Optimisation of Intensive Rotting Processes

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Prozessoptimierung von Intensivrotteverfahren

Abstract

The optimisation of intensive rotting processes is carried out by specific active aeration and watering, interacting with each other, as well as by waste turning and moving respectively. The present lecture will introduce basic approaches of calculation for the control of intensive rotting processes which were acquired by the consulting engineers of gewitra mbH. These computing procedures are applied for different dimensioned intensive rotting processes, tunnel and container systems in particular. Likewise, they will be continuously developed based upon further operational experiences.

Keywords

Intensive rotting process; aeration; watering; waste turning and moving respectively; kinetics, stoichiometry and thermodynamics of aerobic degradation; heat removal and water removal with exhaust air.

1 Introduction

The mechanical-biological waste treatment (MBT) is divided into the mechanical processing and the subsequent biological treatment in the form of aerobic processes (intensive rotting, postmaturation) or anaerobic processes (fermentation). The main emphasis of the present article lies in the intensive rotting process of MBT plants, which is especially characterized by active aeration. The aeration has the function of introducing oxygen into the system on the one hand and on the other hand of removing excess heat from the system. Together with the heat also water is removed from the system with the exhaust air, so that an unintended biological drying of the waste material is caused and an aeration-dependant watering is necessary.

The aeration and watering intensity necessary for the optimisation of intensive rotting processes has to be adapted to the respective boundary conditions, including the biologically degradable organic part and structure of the waste material, process or detention time as well as humidity and temperature of the air flows.

The determination of the optimised process control of intensive rotting processes is based on the following calculation approaches:

- Kinetics of biological degradation and conversion processes
- Stoichiometry and thermodynamics of aerobic degradation and conversion processes
- Thermodynamics of the air flows

2 Boundary conditions of the process

2.1 Intensive rotting systems

Owing to the dimension considering the treatable waste wet mass (WM) two essential intensive rotting systems can be differentiated: in the Container Intensive Rotting 18 mg WM per container at an average are treatable, in Tunnel Intensive Rotting however, 240 mg WM at an average (see Table 1).

Table 1 Dimensions of intensive rotting systems

	Container system	Tunnel system
System volume	approx. 35 m³	approx. 430 m³
Waste wet mass	approx. 18 Mg WM	approx. 240 Mg WM
Waste filling level	approx. 1.8 m	approx. 3.7 m

Figure 1 shows the thermodynamic system of intensive rotting systems with the air flows, which are normally controllable via the fresh air flap and the recirculated air flap, and the online measuring parameters. The waste temperature or exhaust air temperature and the oxygen content in the exhaust air act as controlling parameters.

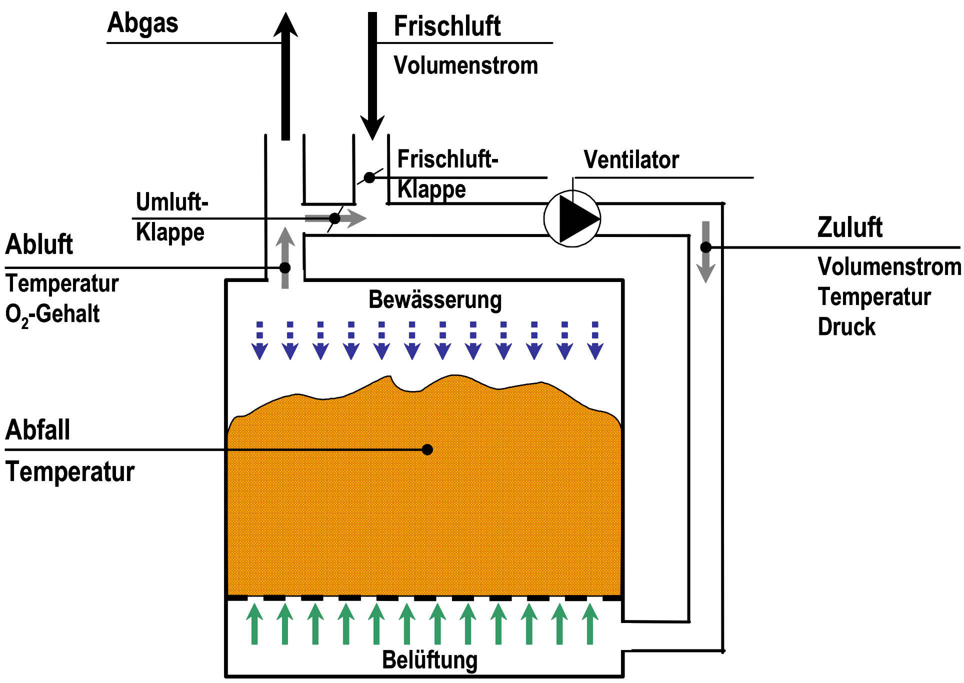

Figure 1 Thermodynamic system of intensive rotting processes

Explanation of the German terms contained in the figure:

- *Abgas – waste gas*
- *Frischluft, Volumenstrom – fresh air, volume flow*
- *Umluftklappe – recirculated air flap*
- *Frischluftklappe – fresh air flap*
- *Ventilator – fan*
- *Abluft, Temperatur, O_2-Gehalt – exhaust air, temperature, O_2-content*
- *Abfall, Temperatur – waste, temperature*
- *Bewässerung – watering*
- *Belüftung – aeration*
- *Zuluft, Volumenstrom, Temperatur, Druck – incoming air, volume flow, temperature, pressure*

2.2 Process control

2.2.1 Optimal process conditions

The essential influential factors on aerobic degradation and conversion processes are the oxygen content, the temperature and the water content of the system, i.e. of the waste material. Different practice-relevant studies have shown that the following process conditions are regarded as optimal:

- **Oxygen content**
  Oxygen enters into the metabolism of the aerobic respiration as reactant. According to SOYEZ et al., 2000 a minimum oxygen concentration of approximately 16 to 18 % vol. is assumed to maintain the propulsive force of the biological process and to permit unlimited reactions. A significant deceleration of the microbial activity occurs according to KRANERT, 2000 at an oxygen content of less than 10 % vol. in the exhaust air.
- **Temperature**
  The energy released in the exothermically running aerobic degradation reactions in the form of heat causes process temperatures of 80 °C and more. The optimal process temperature however, i.e. the waste temperature, lies according to SOYEZ et al., 2000 within the range of 50 to 60 °C.
- **Water content**
  Microorganisms can take in nutrients only in dissolved form, so that the system has to have a sufficient amount of water and optimal reaction conditions have to be established for the biological degradation and conversion processes. According to SOYEZ et al., 2000 a guideline value of 45 to 55 % water referred to the wet mass (FM), i.e. values within the range of water saturation, should be aimed at in residual waste treatment.

2.2.2 Measures of process optimisation

The establishment of optimal process conditions is realized by controlling the aeration and watering as well as by turning and thus moving the waste material.

- **Aeration**

  Aeration mainly has the function of introducing oxygen into the system on the one hand and of removing heat from the system on the other hand. As the exhaust air temperature is higher than the incoming air temperature the exhaust air absorbs moisture and therefore reduces the temperature and the water content of the waste material.

  Depending on the degradated organic substance, an incoming air volume of between 2 and 15 m³ per kg of degradated organic dry mass (oDM) is necessary for the coverage of the stoichiometric oxygen demand. However, the setting of a system temperature of 55 °C requires an incoming air volume of between 22 and 150 m³/kg oDM. The water removal associated with this heat removal through the exhaust air is 6 kg/kg oDM at an average [MÄHL, 2005].

- **Watering**

  On the one hand, watering has the function to set an optimal water content for the beginning of the process. On the other hand, the moisture removal with the exhaust air has to be compensated by continuous watering, which is basically depending on the aeration intensity.

- **Turning**

  The turning of the waste material causes a homogenization (complete mixing of the waste substances) as well as an agitation and thus an enlargement of the air-filled porosity, so that the potential air flow rate is increased.

3 Process simulation of intensive rotting processes

3.1 Kinetics of biological degradation and conversion processes

The degradation kinetics of biological waste stabilization processes are described in Figure 2 by a first-order reaction which is based on the following boundary conditions:

- **Respiratory activity AT_4**

  The parameter respiratory activity (AT_4) is reduced from $AT_{4;In}$ = 80 mg O_2/g DM to $AT_{4;Out}$ = 20 mg O_2/g DM. The detention or the process time in intensive rotting is 28 days.

- **Waste mass**
  The water content WG_{In} is 45 %, i.e. 1 Mg wet mass (WM) correspond to 0.55 mg dry mass (DM). The ignition loss IL_{In} is 50 %, i.e. 0.55 Mg DM correspond to 0.275 Mg organic dry mass (oDM).

- **Rate of degradation**
  Due to the boundary conditions chosen here the rate of degradation of the organic dry mass (oDM) is set with approximately 2.4 kg oDM per day at an average referred to an intensive rotting input of 1 Mg WM.

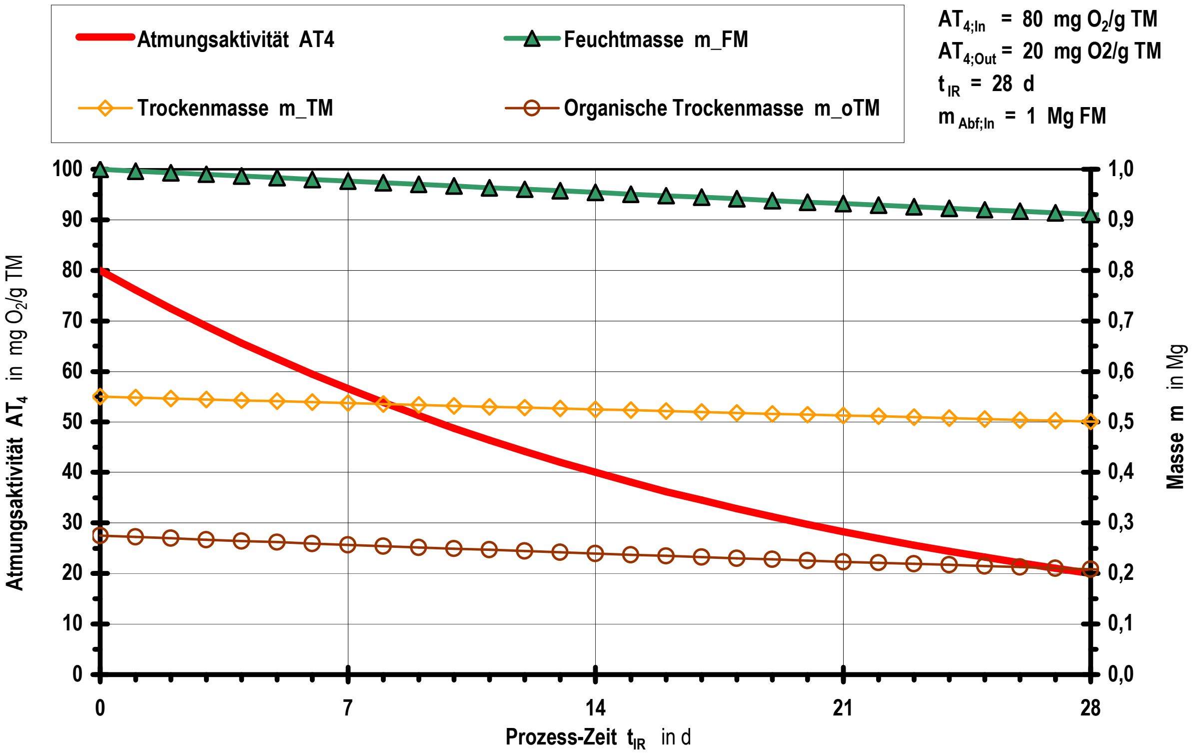

Figure 2 Kinetics of biological degradation and conversion processes

Explanation of the German terms contained in the figure:

- *Atmungsaktivität – respiratory activity*
- *Feuchtmasse FM – wet mass WM*
- *Trockenmasse TM – dry mass DM*
- *Organische Trockenmasse oTM – organic dry mass oDM*
- *Masse – mass*
- *Prozess-Zeit – process time*

3.2 Stoichiometry and thermodynamics of aerobic degradation and conversion processes

A selection of the following organic substances forms the basis of the stoichiometric and thermodynamic calculation of aerobic degradation and conversion processes:

- **Substance groups**
  The substance groups of organic substances contain different carbohydrates, fats, proteins, hydrocarbons and alcohols.

- **Waste fractions**
  The waste fractions include the organic substances that are contained in residual waste from houses, in organic wastes (kitchen wastes as well as garden and park wastes), paper and cardboard as well as in sewage sludge.

The organic substance is converted in a complete aerobic degradation under consumption of oxygen O_2 into carbon dioxide CO_2, water H_2O and ammonia NH_3. In the course of the aerobic degradation reactions energy is released in the form of heat, in the following called heat of reaction.

Table 2 shows the stoichiometric oxygen demand, the metabolic products and the heat of reaction, each time per kg of degradated organic dry mass (oDM).

Table 2 Stoichiometry and thermodynamics of aerobic degradation and conversion processes

	O_2-consumption kg O_2/kg oDM	**CO_2-production** kg CO_2/kg oDM	**H_2O-production** kg H_2O/kg oDM	**NH_3-production** kg NH_3/kg oDM	**Heat of reaction** kJ/kg oDM
Substance groups:					
Min	0.18	0.96	0.20	0.00	- 2 420
Max	3.99	3.09	2.25	0.23	- 54 334
Average	1.56	1.79	0.74	0.02	- 21 266
Waste fractions:					
Min	0.56	1.53	-0.09	0.00	- 7.561
Max	2.82	2.85	1.03	0.19	- 38 476
Average	1.14	1.81	0.29	0.04	- 15 534
Substance groups, waste fractions:					
Average	**1.57**	**1.91**	**0.62**	**0.04**	**- 21 356**

3.3 Thermodynamics of the airflows

In order to determine the necessary aeration and watering during the treatment process the following variations were calculated:

- **Variation 1**

  Incoming air: Relative humidity φ = 0.7; Temperature t = 15, 20, 25, 30, 35, 40 and 45 °C

  Exhaust air: Relative humidity φ = 1.0; Temperature t = 55 °C

- **Variation 2**

  Incoming air: Relative humidity φ = 0.7; Temperature t = 15, 20, 25, 30, 35, 40 and 45 °C

  Exhaust air: Relative humidity φ = 0.9; Temperature t = 50 °C

The theoretically achievable states of the loading cases chosen for the variations differ from each other in the chosen heat removal, i.e. moisture content in connection with the temperature difference of incoming air and exhaust air. **Variation 1** contains the boundary condition that the incoming air entirely streams through the waste material, that it exits with a saturation of 100 % and causes the setting of a waste temperature at 55 °C. **Variation 2** is, considering the necessary amount of incoming air, the harder loading case, because the exhaust air is set at a saturation of 90 % and a temperature of 50 °C, so that due to the lower enthalpy (reduced possible heat removal because $\varphi = 0.9$) and the higher amount of heat to be removed the necessary amount of air is bigger in comparison with Variation 1.

The results of the calculation of the variations are compiled for container and tunnel systems in Table 3 and Table 4 for the following parameters:

- **Volume of the humid incoming air in operating state V_{Zul}**,
  i.e. 15, 20, 25, 30, 35, 40 or 45 °C at $\varphi = 0.7$
- **Volume of the humid exhaust air in operating state V_{Abl}**,
  i.e. 55 °C or 50 °C at $\varphi = 1.0$ or 0.9
- **Removed enthalpy H_{Aus}**,
  describes the amount of heat that is removed from the system with the exhaust air;
- **Removed water vapour mass $m_{WD;Aus}$**,
  describes the amount of water vapour that is removed from the system with the exhaust air;
- **Necessary watering $V_{H2O\text{-}Zuf}$**,
  describes the amount of water vapour that is removed from the system with the exhaust air and that has to be returned by continuous process-watering.

Table 3 Necessary incoming air as well as heat and water vapour mass removed with exhaust air - **Variation 1**

Incoming air	V_{Zul} m³/h	V_{Abl} m³/h	H_{Aus} kJ/d	$m_{WD;Aus}$ kg WD/d	$V_{H2O-Zuf}$ m³ H_2O/d
Container intensive rotting, waste wet mass = 18 Mg WM, water content = 45 %					
(a) 15 °C	**100**	133	914 191	306	**0.31**
(b) 20 °C	**106**	138	914 191	310	**0.31**
(c) 25 °C	**114**	145	914 191	314	**0.31**
(d) 30 °C	**124**	155	914 191	318	**0.32**
(e) 35 °C	**138**	168	914 191	322	**0.32**
(f) 40 °C	**159**	187	914 191	326	**0.33**
(g) 45 °C	**192**	219	914 191	331	**0.33**
Tunnel intensive rotting, waste wet mass = 240 Mg WM, water content = 45 %					
(a) 15 °C	**1 331**	1 774	12 189 218	4 084	**4.08**
(b) 20 °C	**1 415**	1 844	12 189 218	4 136	**4.14**
(c) 25 °C	**1 519**	1 936	12 189 218	4 187	**4.19**
(d) 30 °C	**1 656**	2 060	12 189 218	4 239	**4.24**
(e) 35 °C	**1 844**	2 235	12 189 218	4 293	**4.29**
(f) 40 °C	**2 120**	2 496	12 189 218	4 352	**4.35**
(g) 45 °C	**2 562**	2 921	12 189 218	4 420	**4.42**

Table 4 Necessary incoming air as well as heat and water vapour mass removed with exhaust air - **Variation 2**

Incoming air	V_{Zul} m³/h	V_{Abl} m³/h	H_{Aus} kJ/d	$m_{WD;Aus}$ kg WD/d	$V_{H2O-Zuf}$ m³ H_2O/d
Container intensive rotting, waste wet mass = 18 Mg WM, water content = 45 %					
(a) 15 °C	**146**	183	914 191	295	**0.30**
(b) 20 °C	**159**	194	914 191	300	**0.30**
(c) 25 °C	**175**	208	914 191	305	**0.31**
(d) 30 °C	**198**	230	914 191	310	**0.31**
(e) 35 °C	**232**	263	914 191	316	**0.32**
(f) 40 °C	**290**	320	914 191	322	**0.32**
(g) 45 °C	**410**	437	914 191	331	**0.33**
Tunnel intensive rotting, waste wet mass = 240 Mg WM, water content = 45 %					
(a) 15 °C	**1 953**	2 434	12 189 218	3 929	**3.93**
(b) 20 °C	**2 115**	2 580	12 189 218	3 996	**4.00**
(c) 25 °C	**2 331**	2 779	12 189 218	4 064	**4.06**
(d) 30 °C	**2 634**	3 064	12 189 218	4 133	**4.13**
(e) 35 °C	**3 093**	3 505	12 189 218	4 208	**4.21**
(f) 40 °C	**3 872**	4 262	12 189 218	4 295	**4.30**
(g) 45 °C	**5 468**	5 828	12 189 218	4 418	**4.42**

For the direct transfer of the calculated values to commercial-scale plants it has to be considered that the scales apply under the following boundary conditions:

- **Isothermal proportions**, which cannot be realised on a large scale; in practical operation of commercial-scale plants, a spatial temperature distribution with partly high temperature gradients always has to be assumed.
- **Sufficient air-filled porosity**, which determines both the amount of air and the movement potential of the air within the substrate. The pore volume decreases with increasing process time or respectively detention time due to settlement processes and the degradation of organic substances.

The obtained values for the necessary aeration and watering depend on different boundary conditions which have to be adapted according to the actual process conditions for the prevailing individual case in MBT-plants. Essentially, this includes the heat of reaction, the rate of degradation, the pressure, the relative humidity and the temperature of the incoming air and the exhaust air as well as the possible air flow rate which is determined by the available air-filled porosity and which is increased remarkably during the treatment process by turning and moving the waste material.

4 Summary

The watering of the waste material before the beginning of the process or treatment, which normally takes place in the homogenization drum after the mechanical processing, as well as the aeration, watering and turning during the treatment process serve as measures for process optimisation. Practice-relevant studies in different MBT-plants have shown that for process optimization of intensive rotting processes the following measures are effective and desirable:

- **Watering**
  The watering of the waste material before the beginning of the process or treatment sets the water content of the intensive rotting input. To avoid a constraint of the air flow as far as possible a water content of 45 % has to be aimed for. Therefore, at a water content of between 35 and 40 % in the waste material before the intensive rotting, an amount of water of between 1.6 and 3.3 m³ per container and between 22 and 44 m³ per tunnel has to be supplied.
- **Process-aeration**
  The important aeration requirement consists in the heat removal with the exhaust air in order to set temperatures of approximately 55 °C in the system and thus enable unlimited degradation reactions. The heat removal depends first and foremost on the temperature of the incoming air, i.e. the proportion of fresh air and circulating air in the incoming air. For the variations calculated in Section 0 it arises that at an incom-

ing air temperature of 20 °C an amount of incoming air of 110 to 160 m³/h per container respectively 1 400 to 2 100 m³/h per tunnel is necessary to remove the excess heat from the waste material. The necessary amount of incoming air increases at an incoming air temperature of 40 °C up to values of between 160 to 290 m³/h per container respectively 2 100 to 3 900 m³/h per tunnel. Furthermore, it has to be considered that the actual air flow rate and thus the heat removal is determined by the available air-filled porosity in the waste material.

- **Process-watering**
  With the heat removal also water is removed from the waste material, so that during the whole treatment process for the maintenance of the microbial activity an amount of water of 0.3 m³ per day and container respectively 4.2 m³ per day and tunnel at an average has to be introduced.

- **Turning respectively moving of the waste material**
  The actually possible air flow rate is determined decisively by the available air-filled porosity. The pore volume decreases during the treatment process due to settlement processes and the degradation of organic substances. By turning and therefore moving the waste material the amount of air streaming through the waste material can be increased by four times. Therefore it is recommended to turn the waste material weekly. It turned out that the first turning, which should be carried out around seven days after the beginning of the intensive rotting, is decisive.

The engineering office gewitra mbH carries out works in this regard to take full advantage of the process control in dependence on the prevailing boundary conditions of single MBT-plants and to set it the best way possible. The objectives of the specified process optimisation are:

- Minimization of the process or detention time while maintaining a high degradation performance,
- Reduction of the amount of exhaust air by an innovative exhaust air management,
- Increase of the cleaning capacity of existing exhaust air treatment aggregates considering critical parameters, like carbon, nitrous oxide and odour emissions,
- Improvement of the availabilities of single system components up to the whole exhaust air cleaning.

5 Literature

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