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The State of the Art of Composting

A guide to good practice

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– a guide to good practice –

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0 INTRODUCTION

0.1 Background

An Austrian guideline was first published by the Austrian Ministry for Agriculture and Forestry, Environment and Water Management (BMLFUW) in 2005 (Amlinger *et al.*, 2005a). It supported two ordinances defined in Austrian waste legislation, namely:

1) The Biowaste Ordinance (FLG No 68/1992) which mandates the source separation and biological treatment (mainly through composting and anaerobic digestion) of organic waste since 1995 and
2) The Compost Ordinance (FLG II No 292/2001) which established an end-of-waste regulation for compost produced from defined organic wastes when the resulting compost fulfils quality requirements in addition to obligations for monitoring and external quality assurance.

As a basis for the guideline the BMLFUW launched the study “The State of the Art of Composting – A Baseline Survey” (Amlinger *et al.* 2005b)[1].

The objective of the study was to describe the technical and operational conditions for low-emission process management during all steps of composting as well as the continuous production of high quality compost.

The today’s state of knowledge and experience was gained from:

- 20 years of the authors’ experience in Austria;
- a literature survey; and
- facility planning and reorganizational experience.

When proposing measures for process and management optimisation in order to reduce emissions, the most efficient methods were considered that were also proportionate financially and technically. This complied with the definition of the *“best available technique”* principle of the Austrian Waste Management Act (FLG I 102/2002; §2(8)1). Furthermore, the numerous Austrian composting systems (techniques and operational schemes), including the diverse range of site location, feedstocks and capacities, were considered.

One important premise of the study was not to endanger the well established decentralised, mainly on-farm, composting systems in place in Austria by recommending the introduction of disproportionate technical obligations. This strategy has been broadly acknowledged as an ecological and sustainable system of biowaste recycling since the early 1990s: it complies with many desirable environmental factors, such as the proximity principle, which need to be balanced against specific environment protection aspects, such as employees’ and neighbours’ interests.

0.2 Scope

The guideline describes minimum technical, construction and operational requirements for composting plants processing organic waste as defined Annex I of the Austrian Compost Ordinance (FLG I No 292/2001).

Residual Waste Treatment

The mechanical biological treatment (MBT) of residual waste is not covered in this Guide. The pre-treatment of residual waste aims to reduce the volume and biologically stabilise waste prior to landfilling.

[1] This study describes a comprehensive survey of scientific and technological knowledge, as well as describing practical experiences. This study cites numerous references in the Annex, although only the most relevant references, legislation and standards have been listed.

Therefore material and process related issues differ considerably from the requirements of biowaste composting (which aims to manufacture quality compost for beneficial use). In Austria, requirements for MBT plants have been described in the "Guideline for the mechanical biological treatment of waste" edited by the BMLFUW (2002).

Production of "Manufactured (Artificial) Soils"

In the Austrian Compost Ordinance the addition of (excavated/dredged) 'soil' is only permitted as a supplement in order to optimise the composting process, up to a maximum of 15 % (m/m) of the initial material mixture. This defines the boundary between manufacturing of compost and manufacturing an artificial soil.

If more than 15% (m/m) were to be added, by definition, the final product needs to comply with specific requirements for soil-like materials (manufactured soils) in contrast to compost. These requirements are laid down in the "Federal Waste Management Plan, Supplement: Guidelines for Waste Shipment and Treatment Principles" (BMLFUW, 2006). Application orientated quality requirements and project description for the use of manufactured soil have been described in a series of Austrian standards, namely ÖNORM S 2122 "Soils from waste" Part 1 to 4

0.3 Principles of a successful regulatory framework

In general terms, in order to guarantee traceable and transparent processing of defined organic source materials (organic wastes) into a quality labelled compost products that can be marketed as quality compost or as constituent in growing media and other blends, the following aspects should be addressed in any binding regulatory framework:

- General environmental permit requirements for composting sites;
- Comprehensive and unmistakable definition of admissible "clean" feedstocks;
- Standard requirements of receipt control;
- Process requirements (e.g. hygienisation);
- Record keeping and documentation of all relevant operating steps;
- Product quality definition and scale of parameters to be measured for product declaration and labelling purposes;
- Defined applications dependent upon compost quality (e.g. heavy metal related product classes);
- Product designation in order to avoid misleading interpretation by consumers;
- Regular external quality approval including sampling and analytical methods;
- Competences and rules for controlling of products by the competent authority;
- Product certification by external control bodies;
- Labelling requirements; and
- Minimum recommendations for proper use.

1 Overview of the biology of composting

The aim of composting organic source materials is to transform them through a managed biologically-mediated process into humus-rich material which is suitable for many beneficial applications in agriculture, landscaping and private gardening. Compost is a provider of humified (humus and clay-complex) organic matter and plant nutrients, and serves as an organic soil improver and as a constituent in growing media and other blends.

Under Austrian law, if compost fulfils specified quality requirements and has been processed from defined raw materials it can be classed and marketed as a *product*. One key requirement is the minimum organic matter content of 20 % (m/m); which contrasts it from manufactured or dredged soils, which have much lower organic matter contents. Lowering the organic matter content for compost from 20 to 15 % (m/m) is under consideration by many experts in Austria.

In carrying out efficient and effective composting, composting technologies and associated process management procedures need to compoly with the following basic criteria:

1.) Fulfilment of legal requirements and *best available technique principles* (BAT) with respect to safety engineering, environmental protection, workers and neighbours' health protection etc.;

2.) Low-loss decomposition of the organic source materials into more or less mineralised/humified organic substrates (mature or semi mature compost);

3.) Optimisation of the composting system and process management in order to achieve the minimum possible emissions (odour, other volatile compounds, waste water, bio-aerosols, noise) including systems of record keeping, process control and documentation; and

4.) Regular compliance tests with defined quality requirements of compost products

It is important to note that the optimisation of the composting process in terms of process management and quality achievement is mainly influenced by four basic parameters:

- Composition of the raw materials/feedstocks
- Moisture content
- Aeration (oxygen supply)
- Temperature regime

A basic understanding of the biochemical processes that occur during the controlled decomposition of organic source materials is an indispensable pre-requisite for proper, quality-orientated composting process management.

Composting is a *self-heating* (exothermic) degradation process, which depends mainly on material mixture, moisture, volume and particle size distribution, as well as the extent of agitation and aeration. Composting is often managed to maintain a desired temperature range, which selects for certain communities of micro-organisms. These can be broadly categorised as:

- Psychrotolerant – 4 to 20 °C Bacteria and mould fungi
- Mesophilic 15 to 42 °C Bacteria, including a specific group called the actinomycetes, and fungi
- Thermophilic 45 to 75 °C Bacteria, including the actinomycetes and other spore-forming genera, such as *Bacillus spp.*

The following optimum temperature ranges during composting are summarised in Table 1.

Table 1: Optimum temperature ranges for differentiated process characteristics

Process requirement	Temperature range
Hygienisation	> 55°C
Decomposition rate; degradation of lignin and lignocellulose compounds / humification	45 - 55°C
Highest microbial diversity; degradation of microbial biomass; degradation of lignin and lignocellulose compounds / humification	35 - 40°C

Based on these principles, and in order to manufacture quality compost, the following temperature phases are desirable:

- Initially, a *hygienisation* or *sanitisation* phase, very often also named as *active rotting phase* where temperatures above 55 °C are maintained for a defined period of time over the entire composting mass. This "high temperature phase" is, as a principle, required by human and animal health related legislation on national or European level (EU Animal BY-Products Regulation] in order to guarantee a minimum degree of thermal reduction of pathogens potentially present in source materials (see Chapter 6.3);
- After this first *high temperature (or active rotting) stage,* the material should be kept below 50 to 55 °C in order to facilitate humification and complexion processes, and to reduce organic matter and nitrogen losses. This can be achieved by mechanical agitation, forced aeration, and by maintaining sufficient humidity.

In general, minimum time-temperature profiles are not deemed obligatory for materials stemming from, then being applied to, on-site composting systems (e.g. green waste or manure from farms).

The *mass balance of composting* of biowaste generally results in the decomposition of organic matter and process gasses, leaving somewhere in the region of 55 to 65 % (m/m) of the initial mass, although this is dependent upon the feedstocks. The proportion of refined compost after the removal of impurities and non-recyclable oversize fraction amounts to approximately 30 – 35 % (m/m). In the case of composting garden and park waste, with a very high proportion of ligneous constituents, the extent of decomposition can be as low as 20 to 30 % (m/m).

2 Treatments which do not comply with *'good practice'* composting techniques defined in this guideline

This section defines the borderline between acknowledged decomposition systems and improper storage or pseudo-treatments of organic materials which do not comply with the state of the art or good composting practices as defined in this guideline.

2.1 Storage and management of raw materials without appropriate pre-treatment and/or controlled degradation

The following treatments are **not recognised as state of the art composting**:

- Storage of certain raw materials without immediate mixing and processing through a managed degradation process every working day (or at least within 24 hours). These include:

  All source separated organic waste from households, food waste, food processing waste, catering waste or organic industrial wastes with high moisture content, fresh grass clippings, manure (if it is of external origin), an all other materials which – if stocked improperly – would lead to increased odour or other gaseous emissions.

  Exempted from this requirement are all ligneous organic residues like straw, dry leaves and any other organic materials with a low biological reactivity and a C/N ratio above ca. 50[2])

- Uncontrolled stockpiling and decomposition of organic materials. Therefore the following features must be guaranteed

  a defined biological and mechanical processing in order to provide homogenous decomposition conditions (see Chapters 4 and 7.2);

  an optimised material mixture; and

  intensive mechanical agitation and water management (turning frequency during the first 6 weeks, at a frequency of 1 to 5 times per week).

- A total composting period of less than 6 weeks. A 5 to 6 week composting time is only acceptable if the following requirements are applied and well monitored:

  Open windrow composting with natural or forced aeration:

  ⇒ specially thorough blending of raw materials, intensive homogenising,

  ⇒ turning with a frequency of 3 to 5 times a week during the first 21 to 28 days;

  ⇒ windrow height maximum < 1.5 m

  First intensive decomposition stage in a closed in-vessel rector system (e.g. box or tunnel):

  ⇒ Mechanical agitation at least once per week

  ⇒ After extraction from the reactor during the following two weeks the composting material must be turned at least three-times a week if forced aeration is not applied, or turned at least once per week with forced aeration

2.2 Treatment on unsealed soil without pavement and without controlled waste water collection and treatment

Reception, tipping and pre-treatment of raw material, and the active decomposition phase has to be carried out, in principle, on sealed ground (see Chapters 7.1, 7.2, 7.3).

Exceptions may be granted for garden and park waste (green waste) up to an annual treatment capacity of 300 m³. Detailed requirements are listed in Chapters 7.1, 7.2, 7.3).

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2 See Table 17 with C/N figures of typical compost feedstocks as a guide.

2.3 Dry stabilising of organic material in systems with forced aeration

In enclosed (in-vessel) composting systems (e.g. tunnel and box composting) degrading materials are typically cooled and dried by means of watering and aeration before extracting them after about 7 to 21 days of intensive treatment. The decomposition stage achieved often does not fulfil the requirements for controlled maturation (see also 7.3.3). The potential for odour emissions from this material remains, and can be exacerbated when the material is watered again.

The main purpose of closed reactor systems is the controlled decomposition and stabilisation of organic feedstocks to an extent that, following the first intensive degradation phase, subsequent degradation in the open (non-enclosed) does not create major odour problems. If this is not achievable then the process technology does not comply with the state of the art or BAT requirements of composting (see Chapter 6.1).

A minimum retention time of 14 to 28 days and the achievement of minimum stability criteria may be defined as requirements for decomposed material extracted for maturation in open windrows without requiring further process air treatment (e.g. through a *biofilter*; see Chapter 7.3.3).

2.4 "Over-heating" organic materials to temperatures in excess of 70 °C

Temperatures above 55/60 °C can constitute sub-optimal microbiological conditions for efficient, controlled degradation processes. Additionally, above 65/70°C odour creating compounds evolve and the synthesis of humic substances is suppressed.

Thus composting systems which systematically maintain temperatures > 70 °C do not comply with good practice and the state of the art of composting.

2.5 Addition of fresh, non-sanitised raw materials to compost during maturation

Within the framework of a controlled and continuous composting process, and in order to safeguard compost quality, it is undesirable to add non-sanitised organic waste materials to compost during the maturation phase. All materials within one compost batch should be in approximately the same stage of decomposition and humification at any time.

Additives mixed with compost at a later stage may be either of mineral character (stone dust, etc.) or well stabilised organic materials (e.g. oversize screenings or mature compost, bark).

3 Typical pre-processing methods – anaerobic storage and fermentation and slow fungal decomposition with inoculants

In recent years some composting plants have introduced pre-processing methods such as an anaerobic fermentation (ensiling) step prior to systematic aerobic composting. Fermentation is carried out under complete or partially anaerobic conditions after applying specific inoculants and breaks down typical odour causing compounds. The proposed processes lead, either to a material similar to silage, colonised predominantly by lactate acid bacteria, or a slow, predominantly fungal decomposition.

3.1 "Predominantly fungal aerobic, facultative anaerobic pre-composting without physical agitation"

This pre-treatment lasts for between 16 and 20 weeks and is carried out in piles up to 4.5 meters high. The material is treated with fungally-dominated inoculants and is not turned. The goal is to ensure the slow transformation of the easily degradable C- and N- sources as well as the potentially odour producing compounds.

The addition of sufficient and well shredded bush and tree cuttings as well as other garden and park waste is of significant importance: It serves as a C source and supports fungal growth, which is the prerequisite for the metabolism of ligneous compounds. The heaps do not need to be covered with geo-textile or similar covers.

There is no documented experience available about the process parameters (temperature, odour emissions, fungal growth throughout the cross-section of the heaps, formation of humic substances, decomposition dynamic) or green house gas emissions and ammonia during these treatments.

It is obvious that without additional forced aeration systems an effective decay of odour relevant substances can only take place if sufficient air exchange is provided. Therefore the following parameters must be observed:

- Sufficient structural material is incorporated to provide air-filled pore space throughout the pile;
- Homogeneously distributed moisture above 50 % (fresh matter).

The following aspects may still cause problems and therefore merit further investigation:

- Increased methane and nitrous oxide emissions due to the pile height;
- Increased press and process water leaching during the initial decomposition stage because the material is not turned and unbalanced blending with dry materials cannot be corrected;
- Uncontrolled, zone wise dry stabilisation. Those zones cannot be included in the proper decomposition and fermentation process;
- Not covering the material with a fleece or an alternative organic material cover. Depending on weather conditions the upper surface layer of about 30 cm may fall dry and is not integrated into the decomposition process. If animal by-products are treated these may remain unprocessed on the pile surface, accessible to birds for several weeks[3].

3.2 "Anaerobic lactic acid pre- fermentation"

This silage-like pre-fermentation and storage technique is only suitable for easily degradable feedstocks with low contents of ligneous materials (e.g. grass clippings, food and kitchen waste, fresh leaves etc.).

After careful mixing, the material is sprayed with an inoculant preparation containing a range of bacteria which support strict or facultative anaerobic fermentation processes. Piles of approximately 2 meters of

[3] Note: open windrow systems may be adopted for composting of Category 3 Material based on national regulations and being approved by the competent authority.

homogenously inoculated raw material are covered with a silo plastic sheet in order to exclude oxygen. After 2 to 8 weeks of fermentation the *'biowaste silage'* is mixed with shredded bush and tree cuttings and other green waste and composted in open windrows under aerobic conditions. By that time all nuisance causing odour compounds should have be metabolised.

This method has been used successfully, especially during the winter season with low temperatures, high amounts of snow and when food waste is the predominant fraction of source separated household waste.

Notwithstanding, the following aspects have to be observed carefully:

- The changing composition of feedstocks may cause inadequate fermentation conditions. The process needs more cautious management that simple silage processing. Increased methane emissions can be an undesirable consequence;
- The transition of the material from anaerobic conservation to aerobic composting may result in spontaneous odour emissions, caused by varying material properties (N-content) as well as fermentation conditions; and
- Systematic investigations have not yet been reported extensively in the peer-reviewed literature.

3.3 Conclusions

The described pre-processing methods are acknowledged as good practice in composting if the following pre-requisites are fulfilled:

- Homogenous blending of feedstocks is carried out;
- Even distribution and maintenance of moisture, taking into account the total water holding capacity of the material mix and the requirements of the biological process involved;
- Only feedstocks which are deemed suitable for the silage process described in method 3.2 are used;
- Immediate and regular mechanical turning of the material during the initial composting phase is carried out. Thermal hygienisation needs to be attained (> 55°C) as well as all framework conditions of a well managed aerobic maturation phase;
- Covering the fermenting piles with either a geo-textile fleece in method 3.1 (aerobic fungal process), or gas tight foil in method 3.2. (anaerobic silage process); and
- The aim of the process is to provide the effective and controlled degradation and neutralisation of odorous compounds.

4 Compost feedstocks – Specific requirements with respect to process, potential emissions and quality aspects

Among the feedstocks for composting it is important to distinguish between decomposable organic materials (e.g. kitchen waste, park and garden waste, bark, agricultural wastes, stabilised sludge) and mineral additives (such as stone dust, ash, excavated soil etc.).

Additionally, it is also important to ensure that sufficient materials are available to enable an optimal mix of materials in order to maximise composting (e.g. to maintain structure and the C/N ratio). This may mean that small scale composting plants keep certain materials in stock for this purpose (e.g. shredded tree and bush cuttings, straw etc.).

4.1 Organic waste suitable for the production of high-quality compost or digestion residue

It is of crucial importance to identify suitable and legally authorised feedstock materials for the production of marketable compost. The choice must be made in such a way that they do not introduce contaminants that would prevent quality compost from being manufactured.

The Code numbers of the European Waste Catalogue[4] (EWC) in most cases give reference to the origin of waste, which can be ambiguous. In order to avoid misleading interpretation and confusion, more precise categorisation of organic waste materials is needed. However, a first rough ***categorisation*** would be:

- **Food waste:** the mixture of both cooked and raw materials left over after the preparation and consumption of human food; the origin can be either private (households), or from restaurants, canteens, bars, etc.
- **Garden and park waste**: the mixture of botanical waste (e.g. grass, tree and shrub prunings, flowers etc.) derived from private gardens (i.e. families) or from public areas such as parks, playgrounds, etc.
- **Other organic waste from agro-industries:** waste from food and animal feed processing or the processing of agricultural products for other purposes.

The waste categories describing type and origin of the most important organic waste types in the European Waste Catalogue are given below in Table 2.

Table 2: Important organic waste types used in composting as specified in the European Waste Catalogue

Description	Waste EU-code	Notes
Kitchen and canteen waste (food waste)	20 01 08	from households, restaurants, canteens, bars, coffee-shops, hospital and school canteens, etc.
Waste from public markets	20 03 02	only biodegradable materials equivalent to codes n°200108 and n°200201
Garden and park waste (yard waste)	20 02 01	from private gardens and public parks and areas, etc.
Wood waste	20 01 38	not containing dangerous substances; no furniture and bulky household-waste

Source: EU codes according to Commission Decision n° 2001/118/EC

The EU Waste Codes from the EWC does – for the purposes of biowaste treatment – not reach far enough in order to avoid misinterpretation, therefore we strongly recommend using a system which characterises the waste type and its quality. When including the origin therein the objective of the EWC is fully met.

[4] Commission Decision n° 2001/118/EC

Table 3 shows a comprehensive list of authorised feedstock materials for biological treatment (composting or anaerobic digestion), as well as indicating the category of origin. Within a flexible approval procedure for compliance, regulation needs to be sufficiently flexible to accommodate the possibility to add further materials.

Additives are sometimes added to composting mixes to facilitate the process, and these are listed in Table 4 below.

4.1.1 Organic feedstock materials

The following Table 3 is a summary of admissible feedstocks for composting from the Austrian Compost Ordinance (FLG II No 292/2001). A detailed update of the positive list of admissible feedstocks for biological treatment with requirements for receipt control is published in the Austrian standard ÖNORM S 2201: Biogenic Waste – Quality requirements.

Table 3: Suitable Organic Feedstock Materials for Composting

Feedstock group	Authorised feedstock	Quality and receipt control requirements; remarks
organic household waste, separately collected		Biowaste from municipal collection system; including feedstock of below
organic waste from the gardens, park and public greens	grass trimmings, lawn cuttings (lawn mowing), hay	Not from green belts or strips of highways and similar highly frequented roads
	leaves	
	flowers Fruits and vegetable waste	
	bark	Lindane-free bark only (limit value if contamination is suspected: 0.5 mg/kg d.m.)
	bush and tree cuttings also shredded	
vegetable waste, particularly from the preparation of foodstuffs	Fruit and vegetable residues	
	cereals	
	tea and coffee brew	
	vegetable catering waste	
animal waste, particularly from the preparation of foodstuffs	eggshells	
	animal catering waste	Only category 3 material according to Article 6, Reg. (EC) No. 1774/2002
	spoilt food of animal origin	
organic residue from **commercial, agricultural and industrial production**, processing and the sale of agricultural and forestry products	crop residues (straw, vines etc.)	
	hay	
	spent hops, kernels, shells, grist or the residue produced from pressing (e.g. from oil mills, brewer grains, pomace)	not treated with organic extracting agents, which may cause residues in of those agents in the compost
	yeast	
	unpolluted sludge or the residue from press filters used in the separate sewage collection systems of the food, luxury food and feeding stuffs industry	
	spoilt feeding stuff and feeding stuff residues spoilt seeds	seeds not treated with fungicides only
	tobacco waste	
	hoof and horn meal and chippings, animal hair, feathers	Only category 3 material according to Article 6, Reg. (EC) No. 1774/2002

Feedstock group	Authorised feedstock	Quality and receipt control requirements; remarks
-	Paunch waste	
	liquid and solid animal manure	According to the definition of Article 5 and Annex VI paragraph 14, Reg. (EC) No. 1774/2002
	bark	Lindane-free bark only (limit value if contamination is suspected: 0.5 mg/kg d.m.)
	wood (solid or chippings); saw dust/shavings	Untreated wood only
	Cane trash, molasses and other residues from sugar processing and final confection	
	cocoa shells	Testing of each delivery is required; the following limit values must be observed: lindane 0.5; DDT 0.3 [mg/kg DM] total of aldrin, dieldrin, endrin, heptachlor, the total of HCH, DDT and DDE, chlordane and hexachlorobenzene: 1 [mg/kg DM]
	gelatine residue	The processing requirements of Annex VII, chapter VI, letter A of Reg. (EC) No. 1774/2002 must be confirmed by the waste holder where the gelatine residue is delivered from
	"floating" sludge or the residue from press filters in fattening farms and slaughterhouses	Hygienisation requirements of REG (EC) n° 1774/2002 must be observed
other organic materials	underwater plants (e.g. algae, sea grass)	
	separately collected organic cemetery waste	Only accepted directly from a cemetery where a separate collection system is in operation
	bacteria biomass and fungal mycelium from the pharmaceutical industry	
	compostable packaging materials produced of renewable raw materials	e.g. wood fibre, cotton fibre, jute, disposable tableware from non-chemically modified vegetable starch Approved according to EN 13432
	paper	Paper that comes into contact with foodstuffs or which has been used in the collection and recovery of biowaste not containing plastic laminating
municipal sewage sludge	sludge from municipal sewage treatment plants	Quality requirements: Aerobically or anaerobically stabilised sludge only. The limit values for heavy metals: Cd 3 mg/kg d.m. Cr 300 mg/kg d.m. Cu 500 mg/kg d.m. Hg 5 mg/kg d.m. Ni 100 mg/kg d.m. Pb 200 mg/kg d.m. Zn 2000 mg/kg d.m. in the event of doubt owing to certain discharger structures AOX: 500mg/kg d.m.;
Residues from anaerobic digestion (biogas plants)		It must be verified that only the feedstock listed in this and the ren-

Feedstock group	Authorised feedstock	Quality and receipt control requirements; remarks
		dered fat content from anaerobic treatment have been supplied.

4.1.2 Auxiliary agents and additives

Additives are substances added in low quantities (in total maximum 5% m/m, or in the case of excavated or dredged soil maximum 15% m/m) which are mixed to the organic feedstock materials in order to optimise the decomposition process. These include specific preparations and agents such as *Bio-Dynamic preparations* and other inoculants. The main functions are:

- Minimising odour emissions (stone dust, matured compost, bulking agents, bark);
- Sorption of surplus press and process water (dry matured compost, bentonite, shredded bush/tree cuttings, straw etc); and
- Activation of microbial complexion (matured compost, bentonite, loamy soil).

Auxiliary agents such as inoculants or herbal preparations are sometimes added at homeopathic doses in order to accelerate, or harmonise the decomposition process or to increase final product quality.

A list of permitted additives summarised from the Austrian Compost Ordinance (FLG. I No 292/2001) is shown in Table 4.

Table 4: Suitable additives for process optimisation

Type of Additive	Example	Quality and receipt control requirements; remarks
rock dust	basalt dust	
	diabas dust	
	lava dust	
clay	bentonite	
lime	fertilising lime, quick lime	
carbonated lime from the sugar industry		
bone meal		Only category 3 material according to Article 6, Reg. (EC) No. 1774/2002
ashes from biomass firings	ashes from plants	max. 2% m/m, no fine fly ash;
excavated or dredged soil and earth sludge	naturally undisturbed, unpolluted soil; wash sludge from fallow crops (potatoes, beets);	max. 15% m/m The following limit values [mg/kg d.m.] must be observed: As 30, Cd 1.1, Cr 90, Cu 90, Hg 0.7, Ni,55, Pb 100, Zn 450, PAK (16) : 2, Sum of Hydro carbons: 200. These shall be examined in the event of doubt, e.g. in cases of obvious oil pollution or where origin is problematic.

4.2 Feedstock contaminants

Compost quality approvals are usually made on the final product. Specific analytical requirements and compliance testing for feedstock materials are only required for specifically defined sources, for example, where an increased contamination can be suspected or if the origin cannot be recorded satisfactorily. The main contaminants of concern are described below.

Potential toxic elements and persistent organic pollutants

The potentially toxic elements (PTEs) addressed in compost regulations are: Cadmium, Chrome, Copper, Lead, Nickel, Mercury and Zinc.

The potentially toxic pollutants (POPs) that have been discussed for specific compost standards are: dioxins, furans, PCBs, PAHs.

A European evaluation of PTEs and POPs including pesticides in composts showed that due to the origin and the background concentration a systematic and regular assessment of source separated organic feedstocks for composting is not needed (Amlinger *et al.*, 2004).

Specific feedstocks of certain origins may need to be analysed for compliance testing (see Table 3).

Physical impurities (plastics, metals and glass)

Impurities or physical contaminants such as plastics, glass and metals occur mainly in separately collected organic household waste, restaurant waste, and organic waste from cemeteries, due to incorrect sorting by citizens.

The impurity content in source separated biowaste ranges between 0.5 and 5 % (m/m). Impurities need to be segregated from the organic feedstocks, during decomposition or from the refined compost, by means of hand sorting or screening, respectively, in order to provide a high quality and visually clean product.

However, minimum requirements for acceptable source separated organic household waste should define an acceptable maximum level of physical contamination in order to facilitate continuous quality production. Efficient waste information and public relations work by municipalities, coupled with a control system to monitor the sorting behaviour of citizens should help provide high levels of purity. Generally a maximum of 1 % physical contaminants in the fresh matter should be acceptable. In densely populated areas with semi detached houses and a high proportion of high rise buildings and flats 2 % may be acceptable. If these values are exceeded, removing these contaminants becomes more costly and time consuming, and limits the recycling the organic oversize fraction after screening, as mainly impurities, mainly plastics, accumulate.

Contracts with the municipality or the responsible waste collector should therefore include the right for the compost producer to reject the receipt of highly contaminated biowaste, if the sorting facilities in place would not be able to remove them and thus guarantee the desired compost quality.

4.3 Feedstock properties – effect on the composting process and emissions

Feedstock properties can affect both the rate, hence efficiency, of degradation, as well as emissions. The principal factors are discussed below:

Moisture content

The water (moisture) content of composting feedstocks may vary considerably, and is partly dependent upon the structure and water holding capacity of the materials. A balance needs to be struck between ensuring there is sufficient pore structure in the composting mass to allow gasses to migrate, and ensuring that particles in the mass are covered with a film of water to enable the micro-organisms to carry out their function. The optimum moisture content is 45 – 50% (fresh mass) for poorly structured biowaste and 45 – 60% (fresh mass) for well structured materials.

Bulking agents

The addition of *bulking agents* is often required in order to create the necessary water-free pore spaces and enable gas exchange to take place in the compost pile. The optimum proportion depends on the active decomposition system (mechanical agitation, forced aeration, diameter of heaps etc.), the bulking properties of the material, and water content of the mix.

pH-value

pH is a measure of the acidity or alkalinity of a substance. In general, decomposition works best when the pH is neither too acidic, nor alkaline, however, in many instances this may be out of the control of the site manager. For example, a high proportion of fresh kitchen and vegetable waste may result in a low pH-value (between 4 to <6) due to the release of short chain fatty acids. This causes a major slow down of the organic carbon decomposition during the initial 3 to 7 days (*lag-phase*). On the other hand, sludge treated with quick lime may have a pH-value > 12 which also hinders decomposition if not mixed with appropriate feedstock amendments. Lime treated sludge generally needs a comparatively high proportion of amendment (e.g. 40 to 60 % v/v of shredded green waste) in order to reduce the pH below 8 within 1 to 3 weeks. (By comparison, polymer stabilised sludge often has a pH between 6.5 and 7).

C/N-ratio

Organic carbon and nitrogen sources need to be offered in a balanced and accessible proportion to the successive evolving microbial communities within the composting mass. A surplus of easily available nitrogen (C/N approximately < 15 - 20:1) can lead to high N losses in the form of Ammonia (NH_3) and Nitrous oxide (N_2O). However, materials with high carbon to nitrogen ratios may compost slowly, as nitrogen will be limiting. A target value of between C/N = (20) 25 to 35 (40) : 1 is desirable for optimum composting (see also Chapter 7.2).

5 Quality management – General requirements for documentation and record keeping

This Chapter presents an overview of the key principles of quality management in compost production with special consideration of operational procedures and the documentation system.

It closely relies on the Austrian Standard ÖNORM S 2206 Part 1 (2004).

The documentation system is divided into *general data* about the composting plant, a description of the operational plant and the operational procedures which are recorded in an operational diary. The key composting stages and procedures which make up the day to day management of the production process are as follows:

- Reception of suitable input materials;
- Pre-treatment;
- Composting process;
- Sanitisation;
- Compost refining (e.g. screening);
- Storage and declaration of compost products; and
- Complaints management.

Measures which are carried out on a regular basis need to be laid down in an operating plan. Those measures shall be recorded in the operational diary (either on paper or electronically).

5.1 General data

General data comprise a summary of operational and plant data that shall be collected and stored in a centralised place. The following data shall be included (where applicable to the specific plant in question):

- Legal basis (e.g. complete approval file including the technical report, technical project, all administrative orders, permits – in a clear and easily accessible form, operator contract);
- Site of the composting plant (including land registry data on the plot and facility plan);
- Receipt and delivery times (opening hours);
- Data on the licensee (operator, owner, waste owner number, compost producer, addresses, telephone numbers, contacts);
- Managing director under commercial/trade law;
- Operational manager in charge (contact);
- Employees: number, tasks, responsibilities, plant-related matrix of responsibilities, including relevant training certificates;
- Compost production pursuant to legal provisions (e.g. National Biowaste Ordinance or Compost Ordinance);
- Material flow: list of material received, quantity of finished compost produced;
- Compost production (m^3 compost/year);
- Organisation of quality management and assurance (e.g. quality manual, software, documentation system): reference to the place where the relevant documentation is kept;
- Laboratory contracted for external quality control;
- File with compost declarations in compliance with compost test reports; and
- Membership of a quality assurance organisation; name of the organisation, contact in charge.

5.1.1 Plant description

The plant description shall include a process model (see Annex C 1) identifying the control points. Further process control records describing the assessment of the operational procedures should be kept.

The processes and procedures applied in the composting plant shall be described in the form of a process model describing at least the following features:

- Type of raw materials;
- Treatment steps;
- Any further processing measures; and
- Documentation of control points and measures.

The process model shall include details of the quality management system. All operational steps shall be in line with that model.

Process control measures shall be recorded and corresponding operational procedures must be laid down in a quality manual with operating instructions. Records of process control are, for example, temperature measurements, measures to minimize odour, aeration, turning, watering, covering and screening.

5.1.2 Odour minimisation

From reception to the delivery of finished compost, odour emissions and impacts on ‘sensitive receptors’ shall be minimized by regular management processes (e.g. mixing, turning, watering, forced aeration, biofilter) as well as by taking account of prevailing weather conditions and the wind direction relative to those sensitive receptors.

5.1.3 Cleanliness of the plant and draining of waste water

In line with the material throughput and the activities performed, the plant shall be kept clean with a view to ensuring trouble-free operation. In particular, regular and timely measures need to be taken to check drainage facilities, to drain off surface water/leachate, to check the free capacity of leachate basins as well as to examine control drains.

5.1.4 Adequate availability of machinery capacity/machinery failure

To ensure adequate availability, the measures to be taken in the case of machinery failure or staff shortages shall be defined (e.g. in a contingency plan).

5.2 Input materials

Input materials shall be biodegradable materials that have been separately collected and have not been mixed, combined or contaminated with other potentially polluting waste, products or materials. Municipal sewage sludge and mixed municipal waste are excluded from the scope of this guideline.

Measures shall be taken to ensure that receipt and acceptance of input material does not give rise to an unacceptable nuisance, in particular through odours, and does not interfere with the treatment and composting process.

The plant’s operator shall ensure that only input materials are accepted which are listed in the consent for the composting facility.

For that purpose, the operator shall meet the following requirements:

- Presence of a technically qualified person during opening hours and immediate receipt control of the materials delivered;
- If the plant is not permanently staffed, the facility shall be equipped with a lockable gate or barrier and provided with a sign indicating the opening hours and pointing out that raw material must not be delivered outside the indicated opening hours;
- Protection of the premises against unauthorized access (at least a warning sign);
- The plant's operator shall document both the receipt and the rejection of material together with the date of delivery, type, mass, origin and supplier;
- Depending on the type of materials delivered, care shall be taken to store each type of material separately so that the desired composition of a compost batch and compost quality can be achieved (e.g. for organic farming);
- Material supplied shall be considered accepted after visual receipt control and unloading at the designated area on the plant's premises with the permission of the plant's operator. Without the operator's prior consent, raw material shall not be deposited outside of the opening hours for the receipt of materials and, therefore, shall not be considered accepted (non-consensual deposition);
- Document all input materials (allocation to batches, intermediate storage), off-specification batches etc.;
- Document all measures taken to reduce odour emissions during reception and pre-treatment;
- The plant operator, or the responsible person in charge, shall document whether the materials delivered are stored temporarily or directly used in a compost batch; and
- Document the storage and treatment routes of materials which are not used for composting (e.g. separated impurities, off-specification compost batches, chopped wood).

5.3 Pre-treatment

Pre-treatment (shredding, mixing, adjusting the material's moisture) aims to produce an optimum compost input mixture for the subsequent composting process.

Materials causing intensive odour emissions shall be treated in a way to minimize odours on the day of delivery within a reasonable time frame (e.g. mixing, piling up, covering).

If necessary the separation of impurities must be applied if technically feasible.

5.3.1 Shredding

If necessary, the input materials shall be shredded. Thereby, for example, the fibres of bulky, lignified materials should be broken up.

5.3.2 Mixing

Depending on the type of material, its structure, odour potential and water content, specific composting mixtures shall be produced in order to minimize odours as well as to obtain an optimal particle size distribution and structure.

It is important to ensure that the pre-composted material contains appropriately structured material in order to guarantee optimum decomposition conditions (adjustment of the C/N ratio, structural stability, water content, odour minimization etc).

5.3.3 Intermediate storage

This shall be carried in a separately designated area.

5.3.4 Batch formation and documentation

The details pertaining to batch formation shall be stated in the operational diary. A batch record shall contain the following data:

- Type of input materials, including additives and their mixture;
- Origin of the input materials (intermediate storage or delivery note);
- Quantity;
- Date of pile formation;
- Windrow type (e.g. triangle, table, trapezoid);
- Batch location; and
- Batch code.

5.4 Management of the composting process

Each composting batch shall undergo an intensive decomposition and maturation in accordance with defined control points in the operational plan.

5.4.1 Intensive decomposition phase

The intensive decomposition phase needs to include thermal hygienisation in order to provide the necessary reduction of human, animal and plant pathogens.

During the intensive decomposition phase, optimum conditions shall be ensured to support the decomposition processes.

Intensive decomposition may take place in closed or open systems and with or without forced aeration.

Requirements for time-temperature profiles in closed and open composting systems are given in Chapter 6.3.3.2.

With regard to composting facilities treating animal-by-products (ABP) national requirements for sanitisation under the EU Animal By-Products Regulation (Reg. (EC) No. 1774/2002 and Reg. (EC) No. 208/2006) shall be complied with.

During the intensive decomposition phase, operational measures (dates of turning, watering, control of forced aeration, subjective assessment of odour) shall be carried out to ensure optimal decomposition conditions are maintained and odour emissions minimised.

The following measures and process control data points shall be recorded in the operational diary:

- Date;
- Temperature measurements during sanitisation;
- Determination of the water content (e.g. measurement, squeeze test);
- Watering;
- Turning;
- Aeration; and
- Any other measures, such as covering heaps with a fleece; and
- Screening.

5.4.2 Maturation

Maturation follows immediately after the intensive decomposition phase. Degradation is complemented by transformation processes which form new complex humic substances at temperatures of less than 40 to 50 °C.

In order to facilitate this, during maturation, care shall be taken to:

- Prevent anaerobic conditions caused by excessive humidity or compaction due to structure and windrow height (e.g. by turning as required);
- Prevent drying out;
- Reduce dust emissions during manipulation (adjustment to an optimum water content, appropriate cleaning of roads);
- Prevent re-infection resulting from the introduction of pathogenic micro-organisms from raw material batches not yet sanitised; and
- Prevent the introduction of seeds (preventing vegetation growing on compost windrows).

The procedures carried out during maturation that shall be recorded for each batch include:

- Covering;
- Watering;
- Turning;
- Aeration;
- Any other measures, such as covering with fleece, screening etc.

5.5 Storage of compost

Stabilised and matured compost shall be stored:

- Either on sealed ground with appropriate rainwater and leachate drainage and collection, or
- On open topsoil, respecting precipitation and licensing requirements (if required coverage by fleece or under roof to prevent nutrient leaching, prevention of water logging).

The documentation of storage shall cover at least the following data:

- Designation of the storage area(s)
- Unambiguous batch code and declaration of the compost batch(es)
- Records on the quantity and customers or utilisation for own purposes.

5.6 Management of complaints

Within the framework of complaints management, the following minimum documentation shall be kept:

- Name, address and telephone number of the complainant;
- Date and time when the complaint was received;
- Subject of the complaint;
- Work performed at the time of the complaint;
- Weather conditions (e.g. temperature, wind direction, precipitation); and
- Operational measures taken in response to the complaint.

6 Basic requirements for low-emission process management

Emissions at a composting facility can roughly be differentiated into three major emission pathways, namely:

- ➔ Water (press water, process water, condensate, percolate);
- ➔ Air (odours, dust, bio-aerosols, inorganic and organic volatile compounds and gaseous emissions, noise); and
- ➔ Soil (wind-blown litter from physical impurities)

The following important emissions shall be considered:

- ■ Odour
- ■ Liquids (leachates and surface run-off)
- ■ Bio-aerosols with potential health threats to workers and neighbours
- ■ Dust
- ■ Volatile compounds including greenhouse gases
- ■ Noise

Table 5 describes the relevant emissions and their origin during the course of the entire composting process indicating where they are most likely to arise.

Table 5: Facility compartments and process steps of relevance to emissions

Process section	Constructional Device	Emissions[2] via		
		Water	Soil[3]	Air[4]
Tipping area	Bunker, buffer storage	Press / process water	none **	Odours, noise (dust) (bio-aerosols)
Pre-treatment	Screening, separation of impurities, mixing etc.	Press / process water condensate from waste air treatment	none **	Odours, noise (dust) (bio-aerosols)
In vessel - intensive decomposition *	Reactor, tunnel, drum, (windrows)	Press / process water, condensate	none **	Odours, bio-aerosols (noise)
Open - post decomposition (maturation)	windrows (evtl. encapsulated) (Reactor, tunnel)	Press / process water (condensate)	None **	odours, dust, (bio-aerosols) (noise)
Post-treatment (final treatment)	Screening, density separator etc.	none	none	odours, dust, bio-aerosols, noise
Final product	Compost storage	none [1]	Heavy metals, other contaminants	odours, dust, (bio-aerosols) (noise)

[1] in areas with high rain falls this area should be under a roof
[2] Factors in brackets ( ) ... denotes only limited events or it is dependent upon the technology applied
[3] under the assumption that all activities are carried out on a paved ground
[4] the release of other gaseous emissions may be expected mainly during the main / intensive decomposition stages
* In this table intensive decomposition is defined as the period of initial decomposition which is performed in an in-vessel / encapsulated device (e.g. reactor) with forced aeration and waste air treatment.
** assuming the area is paved.

In addition to the selection of a suitable location and a working plan adapted to site conditions, the main parameters influencing the impact a composting plant has on its environment are:

- ■ Total plant capacity i.e. processing capacity relative to the actual daily throughput;
- ■ Type and properties of the treated feedstocks;
- ■ Chosen composting system, technology and equipment;
- ■ Grade of encapsulation of odour emitting processes and facilities;
- ■ The odour reduction capacity of encapsulated treatment facilities; and
- ■ Operational/process management procedures with respect to measures minimising emissions.

Key parameters of quantitative and qualitative environmental impacts are:

- Site / location;
- Material properties (see Chapter 4.2);
- Process capacity of available man power and machinery (actual daily and weekly throughput capacity);
- Technical equipment in the different process sections; and
- Emission reducing measures (e.g. biofilters).

It has to be noted that the assessment of potential emissions must always take into account the site specific conditions, in particular with regard to odours and bio-aerosols. A site independent evaluation shall not be carried out.

6.1 Management of odour emissions

Unfortunately, odour emissions cannot always be prevented, even under the best management conditions.

The formation of odorous substances and their subsequent release from the composting mass can be allocated to five decomposition stages, which are described in Table 6 below.

Table 6: Decomposition and temperature dependent phases associated with the formation of odour active substances

Composting phase and temperature range	Typical odour active compounds [1]	Dominating odour perception	Odour unit [OU m^{-3}]	Duration of this phase [2]	pH-value of the degrading material
Mesophilic start phase (15-45 °C)	fatty acids, aldehydes, alcohols, fatty acids esters, ketones, terpenes, sulphides	alcoholic-fruity, cheese, sweat	6.000 - 25.000 [3]	several days to max. one week	4 to 6
Initial self heating phase (45-65 °C)	see start phase	see start phase	Peak values: 30.000 [4]	several days to max. one week	4 to 6
Thermopile phase (> 65 °C, partly > 70 °C)	ketones, sulphur-organic compounds, terpenes, pyrazine, pyridine, HDMF, Ammoniac	Sweet, fungi, high temperature rotting smell, unpleasant-mouldy	1.000 - 9.000 [3] t > 10.000 [4]	several days to several weeks	6 to > 7
Cooling phase (65 - 45 °C)	sulphides, ammonia, terpenes	mouldy -pungent, ammoniacal	150 - 3.000 [3]	> 12 weeks	to > 8
maturation (< 45 °C)	humic substances	fungal, earthy	< 500 [4]	several weeks	> 7

[1] not comprehensive
[2] varies depending on composting system
[3] Pöhle (1994)
[4] authors' investigations

6.1.1 Key elements of process management to reduce odour emissions

The management tools aimed at effectively reducing the formation and release (emission) of odorous substances are:

- Mixture of the initial feedstock blend;
- Temperature profile;
- Moisture content; and

- Free pore space for oxygen (fresh air) supply.

One of the most important measures is the homogeneous mixing of different raw materials which helps establish adequate free pore space, continuous air exchange and, if optimised water content (moisture level) is provided, decomposition of the primary/easily degradable organic substances. The correct mixing of bulking agents therefore has to be managed carefully, and considered to be the most important pre-treatment measure. Suitable bulking agent need to be in stock at any one time!

The temperature regime is another key factor influencing odours. High temperatures > 65/70 °C diminish the microbial diversity and thus slow down the decomposition process. Intermediate metabolite substances with high odour intensity are more likely to be generated. Intensified aeration or mechanical agitation, changing the heap diameter and watering can counter steer the effects of overheating.

Optimised water content at any stage of decomposition is a pre-condition for proper odour management. Process water and condensates may constitute a significant source of odours. An excess of water may cause anaerobic conditions especially in the bottom of windrows. Therefore besides operating an effective watering system, sites also need to ensure continuous drainage of both process and surface waters. In closed reactor systems regular measurements of the water content together with water balances allow for optimised water management, thereby minimising odour potential.

Furthermore, the sufficient supply of oxygen to the microbial community must be guaranteed at all stages of composting. These are described in Table 7.

Table 7: Measures to prevent oxygen deficiency during composting (Bidlingmaier & Müsken, 1997)

Measures against water surplus	Reducing the water input: ■ Choose dry feedstocks with a high water retention capacity ■ Add dry additives (chopped/shredded wood, bark, sawdust, dry compost etc.) ■ Cover open windrows with a geo-textile, a layer of shredded wood, mature compost or straw Increase water release: ■ Intensify forced aeration ■ Increase turning frequency without risking cooling down the process too rapidly ■ Uncover the windrows on days with high evaporation potential ■ Expose windrows to main wind direction
Measures to improve structure	■ Mix additional bulking agents ■ Increase bulking agents especially in the bottom of the heap. Create a basic layer with structure forming shredded wood
Composting technology	■ Set up loose, well structured windrows for the initial intensive degradation phase ■ The maximum height of a pile/windrow depends on • decomposition age (the more mature, the higher piles can be) • structural stability of the whole mixture • forced aeration system (alternating positive [blowing] and/or negative [sucking]) ■ In dynamic and semi-dynamic systems new accessible surfaces are created and air exchange rates are increased.

In open windrow systems without forced aeration operators need to ensure that there is sufficient and continuous air exchange as far as the central zone of the windrow. Those systems need to carefully balance windrow diameter, material composition (free air space, water content, structural stability) and turning frequency.

In areas or seasons with high precipitation, reduced water evaporation can lead to water logging if windrows are not covered with hydrophobic geo-textiles or placed under cover.

Natural aeration in open windrow systems is based on the principle of convection and do not require the waste air to be treated as long as the process is managed properly. However, during the preliminary decomposition stages, mechanical agitation can cause considerable odour emissions if the described parameters are not observed carefully. Therefore in open windrow systems the site specific conditions have to be considered carefully together with the feedstock properties and daily process management operations, taking into account when the potential for odours to be generated.

The different forced aeration systems also differ in their ability to prevent odours. Negative aeration (sucking) systems may increase the problem of „wet feet“ by transporting water from pores in the composting mass to the bottom of the heap, contributing to press and process water. Additionally, forced aeration may also reduce free pore space in this bottom zone thereby creating major emission potential, especially during turning. The high odour concentrations in the air pipes of negative aeration systems are not only caused by the direct highly concentrated waste air from the heaps but also from process condensates. This liquor will require specialist treatment.

The air drawn through the composting mass in negative aeration systems will be odorous and will therefore require treatment (e.g. through a biofilter).

Negative aeration systems in enclosed halls create less steam and therefore improve the hall atmosphere. However, the entire waste air has to be treated in a biofilter, whereas in positive pressure systems a certain proportion of the waste air is already deodorised by the microbiological active surface layer of the heaps or windrows. This causes higher deodorisation capacities in negative compared with positive aeration systems. In addition waste air recycling is not possible in negative aeration systems.

Those disadvantages of negative pressure systems do not occur in box or tunnel systems.

6.1.2 Specific measures to reduce odour emissions from open windrow composting systems

Operational measures to prevent and control odours in open windrow composting systems include:

- The immediate and efficient processing of delivered waste material;
- Using highly structured raw material (maintaining sufficient storage /supply of bulking agents);
- Managing the decomposition process (e.g. regular turning to avoid anaerobic zones forming in windrows, limiting the size of the windrows depending on structure-stability and turning- and/or aeration-system);
- Keeping the facility clean (regular cleaning of surfaces, equipment and all traffic routes etc.); and
- Turning the windrows only when there is an advantageous wind direction.

Another important factor to consider when assessing odour emission potential in open windrow composting is the annual extent of precipitation.

On sites with high annual precipitation, covering windrows (e.g. with a fleece/geo-textile) must be considered if no roofed structure is available. The risk of exceeding the water capacity of the composting material is greatest with smaller windrows, especially during late decomposition/maturation stages (where the evaporation rate is diminished). In that particular respect, due to their favourable surface area/volume ratio larger windrows (ca. > 1.50 m high) and table windrows are less vulnerable to water logging through precipitation.

Windrows with an inherently high water content run a greater risk of anaerobic zones forming (due to the pores filling with water, rather than allowing gasses to migrate) and causing odour nuisance. Moreover wet materials handicap the final value-added stages of the composting process (sieving, segregation of impurities).

In addition to the above, the following optional measures to prevent and manage odours can be considered:

- Adding soil or mature compost to the input material (up to ca 10 % (m/m)) thereby creating a sorption matrix for leachate water charged with odour active substances to bind to;
- Ensuring that the temperature of the composting material does not exceed 65 °C and should stabilise as soon as possible at about 50 to 55 °C;
- Covering smaller windrows (< 1.5 m high) with a water repellent fleece; or

- Maintaining an oxygen content in the decomposing material of at least 5 % (v/v; measured using probes).

Also the sum of CO_2 and O_2 concentration being repeatedly detected above 20,8 % (v/v) indicates that anaerobic conditions may be relevant.

Experience shows that the O_2 concentration in the composting mass should not fall below 5 % (v/v). Normal values during the initial rotting stages may be found between 7 and 12 % (v/v) O_2, CO_2 and CH_4 concentrations should not exceed 10-12 % (v/v) and 1 % (v/v), respectively.

6.1.2.1 Covering compost windrows with organically active layers (biofilter) or semi-permeable membranes

One possibility for small to mid scale compost facilities with an open-air windrow system is to cover the windrow during the intensive decomposition stages, when odour potential is at its greatest. In this respect several cover materials can be considered:

- Readymade, mature compost;
- Shredded fresh or partly rotted tree and bush cuttings as well as the oversize fraction of compost screenings; or
- Semi-permeable membranes.

In covered windrow systems odours only occur during turning and if the windrows are not covered immediately after agitation. Controlled coverage can reduce the total emissions significantly. This is also the case when applying forced pressure aeration.

Covering windrows with a layer of biological material (e.g. mature compost) not only acts as a biofilter, it also helps condense some of the water vapour containing odorous substances as it is at a lower temperature than the actively composting mass. When an optimised material mix has been achieved, it can be estimated that within this time span the intermediate products which might cause odour problems are already degraded and caught by the organic biofilter layer. An important condition for the overall reduction effect is that within the first 10 to 15 days the compost is not turned.

Additionally, in order to reduce the emissions of greenhouse gases the following parameters must be observed:

- Covering piles with a biofilter made up of a 10 to 15 cm layer of fresh or partly composted shredded material or mature compost; or
- In systems with no forced aeration, forming windrows into a triangular shape with a maximum height of approximately 1.5 m in addition to an optimal structure, helps guarantee continuous air exchange by means of the chimney effect; or
- Using homogeneous material with a C/N ratio of 25 to 35 : 1; or
- Ensuring that the thermal hygienisation stage (described in Chapter 6.3.3) is eventually achieved during the later composting stages.

Semi-permeable membranes (e.g. Gore™ Cover System, Biodegma) provide some advantages. They guarantee even air flow distribution and waste air diffusion in aerated windrows. Air flow along channels of least resistance is largely prevented, and, above all, rainwater is drained off, thereby preventing excessive moisture. Condensation of the water saturated exhaust air and the creation of a microbial "film" on the rear side of the membrane effectively act to prevent odour emissions.

Covering the composting pile with a *geo-textile (compost fleece)* has only an indirect odour reducing effect mainly through the drain-off of rain water and an improved maintenance of evenly distributed humidity. The latter enhances homogenous decomposition over the whole heap, including the surface layer. Though no *biofilter effect* can be expected, condensation is found to be similar to coverage with organic layers or semi-permeable membranes.

The effects of covering windrows are lost during mechanical agitation, although, the resulting impact load is reduced to this limited time window during turning.

6.1.3 Technical aspects of waste air treatment

Deodorising the waste air from composting plants for a partly enclosed facility is a key management tool as far as potential effects on the neighbourhood is concerned.

The main technical solutions include:

- Biofilter;
- Scrubbers; or
- Bio-membrane systems.

All these technologies follow the same principle: communities of micro-organisms have the capability to degrade and mineralise organic and also some inorganic waste air constituents into non-odorous degradation products under aerobic conditions.

In order for these biological waste air treatment systems to function effectively the following conditions must be observed:

- In order to be removed the waste air compounds must be soluble in **water**;
- They must be **degradable by biological means**;
- The degradation products need to be **non-toxic**;
- There must not be too large quantities of **dust and fat**, as they reduce efficacy; and
- The **exhaust air temperature** should be maintained between 15 and 45 °C (optimum 25 to 35 °C).

Also inorganic gases such as hydrogen sulphide or ammonia can be oxidised microbiologically. The decomposition products of these compounds (sulphur, sulphate or nitrate) accumulate in the filter medium and may change the pH value of the washing water or the filter medium itself.

6.1.3.1 Biofilters

The most commonly used types of bio-filters nowadays can be classified in (mostly open) plane filters and encapsulated container filters. Special shapes of closed filters are tower and floor filters.

Operation and maintenance of biofilters

The operation of a biofilter, whether or not it is combined with a scrubber, requires ongoing management and maintenance, as it is a biologically mediated process. Failure to maintain a biofilter will significantly reduce its effectiveness. The Austria *ÖWAV-Regelblatt 513 (ÖWAV Guideline 513)* has been used as reference guideline in this document.

The following should be observed:

- The maximum allowable volume load of the biofilter medium should not be exceed during controlled operation;
- Dimensions and operation of the filter should be carried out according to the requirements of the Austrian ÖWAV-Regelblatt 513, the German VDI-Guideline 3477
- The volume load of the biofilter should not exceed 100 m^3 of exhaust air m^{-3} biofilter medium h^{-1}. By reducing the nominal volume load to 50 m^3 exhaust air per m^3 filter material the removal of odours can be enhanced;
- A high NH_3 load in the exhaust gas necessitates a preceding treatment with an acid scrubber;
- Replacing part of the filter material should not reduce the purification efficiency of the residual segments (redundancy);
- Compliance with the allowed maximum exhaust air value should be factored into the calculated maximum allowable volume load;
- The humidity of the filter material should be kept at the optimum operational level by appropriate measures (e.g. through an air humidifier, irrigation facility);

- The extractor fan needs to be configured and capable of operating at increased pressures caused by compaction of the filter medium;
- The relative humidity of the supply air should be kept at saturation (supplied through an air humidifier);
- The supply air temperature should be kept between + 10 und + 40 °C (optimum at 25 - 30 °C);
- The filter medium must be built in such a way that the waste air is distributed evenly through it and may not escape along the boundary between filter medium and container walls;
- Variability in the composition of the input gas load should be minimised;
- In order to prevent the blocking of the lower filter layers and the air distribution devices, dust should be removed from input gas as far as practicable;
- The pH-value of the biofilter medium should range between neutral and slight acidic; and
- The filter medium must be replaced periodically before it reaches the end of its active life.

Obligatory maintenance and control measures include the following (preferably daily) checks:

- Visually inspect the filter surface (to look for the occurrence of channels of least resistance where the air is released, compaction zones); preferably early in the morning (when steam formation is likely to be at its greatest due to cooler ambient temperatures);
- Measure the inlet air temperature and the air flow volume;
- Inspect the inlet air humidity in order to correct possible drying of the filter medium in due time; and
- Measure the counter pressure of the filter in order to detect compaction zones in the filter medium.

Other regular maintenance checks include:

- Monitor the filter efficacy by olfactometric measurements at least once a year;
- During dry periods frequent destination of the water content in the filter medium. During other periods visual inspections or measurements at longer intervals
- Undertake mechanical agitation of the filter surface if waste air escapes along uneven distributed channels or if vegetation arises;
- Cover the filter with fresh filter medium or other suited materials (e.g. bark mulch) in order to balance mechanical settlements;
- Sampling of the filter medium: determination of the pH-value, eventually electrical conductivity and organic matter content;
- Checking the functional control of the irrigation system and the moistening device for the inlet air (where fitted);
- Cleaning of fans, inlet air channels and pipes and the air distribution between the filter sections and moistening device for the inlet air (where fitted);
- Measurement of oxygen, ammoniac and hydrogen sulphide in the inlet air;
- Testing the filter efficacy by means of the reduction of odour units (> 95 % at > 5.000 GE/m³ in the inlet air, > 90 % at > 2.500 GE/m³ in the inlet air);
- Measurement of the exhaust air distribution with a sampling cap (stratified sampling points); and
- Measurement of organic matter (loss of ignition), water capacity and pore volume.

Regular determination of nutrients (C, N, P) in the filter medium is, in principle, not necessary, but depends on the specification of the filter medium.

All measurements and inspections must follow a control plan with a dedicated checklist.

Where fitted, a preceding scrubber system also must be inspected and maintained in regular intervals.

Possible reasons for the occurrence of odour emissions as a result of malfunctioning of the waste air treatment system include:

- The biofilter medium is exhausted, resulting in a continuous decrease of the purification capacity and efficacy; as a consequence, the biofilter medium does not fulfil the necessary technical requirements. It tends to compact, degrades unevenly or needs a lot of maintenance (high pressure loss, uncontrolled breakthrough of exhaust air, frequent mechanical loosening);

- The water in the biofilter medium is not balanced which leads to the emergence of dry zones;
- The inlet air supply is not distributed evenly (e.g. perforations in the filter base floor become blocked), or preference channels are formed in the medium which mean that only a fraction of the biofilter medium is used, which leads to increased emissions and potentially to complete breakthrough of the exhaust air;
- Biofilter inspection and maintenance is neglected which results in a number of problems, e.g. uneven air release, dry zones which are not recognised in time; and
- The air management of enclosed facilities is incorrect or the preceding scrubber or the waste air conditioning systems do not to work properly. As a result, the biofilter is charged with high odour concentrations or too high temperatures.

Table 8 shows the results of a survey on the frequently occurring malfunctions at a facility for waste air purification (Biofilter), the effects on the emissions and possible solutions. As mentioned above, the determination of nutrients in the biofilter medium in most cases can be neglected as the filter generally is exchanged before nutrient deficiency becomes problematic.

Table 8: Effects and adjustments of malfunctions of a biofilter by a facility operator

problem	Consequences	Necessary measures
High odour units in the inlet air (e.g. from compost piles with negative aeration)	High filter charges. Despite high efficacy, increased exhaust air concentration	Change the composition of compost source materials, inlet air conditioning, e.g. precede by a scrubber
High variability in odour units and /or high temperatures in the inlet air	High variability in the nutrient content in the supply air and the milieu for the micro-organisms	Mixing of different air flow sources, eventually conditioning of inlet air
Quick or uneven degradation of the filter medium	Increase in the counter pressure in the filter, uneven efficacy, environmental gas breakthrough	Regular loosening or exchange of the filter medium, use filter media with a high operating life
Drying out of the filter medium	Decrease of the efficacy resulting in gas breakthrough	Moistening of the inlet air and of the filter surface
Uneven distribution of air supply to the biofilter	Decrease of the efficacy resulting in gas breakthrough	Regular inspection and cleaning of the supply air channels
Uneven air flow	Decrease of the efficacy resulting in gas breakthrough	Regular inspection, loosening of filter medium, removal of dried out zones
Filter medium is exhausted	Decrease of the efficacy resulting in gas breakthrough	Regular inspection, loosening or exchange of the filter medium
Nutrient deficiency in the filter medium	Decrease of the efficacy resulting in gas breakthroughs	Regular inspection, loosening of the filter medium

6.1.3.2 Scrubber systems

The most important technical principles and scrubber systems include:

- Activated sludge process;
- Spray scrubber;
- Column scrubber;
- Sprinkle bed scrubber;
- Packed tower scrubber / solid state bedding; and
- Tricking filter; percolating filter.

Scrubber systems are similar to biofilters in that they require a large contact area in order to achieve rapid and intensive exchange between vapour and liquid phases.

In composting systems, exhaust air scrubbers have limited applications. Due to short contact times between exhaust air and washing medium the elimination of odorous substances may not be satisfactory. Additionally, peak loads may only be buffered to a low extent. Therefore scrubbers in high capacity composting plants are only installed as a preceding device (e.g. to reduce the ammonia content) before a conventional biofilter.

Table 9: Examples of chemical and oxidative scrubber systems (after Jüstel, 1987 and Krill *et al.*, 1994)

Washing agent Solvent	Reaction of the absorbent	Absorbent	Stripped compounds
Water	alkaline	Sodium hydroxide Potassium hydroxide Sodium bi-carbonate among others	Hydrogen sulphide Organic acids Phenol, cresols Mercaptane
Water	acid	Nitric acid	Ammonia
		Sulphuric acid	Ammonia Amines Pyridines
Water	oxidising	Potassium permanganate Hydrogen peroxide [1] Ozone [1] sodium hypo chlorite [2] Chloride [2] among others.	Hydrogen sulphide Sulphur dioxide all organic odour compounds
[1] additional UV-radiation increases the reactivity [2] Application is questionable, because toxic or explosive and/or hardly degradable oxidation products may be formed			

6.1.3.3 Thermal and catalytic systems

Organic air pollutants, micro-organisms or offensive waste gas components/odorous substances, essentially composed of carbon, hydrogen, nitrogen and oxygen, can be converted into CO_2 und H_2O by combustion at 800 - 1200 °C (regenerative thermal oxidation [RTO]). An adverse side effect of this process is the formation of undesirable waste gas components (e.g. CO, NOx). During the combustion of sulphurous substances, the formation of SO_2 and SO_3 takes place, whereas nitrogenous substances result in NO and NO_2 in the exhaust gasses. The complete combustion depends on following parameters, based on sufficient oxygen supply (hyper-stochiometric O_2):

- Concentration and type of substance to be oxidized;
- Preheating to ignition temperature;
- Residence time and turbulence in the combustion chamber;
- Final temperature in the combustion chamber; and
- Flow-conditions in the combustion chamber.

Generally natural gas, liquid petroleum gas or fuel oil are used as additives in order to ensure low-pollutant combustion. Fields of application are e.g. waste gas from:

- Chemical and petrochemical processes;
- Solvent and plasticiser processing;
- Food- and semi-luxury-industry;
- Desiccation and processing of industrial wastes and sludge;
- Animal waste processing; and
- Mechanic-biological waste-treatment.

The operation of regenerative thermal oxidation (RTO) systems is energy intensive. In energy-optimised systems (ca. 95 % thermal efficiency) an energy consumption of 9 to 14 kWh thermal capacity per 1,000 m^3 waste gas must be calculated. Since the according thermal capacity is not contained in the waste gas of composting facilities – 1.5 to 2 g TOC ($C_{tot.}$) /m³ are necessary – the necessary thermal capacity must be provided through external energy. From this a fuel consumption of ca. 0.7 to 1.1 m³ natural gas per 1,000 m³ waste gas has been calculated. Natural gas is a fossil fuel resource and therefore the CO_2-waste gas is rated climatically-relevant.

The investment and operational costs for an RTO are probably excessive for a state of the art composting facility, considering the low-contamination waste gases originating from enclosed facilities.

6.1.4 General strategies and methods for remedial action and trouble shooting

Avoidable emissions, which do not comply with the state of the art principles, can be eliminated by:

1.) Technical measures (avoidance of planning errors and technical remediation measures);
2.) Modifications in plant management (operational measures);
3.) Professional reaction to objective and subjective (neighbour complaints) operational problems and failures.

Points 2 and 3 above form part of a regular internal quality management system that should be in place at all composting plants.

It is important to distinguish between emissions that affect employees (occupational exposure) and neighbouring inhabitants (environmental exposure) on the other hand.

6.1.4.1 Minimum requirements for an Internal Operation Concept (IOC)

An IOC supports all aspects of the process flow at a facility. This can only be achieved by explicit instructions, competence, motivation and training of the operational staff in controlled operation and trouble shooting, in particular.

All appropriate staff must undergo a sensitisation process for all aspects of emission control and reduction. Explicit instructions / briefings for a low-emission operation of a composting plant should include:

- All necessary instructions to minimise odour emissions during operation (e.g.: air management, effects of composting management, avoidance of diffuse odour sources etc.);
- Where appropriate, an explicit instruction to control and maintain the exhaust air treatment facility;
- Specifications for trouble shooting as explicit as possible including instructions for necessary repair work; and
- Where appropriate, training and instructions for conducting analytical measurements in an in-house laboratory.

The following principles should be in place:

- On the basis of appropriate experience and eventually training, the operational staff should be able to run all plant components according to the established rules. This requires the presence of at least one responsible person in charge during operation time. An emergency plan has to ensure that a team in charge reaches the plant in due time to solve the problem out of hours;
- A service plan guarantees the maintenance of crucial plant components at regular intervals (dust removal, supply- and exhaust-air aggregates, biofilter etc.). Operating life and the lifetime of the aggregates, manufacturers' guidelines and appropriate supply of spare parts have to be considered;
- Continuous logging of local climatic conditions, including the following meteorological data:
    - temperature
    - wind direction and strength
    - rainfall
    - humidity
- Receipt control for treated waste in each plant section; and
- In-house controlling of both the water content (moisture) and pH-value in composting materials and biofilter media.

The prevention of avoidable odour emissions from **in-vessel composting plants** also requires the following procedures be in place:

- All traffic routes, loading and delivery areas are cleaned at least once on every working day in order to prevent diffuse odour sources arising;
- Gateways are only opened in cases of operational necessity and closed as soon as possible (installing detectors, which signal open gateways to the control room is recommended);
- Gateways are opened and closed automatically (e.g. remote control in the driver's cab of the wheel loader);
- No waste material should be stored outside in an uncontrolled manner (e.g. it should be in a sided bunker or similar);
- Plant components, in which odour loaded exhaust air is discharged (multiple-shift usage of airflow), have to be directed into other closed and aerated plant components or into a biofilter;
- The control programme for all venting devices has to include every single plant component
- In aerated plant areas, operating the system under a slight negative pressure prevents diffuse escape of odours; and
- It is imperative to meet the guidelines for the maintenance and operation of filters.

6.1.4.2 Dealing with complaints

According to the Austrian ÖNORM S 2206-1 (2004) "Requirements for a quality assurance system for composts - Part 1: Principles for quality assurance of a company and of the internal technical processes" the following information has to be documented in the context of managing complaints, as a minimum:

- Name, address and telephone number of the complainant;
- Date, time of the complaint;
- Subject of the complaint;
- Operations carried out at the time of the complaint;
- Weather conditions (e.g. temperature, wind direction, rainfall);
- Operational measures due to the complaint;
- Communication with the complainant.

The ÖNORM S 2206-1 (2004) also requires the company to reply to the complainant immediately.

Table 10 summarises the possible sources of odour emissions and preventive mechanisms. The possible measures range from operational adjustments to the refitting of single devices or plant components.

Table 10: Possible sources of odour emissions (see also the German guideline VDI 3475 Sheet 1, 2003)

Section of facility	Problems	Consequences	Necessary preventative or remediation measures
Traffic areas	Contamination with dust and mud	Diffuse odour emissions	Adhering to a strict cleaning programme
Bunker	Odour emitted during tipping combined with wet source materials	Increased odour emissions (transferring to subsequent sectors of the process)	Shorten the collection interval for bio-waste, immediate pre-treatment and mixing of critical source materials (catering, market waste etc.)
	Prolonged buffer storage of wastes (e.g. resulting from stand stills of the process)	Increased odour emissions (transferring to subsequent sectors of the process)	Co-operation with other composting plants, emptying and pre-treatment of waste each working day
	Leachate from collection trucks	Increased odour emissions in the tipping area and on traffic routes	Equipping vehicles with a separate collection tank for leachate, regular cleaning
	Open doors	Diffuse odour emissions	Automatic doors, separation of tipping area from bunker (lock function; mainly used with low bunkers)
Pre-treatment	Wet source materials	Blocking of equipment, leachate etc., resulting in increased odour emissions	Sufficient bulking agents in stock to blend with wet input materials
	Defective material transmission between different devices	Uncontrolled material loss and contamination of the floor and the aggregates, resulting in increased odour emissions	Refitting of malfunctioning or improved facility components. Change of material composition (C/N-ratio, structure, increasing water capacity by adding stone dust, mature compost, loamy soil)
	Odour producing, mechanically separated residues	Increased odour emissions from containers	Covering of containers if located outdoors or siting them in the enclosed area of the facility with air conditioning
Composting	Material manipulation in unsuitable weather or wind conditions (open windrows)	Increased odour emissions in the direction of neighbours	Reorganisation of the operating procedure
	Too little bulking agent in the total material composition	Low oxygen supply (reduced pore space) resulting in increased odour emissions	Increase bulking agent ratio, enlarge screen mesh size of the shredder machine, reduce diameter of compost piles, enhance active aeration (where applicable)
	Diminished decomposition rate	Increased odour emissions when extracting the material from compost reactors, in the maturation area and final storage	Optimisation of process management, eventually reducing the throughput or enhancing the capacity of the intensive composting stage
	Moisture (too wet / too dry)	Increased odour emissions	Optimisation of the watering system
	Too high temperatures	Increased odour emissions	Active aeration, reduce diameter of compost heaps
	Diameter/height of compost heaps / windrows too large	Compaction at bottom of the heap (forming anaerobic zones), malfunction of aeration system (particularly with negative pressure aeration)	Reduce diameter or height of compost heaps
	Enforced / intense aeration is too great	“Blow drying” of the material, resulting in diminished decomposition rates (see above)	Optimisation of the aeration process

Section of facility	Problems	Consequences	Necessary preventative or remediation measures
	Inappropriate design of negative aeration system	Accumulation of condensate in the ventilation pipes, resulting in increased odour emissions	Installation of process water flaps, isolation of pipes
	Careless management of emission reducing measures (e.g. coverage of open windrows after turning)	Significant increased odour emissions	Optimisation of the operating procedure
Maturation	Defective material transmission between different devices	Uncontrolled material loss and contamination of the floor and devices resulting in increased odour emissions	Refitting of malfunctioning or inappropriate facility components
	Odour producing mechanically separated residues (predominantly from fresh semi-matured compost)	Increased odour emissions from containers	Covering of containers if located outdoors or general placing in the enclosed area of the facility with air treatment
	Insufficiently matured compost material	Increased odour emissions	Optimisation of process management, eventually reducing the throughput or enhancing the capacity of the composting area
	Loading activities in open areas	Increased odour emissions (predominantly from fresh semi-matured compost)	Enclosure or installation of discharge tubes
Compost storage	Inappropriately managed and stored compost heaps	Re-self-heating, increased odour emissions when the compost is turned	Refitting of the operating procedure (e.g. regular turning, reduce height of compost heaps, forced aeration)
	Exceed storage capacity	Increased odour emissions	Removal of surplus composts from storage, enlargement of storage area
	Excessive throughput at site	Reduced maturation time, overflow at all facility sectors, increased odour emissions	Strict limit on the daily throughput, co-operation with neighbouring composting plants
All sectors	Poor level of cleanness	Produces diffuse odour sources	Strict adherence to the cleaning programme (at least on every working day)
	Lack of time, shortage of staff	Improper operation, inspection, maintenance, resulting in increased odour emissions	limitation of the daily throughput, increase staff, contingency plan to cover staff illnesses
	Poor process air management	Excessive waste air flow, resulting in increased emitted odour load	Strict observation of the technical manuals, eventually refitting or optimisation of the aeration devices
	Wrongly designed aeration devices with too little suction performance	Odour emissions from leakages at the hall surface	Eventually refitting or optimisation of the aeration devices
	Insufficient waste air purification (inappropriate design or capacity)	Increased odour emissions	Maintenance and inspection plan, eventually refitting or optimisation of the aeration devices
	Poor failure management procedures	Breakdown of facilities longer than necessary	Contingency plan described in operation manuals in the case of plant failures including staff training
	Open doors and doors in enclosed facilities	Release of diffuse odours from inside	Strict observation of the technical manuals, install automatic doors with remote control, central supervision of all doors

At facilities that operate open or partly enclosed systems located at sites with problematic dispersion conditions, site procedures would need to be modified in order to prevent problems arising. As a minimum, each site should:

- Operate an on-site weather station;
- Run an online dispersion simulation programme; and
- Undertake modified operating procedures to accommodate certain weather conditions likely to give rise to odour problems.

In this way the staff should be able to recognise critical situations in the facility environment and to take appropriate measures in order to reduce an emission incident occurring.

6.1.5 Summary: Failures in planning operation

The following are the principal operational issues that may generate odorous emissions at a composting facility. They have been compiled based on practical experience:

(a) Planning failures

- Underestimating the odour emission potential of the chosen composting system during the planning stages. These result in insufficient measures being specified to either reduce or eliminate odour formation / dispersal.
- Insufficient dimensioning of the main composting area or facilities. This often leads to incomplete degradation, producing unstable compost with a high odour potential, which can be emitted during processing, such as screening.[5].
- In enclosed or partly enclosed facilities, insufficiently equipped and incorrectly dimensioned waste air treatment installations

(b) Operation

- Inadequate site management in relation to emissions control procedures (e.g. not respecting certain weather conditions at open air systems, keeping doors open in enclosed systems);
- Inadequate feedstock pre-treatment;
- Underestimating the effect of “small” odour sources (e.g. open containers for over-screens and residues, water retention tank, open discharging or loading of *fresh compost*);
- Insufficient control and maintenance of waste air treatment facilities (e.g. following a strict biofilter maintenance plan, maintaining the biofilter bedding material, conditioning of the raw gas);and
- Technical malfunctions within the composting facility resulting in non-planed conditions of operation and subsequently in increased emissions (e.g. emergency plan in case an item of equipment is out of action).

(c) External impacts

- Underestimating the impact of neighbours’ complaints. This may lead to problematic relations arising, in which it becomes difficult to establish “acceptable” conditions in the environment surrounding the plant. This may then lead to unnecessary complaints being received, even if odour emissions meet all the necessary standards;
- Delaying taking action to resolve odour problems (e.g. by taking unnecessary short term cost or image savings); and
- Establishment of new residential settlements or industries at the borders of the composting plant (encroachment).

[5] This may further result in low germination and plant growth performance, due to its immaturity. For example, the Dewar Self Heating test as used in Germany may give a degree of stability of grade of II instead of IV, which is required for mature compost. This test is not conducted in Austria on a routine basis.

Summary of typical technical and operative mistakes resulting in odour problems

- Delivery of odorous feedstocks to the site (e.g. organic wastes that have been collected on a fortnightly basis from households - these could therefore have been contained in wheeled bins for up to 14 days during the summer months. Ideally these wastes should be collected weekly during the summer.);
- Intermediate stockpiling of wastes prior to further treatment (mixing) in the tipping area (e.g. in the case equipment failure or the facility is closed);
- A general lack of structural materials to mix with feedstocks that have a high moisture content (>65 % water content);
- Pre-treatment (shredding) resulting in material that is too fine thereby creating insufficient structure and pore space within the composting mass. This may lead to the formation of anaerobic pockets, and associated fermentation by-products;
- Failing to capture and drain adequately the leachate formed during the collection of organic wastes in the tipping area (bunker);
- Unintended opening of doors of an enclosed facility, especially the in tipping, pre-treatment and main composting areas;
- Neglecting to clean regular all traffic routes, in particular the in tipping, pre-treatment and main composting areas;
- Mechanical agitation of odorous materials during inappropriate climatic conditions (e.g. when the wind is blowing in the direction of residential dwellings) or during temperature inversions, when odours would not be dispersed adequately. These are relevant at open-air composting sites, or where materials are stored out-of-doors before treatment; and
- Excessive feedstock throughput i.e. processing more material than the site can accommodate, very often leads to the following problems arising:
  - Curtailed retention time at enclosed composting facilities (e.g. boxes, tunnels) resulting in insufficient stabilisation during the first decomposition phase;
  - An increase in the dimensions of the windrow / heap, even if the turning intervals and proportion of structural material are kept at the same level. Again stabilisation and humification do not occur as efficiently, especially during the initial stages of decomposition, thereby increasing the potential for odours to be generated;
  - Overloading the compost storage areas with heaps that are too high. These need to be mechanically turned regularly to prevent odour formation;
  - Overloading waste air treatment systems due to increased odour loads stemming from excessive throughputs across all parts of the composting facility; and
  - Operating procedures not being carried out with due care and attention due to time constraints, leading to inadequate or unduly late maintenance and cleaning activities.
- Incorrectly designed loading systems (e.g. conveyers) between different zones within the facility, resulting in the build up of residues which then create diffuse odour sources;
- Inadequate or inappropriate responses to operational / equipment failures For example, if the tipping and pre-conditioning areas are out of action, this may lead to the uncontrolled storage of raw feedstocks elsewhere on the site; and
- Failure to manage exhaust air treatment systems at enclosed facilities correctly (e.g. treating air streams from multiple sources) thereby causing increased waste air volumes and elevated emitted odour loads above the capacity limits of the systems.

6.1.6 Guideline values for good operational practices to minimise odour emissions

6.1.6.1 Olfactometric odour assessments

The establishment of odour thresholds by using test persons is an objective analytical procedure that has been described in a European standard (DIN EN 13725).

Odours are generally measured using a panel of test persons, who are presented with the test gas diluted in an odour-free gas. They sniff the gasses through a 'sniffing port' and are asked to report the presence / absence of an odour. The method is based on dilution of the sample to the odour threshold (the point at which the odour is only perceptible to 50 % of the test panel). The odour concentration is derived from the dilution required to reach the threshold, and is quoted in European Odour Units per volume of air (OU_E/m^3).

Response deviations of up to three dilution steps as a rule can be expected in individual measurements (12 series, 3 repetitions, 4 test persons; VDI, 2002). Variations at the 95-%-confidence interval may reach a factor of 3 within repeated measurements in the same lab. That means that for a true mean value of 300 OU m^{-3}, single measurement results of 200 up to 450 OU m^{-3} would be acceptable. A comparison between different labs has suggested even greater variance (by a factor of four) [6].

Thus limit values for odour concentrations must be set carefully and measurements and value interpretations need to accommodate allowable deviations between individual measurements.

Due to the complexity of odour measurements and their interpretation, an example has been described below:

For example, if a limit value of were set for a biofilter source, individual results of between 250 and 1000 GE m^{-3} determined in repeated measurements carried out by the same laboratory could be obtained. If this limit value were to be set as an absolute threshold which may not be exceeded by any individual measurement, then the 'real' limit value would need to be 250 OU m^{-3} in order guarantee that the mean value of repeated measurements would be below 500 OU m^{-3}. In practice this value is very unlikely to be met under typical operating conditions, and would not be necessary if the principle of *no raw gas odour in the biofilter exhaust gas* is met. This approach is supported by the fact that odours emitted from open horizontal bio-filters, if operated correctly, reach as far as 100 meters as a rule (Both *et al*., 1997).

It is now possible to predict odour emissions (frequency and intensity) and dispersal from planned composting facilities based on knowledge about potential feedstock characteristics, operating procedures and technologies employed, local climatic conditions etc. This is an important tool in order to assess projects sited in critical locations. Experience also shows that if a minimum distance to settlements is observed, coupled with the application of basic management tools, then odour problems can be avoided at open windrow composting systems.

Thus the choice of the location of a composting site is the most important element in preventing odour problems. Therefore many countries have established minimum distance criteria between composting sites and 'sensitive receptors'. They are simple to handle but less flexible than individual site-specific assessments based on odour prognosis models. Where minimum distances have been specified, modelling would only be necessary if the distance to next settlement falls below a certain critical figure.

In order to keep such approval distance standards flexible, minimum distances should depend on annual throughput and the type of material composted.

6.1.6.2 Minimum distance requirements from residential and industrial areas and requirements for undertaking detailed odour emission modelling

Odour modellling can be carried out for any composting facility, taking into account probability calculations for emission events, as well as accommodating local climatic condictions e.g. temperature inversions.

[6] Die Geruchsstoffkonzentration ist der absolute Reziprokwert der Verdünnung an der Geruchsschwelle in [GE/m³]. Deshalb repräsentiert die Obergrenze die *höhere* Geruchsstoffkonzentration [VDI, 2002].

Measures taken to limit odour emissions from composting plants should take into account the following conditions:

- Throughput;
- Types of materials treated;
- Site specific conditions (distance from neighbouring dwellings, meteorological circumstances etc.);
- Existing operational procedures for reducing emissions and infrastructure to treat waste air; and
- The use of devices to determine compliance with technical requirements.

In addition odours that are not classified as unpleasant should be included when computing the total odour load. Specifically, this must include exhaust gas from biofilters as well as other odour sources such as mature compost.

Minimum distance regulations are simple but relatively inflexible, however, they have proved to be of value in practice. Depending on the site and technology proposed, a more flexible approach taking into account the site-specific conditions should be favoured. Based on existing technologies and good management practices (e.g. exhaust air treatment in closed systems), emissions can be reduced to an extent that unacceptable nuisance to neighbours would not occur.

Based on practical experience gained about the strength of odour sources emitted from different composting systems and their impact on the environment, minimum distance rules as well as requirements for detailed emission assessments (see 6.1.6.3) have been established. These depend upon:

- The individual site conditions;
- The type of material treated; and
- The annual throughput at the site.

This standard procedure is applied for both, open and in-vessel composting systems because inadequate process management in both systems may create odour events which need to be planned, especially when minimum distances are not adhered to.

Standard distance rules for composting plants and conditions for carrying out detailed odour modelling

A detailed odour modelling exercise need only be performed if minimum distances to the nearest settlement (sensitive receptor) are not met. If the outcome of the modelling suggests that unacceptable levels of odours are likely to arise, then two options are available:

(i) Change of location; or

(ii) Planning an enclosed in-vessel composting system with integrated waste air treatment (biofilter) guaranteeing a defined maximum odour emission rate and concentration.

Table 11 lists the minimum distances that should be observed when planning composting plants. If the given critical distances between potentially odour emitting sites of operation and nearest settlements are not met, then a detailed odour modelling exercise must be performed in order to assess the suitability of the location based on the probability of the occurrence of nuisance to the neighbourhood caused by odour problems. The critical distances depend on annual throughput and material types.

Table 11: Suggested minimum distances between composting plants and sensitive receptors.
If distance thresholds for certain throughputs and material types are not met a detailed odour modelling assessment must be performed.

A) Open systems

Green waste only [1]							
Annual throughput	**≤ 1.000 t**	**1.001-5.000 t**	**5.001 – 10.000 t**		**10.001 – 20.000 t**		**> 20.000 t**
Distance threshold [2] open windrows to standard protection site [3]	**< 300 m**	**< 300 m**	**< 300 m**	**> 300 m**	**< 500 m**	**> 500 m**	**< 1.000 m**
	OA [4]	**OA**	**OA**	✔	**OA**	✔	**OA**

Biowaste or sewage sludge composting				
Annual throughput	**≤ 1.000 t**	**1.001-5.000 t**	**5.001 – 10.000 t**	**> 10.000 t**
Distance threshold [2] open windrows to standard protection site [3]	**< 300 m**	**< 300 m**	**< 500 m**	**< 1.000 m**
	OA [4]	**OA**	**OA**	**OA**

B) Enclosed systems

Green waste only [1]					
Annual throughput	**≤ 1.000 t**	**1.001-5.000 t**	**5.001 – 10.000 t**	**10.001 – 20.000 t**	**> 20.000**
Distance threshold [2] closed facility to standard protection site [3]	**300 m**	**300 m**	**300 m**	**300 m**	**300 m**
	✔	✔	✔	✔	**OA**

Biowaste or sewage sludge composting				
Annual throughput	**≤ 1.000 t**	**1.001-5.000 t**	**5.001 – 20.000 t**	**> 20.000 t**
Minimum distance [2] closed facility to→ standard protection site [3]	**< 300 m**	**< 300 m**	**< 500 m**	**< 1.000 m**
	OA [4]	**OA**	**OA**	**OA**

C) Sensitive neighbours

Sensitive neighbours include *hospitals, convalescent homes, health resorts etc.*
A detailed odour modelling exercise independent of type of material and quantity treated at a distance of <u>less than 1 000 m is required.</u>

✔ … no odour prognosis needed **OA … odour modelling obligatory**

[1] Green waste in this respect is defined as: organic waste from gardens and public greens (leaves, tree and bush cuttings, flowers, fruit, vegetables, bark), organic cemetery waste, seeds, and dry agricultural harvest residues, straw, hey, cereals, bark, vines, untreated wood, sawdust. Green waste may include also source separated kitchen waste from households at a maximum proportion of 10 % w/w).

[2] Distance between the outer border of the facility sector where the source of odour emission can be expected (border of composting area, biofilter, composting hall etc). and the potential receptor

[3)] *standard protection site*: (= sensitive receptor) locations which are utilised as: residential dwellings, city centres, recreation and sport facilities, schools, public parks, play grounds, camping sites, restaurants.

[4)] The competent authority can in the case of a capacity of ≤ 1000 t a-1 decide to abstain from performing a detailed odour assessment

When the minimum distance between the site and the nearest sensitive receptor is exceeded (Table 11), a detailed odour model need not be carried out. This is the case for all composting plants which are at least 1,000 m from a sensitive receptor, irrespective of their size.

Additional conditions when an odour assessment is required:

a) Open and (partly) enclosed in-vessel systems:

- As an exception of the above described standard, under unfavourable meteorological and topological situations an odour assessment may be required for low throughput sites

b) Enclosed / in-vessel systems:

- When the residence time of the composting material in the enclosed reactor is less than two weeks, when the distance to residential areas is less than 500 m.

Procedure for existing facilities

It is unreasonable to apply the above minimum distances or to require a detailed odour assessment to existing composting facilities. Precautionary measures can be applied in situations where repeated problems have been documented. With respect to the principle of proportionality, operational measures should be prioritised (e.g. reducing throughput at the site, amending the material composition and the process management procedures, optimising the air management system etc.) as a priority before changes are made to infrastructure.

Only if external approval covering dispersion calculations and odour measurements have clearly shown that all existing measures did not result in any improvement, enclosing the facility and introducing a waste exhaust air treatment system, may be required.

Minimum criteria for treated waste air following treatment through a biofilter:

- The odour concentration in treated waste air should be < 500 OU/m³, as mean value of repeated measurements. Deviations due to analytical procedure variances have been included in this limit value.
- If the odour load of the purified exhaust air was not taken into account, raw gas odour must not be detected in the purified waste air.
- A maintenance and management regime for the biofilter must be carried out, including regular documentation describing operating parameters (*in Austria:* according to *ÖWAV Regelblatt 513 „Betrieb von Biofiltern")*
- Dust emissions in the waste air must not exceed 10 mg/m³ [7]

The operating procedures should be specified in the consent paper and technical description of the biofilter.

6.1.6.3 Key elements in carrying out a detailed odour assessment

Site assessment

The physical features of the composting site have to be established:

- **Distance** to relevant settlements (sensitive receptors) taking into account the current use of the site;

[7] Taken from Technische Anleitung zur Verwertung, Behandlung und sonstigen Entsorgung von Siedlungsabfällen, TA Luft, 2002.

- **Meteorology**: wind dispersion (direction, velocity, turbulence); tendency of the site to experience temperature inversions; and other local climatic conditions;
- **Topography,** especially the potential to be subjected to cold air flows; impact of the site (including structures) on the wind dispersion.

Emission prognosis

The assessment of odour emissions should include the following:

- Description of **odour sources** (all relevant facility sectors, e.g. tipping area, pre-treatment, intensive composting area, storage area etc.) with the local and temporal distribution of potential odour emissions;
- Estimation of odour **emission rates** based on the proposed facility layout, literature data and measurements taken from comparable composting plants with similar materials composition;
- Estimation of the impact of **non regular operation conditions** and **failures**;
- Compilation of **emission data** (which will be used as basis for dispersion calculations); and
- Inclusion of potential **additional neighbouring emission sources** (in line with the definition used in the German Odour Emission Guideline, GIRL, 2004) outside the composting facility (e.g. waste water treatment plant).

Assessing odour emissions

There are two main ways to assess odour emissions:

(i) *computation of odour dispersion using mathematical models* – these may be used for new and existing facilities [8]

(ii) *direct on-site inspection* – these can only be used at established operational facilities [9]

- **Dispersion calculation estimating odour emissions,** can be carried out using the German *TA-Luft 1986* (*factor-10-model*) or *TA-Luft 2002* (*program AUSTAL2000*) programmes assuming the individual standard operating conditions of the composting facility at the planed throughput capacity are specified.
  - The calculation of additional / external loads is done using the German Odour Emission Guideline/GIRL)**Fehler! Textmarke nicht definiert.**.
  - Comparing the proposed site against other existing facilities with a comparable design and capacity is also valid.
- **Estimating odour emissions by on-site inspection.** There are two methods that can be used to determine the frequency of identifiable odour events:
  - **Grid Measurement**: VDI 3940 sheet 1 (draft) 2003-11
  - **Plume Measurement:** VDI 3940 sheet 2 (draft) 2003-11

  Inspections of the environment at a composting facility (e.g. by using the method described in GIRL) are only viable if:
  - The specific location of an odour source cannot be established, preventing a modelling exercise being carried out;
  - The impact of an existing composting facility needs to be evaluated when the emission potential might achieve critical thresholds
  - The site-specific meteorology and/or topography do not allow a dispersion calculation to be conducted.

[8] E.g. following the German TA-Luft 1986 (Factor-10-model) or TA-Luft 2002 (program AUSTAL2000)

[9] *a) Grid measurement*: VDI 3940 sheet 1 (draft) 2003-11. *b) Vane measurement*: VDI 3940 sheet 2 (draft) 2003-11

It must be noted that *grid measurements* are costly and very time consuming and the result affords no greater degree of confidence than a well conducted emission calculation.

The *plume measurement* on the other hand, is a practical and inexpensive alternative providing valid results.

- **Assessing emissions**: The assessment follows the German Odour Emission Guideline (GIRL; Total Impact [=IG]):
  - (a) For sensitive receptors with the following dedicated uses: residential areas, municipal centre zones, leisure and sports grounds, health resorts and recreation areas, schools, public parks, play grounds, open air baths, camping resorts, tennis halls, golf course, restaurants, the relative yearly impact time of the odour may not exceed 10 % of the total hours per year.
  - (b) For sensitive receptors in areas with the following dedicated uses: *commercial and industrial areas, villages, mixed residential areas, shopping centres,* the relative yearly impact time may not exceed 15 % of the total hours per year.

    The sensitive receptor is defined in this context as a stationary receptor, such as a habitation or permanent work place.
  - (c) Meeting limit values can be assessed either through dispersion estimates or on-site inspection methods.
- Accommodating potential **non regular operational conditions (e.g. plant failures)** and estimating the resultant frequency and intensity of odour emissions in the area surrounding the composting plant.
- Assessment of the **topographic and meteorological conditions** at the composting site. A description of the wind data used and an analysis of dispersion conditions where a low air exchange rate could be expected (e.g. inversion, cold air currents etc).

Existing sources of odour emissions in the environment of the facility need to be considered and are referred to as pre-load. This existing pre-load can be neglected if the additional impact of the proposed composting site falls below the *"irrelevance limit"* (i.e. the odour threshold is exceeded in less than 2 % of the annual number of hours). There is a certain flexibility in the interpretation of measured data. In mixed areas that are predominately commercial or agricultural in character, higher emission rates can be permitted, which then fall between those allowed for residential and industrial areas.

6.2 *Basic technical requirements – hardstanding and water management systems at open composting sites*

Generally, leachate and run-off water may not be allowed to drain off into the soil without prior treatment, as it has the potential to pollute ground and surface waters.

With the exception of facilities treating up to 300 m³ per year of garden and park waste as the sole feedstocks, composting must be carried out on an area of hardstanding. The requirements for composting on unpaved open ground are specified in Chapters 7.3 and 7.4.

6.2.1 Construction principles for paved open composting areas and waste water storage and management systems

Two main elements have to be considered when constructing paved open windrow composting plants:

- The pad needs to be constructed out of a sealed pavement (hardstanding) and capture waste water (leachate and run-off) in order to prevent any uncontrolled release of waste water to ground or surface water; and
- Appropriate dimensioning of the intermediate waste water tank taking into account the site size and rainfall in order to hold leachate (water that has percolated through the feedstocks) and run-off from precipitation from all paved areas where compost or raw material is stored or treated.

In addition, a waste water management plan must ensure adequate treatment and reuse of the waste water.

The sealed area must cover the following sectors of the composting plant:

- The tipping area for all input materials with the exception of woody materials (tree and bush cuttings), straw or similar non active, carbon rich, dry feedstocks;
- The storage area for non woody materials (biowaste, kitchen waste, sludge, all materials with high water content and a high fermentability potential)
- The pre-treatment area where feedstocks are mixed, with the exception of the area where woody materials tree and bush cuttings) only are shredded;
- The active decomposition area, irrespective of whether it is roofed or not. (There is an exception for small-scale green waste composting, see Chapter 7.3);
- The maturation area (with the possible exception indicated in 7.4); and
- The storage area for mature compost (with the possible exception indicated in 7.6).

6.2.1.1 Construction of the hardstanding and lagoon

The principal construction of the sealed pavement for open composting plants is illustrated in Fig. 6-1

Fig. 6-1. Basic construction of plane and pavement of an open composting area	**Fig. 6-2 Layer construction of a water retention basin sealed with PE-HD film**

Fig. 6-2 illustrates the construction scheme of a waste water retention basin sealed with a PE-HD film.

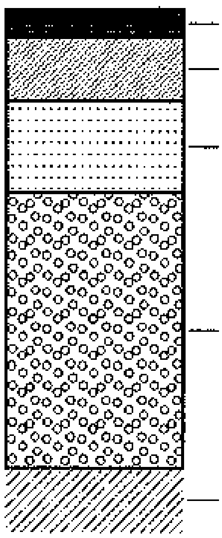


Fig. 6-1. Basic construction of plane and pavement of an open composting area

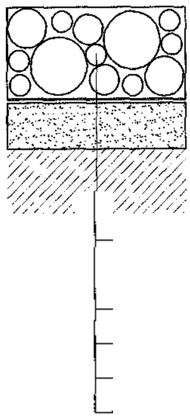


Fig. 6-2 Layer construction of a water retention basin sealed with PE-HD film

Further examples of open windrow composting pants and constructive elements are shown below.

Fig. 6-3. Two examples of typical paved open windrow composting plants with one sided slope of ca. 5 %

Fig. 6-4. Windrows without geo-textile coverage

Fig. 6-5. Small scale agricultural composting

on pavement with one-sided slope	with pulled windrow turner
	
Fig. 6-6. Slope of sealed composting plant drains the water into a simple gully	**Fig. 6-7: biological water purification in reed grass beds and water retention basin**

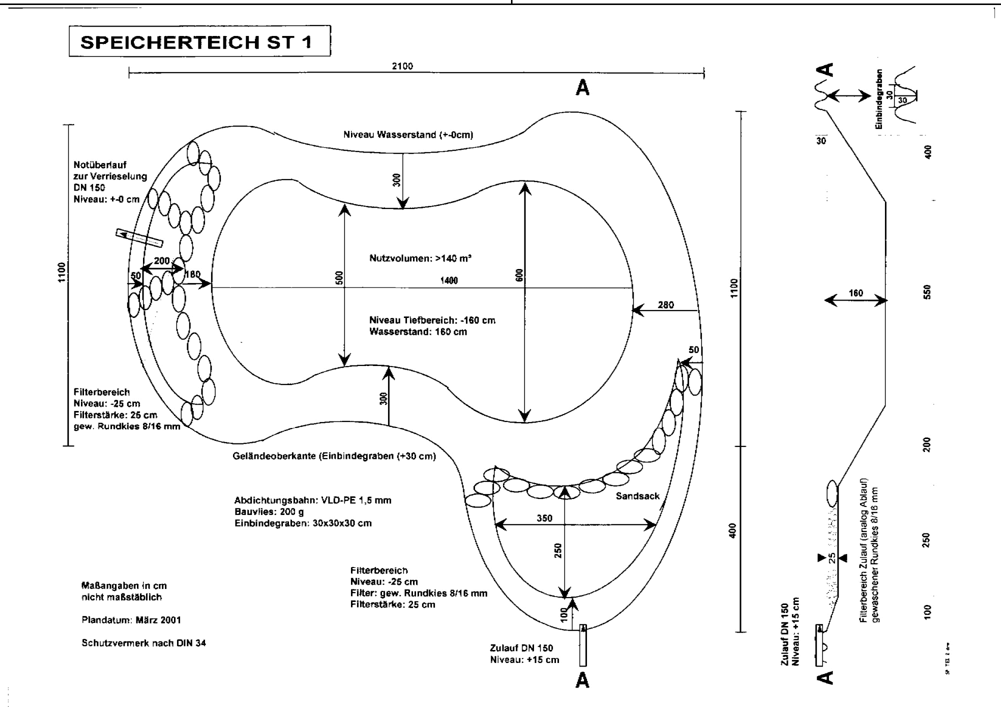


Fig. 6-8. Construction scheme of a water retention basin with shallow water zone[10]

[10] Source “Ökologisches Projekt Graz”; http://www.bioklaeranlagen.at

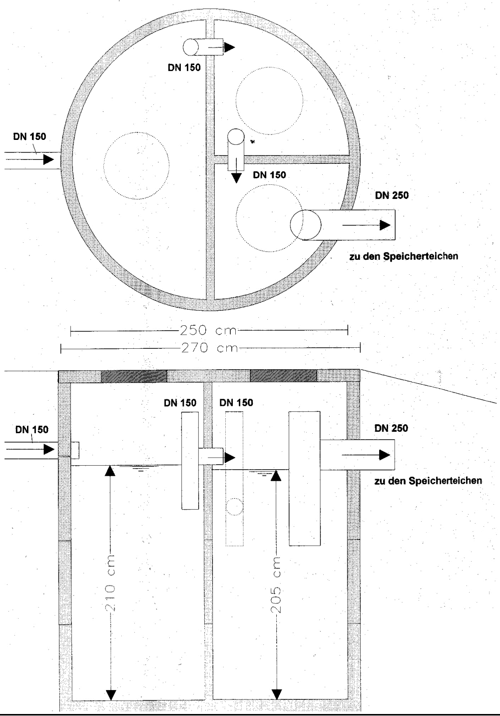
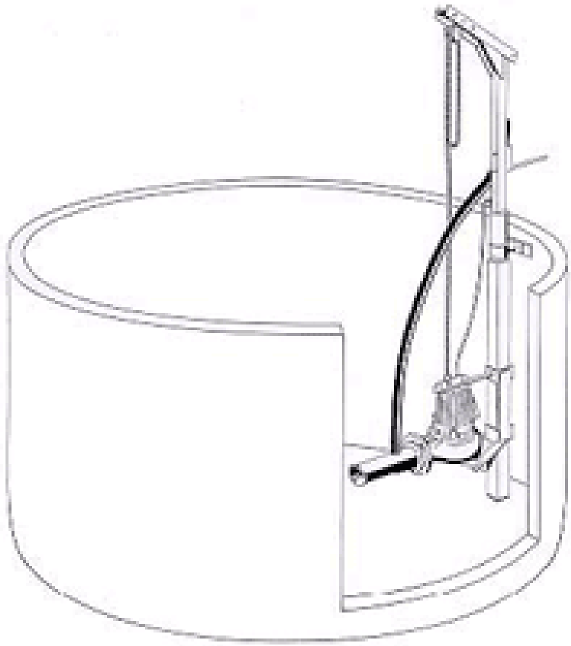
	

Fig. 6-9. 3-Chamber sewer/solids separator. [11]	**Fig. 6-10. Standard waste water tank. (NB This needs to be constructed out of acid resistant concrete.**

6.2.2 Waste water management

6.2.2.1 Origin and types of waste water

Waste water at a composting facility arises from a number of different sources and stages during composting:

- Press water (often called leachate, which is water that has percolated through composting material);
- Process water (resulting from the metabolic activity inside the composting pile);
- Condensate on equipment and in pipes;
- Waste water from cleaning activities;
- Precipitation water in open areas (run-off water from compost piles surface as well as from traffic routes); and
- Precipitation water from roofs.

6.2.2.2 Waste water collection and use

Waste water needs to be collected and treated according to the requirements of water protection principles i.e. to prevent pollution of ground and surface wasters due to its high biological oxygen demand and nutrient content.

[11] Source “Ökologisches Projekt Graz”; http://www.bioklaeranlagen.at

It is important to note that waste water arising in areas where the composting feedstocks have not been sanitised fully to destroy unwanted pathogens or weed seeds / propagules (e.g. tipping areas, storage of untreated feedstocks, the first active decomposition where temperatures are below > 55 °C) should not be used to add moisture to sanitised compost piles (e.g. mature compost where no further thermal hygienisation could be expected), in order to prevent re-contamination of the compost.

Figure 6-11 illustrates an overview of possible treatment and uses of waste water from composting plants.

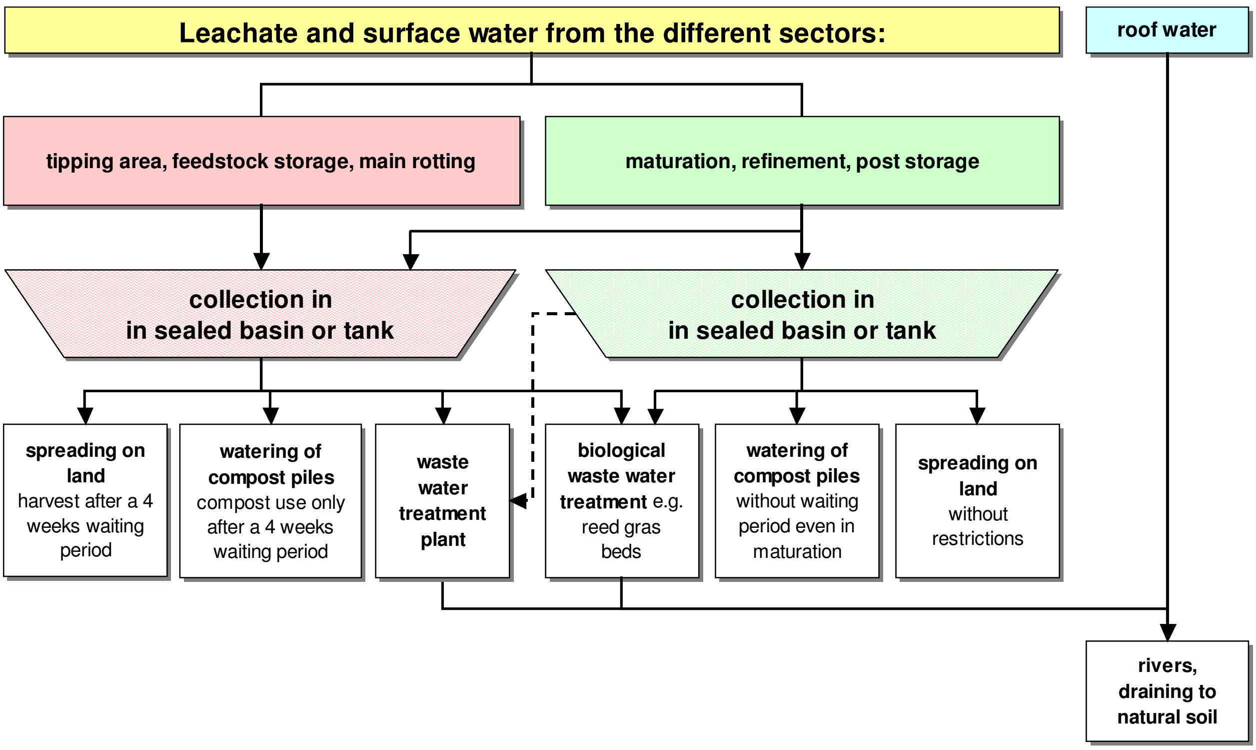


Figure 6-11 Options for waste water collection, treatment and use

6.2.2.3 Construction elements of a wastewater drainage system

All storage and treatment areas must allow for the controlled drainage of all liquids (i.e. those originating from the feedstocks, storage, active composting and precipitation) to avoid water-logging at the windrow-base. This is achieved by constructing the composting pad on a slight slope to avoid water stagnating. The slope of the site is determined by the windrow height, annual precipitation, existence of roofing, the method of aeration and the presence of drain/aeration tubes. Minimum slopes are summarised in Table 12.

Table12: Minimum slope (in %) requirements for composting areas depending upon the annual rate of precipitation, windrow height, roofing, aeration method and discharge channels.

	Minimum slope for windrow- systems [in %]				
Windrow dimensions	**open** Annual precipitation (mm)			**roofing**	**Drain and aeration tubes below the windrows**[1)]
	<450	**450-900**	**>900**		
triangular windrows < 1.5 m in height	1%	2%	3%	1%	1%
trapezoidal windrows > 1.5 m in height	1%			1%	1%

[1)] ... In the case of composting on slabs with submerged drain/aeration tubes the site is not required to have a slope.

However the drain off of water after a storm, at maximum capacity utilization, must be guaranteed.

In the case of an 1% slope, the following factors need to be considered:

- The technical precision of a 1% slope, with its obtainable tolerances, reaches its limits with larger areas and distances. Therefore special requirements must be met regarding the precision of levelling, frost-substructure, bitumen-bearing-layer, asphalt or concrete paving. Any imprecision during construction or under a heavy load may result in settling which can inhibit water drainage;
- A 2% slope is recommended for "safety reasons" where active composting is carried out without any forced aeration system in place; and
- With covered composting areas, which are independent of precipitation, the material combination and the watering system must be adjusted to ensure the maximum water-holding-capacity of the windrows during the composting process Is not exceeded.

The slope should not exceed 5% as shifting (undesired relocation) of the windrow may require additional materials handling.

For submerged discharge channels a slope of 0.5 to 1 % may be considered sufficient in the channels.

For the purpose of efficient site operation using turning machines it is recommended that slopes at right angle to the windrows should be avoided. It is important to ensure that leachate from a windrow cannot transverse and get be absorbed by another windrow, as it may lead to cross-contamination.

The tipping area and intermediate storage areas used for kitchen waste or materials with high water content need to have efficient drainage systems for leachate. A minimum slope of 3% for these areas is therefore required.

6.2.2.4 How to calculate the dimension of a waste water tank or basin

Following the Austrian construction sheet for agricultural composting sites the amount of leachate water of the area covered with compost piles is estimated using the ration of 0.028 m³ leachate holding capacity / m² of hardstanding. In addition two further precipitation data have to be taken into account:

- The two days 'storm' precipitation estimated on the basis of a one in five year event has to be accommodated within the volume of the waste water tank or basin; and
- The average annual rainfall in the area.

The calculation resulting in the largest tank size has to be considered for the planning of the compost site.

The calculations based on a number of different annual rainfall data are illustrated in Table 6-13.

Table 6-13. Minimum storage volumes for leachate and precipitation water from the sealed areas of a composting plant (ÖKL,1993)

Annual precipitation [mm]	**Volume of tank or retention basin *[m³/m² sealed area]***			
	Precipitation	**Leachate**	**Total**	**+ 20 % safety factor**
< 700	0,03	0,028	0,058	0,070
up to 900	0,05	0,028	0,078	0,094
up to 1100	0,08	0,028	0,108	0,130
up to 1400	0,12	0,028	0,148	0,178
> 1400	0,17	0,028	0,198	0,238

For example, a location that receives an annual rainfall of 900 mm and has an unroofed composting pad of 4000 m² would need approximately 400 m³ storage volume for waste water.

The minimum storage capacities following a one in five year 48 hour rainfall event are summarised in Table 6-14.

Table 6-14. Minimum storage volumes calculated on the basis of a one in five year 48 hour rainfall event (ÖKL,1993). Volumes are shown in m^3.

		Storage capacity in m^3				
2 days rainfall event within 5 years		**Sealed area in [m²]**				
l/m²	**m³/m²**	**500**	**1000**	**2000**	**4000**	**8000**
48	0,048	24	48	96	192	384
61	0,061	31	61	122	244	488
72	0,072	36	72	144	288	576
83	0,083	42	83	166	332	664
95	0,095	48	95	190	380	760

6.2.2.5 Guidelines for waste water prevention and management

It is always best to prevent waste water arising in the first place. However, where this is not possible, a number of measures can be taken to manage these liquids effectively. Good practice measures to prevent and manage waste waters are summarised below:

- Covering open windrows with geo-textiles or composting under a roofed structure → this reduces the formation of leachate and helps improve run-off management;
- Mixing feedstocks with additives that provide a good structure and water holding capacity (e.g. shredded wood, bark, straw, oversize screenings, sawdust, leaves at a percentage of at least 20 % (v/v), loamy soils and mature compost (between 5 to a maximum of 15 %) → this increases the water holding capacity and absorbs leachate and process water;
- Composting on an organic, structure-rich foundation (e.g. shredded wood, bark, straw, oversize screenings, sawdust);
- Frequently turning windrows to increase the rate of evaporation of water; and
- Adjusting the initial moisture content of the feedstocks to between 55 to 60 % (v/v).

6.3 Hygiene related process and product requirements

6.3.1 Introduction

Human, plant and animal pathogens are micro-organisms that can cause illness or disease in their hosts. They can be either bound to solid materials, be suspended in water, or released into the air as a bioaerosol. Pathogens are typically bacteria, fungi or viruses.

From a human hygiene standpoint it is helpful to differentiate between faecal pathogens (those that emanate from manures and other faecal sources) and can infect individuals through ingestion, and those that are present naturally in feedstocks and are responsible for carrying out the composting process. The latter are usually problematic when they are formed into bioaerosols.

Composting plants need to *"guarantee the overall reduction of pathogens"*, therefore a flexible approach in process management, incorporating time-temperature regimes and recording demands for the different technological solutions is required.

In order to guarantee that 'safe' composted products are marketed, in principle three strategies (or combinations of) can be adopted:

1.) Validation of a defined composting system by testing the reduction of artificially introduced test organisms as an obligatory element during the consent process (used e.g. in Germany, Luxembourg);

2.) Requiring that the mass of compost be raised to a minimum temperature for a minimum period of time; and

3.) Investigation of defined indicator micro-organisms in final products as part of a quality assurance scheme.

In most of the countries a combination of temperature/time and end product tests (typically using *Salmonella spp. or Escherichia coli*) is used to monitor and ensure sanitisation takes place. There is considerable agreement that temperatures higher than 55 degrees Centigrade and below 65 degrees Centigrade have the desired effect, though the duration for which this must be achieved shows some variation, and is dependent upon feedstock and processing conditions (e.g. open windrow vs. in-vessel).

Following long term experience in several countries it is not recommended that a validation system for catering waste be introduced.

In order to achieve a satisfactory hygienisation effect two phases of the composting process are of equal importance:

- The ***thermal hygienisation*** stage – this results in a significant reduction in numbers of pathogenic micro-organisms stemming from the source materials; and
- The ***subsequent stabilisation and maturation phase*** – this ensures the microbiological stabilisation of the final product (compost). This is achieved by reducing the substrate available for pathogenic re-growth, and by shifting the microbial population in favour of soil born species. The latter out-compete many pathogens, and release natural antibiotics and other antagonistic factors.

Further it is important to note that the achievement of higher temperatures (> 60 to 65 °C) may slow down the composting process and create intermediate products which may cause additional odour emissions. As such, process controls of this nature may not lead to optimum rates of compost production.

6.3.2 The EU Animal By-Products Regulation – its key impacts on composting

6.3.2.1 Basic elements

The Animal By-Products Regulation (ABP-Reg) (EC) no. 1774/2002 together with its manifold amendments and follow-up regulations must be respected in national treatment requirements. The Regulation has been revised and will be adopted in the second half of 2009.

Based on the basic structure and the hygienisation requirements of the ABP-Reg it permits a differentiated set of processing rules depending upon the feedstocks to be treated.

This overview has been based on the draft regulation as issued by the EU Parliament and Council on 31 July 2009 (2008/0110 (COD);PE-CONS 3639/09)[12], which will update the 2002 regulation. The referencing of articles and paragraphs below stem from this draft. It should be noted that they might change after final adoption of the regulation, however, for composting and biogas (anaerobic digestion) plants treating ABPs nothing substantial has changed in the main text.

The Commission started the work on the Annexes within the "comitology procedure". Here again, the relevant requirements for hygienisation and treatment will be laid down. It is planned to adopt the Annexes in the first half of 2010.

<u>For processing in composting and biogas plants only materials of Category 2 and 3 may be treated</u>.

<u>Category 2</u> materials do not originate from materials of high risk of contamination with prion particles (that may cause diseases known as transmissible spongiform encephalopathies [TSEs, such as the bovine version, BSE]), which are classed as Category 1 materials. Category 2 materials remain of concern due to potential contamination with other potentially significant pathogens or substances e.g. pharmaceutical residues. They may be derived from imported goods from outside the EU which do not meet all appropriate regulations or from waste water at slaughterhouses.

"Manure, non mineralised guano and digestive tract content" have also been classed at Category 2 materials. However, these materials may be composted or treated in a biogas plant under national law with far reaching relaxations or similar constraints to Category 3 material.

Article 10 defines **Category 3 material**. This is of utmost importance for composting and AD.

The principles in relation to potential risk factors have not changed in the most recent draft compared with the 2002 Regulation. Category 3 materials have been classed as ABPs that:

- *… are usually from material or animals fit for human consumption*
- *… are not intended for human consumption*
  - *… for commercial reasons*
  - *… due to problems of manufacturing or packaging defects or other defects from which no risk to public or animal health arise*
- *… did not show any signs of disease communicable to humans or animals*

This characteristics has to be approved for all types Category 3 materials, irrespective of their origin be it a slaughter house or any other origin (e.g. a farm). All types of, *hides, skins, hooves, wool, feathers, horns, hair, pig bristles, and raw milk* are included.

New materials to be included in the latest draft include: *centrifuge or separator sludge from milk processing*, as well as pet food and feeding stuffs of animal origin fulfilling the above mentioned requirements.

The definition of *<u>'former foodstuff'</u>* (point (f)) which are traditionally treated in composting and biogas plants has changed slightly. It now reads:

[12] Proposal for a Regulation of the European Parliament and of the Council laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (Animal by-products Regulation)

'products of animal origin, or foodstuffs containing products of animal origin, which are no longer intended for human consumption for commercial reasons or due to problems of manufacturing or packaging defects or other defects from which no risk to public or animal health arise;

Finally point (p) is *'catering waste other than as referred to in Article 8(f)'.* This is all catering waste which does not include *'catering waste from means of transport operating internationally'.*

6.3.2.2 Restrictions on the use of organic fertilisers and soil improvers derived from ABPs

Article 11 lays down the *restrictions on use* of ABP derived materials. In this context the 21 days waiting period after application of organic fertilisers before harvesting of herbage or direct grazing is included. In principle this has been taken from Regulation (EC) No 181/2006 with only slight changes. It reads:

Article 11 par. 1.

'The following uses of animal by-products and derived products shall be prohibited:

….

(c) 'the feeding of farmed animals with herbage, either directly by grazing or by feeding with cut herbage, from land to which organic fertilisers or soil improvers, other than manure, have been applied unless the cutting or grazing takes place after the expiry of a waiting period which ensures adequate control of risks to public and animal health and is at least 21 days'

These *conditions for the feeding of farmed animals …., in particular a modification of the waiting period* may be laid down and specified in the Annexes via the "comitology procedure".

6.3.2.3 Marketing ABP-derived products

Article 32 lays down the rules for the placing on the market of organic fertilisers and soil improvers. Here *digestion residues from transformation into biogas and compost* are explicitly mentioned.

The definition of *"organic fertiliser"* and *"soil improver"* is:

'it means materials of animal origin used to maintain or improve plant nutrition and the physical and chemical properties and biological activities of soils, either separately or together; they may include manure, non-mineralised guano, digestive tract content, compost and digestion residues'

Member States may adopt or maintain national rules which go beyond the requirements of the regulation but need to provide justification *'on the grounds of the protection of public and animal health'*.

Detailed marketing and implementation rules may be laid down via the "comitology procedure".

6.3.2.4 Composting and AD of Category 2 material and manure

Before being treated in a composting or AD plant, Category 2 material is required, in principle, to undergo *pressure sterilisation* and *permanent marking of the resulting material* (Art. 13(e)).

'Manure, digestive tract and its content, milk, milk-based products, colostrum, eggs and egg products' are exempted from this requirement *if 'the competent authority does not consider this to present a risk for the spread of any serious transmissible disease'*.

This means that if the competent authority decides –this is acceptable, then such materials may be treated in either a composting or biogas plant without any preceding hygienisation measures.

Here (in point (f)) the *competent authority* may also allow *the application to land without processing, in the case of manure, digestive tract content separated from the digestive tract, milk, milk-based products and colostrums'.* Again this has to be considered *'not to present a risk for the spread of any serious transmissible disease'*.

6.3.2.5 Composting and AD of Category 3 material

All Category 3 material can be processed in compost and biogas plants. As indicated above, detailed provisions and national exemptions have been developed for catering waste and other Category 3 materials.

A new provision refers to the <u>application on land</u> of *raw milk, colostrum and products derived therefrom <u>without processing</u>*.

6.3.2.6 The exemption for Category 3 Catering Waste

Article 15 *'Implementing measures'* provides the basis to define *'<u>parameters for the transformation of animal by-products, including catering waste, into biogas or compost</u>*. These measures shall be laid down in the Annexes via the "comitology procedure".

However – **and this is most important for the adoption of national hygienisation rules for catering waste treated in composting and biogas plants** –paragraph (2)(a)(ii) includes a similar exemption for the treatment of catering waste in compost and biogas plants as already known from in Art 6(2)(g) in Reg (EC) 1774/2002, it reads:

Article 15: Implementing measures

1. Measures for the implementation of this Section [may be laid down relating to the following:

……..

(b) parameters for the transformation of animal by-products, including catering waste, into biogas or compost;

……..

2. Pending the adoption of rules referred to

(a) in points (c), (f) and (g) of the first subparagraph of paragraph 1, ***<u>Member States may adopt or maintain national rules for</u>****:*

(i) …………..;

(ii) ***<u>the transformation of animal by-products referred to in Article 10(p) [=catering waste]</u>****;*

This refers to the Section 2 "Disposal and use" which, includes all aspects of handling and treatment of catering waste in biogas and composting plants. Therefore existing national treatment rules would not be affected. It also means that national rules can be implemented at any time in the future as long as common rules on an EU level (which would be laid down in the Annexes of the ABPR) are not adopted.

However, and this is important, independent from national processing and hygienisation requirements in place, composting and biogas plants treating Category 3 material (including catering waste) need to be approved according to Art. 24. There is no particular guidance on the approval procedure under this article.

6.3.2.7 Collection and transport

Article 21 (4) of the draft Regulation exempts catering waste from the general collection, transport and traceability provisions. It reads:

'Operators shall collect, transport and dispose of Category 3 catering waste, in accordance with national measures foreseen in Article 13 of Directive 2008/98/EC.'

This Article 13 '*Protection of human health and the environment'* of Directive 2008/98/EC (Waste Framework Directive) says:

'Member States shall take the necessary measures to ensure that waste management is carried out without endangering human health, without harming the environment and, in particular:

(a) without risk to water, air, soil, plants or animals;

(b) without causing a nuisance through noise or odours; and

(c) without adversely affecting the countryside or places of special interest.'

This means national implementation of the Waste Framework Directive is the relevant legislation to be respected for collection, transport and disposal of Category 3 Catering Waste.

6.3.2.8 Quality assurance (‘*own checks*’) and HACCP

Article 28 establishes the principle of operators carrying out their *own checks* in order to demonstrate compliance with the Regulation. However, this refers to those measures and provisions which apply only to a particular ABP or specific treatment.

The 2002 ABP Regulation, sets out the principle of Hazard Analysis and Critical Control Points (HACCP) procedures as a general requirement in Article 29.

If taken seriously this would pose a tremendous and disproportionate burden to operators in most cases. Therefore it is important to recognise that the Regulation took a more relaxed approach by saying in paragraph 1:

> *‘Operators carrying out one of the following activities shall put in place, implement and maintain a permanent written procedure or* ***procedures based on the HACCP principles*** *for the:*
>
> *(a) processing of animal by-products;*
>
> *(b) transformation of animal by-products into biogas and compost;*
>
> *…………..”*

The phrase *“procedures based on the HACCP principles”* together with Article 30 is important because this allows a more relaxed and individual interpretation of HACCP principles to be laid down in a voluntary guidance document.

Article 30 *‘National guides to good practice’* is cited here:

> *‘1. Where necessary, competent authorities shall encourage the development, dissemination and voluntary use of national guides to good practice in particular for the application of HACCP principles as referred to in Article 29. Operators may use such guides on a voluntary basis.*
>
> *2. The competent authority shall assess national guides to ensure that:*
>
> (a) *they have been developed in consultation with representatives of parties whose interests may be substantially affected, and have been disseminated by sectors of operators; and their contents are practicable for the sectors to which they refer.’*

6.3.3 Austrian hygienisation requirements in composting

6.3.3.1 General requirements

The following Table 15 provides an overview on the systematic of hygienisation rules, which are dependent on the feedstocks treated.

Table 15: Categories of animal by-products and general hygienisation requirements for composting plants

The definitions and references refer to the 2002 ABP Regulation (EC) No 1774/2002; the implementation is ruled under the Austrian Ordinance on Animal By-Products FLGII No 484/2008

Animal By-Product	**Requirements for Composting Plants**
Category 2 material	
Manure, digestive tract content separated from the digestive tract, milk and colostrum, if the competent authority does not consider them to present a risk of spreading any serious transmissible disease [Art. 5(2)(e) ABP-Reg]	■ Approval according to Art. 15 ABP-Reg ■ Composting permitted without pre-treatment
Carcasses or slaughtered animals not intended for human consumption; animal materials collected when treating waste water from slaughterhouses or category 2 processing facilities with particles > 6 mm; only waste water from category 2 slaughterhouses (*Not-ruminants*)	■ Approval according to Art. 15 ABP-Reg & Hygienisation requirements of Annex VI ABP-Reg ■ May only be composted after processing method 1 (133 °C, 20 minutes, 3 bars, saturated steam) ■ prohibited in composting plants; AD in *biogas plants* only
Category 3 material	
ABP containing wastes from food industry fit for human consumption; Slaughter house wastes not fit for human consumption; Several ABP of healthy animals are not affected by any signs of diseases communicable to humans or animals (hides and skins, hoofs, horns, feathers, shells, hair, milk, fish waste)	■ Approval according to Art. 15 ABP-Reg & Hygienisation requirements of Annex VI ABP-Reg (1774/2002) ■ Slaughter house wastes in *biogas plants* only
Catering waste from private households – group A*: Material from separate collection of organic household waste pursuant the Austrian Ordinance on the separate collection of biowaste (FLG. n° 68/1992), if it includes kitchen and food waste from private households	■ Exempted from the scope of the Austrian Animal By-Products Ordinance ■ National treatment requirements under the waste regime
Catering waste from central kitchens and former foodstuffs – group B* Kitchen and food waste (including used cooking oil) collected from restaurants and central kitchens; former foodstuff – independent of the collection system	■ Approval according to Art. 3 of the Austrian *Animal By-Products Act* (FLG No 141/2003) ■ National treatment requirements ■ Supplementary treatment requirements to *group A* ■ Preferably treated in biogas plants

***** *If the collection of organic waste includes kitchen waste only from* ***private households*** *it belongs to* ***group A****; when kitchen waste is collected from* ***restaurants****, or* ***centralised kitchens*** *the requirements of* ***group B*** *apply.*

6.3.3.2 Group (A)

Requirements for source separated organic waste are set out in the Austrian Ordinance on the separate collection of biowaste (FLG. n° 68/1992). This includes catering waste from private households and all further admissible materials for composting plants as set out in Annex 1 of the Austrian Compost Ordinance (FLG no. 291/2001) which do not contain other animal by-products.

The definition of catering waste is defined in Annex 1 item 15 of the European ABPR No 1774/2002) as follows:

"'catering waste' means all waste food including used cooking oil originating in restaurants, catering facilities and kitchens, including central kitchens and household kitchens"

Catering waste is exempted from the special requirements for collection, transportation and storage as well as from the requirements for composting and biogas plants of Annex VI by the stipulations in Article 6(2)(g) and Article 7(1). This covers **any catering waste stemming from the separate collection of organic waste from households and central kitchens.**

Following the wording in paragraph (14) of Chapter II C. in Annex VI **this also applies when catering waste is processed together with manure, digestion tract content, milk or colostrum**.

In Austria it is recommended to process kitchen waste with a high water content stemming from **centralised kitchens and restaurants** preferably in anaerobic digesters. Nevertheless, if this is of environmental advantage (i.e. reduced transport in rural areas) it is possible to treat catering waste from restaurants in composting plants. Additional treatment requirements for composting plants are required if catering waste from centralised kitchens are processed (***group B***).

The requirement of Paragraph 15 of Annex VI Regulation (EC) No 208/2006 to achieve an equivalent reduction of pathogens as if the treatment requirements of Annex VI are followed is considered to be met if the national rules are applied.

In Austria the general requirements for process monitoring and product requirements are laid down in the *Compost Ordinance* (FLG I no. 292/2001) and process requirements have been defined in this *"Guideline – State of the Art of Composting"* which has been made an obligatory requirement in the *Federal Waste Management Plan 2006.*

Basic process management requirements to effectively reduce potential pathogens

A number of different operational practices can be adopted to maximise pathogen destruction and minimise cross contamination between compost batches at a site. These are discussed below:

- Raw compost batches need to be mixed homogenously. It is important to take into account the different particle sizes of feedstocks, and these may need to be treated separately (e.g. shredded bush and tree cuttings). Preference should be given to using specific mixing devices (e.g. screw systems, windrow turners, drums, dung spreader) rather than using a simple front-end loader;
- The cross-section of open windrows should be limited, especially where finely structured materials (e.g. grass trimmings, kitchen waste, partly dewatered sewage sludge etc) are composted. Windrows greater than 2.0 to 2.5 m in height should be avoided for these materials, as the poor pore structure makes aeration by turning or forced aeration unsatisfactory and anaerobic zones can easily form;
  - A useful guideline to observe suggests that: the higher the compost heap the higher the proportion of bulking agents required and the more frequent turning needs to be (with or without forced aeration) in order to maintain adequate continuous gas exchange between the composting mass and the atmosphere. This must be adhered to by any composting facility through manual actions and technical capacity;
- It is important to avoid the formation of clumps within windrows or on machinery (especially when turning using front-end loaders), as these may form zones of partially- or non-sanitised material, which may cross-contaminate sanitised material. When using bucket loaders a rigorous cleaning programme needs to be implemented to remove material residues from the bucket and other parts of the loader or truck before materials are agitated, especially if they will not be subjected to further thermal sanitation;
- The addition of clayey soil or mature compost (up to ca. 10 to 15 % (m/m)) into the composting mix may help promote humification and stabilisation, thereby resulting in reduced growth potential for some pathogens. However, in doing so, operators need to ensure that the addition of soil does not increase the bulk density of the material and reduce the free pore space so that poor gas exchange takes place.

The following Table 16 provides several variations of time-temperature regimes and recording requirements implemented in national rules across Europe. These are described for both open and enclosed composting systems, with and without forced aeration. All these have been officially adopted for composting of Catering waste and former foodstuff in Austria.

Table 16: Time temperature regimes specified for the indirect control of sanitisation during composting

Minimum Temperature	Duration - Records
Open and enclosed Windrows (including halls) +/- forced aeration	
55 °C	Automatic, continuous recording with probe; minimum temperature to be met over a time span of 4 hours, each after 5 mechanical turnings; total recording period: 10 days
55 °C	Discontinuous recording at least once per working day*; minimum temperature to be met on all recording days, within a total recording period of 10 days; at least 3 mechanical turnings
60 °C	Discontinuous recording at least once per working day*; minimum temperature to be met on 3 x 3 recording days, within a total recording period of 14 days; at least 2 mechanical turnings
65 °C	Discontinuous recording at least once per working day*; minimum temperature to be met on 2 x 3 recording days, within a total recording period of 14 days; at least 1 mechanical turning
Enclosed and in-vessel systems with forced aeration (e.g. boxes, tunnels)	
55 °C	Automatic continuous recording with probe; minimum temperature to be met over a time span of 4 days within a total period of 10 days
65 °C	Automatic continuous recording with probe; minimum temperature to be met over a time span of 3 days within a total period of 10 days

* The automatic, continuous recording with probes is permitted

When considering sanitisation during composting is important to note the following:

- In cold climates, problems may occur through cooling of the windrow surface in open systems. One possible solution is to increase the windrow diameter and the proportion of bulking agents (to reduce the surface area to volume ratio). Generally windrows of 1.5 m in height are of a sufficient volume to induce and maintain the needed temperature. The aeration system in enclosed systems must be adjusted during the winter months. Priority has to be made to ensure accurate inspection and supervision of the decomposition process (temperature/ humidity), especially during the early sanitisation phase.
- A well designed maturation process is the key to safeguarding the biological stability of the final product. The re-growth potential of pathogenic bacteria which have either survived the sanitisation phase or have been introduced by re-contamination can be reduced effectively through effective stabilisation of the substrate. It is important to note that dry stabilisation of the substrate in enclosed reactors, does not achieve this, as un-decomposed feedstocks will still provide many micro-organisms with nutrients and food for re-growth if the material is re-wetted. Controlled composting needs to be performed at optimal temperatures and humidity including accurate mechanical turning.
- The composting facility needs to be designed in such a way that vermin cannot gain access.
- Re-contamination from non-sanitised feedstocks must be prevented through physical separation of the tipping, pre-treatment and main composting areas from all other facility sectors. When windrows are turned, material should always be transferred from the sides of the tipping area towards the maturation area.
- Non-sanitised process water and contaminated precipitation water from the active decomposition area may only be used for watering windrows which still will be exposed to temperatures above 55 degrees Celsius (i.e. material that has not been subjected to a complete sanitisation phase; and
- The storage and treatment of sanitised compost (whether fully mature or not) must be completely separate from the active decomposition area.

6.3.4 Record keeping as indirect approval of the hygienic efficacy of the process for Group A feedstocks

In order to provide evidence of the process management actions taken to effectively reduce pathogens, the following records must be taken

- Temperature measurements pursuant to Table 16
  - In the phase following the thermophilic stage (where the temperature of the composted material remains below 40 °C) temperature measurements need to be performed at least once per week
  - Measurement points must be placed in the pile centre at least 30 cm above the base of the pile and 30 cm below the surface of the compost heap
- **Control and determination of moisture content**
  - Adequate moisture content is essential during the thermal sanitisation and the mesophilic cooling phases, where the microbial degradation and stabilisation takes place. It is important to monitor the moisture content of the composting materials during these phases: at least once a week or at the time when discontinuous temperature measurements are taken.
  - A simple hand "squeeze" test or visual inspection is generally sufficient
  - Records may take the form of a simple rating system (too dry – just right – too wet)
  - In enclosed reactors the humidity can be recorded automatically with probes and data logger
- Times when mechanical agitation (turnings) take place
- Watering or irrigation of compost batches, which need to include:
  - Time of watering
  - Origin of irrigation water (e.g. fresh water, percolate from in-vessel reactors, process water collected from the active decomposition or tipping areas, or drainage water from roofs or maturation, final refinement or storage areas)
  - In the case of enclosed composting systems: batch wise records of added water quantities are required
- Aeration times / intervals in forced aeration systems
- Addition of feedstock materials during the composting process including the blending with other compost batches
- Coverage with geo-textiles or organic covers
- Screening

The process documentations should be attached to the sampling protocol and provide additional information to be submitted to the external control body (e.g. quality assurance organisation) or laboratory.

With the exception of temperature recordings (Table 16), the process management documentation described above need not be repeated for each individual batch if the material composition and processing is identical. In this case a general process description and generic documentation is acceptable, however, it must also be submitted to the laboratory and external quality assurance organisation.

6.3.4.1 Group (B):

This includes kitchen and food waste (including used cooking oil) collected from restaurants and centralised kitchens; former foodstuffs [Art. 6(1)(f) ABP-Reg] which has not been in contact with any animal by-product referred to in Articles 4 and 5 and points (a) to (e) and (g) to (k) of Article 6(1) of Regulation (EC) No 1774/2002 or with other raw material of animal origin – independent of the collection system employed.

In addition to the basic requirements for Group (A) the following conditions must also be adhered to:

- Mixing and treatment of delivered catering waste or former foodstuff immediately after tipping with suitable bulking agents and structural materials in order to initiate an effective composting or pre-fermentation process;
- Special care needs to be taken during pre-treatment and conditioning in managing feedstock ratios and properties (i.e. water content, C/N ratio, poor volume and gas exchange, odour management);

- In open windrow composting without waste air treatment: in addition to the basic principles of Group (A), the following also need to be carried out:
  - Cleaning of all traffic areas and facilities,
  - Preventing the transfer of non-sanitised material into the maturation and final product storage areas
  - Ensuring that the entire mass of the composting material is subjected to the sanitising temperatures described in Table 16
  - Covering the windrows with fresh or mature compost, shredded material or geo-textiles (compost fleece) throughout the thermal sanitisation period (generally 10 to 14 days)
- Implement a management plan to combat vermin including documentation of the measures taken
- Ensure complete spatial separation between areas where animals are kept from any facilities where ABPs are stored or processed, in order to avoid any transmission of animal pathogens. In accordance with local conditions, measures may be necessary to avoid access of wildlife and domestic animals onto the site.
- Equipment for cleaning /disinfection of containers or vehicles
- Determination of a cleaning procedure of the entire facility
- Installations and equipment must be kept in a good state
- Immediate processing of feedstocks upon reception
- Continuous process monitoring and documentation of the relevant process parameter
- Compost must be handled and stored in such way as to prevent recontamination
- Regular measurements of microbiological parameters in the end products (compost) according to the Austrian Compost Ordinance.

6.3.4.2 Cleaning and disinfection of transport and collection devices used for catering waste

The following provisions for the cleaning and disinfection of transport and collection devices apply for catering waste from restaurants and centralised kitchens and former foodstuffs only (*group B*) – irrespective of the collection system used. Collection containers must be cleaned after each use at least with hot water (e.g. with a steam jet). The clean containers need to be kept in dry and clean condition until their next use. At regular intervals – adjusted to reflect different collection frequencies, but at least once per month – the containers must be disinfected with a suitable disinfection agent.

The cleaning must be done in such a way that any contamination of the environment from either aerosols or waste water is avoided – i.e. of clean containers or of sanitised compost.

Therefore, a designated cleaning area needs to be established. It must be located at a sufficient distance away from composting activities, and be physically separated from areas where animals are kept, and feeding stuffs and bedding materials are stored.

The cleaning site needs to have adequate drainage, collection and disposal facilities for waste cleaning water, including used disinfectants and other cleaning agents. The responsible person must ensure that a cleaning plan, including the methods of cleaning and disinfection and its documentation, are in place.

6.3.4.3 Obligations for collecting catering waste and former foodstuffs

Independent of the collection system used the collection of catering waste from restaurants and centralised kitchens must be performed at least once a week. Pursuant to Article 10 of the Animal Material Act (FLG I no.141/2003) a written contract with an authorised company is mandatory.

Exempted from the obligation of a written contract are private households, if the ABPs are delivered directly to an approved collection point or the ABPs are collected by a municipal collection system (e.g. through a *biobin collection*) [Art. 10 Animal Material Act (FLG. I no.141/2003)].

6.3.4.4 Approval of collection enterprises and composting and biogas plants for the collection and treatment of catering waste and former foodstuffs.

Enterprises and individuals that collect or treat catering waste from restaurants and centralised kitchens as well as former foodstuffs must be approved according to Article 3 Animal Materials Act FLG no. 141/2003. Approved enterprises are listed in an electronic register of the Federal Ministry for Health and Women.

Exemptions from this obligation of approval and registration are granted for collection enterprises and treatment plants of catering waste, which originate in private households and are collected by means of a regular municipal collection system (*group A*).

6.3.4.5 Requirements for composting plants treating further category 3 materials [Article 6(1) (a) to (e) and (g) to (k) ABPR (EC) No 1774/2002],

Here the treatment and processing requirements set in the EU ABPR and its implementation rules apply.

6.4 Bioaerosols management

A bioaerosol is an aerosol (tiny particles suspended in the air) of micro-organisms and / or other biological particles. It may comprise one or more of the following: bacteria, endotoxins (comprising the outer cell wall of some bacteria, called lipopolysaccharide), enzymes and other proteins, fungi (cells and their spores), glucans, mycotoxins and viruses.

In this Guide we have not attempted to discuss the potential risks that individuals (employees at a composting site or neighbours) may be exposed to. Rather we have summarised experience in bioaerosol minimisation and worker protection gathered from over 20 years' experience in biowaste composting, covering the diverse range of technologies and operational practices carried out.

Please note:

> *The growth of a microbial community during the course of the decomposition of organic materials is inherent to the composting and microbiological decomposition processes. Consequently, the aim of any guidance is not to reduce the level off microbial abundance, but to decrease the evolution of aerosols as efficiently as possible and thus protect workers effectively.*

6.4.1 General protective measures for employees

Protective measures cover process, construction and transport technology, as well as direct protection measures for workers.

Ill health in any individual is determined by a multitude of factors. This makes it inherently difficult to provide generic statements about the effects of exposure to bioaerosols. Employees react differently, based on their biological susceptibility, fitness, health, age, gender specific differences, and social factors. In the case of exposure to hazardous substances, occupational medical screenings are an instrument to determine whether individual sensitivities may be causal to a specific health risk (LASI-LV 13, 1997).

The following text lists general protective measures for employees in waste and wastewater treatment operations (as set out in the trade-concept for organic materials AUVA; Reinthaler *et al.*, 2000):

- The storage and consumption of *drinks, food, medication, and stimulants (cigarettes)*, as well as the use of cosmetics, at the workplace is prohibited, unless it is in a designated 'clean area'.
- Prior to eating, drinking, taking medication, smoking and use the toilet, *hands must be washed* to prevent infection. Wash places must be available with skin cleansers, skincare, and skin protection products, as well as single use towels in dispensers.

- The employer must provide employees with free and appropriate *work and protective clothing,* as well as *personal safety equipment* (PSE). Employees are obligated to wear these accordingly. Employers have to enforce their use and may not tolerate non-use. Employers are responsible for the cleansing, servicing and maintenance of work, and protective clothing, as well as the PSE. Work and protective clothing must be taken off before entering leisure areas and canteens, in case there is any danger of contamination from organic working materials. Work and personal clothing must be kept separately from non-work clothes and personal items.
- *Injuries* to the hands and exposed skin must be treated appropriately. Any injury, especially with hypodermic needles must be reported to superiors and the employee must be taken to a doctor or to hospital. All injuries must to be documented in writing.
- Employees must be informed annually, comprehensibly and verifiably, about possible risks to their their health, hygiene and safety measures to be taken by both employees and employers, measures that need to be taken to avoid exposure to danger, and the use and wearing of personal protective clothing, including PSE.
- The employer must ensure that measures are in place to reduce worker exposure to organic substances, by establishing a hygiene plan and a skin-protection plan.
- With activities that expose employees to hazardous substances that may result in *occupational diseases*, all employees need to undertake an medical examination prior to starting work (aptitude examination) and periodical follow-up examinations are carried out for the duration of the occupation (follow-up examinations)
- The cost of undertaking aptitude- and follow-up examinations must be absorbed by the employer according to the Austrian Workers Protection Act.
- The health and safety of *external contract workers* and of facility-own workers located on external facilities, must be coordinated by the employer.

6.4.2 Measures to protect workers at composting facilities

A distinction can be made between **operational, technical** and **person** related measures, and these are described below.

Operational measures

- With manual work during the building, turning and discharge of windrows, respiratory protection should be used (employing P3 filters). Furthermore, compost turners should be equipped with dust covers and moisture injection equipment, in order to reduce the release of dust. Temporal coordination with prevalent winds and attention to land-use in the vicinity can help reduce exposure to neighbours;
- Immediate processing of organic waste from households, catering establishments etc should be carried out in order to prevent attracting rodents, birds and insects;
- Regular cleaning and decontamination of the areas of the facility that are exposed to fresh feedstocks (i.e. that have not been sanitised) should be carried out, so as to reduce unwanted microbial growth;
- The operational processes should be designed to avoid employees working permanently in the intensive composting areas;
- The cleaning and servicing of equipment used in the intensive composting area should be undertaken in non-contaminated areas.
- During the main composting process, the intensive decomposition area of an enclosed facility should only be entered for process control, cleaning and servicing purposes. Workers should wear respiratory protective equipment (fitted with a P3 filter) or an breathing mask;
- The ventilation system should be cleaned and serviced regularly according to the manufacturer's instructions, and verifiably checked for operation at least once a year. Doors and windows should be kept closed during operation. The cleanliness of the control cabin should be maintained.
- With cleansing and servicing work, which generate considerable amounts of microbial aerosols (e.g. biofilter exchange), respiratory protection (fitted with P3 filters) should always be worn.

- With the exception of the composting area, the driveways and manipulation areas should be kept dust-free and should be cleaned regularly, preferably with a sweeper or industrial vacuum cleaner. With the use of high pressure cleaner respiratory protection (P3 filters) should be worn. Cleansing with a broom should be avoided.
- The driveways should be moistened and cleansed regularly;
- The surfaces of stored mature compost should be moistened and covered (e.g. with a compost fleece); and
- Avoid untreated process water from coming into contact with sanitised composting materials to prevent contamination.

Technical Measures

Technical measures for worker protection are primarily measures to improve air quality. This influences stationary workplaces and mobile workplaces in vehicles, where outdoor air should be supplied. These are discussed below:

- The manipulation of feedstocks (collection/acceptance, processing, and contaminant separation) should, wherever practicable, take place using technical equipment rather than by workers manually;
- Implement a negative pressure system in all indoor parts of a facility, so that dust, bioaerosols, odours, and other gaseous emissions can be removed;
- Vehicles and control areas that are used to handle and process kitchen waste and compost, should be supplied with an enclosed, air-conditioned cabin with an air supply independent from the outer air (e.g. compressed air) or a suitable filter system (filter class S and activated carbon canister). Such cabins need to be maintained in a clean condition, and air-conditioning and filter units need to be serviced appropriately. Employees must be instructed not to open windows during operation.
- All employees need to be instructed that they must comply with the worker-protection-measures installed;
- Areas that are exposed to feedstocks must be designed for easy cleaning and incorporate anti-slip walkways;
- Conveyor belts must be designed to avoid contamination between feedstocks. Areas where materials may fall from conveyors should be avoided or enclosed. Stationary indoor conveyors should be enclosed to minimise dust and aerosol emissions and discharge points should be equipped with additional vacuum systems;
- All equipment, instruments and installations must comply with all relevant regulations (e.g. CE certification); and
- Air-conditioning/ventilation systems should be installed in the areas designated for delivery, sorting cabins, screening or blending compost, where, on average, a person works for more than two hours a day.

Person-Related Measures

- All businesses must comply with all relevant worker-protection regulations.
- Occupational medical as well as safety-related care must be in place.
- All workers must be vaccinated against diphtheria, tetanus and poliomyelitis; where necessary booster vaccines must be offered. Immunization against hepatitis A and B is strongly advised. In the case of workers who manually handle garden and park waste, an additional FSME (meningitis) vaccine is advisable. Employers must ensure that all employees, to whom the vaccination is made available, are informed about the advantages and risks of vaccination and non-vaccination.
- The wearing of protective personal equipment (protective clothing, gloves, respiratory protection: P3 filter masks) should be in accordance with trade regulations (PSA safety ordinance). During sorting of feedstock, workers should always wear gloves to protect the hands against cuts and punctures. Protective footwear (boots incorporating a steel toe cap and insole) should always be worn within the whole working area;
- Smoking, eating and the consumption of food is only allowed in specially designated areas (e.g. lounge);

- All workers should be required to change of their work clothing before leaving the facility;
- Sanitary facilities should be available for personal hygiene purposes (e.g. toilets, wash basins and showers). They should be equipped with a separate clean an dirty area.
- The employer shall ensure that all work clothes are cleaned regularly;
- Site rules should prohibit any unprotected persons from staying in an enclosed composting area. This also includes areas with forced ventilation, during compost turning including immediately afterwards. Additionally the general worker protection regulations regarding the working in enclosed shafts and containers must also be obeyed; and
- Regular information and training of employees regarding workplace safety and health must be carried out.

Reducing the formation and dispersal of bioaerosols

Assessing the risks to human health from exposure to bioaerosols is inherently problematic, due to the lack of dose-response relationships (Böhm *et al*., 1998). As such, "acceptable" maximum exposure levels or occupational exposure standards cannot be established. Therefore composting facility operators need to establish measures (both technical and operational) to minimise bioaerosol and dust formation. These are discussed below:

- An appropriate distance between a new plant and residential areas (sensitive receptors) should be established. Investigations have shown that in distances of 150 to 200 meters – depending on topography and dominant wind direction – natural background concentrations are attained (Amlinger *et al*. 2005b);
- In in-vessel systems (box/tunnel) extremely high bio-aerosol concentrations occur – biofilters reduce these levels but discharge them continuously to the atmosphere. Moistening the exhaust gas with spray or sprinkler systems can reduce the aerosol load significantly;
- During the turning of windrows in open systems, temporary higher emissions occur than are discharged via biofilters. Averaged over time (taking into account turning and rest periods) the emissions from open windrow systems do not differ from in-vessel systems;
- All materials handling areas and traffic routes need to be kept clean and moist (although water should not be allowed to build up and stagnate, as this will create an odour source);
- Sub-optimal decomposition in enclosed systems (heterogeneous humidity, degradation and temperature, dry stabilisation, or pseudo-stabilisation by drying the material by means of intensive aeration or a retention time of less than 14 to 21 days without any turning of the material) may lead to increased bio-aerosols emissions (e.g. *Aspergillus fumigatus*, mould spores) upon extraction of the pre-rotted material to an open maturation area.
- Turning and materials handling should only be carried out on moist windrows in open windrow systems;
- In order to reduce the formation of bioaerosols, a number of essential measures can be implemented:
    - Moistening of the windrows before and during every turning. Fog sprays can be effective during manipulation, and some windrow turners allow spray systems to be incorporated.
    - Maintaining appropriate levels of moisture in all composting materials and biofilters:
- In case of critical locations (distance to sensitive receptor is less than 200 m):
    - Materials handling needs to take into account daily climatic conditions;
    - Turning machines should be equipped with rubber aprons to reduce the emission of dusts;
    - Covering small triangle windrows (< 1.5 m height) with fleece in order to avoid desiccation; this reduces dusts and bioaerosols when the material is moved.
- All on-site regulations concerning the health and safety of employees need to be adhered to.

6.5 Management of other gaseous emissions – greenhouse gases, ammonia and VOCs

6.5.1 General remarks and emission factors

Studies conducted on the treatment of organic wastes have shown that microbial decomposition can cause the formation of greenhouse gasses (GHG) (i.e. those that have the potential to contribute towards climate change) e.g. nitrous oxide (N_2O), methane (CH_4) and nitrogen monoxide (NO). Considering the total balance of gaseous emissions, other relevant gasses include carbon dioxide (CO_2), ammonia (NH_3) and non-methane volatile organic compounds (NMVOC). We have summarised below potential air pollutants that may arise during composting and low emission operational practices that may be used to mitigate releases.

During biological treatment the following framework conditions may influence the order of GHG emissions and ammonia:

- Bulking agents providing free pore space and a homogenous material blending;
- C/N-ratio;
- Turning frequency as well as aeration procedure;
- Water management, humidity control and distribution; and
- Temperature control and distribution within the composting mass.

The formation of GHGs as well as climate neutral CO_2 (i.e. CO_2 derived from biogenic plant material) depends very much on the C and N concentration, the substrate's biodegradability as well as the process conditions. Experimental and full scale investigations (Amlinger *et al.*, 2008; Cuhls *et al.*, 2008) showed little reduction for methane (max. 15 %) and no reduction of nitrous oxide emissions in closed reactor systems with waste air treated through a biofilter. Reactor and housed systems therefore do not appear to show any significant advantage with respect to GHG mitigation.

Also a thermal oxidation of the waste air does not reduce the nitrous oxide concentration. In contrast, additional laughing gas is formed by the oxidation of ammonia.

Studies conducted by Gronauer *et al.*, 1997, concluded that: *"open windrow composting does not rank lower than housed composting systems with forced aeration"*.

The most important factors in reducing GHGs emissions are the feedstock mixture and appropriate process management, including an even and constant oxygen supply and humidity throughout decomposition and maturation.

The quantity of GHGs emitted varies significantly; the following have been provided for guidance:

- ***CO_2***: 120 to 250 kg t^{-1} of feedstock composted. It is not considered as GHG since it is produced from natural organic residues equivalent to the natural short term C-cycle;
- ***CH_4***: 100 (good performance) to 250/400 (realistic) to > 800 to 2.000 (low performance) g t^{-1} of feedstock. The extraction of methane in the biofilter is, in average only 5 % to 15 %. The potential contribution of methane emissions by composting (if the entire organic waste material is composted) to the Austrian national methane emission is only 0.1 %.
- ***N_2O***: this very much depends on the C/N ratio, as a low C/N ratio (i.e. a mix with a surplus of N), will emit more than a high C/N mix where nitrogen is limiting. The formation tends to occur during mesophilic composting and the maturation stages at temperatures below 40 °C. The range is between 20 and 180 g t^{-1}, however, under poorly managed conditions, formation may be greater. Additional N_2O may be formed during transformation of ammonia in the biofilter, where it cannot be decomposed further. In Austria, the proportion of N_2O emissions from composting operations relative to the national inventory can be estimated to be between < 1 to 3 %.
- ***NH_3***: Emissions are typically in the range of between 500 and 600 g t^{-1}. In Austria, the proportion of NH_3 emissions from composting relative to the national inventory can be estimated to be between < 0.5 to 1 %.

The percent contributions of composting to total GHG production are very low (0.01% to a worst-case estimate of 0.06% as calculated for Austria and Germany; Amlinger *et al.,* 2008).

6.5.2 Methane (CH_4), (nitrous oxide) (N_2O) and ammonia (NH_3): process optimisation techniques to reduce emissions

Basic prerequisites regarding input materials

- **C/N-Ratio**: Within a narrow C/N-ratio, the NH_3 emissions increase as the composting temperature and ventilation rates increase. A C/N-ratio of > 25 minimises NH_3 and N_2O emissions, however, as the ratio increases (to above 35) the rate of composting will slow down, as N will be rate-limiting;
- **N-rich materials**, (sewage sludge, fermentation residues, specific industrial wastes, poultry manure, household organic wastes [especially when kitchen waste and grass clippings are > 30 %]) must be blended homogenously with a sufficient amount of carbon-rich materials, to balance the C/N ratio;
- **Water content:** Ideally the moisture content should not be above 65-70% (m/m) at the start of the composting process, and should be maintained to between 50 to 60% (m/m) during the process.
- **Bulking/structural materials** (These are required to maintain an adequate pore structure to allow air circulation)**:** The ratio of structure-forming materials (shredded bush and tree cuttings, screen overflow, etc.) should be approximately 40 to 60 % (v/v).
- **Mature compost** – In order to facilitate the efficient formation of humic substances (humification) and the incorporation of volatile carbon- and nitrogen compounds into more complex compounds: the **addition of** approximately 10 to 15% (v/v) **mature compost** is beneficial.

Specific measures to optimise the composting process and reduce the formation of GHGs are summarised in the tables below.

Table A– 1: Specific Measures to Optimise Composting in Open Windrows with Passive Aeration

Measure	CH_4	NH_3 *	N_2O
Increase fraction of structural materials, and / or more frequent turning	**positive**, better O_2-supply suppresses CH_4-formation	**Slight increase in emissions** on account of increased aeration, causes: - increase of pH-value - more evaporation	**potentially negative**, increased O_2-supply in combination with falling temperatures supports N_2O-formation as an intermediate product of nitrification and denitrification
Moisture optimisation through controlled water injection, use of protective covers for protection against precipitation.	**positive**, prevention of wetting and the formation of anaerobic zones	Wetting causes **reductive conditions** (de-nitrification) with accumulation of NH_4^+ Drying causes an increase in emissions of NH_3	Wetting may also cause O_2-deficiency during the latter stages of the composting process, resulting in **de-nitrification** of NO_2^- and NO_3^- resulting in the formation of N_2O

* In early stages emitted NH_3 is not available for possible formation of N_2O at a later stage

Table A– 2: Specific Measures to Optimise Composting in Enclosed Systems with Forced Aeration and Biofilter (box, tunnel, housed windrow)

Measure	CH_4	NH_3 *	N_2O
Increase turning frequency and / or increased aera-	**positive**, better O_2-supply suppresses CH_4-formation	**Slight increase in emissions** possible on account of increased aeration, causes:	**negative**, increased O_2-supply in combination with falling

tion rate		- increase of pH-value - more evaporation	temperatures supports N_2O-formation as an intermediate product of nitrification and de-nitrification
Temperature control 45 – 65 °C after sanitisation	Maximum release during the thermophilic phase on account of limiting oxygen-supply during the intensive conversion period Minimum formation below 45 / 50 °C	Maximum release during the thermophilic phase	Maximum release at ca. 30 °C Minimum formation above 40 / 45 °C
Maintaining moisture at 50 – 60% through controlled water injection	**positive**, prevention of wetting and the formation of anaerobic zones	Wetting causes **reductive conditions** (denitrification) with accumulation of NH_4^+ Drying causes an increased stripping of NH_3 through volatilisation	Wetting may also cause lack of O_2 in a later stages of the composting process, resulting in **de-nitrification** of NO_2^- and NO_3^- by formation of N_2O
Biofilter	**neutral**, minimal reduction	**positive**, partial, up to complete reduction	**negative**, considerable formation - from NH_3-oxidation
Biofilter with preceding acid washing	**neutral**, minimal reduction	**positive**, segregation with acid washing	**neutral** to slightly negative, minor formation from NH_3^- slippage

* In early stages emitted NH_3 is not available for possible formation of N_2O at a later stage

<u>Specific measures to reduce the formation of N_2O in biofilters supplied with NH_3-loads in the waste gas</u>

There are a number of different operational procedures that can be adopted to reduce the formation of N_2O in biofilters. Examples are given below for an enclosed facility with a biofilter:

1) The volatilisation of Ammonia should be supported during the early, high temperature composting stages, especially at high air flow rates. This increasing the C/N-ratio and my help to minimise the N_2O-production at a later stage;
2) Maintaining a process-temperature of between >40 °C to <55 – 60 °C, in order to suppress nitrification;
3) Where there is a high concentration of ammonia in the waste gas, this can be removed by acid washing before the air is discharged to a biofilter;
4) Further measures can also be implemented after the initial high temperature composting phase:
    i) Reduction of the turning intervals during the maturation phase to reduce loss of heat;
    ii) Processing mature compost as soon as possible, to ensure application and incorporation into the soil.

Emission of GHGs – recommendations to operate a low emission system

- There is a basic tendency that a low C/N-ratio, meaning there is an excess of nitrogen in the initial blend, increases the potential formation and release of nitrous oxide (N_2O). Therefore, it is important to ensure a sufficiently high C/N ratio in the original compost blend, which is utilizable during the process (e.g. through the addition of finely ground woody material).
- On the other hand, it has been found that if the fraction of woody materials in the yard waste is too high, the N_2O-emissions may increase, because the incorporation of mineral nitrogen into biomass is not possible. Therefore a carefully adjusted C/N-ratio between (20) 25 and 35 (40) is an important measure to minimise N_2O.
- Multiple turnings of the windrows every week whilst also ensuring an appropriate mix of structural materials (e.g. 40-60% ground woody waste added to kitchen waste) reduces the formation of CH_4. However, with N_2O, varying conclusions have been drawn, with a tendency toward lower emission rates during lower treatment intensity (turning) processes.
- As the process of CH_4 and N_2O-release are inversely related the operation should be geared towards a reduction of CH_4-formation during the early thermophilic composting phases, whereas during the advanced process stages, one should aim to minimise N_2O formation. This means a higher turning frequency during the thermophilic phase (> 45 °C) and a reduced mechanical treatment during the following maturation phase (< 40 – 45 °C).
- Optimisation will always be a compromise where a combination of optimised structural conditions, C/N-ratio and turning frequency according to windrow size should be aimed for, in both open and enclosed systems alike.
- During the thermophilic phase, large windrows, greater than 2 to 2.50 m in height, should be turned at a minimum of every three days in order to reduce methane emissions.
- The referenced study provided no evidence to justify enclosing all composting facilities on the basis of GHG releases, however, in the case of unfavourable local conditions the advantages of odour, dust and NMVOC reduction was highlighted.
- In addition to the effects of ammonia as an air pollutant, high concentrations of ammonia in the raw gas may impair or inhibit functioning of the biofilter, resulting in increased ammonia emissions. Therefore, in case of repeated detection of odour values > 500 OU/m³ in the treated gas, the cause needs to be investigated. If, following a change of input-mix, aeration, moisture and temperature regime, the problem persists a scrubber system (possibly with acid reagents to increase solubility of ammonia) for the segregation of ammonia from the raw gas must be installed.

6.5.3 Volatile organic carbon (VOC) emissions – process optimisation techniques to reduce emissions

The amount of C_{tot} (total quantity of volatile organic compounds) emissions measured using a flame ionisation detector (FID-measurement[13]) is dominated by methane. For a comparison with the parameter Non Methane Volatile Organic Carbon (NMVOC) the FID-result needs to be subtracted from the CH_4-C.

Process control measures (temperature, water-content, aeration, oxygen supply) may influence the amount of VOC emissions considerably. These are discussed below:

- The available data show *C-loads* without methane between 290 and ca. 1.000 g C t^{-1} of feedstock composted in the emitted gas;
- Emission loads for VOCs from enclosed composting facilities with biofilters amount to between 50 – 100 g C t^{-1} of feedstock input (indicating a reduction factor by biofilters for VOC of ca. 80 - 90%), which do not include toxicologically relevant substances;
- The release of available VOCs takes place within the first few days of composting, during the auto heating process. This also applies to the formation and release of natural metabolites by the composting micro-organisms (microbial VOCs);

[13] FID ... Flame ionisation detector

- The majority of VOC-emissions are produced during the composting process. The indicator-components of VOCs are, for example, ethanol, acetaldehyde, 2-butanone, acetone, terpene and other short-chain hydrocarbons. To a great extent they are identical substances to those emitted by plants. For example the biogenic VOC-emission from coniferous and foliage trees is estimated to be between 20 and 100 kg ha^{-1} a^{-1};
- *Frequent aeration and high temperatures* tend to increase VOC-emissions;
- Within the scale of the evaluation of the refernce study for this guideline (Amlinger *et al.*, 2005b) no differences were detected between passive and forced aeration systems. The use of forced aeration can increase the volatilisation of many compounds, therefore from this point of view no advantage can be derived from forced aeration systems;
- Waste air cleaned through a biofilter reduces the NMVOC (C_{tot} without methane) by up to a maximum of 80% to 90%. The volume capacity of the biofilters should not exceed 100 m³ of waste air m^{-3} biofilter substrate h^{-1};
- Impairment in biofilter performance can be caused by high NH_3-loads in the waste gas (see requirements, in the previous section 6.5.2);
- In both cases, the VOCs emitted from composting and MBT systems contain a comparable spectrum of substances, which are ethanol, 2-propanol, ethylacetate, acetic acid, 2-butanone, acetone, limonene, pinene and dimethyldisulfide;
- Unlike MBT processes, the composting of biowaste emits no chlorinated hydrocarbon or fluorinated hydrocarbon (LHKW, FCKW) or other dangerous anthropogenic substances;
- During composting only minor amounts (similar to background concentrations) of n-alkanes and aromatic hydrocarbons (BTEX) are released. Benzene, alkylaromatics and alkanes have been detected but are attributed to vehicle exhaust emissions (loaders, delivery vehicles etc.);
- Conclusions regarding worker protection:
  - The time employees spend working in dirty-gas contaminated areas must be kept to a minimum;
  - During necessary service work doors must be opened beforehand to enable exchange of process air with fresh air and to permit air circulation (possible odour emissions, however, must also be considered);
  - Process air should be removed from enclosed parts of the facility using negative pressure forced aeration;
  - Respiratory protective equipment incorporating an activated carbon filter should be worn.
- The potential total contribution of composting in Austria (490 – 670 t a^{-1} NMVOC emission) towards the national anthropogenic NMVOC -emissions in Austria (232,000 t a^{-1}) is minor, amounting to less than 0.3%[14]. The essential technical and operational measures that can be employed to reduce odour-forming VOCs at open and enclosed composting systems are found in Chapter 6.1.

6.6 Noise Emissions

6.6.1 General requirements

Noise can be defined as unwanted sound. Generally, mobile and/or stationary technical equipment is used on composting facilities (e.g. wheel loader, grinders, screens, turners, ventilators, conveyor belts, blenders), which are a source of noise emission. Furthermore traffic movements to, from and within the site will add to the noise load.

For this reason consideration must be given to noise protection for workers and residents, during both the construction and operation of facilities.

Information regarding the rating of noise emissions can be found in the Austrian regulation[15] (ÖAL) according to trade- and worker protection regulations.

[14] Data for 2001

[15] Austrian regulations (ÖAL-regulations) of the Austrian ‚workgroup' for noise abatement; http://www.oal.at/

Requirements regarding worker-related noise protection:

- At the workplace the noise load may not exceed the noise-equivalent A-rated indicator above 85 dB for more than 8 hours per day given a 40 hour working week.
- With noise loads exceeding this limit protective measures must be taken, as well as appropriate, personal protective equipment (e.g. ear protection) must be provided by the employer. Protective gear must be worn correctly by the employees and inspected through adequate supervision. Failure to wear ear protection must not be tolerated.

Requirements regarding resident-related noise protection:

- The assessment must take the following into consideration: the noise emanating from the facility and the ambient noise levels (basic noise, energy equivalent noise, and noise intensity levels), as well as the local classification and the actual use in relation to the time of the day.
- Standard planning values for authorised noise emission limits are specified in the Austrian norm ÖNORM S 5021-1.

  In principle the normal working hours, Monday to Friday 6 – 22 hours and Saturdays from 8 – 17 hours, must be adhered to. According to local circumstances and proximity to residential areas, the hours of operation may need to be limited to less than this.

7 Quality management at composting plants - a step-by–step guide

Three levels have to be distinguished when describing composting systems:

1.) Single operational sections and functional facility compartments set within the framework of the entire compost production process including environmental management;

2.) The manifold composting technologies which mainly address intensive composting systems and the maturation stage; and

3.) Technical facilities, including the devices, machines and equipment which serve the different process functions during the course of the production process (e.g. shredder machines, mixing devices turners, screens, magnetic separator, wind separator etc.).

The production process can be divided into six functional compartments:

- 7.1 Tipping area with receipt control
- 7.2 Pre-Treatment
- 7.3 Active decomposition phase
- 7.4 Maturation
- 7.5 Final processing
- 7.6 Compost storage

These are shown schematically in Figure 12.

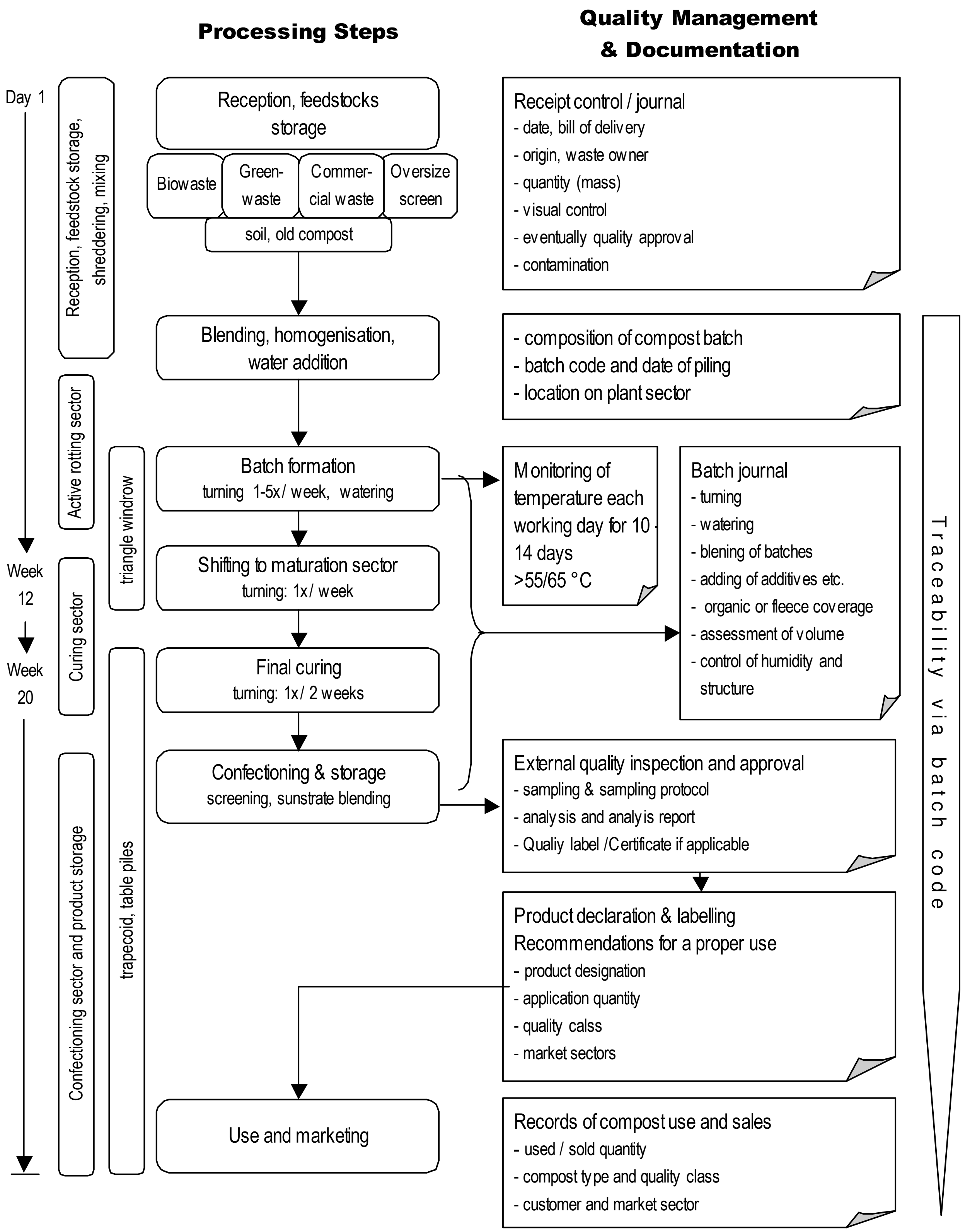


Fig. 12: Example of a process flowchart and quality management measures at a biowaste open windrow composting facility

7.1 *Tipping area with receipt control*

The handover, receipt control, tipping and short term intermediate storage of the composting feedstocks is the first activity under the responsibility of the compost producer.

Special attention needs to be directed towards the quality of the delivered feedstocks during acceptance. Feedstocks need to be identified unambiguously in order to check if they comply with the list of admissible feedstocks (wastes) according to the facility's consent. This includes the traceability of quality as well as origin and the technological processes the materials stem from.

7.1.1 Main functions

Activities carried out in the tipping area include:

- Handover of waste materials and other feedstocks from the transport vehicle;
- Intermediate storage;
- Receipt control: identification of waste type according to the list of allowed feedstocks pursuant to the facility consent;
- Identification and, if necessary separation and rejection of inappropriate batches and contaminated deliveries, especially if no further sorting for contaminants will occur;
- Handover of additives and auxiliary agents (such as stone dust, soil, wood ash);
- Quantity registration (mass in tonnes).

7.1.2 Basic technical and construction systems

Takeover / tipping and intermediate storage of raw feedstocks need to be carried out:

- On a physically separated area from the rest of the composting site, which has an impermeable base (unless woody materials are the sole feedstocks). Ideally this area should be covered with a roof;
- In a bunker with side walls; or
- In a recessed bunker (only advisable when the delivered materials are processed on a day by day basis). Constructional options are:
  - Open, with or without roof
  - Enclosure with an air extraction system

7.1.3 Technical design and equipment used at the tipping and intermediate storage areas

- Protection of the composting plant against unauthorised access. At small scale facilities a sign must be placed on the perimeter, indicating opening times and *"No entry for unauthorised persons"* as a minimum;
- If the composting plant is not completely fenced in and not occupied continuously a gateway must be installed that is locked during non-attended periods. A sign must be placed, giving opening times and indicating *"Deliveries only within opening times"*
- A weighbridge must be installed at facilities accepting > 6.000 t input/year except for composting plants where green waste or bark is the only material treated;
- Pavement and waste water collection:

- This is necessary at the reception site for source separated household waste, catering waste, wet waste from the food processing industry, fresh grass trimmings, other non-woody materials with a high moisture content, such as sewage sludge or other sludge like materials
- The waste water (leachate, precipitation, cleaning water) must be drained off into a water tight tank or retention basin.
- A paved area is not obligatory for woody waste, straw and shredded bulking agent or bark.

- Roofing or enclosure of the tipping area is mandatory if each of the following conditions apply all at once:
  - yearly rainfall >1,400mm,
  - waste delivery throughout the year with an annual throughput of > 3.000 t,
  - More than 30 % of the feedstocks are made up of nitrogen rich materials with high moisture content (e.g. source separated household waste, fresh grass trimmings, moist wastes from the food processing industry, sludge)
  - In the case of enclosed reception areas, a negative pressure air extraction system coupled to a waste air treatment system should be used.
  - Roofing is not required at a separate tipping and intermediate storage area for woody material and stored bulking agents.
- The tipping and intermediate storage areas need to be designed for complete emptying and cleaning;
- There needs to be sufficient tipping capacity (including a buffer in the case of an operational breakdown);
- Separated areas should be maintained for woody green waste and for biowaste and other non woody materials with a higher water and nitrogen content. This is necessary in order to provide separate pre-treatment and allow for specific blending of the initial compost batches;
- Separate tipping and intermediate storage areas for urban and industrial sludges;
- In the case of intermediate storage of source separated urban household waste, physical protection against wind drifting of light fractions (contaminants such as plastics);
- Containers for the intermediate storage of sorted contaminants or batch failures awaiting disposal or further treatment. Those containers must be designated appropriately;
- If (pre-)treatment (e.g. homogenisation, blending of feedstocks) is not carried out on every working day, or at least within 24 h after reception, enclosure of the intermediate storage including waste air treatment, is required when the following conditions are met:
  - at a yearly throughput of > 3.000 t source separated urban household waste (except woody garden waste) catering waste, residues from food industries, fresh grass trimmings and other non woody materials with a high moisture content
- The storage ground must be paved and the surface must be watertight. *Below ground (recessed) bunkers* are not deemed suitable for the storage of biowastes. The surface needs to have a slope of around 2-5 % to ensure effective drainage of leachate, cleaning and rain fall water; and
- The individual storage areas must be clearly designated.

7.1.4 Basic requirements for operation and documentation of incoming wastes

- An authorised person needs to be on site to receive the waste materials
  - The presence of an authorised person on the reception of waste materials during the opening hours of the composting plant is in principle mandatory in order to guarantee correct receipt control.
  - An exception may be granted for the delivery of organic household and green waste which is collected on behalf of the municipality. In that case
    - ⇒ The material must be tipped and stored on a separately designated location ,
    - ⇒ The material must be treated by the compost producer within 24 h after delivery.
    - ⇒ The delivery time must be pre-determined in the contract

⇒ The contractor (municipality) has to provide the designation, the waste type, quantity and origin of waste using an electronic system (chip card) or by another suitable means.

- The separate storage of different waste types is necessary to create distinct products (e.g. green waste compost, biowaste compost, bark compost, sludge compost);
- A delivery is only defined as having taken place in a legal sense, after formal receipt control and approval of compliance by an authorised person. No tipping of materials can be accepted at times other than the official opening hours without the agreement of the compost producer (otherwise such a delivery would constitute a *consent less deposit*);
- The takeover of feedstocks has to be recorded including:
  - Type/designation, quantity and origin of feedstock/waste
  - Allocation to a compost batch (unequivocal batch number, waste type, quantity) or intermediate storage
  - Rejected batches
- It should be obligatory to immediately (pre-)treat or place in an intermediate storage area all source separated urban household waste (except woody garden waste), catering waste, residues from food industries, fresh grass trimmings and other non woody materials with a high moisture content each working day, or at least within 24 hours. All measures must be documented in an operating journal.

  Pre-treatment measures include:
  - Blending of wet with dry materials and bulking agents
  - Addition of odour and water binding additives
  - Covering of small piles (< 1.5 m in height) of feedstocks with geo-textiles if heavy rainfall can be expected
  - Adjustment of the correct C/N ratio and moisture,
  - In the case of stabilised urban sewage sludge intermediate storage is possible in order to achieve optimum material management and to bridge periods until the compost batch can be mixed with appropriate amendments before composting. Input/output balance of the sludge stock has to be recorded in an operational journal.
- Periodical cleaning
- Removal of contaminants and other extraneous constituents. Plastic bags containing organic materials must be teared open and the contents removed.
- The rise of woody green waste may show a considerable seasonal variation. Intermediate storage areas therefore need to be dimensioned to accommodate these seasonal fluctuations.

7.2 Pre-Treatment

7.2.1 Main functions of pre-treatment

The pre-treatment of composting feedstocks aims to optimise the compost batch for the composting process. The objectives are to:

1.) Ensure the continuous decomposition at low material loss rates (i.e. to conserve organic carbon and nitrogen) (→ ratio of carbon and nitrogen sources which are available for the microbial community);

2.) Maintain gas exchange and heat transmission within the composting mass by means of an adequate ratio of structural material (→ free pore space);

3.) Have a low level (preferably none) of contaminants, a balanced nutrient content with respect to the envisaged compost use and the formation of stable humus compounds (clay-humus complex).

Hence, the main *functions* of the pre-treatment process are to:

- Remove contaminants
- Shred wood, tree and bush cuttings with tearing and crushing devices
- Mix and homogenise the feedstocks
- Adjust the composting parameters:
  - moisture,
  - C/N-ratio,
  - air filled pore volume (structure),
  - mixing of additives and auxiliary agents in order to optimise composting conditions and enhance final product quality.

7.2.2 Sorting and separation of contaminants

Separation of contaminants and extraneous constituents is often a requirement when processing source separated organic household waste. It is an important step, forming part of the of the quality management system, in order to guarantee marketable compost products of high quality.

7.2.2.1 Techniques used to remove contaminants during pre-treatment

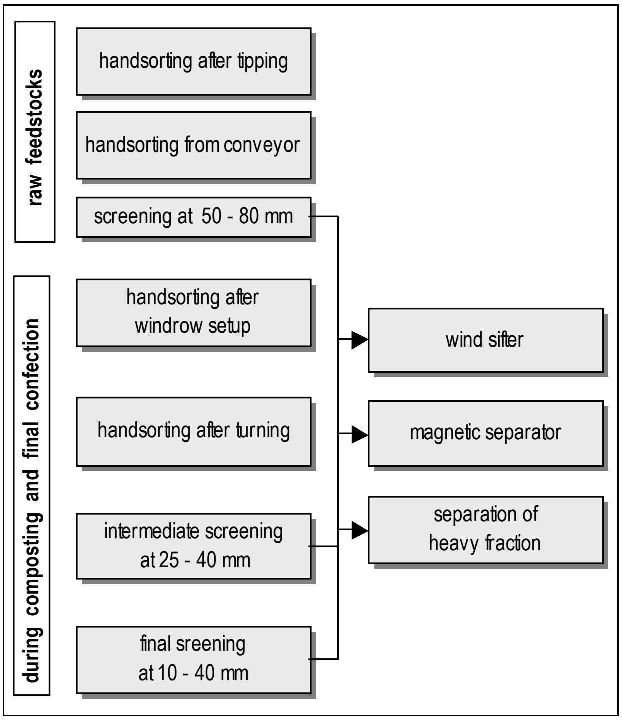


Fig. 13: Systems of impurity separation

The main parameters which determine the separation technologies are the density of the contaminants, their size and form.

The following methods are frequently used in the compost industry:

- Manual selection by handpicking or by using a pitchfork immediately after receipt of bio-waste,
- Selection by hand from a sorting conveyer that is enclosed and equipped with air conditioning,
- Screening of the bulky fraction using a mesh size of between 50 and 80 mm,
- Magnetic separation of ferric metals,
- Density separator for non-ferrous metals,
- Wind separator.

Hand sorting

- **Protective clothing**
    - Workers should wear filter masks (fitted with a P3 filter) in the case of dust formation and in (partly) enclosed facilities.
    - Protective working gloves should be worn to protect against stab/cutting injuries caused by sharp objects

Separation of impurities in a sorting cabin (sorting conveyer)

The manual separation of impurities in enclosed cabins using sorting conveyers are mainly installed in large-scale composting plants (> 10.000 – 15.000 t yearly throughput). The most critical issue of sorting plants is the safeguarding of the workers' health.

- **Function**

The segregation of impurities or extraneous materials that can be differentiated by colour and shape from organic compostable materials.

- **Technical and constructional design**

Permanent working places for manual sorting should only be placed in sorting cabins with air conditioning and effective air change systems. Hand sorting of green waste can be carried out outdoors. However in the case of occasional working places dust masks need to be worn.

Doors of sorting cabins need to close automatically. The air above the conveyer should be sucked off along the entire sorting line. The capacity of the aeration device should guarantee that the air inside the sorting cabin does not lead to any ill health of the workers. The ventilation facility has to be cleaned and maintained according to the producer's manual, at least once a year.

Any other automatic sorting or screening processes need to be installed outside of the sorting cabin. Some minimum requirements are:

- maximum working width: 0.6 m
- maximum conveyer width 1 m
- preferably two opposite working places
- conveyer speed
    - one working place: 0.1 – 0.2 m/sec (ideal: 4 - 10 m/min) independent of the particle size, throughput and density
    - two working places: in practice frequently reported: 0.5-0.8 m/sec,
- only one layer of material
- illumination: minimum 500 Lux

- **Bioaerosol emissions**

Pre-treatment and sorting exposes workers to micro-organisms which were already present in the raw materials. In addition to air pollutants, sharp objects constitute a potential threat to the workers in sorting cabins (e.g. syringes), as they can penetrate the skin and cause infections. Therefore with respect to the health protection of workers permanent sorting places in composting plants are not recommended. Mechanical alternatives such as screening, wind separation, magnetic separation should be preferred.

Although dose-response relationships have not been established for bioaerosols, it has been suggested that concentrations of airborne bacteria and fungal spores should not exceed a range between 5,000 and 10,000 colony forming units (CFU) m^{-3}. If these orientation values are reached additional measures need to be carried out in order to reduce the concentration (Pretz, 2002; Böhm *et al.*, 1998).

Following the German technical rule for biological working substances (TRBA 211) the technical control value for mesophilic fungi is $5x10^4$ CFU/m^3. This value has to be adhered to through regular measurements.

Pre-screening of the coarse, bulky fraction and bulky impurities

Generally the screening of the course fraction is carried out at 60 to 80 mm and can be performed at several stages during materials processing:

- immediately in the tipped raw material,
- after handpicking of impurities or sorting in a sorting cabin from a conveyer,
- after crushing and/or homogenising,
- after the first intensive composting phase of approximately 4 to 8 weeks (intermediate screening).

It has to be considered that if fresh organic waste is screened a comparatively high percentage of organic particles adhering to the extraneous materials as well as valuable structure material may also be separated.

In the case of an intermediate screening after 4 to 8 weeks of composting mesh sizes of between 20 and 40 mm are used. At that stage of composting a mesh size below 25 mm is not recommended as valuable structural material may be inadvertently removed. The optimum mesh size is generally between 25 to 35 mm. The throughput capacity lies between 50 - 100 m^3 h^{-1}.

It is recommended that intermediate screening be combined with a magnetic and wind separator.

Magnetic separator

A magnetic separator in large scale biowaste treatment plants reduces possible inputs of heavy metals like chromium and zinc into the compost, as these elements are often galvanised with iron to make a variety of products.

Wind sifter

Wind sifters are rarely applied to fresh waste materials due to the general high water content of organic household waste and adherence to light plastics, which reduces the efficiency of the separation procedure. The result can be considerably improved when applied after 4 to 6 weeks of composting.

Wind sifting and a magnetic separator should be installed if organic household waste is treated and the mean contamination is generally > 5 % /w/w. This prevents the enrichment of the oversize fraction with impurities.

7.2.3 Crushing (shredding)

7.2.3.1 Shredding objectives

Bulky, woody materials such as branches with a diameter > 4 cm or rootstocks are generally inaccessible to microbial degradation. Therefore the particle size has to be reduced in order to increase the active accessible surface for the micro-organisms. This is an important precondition for the efficient formation of the intermediate compounds during humus synthesis.

A second objective of crushing woody materials is the creation of bulking agents to obtain adequate feedstock mixes at the start of the composting process. As described previously, bulking agents are used to create an adequate proportion of air filled pore space and, as a result a continuous aerobic decomposition process. The air filled pore space at the start of composting should be approximately 50% (v/v).

Ideally shredders should crush woody wastes (rather than chippers that create a clean cut), as this increases the available surface area for composting to take place. Slowly rotating devices are preferred.

Depending on the overall composition of treated feedstocks, both types of shredder woody material (course and fine) must always be held in stock.

Dust and bioaerosols emissions during shredding

Shredding of woody raw materials may cause an enormous dust and also potentially bioaerosols to be emitted. Therefore staff who have to work in the surroundings of a shredder will need to wear dust masks fitted with a P3 filter.

The driver's cab in materials handling vehicles must be equipped with an air conditioning system fitted with an aeration system that either works independently from the outside air or is fitted a suitable filter (filter class S, activated carbon filter).

An efficient reduction of dust and bio-aerosols emissions can be achieved by spraying water or fogging onto the shredding process. However if the shredder machine is installed in an enclosed house the air must be removed through a negative pressure ventilation system.

With respect to dust and bioaerosol emissions, slowly rotating shredding devices should be used.

Other protective measures for the staff

Stones and other objects can be ejected from the rear end of shredders at very high speeds. Therefore it is very important that no persons are allowed to be near a shredder during its operation.

7.2.4 Homogenising and blending of input materials

One primary goal of conditioning raw feedstocks for composting is to achieve the maximum possible moisture levels and at the same time provide sufficient pore space in order to enable adequate gas exchange within the piles. The idea is to achieve those optimum decomposition conditions without any additional turning, watering or any other manipulation of the material. In enclosed systems with forced aeration an even and moderate air stream needs to be supplied.

Only homogenous and thorough blending of the different feedstocks enables efficient composting conditions. Mixing facilities and devices therefore, must be available at all times.

In order to obtain optimised microbiological transformation, the following factors need to be established:

- The presence of available "free" water
- Sufficient and evenly distributed pore space for continuous aeration and gas exchange
- A well balanced C/N ratio.

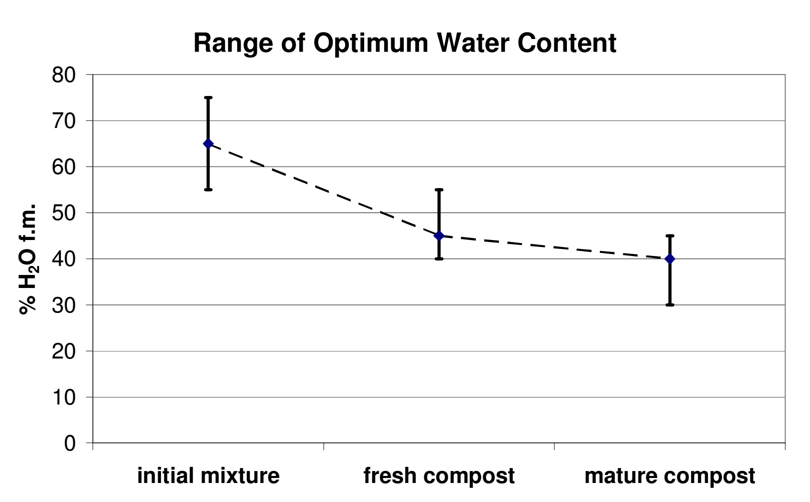


Fig. 14: Range of the optimum water content during proceeding decomposition and maturation process

The presence of freely available water

The optimum water content of the feedstock mixture depends on the water holding capacity and structure/particle size distribution.

In homogenously mixed materials a moisture content of up to 75 % in the fresh matter is possible.

The water content providing best composting conditions decreases with the ongoing decomposition and mineralisation process: on average from 65% in the initial composting phase down to 40/35 % fresh mass during final maturation.

The need for air-filled pore volume

The minimum proportion of air-filled pores is typically 30 - 50% (v/v). This provides a sufficient oxygen supply. In addition the excess CO_2 and heat released from the pile can be vented out of the mass. Consequently, food waste, fresh grass clippings or any other material with a high bulk density (low free pore space) must be blended with shredded bush and tree cuttings in order to provide the necessary mechanical structure stability. Otherwise natural aeration by convection cannot be achieved. It is important to remark that also forced aeration systems may fail to provide the minimum oxidative conditions if the air-filled pore volume is too low.

C/N-ratio

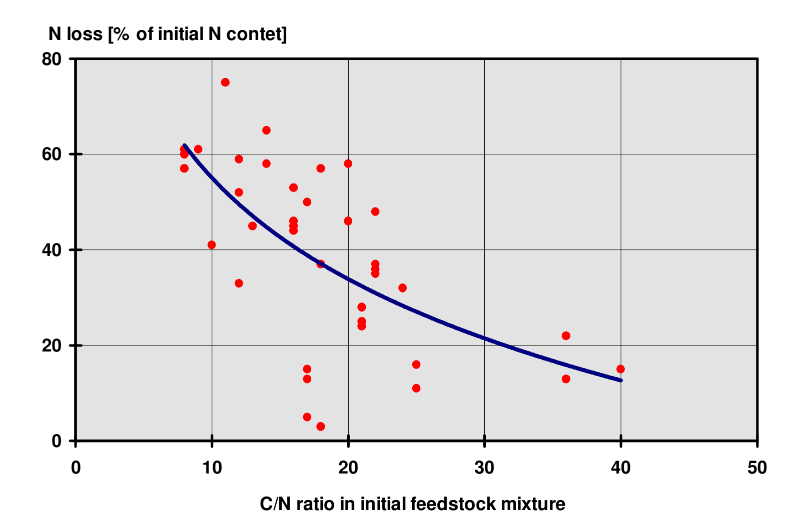


Fig. 15: N loss during composting depends mainly on the C/N ratio in initial feedstock mixture

It is of primary importance that microbiologically accessible C and N sources are provided in a well balanced ratio.

The aim is to prevent:

- Excessive ammonia emissions caused by a surplus of available N sources
- Inhibition of decomposition and humus formation due to a lack of available N sources.

The guide value for a optimised C/N ratio in the initial material mix is:

(20) 25 - 35 (40) : 1

The following table gives example C/N ratios of the most important feedstocks.

Table 17: C/N ratio of typical feedstocks used for composting

Feedstock / material	C/N ratio	Feedstock / material	C/N ratio
Manure		**Green waste**	
Liquid manure (urine)	2-3	Grass clippings	12-25

Poultry manure without bedding material	10
Compost from cattle manure	10
Poultry manure + straw	13-18
Cattle manure (with little straw)	20
Horse manure	25
Cattle manure + high proportion of straw bedding	30
Biowaste	
Vegetable waste	10-20
Food waste (restaurants)	12-20
waste from fruit processing	15-25
Mixed kitchen waste	20-23
Flowers and mixed plant tissue	20-60
Kitchen waste	23
fruits	35
Paper waste	120-170
Mixed fine garden waste	20-60
Potato plants	25
Bulky bush cuttings, shredded	23-31
Mixed leaves	30-60
Leaves (alder, ash, hornbeam)	25
Leaves (linden, oak, birch, cottonwood, beech)	40-60
Needles conifers	30-100
Straw (barley, legumes)	40-50
Straw (oat)	60
Straw (rye, wheat)	100
Bark	100-130
Pure ligneous tree cuttings	100-150
Others	
Peat	30-50
Saw dust	100-500
Paper and cardboard	200-500

Source: Amlinger et al. (2005b)

Formulas used to calculate the C/N ratio in the initial feedstock mix-

(A) Calculation of the resulting C/N ratio (C/N_M) of a blend of given quantities (t) of (n) feedstocks with known individual C/N ratios ($C/N_{1 \ldots n}$)

$$C/N_M = \frac{\Sigma\,(C/N_{1 \ldots n} \bullet t_{1 \ldots n})}{\Sigma\, t_{1 \ldots n}}$$

C/N_M .... C/N ratio of final blend

$C/N_{1 \ldots n}$ .... C/N ratio of individual feedstocks 1 … n

$t_{1 \ldots n}$ .... quantity (tonnes) of individual feedstocks 1 … n

(B) Calculation of the necessary quantity (t_X) of an individual feedstock with known C/N ratio (C/N_X) in order to obtain a required C/N ratio in the final mix of raw compost materials (C/N_M)

$$t_X = \frac{t_A\,(C/N_M - C/N_A)}{C/N_X - C/N_M}$$

t_X.... necessary quantity of an individual feedstock with known C/N ratio to be added

C/N_X .... C/N ratio of the individual feedstock to be added

t_A... quantity (tonnes) of the given material mix for which the C/N ratio needs to be adapted

C/N_A .... C/N ratio of the given material mix for which the C/N ratio needs to be adapted

C/N_M .... required C/N ratio in the final mix of raw compost materials

Procedures and techniques for blending and homogenising the initial raw compost mix

The mixing of the individual feedstocks (e.g. source separated kitchen and food waste with garden and park waste, shredded bush and tree cuttings) can, in principle, be done with the same machines and devices as used for mechanical agitation and turning of the compost heaps (e.g. a front-end loader, windrow turner, solid manure spreader). Specific mixers (drums, screw mixers, mash master and similar) only become cost effective when they treat in excess of 50 t daily throughput.

Most of these devices enable the operator to add water and additives (like stone dust, soil, mature compost) which are then homogenously mixed into the material.

The most commonly used method in windrow composting is to layer the main components of the feedstocks and additives along the whole length of the windrow, then to mix the materials together using a turning machine. This has been proven to be very effective, especially with heavy and sludge like materials (sewage sludge) which have to be mixed with bulky shredded material.

Mixing drums show good results only when the materials are retained in the drum for between 30 to 60 minutes at a turning speed of 13 to 15 rotations per minute.

The most common mixing device is a screw mixer which also provides a gentle crushing function.

7.3 Active decomposition phase

7.3.1 Definition

Within the active decomposition phase (intensive degradation phase; thermophilic phase) an intensive microbial degradation of the easily degradable organic substances takes place.

The active decomposition phase is defined as the thermophilic process stage which ends when temperatures fall below *45 °C.*

Irrespective of the intensity of mechanical agitation, aeration and material composition a total timeframe of between 5 to 10 weeks is typical.

The active decomposition phase can be carried out in one or two stages:

- **One Stage System:**
  - The entire thermophilic phase is performed in a continuous composting system until the required stability for maturation is achieved (typical example: windrow composting with regular turning with passive or with forced aeration).
- **Two Stage System:**
  - The first decomposition stage is carried out in a technical in-vessel composting system (e.g. box or tunnel). After a defined period of time (even though the resulting product would not fulfil the required stability criteria for mature compost), the composting material is removed from the reactor and placed in a second decomposition area, where a second thermophilic phase follows. This takes place on either a passively aerated open pad, or in another enclosed system with forced aeration.

The most important composting systems used in practice are:

- **Open windrow composting** with passive or forced aeration with varying turning frequency and windrow shapes and sizes;
- **Housed windrow composting** with forced aeration with varying turning frequency and windrow shape;
- Windrow and partly encapsulated windrow composting with forced aeration and covered with **semi-permeable membranes** (e.g. Gore™ Cover System);
- **Box or container composting** with forced aeration with varying turning frequency;
- **Tunnel composting** with forced aeration (batch wise);
- **Drum composting** dynamic system, which can be operated continuously (although this is not employed very frequently)

Table 18: Comparison of enclosed housed or reactor systems with open windrow composting systems with respect to decomposition and operational parameters (modified from Raninger *et al.*, 1999)

Criterion / control parameter	Enclosed composting systems	Open windrow composting
Process control	Possibility to technically control composting parameters like O_2 supply, CO_2 concentration in the exhaust air, temperature, humidity. Most importantly in enclosed systems is the maintenance of sufficient water content as well as avoiding dry stabilisation at an early stage. In addition a weekly to fortnightly turning is applied in order to re-structure the piles. Water is applied mostly by sprinklers. In most facilities after hygienisation and intensive rotting the material is extracted from the rotting box or tunnel and further composted on a hard surface with forced aeration.	Process control is done via turning. Watering is preferably done by spraying during turning with water injectors installed at the turning machine Visual humidity control or by squeeze test Temperature control with calibrated manual temperature probe or with online supervision of temperature and wireless transmission to a computer based monitoring system. Optional: O_2 or CO_2 measurements by probes
Dependency on climatic conditions	In principle independent from weather conditions	Dependent upon weather conditions. In the case of roofed facilities and if windrows are covered with fleece (geo-textile) widely independent from precipitation. Fleece coverage can only be handled efficiently with a mechanical fleece winding device
Waste water management	Recycling of waste water into the process and the extensive removal of water saturated exhaust air via the biofilter closed systems usually do not produce any excess waste water. As a rule, drained waste and surface water from storage and open maturation areas – depending on climatic conditions – can also be used for the watering during the intensive decomposition phase.	In the case of roofed compost areas or in locations with little rainfalls (< 400 to 600 l/m²) and if the humidity is managed properly excess water can be extensively avoided. Without roofing, contaminated leachate and surface water must be drained off and stored in a leak proof retention basin. The waste water is, to a large extent, used for watering during the composting process. Excess water can be spread on land (depending on a positive approval by the competent authority), delivered to a waste water treatment plant or purified in a reed bed.
Hygienisation	An effective thermal hygienisation at a temperature of > 55 °C can be guaranteed for the entire material if (i) adequate humidity and (ii) aeration (sufficient pore volume and structure stability) is provided throughout the cross-section of the piled material. At least one mechanical turning is required in order to include all material compartments in the optimum microbiological decomposition conditions	The same is valid for open windrow systems. In addition 3 to 5 turnings during the high temperature phase are required.
Exhaust air management	Capture of waste air includes the options: (i) recirculation, (ii) raw gas treatment and conditioning, (iii) cooling (iv) purification by a biofilter (v) stripping of excess ammonia by a wet scrubber system (vi) oxygenation etc. A considerable problem of housed systems is the fact that it needs an enormous energy consumption to provide the necessary oxidative conditions in the hall atmosphere.	Without forced aeration systems odour emissions and possible excess GHG and ammonia emissions can be prevented by close observation and control of the parameters (i) material composition, (ii) humidity (iii) cross-section and pile size (iv) turning frequency (v) coverage with fleece, (vi) choice and consideration of the location relative to sensitivereceptors.

Criterion / control parameter	Enclosed composting systems	Open windrow composting
Decomposition rate	Shortening of the composting time and effective degradation of easily decomposable organic compounds during the controlled intensive / high temperature rotting phase of 2 to 3 weeks (under optimised composting conditions, this can be up to 50 % degradation of the original organic dry matter in the case of typical organic household waste). This entails less demanding requirements during a second decomposition phase and maturation	In intensive processing schemes (optimised material mix, high turning frequency , precise water, air and temperature management) a stable and well humified end product can be obtained after 6 to 12 weeks If sufficient space is available also less intensive and more moderate processes are possible. Turning frequency can be reduced to 7 to 10 days. Here, initial material mixing must be done specifically careful and the windrow size (height) must be reduced to approximately 120 cm.
Footprint required	This varies a lot and depends on the applied composting systems during the intensive rotting as well as maturation phase. The range is 0.3 to 5.2 $m^2 t^{-1}$.	At optimised operational and process conditions the footprint can be reduced to 1.2 $m^2 t^{-1}$.
Personnel, man power required	Reduced work places due to far-reaching automation of the process and process control.	One well trained plant operator can produce up to 5,000 t compost per year. Prerequisite is that the facility is equipped with well functioning devices and machines (automotive turner, high capacity loader, screening machine etc.)
Odour emissions and management **See Chapter 6.1**	Can effectively prevent odours due to forced aeration and exhaust air recirculation. The waste air is either used to aerate piles in maturation stage (biofilter effect, supply with heat and humidity) or it is treated in a biofilter system with or without preceding wet scrubber. A crucial pre-requisite is the well designed and effective decomposition during the main, intensive composting phase avoiding untimely *cooling* or *drying out (dry stabilisation)*. Otherwise significant odour problems occur after extracting the raw compost from the enclosed facility.	A well adapted material mix, the addition of mature compost and soil, a balanced watering and oxygen supply by mechanical turning may reduce odour emissions effectively. Under routine operational conditions at a distance of 300 m no odour problems should occur.
Feedstocks **See Chapter 4**	Enhanced flexibility of the process, capable of treating a broad range of specific feedstocks with respect to highly reactive organic matter, humidity, structure etc. As a rule less bulky and shredded garden waste is needed. Forced aeration allows a lower pore volume and a higher space loading of organic dry matter compared with windrows.	Specialised training programmes shall enable personnel at composting facilities to handle feedstocks and to operate the entire process in an appropriate way. Even more problematic protein and water-rich input materials can be treated adequately without creating major problems.
Greenhouse gases	**See Chapter 6.5**	

Table 19: Composting systems and facilities – a short comparison (modified from Raninger *et al.*, 1999)

	⇒ **Advantages**	⇒ **Disadvantages**
Automated turning systems (e.g. Wendelin)	■ Continuous material flow is possible ■ Regular and flexible turning ■ Lowers footprint ■ Recirculation of exhaust air is possible	■ Increased investment costs compared with a simple floor ■ Increased operational costs (energy, abrasion) ■ Problems with corrosion and working conditions in compressed aeration systems ■ Less flexibility in case of breakdown of the turning device ■ No process control and management of the specific feedstock mix ■ Inadequate humidity control ■ In negative pressure aeration systems high energy and water losses
Compost tunnel and box	■ Batch wise processing ■ Process control may be adapted to specific feedstock properties ■ Mechanical machines and facilities are outside of the corrosive atmosphere ■ Modular construction and facility planning possible ■ Simultaneous treatment of varying feedstocks and raw compost ■ High aeration rates with oxygen control (> 14 % (v/v) O_2); recirculation is possible ■ Recycling of percolate ■ Operation with loader in emergency cases ■ Shortened composting time ■ Waste water free process because the water is circulated via the exhaust air stream ■ If well managed, reduced occupational exposure to dust and bioaerosols	■ Requires highly qualified personnel ■ Mechanical agitation during active composting phase is only possible when the material is extracted from the box or tunnel ■ Sophisticated technology for filling and extraction required ■ Problems with odour and bioaerosol emissions if the stabilisation is insufficient at the time when the compost material is extracted from the reactor.
Hardstanding with integral aeration channels	■ Low investment costs ■ Low requirements for qualification for workers	■ High raw gas load ■ Missing process control ■ Very little control of humidity ■ Waste waters require management

	⇒ **Advantages**	⇒ **Disadvantages**
Open windrow composting	■ Suitable for decentralised treatment structures ■ Treatment close to the point of use and application ■ Lowest investment costs of all composting options ■ Low qualification demands, part time farming possible ■ Waste water recycled to process or applied to agricultural land ■ Compost producer identifies with the product he produces and uses.	■ If fresh and humid biowaste (kitchen waste and similar) feedstocks are treated a higher proportion of bulky structural material and additives are needed (straw, crushed bush and tree cuttings, stone dust etc.) ■ No waste air capture and treatment (may lead to high odour emissions during turning) ■ No or very limited automated process control ■ Without roofing, waste water quantity depends of precipitation ■ Minimum distance to permanent dwellings, residences, working places 300 m

7.3.2 Basic requirements for infrastructure, machinery, technical equipment and operational quality management

7.3.2.1 Basic Functions

These are to:

- Ensure the decomposition and transformation of easily degradable organic substances;
- Minimise potential odour emissions;
- Create an intermediate decomposition product with a low odour potential in one or two process steps;
- Minimise the emission of greenhouse gases; and
- Ensure that the entire material is exposed to the desired sanitising temperature (> 55 °C) over a defined time span (see Chapter 6.3).

7.3.2.2 Potential Emissions

- Odour due to the degradation of organic primary substances;
- Liquids (e.g. process, condensate, precipitation water);
- Dust and bioaerosols during handling of the materials;
- Further gaseous emissions (VOC, NH_3, N_2O, CH_4);
- Noise caused by aeration and turning devices; and
- Material drifting during manipulation.

7.3.2.3 Minimum Requirements for site infrastructure and technical equipment

- Machinery suitable for charging, extraction and manipulation of a variety of materials;
- Properties of the hardstanding:

  Option A – paving

  - watertight pavement including a drainage and intermediate storage system for waste water

  Option B – intensive composting phase on open unpaved ground may be authorised only for the treatment of garden and park waste (green waste) at a maximum capacity of 300 m³ input per year. The following conditions have to be met:

- A maximum of 100 m³ of raw material, composting or refined compost may be placed at the same time in any one place;
- Permitted source materials include:
  - ⇒ Leaves, tree and bush cuttings, hay, other botanical garden and park waste and dry agricultural residues (straw, spelt, etc.);
  - ⇒ A maximum proportion of 20 % (v/v) of fresh grass clippings, fruit and vegetable waste, organic household waste (bio bin), fresh harvest residues from horticulture and agriculture, stable manure is permitted
- During rainy periods the windrows must be covered with a water draining geo-textile (fleece);
- <u>Requirements for the composting site</u>
  - ⇒ The surface should be on a slight slope (ca. 3 - 5%) and no mould
  - ⇒ Minimum distance from surface waters: > 75 m
  - ⇒ Minimum distance from a spring or well: > 100 m
  - ⇒ Annual relocation of the composting site is not necessary as the surface soil under the composting piles tends to compact and become blocked by fine sediments
  - ⇒ Composting is not permitted in water protection areas
  - ⇒ Composting is not permitted on light sandy soils or gravel with an high percolation potential
  - ⇒ Composting is not permitted on sites which where there is the potential for landslides or floods
  - ⇒ Composting is not permitted on sites where the groundwater level is less than 200 cm below the soil surface

- Roofing or coverage with geo-textile:
  - *<u>Coverage with geo-textile.</u>* In areas with a yearly precipitation of > 1.000 mm a geo-textile must be kept available in order to cover the windrows in the case of heavy rain falls. This applies specifically for windrows with a diameter of less than 1.5 m at the time of tipping. If a forced aeration system is applied a geo-textile is not mandatory. The key functions of a geo-textile are to:
    - ⇒ Partly retain condensate;
    - ⇒ Drain precipitation water off the windrows;
    - ⇒ Maintain effective gas exchange;
    - ⇒ Reduce the attraction of birds.
  - Roofing is necessary if the following criteria concurrently apply:
    - ⇒ Annual precipitation > 1,400 mm;
    - ⇒ The site is in operation during the whole year
    - ⇒ Annual throughput at the site is > 3.000 t
    - ⇒ More than 30 % (v/v) of the following feedstocks are composted: materials with a high moisture and nitrogen content (e.g. biowaste with a high proportion of kitchen waste, fresh grass clippings, humid wastes stemming from food industry, sludge).
- Equipment to regularly measure temperatures within windrows;
- Technical equipment (e.g. windrow turner) to ensure that necessary gas exchange takes place;
- Technical equipment for watering the material when required.

<u>Supplementary process management equipment</u>

- Measurements of oxygen, carbon dioxide and / or methane in compost piles or exhaust air
- Automated process regulation and/or process control (temperature, oxygen, water content) using monitoring devices (e.g. data logger)
- Roofing for low throughput quantities of biowaste or in low rainfall areas
- Enclosure of the system or in-vessel systems

7.3.2.4 Requirements for process management and documentation

Ensuring adequate decomposition (continuous composting of easily degradable organic substances)

- Irrespective of the chosen composting system the aim of the intensive composting phase is to ensure the continuous decomposition of the easily degradable organic substances including intermediate metabolites like organic acids etc. Thus the main task is the creation of optimum composting conditions. This is mainly done through
  - Ensuring adequate gas exchange takes place
  - Maintaining the moisture content throughout the composting mass

Ensuring adequate gas exchange

- *Static in-vessel systems with forced aeration*
  - The oxygen content in the exhaust air from close composting reactors with forced aeration should not be below 14 % (v/v)
  - The continuous supervision and process regulation of the aeration device and function is mandatory
  - In the case of breakdown of the aeration system a control system needs to be in place to enable emergency operation of the ventilation devices or the immediate extraction of the material without any delay. This is necessary to prevent transformation into an anaerobic process.
  - The distribution and diameter of the aeration vents/slits that directing the air stream into the composting mass must ensure there is an even distribution of the air;
  - In addition to the forced aeration, as a result of the natural compacting process, the material needs to be turned mechanically at least once per week.
- *Open windrow systems*
  - Appropriately sized turning machines must be permanently available and ensure that mechanical treatment of the windrows is possible whenever it is demanded by the process.
  - Structural materials must always be kept in stock in order to correct the material composition of individual batches.
  - The turning frequency is dependent upon the following parameters:
    - ⇒ Cross-section / height of windrows
    - ⇒ Proportion of bulking agents (density) and fresh feedstocks with an high nitrogen content
    - ⇒ Turning needs to maintain a continuous homogeneous decomposition process
    - ⇒ Thermal hygienisation (sanitisation) occurring uniformly across all parts of the compost profile.
  - As far as the formation of greenhouse gases is concerned, systematic investigations into open composting systems with windrows higher than 1.5 m coupled with a low turning frequency (ca. every 2 to 4 weeks) are limited. Based on an understanding of the biochemical transformations that take place in a composting heap it can be concluded that at a turning frequency of less than two times per week during the first 1 to 4 weeks and at a windrow height of about 1.5 to 2.5 m natural aeration by convection (chimney effect) would not guarantee an adequate supply of air.
  - With respect to minimising methane emissions at open window systems without forced aeration and with a windrow height of > 1.5 m to 2.5 m, windrows should be turned every 3 – 4 days during the initial high temperature composting stage.
    - o

Maintenance of moisture content, exhaust air treatment, temperature control and waste water treatment systems

Control of humidity

- During the entire decomposition process (irrespective of the process stage) it is important to ensure regular and homogenous watering of the composting materials; this is especially important during the intensive initial composting phase until temperatures fall to around 40 °C.

Exhaust air treatment

- Exhaust air treatment is required in enclosed reactor systems (box, tunnel) or housed systems on aerated floors as well as in open windrow composting equipped with a negative pressure aeration system. Wet scrubbers and biofilters reduce odorous compounds, ammonia, and other non-methane volatile organic compounds (NMVOC) as well as dust. [See Chapter 6.1(*odour emissions*) and 6.5 (*other gaseous emissions*)].

Temperature control

- After thermal sanitisation (see Chapter 6.3) the temperature should be kept below 55 °C at a humidity of between 45 - 55 % (w/w) fresh mass.
- Maintaining temperatures above 65 °C should be avoided (see Chapters 2 and 6.1).
- In enclosed systems the continuous air flow and high air flow rates may result in dry stabilisation. This has to be avoided by moistening the input air, regularly watering the composting material and artificially cooling the aeration system.

Water management

- As a rule process water and other contaminated water from open sealed surface areas is collected in leak proof basins and used to water the compost heaps. Due to anaerobic conditions in the leachate water tank odour emissions may occur. Therefore an aeration system (for example as used in slurry storage) and the addition of clay dust, lime stone dust, mature compost or straw dust to the stored water help absorb odorous compounds.
- During the high temperature phase the quantity of water added should always be adapted to the water holding capacity of the material. This should be done in a way such that the formation of process and leachate water is avoided as far as possible.
- The spatial arrangement of the piles and windrows must ensure that leachate water stemming from the initial and non-sanitised composting materials does not run into areas with maturing or finished compost that will not undergo a further thermal sanitisation phase. In this way cross contamination can be avoided.

  ➔ see also Chapter 6.2.2.

Emission management

See Chapter 6.

Record keeping and documentation

During the intensive composting stage the following activities and data must be recorded in the operational diary:

- Feedstock composition of the individual compost batches;
- Temperature;
- Moisture assessment (either a visual estimation or by using the squeeze test);
- Watering;
- Turning;

- Aeration;
- Additional activities, such as covering windrows with fleece, intermediate screening, merging of compost batches; and
- Location of compost batches.

7.3.3 Minimum stability requirements for materials being extracted from in-vessel to open composting systems

Several static and dynamic parameters may give information about the biological stability or residual biodegradability of the feedstock or partly decomposed material. Examples include: respiration activity after four days [AT_4], dynamic respiration index [DRI], fatty acid detection, particle size distribution [porosity], C/N-ratio, growth test with indicator plants (cress, barley, Chinese cabbage etc.) among others. The latter test methods primarily assess phytotoxicity i.e. the maturity of the compost.

Based on the experience with mechanically biologically treated residual wastes respirometric methods, in addition to measurements of fatty acids, are recommended to estimate the biological stability of partly decomposed organic materials.

Here we provide an example of the measurement of the respiration activity [AT_4] that has been adopted in the framework of the Austrian mechanical biological treatment (MBT) guideline as well as the German Emission Protection Ordinance. The Austrian MBT guideline defines a threshold value of 20 mg O_2 g^{-1} dry matter for partially decomposed material before it may be further composted in open windrows. It is assumed that materials which exhibit an activity less than the indicated limit would not cause further considerable emissions (e.g. odours, greenhouse gases). In addition, the minimum time span for aerobic treatment in enclosed reactors is four weeks.

In order to reach the required stability level, the treatment of biowaste for two to three weeks in a technical composting system is required. The aim is to reduce the odour potential to a level where no further problems would be expected during regular operational conditions without waste air treatment during maturation.

Measurements of the respiration activity should be conducted at least twice a year or at least every 3000 tonnes of treated biowaste. Measurements should be repeated when significantly differing feedstocks are used (e.g. biowaste, green waste, sewage sludge).

If the limit value is not met the treatment duration must be prolonged or a second phase of enclosed intensive composting applying forced aeration and waste air treatment must follow.

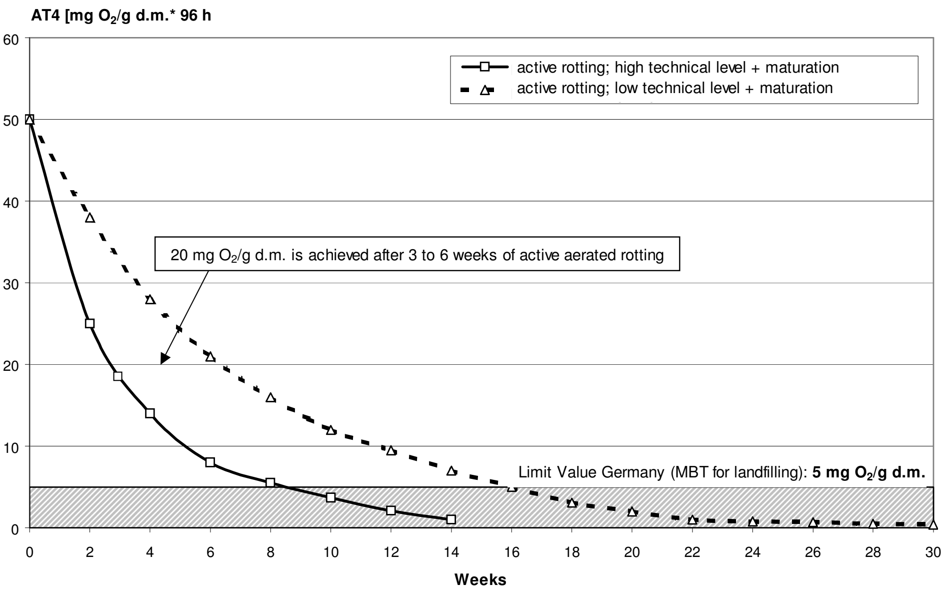


Figure 16: Respiration activity (AT_4) of residual waste rotting (Wallmann *et al.*, 2003)

In order to achieve the necessary stability level (AT_4 of less than 20 mg O_2 g^{-1} dry matter) in order to prevent considerable odour emissions, biowaste must be composted in enclosed boxes or tunnel systems for at least three weeks.

Figure 17 presents results of biowaste and green waste composting processes in open windrows with turning rates of between 3 and 7 days. It shows clearly that the biological activity reaches the same stability level in enclosed systems with forced aeration compared with open windrow processing if the process is managed according to good practice guidelines.

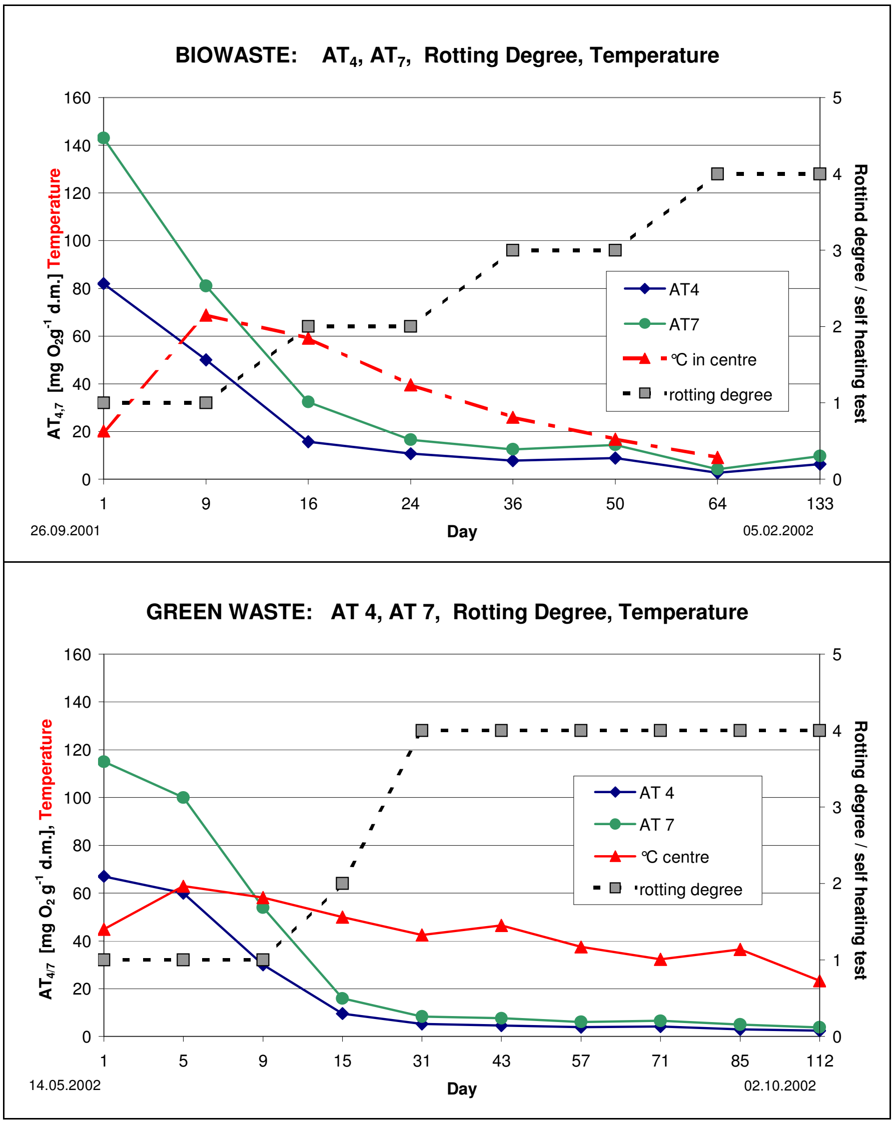


Figure 17: Change in the aerobic biological activity tested using the respirometric test over 4 and 7 days of incubation (sapromat: AT_4 und AT_7) and the self heating test (Amlinger & Peyr, 2003)
Top: BIOWASTE: open windrow composting – with a high proportion of food and kitchen waste
Bottom: GREEN WASTE: open windrow composting – garden and park waste only; both, mechanical turnings: 1 – 2 times a week.

7.3.4 Description of key composting systems

The description of the composting systems as used in Austria have been described in the basic study to this guideline (Amlinger *et al,*, 2005b).

In order to present the diverse variability of open windrow-composting-systems and to take into consideration practical experience, representative facilities were chosen in co-operation with the Austrian Compost & Biogas Association, which had been evaluated by their controlling and advisory body. For the description of the individual procedure types some individual facilities served as examples, but in most cases the experience of the authors and results of several facility operators were combined in the assessment.

Here, we just summarise some key features of the survey on open windrow composting systems.

7.3.4.1 Some data from the practice survey on open composting techniques used in Austria

Duration of the composting phase

Feedback on the duration of the composting phases showed a considerable variation. This may have resulted by the lack of a precise definition of “active composting phase” (thermophilic phase), “maturation phase” and “storage for maturation”. The results are shown in Table 20.

Table20: Duration of the composting phases

	active composting phase (thermophilic phase)	maturation phase	storage for maturation
Duration	2 – 15 weeks	5 – 15 weeks	4 – 8 weeks, according to need
Turning intervals	mostly weekly 1 – 14 days	7 – 60 days	21 – 60 days, no turning

Windrow dimensions

A variety of windrow-geometries were typically found in practice. Typical trapezoidal windrows were mostly found in enclosed facilities with forced aeration and automated turning systems.

Table21: Typical windrow shapes and dimensions of windrows

			
height	1.2 – 3 (6) m	2 – 2.5 m	1.5 – 4 m
width	3 – 6 m	4 – 6 m	6 – 75 m
length	30 – 160 m, optional	30 – 60 m, optional	8 – 85 m, optional

Footprint, area demand

The footprint of the evaluated composting facilities ranges, depended on the composting system, ranged from 0.5 – 5 m^2 t^{-1} input feedstock. It reduced with increased windrow height, premature removal to storage for maturation in large volume trapezoidal windrows and with increased processing intensity. The first two factors reduce compost quality.

The following Table 22 provides the range of area required to operate open windrow systems which build the baseline for the technical description in licensing compost plants.

Table 22: Range of footprints of open windrow composting plants depending on turning technology, pile size and process management (turning frequency etc.)

Quantity of input material (m^3 or tonnes) per area unit (m^2)	1.0 – 2.5 m^3/m^2	0.6 – 1.5 t/m^2
Area demand (m^2) per m^3 or tonnes of input material	1.0 – 0.4 m^2/m^3	1.67 – 0.67 m^2/t

7.3.5 Open windrow composting without forced aeration

The pre-treatment of input feedstocks aims to establish an appropriate pore volume ratio at the *highest possible* moisture content, so that the oxygen supply can be maintained for as long as possible, without additional technical measures – turning, water addition, etc.

The key stages during open windrow composting are illustrated in Figure 18.

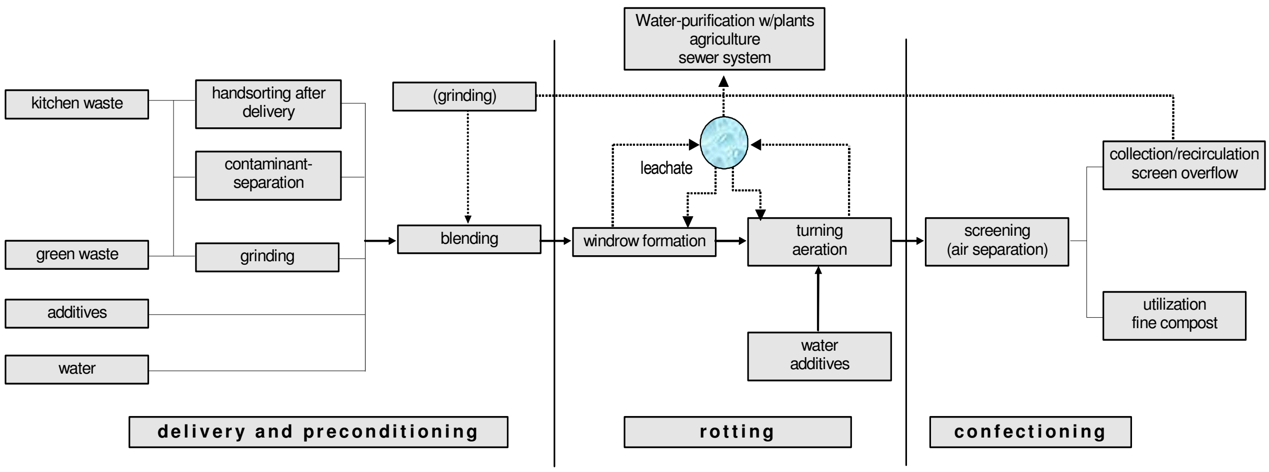


Fig.18: Flow chart illustrating the key processing stages during open windrow composting of organic wastes

Triangular windrow [height: 1.0 to 1.5 m]

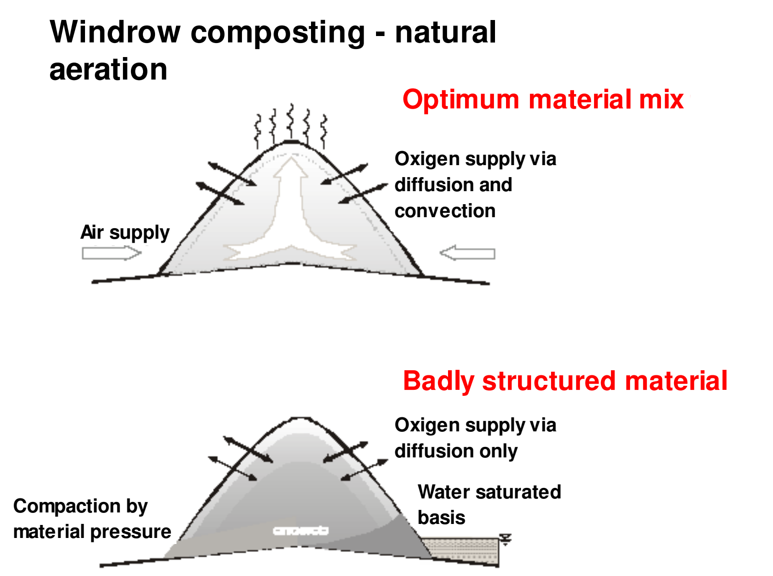


Fig.19: Dependence of passive windrow aeration (chimney-effect, convection) on material structure (Binner, 2003b)

The triangular windrow shape has been proven in practice to be the most ideal form of windrow composting. An optimal combination of windrow diameter, material blend, moisture, gas exchange and use of a compost turner, allows for compostable materials to be transformed biologically into a **stabilized compost**, within a very short period of time (6 – 8 weeks).

The microflora, which is active in a composting process, needs more than 50% moisture from the beginning of the process as well as an adequate pore volume. Therefore the ideal windrow dimensions are 3 m base width, by 1.4 m in height. The shape of the triangular windrow should not be bulbous, to keep the material pressure inside the core to a minimum. This shape can only be achieved with compost turners that are designed for the proper windrow shape.

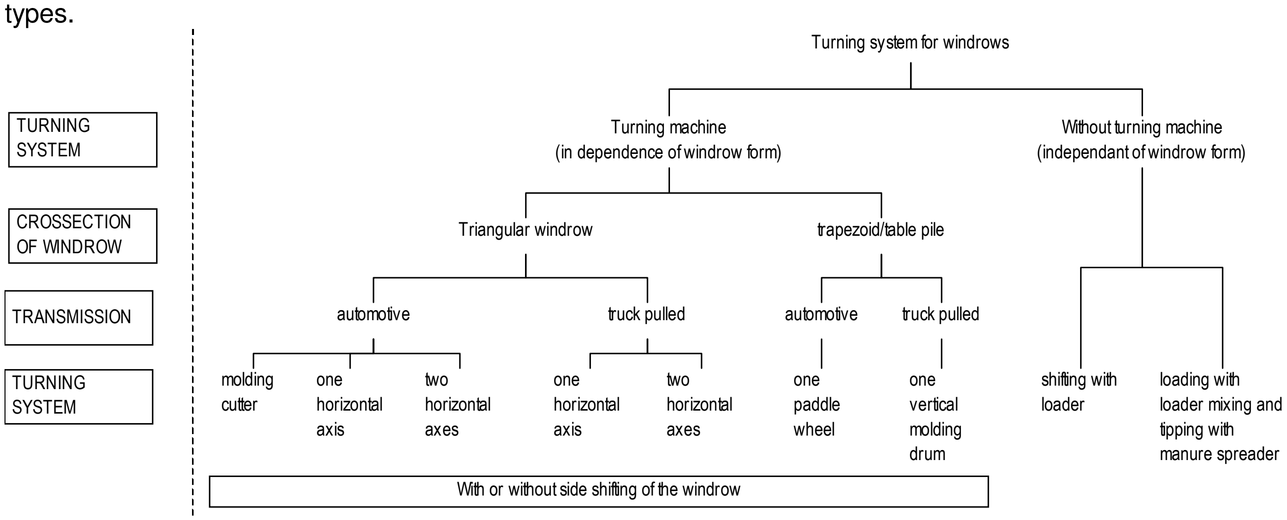
In practice, windrow diameters ranging from 1.8 – 4.0 m width and 0.8 – 2.5 m height, depending upon the of the compost turner, were found in the survey.

Trapezoidal-windrows

Large trapezoidal windrows were found in green waste composting with restricted space availability. At a windrow height up to 4 m there is a great need for structural materials. Continuous composting cannot be maintained because of the formation of compaction zones.

Compost turners

Compost turners were specifically designed for triangular and trapezoidal windrows, which can be self propelling or pulled by a device (e.g. truck or tractor). The following chart provides an overview of the most common turner types.



7.4 Maturation

Maturation is defined as the composting phase following the active decomposition phase, where stabilisation and humification are completed, resulting in a mature readily refined compost product.

The active decomposition phase is completed if the temperature can be sustained below 45 °C. This indicates that the biotransformation of the easily degradable organic compounds in the composting materials has occurred, hence the oxygen demand and the exothermic processes have reduced.

Thus maturation starts after the first five to ten weeks of active decomposition.

The time needed for adequate maturation depends on the feedstock material (available C sources), the intensity of process management (i.e. turning intervals, aeration, water management) and the intended quality of the final product (fresh or mature, well humified compost).

However as a guideline the temperature of well-matured compost should not exceed ambient temperature or at least 35 °C.

7.4.1 Basic functions

- Decomposition and transformation of more stable organic substances (cellulose, lignin) under mesophilic and psychrophilic conditions;
- Synthesis of ligno-proteins and phenolic constituents that are precursors in the formation of humic substances. The synthesis of humic substances by polymerisation processes and formation of the clay-humus complex;
- Non-thermal hygienisation (stabilisation) by means of an intensive degradation of the microbial biomass (see Chapter 6.3);
- Preparation or final processing of the final compost product that does not create any further emissions of environmental significance.

7.4.2 Possible emissions

- Odour

  Type and quantity of emissions during maturation are influenced by the following factors (VDI Richtlinie 3475, 2003):
  - Biological stability achieved so far

    If the duration or intensity of the active decomposition phase is performed unsatisfactorily (e.g. dry stabilisation in enclosed reactors) emissions during the maturation phase can be significant. This can be a consistent problem when the active decomposition phase is shortened due to inappropriate under-sizing of the facility.
  - Particle size distribution, water content and temperature, mechanical treatment and aeration
- Nitrous oxide (N_2O)
- Liquid emissions (condensate in the case forced aeration systems)

  As a rule process water may not be expected. Since the water holding capacity and extent of evaporation are continuously reduced during maturation, emissions mainly originate from rainfall or irrigation.
- Dust and bioaerosols emissions may occur when dry materials are turned or from traffic routes
- Noise by ventilation and turning devices
- Drifting of dust and fine particles as well as plastics via wind if compost heaps are not covered

7.4.3 Requirements for infrastructure and technical equipment

Maturation is mainly carried out in triangular, trapezoidal or table windrows, and occasionally in open boxes or halls with forced aeration.

Even though the oxygen demand of the micro-organisms during the maturation is reduced significantly compared with the active composting phase, sufficient gas exchange and a well adjusted moisture content still needs to be maintained. Due to the reduced structure of the composted material during the late composting stages windrows with a diameter above 2.5 m in height are not recommended.

Minimum equipment

- Machinery suitable for turning and material manipulation;
- Devices for temperature measurements;
- Devices for maintaining the optimum water content; and
- Surface characteristics of the maturation area should be:

  Option A –paving

  - Watertight pavement including a drainage system and intermediate storage for the waste water at composting facilities meeting the following characteristics:
    - ⇒ Annual throughput > 6000 t

  Option B – Maturation on unpaved open ground

  - This can only be authorised at composting facilities with an annual throughput < 6000 t
  - Requirements for the composting site
    - ⇒ The surface should be on a slight slope (ca. 3 - 5%) and no mould
    - ⇒ Minimum distance from surface waters: > 75 m
    - ⇒ Minimum distance from a spring or well: > 100 m
    - ⇒ Annual relocation of the composting site is not necessary as the surface soil under the composting piles tends to compact and become blocked by fine sediments
    - ⇒ Composting is not permitted in water protection areas
    - ⇒ Composting is not permitted on light sandy soils or gravel with an high percolation potential
    - ⇒ Composting is not permitted on sites which where there is the potential for landslides or floods
    - ⇒ Composting is not permitted on sites where the groundwater level is less than 200 cm below the soil surface

- Roofing is necessary if the following criteria concurrently apply:
  - Annual precipitation > 1.400 mm,
  - Operation during the whole year
  - Annual throughput > 3.000 t

7.4.4 Requirements for process management and documentation

Requirements for optimal process management

- Enabling decomposition and transformation of organic substances:
  - By facilitating appropriate levels of gas exchange through:
    - ⇒ regular turning with either passive or forced aeration

      Mechanical manipulation creates new active surfaces and induces accelerated microbial activity, this consequently increases oxygen demand, and has to be considered carefully.
    - ⇒ Maintenance of the necessary structure (pore space)
  - By maintaining the moisture content appropriate to the composting stage (ca. 45 to 55 % w/w fresh mass)
  - By avoiding dry stabilisation or excessive moisture through
- Permanently covering windrows less than 1.5 m height and in locations with a yearly precipitation of more than1,000 mm with geo-textile covers. This requirement takes into account the decreased water holding capacity and pore space of compost in the curing stage and the need to reduce the moisture content in order to provide optimised conditions for final processing (screening, wind separation etc.)
  - Where the maturation phase is conducted on open ground in windrows of less than 1.5 m in height, they will need to be covered with geo-textiles to protect them during heavy rainfall events
  - Trapezoidal or table windrows with a larger cross-section must not be covered. It has to be noted that windrows above 2.5 m in height are disadvantage product quality due to the potential formation of anaerobic zones.
- Adjusting the final moisture content for the subsequent process steps (final confection, storage, screening, packaging etc.).

Documentation requirements

The following measures and dates have to be recorded in the daily journal:

- Temperature measurements
- Determination of the moisture content (squeeze test)
- Watering or irrigation
- Date of turning
- If applicable aeration
- Further measures such is covering windrows with geo-textile covers, screening etc.

7.5 *Final processing*

Final processing of the compost is generally performed after the curing phase. Under certain conditions specific measures can also be done at earlier stages. In that case physical conditions and workability of the material (water content, structure, odour potential) must be considered carefully.

Final screening using mesh sizes < 15 mm at process stages where the temperature level cannot be kept below 45 °C is not recommended. This may result in the formation of zones with distinct reductive conditions and may delay stabilisation/humification. In addition denitrification processes can support the creation of ammonium, ammonia and nitrous oxide (N_2O).

7.5.1 Basic functions

Main functions of final processing:

- Production of marketable compost for certain applications that require defined maximum particle sizes. Ideally non-decomposed bulking agents will also be removed during this screening stage;
- Separation of any remaining extraneous materials (contaminants) such as plastics, metals, glass etc.

Main measures:

- Mechanical sorting of excess particles (bulking agents);
- Mechanical sorting of impurities;
- Post process shredding; and
- Adjusting the moisture content.

7.5.2 Possible emissions

- Odour (specifically if in the final processing is done with compost which has not matured sufficiently);
- Dust and bioaerosols;
- Noise; and
- Wind drifting of light fractions (e.g. fine compost particles, plastics).

7.5.3 Infrastructure and technical equipment

Minimum requirements:

- Stationary or mobile screening machine;
- Separate storage area for the screened over-size fractions;
- When the over-size fraction of source separated biowaste from households with high plastic contamination is recycled into the composting process: a wind separator is required to remove the light fraction;
- Roofing in the case of a annual precipitation of more than 1,400 mm; and
- Dust decontamination of exhaust air in the case of stationary screening in enclosed halls.

Not obligatory, supplementary equipment:

- Magnetic separator (can be used for the fine as well the over-size fraction);

- Ballistic/density separator;
- Loading and packaging facility; and
- Blending facility for the production of substrates and growing media.

7.5.4 Requirements for process management and documentation

Ensuring quality compost production

- Irrespective of the final application of the compost physical contaminants must be sorted out and the maximum particle size (mesh size of the screener) chosen accordingly.
- Adjustments need to be made to the water content
  - The water content must be adapted in accordance with particle size and water holding capacity. The overall physical conditions must facilitate the transport and further treatment of the compost.
  - Only fresh water or separately stored runoff water from the curing area may be used for watering
- Merging of different compost batches in the course of the final processing
  - Homogenising and complete mixing of the compost in order to achieve consistent quality with respect to nutrients and the fulfilment of compost quality classes (heavy metal limit values)

4.) Reassignment of a new unequivocal batch numbers

Disposal of separated contaminants and regular storage

- Separated contaminants must be stored in clearly designated containers; disposal must be well-documented in the operational records;
- Secondary contamination of refined compost must be avoided; specifically re-contamination with un-sanitised raw feedstocks by using a loader which has not been cleaned properly or through process water from the waste water tank of the active decomposition phase.

Low emission operation and worker protection

- Odour
  - As indicated above odour emissions may be only expected if final processing is carried out on compost that has not been sufficiently matured.
  - Where this is the case the precautions described in Chapter 6.1 must be observed
- Dust and bioaerosols
  - The higher proportion of fine particles and the low water content in matured compost induces an increased dust formation and consequently potential emissions of bioaerosols. Thus it is important that the material at the time of screening has an optimum moisture content;
  - The screening of immature, dry stabilised material has to be avoided
  - Workers should wear dust protective masks (P3 filter masks). Driver's cabs should be equipped with an air conditioning and dust filter system
- Noise
  - All machines must comply with national regulations concerning the maximum noise production under routine operation conditions
  - In the case of not enclosed permanent working places all staff need to wear ear protection
- Wind drifting of light fractions (e.g. fine compost particles, plastics)
  - In exposed situations with frequent strong winds, barriers shall be established (earth walls, hedges, fences etc.)

7.5.4.1 Screening

Screening is carried out mostly by drum screens, although some large facilities use star screens. Screen sizes are: 10 mm for growing media substrates, 10 – 25 mm for application in agriculture and 40mm for use as a mulch material.

The fraction of screen overflow is dependent upon the material and the screen mesh size and therefore varies greatly. The data in table 8-5 relate to the screened batch, in relation to the total input of the facility. The screen overflow fraction is reduced since part of the material is reintegrated into the operation. The chosen screen mesh size influences the throughput rate of the frequently used down-stream air separator.

Table23: Mesh size, fraction of screen oversize and capacity of the air separator in connection with fine-processing

	Mesh size			
	10 mm	**15 mm**	**20 mm**	**40 mm**
Screen oversize	10 – 70 % (v/v) < 10 – 45 % (m/m)	< 10 – 25 % (v/v) < 10 – 25 % (m/m)	n.i.	n.i.
Throughput rate air separator	30 - 45 $m^3 h^{-1}$	40 $m^3 h^{-1}$	50 $m^3 h^{-1}$	n.i.

n.i. … no information available

Table24: Screen types used in fine-processing of compost

Type	Description	Comment
Drum screen	Perforated drum, throughput rate and screen characteristic are defined by perforation-size, rpm, built in structures and bevel.	most common, especially as mobile unit
Star screen	Circular and resonance vibration with staggered screening-box with a crank drive, adjusting of the separation capacity by mesh-size and bevel.	Mostly stationary in large facilities
Vibration screen	Bevelled screening-box; adjustment through: hole shape, size, frequency, vibration deflection	mostly pre-ground materials used

For trouble free operation the finished compost should have a dry matter content of ca. < 55 % (m/m) fresh mass. With a perforation of 25 mm the sieve residue amounts to ca. 30 - 40% of the finished compost or 20 % of the raw material.

7.5.4.2 Wind sifting

Wind sifter have been in use more frequently since the mid-1990s. They serve mostly to separate light plastics from the screen overflow, to allow for reintegration into the initial compost mix as an inoculum and structural material. Without this measure an accumulation of plastics in the compost would take place, which would reduce in size during compost turning and inevitably end up in the fine fraction of the finished compost.

Main benefits are:

- Few moving parts and therefore wear-resistant;
- A good separation effect is achieved, high volume throughput (sifter loading: 0.05 to max. 0.35 kg m^{-3} air);
- Can be used in combination with screens; and
- Allows for stationary and mobile use.

Possible disadvantages are:

- Only partially circulating air possible;
- Possibly dust emissions occur with dry fine-material.

Technical variations and designs

Type	Description	Comment
Rotational wind sifter	Consisting of a rotating bevelled drum, settling chamber, diffused-air aeration	Use for household waste and secondary treatment of compost
Zig-Zag-Windsifter	Vertical zig-zag-shaped channel that air passes through from bottom upwards; separation rate mainly regulated by the air stream; for higher separation rate several sifter stages	Use for household waste and secondary treatment of compost

7.5.4.3 Magnetic separator

Magnetic separation serves to remove ferrous metals and is usually used in combination with a wind sifter down-stream of the discharge conveyor moving the heavy fraction resulting from the separation of the screen overflow. Application, layout and construction of magnetic separators vary and can be adapted to the specific conditions of the operation.

Table25: Types of magnetic separators used in composting

Type	Description	Comment
Magnetic drum separator	Magnetic drum as deflection roller for deflection or lifting of ferromagnetic particles from the stream, discarding or lifting operation, disc- or lateral design	Use for household waste and secondary treatment of compost
Magnetic conveyor separator	Super-structure-conveyor-magnet; magnet with continuous conveyor, extracts magnetic particles laterally or lengthwise from the material-stream; discarding operation; disc- or lateral design, with permanent- or electro-magnet	Use for household waste and secondary treatment of compost

7.5.4.4 Heavy fraction separation

Large composting facilities use wind sifters and air-settling separators to remove glass, earthenware and other cullet with a relatively high specific weight. Ballistic separators have not been proven to be successful. More recent developments were applied to zig-zag wind sifters, floating wind sifters and stone separators (settling separators) (Ehrig, 2003).

Collision separators sort according to elastic characteristics in particular their malleability. Single grains are dropped onto a bevelled surface and are deflected at different trajectories.

- Prerequisite: narrow particle size range → best for homogenous fine-compost
- Separating capacity: in mineral products up to ca. 85 % of the stones can be separated

Sorting according to elastic characteristics: utilization of differences in the material hardness		
Cascade-heavy fraction separator	Feeder moves the sorting-stream to deflector-rotators, which pull elastic material along and discards hard materials	Processing of raw compost for separation of hard, inorganic particles

7.6 *Compost storage*

During this final stage of the entire compost production process the majority of the nitrogen is bound to humic substances (> 90 %). Humification (mineralisation) and clay-humus complexion proceed at a low but steady activity level, especially if adequate moisture levels are maintained.

This makes it necessary, even during the final storage of screened compost, to provide aerobic conditions. If the screened material (mainly at a mesh size of 10 to 25 mm) is stocked in piles of 1.5 to several meters in height, it compacts easily resulting in a reductive, anaerobic zones forming. The consequences are: denitrification, formation of ammonia, nitrous oxide (N_2O), sulphides and consequently possible low performance in germination and growth tests (i.e. it remains phytotoxic).

In addition exposing the compost to any excess of water must be avoided not only to prevent anaerobic conditions forming, but also in order to prevent plant nutrients from leaching and being drained off.

7.6.1 Basic functions

Main functions of compost storage:

- Well managed storage in order to maintain a final product that is appropriate for use in a number of different markets without causing any odour emissions;
- Regular turning and adjustment of the moisture content until the compost is used or marketed;
- Compost that has more or less completed the decomposition process (stable); and
- Storage of ready-made compost in order to bridge market fluctuations.

Important measures:

- Protection against rainfall;
- Protection against drying out;
- Protection against contamination (wind drifted seeds, re-infection with not sanitised materials adhering to loaders etc.);
- Mechanical agitation (turning) or aeration;
- Depending upon the marketing concept, loading onto lorries or packing into sacks; and
- Producing blends with mineral additives or peat.

7.6.2 Possible emissions

- Surface water from rainfall which might be contaminated with compost residues. If stored under roof or covered with geo-textile no process or percolation water may be expected
- Dust – wind drifting of fine compost particles

7.6.3 Infrastructure and technical equipment

Minimum requirements:

- Storage capacity for at least a quarter of the mean yearly compost production (external storage sites may be accommodated within this)
- Protection against rainfall and nutrient leaching
  - Depending on the climatic conditions roofing or covering with geo-textiles of stored composts

Non obligatory, supplementary equipment

- If not stored under a roof, the complete sealing of the surface is of advantage to enable continuous and clean material manipulation independent of the climatic situation. This is not obligatory if covering with geo-textiles is available to protect the compost against high rainfall events.

Requirements for the storage of composts on unsealed open ground

- At a yearly precipitation of > 1000 mm stored composts must be roofed or must be covered with geo-textiles in the case of heavy rainfalls respectively
- Requirements for an unpaved ground
  - The surface should be on a slight slope (ca. 3 - 5%) and no mould???
  - Minimum distance from surface waters: > 75 m
  - Minimum distance from a spring or well: > 100 m
  - Annual relocation of the composting site is not necessary as the surface soil under the composting piles tends to compact and become blocked by fine sediments
  - Storage is not permitted in water protection areas
  - Storage is not permitted on light sandy soils or gravel with an high percolation potential to the ground water body
  - Storage is not permitted on sites which where there is the potential for landslides or floods
  - Storage without fleece coverage for a period of more than 3 weeks should not be carried out on sites where the groundwater level is less than 200 cm below the soil surface

7.6.4 Requirements for process management and documentation

Duration of compost storage

- Depending on the intended compost use, maturation/stability, marketing in relation to the material throughput, storage of compost may last from one day to several months
- Sieved, fine compost should only be stocked in windrows or heaps (maximum height 3 m) if sufficient stability/maturity has been achieved. The higher the compost heap the more frequent the compost must be turned. However the temperature should be constantly sustained below 30 °C otherwise it goes against the requirements described in Chapter 7.4 Maturation.

Turning of processed compost

- Compost, even when sieved and matured to a certain *stability* level is still a biologically active organic material. Organic matter contents range between 20 and 45 %. Regular mechanical manipulation/turning is necessary in order to provide the oxygen demand for the residual microbial activity. As a rule, turning intervals of 3 to 4 weeks would meet this requirement.

Further requirements

- Avoidance of secondary re-contamination with pathogens caused by using machines contaminated with material which had not undergone thermal sanitisation or process water stemming from the tipping area or the active decomposition phase
- Unequivocal designation of the individual compost batches and a traceable allocation of the compost batches to the declaration sheets, quality approval, compost certification and labelling.

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9 Glossary – basic definitions

ABP / ABPR	Animal By-Products / Regulation. ABP as defined by the Animal By-Products Regulation (EC) no. 1774/2002. The regulation is being amended between 2007 and 2009. The new regulation will be published between September und December 2009.
Agricultural composting (AgrC)	Composting facility run by farmers with the main purpose to use the compost as organic fertiliser and soil amendment on the own farmland. This includes composting schemes which are operated by cooperatives. Input materials are restricted to source separated organic household waste (*brown bin*), green waste, manure and eventually waste from agro-industries and catering waste from restaurants. Agricultural composting should follow the principle of decentralised composting
Anaerobic digestion (AD)	Fermentation process of organic feedstocks under anaerobic conditions with the objective to produce a methane-rich gas as renewable energy resource, liquid or solid digestion residues (digestate) can be used as organic soil amendment. Solid digestate can be composted together with structure material or other organic feedstocks and used like compost.
Biowaste	Traditionally: Source-segregated biodegradable waste of an organic or putrescible character. It is used in line with the term *'organic waste'* which represents the source separated fraction of municipal waste collected from households and similar premises. In the context of this report it does not include *'former foodstuff' from retail premises which include meat or is in contact with raw meat.* Definition of draft revised Waste Framework Directive: 'biodegradable garden and park organic waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants'
Biowaste compost (BWC)	Compost produced from biowaste
Compost batch	A separately stocked pile of rotting material or ready made compost manufactured in a uniform process.
Compost classes	Compost classified according to quality levels. In many cases, the classification refers to heavy metal concentration classes, which are related to specific use restrictions.
Compost declaration	The classification of a compost batch in a quality class, stating at least one possible area of application based on the test results and the report from the last external quality inspection.
Compost products	Composts fit for use
Compost specification	Information which specifies compost properties for an application
Compost types	Composts made from specified categories of source materials
Community composting	Activities range in scale from individuals or small groups working on allotment sites or promoting home composting, to social enterprises with Local Authority contracts providing kerbside collection services. In any case the local community is involved in the management of the organic waste they are producing and are not-for-profit and locally accountable organisations. Scales of treatment capacities range between < 10 to 100 m³ /y (www.communitycompost.org/index.htm [29/11/2008])
Decentralised biowaste management and composting	'Decentralised' here includes: Any source separation and composting scheme for organic household waste and green waste which implies not more than approximately 30 km distance between the point of collection and the composting plant (*proximity principle*). This figure is an approximation. In sparely populated areas with a distance of more than 30 km from the next settlement this would mean that it should consider to install its own small-scale composting plant. In principle decentralised schemes can be performed by means of:

	■ Home composting, On-site and Community composting as a mean of waste prevention ■ Municipal Green Waste Composting (MGWC) ■ Agricultural (on-farm) Composting of source separated organic household waste and green waste with the aim of predominantly using the compost on the own agricultural land ■ Composting plants with a maximum yearly throughput of approximately 5000 tpa, by respecting the proximity principle
External compost quality approval	: checking of compost quality on behalf of the compost producer by means of regular sample taking and analytical measurements by an authorised laboratory giving a statement of compliance with the requirements for the processing and product of compost
Food waste	For this report we use the term food waste synonym to organic kitchen waste or catering waste from domestic origin and restaurants. It does not include former food stuff from commercial sources as defined by the EU Animal By-Product Regulation.
Garden waste	Vegetation waste from private gardens
Garden and Park waste (Green waste)	Vegetation waste from gardens, parks, landscape maintenance including tree cuttings, branches, grass, leaves, prunings, old plants and flowers.
Green waste compost (GWC)	Compost produced from green waste
Heavy metals	Even if chemically not fully correct we use heavy metals for the potential toxic elements Cd, Cr, Cu, Hg, Ni, Pb and Zn
Home composting	Or backyard compost; composting of organic kitchen and garden residues treated on the property of its origin, the private garden. The compost is recycled to the own garden property. Depending on household size, garden size and management the scale is between < 1 to 5 m^3 per year (ca. 0,75m^3 per 100 m^2 garden)
Mixed waste compost (MWC)	Unless otherwise specified, this refers to compost derived from refuse, or from a biodegradable fraction which is separated from the refuse following its collection within the residual waste stream
MS	Member States of the European Union
MSW	Municipal solid waste
Municipal green composting (MGC)	Collection and composting of the municipal (public) park and garden waste together with source separated green waste from private gardens and eventually commercial or other entities by the responsible department of a Local authority
OFBMW	Organic fraction of biodegradable municipal waste. As defined by the National Strategy for Biodegradable Waste this comprises mainly food and garden waste from the household and commercial sector
Pre-processing	Methods of starage and intermediate stabilisation such as an anaerobic fermentation (ensiling) step prior to systematic aerobic composting. It uses in most cases specific inoculants
Proximity principle	Advocates that waste should be disposed of (or otherwise managed) close to the point at which it is generated, thus aiming to achieve responsible self-sufficiency at a regional/or sub-regional level Proximity Principle seeks to promote the management of wastes as close to their point of production as possible. The transportation of waste itself can have a negative impact on the environment as well as being extremely costly. The Proximity Principle therefore strives to follow environmental best practice as well as offering a cost-effective method for waste disposal. (National Waste Strategy for Scotland)
QAO (Quality Assurance Organisation)	Organisation carrying out the external independent quality assurance scheme for composting plants. In most of the cases this includes the awarding of a quality label for the certified compost products

QAS (Quality Assurance System)	External independent quality assurance scheme for composting plants. This includes the approval of plant operation (process management) as well as product certification according to existing compost standards.
QM (quality management)	Management required for the entire process of compost production. It starts from the receipt control of delivered feedstock materials and ends with final product storage and dispatch of compost to the customer. QM systems comprise a traceable documentation system to be checked by external QSO or the competent authority if it is part of the licensing and compost related legislation.
Residual waste	This is waste collected from households, commerce, and industry, which has not been separated at source.
Stability / maturity	Stability is the level of biological activity in compost. Unstable compost consumes nitrogen and oxygen in significant quantities to support biological activity and generates heat, water vapour and carbon dioxide. Stable compost consumes little nitrogen, oxygen and generates little heat and carbon dioxide. If stored improperly or unaerated unstable compost can become anaerobic giving rise to methane, nitrous oxides and ammonia which creates an odour nuisance. Continued decomposition when these unstable composts are added to soil or growth media may have negative impacts on plant growth due to reduced oxygen in the soil root zone, reduced available nitrogen, or the presence of phytotoxicity compounds. Maturity can be defined as the point at which the end product is stable and the process of rapid degradation is finished, or, a biodegraded product which can be used in horticultural situations without any adverse effects. Maturity is a measure of the compost's readiness for use.
VFG	Vegetables, Fruit, and Garden waste. It has special significance in regions where *brown bin* collection is restricted to pure meat excluded source separated organic waste from households. (mainly rolled out in Flanders/Belgium and The Netherlands

10 Acronyms and annotation

% (m/m)	mass related percentage
% (v/v)	volume related percentage
a	year (*L.*) annum
ABP	Animal By-Products
ABPR	Animal By-Products Regulation (European Commission № 1774/2002)
ACP	Agricultural Composting Plants
AD	Anaerobic Digestion
AgrC	Agricultural Composting
ASP	Application Service Provider
BAT	Best Available Technique
BGBl	Bundesgesetzblatt → Federal Law Gazette (FLG)
BSE	Bovine Spongiform Encephalopathy
C	Carbon
°C	Celsius/centigrade
ca.	about, approximately, (*L.*) *circa*
CaO	Calcium Oxide
Cat.	Category, in the context of an catogry of animal by-products as defined by the EU Animal By-Products Regulation
Cd	Cadmium
CEN	*Comité Européen de Normalisation* (*F.*) (Belgium) - European Committee for Standardization
CH_4	methane
CO_2	carbon dioxide
COM	[European] Commission
Cr	Chromium
Cu	Copper, (*L.*) *cuprum*
d.m.	dry matter
e.g.	for example, (*L.*) *exempli gratia*
EC	European Communities
equ	equivalent
et al.	and others, (*L.*) *et alii*
etc.	and so on, in similar respects, *(L.) et cetera*
EU	European Union
EWC	European Waste Catalogue
ECCP	European Climate Change Programme
f.m.	fresh matter
FLG	Federal law gazette
G&P	Garden and Park [waste ; compost]
GHG	Greenhouse Gas
GWC	Green waste compost
h	hour(s)
H_2S	Hydrogen sulphide
ha	hectare
HACCP	Hazard Analysis Critical Control Point
Hg	Mercury, (*L*) *hydrargyrum*
i.e.	that is [to say], *(L.) id est*
IPCC	Intergovernmental Panel on Climate Change (United Nations)
K	Potassium, *(L.) kalium*
kg	kilo

LCA	Life Cycle Assessment
m^2	square metre
m^3	cubic metre
MBT	Mechanical Biological Treatment
Mg	Magnesium
MS	Member State(s) [of the European Union]
MSW	Municipal Solid Waste
N	Nitrogen
n.a.	not available
N_20	nitrous oxide
Ni	Nickel
OC	Organic Carbon
OM	Organic Matter
P	Phosphorus
Pb	Lead, (*L.*) *plumbum*
pH	Quantitative unit of measure of acidity or alkalinity, (*L. pondus Hydrogen*i)
QAS	Quality Assurance System
QM	Quality Management
SOM	Soil Organic Matter
t	tonne (metric 1,000 kgs) / ton (imperial)
t/a	tonnes per annum
VOC	Volatile Organic Compounds
WFD	Waste Framework Directive
Zn	Zinc

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