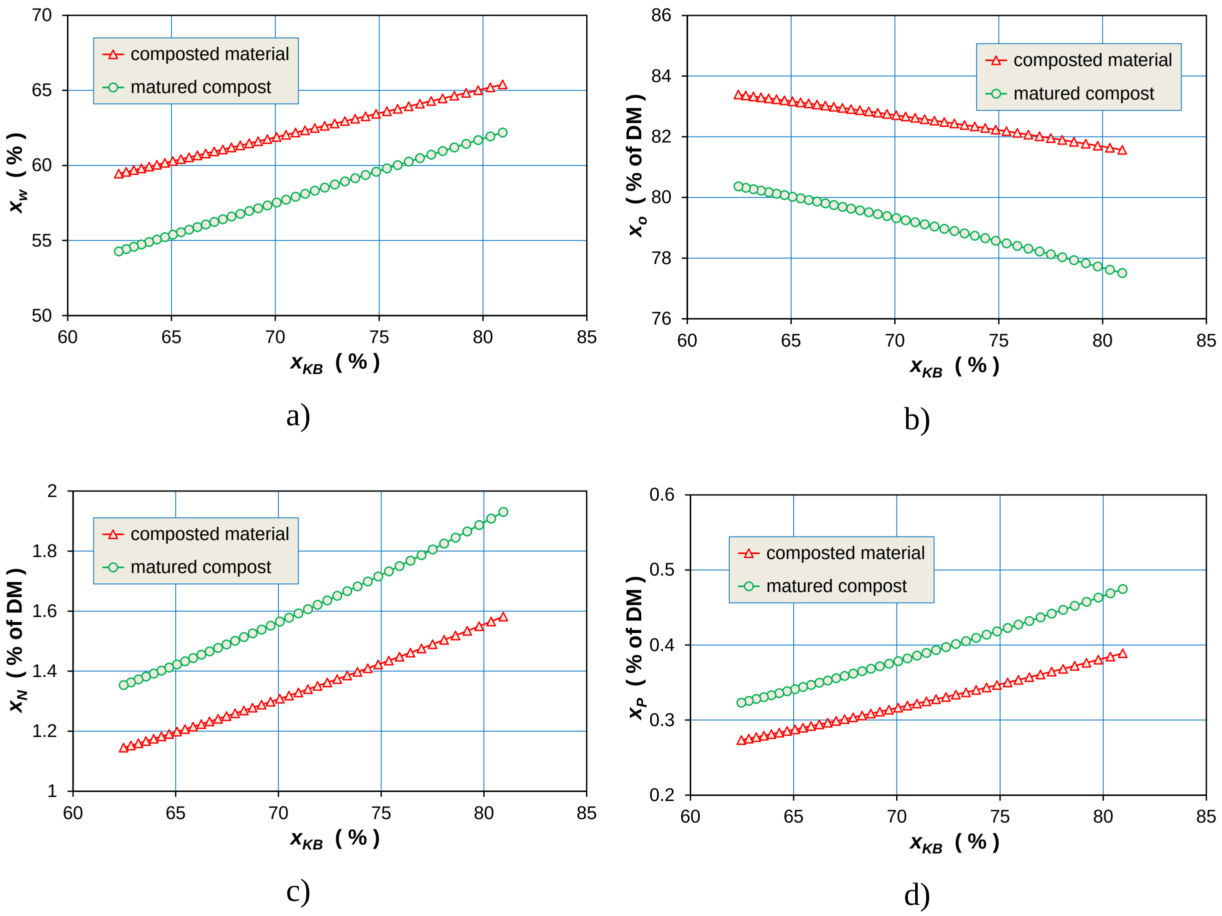
Composting is one of the effective and efficient methods of disposal and recovery of biodegradable waste. In order for the composting process to take place optimally and the produced compost to be characterized by the required composition and properties from the point of view of its further use, it is necessary to ensure a suitable composition of the composted material and the optimal process conditions for its production. For this reason, the methodology for calculating the composition of the composted material is presented. Since composting is a microbiological aerobic process, from the point of view of its optimization, it is important, among other things, to ensure sufficient aeration of the composted material. An important process parameter in the design of the aeration system is the pressure drop of the air flowing through the layer of composted material. The methodology for calculating the pressure drop in the porous layer during forced aeration of the composted material is presented in Chapter 4.

Tab. 3 Balance table of composting a mixture consisting of kitchen biowaste ($x_{KB}$ = 65 %), wood chips ($x_{WC}$ = 30 %), and inoculating matured compost ($x_{RMC}$ = 5 %).

| | **weight (t)** | **substance content** | | | |
|---|---|---|---|---|---|
| | | **moisture (%)** | **organic matters (% of dry matter)** | **N (% of dry matter)** | **$P_2O_5$ (% of dry matter)** |
| **kitchen biowaste** | 5760 | 70 | 80 | 2 | 0.5 |
| **wood chips** | 2650 | 40 | 87 | 0.3 | 0.05 |
| **inoculating matured compost** | 442.63 | 55.39 | 80.02 | 1.42 | 0.34 |
| **composted mixture** | 8852.63 | 60.29 | 83.17 | 1.2 | 0.29 |
| **weight loss** | 2213.16 | 31.10 | 15.74 | 0 | 0 |
| **produced matured compost** | 6639.47 | 55.39 | 80.02 | 1.42 | 0.34 |
| | **C : N ( – )** | **substance weight** | | | |
| | | **water (t)** | **organic matters (t)** | **N (t)** | **$P_2O_5$ (t)** |
| **kitchen biowaste** | 20 : 1 | 4032 | 1382.4 | 34.56 | 8.64 |
| **wood chips** | 145 : 1 | 1060 | 1383.3 | 4.77 | 0.8 |
| **inoculating matured compost** | 28.13 : 1 | 245.15 | 158.03 | 2.81 | 0.67 |
| **composted mixture** | 34.69 : 1 | 5337.15 | 2923.73 | 42.14 | 10.11 |
| **weight loss** | | 1659.87 | 553.29 | 0 | 0 |
| **produced matured compost** | 28.13 : 1 | 3677.28 | 2370.44 | 42.14 | 10.11 |

Tab. 4 The values of the main process parameters of forced aeration of composted material.

| **Parameter** | **Symbol** | **Value** |
|---|---|---|
| porosity values of composted material | $\varepsilon$ ( – ) | 0.3 to 0.5 |
| specific surface of composted material | $a_v$ ($m^2.m^{-3}$) | 600 to 12000 |
| air temperature | $T$ (°C) | 20 and 70 |
| extra-layer airflow velocity | $u_0$ ($m.s^{-1}$) | 0.001 and 0.002 |
| pressure drop per unit thickness of composted material | $\Delta p_{z1}$ ($Pa.m^{-1}$) | max 446 |



a) b) c) d)

Fig. 4 The influence of the mass fraction $x_{KB}$ of kitchen biowaste in the composted material on the substance composition of the composted material and the produced matured compost:
a) mass fraction of moisture $x_w$, b) mass fraction of organic matter in dry matter $x_o$,
c) mass fraction of nitrogen in dry matter $x_N$, d) mass fraction of $P_2O_5$ in dry matter $x_P$.

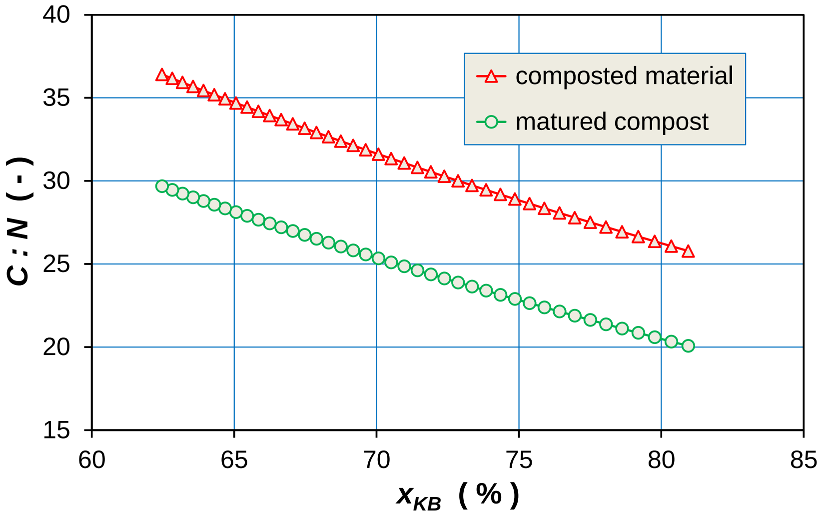
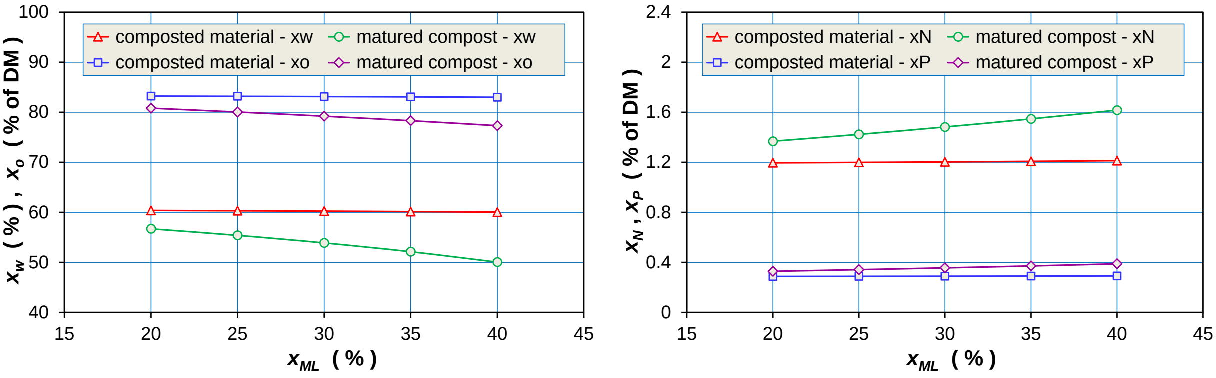


Fig. 5 The influence of the mass fraction $x_{KB}$ of kitchen biowaste in the composted material on the mass ratio of organic carbon and nitrogen C:N in the composted material and in the produced matured compost.



a) b)

Fig. 6 The influence of the relative weight loss $x_{ML}$ of the composted material on the substance composition of the produced matured compost, assuming a constant mass ratio of the composted material components ($x_{KB}$ = 65 %, $x_{WC}$ = 30 %, $x_{RMC}$ = 5 %):
a) mass fraction of moisture $x_w$ and mass fraction of organic matter in dry matter $x_o$,
b) mass fraction of nitrogen in dry matter $x_N$ and mass fraction of $P_2O_5$ in dry matter $x_P$.

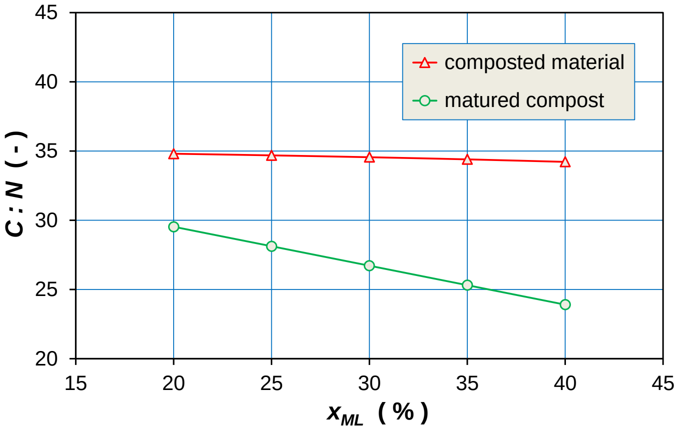


Fig. 7 The influence of the relative weight loss $x_{ML}$ of the composted material on the mass ratio of organic carbon and nitrogen C:N in the produced matured compost, assuming a constant mass ratio of the composted material components ($x_{KB}$ = 65 %, $x_{WC}$ = 30 %, $x_{RMC}$ = 5 %).

The process of intensified composting of kitchen biowaste in closed composting reactors is analyzed in more detail. The optimal composition of the composted material and the optimal conditions of the composting process are specified (Tab. 1) in order to produce compost characterized by the required properties (Tab. 2). By means of several graphical dependencies, the specific connections between the composition of the composted material and the composition of the produced compost are documented (Fig. 4 and Fig. 5), which is also significantly influenced by the level of material transformation during composting (Fig. 6 and Fig. 7). From the process point of view, the graphs in Fig. 8 show a direct connection between the pressure drop $\Delta p_{z1}$ of air flowing at a defined velocity $u_0$ through a layer of composted material with a thickness of 1 m and the structure of this layer, which is defined by the specific surface of the particles in the layer $a_v$ and by the layer porosity ε.

It should also be mentioned that the process of the biowaste treatment by composting does not contribute to reducing the carbon footprint, which is a certain disadvantage compared to the alternative method of microbiological disposal of biowaste by anaerobic digestion. During the anaerobic digestion process, the resulting gaseous product (biogas, containing mainly methane and carbon dioxide) is captured. The obtained biogas can be further used, most often as a fuel in cogeneration for the production of heat and electricity.

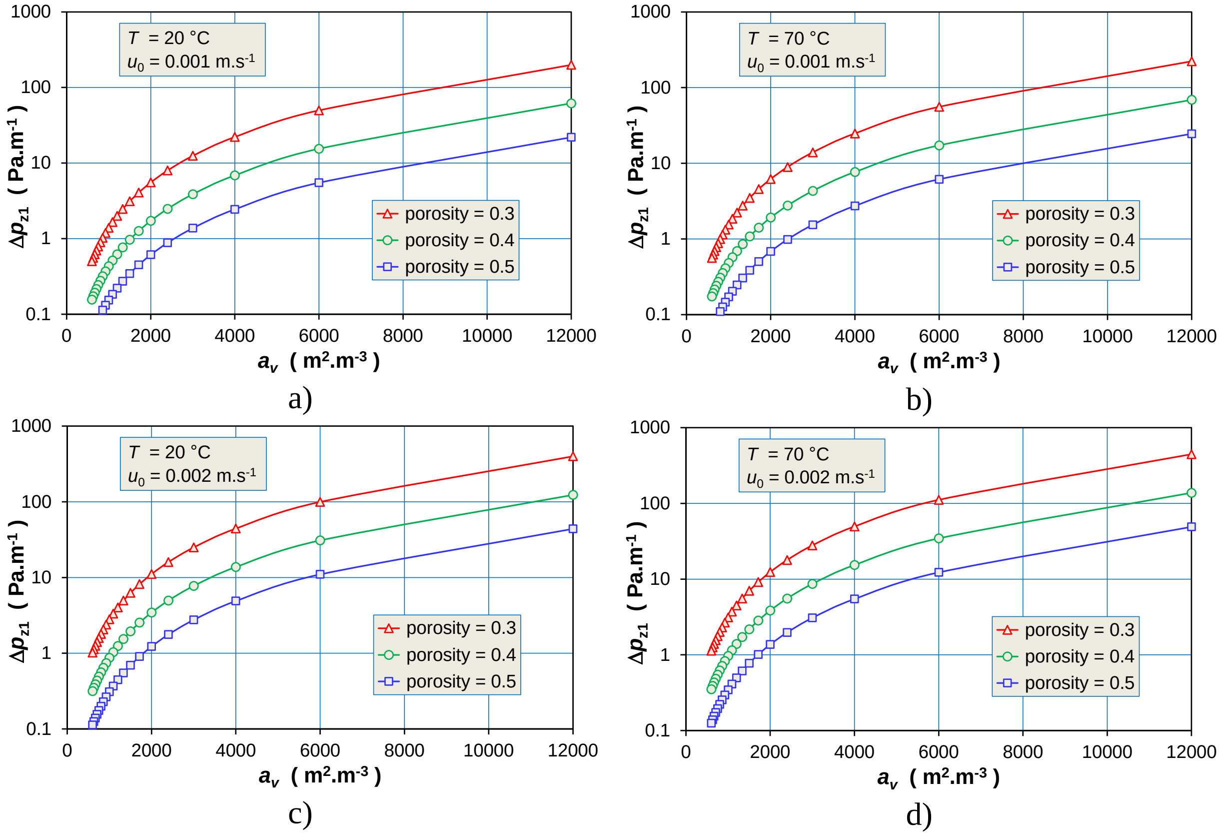


Fig. 8 The dependences of the pressure drop $\Delta p_{z1}$ of air flowing through a layer of composted material with a thickness of 1 m under different conditions (air temperature $T$, characteristic air velocity $u_0$, layer porosity ε) on the specific surface of the particles in the layer $a_v$: a) $T = 20$ °C, $u_0 = 0.001$ m.s$^{-1}$, ε = 0.3 to 0.5, b) $T = 70$ °C, $u_0 = 0.001$ m.s$^{-1}$, ε = 0.3 to 0.5, c) $T = 20$ °C, $u_0 = 0.002$ m.s$^{-1}$, ε = 0.3 to 0.5, d) $T = 70$ °C, $u_0 = 0.002$ m.s$^{-1}$, ε = 0.3 to 0.5.

## ACKNOWLEDGEMENTS

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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