Biological Waste Treatment

Unit 5

Composting Techniques

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5 Aerobic technics

5.1 Basic Potentials for Composting

The composting of municipal waste should generally be categorised into self-com-posting backyard composting, which can be seen as a measure for waste avoidance, and composting in technical plants.

Backyard composting of household waste has special importance since

- no permit is required for construction and operation
- no emissions are produced due to external collection and transport
- the produced composts themselves are utilised. As a result attention is paid by the households to ensure that the compost is free of foreign matter and the marketing costs do not apply.
- the environmental consciousness is increased by the activities related to backyard composting
- no costs for collection, transport, compost production and on-site marketing are created
- the amount of waste to be disposed of is reduced.

It should be considered that backyard composting can only be determined for partial currents under waste management aspects on a level of regional authority. With respect to the current hygiene discussion refer to the chapter "Hygiene". Collection, transport and treatment in technical plants is necessary for biowaste, which is not disposed of by means of backyard composting (see *Chapter 5.1.1 Backyard Composting*).

5.1.1 Backyard Composting

The decision at the household level as to what extent backyard composting is carried out depends on many factors, the most important of which are subsequently concisely represented. [33], [43], [44].

5.1.1.1 Local Conditions

An area to place the composter and a garden for compost use are both necessary with respect to both the possibilities of backyard composting as well as the closed loop circulation of the compost as soil conditioner or secondary resource fertiliser. If kitchen waste is also composted along with garden waste a deposit area of at least 25 m^2/E [44] should be available as to avoid over-fertilisation.

5.1.1.2 Composting Technology

The applied composting technology determines the handling and the respective work effort involved, the total aesthetic impression, the decomposition process depending on the atmospheric conditions and possibly disturbances. In the field layer-wise piling of the waste in a windrow or in an open composter (such as wooden or plastic slat systems) is preferred (*Figure 5.1*). Constructions made of galvanised meshed metal baffle or wire gauze are not recommended due to the corrosive characteristics of the compost, which causes the displacement of the zinc into the compost. In the last few years closed systems with perforated side walls, floor grates, some even insulated, have been increasingly introduced to the market for the intensification of the decomposition process, higher aesthetic standards and as protection against rodents and birds. The handling of these closed systems with respect to removal of the finished compost (e.g. through flaps or side wall segments) is, however, complex and does not have any advantages over the simple slat systems. In winter large windrows and silos have a clear advantages due to their surface to volume ratio, along with less heat radiation. By the same token composters with insulation exhibit significantly better efficiency of degradation. The necessary decomposition time is approximately 6 weeks for mulch material, approx. 6 - 12 months for matured finished compost. Here at least one turning is necessary.

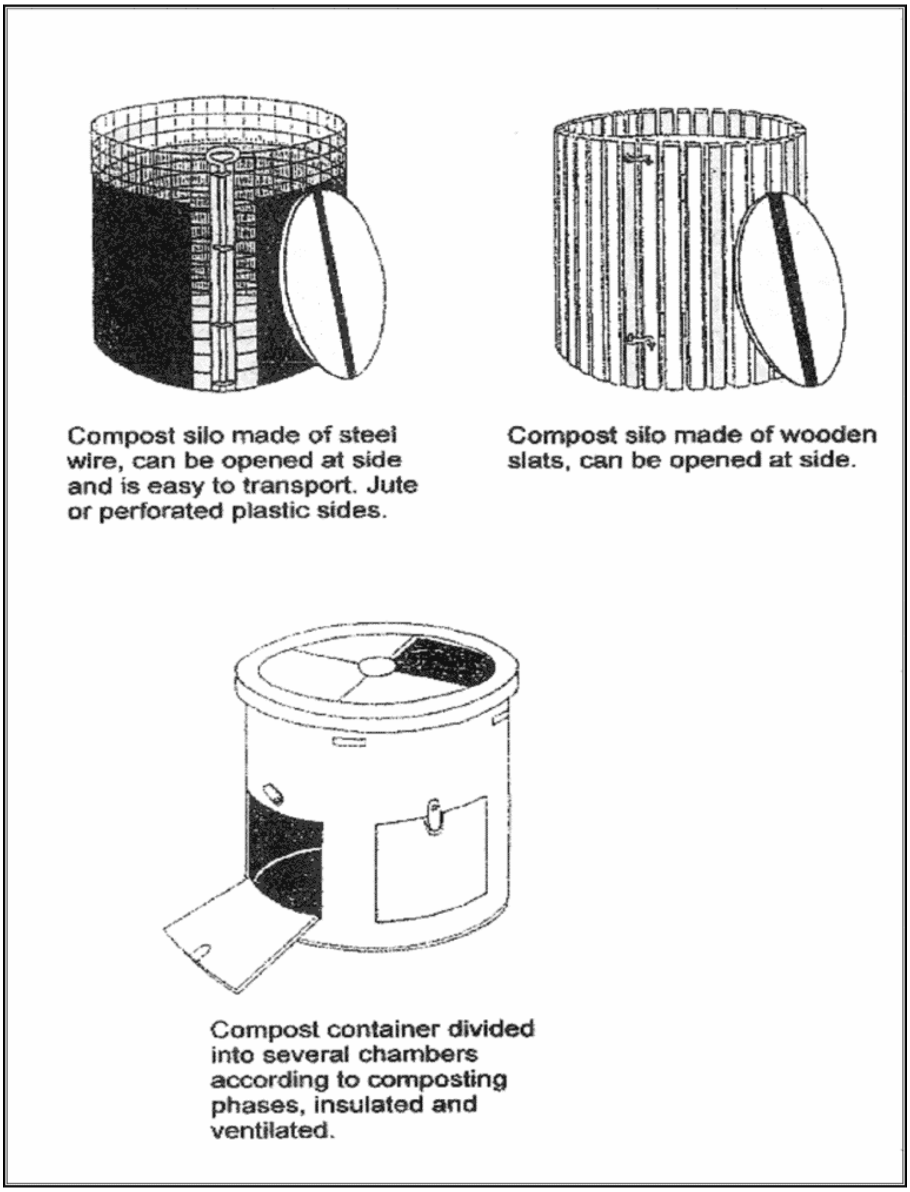

Fig. 5.1: Composter for Bachyard Composting

5.1.1.3 Waste Management

Waste management constraints have a significant influence on backyard composting. Aside from container volume supply in the case of the residual waste container, the fee structure (probability scale (contra-productive) and/or reality scale (supportive)), the fee assessment of the biowaste collection, fee discounts for backyard composters and potentially subventions for backyard composting (e.g. partial payments for composters) effect the behaviour or the population towards waste. The portion of composting garden-owners ranges from 65% (municipalities >10,000 pop.) through 85% (municipalities <1000 pop.) [44]; the total amount of waste composted within the household is currently estimated to be around 5 million Mg/a. In Germany, that means 60% of the material which is composted in technical plants

5.1.1.4 Motivation and Level of Awareness

In order to avoid aberrations and set-backs households that operate backyard composting should be motivated accordingly. This applies in particular to the choice of basic composting material, the avoidance of undesirable emissions, the composting technology and the use of the compost in order to exclude the possibility of over-fertilisation. The amount of work and time involved in backyard composting (composter feeding, composter maintenance, turning and sieving) requires high motivation, which should be supported with the appropriate public relations work in connection with fee advantages. Aside from the distribution of information on the advantages of backyard composting and its implementation (e.g. compost handbook from the German federal environmental agency) [2] good experience was had with targeted training courses by garden professional consultants. In smaller gardens even the composter itself is an important factor (with reference to aesthetic acceptance).

Below several essential factors for successful backyard composting are specified:

In general all garden waste is suitable for composting, as long as it does not contain any phytopathogenous components (e.g. plant infection illnesses). Tree and shrub clippings should be put through the chipper before composting. Shredders are better than cutters since the surface area that is biologically effected is increased. Grass clippings should be applied to the compost wilted and/or mixed. Types of foliage with high portions of tannic acid are difficult to degrade (oak, walnut, chestnut, poplar, birch, acacia).

Kitchen waste can be composted well; albuminous waste (meat and sausage products, cheese) and prepared catering waste should not be composted without consideration for rats and mice, as well as fly larvea. If necessary it should be covered with soil or matured compost and possibly lime. Newspaper and coarse board without plastic coating is also good for composting as a structural material. The contents of vacuum cleaner bags, as well as coal ashes, do not belong on the compost pile due to their contaminant content.

In terms of an ideal decomposition process attention should be given to good ventilation. Therefore closed trenches or closed containers without perforation are not suitable. An adequate water supply is essential; in the case of dry waste and longer aridness watering is suggested. Too much water should also be avoided since there is then too little free air space and the air supply is affected (endangering the decomposition formation). Mixing different basic composting materials improves the pore structure, water content and nutrient supply of the micro-organisms. Matured compost functions as a starter when applied to a new compost pile due to the microbes it contains. Additional bacteria compounds (starters) are unnecessary. Loamy gardening soil and clay minerals as a part of the clay-humus-complex (permanent humus) are of advantage with pure sand soils. After a decomposition time of around 3 months the compost pile has to be turned. Here the water content can also be regulated.

A shady spot in the garden, which is sheltered form the wind, is recommended. The *Location* subsurface has to be water permeable and best laid out directly on the ground (prevention of the formation of moisture build-up, more favourable for earthworms etc.). The concerns of the neighbourhood should be taken into consideration for the location selection.

Neighbourhood composting can be noted as a special case of backyard composting (Example: City of Zurich) [3]. Here backyard composting is carried out collectively by the inhabitants of multi-storey housing. In the city of Zurich 450 composting locations of this sort are in operation to process the biogenous waste of approx. 17,000 inhabitants.

Here the following conditions should be maintained:

- Good, permanent informational work has to take place
- Motivated supervising groups, which assume the responsibility and implementation of composting, are necessary.
- The housing administration has to approve the composting.
- Sufficient green space has to be available (rule of thumb: green space/building area >2)
- The design of the composting location must be functional and fulfil the aesthetic needs
- A social and optical integration of the composting location into the settlement is therefore necessary.

Aside from the altruistic theme "practising environmental protection" and potential fee savings the encouragement of social contact and improvement of the surroundings due to the corresponding open space design and use (e.g. berry and wild flower garden) should, above all, be noted as advantages. [24]

It should be observed that neighbourhood composting is dependant on the dedication of the individual and the acceptance of all inhabitants. To what extent urban settlements with heavy population fluctuation can secure the functional safety of neighbourhood composting is questionable. [18]

5.2 Technical Composting Systems

For the composting of larger quantities of separately collected biowaste technical plants are necessary. Thereby one should differentiate between decentralised and centralised plants.

An objective classification into "decentralised" or "centralised" plants is not possible in general. With respect to the situation in the Federal Republic of Germany with obligatory disposal regional entities on the county and city level the classification can take place based on the number of inhabitants with access or the unit throughput. At the same time this classification also includes the type of operation.

The maximum number of inhabitants per unit can be set at 10,000 and/ or the max. throughput at less than 1000 Mg/a. The operation of the unit is carried out by a gardening centre or farms, which operate the unit with their own personnel and in the machinery ring organised machine park through to the own use of the compost.

Composting of green waste has already been being carried out decentralised in many regional entities for many years. Decentralised systems are not common for biowaste composting. The compost yards in the rural district of Ebersberg are one example (throughput approx. 650 Mg/a), [23]. In *Table 5.1* the advantages and disadvantages of the decentralised process are listed.

In decentralised units the composted amounts are marginal due to the developments in recent years with a high level of access in urban areas, emission reduction, the necessary organisational work, quality control and costs combined with increasing transfer of the planning, construction and operation of composting plants to disposal companies. The tendency exists towards plants with increased throughput. [17]

Tab. 5.1: Advantages and Disadvantages of Decentralised and Centralised Composting (according to [4] et al)

Criteria	Decentralised Composting	Centralised Composting
Plant size	< 1000 Mg/a	>> 1000 Mg/a
Inhabitants with access	< 10,000 I/Plant	>> 10,000 I/Plant
Settlement structure	Rural structure	Rural and urban structure
Permitting procedure	< 0.75 Mg/d; potentially needs building permit	> 0.75 Mg/d (6570 Mg/a) emission protec tion permit. Simplified process through 87,600 Mg/a
Biowaste treatment technology	Manual sorting of coarse foreign materials from the windrow. Chopping of garden waste by chippers, mixing through sprea ding	Mechanical processing technology de- pending on processing: decompacting, screening, Fe-removal, foreign substance removal, homogenisation, mixing
Decomposition technology	Open windrow process (without forced ventilation), in part with turning. Mobile aggregate.	Open and encapsulated processing tech- nology, intensive decomposition process, often and, if necessary, automatic turning, decomposition control, watering, usually permanently mounted aggregates, screening out, densimetric separation, sighting generally by attached aggregates
Fine processing tech- nology	Screening through mobile aggregate	
Plant operation	Composite system. Exchange of person- nel and machines (e.g. machinery ring)	Personnel and machines on location, lo cal entities, disposal companies

	Agriculture, GA-LA-BAU	
Emissions	Freight is marginal through small plant, concentrations relatively high since there is no encapsulation	Relatively large freight due to large plant, concentrations are relatively low in the case of plant encapsulating
Specific surface area requirement	Relatively high, since there are large dis- tances and work area compared to de- composition space	Relatively low due to favourable surface are use, among others by a compact de composition system
Location selection	Several locations necessary, usually diffi- cult	Only one location is necessary, accep tance difficulties
Local identification	Relatively high, since it is manageable and close to the drainage area	Low, as a result usually little acceptance
Transport distances	Short distance to collection area and to compost use area, little transport needed	In part long approach distances from local entities, long distances to area of use, much transport needed
Compost quality	Fluctuating due to local and temporal fluctuations, intensive decomposition supervision requires great deal of work	Relatively constant since local and temporal compensation is possible, decomposition process and foreign substance removal is possible in a more targeted manner
External control	Requires a lot of work, not as manageable due to more individual plants	Easily manageable since there are com paratively few plants
Organisational work	High due to the exchange of personnel and machines	Relatively low since personnel and machi nes are on location
Marketing Specific costs	Local sales potential, high identification with the product, depends strongly on plant operation and marketing costs as a result of	Time-consuming, interregional marketing is generally necessary. Relatively high portion of capital expenses, especially with technically-complex plants; substantial cost digression with increasing throughput

	simple technology usually less in comparison	

5.3 Composting Technology

5.3.1 Principle Composition of Composting Plants

The process procedure in biowaste composting plants can be basically divided into the steps represented in *Figure 5.2*. Often it is advantageous in the field to establish the individual steps as operational units in order be able to clearly define the interfaces and assign the functions.

5.3.1.1 Receiving and Mechanical Processing

A) Weighing and Registration

All delivered waste, as well as the material flow that leaves the plant such as compost, removed Fe metals, in addition to sorting, screening and optically removed residues, are weighed and registered in the entrance area. Here the transport vehicles should normally be weighed when entering or leaving the site in order to record actual transported material quantitatively. In the case of frequently implemented vehicles (e.g. collection vehicles) only one weighing of the full vehicle takes place in the field and the load weight is calculated by using knowledge of the vehicle tare weight (mean value), e.g. establishing the load weight based on the vehicle tag. Fee revenues should be recorded.

These measures are necessary in order to make a mass balance of the material flow possible, to provide for internal and external accounting (waste fees, compost revenues) and conduct optical control of entering and exiting vehicles and their loads. With respect to efficient clearance and minimisation of the administrative costs is advisable to automate the weighing and payment procedures by means of electronic data processing systems.

B) Receiving and Interim Storage

Although it is possible, in principle, to do without interim storage options (e.g. in composting plants with very little throughput or plants with regular material delivery) it is generally necessary to allow for it. It should perform the following functions:

Defined delivery area for the vehicles; no external vehicle traffic in the processing and decomposition section

Interim storage possibilities for individual batches for later homogenisation

Optical control of the delivered batches with the possibility of removing coarse wrong sorting or extremely contaminated deliveries.

Creation of the possibility for simultaneous delivery by different vehicles

Buffer for peak loads and short operational interruptions

Guarantee of continuous throughput for the following processing, (decoupling of delivery and processing).

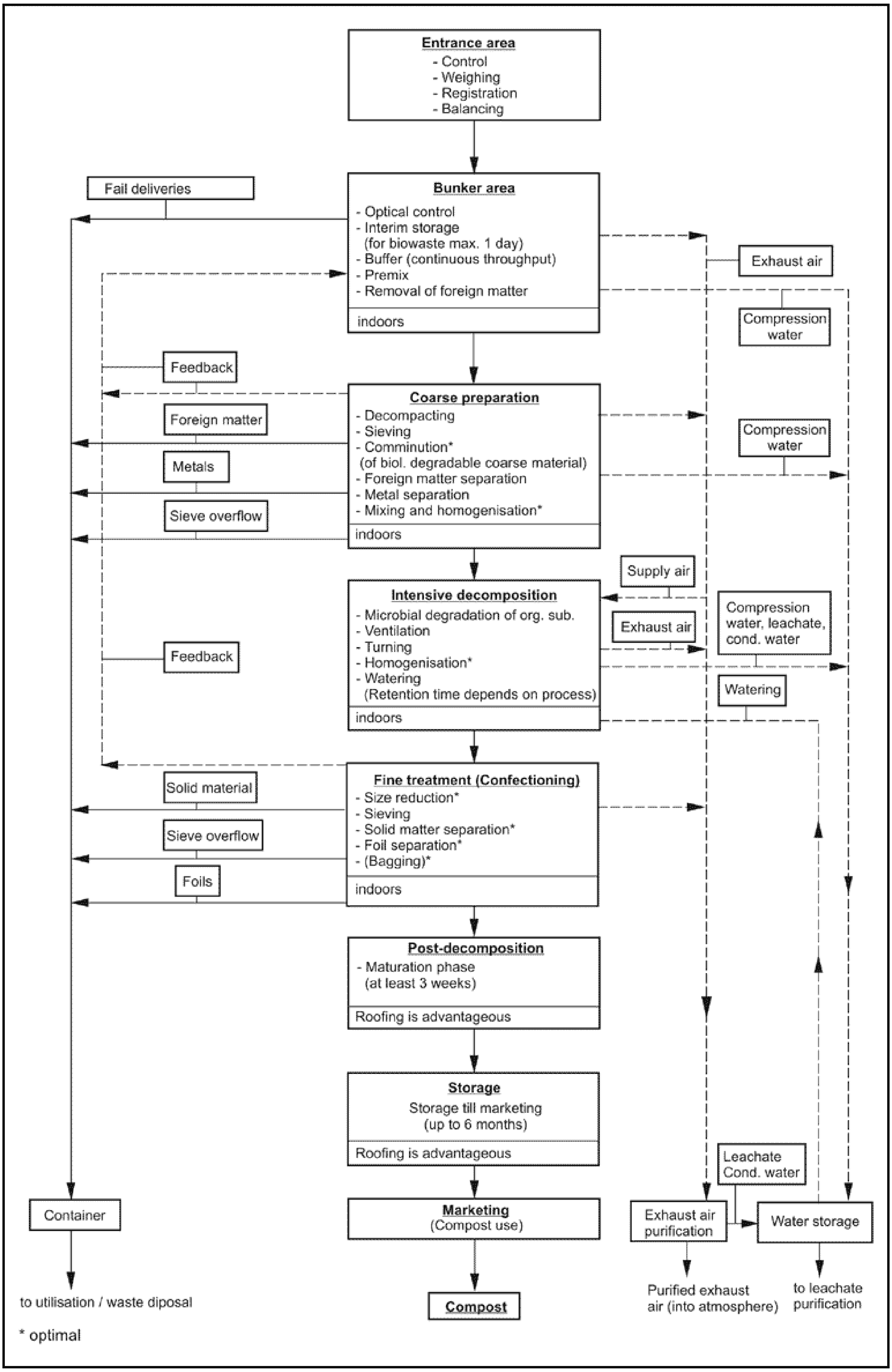

Fig. 5.2: Process Schema of a Biowaste Composting Plant

This interim storage should be limited to one day for biowaste in order to avoid the formation of odours and leachate combined with emissions associated with potential self-heating or an anaerobic reaction. The delivery area should be closed in to minimise emissions so that targeted exhaust air ventilation is possible in individual areas.

For plant waste that is to be used as bulking agent (e.g. tree and shrub trimmings) other interim storage should be planned depending on the collection system and rate. These bulking agents can generally be stored in an open storage for several weeks.

C) Coarse Treatment

With the treatment of the waste before composting three goals are pursued:

- Production of a basic composting material that is free of foreign and disturbing substances
- Adjustment of the optimised characteristics of the decomposition material
- Selection of the disturbing materials of subsequent process steps.

This treatment process is generally necessary since it can be assumed that the biowaste has a hazardous and foreign material content of more than 2% in the case of extensive area-wide collection despite high separation effectiveness and that, due to the container system, the delivery of coarse waste elements can not be ruled out. The subsequently described process steps are suitable for this purpose, which are either carried out in the respective specifically designated aggregate or several functions are assumed by individual aggregates. In general, not only the selection of the appropriate aggregate itself is of significant importance for successful and sensible treatment, but also the calibrated order of the aggregates among one another.

Size reduction has the task of decompacting the delivered waste and reducing its unit size so much that no clogging results in the subsequent process steps or problems with particles whose measurements are too large for the conveyor aggregates whereby material can not be fed continuously through the plant (e.g. positioning itself transversely or falling from the conveyor belt, clogging at transfer points etc.). The main task, with respect to composting, is enlarging the specific surface area of the waste and as such make it more microbially susceptible, as well as improve the absorbency of water or additives. At the same time a certain level of homogenisation can be achieved. Size reduction is not to be carried out generally with all biowaste. Depending on the size reduction method (e.g. hammer mill) the danger exists that cell water from the waste could be set free and result in agglutination or the formation of leachate. Size reduction of the entire biowaste leads to more wear on the size reduction aggregate, mostly due to abrasive elements (sand etc.), than if only certain fractions are reduced. It would lend itself to only reduce certain batches completely that are made up of coarse material (e.g. tree and shrub trimmings), while only the oversize particles are reduced from the biowaste from separate collection. The material should be feazed out by size reduction so that the surface area is increased (beating, tearing, squishing); chipping and cutting are only somewhat appropriate methods.

Often biowaste in households is collected in tear-resistant paper or plastic bags, although the local authorities may not advise it and in some municipalities the disposable collection system is implemented as a sack system. In both cases it is necessary to open the sacks for a targeted subsequent treatment or sorted decomposition process. This is realisable in aggregates for this purpose or e.g. during the size reduction or screening process.

Screening has the function, as a part of the coarse treatment process, of classifying the waste into the desired particle sizes. Here oversize particles that could inhibit the subsequent processing cycle should be separated out. At the same time coarse and non-degradable foreign materials (e.g. plastic bags) can be removed for subsequent foreign material removal and biowaste is isolated from the material for separate size reduction. The screening size here is around 60 to 100 mm. The screening of the fine fraction with the goal of reducing the heavy metal load of the compost is not feasible with biowaste since it can not be effectively separated due to the high water content and the associated adhesion on coarser constituents (clumping, clogging of the screening sieves).

Aside from the removal of coarse noticeable foreign materials (e.g. coarse iron parts, tree trunks etc.) in the receiving area the removal of foreign materials from the biowaste is sensible in order to keep non-compostable constituents or hazardous material out of the decomposition process. Since this separation can only be carried out manually (as of recently mechanically with robots as well, although this is in a rudimentary stage) only the fraction flows should be treated, with which the removal is effectively possible. This generally means that the entire flow of biowaste can not be sent through selection, also due to hygienic concerns.

Since the delivered biowaste often does not have an optimal composition for composting with respect to its structure and its water content, depending on the catchment area, the collection system, the season and the given biowaste definition, it is necessary in such cases to be able to add water, bulking agents or other additives. The even distribution is guaranteed by a mixing aggregate. In the field it is sensible to add approx. 10 to 30 weight-% of bulking agents depending on the above mentioned conditions. The water content in biowaste should be in the area of about 50 to 65 % with consideration for a regulated air and nutrient supply.

For improving the surrounding conditions for the micro-organisms and thereby intensifying the decomposition homogenisation is advantageous in order to ensure diverse substrate composition locally. This homogenisation is not necessarily required but can make intensification of the decomposition process possible especially with static decomposition systems. In this case retention times of at least 20 to 30 minutes are necessary in the homogenisation aggregate. The mixing can take also place satisfactorily in smaller plants in connection with size reduction aggregates or screening (screen drum). In all cases homogenisation requires an aggregate.

The separation of iron contingents can take place according to the magnetic principle. In this separation does not deal mainly with the actual iron fraction that is not detectable in smaller particle sizes after the decomposition process; at the same time hazardous material removal is possible since the heavy metals in steel or in combination with iron metals (e.g. coating, joining elements, among others) can be selected. This separation should take place in the positions in the process, in which these materials are more easily accessible due to proceeding processing steps.

5.3.1.2 Intensive Decomposition

Intensive decomposition forms the core of composting plants. There organic substances are decomposed by micro-organisms by being converted into new organic compounds, in part also as a substance from its own compound, gases (especially carbondioxide) and water. The goal is the recovery of a soil improver with defined character properties. The decomposition systems should be designed and controlled accordingly so that the oxygen supply is ensured in the entire decomposition system and the water content is in an optimal range (free air space). Decomposition guidance with operational safety has to be guaranteed. Emissions should be reduced depending on the location, which is only possible in many places with encapsulated decomposition systems with respect to today's permitting practice. Therefore the surface area demand should be maintained at a minimum for reasons of economy.

The decomposition times are dependant on the required degree of composition at the end of the intensive decomposition phase and range from a period of a few days to up to around 12 weeks, which inevitably influences the following maturation phase.

Fresh compost with the degree of composition II should be produced within a decomposition time of 8 to 10 days, matured compost with the degree of decomposition IV are not to be produced in less than 8 to 10 weeks even with optimal operation management.

5.3.1.3 Fine Treatment (Confectioning)

Fine treatment, which typically takes place after the intensive decomposition, serves to produce defined compost qualities (e.g. in compliance with BGK (German Federal Compost Quality Assurance)) with respect to particle size, heavy solid matter and foreign matter content.

In the case of highly receiving-oriented plants with alternating quality requirements the fine treatment should logically take place shortly before the compost is handed over. In this treatment process it is therefore carried out after storage in such cases.

Interim storage should be carried out before fine treatment, especially in semi-dy-namic decomposition systems with very high hourly discharge capacities, in order to make continuous utilisation possible and along with it an economically sensible layout of the fine treatment. These interim storage capacities should be oriented on the discharge capacity of the decomposition and throughput capacity of the fine treatment.

Depending on the decomposition system, especially the type of discharge system, the compost may be available in larger agglomerates (e.g. chunks). In order to improve the handling and the yield of the fine treatment a size reduction unit can be installed. Here larger pieces of the structure material should be crushed which, de-

pending on the screen size, reduces the screen overflow. Since the size reduction capacity has to be relatively low compared to coarse treatment small aggregates (usually rapid rotors and lump dispersers) can be implemented.

In order to produce defined compost according to its area of utilisation screening is necessary. The screen sizes are here according to customer demands at 8 to 12 mm (fine particles), 16 to 20 mm (medium particles), 20 to 30 mm (coarse particles). [1]

Oversize particles can be refed as a bulking agent or released as mulch material.

Materials with high density such as glass and clay shards, as well as stones, should be removed from the compost to improve the compost quality. To what extent heavy solid matter separation should be carried out depends on the purity of the processes biowaste and customer expectations. In smaller plants this step is usually omitted.

A foil separator can follow, if necessary, in order to remove plastic foil. This is not generally necessary for small particle sizes since the foil is larger than 10 mm in the fraction; one area of use can be seen in the improvement of the return material (oversized particles).

In individual cases mixing aggregates for mixing in additives should be implemented for the production of composting soil, culture substrates or fertilisers. These have to be adapted to the specific conditions.

In special cases compost is briquetted in order to produce substrate fertilisers. Whereby the briquettes may be dried for better storability, if necessary.

Bagging has the advantage of simplifying the storage and transport of the compost when marketing through chain stores or targeted sale to small-scale customers. At the same time an advertising effect is provided by bagging; the bag can serve as information carrier e.g. pertaining to the contents and compost use.

5.3.1.4 Maturation Phase

A maturation phase should be planned to achieve the degree of decomposition V and to guarantee the plant compatibility of the compost. This should take place directly after the intensive decomposition or fine treatment depending on the above mentioned conditions.

In decomposition systems with a decomposition time of less than 12 weeks the maturation phase for achieving plant compatibility unavoidable. The maturation phase makes it possible to balance out the fluctuations of the degree of decomposition that occur in the practical operation of a plant and thereby guarantee the continuous plant compatibility of the delivered compost (post maturation).

In contrast to the intensive decomposition process no targeted controlling is necessary. The decomposition times depend on the type of intensive decomposition and should generally last from 3 to 4 weeks.

5.3.1.5 Storage

Constant compost sales are usually not given. The main sales periods are generally in spring and fall, so that an interim storage capacity of around a half a year should be possible.

5.3.1.6 Inner-Operational Transport

With respect to continuous operation and due to labour medical reasons the transport within the plant should take place extensively in automated and disturbance un-susceptible transport equipment. In storage areas the transport should takes place by means of front-end loaders. Whereby attention should be given that the cabin is cli-mate-controlled and with filters in order to keep pathogenic micro-organisms out of this work place.

5.3.1.7 Measures for Emission Reduction

In all treatment steps attention should be paid that the emissions are reduced according to requirements. This has substantial significance for inner-operational interests (labour protection, cleaning work, repair work of construction parts and machines), as well as for the impact of the plant on the surroundings, its permissibility and acceptance. (see *Figure 5.3*)

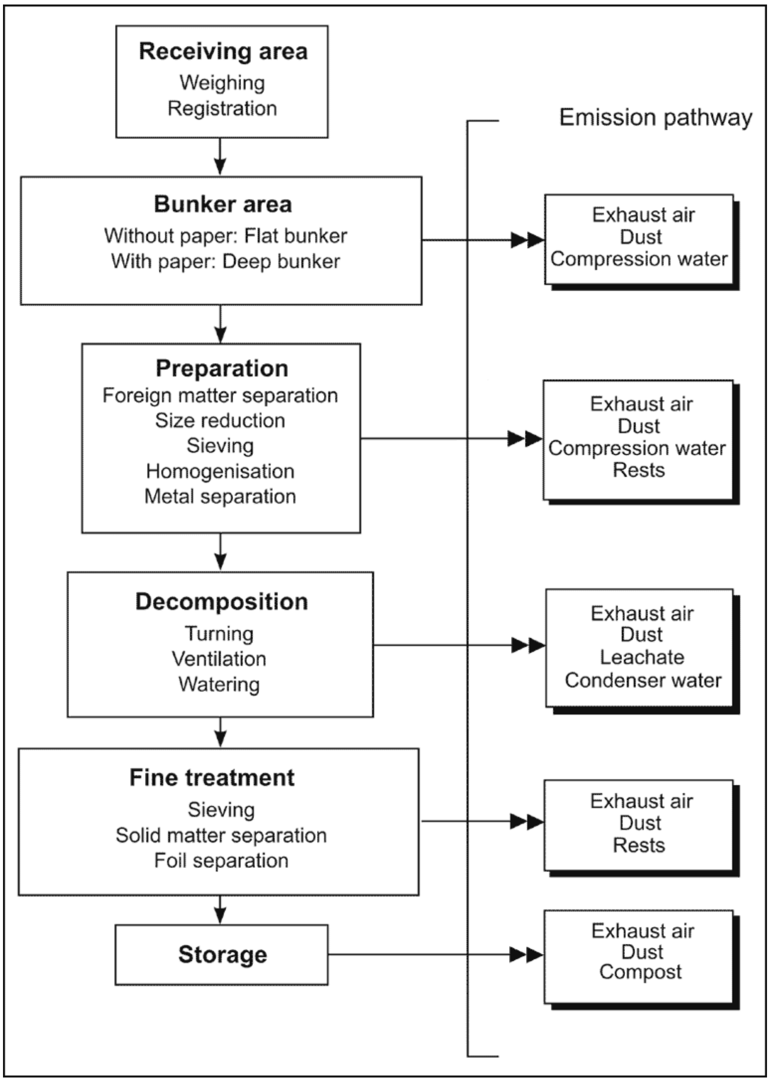

Fig. 5.3: Basic Flow Chart of a Biowaste Composting Plant

5.3.1.8 Special Features of Small Plants

Decentralised small plants can not usually be operated in an economically-effective way within the above mentioned treatment process. Therefore different process steps are omitted in the field.

Weighing and registration

Use of the local municipal weighing station

Alternative: Estimating based on volume

Receiving and interim storage

Direct delivery for coarse treatment or to the decomposition space

Coarse treatment

Size reduction of tree and shrub trimmings externally or by means of mobile units

Decompacting with tractor or manually (Hygiene!)

Screening does not apply due to mobile aggregates

Foreign material selection with tractor or manually (Hygiene!)

- Mixing and homogenisation
- with tractor or turning machine
- Magnetic separation usually does not apply
- Intensive decomposition and maturation can often not be directly differentiated. Use of simple windrow process.
- Fine treatment by screening using a mobile screening machine. Further confectioning does not apply.
- Storage appropriate to the demands of the storage spaces planned for this purpose, potentially external.
- Inner-operational transport by tractor and/or turning machine
- Measures for emission reduction are limited to surfacing the area for leach-ate and effluent collection. Potential covering of the windrows by means of an appropriate fleece. Otherwise the emissions should be reduced by operational measures such as turning etc.

5.4 Technical Facilities

5.4.1 Facilities for Weighing and Registration, Entrance Area

The vehicle weighing station is made up of a reinforced steel tub and reinforced steel foundation on which the weighing bridge of reinforced concrete rests. Three weighing station principles are typical:

- Mechanical:
  - All weighing station elements through to the taring equipment is mechanical. Weighing station and taring facility are situated next to one another.
- Hybrid:
  - Mechanical substructure with tension load cell and strain gauges.
  - Electrical data transfer of the measurements.
- Electromechanical:
  - By means of pressure weighing cells with strain gauges the measurements are determined, transferred and converted electronically into the measurements.

Today, electrical recording of the measurements is common in new plants with simultaneous evaluation in electronic data processing units for the preparation of delivery slips, invoices and mass balances. Vehicle weighing stations with a width of 3m should be able to weigh a whole freight trailer, especially in larger plants (length 18m).

In small plants one weighing station is sufficient, in larger plants there should be a weighing station located in the entrance and exit areas. It is advantageous to construct the weighing cabin so high off of the ground that the weighing station personnel can speak directly with the lorry driver. It is sensible to erect a roof covering as rain protection for the exchange of forms. It should also be planned so that it is possible to drive around the weighing station.

5.4.2 Facilities for Receiving and Interim Storage

Three types of facilities are of importance for the receiving and interim storage of delivered waste:

- Deep bunker
- Flat bunker
- Apron conveyor bunker

Table 5.2 shows the fundamental advantages and disadvantages of the bunker types.

The resulting development was that flat bunkers are usually used today. Bunker emptying of deep bunkers is usually carried out with a crane, in isolated cases also with apron conveyor feed bunkers, in flat bunkers with front-end loaders, with apron conveyor feed bunkers, box feeders or drag chains in the form of channel conveyors.

In plants with a size reduction step as the first processing step a direct feeding into the chopping machine with a front-end loader usually takes place. Generally, one should pay attention that the feeding aggregate is appropriately dimensioned (min. width 1.5 m) and these do not have small conical forms, since proper operation is not guaranteed due to bridging. Due to operational reasons, the interim storage time of the feeding aggregate should be at least 20 to 30 min. in flat bunkers, and with the sole use of an apron conveyor bunker at least 1 to 2 hours.

The feeding aggregates in flat bunkers can either be arranged so that the filling level is the same as the tipping level or is elevated above it. The elevated construction exhibits advantages with respect to the amount of construction work and safety from unintentional falling, accessibility for repairs, as well as the ceiling.

The bunker area should be designed so that the tipping and feeding processes take place in a closed-in area with closed gates. In the case of multiple gates reciprocal locking is necessary in order to avoid the loss of dust, germs and odours into the environment. In addition the bunker should be maintained under negative pressure (air suction, oxygen exchange > 3/h).

Tab. 5.2: Characteristics of Different Bunker Types

	Deep Bunker	Flat Bunker	Apron Conveyor Bunker
Area Requirement	Middle, due to large heaping height	Large, since the heaping height is limited to approx. 2m	Small
Feeding	Good, since several feed openings are possible	Traffic guidance is difficult	With several parallel bunkers good, otherwise limited area
Emissions from Material	Large amounts of compression water (heaping height	Small amounts of compression water	Small amounts of compression water
Coarse Separation and Controlling	Only insufficiently possible	Possible	Generally not possible
Malfunction Susceptibility	Higher than with flat bunkers (crane unit)	Low	High, since there is no bunker option in the case of a defect
Cleaning	Difficult	Easily possible	Difficult
Construction Height of the Hall	High (more than 10 m)	Flater (at least 6 m clearing height)	Flater (at least 6 m clearing height)
Separation of Storage and Other Operations	Good	Not clearly defined	Good
Storage Capacity	High	Middle to sufficient	Low
Vehicle Emissions	Low	High due to frontend loader	Low
Flexibility	High to medium	High	Low
Costs	High	Medium	Low
Use of Height Differences for Treatment	Good, due to large dumping heights	Low to medium, since there are only low ceilings	Low to medium, since there are only low ceilings

5.4.3 Treatment Facilities

The aggregates implemented in biowaste composting plants are subsequently represented.

5.4.3.1 Size Reduction Aggregates

The following factors should be taken into consideration while selecting size reduction aggregates:

Coarse materials such as tree trunks, as well as rocks and iron elements should not destroy or block the size reduction aggregate, but rather exit unchopped or be held back by a reversible turning direction. Highly fluctuating structural properties and high water content should not negatively influence the functional capabilities. Aggregates that require explosion protection (e.g. slow mover) are advantageous for many areas of use.

The emissions of noise, dust and exhaust gases should be minimised. Noise and dust emissions can be easily reduced by means of an encapsulated construction or the elevation in closed buildings with targeted air ventilation. In aggregates that are self-powered with incineration motors attention should be given to low-exhaust motors. In the case of size reduction aggregates that are constructed in the open compromises generally have to be made with respect to emissions.

Depending on the targeted use (coarse treatment, fine treatment) attention should be given to selective size reduction so that separated materials remain selectable in subsequent process steps. By the selection of appropriate substances for the size reduction tools one should work towards no heavy metals from abrasion are additionally brought into the decomposition product (no Cr-Ni-steel use).

In association with low malfunction susceptibility and low maintenance work or easy repair possibilities, as well as user-friendly elimination of coarse foreign substances the aggregated should be able to be operated with a small number of workers. The potential for constant high throughput capacity of different materials should be given.

The size reduction aggregates can be classified into fast and slow moving mills according to the rotational speed of the size reduction tool.

Generally fast-movers are not suitable for wet and soft material. These aggregates are, however, suitable for the size reduction of tree and shrub trimmings, as well as the confectioning of matured compost, even though they include disadvantages with respect to noise and dust production, as well as the danger of explosion (dust explosion) or a chipping effect. Slow-movers have perpetuated themselves in coarse size reduction of biowaste and bulky materials. They are, however, sensitive to coarse foreign materials (see above).

Table 5.3 shows the fundamental function principles, the advantages and disadvantages, as well as the areas of use and costs of the size reduction aggregates.

Tab. 5.3: Fundamental Function Principles, Advantages and Disadvantages, as well as Area of Use and Costs of Size Reduction Aggregates

Aggregate	Size Reduction Principle	Process Description	Advantages	Disadvantages	Area of Use	Costs
Spiral Mill (Screw Mill) (S) *Figure 5.4*	- Shearing off - Grinding	- Two or three-rotor reciprocally turning horizontal Screw- - Additional breaking on housing - Revolutions and expansion space is variable - Hydraulic power - Potential of removing foreign materials with a crane (gripper) is provided	- Robust - Good maintenance of structure - Selective size reduction with respect to foil - Low dust and noise emissions (with encapsulation of the hydraulic aggregate)	- Coarse foreign materials are not reduced in size (tree trunks) - Foreign materials can in some cases destroy the mill or power aggregates	- Biowaste completely or partial flows - Tree and shrub trimmings - Focal-point-like stationary plants - Proven for biowaste composting plant	relatively high
Screen Grater (S)	- Crushing – Tearing - Classifying	-Standing cylinder with two decks - Upper deck tear and screen hole panels - Waste is scraped over the upper panel by a rotating arm - Screen transmittance is continuously swept	- High efficiency, high selectivity	- Susceptible to wear - Really high amount of residue - Discontinuous residue discharge - Low throughput capacity (max. 5 Mg/h) - High energy requirement	- Originated in household waste composting - Suitable for biowaste - Unsuitable for tree and shrub trimmings - Still only one plant in use (Heidelberg); is no longer built	very high

Aggregate	Size Reduction Principle	Process Description	Advantages	Disadvantages	Area of Use	Costs
		away and di-scharged				
Cutting Mill (Cutter Roll Mill) (S)	- Cutting - Shearing	- Two/four rotors - Chamber-like offset counter-rotating blades	- Reversible in case of clogging (see also spiral mill) - Selective size reduction - Low dust and noise emissions	- Sensitive to large metal parts - High wear (lubricating gel effect) -High maintenance work - No grinding	- Tree and shrub trimmings - Straw - Not recommendable for biowaste - Seldom used	similar to spiral mill
Hammer Mill (F)	- Beating - Tearing - Shearing	- One or two rotors - Rotating discs with pendulating suspended hammers - One rotor: breaking by tearing chambers - Two rotors: Counterrotating - Partial ejection device for heavy reducible parts	- High size reduction effi-ciency - Even particle distribution - High frequency of maintenance - High throughput capacity possible	- Relatively high energy requirement - High wear - Requires high maintenance - Danger of explosion - Partial chipping with open discharge - No selective size reduction (e.g. for glass, plastics)	- Tree and shrub trimmings - Limited use for biowaste - Compost confectioning (fine treatment) - Often used as mobile machine (green waste size reduction, impact drum crusher)	compara-tively low for mobile machine
Impact Mill (F)	- Beating - Tearing	- One rotor - Rotary drum with 6 to 8 blow bars - Pedulating	- High size reduction effi-ciency - Wear and energy requirement low	- Danger of explosion - No selective size reduction - Problems with	- Tree and shrub trimmings - Not recommendable for bio-waste	similar to hammer mill

Aggregate	Size Reduction Principle	Process Description	Advantages	Disadvantages	Area of Use	Costs
		suspended im-pact panels on housing - Material is thrown against im-pact panels - Size reduction on cracks and panels	compared to hammer mill - High throughput capacity possible	dense, bulky materials	- Compost confectioning (fine treatment) - Also used as mobile machine (tearing drum chipper)	
Chipper (F) (Drum Chipper)	- Shearing - Cutting	- Principle of the cutting mill	- High degree of size reduction	- Sensitive to metal parts - High wear - High noise emissions - Chipping effect - Chopping not grinding - Relatively low throughput capacity - Requires high maintenance	- Tree and shrub trimmings - Straw - Not recommended for biowaste - Sieve overflow (wood) - Plant waste composting plants	relatively low
Mulching Machine (S)	- Crushing - Tearing	- Grinding by rotating shaft with tearing teeth - Material is reduced in situ and mixed (tractor-additional machinery)	- Easy to operate - Produces a large specific surface area (grinding)	- Uneven chopping (high number of pieces after size reduction)	- Tree and shrub trimmings - Straw - Mixing of biowaste and bulking agents - Plant waste	relatively low

Aggregate	Size Reduction Principle	Process Description	Advantages	Disadvantages	Area of Use	Costs
					composting plants	

Decomposition drums can be used as combined size reduction and mixing aggregates (see below), hard and tenacious materials are not chopped, which is an advantage for the later removal of foil, stone, etc., but a disadvantage for removing tree and shrub trimmings.

With respect to higher throughput capacities automatic feeding by an apron conveyor bunker or similar offers an advantage. In order to prevent clogging it is sensible to have large sections and boundary walls that are as high as possible.

Fig. 5.4: Screw Mill (photo: Bühler)

Separate slow-running bladed rotors are possible for use as decompactors (e.g. opening of bags), however, they require a lot of maintenance due to the slinging of long-fibre or tenacious materials (e.g. textiles, foil). Short closed drums with blades welded onto the drum wall can be implemented just as well. Since decompacting is possible in connection with size reduction aggregates or with drum screens through welded-on blade strips composting plants usually do not have separate decompacting facilities.

5.4.3.2 Screening Aggregates

The following requirements must met with screening aggregates:

Clogging should be avoided by means of self-cleaning equipment attached to the screen (e.g. brushes, chains for drum screens) or flexible sieve (e.g. stretched shaft screen). Daily cleaning of long, tenacious materials, which become lodged in the holes generally during coarse screening, is usually unavoidable. The exchange of sieves (e.g. changing of the screen perforation) should be easily possible.

In order to achieve high screening efficiency attention should be given that the retention time in the screening aggregate is sufficient, which can be attained by means of long screen stretcher, as well as accumulation strips (barrages) and large open perforation. Attention should be paid to sufficient dimensioning of the sieves or drum diameter, especially for coarse screening, in order to also be able to sensibly screen out pieces with a length of 1-1.5 m.

Large, bulky materials require screening aggregates with large screen areas, wet screening material causes clogging, agglomeration and caking in screens with a small perforation diameter and therefore insufficient screening efficiency, especially in non-flexible sieves.

The screen grated should be mentioned as a combined size reduction and screening aggregate (see Size Reduction, *Table 5.3*).

Fig. 5.5: Drum Screen (Photo: Bühler)

Fig. 5.6: View into the Drum Screen (Photo: Ingenieurgesellschaft Abfall)

Tab. 5.4: Screen Types Mainly Used in Biowaste Composting Plants and Their Areas of Use

Screen Type	Process Description	Advantages	Disadvantages	Areas of Use
Vibrating Screen, Shaking Screen	Flat screen, slightly angled, elliptically or circularly free-running eccentric-powered	- Relatively low price - Simple feeding possibility - Low construction height	- Covering the screen holes by large materials - Relatively high amount of cleaning work (clogging, jamming) - Insufficient screening capacity with wet materials -Little decompacting effect	Dry, rich in structure waste, limited use for composting plants
Drum Screen (see *Figure 5.5* and *Figure 5.6*)	Rotating, cylindrical or polygon drum. Retention time variable by angle	- Good decompacting effects - Mixing effect	- Dust production (encapsulating required) - Clogging,	- very suitable for coarse treatment and for relatively dry compost (fine

Screen Type	Process Description	Advantages	Disadvantages	Areas of Use
	adjustment. Drum powered generally by friction wheels from outside or gear wheels	- Good screening effects due to agitation - Robust - Combinable with mixing aggregate (e.g mixing drum) to form an aggregate <	plaiting with small screen holes and wet material - Large construction height - Expensive	treatment) - Often used as mobile aggregate
Shaft Axle Screen	- Elastic screen deck, which is alternately pressed and stretched by a counterrotating eccentric - Screen openings are held open by the acceleration force - slightly angled or cascading construction	- Little clogging even with wet materials - Good screening effects - Little cleaning required	- Relatively small width, therefore not suitable for coarse waste - Feeding aggregate is necessary - Screen deck with relatively short life-span - Expensive	Often used for compost (fine treatment)
Comb Roll Separator (Disc Separator)	Discs attached to shafts that mesh chamber-like. Discs turn in the conveyor direction, slightly - extremely angled construction - Partial high spinning of the screen material	- No clogging due to spinning motion - High screening capacity	- Entanglement of fibre-like and tenacious material, therefore high amount of cleaning necessary - Low screening efficiency - Screen sizes difficult to alter - Heavy weight - Complicated technology	Compost screening (fine treatment) - Limited use for coarse treatment - Seldom used as of yet

5.4.3.3 Magnetic Separator

Since the magnetic metals should be removed continuously throughout the flow overband magnets designed for this purpose should be implemented with removal belt or magnetic conveyer rollers or drums. The magnetic effect functions by means of electrical or permanent magnets (hard ferrite). The lifting force and with it the separating effect depends greatly on the pulling distance. Therefore, the magnetic conveyor rollers and drums have an advantage. One should bear in mind that , in general, the Fe metals in biowaste are not loose, but rather have to be extracted from a material layer. Therefore, the layer height, bulk weight, water content and particle size have considerable influence on the separation efficiency.

Overband magnets with removal belts are tried and tested aggregates with for large metal components with respect to lay-out flexibility. The magnetic separator can be mounted lengthwise or transversely over the conveyor belt. In the case of transverse mounting it should be made sure that the approaching flow width of the magnet is selected so that the Fe metals to be removed is held securely over the belt bulk. With consideration for the material flow it is better to situate the overband magnet separators lengthwise in the area of the belt discharge, although it is more complicated in the lay-out of the total construction, since the loosened material does not require as much deflecting force. Thereby the band roller should made of non-magnetic mate-

rial. Very high separating effects are achieved when the overband magnetic separator is mounted over a vibrating conveyor channel since the bulk flow is loosened, the removable components lie distributed and the purity of the Fe fraction is increased because non-magnetic materials (e.g. paper or foil that is lying on top of the Fe metals) remain in the vibration channel.

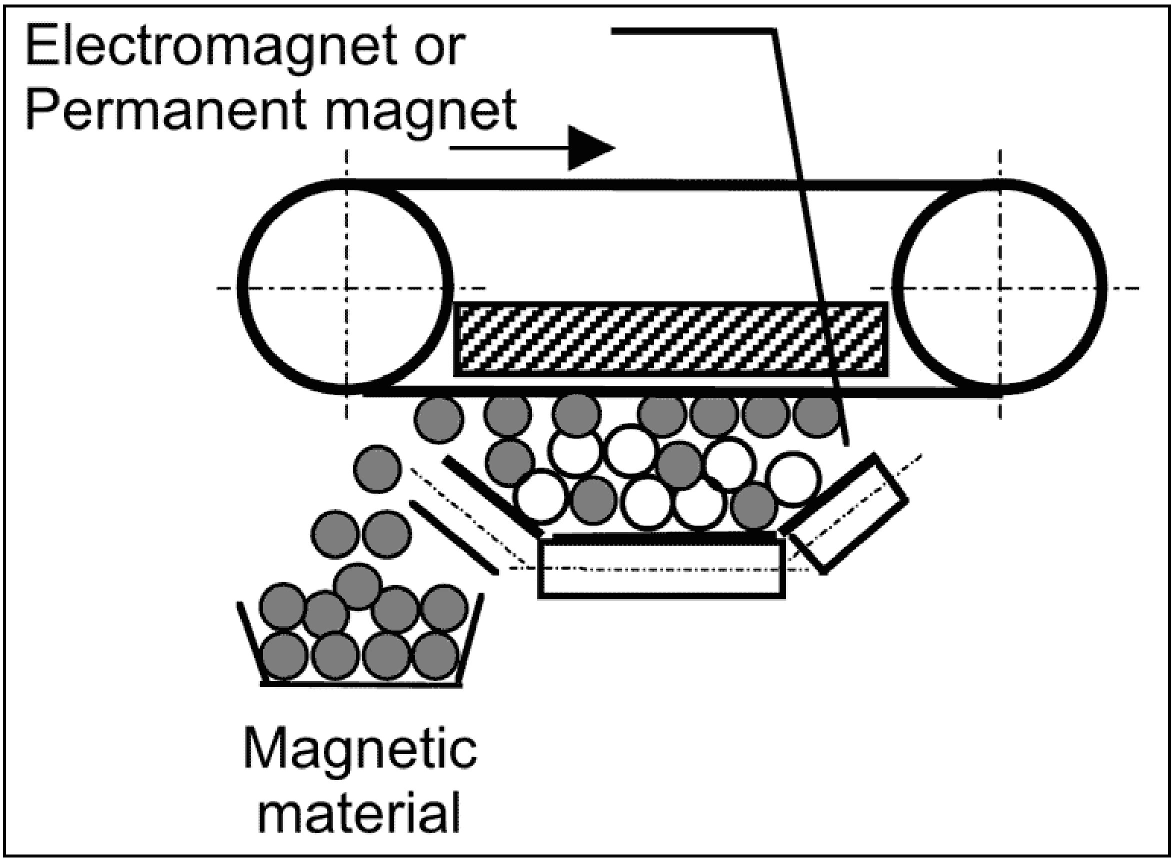

Fig. 5.7: Lay-out of an Overband Magnetic Separator (according to [36])

Tab. 5.5: Magnetic Separators used in Biowaste Composting Plants

Magnet Type	Process Description	Advantages	Disadvantages
Overband Magnet (with removal belt) (see *Figure 5.7*)	Permanent magnet block in frame construction with circumferential rubber removal belt, discharge after leaving the magnetic field	- Flexible lay-out, -Good separating efficiency	Limited separating efficiency with very coarse material due to large gaps
Magnet Band Roller	Driving roller at the end of a bulk conveyor belt. Non-magnetic material is discharged perpendicularly (gravity). Magnetic underneath the belt until deflecting angle at the drum end is reached.	Relatively low cost	Relatively low cost
Relatively low cost	Magnetic roller mounted separately from conveyor aggregate (belt, vibration channel). In part mounted in the free falling material flow	High separating efficiency	- Complicated total construction - Expensive - Limited flexibility

5.4.3.4 Mixing Aggregates

Aggregated especially meant for mixing and homogenising are only used in larger plants due to financial reasons. In smaller plants this function is carried out as part of size reduction, screening or in the area of decomposition (by mixing in decomposition drums or turning). If the addition of water is necessary it is possible enough by spraying the decomposition material before the decomposition begins over a bulk conveyor. During decomposition water can be dosed while turning. The mixer types can be classified into extended-period and short-period mixers depending on the dwell time of the mixing material in the mixing aggregate. While extended-period mixers make an additional homogenisation and in part selective size reduction possible, which means that solid material batches can also be mixed well, the short-period mixers are especially suitable for pasty materials or rather an even moisture distribution in the decomposition material. Mixing drums assume the function of pre-decomposition aggregates during very long dwell times of several days. Mixing drums are, in part, implemented as aggregates in connection with screen drums. The flexibility and adaptation to different material flows is, however, significantly limited with respect to the separating efficiency and dwell time.

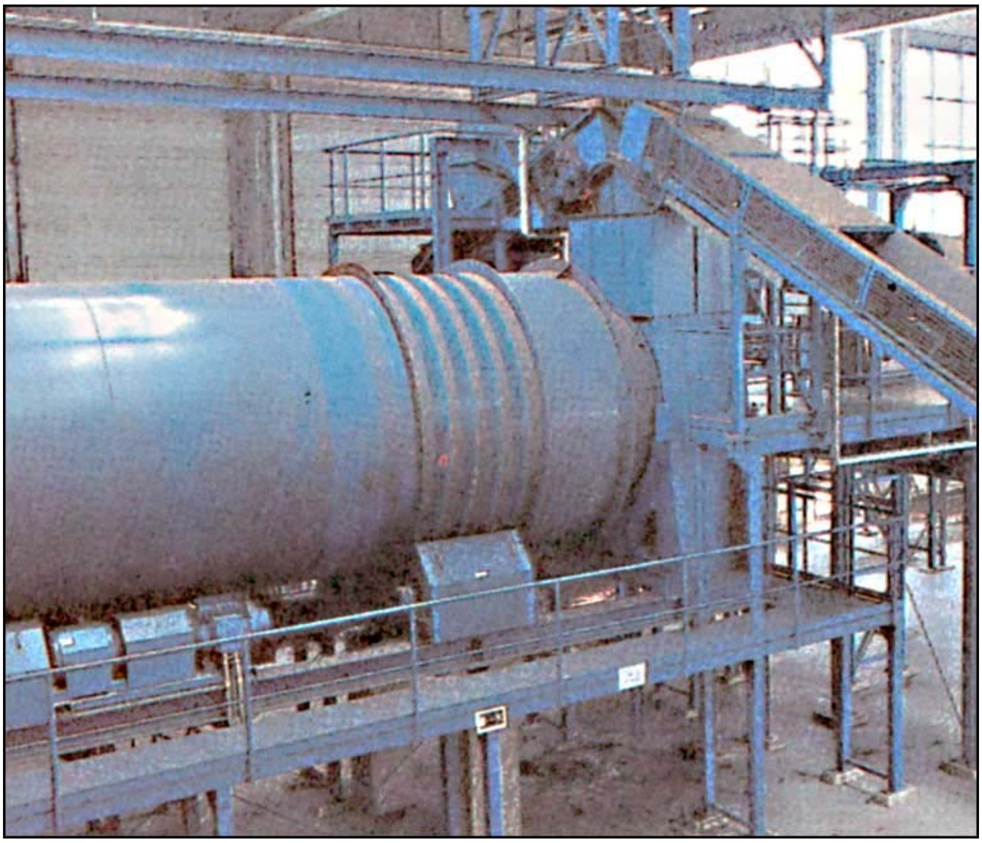

Fig. 5.8: Mixing Drum

Fig. 5.9: Double Shaft Mixer

Tab. 5.6: Mixing Aggregates Used in Biowaste Composting Plants

Mixing Aggregate Type	Process Description	Advantages	Disadvantages
Mixing Drum (Drum Mixer) (see *Figure 5.8*)	Cylindrical drum with fixed guide baffles. Dwell times of 20 min. to approx. 2h, 13-15 rpm. Homogenisation and selective size reduction effects. Mixing mostly radial, limited axial (continuous feeding necessary). Also possible as mobile aggregate	-Good mixing and homogenisation efficiency - Coarse material easily mixed - Dwell times variable due to angle and rotation speed - Tried and tested aggregate	- Large measurements - Relatively expensive - Complicated feeding (construction height)
Double Shaft Mixer (see *Figure 5.9*)	Counterrotating shafts with paddle equipment in vat	- Good regulation of water content possible -Dosing of pasty material feasible. - Small measurements - Relatively low cost -Proven for prescreened biowaste	- Addition of material with coarse structure not possible - Consistency range has to be maintained (45-60% water content)

5.4.3.5 Foreign Material Removal

The removal of foreign materials including the transfer of control functions can currently only take place in a visual manner for raw materials with subsequent manual or mechanically-supported separation or removal, aside from magnetic separation or particle size removal. For this reason the screened waste, in biowaste composting plants usually the oversize particles, is to be applied to a slow-moving sorting belt (v<0,2 m/s) with sufficient width (approx. 1 m). For sensible removal the height of the material flow on the belt should be limited to less than 10 cm. A preceding even distribution (e.g. by vibration channel) is of advantage. In manual removal the foreign materials (negative sorting) is taken by hand and thrown by means of a drop chute into a container below. The sorting station, whose measurements or number of workspaces depend on the throughput capacity, is to be constructed encapsulated and climate-controlled. The requirements of labour safety, especially noise, dust and germs, is to be complied with by means of appropriate air circulation and ventilation (>15/h). The lay-out should be selected so that standard containers and basins can be placed underneath the drop chute in order to receive the sorted out valuable matter. Belt systems are not typical for such as this in biowaste composting plants.

In order to improve the work situation computer-supported sorting stations are being installed today. The material to be sorted is recorded by video cameras and displayed on a screen. Visually recognisable foreign materials are selected by the personnel per mouse click on the screen display and removed by a co-ordinate controlled robot. This system is realisable with low quantities of foreign materials. When there are large quantities of foreign materials the selectivity is low especially

due to the non-controllable removal height in the third dimension such that a relatively large portion of compostable materials would also be removed. (Example: Kompostwerk Häldensmühle (Marbach)).

5.4.3.6 Aggregates for the Removal of Heavy Solid Matter and Foil

The separation of heavy solid matter and foil can only be carried out effectively in materials with low water content since otherwise the separation effect is insufficient due to the bonding of the matter with the very moist materials or material agglomeration. Therefore, this matter is generally removed from the matured compost (water content under 45 %). In small plants or in the case of input materials with a very small portion of the matter mentioned above these aggregates can be omitted no matter which area the compost is used in. Air classifiers and air jigging machines (stone removers) are implemented for the removal of heavy solid matter. Foil can be removed by air classifiers, ballistic systems are not used due to their low degree of separation.

Heavy solid matter removal usually takes place in fine compost; air classification for foil (in individual cases) is generally carried out in coarse compost or oversized particles (return material). Hereby simple solutions (e.g. belt drop with crossing air flow) have also been proven to be suitable with sufficient effectiveness.

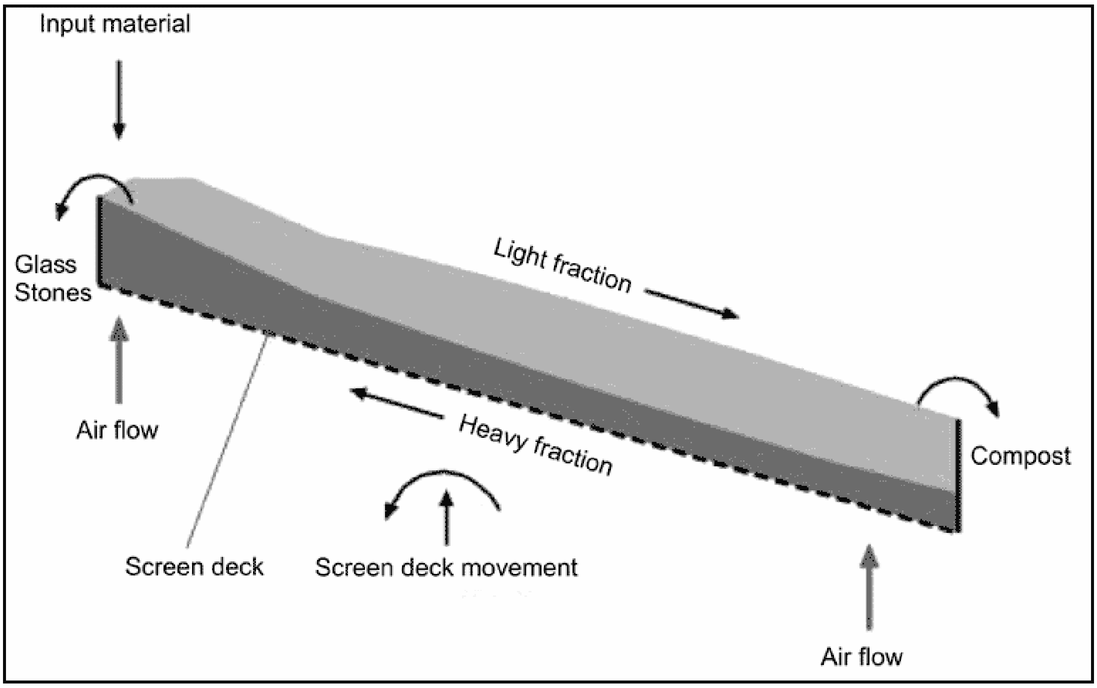

Fig. 5.10: Principle Schema of a Stone Remover [according to 11]

Tab. 5.7: Aggregates for Foreign Material Removal

Classifying Aggregates	Process Description	Comments
Zigzag Air Classifier	Material feed from above, light material removed from the top, heavy material removed from the bottom. In bends distribution and as a result better separation Walls covered with rubber channels to avoid accumulation Feeding and discharge by rotary gate valves. Closed air circulation in cycle. Cyclones for light material removal.	- Relatively large measurements -Relatively large amounts of air necessary
Suspended Air Classifier	Standing, cylinder conical towards the top with screen decks (perforation approx. 3mm). Rotating scraper on screen deck for heavy material. Feeding and discharge, see above.	- Rather rare in composting plants -Relatively large amounts of air necessary
Air jigging Machine (Stone remover) (see *Figure 5.10*)	Fluidised bed principle. Angled vibrating screen (perforation 1.5mm), air flow from below so that the light fraction is lifted slightly Light fraction (compost) is carried towards the bottom by gravity and the heavy fraction upwards by the screen deck movement towards the screen edge. Guided air circulation, dust removal by cyclone	- Constant screen deck coverage necessary - Proven aggregate for heavy solid matter removal

5.4.3.7 Transport Aggregates (Conveyor Aggregates)

The transport of the material to be processed to the individual processing steps, the discharge from the aggregates, as well as frequently the feeding of the decomposition facilities is carried out in composting plants by conveyor equipment. These are of significant importance for a proper processing procedure and constant feeding of the aggregates. They are spatially significant features due to their large measurements in order to overcome great heights and long distances; the cleanliness of the processing halls is influenced significantly by the constructive execution of the conveyor equipment and the respective transfer points, at which consideration should be given to clogging and malfunction-free, as well as low maintenance, construction.

The selection of conveyor equipment is especially influenced by the following factors:

- Type of transported material

  Here main emphasis is placed on the particle size distribution and form, as well as water content. Bulky materials, loose constituents, as well as dusty or thixotrope materials, in particular, present special needs.

- Incline

  The selection of the conveyor aggregate is given depending on the existing distances in order to overcome the height difference. Inclines of distinctly more than 20° only allow for a limited selection of aggregates since the loose material (e.g. apples, oranges) would otherwise not be able to be transported.

- Soiling by transport aggregates, belt cleaning

  Non-encapsulated conveyor equipment (belts), in particular, can cause significant soiling from compost on the underside of the belt, which would make daily cleaning of the floors under the belts necessary due to the shaking off of sticky solid constituents in the area of rollers, refractional areas, among others. With respect to working hygiene and optically acceptable operation, along with economical method of operation, this point should receive special attention.

- Maintenance, operational safety

  Aggregates should be selected that require low maintenance since the efficient functioning of the conveyor equipment significantly influences the operation of the plant. Malfunctions should be able to be easily remedied. The possibility of being able to reach all important parts of the plant with platforms along the conveyor aggregates is advantageous. Attention should be paid so that the in the areas of transport of coarse material, in particular, the conveyor equipment is wide enough (min. 1 m).

In *Table 5.8* the fundamental conveyor equipment used in composting plants is described.

Tab. 5.8: Conveyor Equipment in Composting Plants

Conveyor Aggregate	Functional Mode	Advantages	Disadvantages	Area of Use
Ribbon Belt	Rubber belt with steel or plastic mesh inlay. Material rests on	- High conveying capacity - Low dead	Max. incline 20°	Unchopped waste, coarse oversized particles, sorting

	belt during transport procedure	weight - Very robust - Easy to clean (brushes) - High operational security - Low maintenance		area, distribution belts for compost
Trough Belt	See above. Secure against falling material from the side due to angle of the upper carrier shafts up to 45°	See above	See above	Treated decomposition material, Fe metals
Runner Belt	See above. Larger ascent possible due to cross runners. Secure from slipping and rolling	Large inclines (up to approx. 45°)	- Difficult to clean - Expensive	Coarse compost, fine compost with steeper inclines
Shaft Edge Belt Conveyor (Box Conveyor)	Rubber belt conveyor with shaft box on the side (for deflection) and appropriately high pusher runners (conveyor pockets)	Inclines up to 70°	- Difficult to clean - Expensive	Treated decomposition material
Vat Chain Conveyor	Pusher (chain principle) scrape material over fixed vat floor. Encapsulated system. Floors made of metal or ceramic (wear-resistant).	- Inclines up to 90° - Generous routing - Angle etc., discharge position selectable - No contamination in the area of the VCC due to	- Relatively expensive - Prone to malfunction (jamming) - Not suitable for coarse materials	Treated decomposition material

		encapsulation		
Screw Conveyor, Spiral Conveyor	Conveyor screw (normal screw or spiral form. flat iron) into conveyor vat (usually PE-lined) Encapsulated construction easily possible	- Easy maintenance - Simple technology - Feeding and discharge variable - Inclines up to nearly 90°	- Friction in vat (wear layer) - Relatively high power requirement	- Small conveyor capacity - Short distances, e.g. distribution of compost - Screened material - Not suitable for un-chopped coarse waste
Oscillating Conveyo-	Vibrating channel horizontal to slightly angled downwards	Isolation of materials	Only as supplement for other aggregates	- Feeding area before aggregates - Short transport distances

5.5 Decomposition Systems

5.5.1 Fundamentals

All composting procedures are based on the same scientific findings. Microorganisms, responsible for the aerobic transformation of the organic substances, need optimal living conditions like

1. A sufficient nutrient supply
2. Supply with oxygen and water and
3. Corresponding environmental ambience.

A decisive factor of the course of the decomposition process is the structure of the decomposition material. A high air pore volume is the only guarantee for the microorganisms to be supplied with sufficient oxygen thus enabling their high activity and a following optimal decomposition.

A further important parameter is the water content of the decomposition material because micro-organisms can take up nutrients only in a soluble form. The water content should not fall below 40 % and should not exceed 65 % during the intensive decomposition phase. Lower water contents inhibit the activity and higher contents restrict the air pore volume that is available for the oxygen supply to a great extent.

The aforementioned parameters show that intensive decomposition is the decisive process step in a composting plant and that the adherence to these frame conditions is a pre-condition for an optimal decomposition process.

A nutrient supply is fundamentally established at the composting of household wastes with or without paper and/or green wastes. The hygienisation of the decomposition material is guaranteed by an intensive decomposition process with temperatures of more than 60° that last several days.

The composting of faeces and sludge from faeces is a method well-known and practised during centuries to utilise the fertilising value and the organic matter of these wastes in plant production and thus closing the natural loop. As a whole the production of composts from waste water sludge (AS) as a biological recycling process offers a high environmental compatibility, if the original material is not overloaded with harmful matter. If the marketing and sales problem is solved satisfactorily for the produced soil improving compost, tested technologies are available to produce a high-class and hygienically irreproachable compost material. The harmful matter content can be effectively influenced only by controlling the discharge sources of wastewater up to the establishment of primary sedimentation step. The adherence to quality criteria during sludge compost production guarantees that only a product with a clearly defined consistency and ingredients is sold by the producer.

Explanations for a technical realisation are following in Chapter 8 Composting of sludges from waste water purification.

5.5.2 Course of the Process

Figure 5.11 shows the principles of the process course on a plant for the decomposition of biowaste. Identical process parts, equally important for all process types and their machinery, shall be introduced in the following.

4 The receiving and bunker area,

5 The coarse treatment of the input materials (see Chapter 5.5.2.1 Receiving, Storage and Coarse Treatment),

6 Fine treatment of the final product (compost),

7 The storage area and

8 The exhaust air purification (see Chapter 5.5.2.3 Fine Treatment, Interim Storage and Exhaust Air Purification)

A few fundamental interesting frame conditions for the decomposition are additionally explained (see *Chapter 5.5.2.2 Biological Step - Decomposition Process*).

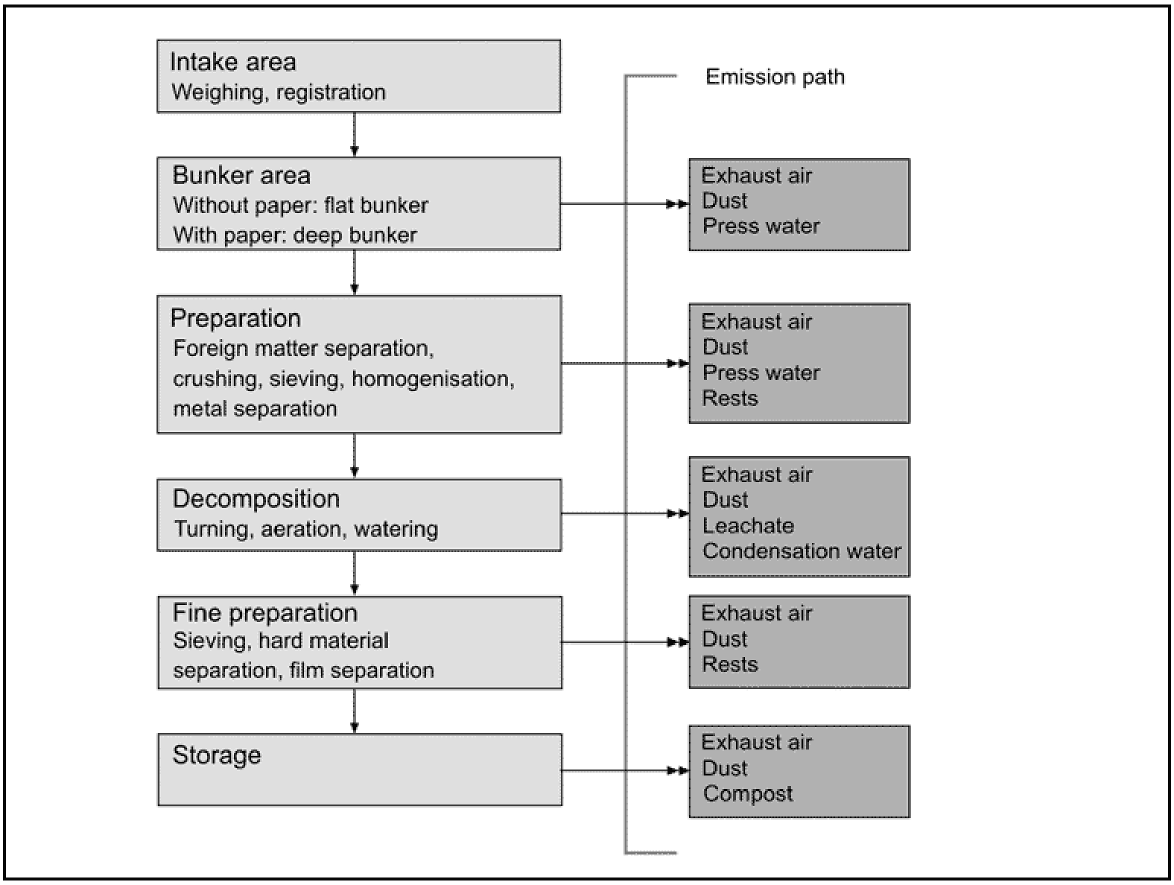

Fig. 5.11. Principle of the course of the process for a biowaste composting plant

5.5.2.1 Receiving, Storage and Coarse Treatment

The design of the bunker area depends on the plant size and on the shape and consistency of the delivered waste. The consistency of biowaste makes a storage before treatment over a longer period impossible. Therefore, a flat bunker must be provided which has to be cleared every working day. Deep bunker plants are only sensible if there is little space available or the paper fraction is collected together with the biowaste (low water content, improved structure). In cases where besides biowaste other waste e.g. from trade or industry are processed, it will be necessary to provide separate stacking or proportioning devices.

According to the emission situation may it become necessary to separate the receiving area from the actual bunker in such a way that a vehicle sluice which minimises odours and dust should be installed.

The following criteria are relevant for the conception of coarse preparation of the input materials.

9 Pre-sorting regarding the separation of the compostable fraction is not necessary. However an impurity selection must be considered in order to separate large-sized undesired materials. A permanent working place for theseparation of impurities (sorting place) seems to be only reasonable if a selection from a material stream enriched with disturbing materials has to bemade (e.g. screen residues in coarse preparation) and the material must not necessarily be checked all over the process.

10 If the paper fraction is collected together with biowaste an additional comminution of the waste before the mixing and homogenisation step must be provided, this is valid and

recommended also for a high portion of gardenwastes in the biobin.

11 Green waste should be stored and comminuted at a separate place where it can be easily added (e.g. at raw compost homogenisation).

12 A further decomposition of the compost material and homogenisation needs a mixed aggregate that should be included in the planning, which should also be realised regarding the screening phase (drum screen with a sufficiently long retention time).

13 The separation of the oversized particles (screening) that will disturb the further process is necessary and above all plastic bags, which can always be found in the biowaste, despite a pre-sorting vessel and not comminuted bushes.

14 A magnetic separator impedes the input of metallic impurities which have a great influence on the heavy metal content in the compost.

5.5.2.2 Biological Step - Decomposition Process

The decomposition process must be carried out in such a way that the optimal decomposition conditions through aeration control and/or a regular re-stacking is guaranteed. A minimum of turning processes is also necessary on account of the hygienisation of the outer windrow layers (low temperature, transport into the core of the windrow). The windrow height must be limited in correspondence to the biowaste structure, in order to sustain a sufficient air pore volume (compare *Chapter 2.3.3 Pore volume/bulk density* and *Chapter 3.3 Aeration*).

On account of odour emissions the actual approval system for waste composting plants calls for **closed decomposition systems**. This is a demand of the Technical Data Sheet of Urban Wastes at least in larger plants. The installation of a constant working place in closed hall-systems is not possible (high air humidity, fungus spores etc.) which requires e.g. the use of a fully automatic re-stacking device while windrows are composted (compare *Chapter 5.6.2.4 Ventilated Windrow Composting (Modular Plant Type IV)*and *Chapter 5.6.2.5 Nonventilated Windrow Composting (Modular Plant Type V)*).

The decomposition time depends on the decomposition degree that should be achieved (determined according to the standards of the German Compost Quality Assurance Organisation), respectively the plant compatibility of the final product. Fresh compost with decomposition degree II can be produced already after 8-14 days, mature compost (decomposition degree IV or even V) needs a production time of 8-16 weeks even with an optimal plant operation.

The processes described in *Chapter 5.6 Classification of the Composting Systems*, differ in the time needed for intensive decomposition (pre-decomposition) and the desired compost maturity. There are two ways to work on an intensive decomposition system either with a final product of a mature compost (decomposition degree IV-V) that integrates main and subsequent decomposition (e.g. System Wendelin, see *Chapter 9.4.5 Data sheet Bühler (quasi-dynamic process)* or intensive decomposition with a final product of a hygienised fresh compost (decomposition degree I - II, see e.g. *Chapter 5.6.2.1 Box and Container Composting (Modular Plant Type I)*) that requires subsequent decomposition to achieve higher decomposition degrees.

In the area of subsequent decomposition the processes scarcely differentiate from each other. In all composting plants this decomposition step proceeds overwhelmingly in table or triangular windrows (see *Chapter 5.6.2.4 Ventilated Windrow Composting (Modular Plant Type IV)* and *Chapter 5.6.2.5 Nonventilated Windrow Composting (Modular Plant Type V)*). The oxygen supply in this decomposition step proceeds either through forced aeration (pressure or suction.

5.5.2.3 Fine Treatment, Interim Storage and Exhaust Air Purification

The fine treatment (confectioning) of the compost serves quality improvement, whereby, depending on the sales market different screen cuttings, a densimetric and a foil separation come into question. A subsequent preparation of the composts, like e.g. the production of soil or **bagging** is possible. However, these last named process parts should be covered by the price of the final products, as the costs arising from these measures cannot be added to waste disposal without a reasonable explanation (see *Chapter 5.3.1.3 Fine Treatment (Confectioning)*.

The main selling times for composts are usually in spring and autumn, therefore should it be possible to store at least a half years' production. In cases where no big compost storage is possible on account of a lack of space, long-termed sale contracts (e.g. with soil producers) or the use of external storage capacities may be helpful.

Residues (approx. 5-10% of the input material) arise at coarse and fine treatment. Corresponding possibilities or interim storage and transport must be provided.

Biofilter/ biowasher or a combination of both are usually used for exhaust air purification. In unfavourable locations regarding an immission prognosis could it be- come necessary to completely encapsulate the biofilter and to transport the exhaust waste stream over a chimney.

5.5.3 Mass balance

The example of a mass balance relevant for all composting processes which produce mature compost (decomposition degree IV) is shown in *Figure 5.12*. The quoted percentages are weight % and are related to the waste amount delivered to the plant,

with an impurity content below 5% for the example. At an orderly decomposition and material preparation remain 30% of the input quantity as compost that can be sold and 7% as residues which must be brought to another disposal. The degradation within the organic dry mass in this calculation is assumed with 55%.

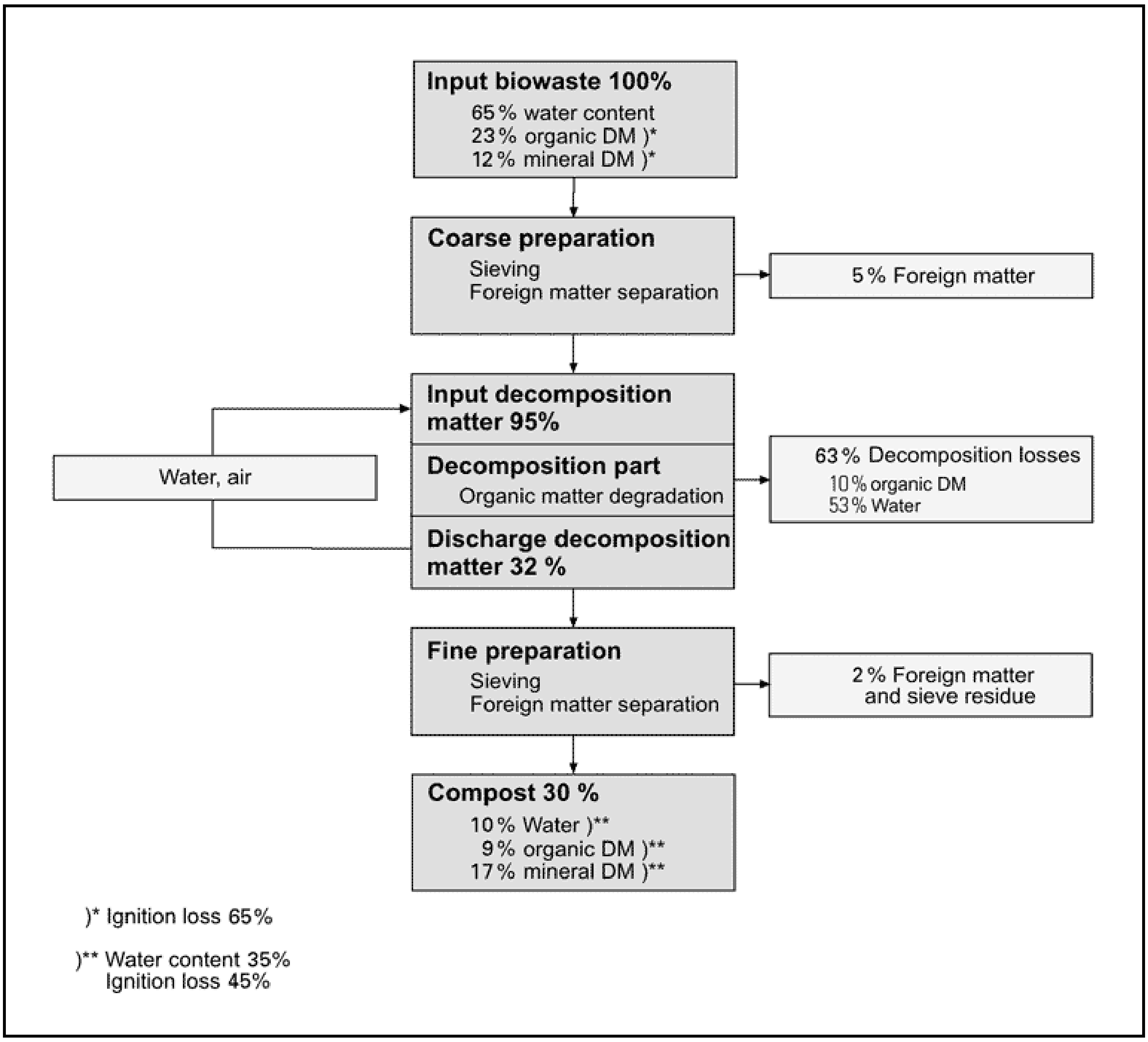

Fig. 5.12: mass balance of Biowaste Composting

5.5.4 Energy Requirement

The energy requirement at composting plants depends above all from:

15 The degree of mechanisation

16 The aeration efficiency

17 The plant throughput

Contrary to the digestion processes no primary energy but only heat energy can be recovered from a composting process. This happens partly by means of heat exchangers in exhaust aeration streams whose energy supply can be used to preheat added aeration streams or for warm water preparation respectively room heating.

This is the reason why the energy consumption for all the aggregates necessary for the process must be covered by purchases from other sources (as a rule electric current and diesel fuel). Assumed for the following process sizes are:

"small plants": 0.03-0.10 MWh/Mg

"medium-sized plants": 0.04-0.08 MWh/Mg

"large plants": 0.02-0.06 MWh/Mg

The statements refer to the annual throughput and are strongly dependent on the chosen decomposition technology. For most of the decomposition processes, however, a distinct connection between the plant size and the specific energy consumption exists.

5.6 Classification of the Composting Systems

5.6.1 Classification According to the Transportation of the Compost Material (Turning)

The momentarily offered composting processes can be classified roughly in three technical categories to which in turn process characteristics have to be allocated.

Static Processes

- Windrow composting without turning
- Triangular-/rectangular windrow
- Table windrow
- Stacked brick process
- Container-/box composting

Quasi-dynamic Processes

- Windrow composting with turning
- Triangular-/rectangular windrows
- Table windrows
- Open decomposition cells with revolving
- Closed reactors with revolving
- Decomposition tower
- Tunnel reactor

Dynamic Processes

- Closed revolving drum
- Screening decomposition drum

To move the compost materials (turn) is the main aspect of this classification. In practical operation different types are often combined, e.g. rotting boxes/windrows or revolving drums/windrows.

In the following explanations are examples of solutions for each category with data sheets, which are actually offered from different manufacturers. These examples are not exhaustive, they just serve to show the strong and weak points of the individual principal process possibilities.

As all the presented processes include a coarse treatment and compost confectioning and can be distinguished from each other just in the decomposition part, the characteristics of the initially named plant parts are mentioned in the description only and a presentation of the individual plant flow charts was abandoned. Furthermore, all the plant manufacturers are able to furnish coarse and fine treatment depending upon customer request respective to the local conditions (e.g. waste composition).

5.6.2 Classification into Modular Plant Types

The composting systems momentarily available on the market can be classified in 6 modular plant types, as follows:

Modular plant type I - box and container composting (see Chapter 5.6.2.1 Box and Container Composting (Modular Plant Type I) and Chapter 9.1 Box- and *container composting*)

Modular plant type II - tunnel and windrow composting (see Chapter 5.6.2.2 Tunnel and Channel Composting (Modular Plant Type II) and Chapter 9.2 Tun*nel and channel composting*)

Modular plant type III - decomposition drum (see Chapter 5.6.2.3 Decomposition Drums (Modular Plant Type III) and Chapter 9.3 Decomposition drums)

Modular plant type IV - windrow composting, aerated (see Chapter 5.6.2.4 Ventilated Windrow Composting (Modular Plant Type IV) and Chapter 9.4 Aerated *windrow composting*)

Modular plant type V - windrow composting, unaerated (see Chapter 5.6.2.5 Nonventilated Windrow Composting (Modular Plant Type V) and Chapter 9.5 *Unaerated windrow composting*)

Modular plant type VI - special processes (brick composting, tower composting) (see *Chapter 5.6.2.6 Special Procedure (Modular Plant Type VI)* and *Chapter 9.6 Special processes*)

When the processes are classified into the modular plant types simplification within the processes has to be carried out, which, however, does not change the flow-chart of the individual systems. So, e.g., all process steps which are necessary for the preparation of the biomaterial (e.g. metal separation, homogenisation, screening etc.) were concentrated in one block "preparation/treatment". The same is valid for the block "fine treatment". The aforementioned plant modules will be described as general process steps below.

5.6.2.1 Box and Container Composting (Modular Plant Type I)

Both composting systems are very similar in their process. The intensive decomposition in both systems takes place in an enclosed room with forced aeration and with full exhaust air collection. The content of a reactor fluctuates between 20 and 60 m^3.

The aeration of the reactors is usually carried through in perforated bottoms. Intensive decomposition lasts between 7 and 14 days and is determined to achieve a maximal decomposition during that time with a thorough hygienisation of the material.

The advantage of this process is the full monitoring of the decomposition parameters

- Temperature,
- CO_2-content and
- O_2-content

  and control of

- Aeration intensity and thus
- Decomposition.

A big advantage is also that emissions of all kinds can be collected easily and the odour emissions are minimised directly at the beginning of decomposition.

The degree of decomposition I to II can be assumed at the end of the intensive decomposition process. In cases where the material should achieve an even higher decomposition degree, subsequent decomposition in windrows is necessary or the material must pass the reactor once more or an adequate maturation phase is required that allows for the high microbial activity of the material. By refeeding the material discharged from the boxes or containers these systems carry over into the area of quasi-dynamic processes (see below). The investment costs are relatively high in comparison in order to achieve a decomposition degree of IV in the boxes or containers.

Fig. 5.13: Box Composting System Herhof (Photo: Herhof)

Fig. 5.14: Container Composting Sytem ML (Photo: ML)

Fig. 5.15: Container Composting System Thöni (Photo: Thöni)

Both systems have constructions with or without a turning device. The essential dif-ference in both systems is the way the material is transported to intensive decomposition and to subsequent decomposition.

Box composting: the material is filled in the box by means of a front-end loader or a conveyor belt and also transported to subsequent decomposition.

Container composting: the container, after having been filled with biowaste, is transported to the decomposition place by means of a crane or a truck and after the end of intensive decomposition emptied again with the same vehicles.

The companies which are offering enclosed box respectively container systems are for the time being: Herhof Herhof (*Figure 5.13*), ML (*Figure 5.14*), Strabag, Thöni (*Figure 5.15*) and Kirow (see *Chapter 9.1 Box- and container composting*). In *Figure 5.16* the modular plant type is shown as flowchart.

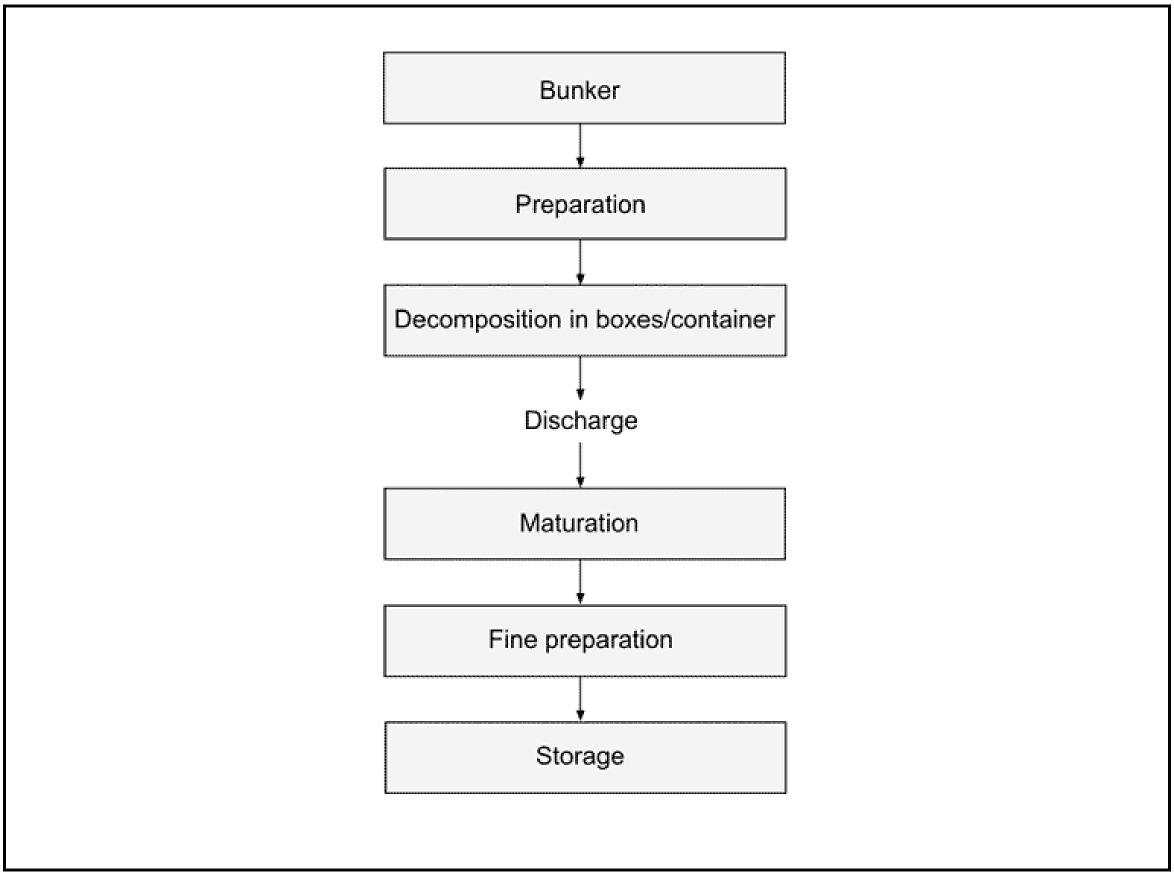

Fig. 5.16: Flow Chart of Modular plant Type I (Box and Container Composting)

5.6.2.2 Tunnel and Channel Composting (Modular Plant Type II)

The biowaste is decomposed in decomposition channels which are open at the top and separated by solid internal partitions. Each channel is separately aerated and turned with a special turning device. This system is offered by Messrs. Sutco. The open decomposition modules of Messrs. BRV and Compac also belong to this group.

Tunnel composting has enclosed channels. This technology lowers the exhaust air volume significantly and minimises odour emissions during the first phase of decomposition, similar to the box and container composting. Tunnels are offered with or without turning devices. A few manufacturers, being on the market (with and without turning devices), are: AE&E, Deutsche Babcock, Passavant (*Figure 5.17*), Gicom, Geotec, Horstmann, Umweltschutz Nord and VAR (see *Chapter 9.2 Tunnel and channel composting*). Passavant has a special selection has whereby not each tunnel is enclosed, but always a group of them.

In contrast to the windrow process the decomposition material is here poured between reinforced concrete walls in the width of 2 - 4 m that form the windrow sides. The forced ventilation takes place through the floor. The length of the rows is approx. 25 - 50 m depending on the system. The decomposition material is turned by a lengthwise navigable turning device on tracks in the width of the row, which can be moved within the rows. Due to the narrow span of the turning device the construction height is lower in comparison with the adequate windrow process and the hall

volume is reduced. Decomposition tunnels with net transport are also used as an alternative to the aforementioned process with turning device, in which the decomposition material is carried lengthwise by turning. Hereby the decomposition tunnel, on the floor of which lies a plastic mesh net, is filled with decomposition material by means of a telescopic conveyor and after a decomposition time of approx. 2 - 3 weeks is removed with a connected net hoist with moulding cutter aggregate. The flexibility with respect to separate decomposition of different materials is greater in comparison to the windrow process with fixed installed turning device, the building constructive complexity, however, likewise.

Fig. 5.17: Row Composting System Passavant (Photo: Passavant)

Today both processes are mainly used as preliminary or intensive decomposition, after which in any case a subsequent decomposition must be carried out, if the production of mature compost shall be achieved. Few manufacturers offer a tunnel system for the total decomposition period, with an adequate decomposition time of 7 to 11 weeks. The modular plant system II is shown in *Figure 5.18* as flow chart.

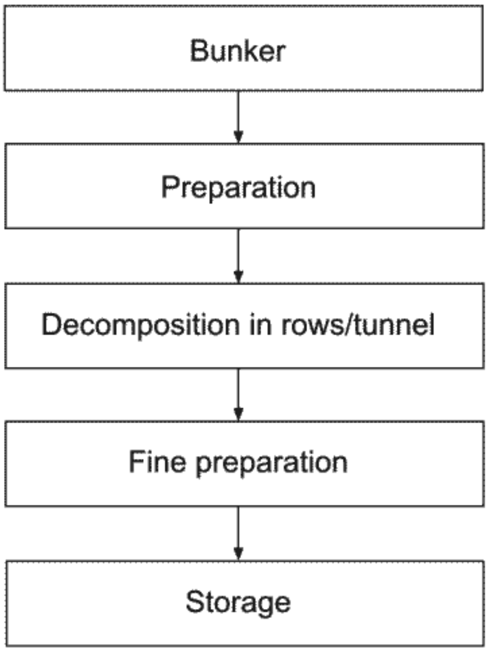

Fig. 5.18: Flow Chart of Modular Plant Type II (Tunnel and Channel System)

5.6.2.3 Decomposition Drums (Modular Plant Type III)

Decomposition drums are mainly used in the area of municipal solid waste composting.

The rotating movement of the drum stirs the material to be composted, i.e. homogenised and comminuted at simultaneous aeration. The drum can be used only as predecomposition or intensive decomposition. The time for pre-decomposition lasts about 1 to 7 days dependending on the plant. Drum systems with short retention times have the task of optimising the treatment of the materials. A hygienisation does not proceed until subsequent decomposition is carried out. Manufacturers of decomposition drums are: Altvater, Envital (*Figure 5.20*), Horstmann and Lescha (see *Chapter 9.3 Decomposition drums*).

Figure 5.19 shows the flow chart of the drum decomposition system. The two lines before and after decomposition must be seen as an alternative, as the various manufacturers offer both versions.

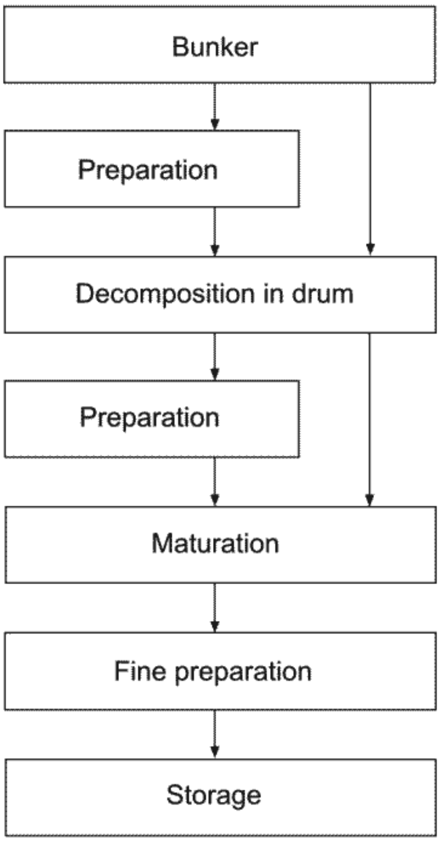

Fig. 5.19: Flow Cahrt of Modular Plant Type III (Decomposition Drum)

Fig. 5.20 Decomposition Drum System Envital (Plant Ansbach/Bechhofen) (Photo: Envital)

5.6.2.4 Ventilated Windrow Composting (Modular Plant Type IV)

On account of arising odours by forced aeration and the reduction of decomposition areas of encapsulated decomposition systems large input quantities are mostly processed in table windrows.

The turning of the windrow is generally achieved by a special automatic turning device and aerated by force (pressure, suction aeration or a combination of both) and watered (in general during turning). In most of the cases the aeration is controlled by the O_2 or CO_2 content. The windrow height is about 3.0 m.

With these processes a mature compost can be produced during 8 to 12 weeks (statement of the manufacturers). The following manufacturers, being on the market, are offering enclosed, aerated windrow composting systems: Bühler (*Figure 5.22*), Thyssen (*Figure 5.23*), Koch - AE&E, Horstmann, Mabeg, Noell, Rethmann and B.Ö.L. (see *Chapter 9.4 Aerated windrow composting*).

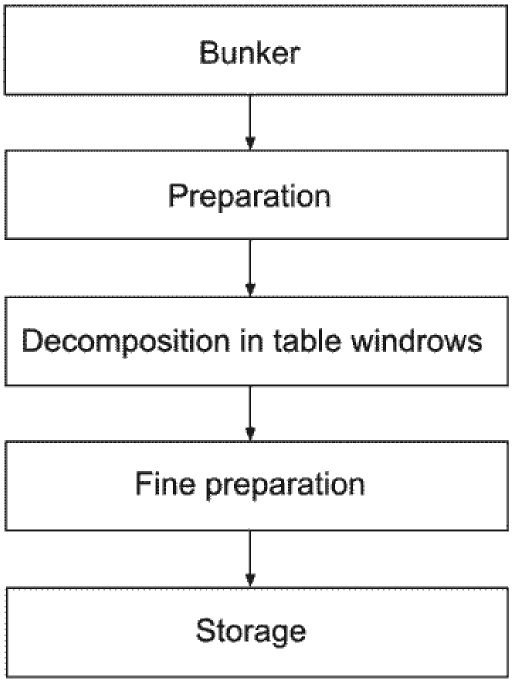

Fig. 5.21: Flow Chart of Modular Plant Type IV (Ventilated Windrow Composting)

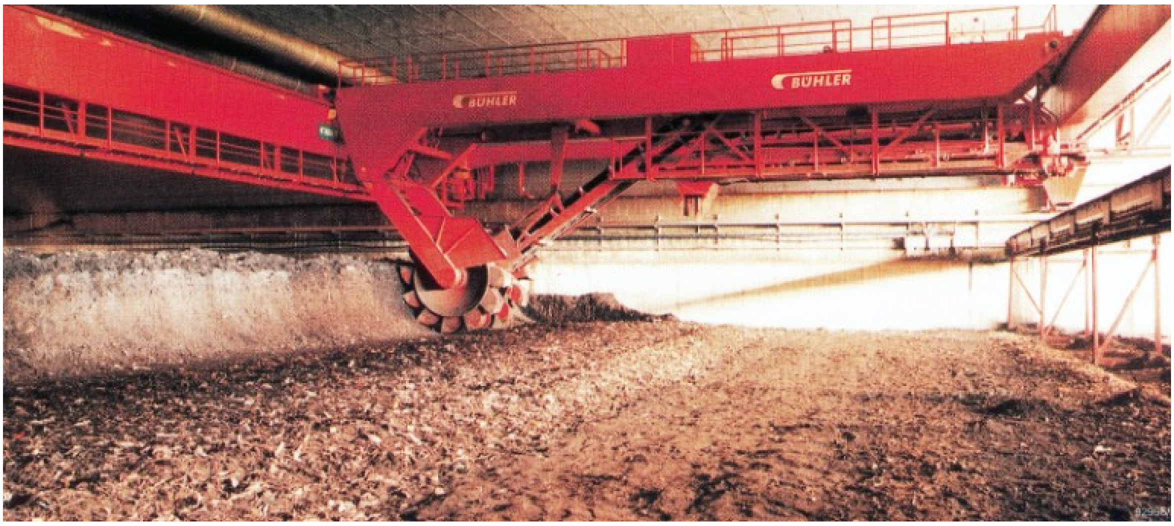

Fig. 5.22: Windrow Composting System Bühler „Wendelin“ (Photo: Bühler)

Fig. 5.23: Windrow Compsoting System Thyssen „Dynacomp“ (Foto: Thyssen)

5.6.2.5 Nonventilated Windrow Composting (Modular Plant Type V)

The oldest and most simple method of composting is the unaerated windrow composting. A heap of biowaste and bulking agent is piled up which is not covered (out-

door windrows). A definite minimum volume is necessary for the windrow not to cool out too rapidly. (see *Figure 5.24*)

The windrows are naturally ventilated. Usually triangle windrows with a maximum height of 1.50 m are used with natural ventilation. Thus ensuring the supply of the micro-organisms with oxygen.

The turning of the windrows is carried out with a front-end loader or turning device. The heap will be loosened and thus aerated by turning.

A maximum height of 1.50 m is here also reasonable. If the windrows are higher (up to 3.0 m) aeration with a bottom plate should be made. A suction aeration is favourable on account of the odour emissions through the open-air construction.

The exhausted air must be transported to a biofilter. The decomposition time lasts, depending on the turning frequency, from 3 to 6 months. This process method is used above all with smaller input quantities of below 6,500 Mg/a (see *Chapter 5.6.2.5 Nonventilated Windrow Composting (Modular Plant Type V)*).

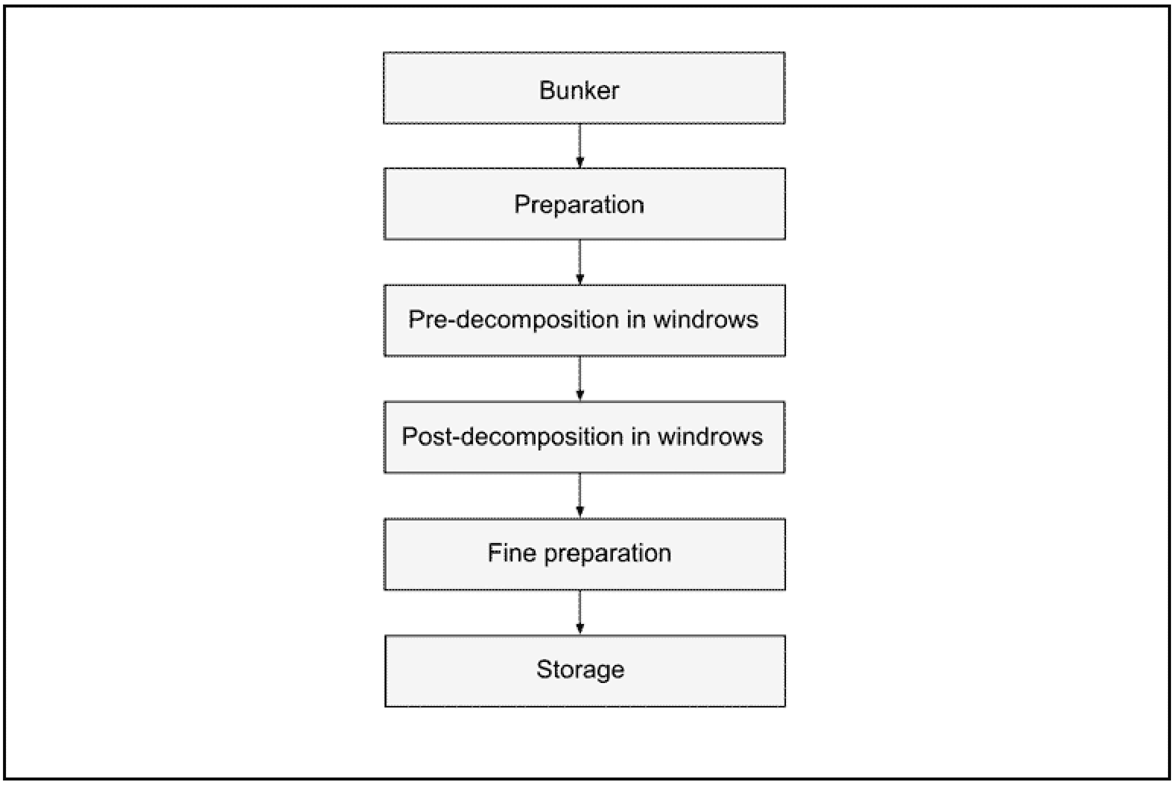

Fig. 5.24: Flow-Chart of Modular plant Type V (Nonventilated Windrow Composting)

5.6.2.6 Special Procedure (Modular Plant Type VI)

Two special procedures are presented within this project. (see *Chapter 9.6 Special processes* and *Figure 5.25*)

Concerned are:

18 Briquette composting and

19 Tower composting

The method of composting with briquettes is a special way of composting as the preparation and decomposition is a completely different process from the usual composting. (see *Figure 5.26*)

The material is compressed into briquettes with a weight of up to 30 kg each, the briquettes are stacked on pallets and then transported into the decomposition hall. The briquettes have a water content of approximately 55 weight-%. The briquettes are slowly drying-out by capillary action and aerobic decomposition processes take place with a simultaneous increase of temperature. Constant watering keeps the decomposition going on for 4 weeks. Thereafter the decomposition stops and the material is preserved [17]. Before treatment the briquettes must be ground. Hereby fresh compost is produced. After repeated humidifying of the material subsequent decomposition can be realised.

According to statements from the producers the decomposition time lasts for 5 to 6 weeks and reaches then a decomposition degree of III or IV [28]. For the time being only Messrs. Rethman is offering this product on the market.

Reactor composting can also be mentioned as a special process in the area of biowwaste composting. However, up to now it has not been accepted. (see *Figure 5.27*) Decomposition usually takes place in a main and a subsequent decomposition reactor (tower). The material is fed by distribution equipment under the roof of the tower and is discharged over a discharging worm. The turning of the material is only realised by refeeding of the material during subsequent decomposition. Then it can also be turned in the reactor itself. The main decomposition time takes 14 days, subsequent decomposition time 28 days more. Aeration of the material is achieved by air injection into the bottom plate. Only a few manufacturers of decomposition reactors are momentarily on the market, e.g.: Steinmüller, Weiss Bio Plants.

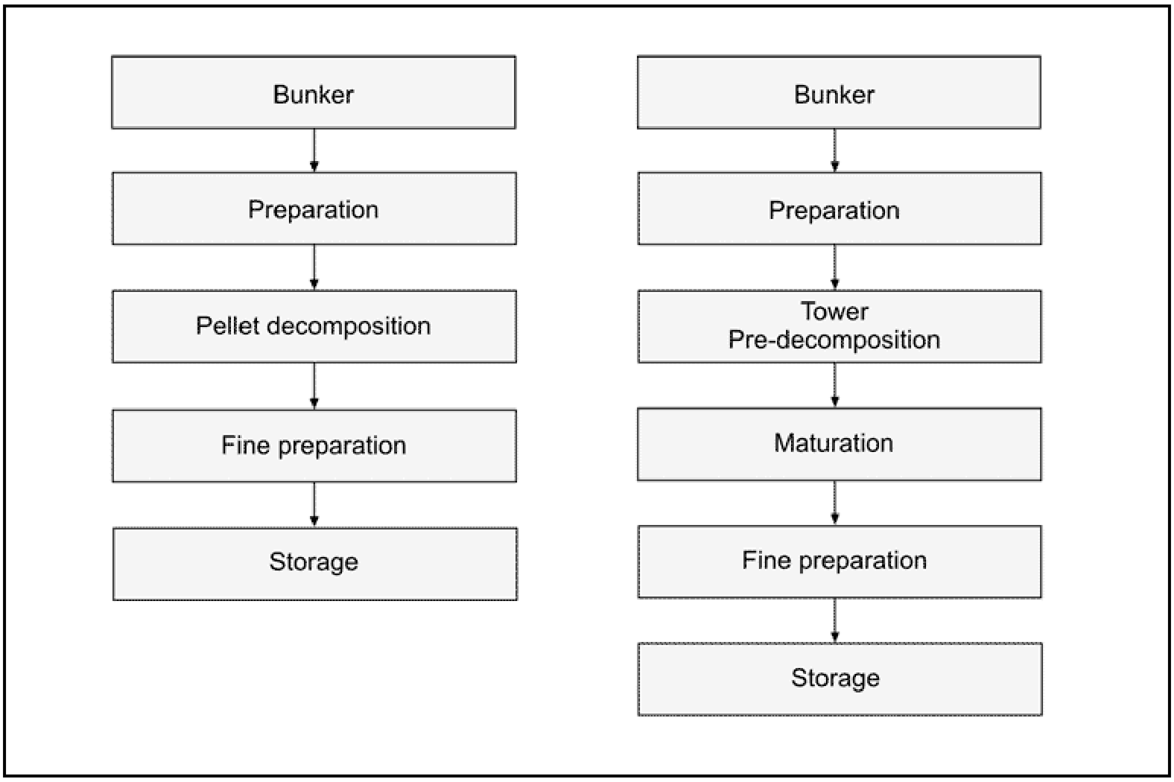

Fig. 5.25: Flow Chart of Modular Plant type VI (Briquette Composting and Reactor Composting)

Fig. 5.26: Bricollare Process (Photo: Rethmann)

Fig. 5.27: Decomposition Tower (Plant Bozen) (photo: Steinmüller)

5.6.3 Factors for Evaluating Decomposition Systems

A large number of suppliers and composting systems have been brought onto the market. The following factors should be taken into consideration with evaluating decomposition systems:

The requirements of product quality are set, for example, in the "Biowaste/Compost Ordinance", which can be found in the leaflet M10 or in the quality criteria of the Federal Quality Association for Compost. Basically, composting has to fulfil the requirements of contagion hygiene, in which pathogens for humans, animals and plants are inactivated or killed. Furthermore, the users expect the inactivation of weed seed.

The plant compatibility or the compliance with a specific grade of decomposition, depending on the respective demands of the composting, has to be given. The decomposition process has to be safeguarded according to the expected product quality.

In order to achieve the required product quality attention should be paid to the potential for decomposition controlling, especially with the aim of short decomposition time and/or little surface area consumption and low emission operation. Through this the quality reliability of product and operation can, in addition, be significantly improved.

Fundamental factors for decomposition controlling are the ventilation (artificial or natural, free air space), the water content and the homogeneity.

Characteristic decomposition parameters are hereby the CO_2-/O_2 concentration in the air space of the decomposition material or in the exhaust air, the temperature in the decomposition material and in the exhaust air, which are used especially for the controlling of the ventilation. The parameter of water content allows for the adjustment of optimal decomposition conditions by the addition of water from outside

(e.g. during turning, air circulation); the factors air space and homogeneity (not directly measurable) should be controlled by the turning frequency according to the requirements of the discharged material.

Emission minimisation should be worked towards especially in larger composting plants and/or close proximity (approx. < 500 m) to emission-sensitive areas (e.g. residential or commercial) or unfavourable wind climate conditions. This is generally achieved by encapsulating the decomposition material. The reduction of leach-ate emissions can be provided for by roofing, whereby odour emissions are also reduced by avoiding wet windrow base and puddles with putrefying water.

The formation of condenser water is substantially influenced by the decomposition process. It occurs in particularly high amounts on the cold decomposition hall walls and in the suction ventilation.

Noise and dust are also emissions that can occur in decomposition especially during turning, distribution and taking up of the decomposition material and which, as the case may be, can be counteracted by enclosure.

The question of plant flexibility or modular set-up plays a significant role in the selection of the decomposition process since biowaste fluctuates, especially seasonally, in amount and composition, different product qualities are often required, bad batches can take place, which should be prematurely removed, and potentially the need for a step-wise expansion of the plant exists. Hereby high plant flexibility and low operational cost are usually values that change in opposite direction.

Especially in encapsulated decomposition systems the construction material should be corrosion-resistant and/or a construction should be selected in which the structural functions are located outside the corrosive areas due to the extremely corrosive properties of the decomposition material (organic acids, ammonia, micro-organ-isms) and the decomposition exhaust air, which is often up to 100 % water-satu-rated.

In addition, the surface and surface requirements are not only important with respect to sealed surface area and built space, but also with consideration for the necessary amounts of air in order to achieve the required circulation values. This has a basic influence on the investment as well as operational costs.

Especially in recent times work safety in the area of decomposition has shifted clearly into focus due to the exposure of personnel to pathogenic germs. If the decomposition system itself is fully-automised and no work places are necessary in the system then a minimisation of this exposure can be achieved.

Work stations in vehicles (e.g. turning device, front-end loader etc.) should only be designed as climate-controlled cabins with appropriate filter element types.

5.6.4 Compilation of Processes

In general, the preliminary decomposition, at the least, should take place in covered and controllable systems for better operation of the decomposition process, but also for emission minimisation.

In *Table 5.12* -*Table 5.15*, the basic decomposition systems for large-scale use currently on the market are depicted. (according to company records, [20], [14], 46] et al.)

Tab. 5.9: Windrow Process with Freely-moveable Turning Device (Examples)

Manufacturer/Process	Short Description of the Process	Turning Capacity/Measurements
Backhus	Self-driving on crawlers, no separate driving tracks necessary, discharge towards the back	Turning capacity 800 - 5000 m^3/h, Triangular windrows, different sizes
MBU	Tractor-pulled drum belt windrow turner, discharge to the side	Table windrows, H=2.5 m Turning capacity 600 m^3/h
Menke	Tractor-pulled with horizontal turning screw, side turner Self-driving with horizontal turning screw, side turner	Triangular windrows H=2.0 m, W=3.5 m Turning capacity approx. 1000 m^3/h Triangular windrows H=2.2 m, W=5.4 m, Turning capacity approx. 1200 - 1400 m^3/h
Morawetz	Tractor-pulled, side turner, turning paddles Self-driving on wheels, turning paddles, discharge towards the back	Triangular windrows H=2.2 m, W=3.5m Triangular windrows H=2.0 m, W=4.5m Turning capacity 500 - 1400 m^3/h
Willibald	Tractor-pulled drum belt windrow turner, vertical milling along the windrow, discharge to the side with conveyor belt	Triangular or table windrows, H up to 3.5m Turning capacity: 400 m^3/h
Komptech/Doppstadt (Topturn)	Self-driving on wheels, spiral-like turning roller portal device, discharge towards the back or to the side	Triangular or trapezoid windrows H up to 2.2 m, W approx. 3.2 - 5.5 m Turning capacity up to 1500 m^3/h
MABEG	On portal device with perpendicular - double-shaft mixer as turning device	Table windrows H=2.5 m

The following terms are related to oxygen and temperature control having assumed that oxygen and temperature are the primary process control parameters:

automatic feedback: oxygen and temperature evolution is followed continuously, and by using a computer, aeration is commenced to satisfy predetermined set points (for oxygen content and temperature levels);

manual feedback: oxygen and temperature readings are periodically taken by personnel to adjust temperature and/or oxygen at pre-set values.

initial condition: oxygen and/or temperature level is regulated within a quite broad range of values by adjusting, at the onset of a composting process, aeration rate or pile size. The term "adjusting" implies very little or no time-course inter vention; and

default condition: there is no deliberate process control. In other words, the na ture of spontaneous self heating "controls" the process.

The term "open" applies to the configuration which allows the material to come into contact with common surrounding air (e.g., windrow, pile, or bay arrangements). Subsequently, in the case of a "container" system, the composting material interfaces only with the clearing space available in the reactor, as the rest of the mate-rial's surfaces come into contact with the reactors walls (e.g., the so-called in-vessel or reactor systems). Both open and container systems might be enclosed in a shed or a building.

Thusly there are combinations of oxygen and temperature control strategy modes which usually are met in real world applications, and are by no means comprehensive. As it can be seen, the composting process is broken down into two main levels of organisation; namely those of process control strategy and process configuration.

The former addresses the conceptual dimension pertinent to managing the microbial ecosystem involved. The configuration module is concerned with materialising the conceptual plan by deciding on variables such as reactor or pile geometry and dimensions, and particular features of the equipment to be used. Hence, terms such as windrow or static pile and so on would not suffice in describing a composting system unless they are used in conjunction with the control strategy engaged each time.

A robust microbial ecosystem management sustains a high process rate, and, thus, entails, among others, the following certain economic and practical benefits:

- Reduced capital and operating costs;
- Minimisation of material handling;
- Odour prevention at its source; and
- Better stabilised compost production.

That way, factors causing a composting project to fail, such as poor public acceptability, and limited compost marketability are restricted from occurring (Panter et al., 1996). It might, consequently, be claimed that composting practices aiming at supporting a wealth microbial ecosystem are the most preferable ones. Nonetheless, different circumstances introduce different constraints, and, therefore, a case sensitive approach should always be adopted. *Table 5.11* provides an overview of pros and cons of some of the most frequently used composting systems.

As indicated by *Table 5.10* and *Table 5.11*, windrow composting might be a good option for managing yard or any other seasonal waste stream at a region with a high land availability. Such a facility should be located sufficiently far away from inhabited areas to prevent odour complains. Aerated static pile (ASP) or aerated pile with turning, assuming forced pressure aeration, might be a good compromise between cost and efficiency but the odour potential is still present. Negative pressure aeration ASP is outclassed by positive pressure aeration ASP which is more efficient and implies a lower cost. Finally, container systems with automatic temperature and/or oxygen control represent the state of the art with regard to processes efficiency and health and safety standards compliance, however, at a higher cost.

Tab. 5.10: Composting System Versus Detention Time (The Composting Council, 1994)

Process Type	**Windrow** (control initial condition, plus water replenishment)	**ASP** (automatic feedback - temperature control, plus moisture replen-ishment)	**Aerated Pile** (control as in ASP, plus turning)	**Container** (control as in ASP)
Processing phase	Duration			
Active	16-40 days	16-30	14-21	4-15
Stabilisation -temperature decreasing	30-60 days	30-60 days	21-60 days	21-45 days
Curing	up to 8 months (turned)	1-3 months (static aerated)	1-2 months (turned, aerated, water added)	1-2 months (turned aerated water added)
Total Time	2-12 months	2-6 months	1-6 months	1-4 months

Tab. 5.11: Advantages and Disadvantages of Common Composting Processes

OPEN TYPE				CONTAINER TYPE	
	Windrow	Ventilated Static Pile (ASP)		Air Recirculation	Air once through
	(Pre-set frequency of material turning -i.e. initial condition)	Negative pressure (control with blowers set on timer is assumed - i.e., initial condition control mode)	Positive pressure (temperature feedback control is assumed -i.e. automatic feedback control mode)	(Temperature and oxygen feedback control -i.e. automatic feedback control mode)	(Temperature and oxygen feedback control -i.e. automatic feedback control mode)
Advantages	1. Low cost option 2. Simple to operate 3. Acceptable compost	1. Useful in conjunction in combination with positive pressure	1. Effective heat removal 2. Low land requirements 3. Faster decomposition	1. Reduced amounts of exhaust air 2. High rate composting 3. Off-gas attainment	1. High rate composting 2. Off-gas attainment 3. Complies with high health and safety

	quality		4. Less prone to odour generation than negative pressure systems	4. Complies with high health and safety standards	standards
Disadvantages	1. Low level process control 2. High land requirements 3. Odour causing 4. Generates dust	1. Difficult to operate (e.g. duct clogging) throughout the material 2. Odour problems 3. Leachate generation 4. Indoors, it causes snowing or raining, and excessive amounts of off-gas to be treated 5. Material stratification 6. Slow decomposition 7. More costly than positive pressure aeration	1. High capacity blower needed. 2. Odour problems 3. Leachate problems possible 4. Indoors, it causes snowing, or raining, and excessive amounts of off-gas to be treated 5. Material stratification	1. Skilful staff is needed 2. High investment and operating costs 3. Need to treat leachate from the condensation chamber	1. Skilful staff is needed 2. High investment and operating costs 3. Need to treat leachate from the condensation chamber 4. More exhaust off-gas to be handled

Tab. 5.12: Composting in Drums

Period of composting: Preliminary decomposition	Period of composting: Main decomposition, subsequent decomposition	Plant size, resp. amount of throughput	Area requirements	Possibility of enlargement	Flexibility, referring to input material	Possibilities of decomposition control (temperature, oxygen, humidity)	Emissions: Odours
System Lecha, 7 - 10 days	8 -10 weeks on heaps	32 m³ per drum (70 m³ planned) 1300-1500 Mg/a per drum	220 m²/per drum with 1 to 2 drums - 150 m² from 3 drums or more. Subsequent decompostion: 1200 m²/drum = 1 m²/ Mg x a (input)	Very good, as construction by modules	Bio and green wastes, also organic trade waste	Temperature and CO2 are meas-ured. Natural aeration. Control by amount of drum rotation. Water can be added	Little
System Envital , 1 - 7 days	5 + 5 weeks on unaerated heaps with automatic restacking, roofing resp. inhousing	3000 Mg/a per drum	0.7/0.6 m²*** average	Very good, as construction by modules	Bio and greend wastes, such as tree and bush cuttings	Measures of the parameters by sensors. Subsequent regulation by means of EDP	Cleaning by means of a biofilter
System Alvahum from Alt-vater , 24 - 36 hours if necessary	1 + 3 months on rectangular heaps (open/roofed/ housed).	Plants from 1500t to 50 000 Mg/a with 1 drum running.	0.7/0.6 m²*** average	Bad, as only 1 drum	Bio and green wastes. Organic waste from trade and industry.	Air input by drum rotation. Humidity can be added	Cleaning by means of a biofilter

	With forced aeration	Mobile plants with 5000 - 10,000 Mg/a per drum			Waste paper and sludges		

Composting system	Emissions: Condensate	Emissions: Seepage water	Compost qualities	Sum of investment	Operating costs	Energy requirements	Process characteristics
System Lecha	No condensate	No seepage water	Compost quality sign	330/280 €/Mg*** average	71/58 €/Mg*** average	15 kWh/Mg input	Pre-comminution of the raw material via screw mill. This includes gentle treatment of the material (good manual selection of impurities). Further comminution in the drum.
System Envital	Separation by means of biofilter	No seepage water	Compost quality sign	330/280 €/Mg*** average	71/58 €/Mg*** average	<20 kWh/Mg input	Green cuttings are precomminuted. Biowaste is comminuted and homogenized in the drum. Thereby gentle removal of impurities and harmful substances
System Alvahum from Altvater	Separation by means of biofilter		No instructions	330/280 €/Mg*** average	71/58 €/Mg*** average	No instructions	Comminution via screw mill (gentle and selective comminution). Further comminution in the drum. Manual selection of impurities.

Tab. 5.13: Composting in Boxes / Containers

Period of composting: Preliminary decomposition	Period of composting: Main decomposition, subsequent decomposition	Plant size, resp. amount of throughput	Area requirements	Possibility of enlargement	Flexibility, referring to input material	Possibilities of decomposition control (temperature, oxygen, humidity)	Emissions: Odours
System Herhof Decompo-sition-box, 7 - 10 days	3 months on ta-ble/triangle heaps, open, roofed, housed	60 m³ per box, amounts to 1250 - 1500 Mg/a. 1500 to 24 000 Mg/a working in operation	0.7/0.6 m²/Mg*** average	Very good - by setting up of further boxes	Bio and green waste, market waste	Computer controlled air supply dependent on CO2 content. Heated recircu-lated air and fresh air can be added in doses. Humidity control is possible	Cleaning by means of a biofilter
System Mab-Lentjes Bio-Container ä, 10 - 14 days	1 + 1 month on heaps	Aprrox. 22 m³ per container. Up to 30,000 Mg/a are planned.	0.7/0.6 m²/Mg*** average	Very good - by setting up of further boxes	Bio and green waste	Computer-controlled regulation rate from measurements of O2 and temperature. Humidity can be added	Cleaning by means of a biofilter

Composting system	Emissions: Condensate	Emissions: Seepage water	Compost qualities	Sum of investment	Operating costs	Energy requirements	Process characteristics
System Herhof Decompo-sition-box	Separation by cooling. Condensate is either added to waste water treatment or used further on.	Closed substance cycle	Quality compost sign	330/280 €/Mg*** average	71/58 €/Mg*** average	20-22 kWh/Mg input material for 1 box through put	Housed-in delivery and mixing area. Comminution and hompgenizing by means of shredder. Simple manual selection of impurities. With large plants - additional sorting belts and perhaps drum screening. Use of waste heat possible. Multiple box throughputs are possible and shorten the decomposition time. Attachment to existing plants (landfilling etc.) lowers the investment costs
System Mab-Lentjes Bio-Container	Separation by coo-ing. Is added to the seepage water	Closed substance cycle	Quality compost sign	330/280 €/Mg*** average	71/58 €/Mg*** average	20 - 25 kWh/Mg Input*	Housed-in delivery and mixing area. Comminution by a cutting rotor.

Tab. 5.14: Row / Tunnel Composting / Briquette Composting

Period of composting: Preliminary decomposition	Period of composting: Main decomposition, subsequent decomposition	Plant size, resp. amount of throughput	Area requirements	Possibility of enlargement	Flexibility, referring to input material	Possibilities of decomposition control (temperature, oxygen, humidity)	Emissions: Odours
Row composting Passavant-Schön-mackers, 3 - 4 weeks	3 -5 months	6500 - 25,000 Mg/a in operation, possible up to 60,000 Mg/a	0.7/0.6/ m³/ Mg*** average	Very good, modular con-struction	Bio and green waste	Measurement of all parameters. Control of air flow rate (forced aeration by suction) via temperature and O_2 content. Pre-heating possible. Spraying possible.	Cleaning by means of a bio-filter. Subsequent decomposition in heap. Eventually cleaning of exhaust air with a bioscrubber
Tunnel composting Babcock, 9 - 11 weeks		1000-1500 Mg/a per tunnel	0.7/0.6/ m²/ Mg*** average	Very good, modular construction	Bio and green waste	Measurement of temperature and O_2 content. Thereby control of forced aeration by pressure.	Cleaning by bioscrubber and biofilter
Composting by bricks	8 -10 weeks, Subseque	From 5000 Mg/a on	10,000 m² (20,000	Bad	Bio and green waste	Limited. Only through	No exhaust air

Rethman, 5 - 6 weeks	nt decomposition		Mg/a) 12,000 m² (40,000 Mg/a)			subsequent moistening.	treatment necessary at the preliminary decompostion. Acceptance via biofilter.

Composting system	Emissions: Condensate	Emissions: Seepage water	Compost qualities	Sum of investment	Operating costs	Energy requirements	Process characteristics
Row composting Passavant Schönmackers	Cooling at heat exchanger. Addition to seepage water.	Closed substance cycle	RAL compost quality sign	4 - 7,5 million € (at 15,000 Mg/a)	Below 35 €/Mg	40 - 45 kWh/Mg input	Batch operation. Various original materials possible at the same time. Automatic re-stacking. Optional manual selection
Tunnel composting Babcock		Closed substance cycle, Preheating possible	No information available.	330/280 €/Mg*** average	71/58 €/Mg*** average	30.7 kWh/Mg** average	Batch operation. Various original materials possible at the same time. Automatic re-stacking. Optional manual selection
Composting by bricks Rethmann	No condensate	No seepage water in the prelimin	Compost quality sign	Approx. 8- 9,5 million € (at 30,000	67/87 €/Mg input	30.7 kWh/Mg** average	Compression of input material into bricks. Manual

		ary decomposition		Mg/a)			selection of impurities possible.

* Average values: Envital, Lescha, ML Control of decomposition only during the preliminary stage.

** Average Values: Babcock, Bühler, Passavant, Thyssen. Control of decomposition during the total process.

*** Average values: Altvater, Babcock, Bühler, Envital, Herhof, Lescha, Passavant, Rethmann, Thyssen (Reference year 1991)

x = Company information 1995

Tab. 5.15: Encapsulated Decomposition

Period of composting: Preliminary decomposition	Period of composting: Main decomposition, subsequent decomposition	Plant size, resp. amount of throughput	Area requirements	Possibility of enlargement	Flexibility, referring to input material	Possibilities of decomposition control (temperature, oxygen, humidity)	Emissions: Odours
Encapsulated decomposition Bühler , 8 weeks	Max. 10 weeks	From 5,000 Mg/a to more than 50,000 Mg/a	Approx. 0,3 m²/Mg, two-storied planning variant with 0,18 m²/Mg	Little	Bio and green waste	Temperature measurement. Controllable forced aeration by pressure. Moistening while restacking	Cleaning by means of a biofilter
Encapsulated decomposition Thyssen-Engineering, 3 months in total		15,000 to 35,000 Mg/a in operation	0,7/0,6/ m²/Mg*** average	Little	Bio and green waste	Temperature measurement (eventually CO_2). Controlling of air volume.	Cleaning by means of a biofilter.
Encapsula	10 weeks,	From	From	Little	Bio and	Controlle	Cleaning

ted de-composition Koch, 8 - 12 weeks, Relocating re-stacking system of the heaps	Self-programming, restacking system	8,000 Mg/a re-locating re-stacking system	15,000 Mg/a, Self-programming re-stacking system, 12,000 m² decomposition hall		green waste	d forced aeration by pressure or suction. Air heating possible. Homogenization and moistening while restacking.	by means of a biofilter. Pre-cleaning with bioscrubbers. Subsequent-cleaning by means of a biofilter.

Composting system	Emissions: Condensate	Emissions: Seepage water	Compost qualities	Sum of investment	Operating costs	Energy requirements	Process characteristics
Encapsulated decomposition Bühler	No information available.	Closed substance cycle	No information available.	300 - 500 €/Mg	50 - 90 €/Mg throughput	36 kWh/Mg bio-waste for total process	Preparation by triple worm mill. Automatic heap restacking (Wendelin System) Compost preparation by means of drum screen, air classifier and densimetric separator
Encapsulated decomposition Thyssen-Engineering	No information available.	Closed substance cycle	No information available.	330/280 €/Mg*** average	71/58 €/Mg***	30.7 kWh/Mg input** average	Preparation of biowaste by means of drum screen and manual separation. Screw mill for green cutting. Drum mixing. Processing of compost by

							means of drum screen and densimetric separator.
Encapsulated decomposition Koch	Colling at heat exchanger. Addition to seepage water	Closed substance cycle	Compost quality sign	Approx. 37 million. € (60,000 Mg/a)	No information available.	No information available.	Preparation by means of drum screen and manual separation. Mixing drum.

5.7 Ventilation System and Areas

It should basically be differentiated between natural and artificial ventilation. In natural ventilation it is assumed that the necessary gas exchange takes place by diffusion of outside air into the air space as a result of concentration differences. The process is supported by convection flows due tot temperature differences since generally there is a much higher temperature in the decomposition material than in

the surrounding area. Natural ventilation requires a large amount of air space, good structure stability and small windrow measurements (dumping height) in order to ensure the gas exchange. It is therefore only realisable in plants with little throughput capacity and high specific required space. The decomposition times are significantly longer than in processes with artificial ventilation.

In artificial ventilation the air is guided through the decomposition material by producing high pressure (compression ventilation) or low pressure (suction ventilation), during which gas exchange takes place. The dumping heights can be up to approx. 3 m, in special cases even higher dumping is possible (e.g. tower decomposition).

Compression ventilation possesses the following advantages and disadvantages compared to suction ventilation:

- Advantages
  - Good distribution of air in decomposition material
  - No wet windrow base due to condensation generation
  - No condensation accumulation in ventilation system
  - Ventilation system is not susceptible to corrosion
- Disadvantages
  - High odour emissions (on the surface of the windrow)
  - No targeted exhaust air collection from the windrow (e.g. for heat recovery use) is possible (Exception: covered box or container system)

By planning the potential for traversability of the suction and compression ventilation the formation of preferred channels can be counteracted; the multiple use of air as a part of the decomposition process (e.g. by suction ventilating fresh material and using the air for compression ventilation of mostly decomposed material) is possible with the appropriate air circulation.

The ventilation areas should be designed tranversible or non-traversible depending on the type of decomposition system. Generally, decomposition areas should be sealed to allow for year-round traversability and the minimise leachate and odour emissions. Potentially occurring precipitation should not run in the direction of the windrow base.

Traversible ventilation areas are mainly produced with slatted prefabricated panels (e.g. Rottair system) or composite blocks with ventilation openings (e.g. Bikovent blocks, ELWU blocks). Hereby leachate and precipitation can be collected by this system at the same time. The system with covered ventilation channels (e.g. Heidenheimer decomposition plates), which is also easy to clean and causes relatively low investment costs. In the box system the ventilation decks are made of perforated sheet metal. (see *Figure 5.28*)

Fig. 5.28: Configuration of a Sealed Decomposition Area (Heidenheimer decomposition plates) (Photo: Ingenieurgesellschaft Abfall)

Non-traversible decomposition areas (e.g. in systems with fixed installed turning devices or decomposition towers) are usually made up of a gravel bed with ventilation pipes (drainpipes), which is covered by geotextile and hardwood carvings (wear layer) and makes even air distribution possible. Perforated sheet metal is used in container systems.

5.8 Maturation Phase and Storage

The microbial activity in the area of the maturation phase depends on the type and duration of the preceding intensive decomposition. In the case of short decomposition times in the intensive decomposition phase (up to approx. 14 days, degree of decomposition I to II) relatively high microbial activity can be expected. This means that good oxygen supply and optimal water content should be maintained over a longer period of time in the maturation phase.

This is possible by means of artificial ventilation, small windrows or regular turning with the potential addition of water. The occurrence of odour emissions should be taken into consideration.

In decomposition processes with longer decomposition times in intensive decomposition (approx. 8 to 12 weeks) microbial activity (e.g. as temperature increase) is also exhibited, especially after preceding fine treatment resulting from an altered

particle structure and potential opening of new surfaces, but it is significantly lower. The maturation periods are shorter compared to the above mentioned process.

The maturation phase generally takes place on triangle, trapezoid or table windrows; hereby the surface requirement of triangle windrows (approx. 1.5 m^2/m^3), with a windrow height of 2 m including access ways, is significantly more than for trapezoid windrows (0.8 m^2/m^3). (see *Figure 5.29*)

It should generally be taken into consideration that occasional turning of the windrows should be possible. The turning can be carried out with turning devices for this purpose (see above). Usually, a front-end loader is used that can simultaneously take care of the distribution and loading of the compost.

With respect to regular year-round operation the surface for the maturation phase should be sealed. Roofing over the maturation phase area is beneficial for avoiding a wet windrow base and odour emissions due to leachate and/or surface water. This is especially true for regions with high levels of precipitation. Complete casing is generally not necessary, especially in connection with the intensive decomposition process, which includes a decomposition time of significantly more than 6 weeks. Completely closed-in maturation phase areas require a higher amount of technical construction work on the part of the building due to condensation with respect to corrosion protection and controlled air exchange. As a result the cost of operation is increased. The duration of the maturation phase is, depending on the process, between 1 to 2 months.

The storage spaces serve as interim storage for the compost until transfer to the compost user. Here a sealed surface is also required for the given reasons; roofing is not absolutely necessary, but it offer the possibility of a low-emission operation independent of the weather.

The windrows should be piled to a height of up to 3 m during the storage time; they are usually piled in trapezoid or table windrows.

Fig. 5.29: Maturation Phase hall (Plant heidenheim, Photo: Ingenieurgesellschaft Abfall)

In many composting plants maturation phase and storage surfaces are in the same area and are not seen are separate entities such that the composting material is directly sold from this maturation are (with storage function).

It is beneficial to install the fine treatment and confectioning and as the case may be the bagging facility near the maturation area.

In the case of mobile fine treatment (e.g. by a drum screen) it often takes place directly on the maturation surface.

If little composting space is available, such as in the case of the production of composting soil, the maturation phase, soil production and storage are sometimes carried out at a different place.

5.9 Building Design and Surface Requirements of Composting Plants

5.9.1 Building Design

Building design and construction of composting plants have significant importance due to various reasons. Listed here are:

- Operational sequence
- Emission reduction
- Costs (construction, operation, repair)
- Work safety (noise, dust, micro-organisms)
- Architectural design and plant image

5.9.1.1 Site Plan

The operational sequence, emission reduction as well as architectural design is influenced to large extent by the **site plan design**.

Generally, it should be observed that the configuration of the buildings follows the material flow. At the same time an organisation of private traffic, waste delivery, compost pick-up, residue transport and visitor traffic should be targeted as much as possible.

As a result of which, the weighing and delivery areas should be located close by one another, while the building for coarse treatment as well as decomposition should be located further away from the entrance area. Maturation, the storage in particular, are next to the delivery areas with high traffic. It should be designed with private customers (cars) and tractor trailers in mind, which therefore makes sufficient dimensioning necessary.

Congestion space should be considered in the planning of the weighing station, which, depending on the throughput capacity, offers room for 2 to 3 tractor trailers without inhibiting the public roadways. A separate deposit area (e.g. container) should be planned for private person deliveries in order to avoid them having to drive onto the waste bunker (accident hazard, emissions). At the same time it is advantageous to combine this area with the possibility for the delivery of other valuable materials (e.g. paper, glass, metal etc.) by providing the respective containers. Optimally, there should be signs indicating a **recycling yard** in this area.

Private visitors should be kept as far away as possible from the plant vicinities. Appropriate parking should, therefore, be available in the entrance area.

As a result the operation building, which depending on the size of the plant and situation can either be an individual building or part of the composting plant facilities, should also be located near the entrance area.

The inner radii, with respect to traffic areas, should be designed so that large waste trucks or compost collectors in tractors with trailers can access the premises in the respective areas without any problems. Fire brigade access should be possible for all buildings.

5.9.1.2 Structure and Design

High emission areas (e.g. delivery, biofilter, compost storage) should be situated so that they are on the opposite side from sensitive built-up areas (e.g. residential areas).

The buildings' heights should be designed so that in the delivery and loading area (flat bunker, storage) they have a clearing height of at least 6 m. Gates should generally be designed with an access height of at least 4 m.

In the areas for coarse and fine treatment the residues (sorting residues, screening residues) should be able to be easily disposed of in containers by tractor trailers. The construction height of the halls are generally determined by the aggregates that are to be set up in them. It is beneficial for the transport of heavy parts, in case repair is needed, to plan for the appropriate crane equipment. In larger plants the total measuring, controlling and regulating technology is put into its own control room, in which the plant is operated and operation data is documented by block schematic diagram or screen. In smaller plants the switching and control cabinets are located in the respective area of the main aggregate (e.g. coarse treatment, decomposition, fine treatment).

Special attention should be given to the areas with lorry or front-end loader traffic and/or the decomposition facilities with respect to the building construction and materials. Generally reinforced concrete is used in the delivery and maturation/storage areas, which provides sufficient access protection. Wood constructions should be protected with appropriate steel constructions.

In closed decomposition systems the high humidity (steam-saturated) high air temperature prevailing there , which is generally higher than the outside temperature, and the aggressive materials contained in the air (organic acids, ammonia) should be considered. This requires special constructive solutions for the structural construction and outer wall surfaces.

Tried and tested is shifting the necessary structural construction to out of the aggressive zones to the outside of the building. Currently the following materials are being used for construction: concrete, (sometimes coated with epoxy resin), epoxy resin coated steel constructions, with aluminium foil clad wood glue bonding, stainless steel sheet metal, foil covering, epoxy resin impregnated plywood. Sufficient insulation for the construction should be taken into consideration, especially in regions with cold winters, due to the danger of icicle and plate formation. In open decomposition halls (e.g. for maturation) the aforementioned problems are not to be expected with the appropriately designed construction. Condensation on the underside of the roof should also be considered here.

Today, the architectural design of the plant is of significant importance with respect to the integration of the plant into its environment and its acceptance.

An architecturally appealing plant should be constructed by the use of appropriate building materials and elements, colour design, landscape planning and site planning. The large building masses, especially in the decomposition area, can be diffused in this manner. The integration of such a plant in a universal image for regional waste management (corporate identity) is beneficial. [37]

5.9.1.3 Surface Sealing

Sealed surfaces that are not covered by waste or compost, and therefore are not under the influence of leachate, do not generally have to be constructed to be watertight. Aside from the substructure (frost protection layer) the pavement should be of asphalt concrete or concrete (e.g. according to ZTV).

In plants with high traffic the driving surfaces should be drained by means of a light liquid separator.

Surfaces that are subject to waste of decomposition material feeding generally have to be constructed so that that are water-tight. Here both systems with smooth surfaces and overlying sealing layer as well as those with drainage layers can be realised. [7]

Sealant systems with smooth surface and overlying sealing layer are:

- Concrete sealing according to DIN 1045
- Bitumen and asphalt sealing

In concrete sealing concrete with high wear and frost resistance, as well as very little water permeability, should be produced with concrete additives and appropriate workmanship. The joints should be executed with permanently elastic joint sealing.

Bitumen and asphalt sealing can also be implemented as a matter of principle, but they have the disadvantage compared to concrete sealing that bitumen sealants can be attacked by the micro-organism activity in connection with high decomposition temperatures and be distorted by loading. Poured asphalt or asphalt matrix covering layers better resist microbial attacks.

The aforementioned sealing systems have the advantage that damaged spots are easily recognisable and repairable.

Sealing systems with an inner-lying sealant layer or drainage layer are:

- Sealing sheets with over-lying composite block pavement
- Mineral sealing with over-lying composite block pavement
- Sealing with over-lying drainage layer

In the case of the systems with composite block paving a PE-HD foil, on top of a fine grade level or three-layer mineral sealing on grade, serves as sealing layer. On top of this a protective and drainage layer is applied, which drains water. A disad-

vantage here is that the damaged spots are not easily identifiable and repair is more difficult.

In the case of sealing with an over-lying drainage layer (usually PE-HD foils with plating made of igneous rock filled hollow blocks, gravel etc.) the danger of damage from continuous traffic is great. The controllability is also more difficult. This type of sealing is, therefore, usually only used on surfaces that do not have driving traffic

(e.g. turners on tracks, biofilters etc.).

5.9.1.4 Waste Water Drainage

The following water can accumulate at the plant:

- Surface water (not contaminated by operation)
- Surface water (contaminated by operation)
- Leachate and condensation
- Household waste water (toilettes, showers)

Water, which is not contaminated by operation, can seep away or be sent into a runoff ditch or the rain water canalisation. One good possibility is to collect the water, store it and use it in the decomposition phase.

Water, which is contaminated by operation, as well as household waste water should be fed into the canalisation or sewage treatment facility suitable for this purpose. Leachate requires special treatment (see *Chapter 5.10.4 Treatment of Waste Water From Composting Plants*) and may , therefore, generally not be fed into the municipal sewage treatment plant.

On surfaces that are not always completely covered by decomposition material it is beneficial to separately collect leachate and non-contaminated surface water by means of sector-wise roof-shaped constructions (incline > 1%) respective to the current use.

Leachate and condensation can also be used to moisten the decomposition material and should, therefore, be collected in separate basins.

5.9.1.5 Miscellaneous Facilities

Aside from these process-specific buildings the following facilities should also be planned (Operational and social area):

- Offices for administration and accounting
- Conference and meeting room (depending on the integration into the other operational facilities)
- Laboratory (for simple composting analysis for self-controlling such as: water content, degree of decomposition, pH-value, salt content, test strips, potentially also more extensive (glowing loss etc.)).
- Workshop (for small repairs)
- Break room for personnel
- Tea kitchen
- Toilette facility
- Black-white areas (changing rooms, showers) according to workplace guidelines
- Storage for replacement parts and material
- Additional rooms for heating, electricity etc.

Further additional facilities depend on the plant size and type. Stated here are:

- Additional recycling yard (see above)
- Fire pond (rain water storage basin), biotope function
- Model garden (for examples of compost use)
- Tanking units (for operation's own vehicles)

5.9.2 Specific Surface Requirement of Composting Plants

The specific surface requirement of composting plants depends, in particular, on the plant throughput, technical level and necessary decomposition time, which is determined by the degree decomposition.

In simple windrow composting plants the specific surface requirement is 1.2 to 2.5 m^2/Mg * a, depending on the windrow processing (turning technique) and the amount of throughput.

In the intensive decomposition process the specific surface requirement fluctuates between 1.0-2.2 m^2/Mg * a with a throughput 12,000 Mg/a and 0.4-0.8 m^2/Mg * a with a throughput of 50,000 Mg/a. ([20], [26] et al.)(See also *Figure 5.30*)

The decline of the specific surface requirements along with increasing throughput capacity is explained by the fact that the traffic circulation spaces, entrance and weighing station area, and in part the areas for the processing aggregates, do not for the most part depend on the throughput capacity.

If only fresh compost (degree of decomposition of I -II) is produced instead of mature compost the specific surface requirement id significantly decreased since the intensive decomposition area can be design smaller and maturation and storage spaces can be omitted.

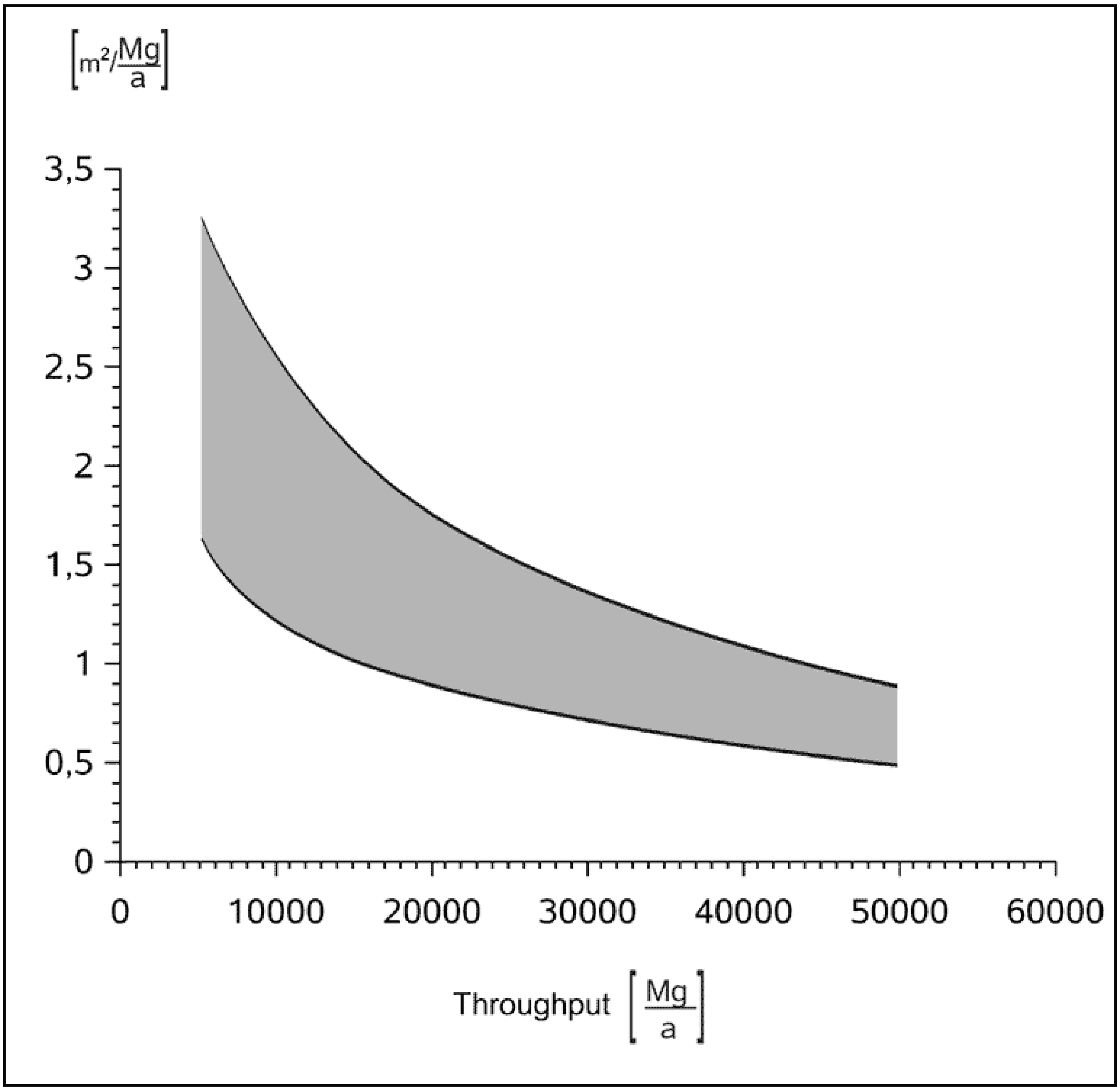

Fig. 5.30: Specific Surface Requirement of Composting Plants

5.10 Emissions and Emission Reduction

The image of the plant and along with it its acceptance is determined mostly by the emissions. Since emissions are always released in the operation of a composting plant regardless what kind of feed material is used, it should be seen to it that the emissions are reduced, depending on the respective location, by construction and process technological measures, as well as appropriate processing for the material.

Generally three emission pathways come from a composting plant:

- Water (leachate, condensation)
- Soil (contaminants in compost)
- Air (odours, germs, noise, dust)

According to the process procedure in composting plants the individual process steps can be classified into the emission pathways displayed in *Table 5.16*.

It should hereby be noted that emissions from the pathway soils can be avoided by providing the appropriate constructions (e.g. complete casing) in the areas of delivery, coarse treatment, preliminary and main decomposition, confectioning and roofed storage. This is also true for encapsulated areas for the emission pathway by air (e.g. dust, noise), which is of significant importance for work safety by the encapsulation within the buildings, but have no outside effect. Other air or water streamed plant internal emissions should be reduced by collection. They, however, also occur outside the building limits (e.g. odours).

Tab. 5.16: Emission-relevant Process Steps in Biowaste Composting [31]

Process Step	Aggregate / Component	Emissions from		
		Water	Soil	Air
Delivery	Bunker	Compacting water/ leachate	None	Odours (dust)
Pre-treatment	Processing (screening, desalvaging, mixing etc.)	Compacting water/ leachate, condensation from exhaust air treatment	None	Odours (dust)
Preliminary Decomposition	Reactor, drum (windrows)	Compacting water/ leachate, condensation	None	Odours
Main Decomposition	Windrows (potentially cased-in reactor)	Compacting water/ leachate (condensation)	None	Odours
Confectioning	Screen, heavy solid material separator etc.	None	None	Odours, dust
End Product	Compost storage	None when covered (water logging!)	Heavy metals, other contaminants	Odours, dust

Subsequently the emission pathways by air (odours, dust, noise) and water (leachate and condensation) are described along with their origins as well as avoidance and reduction measures. The topic of germs, as well as the emission pathway through the soil (for the compost) are dealt with in detail in the chapter "Hygiene" and "Compost Recycling".

5.10.1 Odour

5.10.1.1 Origin of Odours

Materials are set free due to microbial activity and chemical reactions during the decomposition and conversion of organic substances in composting, which cause odour perception by humans. These odorous substances are transported by the air pathway. They can not be classified into a unified chemical property, but as characteristic can be stated [22]:

- Low molecule mass
- Volatility
- Water and fat solubility
- Functional groups and structures

Hereby the odours can be differentiated between according to type, quality and intensity. Depending on their origin they can be classified in accordance with *Figure 5.31*.

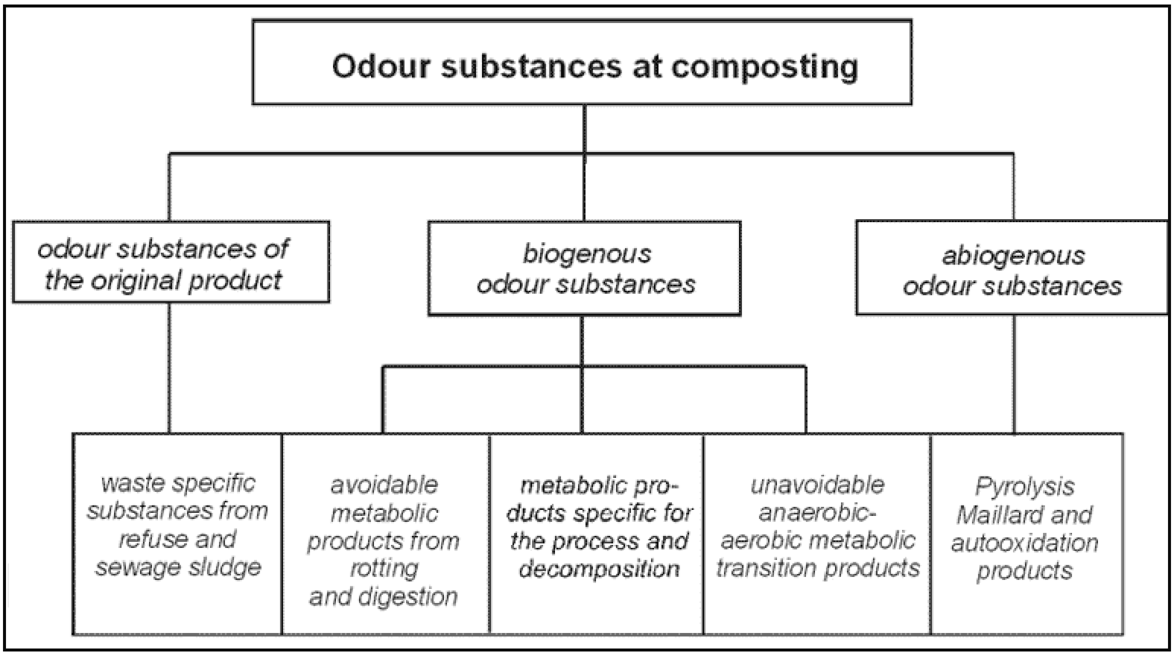

Fig. 5.31: Classification of Odours [22]

The characteristic, odour active substances shown in *Table 5.17* can be determined in the composting process itself, depending on the respective decomposition phase.

In matured compost a typical forest soil odour is observed. This is caused by geosmine, a substance exchange product that id set free by actinomycete.

Tab. 5.17: Characteristic Odour Active Substances in Composting (according to [34])

Phase	Characteristic Substances	Determining Odour Portion
1. Acidic Start Phase	Aldehydes Alcohol Carboxylic acid ester Ketones Sulphides Terpenes	Alcoholic, fruity
2. Thermophilic Phase	Ketones Sulphuric organic compounds Terpenes Ammonia	Sweet, fungus-like Unpleasant, mouldy
3. Cooling-off Phase	Sulphides Terpenes Ammonia	Mouldy, fungus-like, penetrating

Since odours deal with sensual perceptions and have no clear chemical characteristics the measuring system of olfactometry has established itself for measurement. This is defined according to VDI 3881 [41] as controlled presentation of odour carriers and the recording of the sensual reactions caused by which in humans. This is measured with an olfactometer, in which the gas samples to be measured are defined with dilution by neutral air and smelling tests are carried out at different dilution levels (beginning with high dilution) with a probant collective.

When 50 % of the probant collective has a subjective odour perception then the perception threshold is defined at that dilution level. This odorous substance concentration does not give any information pertaining to the quality of the odour; it is strongly dependant on the temperature of the odour source due to the volatility of odours. An odour unit is the number of particles of the odour carriers, which - distributed in 1 m³ neutral air - just causes the perception of an odour (1 OU). The unit for odorous material concentrations, which is deducted from the dilution concentration, is 1 OU/m³.

The calculation of odorous substance concentration takes place by the derivation of the dilution value at the odour threshold divided by ratio formation of mass flow of neutral air to mass flow of the odorous substance rate plus 1. It is given in OU/m³.

The recognition threshold of odours is the concentration of odour carriers at which 50 % of the probants can recognise the quality of the odour. It lies at around 5 OU/m³.

The odorous substance flow, which includes the odour freight and along with it rep-resents the decisive value for the question of the emission concentration, is calculated by the multiplication of odour concentrations and acquired mass flow. It is given in odour units per unit of time (OU/s, OU/h). In the case of odour radiation,

e.g. from windrow surfaces (passive odour emission) freight calculation is difficult. Approximation data is possible by means of model calculations, micro-meteorolog-ical measurements and/or "passive sample taking" from a hood placed over the surface to be measured. The odour radiation is given in OU/m² * h or OU/m³ decomposition volume.

It should be taken into consideration that olfactometric measurement and comparison are only conditionally reproducible, since they depend on the probands (age, physiology, living habits (e.g. smoking)) and the respective predominant air circulation (surrounding temperature, air humidity, air pressure). The olfactomerty can not be used for continuous monitoring of the plant. For this the analysis of the total carbon in the monitored exhaust air by means of a flame ionisation detector (FID). A calibration is possible for specific plants by correlation of the FID measurements and the odorous substance concentration; a general correlation is not viable since gases are also collected by the FID, which have no odour (e.g. methane), on the other hand very odour intensive materials that do not have carbon compounds and can, therefore, not be measured (e.g. ammonia, hydrogen sulphide).

5.10.1.2 Odour Sources

According to the individual process steps the odour sources in composting plants can be classified: [8], [31] et al.

- Delivery, bunker area

  Here the odour emissions are caused essentially by the delivered biowaste. Their odour concentration is 5600 OU/m³ on average in the warmer seasons, in colder seasons at approx. 700 OU/m³. The mean odour radiation can be set at 3,3 OU/s * m². If it is assumed that there is a closed delivery area, the odour concentrations in the bunker are in the range of 50 - 350 OU/m³ (approach: triple air exchange).

- Coarse treatment

  Here the odour emissions depend greatly on the suction ventilation of the aggregates (mills, screens, belts etc.) and the material transfer locations. In different plants the odorous substance concentrations in the room air were measured at 50 - 500 OU/m³ [14]. With encapsulation of the aggregates and systematic suction ventilation a odorous substance concentration of 200 OU/m³ can be assumed (air exchange value 0.5).

- Decomposition part

  Here the emissions are decisively dependant on the type and duration of the decomposition process and decomposition state. The mean odorous substance concentrations for composting raw material are 5000 OU/m³ which equals 4.1 OU/s * m². If fresh windrows are covered, e.g. with chopped shrub trimmings, the mean odorous substance concentration sinks to 1250 OU/m³ which equals 1 OU/s * m².

In **decomposition drums** the odorous substance concentration fluctuates depending on the age of the compost and the rate of ventilation in the range of approx. 5000 OU/m³ (fresh material) and 35000 OU/m³ (after approx. 1 week decomposition time). Odour concentrations in the range of 15000 - 30000 OU/m³ can be expected with a ventilation rate of 5 m³/m³ * h and a dwell time of around 1 - 3 days. The discharge material causes a radiation of 4 (1 day) up to 10 OU/s * m² (7 days).

In **rotting boxes** the odorous substance concentrations also depend on the above mentioned factors. It can be estimated that with a decomposition time of 7 days and air injection 5 m³/m³ * h there will be a mean odour concentration of approx. 30000 OU/m³, and by quadrupling the amount of air injection a concentration of 10000 OU/m³ (decomposition start up to 200 OU/m³) after a week. The discharge material has a radiation of approx. 11 OU/s * m² (mean value at 7 d).

In **nonventilated windrows** the odour emissions are significantly dependant on the decomposition time. The odour emissions increase greatly due to turning procedures and the application of water to dry material due to the high microbial activity on the surface and the thermodynamic rates. Experimental results are listed in *Table 5.18* for nonventilated windrows based on examples. It becomes clear that the degree of composition III can be achieved after the fourth decomposition week at the latest with good decomposition operation and the odour concentrations on the windrow surface are around 600 OU/m³ which equals approx. 0.5 OU/s * m². By covering the windrow the odour emissions could be reduced by up to 75 % during the first 14 days.

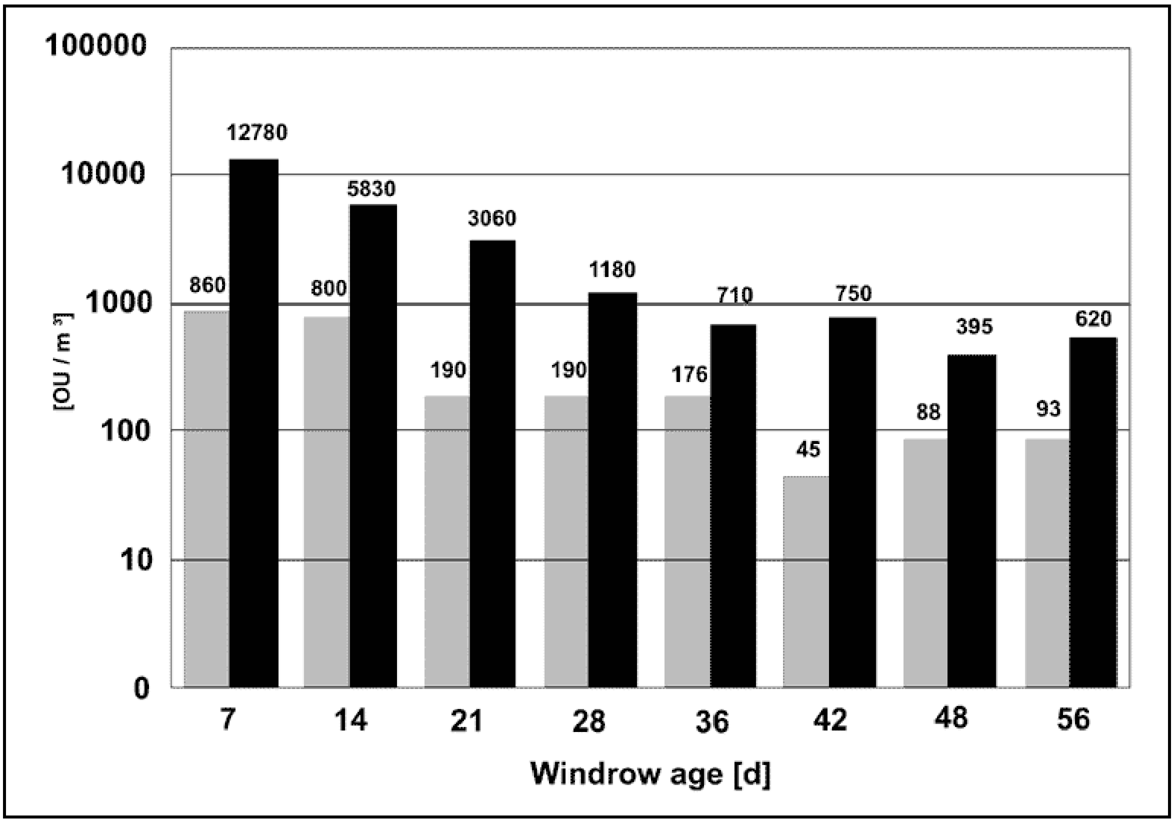

Fig. 5.32: Odour Emissions in Windrow Processing

In **ventilated windrows** the calculation of the odour freight based on the odour concentration is easily possible due to the given air volume flow. In **suction ventilated**

table windrows (decomposition time 10 weeks) should be calculated with a mean of approx. 11500 OU/m³. The odour radiation is comparatively low at approx. 350 OU/m³. In **compression ventilated windrows** an increasing decomposition time with tendency towards decreasing odour concentration can also be stated.

The values lie at approx. 4000 OU/m³ (5th week) and 1000 OU/m³ (after the 6th week). After turning up to 30,000 OU/m³ can be found. Approx. 8000 OU/m³ can be expected as mean value.

Table 5.18: Odour Emissions from Decomposition Processes (according to [8])

System	Limiting conditions	Odorous substance concentrations OU/m³ (rounded)	Odour radiation OU/s * m² (freight)
Composting Raw Material	Freshly poured	5000	4.1 *
	Covered with chopped material	1250	1 *
Decomposition Drum	Fresh material 1 week decomposed Ventilation rate 5 m³/m³ * h ta = 1.5 d - 2.5 d	5000 35000 15000 – 30000	--21-42 *
	Discharge material: 1 d 7 d	4800 12000	4 10
Rotting box	Ventilation rate 5 m³/m³*h	30000	41 *
	Ventilation rate 20 m³/m³*h	10000/200	30 *
	Discharge material: (7 d)	13300	11
Windrow Decomposition Triangle windrows non-ventilated	Resting: 1st week 2nd week 3rd-4th week	5000 -8000 1000 - 2000 200 -500	4.1 -6.6 0.8 -1.6 0.26 - 0.4
	>4 weeks	100 -200	0.08 - 0.16
	after turning:		
	1st week	13000	11
	3rd week	3000	2.5
	Degree of decomposition III	600	0.5
Nonventilated table windrows	Average more than 10 weeks	5700	5
	7 d	13000	12
Briquette pile	4 weeks	600	0.5
Windrow decomposition ventilated	Exhaust air 3 m³/m³ * h	11500	9.6
	Radiation	350	0.3
Suction ventilated table windrow	Resting average	8000	6.7
	After turning (batch: 20% fresh turned)	30000	25
Compression ventilated table windrow	Suction ventilation	2000	3
	Compression ventilation resting	5000	10
Decomposition halls	During turning	up to 30000	40

* referring to OU/s * m³

In **decomposition halls** significant differences are seen with suction and compression ventilation systems. In fully occupied halls exhaust air concentrations of under 2000 OU/m³ are found with suction ventilated table windrows. In compression ventilated table windrows the exhaust air concentrations are approx. 5000 OU/m³ without turning and up to 30000 OU/m³ with turning (1-fold air exchange in the hall).

- Fine treatment and storage

  The odour emissions from the surface of the matured compost are in the range of 80 - 900 OU/m³ (mean value 150 OU/m³). Values in the range of 250 - 1100 OU/m³ are to be expected with dug-on windrows. However, in wet, slightly decomposed windrow bases or water puddles the odour emissions increase manifold.

- Traffic areas

  In traffic areas odour emission of 20 - 200 OU/m³ can be found. A precondition of which is that no wet, decomposing material is lying on these surfaces, otherwise a drastic increase in emissions can also be expected here.

- Biofilter, biowasher

  The biofilter is the essential emission source for the collected exhaust air for exhaust air purification in encapsulated plants. The odorous substance concentrations for functioning filters lie in the range of 50 - 250 OU/m³. Approx. 100 - 150 OU/m³ could be expected as mean value with consideration for its own odour. With this data the problem of reproducibility of olfactometric values should be taken into consideration (see above). In the case of biowashers orienting analyses show that odour emission of approx. 200 - 500 OU/m³ can be expected [14].

5.10.1.3 Measures for Exhaust Air Purification

Exhaust air purification in composting plants is usually carried out with biological processes since the odorous substances are generally well biodegradable. Biofilters and sometimes biowashers are used, in a two-phase process the biofilter is used first.

Biological exhaust air purification through a biofilter is a sorption process, in which the contaminants (odorous material) in the exhaust air are first absorbed in a watery phase by a moist, organic filter material (e.g. shredded burl wood, composted branch trimmings, erica, bark products, compost), the habitat of micro-organisms, and then afterwards disintegrated by the micro-organisms due to oxygen loss. The decomposition mechanism is similar to the principle course of composting. The use of a biofilter process is possible under the following conditions [15]:

- The exhaust air substances are water-soluble.
- The exhaust air substances are biodegradable.
- The exhaust air temperature is between 5°C and 60°C; optimal 15-40°C.
- The exhaust air is moist (>95 % relative humidity).
- The exhaust air does not contain any toxic substances.
- The exhaust air does not contain larger amounts of dust and grease.

These conditions should be met in composting plants.

5.10.1.4 Constructive Execution of Biofilters

The construction of a biofilter is appropriate for the ventilation area of compost windrows. The conditioned exhaust air is fed into the biofilter through a air distribution system that should evenly distribute the exhaust air under the filter body. As such it is guaranteed that the filter material is evenly flowed through.

Plastic grates, floors with gaps made of reinforced concrete, ventilation blocks or a gravel bed with drainage pipes are used. Leachate, which potentially occurs in the biofilter (due to over-moisturising or heavy precipitation) has to be collected under the air distribution system and discharged.

The exhaust air should flow though the filter material perpendicularly from bottom to top. Whereby it should be guaranteed that the edge area of the filter is constructively designed in such a way that there are no crude gas breaches in this area. This can be achieved by either constructing the air distribution system so that no direct entry of the crude air into the edge areas is possible or the filter material can be densified in the edge areas during construction.

In the entire constructive execution of the biofilter system attention should be given to service and maintenance ease. The filter material can easily be freed of plant growth or be exchanged as needed if it is easily accessible. The air distribution system should be as easy to clean as possible. Segmentation of the air distribution system and the whole filter has the advantage that only a partial stand still is necessary for maintenance work or filter material exchange.

In the case of sufficient available space surface filters (see *Figure 5.33*) are usually used. They are easily accessible and as such easy to service and maintain. This type of surface filters are built in sizes up to approx. 2000 m² [15]. If roofed systematic removal of exhaust air is possible e.g. with a chimney. (Example Plant Heidenheim)

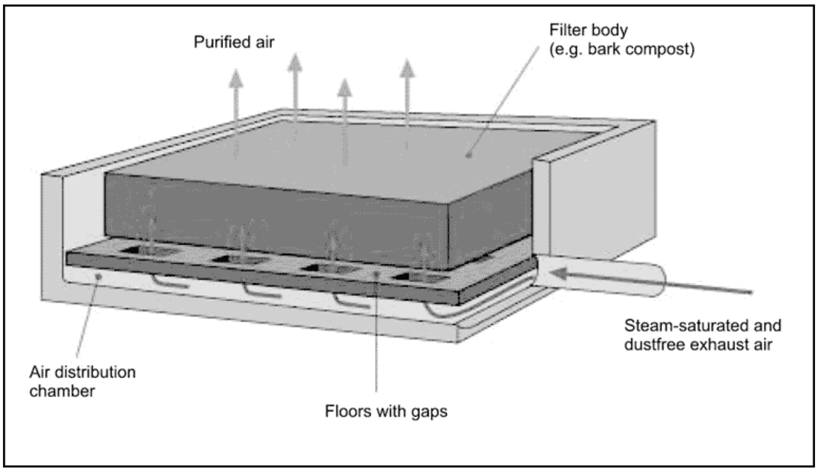

Fig. 5.33: Principle schema of a surface filter [VDI 3477]; [39]

In order to save space surface filters can also be installed, for example, on the flat roof of the composting plant. The exchange of filter material is difficult. Due to statical reasons an appropriate sub-construction for the filter has to be built, since the roof surfaces are usually not designed for such an additional load.

Tiered filters are several surfaces filters over one another. Here space and pipelines can be saved. An open or closed construction is possible, although the closed construction has the benefit that the filter is not as susceptible to changing weather influences and plant growth. The disadvantage of this filter type is the poor accessibility for exchanging the material or servicing the filter.

Container filters are, in principle, not surface filters. In this filter principle the air conditioning, switching and monitoring devices are usually integrated into a container, through which they can easily be transported and set up at another location. They are often implemented in box and container processing.

5.10.1.5 Dimensioning of Biofilter Systems

The dimensioning of a biofilter system depends on the amount of air, the material-specific data of the exhaust air content substances and the type of filter material.

The following measurements can be used for roughly estimating the dimensions: [15] et al.

- Filter surface load: approx. $100 m^3/m^2 * h$
- Filter volume load: approx. $100 m^3/m^3 * h$
- Specific filter load: 0.2 * 106 through 1 * 106 $OU/m^3 * h$

In the biowasher (*Figure 5.34*), as opposed to the biofilter, odorous substances are washed out with a liquid, which is guided in a cycle. The washing liquid is regenerated by micro-organisms (bacteria), as a result of the micro-organisms biologically degrade the absorbed substances under the injection of oxygen. The absorption of the gas-like exhaust air content substances takes place in a washer, the biological decomposition of the substances in activation units, such as they are implemented, in principle, in biological waste water purification. This biological decomposition takes place either in the form that the micro-organisms are available suspended (activation basin) or fixed (percolation filter with biological grass).

In the biowasher with suspended micro-organisms the odour-loaded exhaust air is guided by cross flow or counter flow through spray washers, venturi washers or columns. Activated sludge suspension is used as wash liquid, which is guided from the activation basin in a cycle.

In the process with fixed micro-organisms (*Figure 5.35*) they settle onto the washer equipment, where they absorb the washed out substrate from the exhaust air and the oxygen air with nozzle equipment.

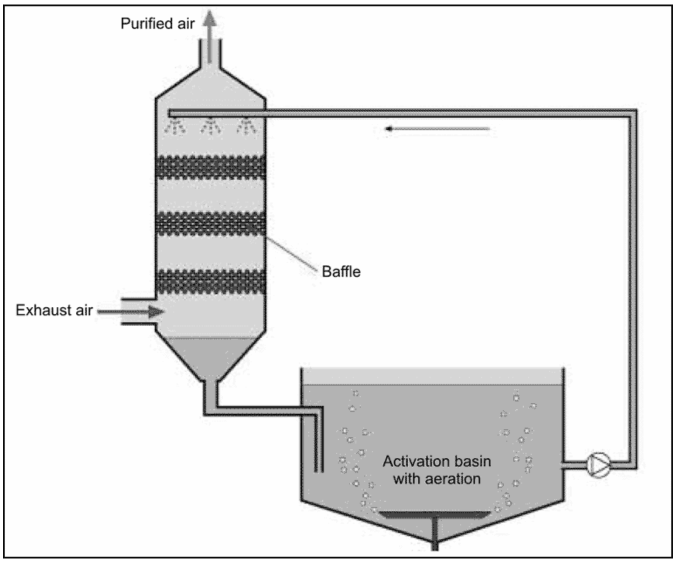

Fig. 5.34: Functional principle of a biowasher with suspended micro-organisms [27]

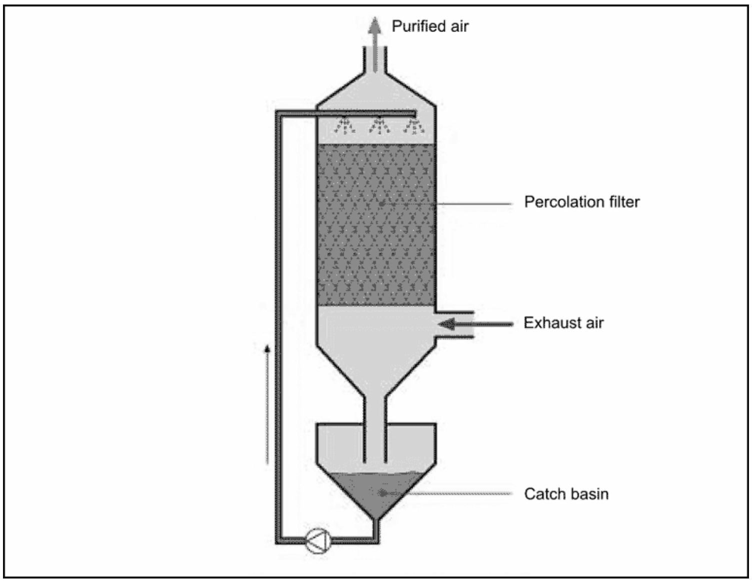

Fig. 5.35: Functional principle of a biowasher with fixed micro-organisms [27]

The dimensioning of the washer can be carried out according to VDI-regulation 3478 [40]. Hereby a packing material surface should be assumed in the range of 100 - 300 $m^2/m^3_{\text{Packing Material Volume}}$. The gas speeds lie around 1 - 3 m/s, the spraying density at 10 to 30 $m^3/m^2 * h$.

The advantage of the biowasher, in comparison with the (open) biofilter is the significantly smaller building volume and a defined emissions source (exhaust gas pipe), whereby the emission point can determined. A disadvantage is that the achieved emission values are, in comparison, twice or three times as high. If the exhaust air does not have a sufficient amount of nitrogen and phosphorus compounds then these should be added to the washing fluid. In the case of interruption or extreme reduction of the amounts of exhaust air or the biodegradeable substances within it should be set up so that the washer can be fed with a nutrient solution.

5.10.1.6 Measures for the Reduction of Odour Emissions in Composting Plants

Three types of measures should be taken in order to reduce emissions:

- Input-related measures,
- Building and process technical measures,
- Operational measures.

In the delivery and bunker area the odour content materials of the delivered biowaste have a significant influence. Especially pasty waste already tends towards anaerobic behaviour in the collection container. Therefore, it is beneficial to collect kitchen waste along with highly structured garden waste with respect to odour aspects especially with warm outside temperatures. Tendencies are also recognisable, which show that the odour emissions significantly increase with longer container standing time in summer. With this mind container emptying should take place in an at least 14-day frequency.

In the area of delivery and treatment odour emissions are avoidable to a great extent with casing and targeted exhaust air guidance. Therefore, casing is generally necessary for a permit for large composting plants today. Minimisation has to be achieved in decomposition, in the case of open windrow processing, by operational measures and targeted leachate guidance (avoidance of wet windrow base). Roofing additionally avoids water being carried in by precipitation and the formation of anaerobic zones at the windrow base and in puddles. The situation can be further improved by air suction from the windrow and its targeted exhaust air purification.

Targeted control of the odour emissions in the area of decomposition can only be achieved with an encapsulated system, which is the only one that is still permissible in some areas.

The maturation and storage do not require encapsulation under the aspect of odour. Roofing is beneficial for the above mentioned reasons.

An important measure is the selection of an appropriate location with sufficient distance to odour-sensitive built-up areas (e.g. residential). The emission are not reduced as a result, but the emission concentration can, however, be significantly positively influenced. As such the spacing requirements in the federal state of North Rhine-Westphalia of the composting plant to a residential area is 300 m, in Hesse 500 m is required for biowaste composting plants. The regulation of higher emission source points (chimneys) is also targeted along these lines. In individual cases the emissions can also be reduced in near-lying settlements by odour protection walls. The collected exhaust air should be systematically deodorised in the appropriate exhaust air purification plants.

It should generally be observed in all encapsulated systems that they are also operated as such. In the delivery area the bunker gates should be oppositely locked so that a draft is avoided. Closed halls should be maintained in a low pressure range by the respective air exchange values so that the air from outside flows inward. Biowaste should not be stored intermediately untreated for more than a day. The anaerobic elements in the decomposition material should be reduced by the production of a suitable decomposition input material (structure, water content, homogenisation (lump formation)). The generation of accumulation water should be avoided. The process should operated in an odour-minimising manner by means of the ventilation and moistening adapted to the decomposition phase. In open windrows turning should only take place under appropriate meteorological conditions (wind direction and speed). The same is true for confectioning (e.g. screening) in the open. Exhaust air monitoring (e.g. by FID) makes additional security (including preservation of evidence) possible.

In the case of biofilters attention should be paid to regulated operation. This means that, aside from the selection of appropriate filter material, continuous operation should be maintained to a great extent. Extreme under-loaded operation should be avoided just as over-loaded operation. Regular control and maintenance of the filter is absolutely necessary.

In considering the emissions of encapsulated plants with appropriate exhaust air purification based on current technological advancements it should be observed that the mixed-odour concentrations in composting plants of up to 10,000 OU/m³ before exhaust air purification are not what determine the emission value and along with it the emission concentrations, but rather the air volume flow since the cleaning capacity of the biofilter also increases with increased input concentrations. As such the minimisation of the exhaust air volume flow should be given priority for the reduction of odour emissions in these plants. This can be achieved by means of, among others, systematic exhaust air flows, small building volumes and air circulation. *Figure 5.36* shows, as an example, an optimised ventilation schema that minimises the odour freight by multiple usage of the exhaust air.

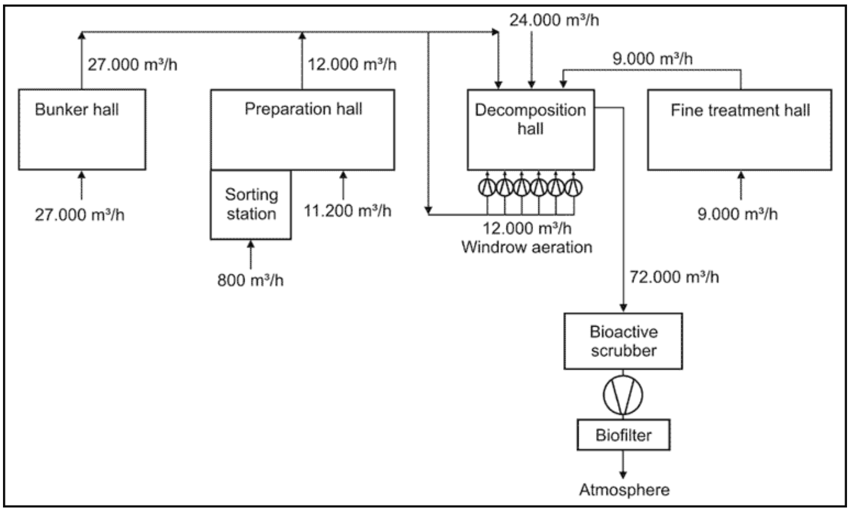

Fig. 5.36: Ventilation schema of a composting plant (encapsulated windrow composting, operation time) (according to [20])

5.10.2 Dust

To date no generally transferable investigations into dust emissions from composting plants exist. Since the decomposition material usually has a relatively high water content dust emissions can occur mainly in the following processing steps with relatively dry material:

- Size reduction of green trimmings
- Relayering of dry decomposition material
- Fine screening
- Heavy solid material separation
- Compost loading
- Traffic areas.

By encapsulating these processing steps no relevant dust emissions can be expected except for in the traffic areas. Dust emissions from storage and loading of compost should be avoided by protecting the halls from the main wind directions.

Dust emissions, which mainly come from coarse dust, are not to be expected with wind protection of the plant and dense plant growth.

5.10.3 Leachate and Condensation

Depending on the plant concept and the decomposition process the following forms of waste water from processing occur:

- Leachate from storage and composting
    - Compression water from the material's own moisture
    - Endogenous leachate (created by direct conversion)
    - Exogenous leachate (created by penetrating precipitation)
- Condensation from exhaust air collection and decomposition systems (halls, soil etc.)
- Condensation from exhaust air purification (biofilter)

The compression water, which occurs in the bunker area depends on the material's own moisture and structure, which can be influenced by the type of biowaste (portion of kitchen waste), amount of paper and the collection and transport system (closed or open), the storage height and dwell time in the bunker. The amount of compression water is negligible during workday emptying, highly structured biowaste and storage heights of less than 2 m. The amount and composition of leachate is equal to the first decomposition phase of windrow processing with open transport systems, high portions of kitchen waste, large storage heights (e.g. deep bunker) and operationally-contingent long storage times.

In nonventilated windrow processing leachate in the amount 14-34 l/Mg can be ex- pected with reference to the moist decomposition material; in some cases up 60 l/Mg is possible.

In combined processing of rotary drum/rotting cell with nonventilated windrows 4863 l/Mg can be found, and in rotary drum processing with suction ventilation 44-56 l/Mg. The increased water discharge in the combined process can be explained by the mechanical loading of the decomposition material (cell water discharge) and condensation from the exhaust air removal and distribution in the primary rotting stage. [13],[9]

In encapsulated systems of windrow decomposition condensation, which occurs in the form of condensation on the hall walls, exhaust air collection and purification, plays an important role quantitatively; it amounts to between 100 and 200 l/Mg.

[19]

The quality of the leachate from windrow condensation is positively influenced by pre-treatment, in-particular. Thusly the BSB5-values and CSB-values in pre-rotted material (decomposition time approx. 2 weeks) lie in the same range as decomposition material that is composted directly on the windrow (decomposition time approx. 4-5 weeks). The ratio of CSB/BSB5 of 2:1 within the first decomposition phase (heavy contamination) exhibits an advantageous ratio for biological purification. (see also *Table 5.19*)

Tab. 5.19: Analyses of biowaste leachate [according to 35]

Parameter	Leachate Biowaste Composting	Mean Value
BSB5 mg O_2/l	10,000-46,000	17,000
CSB mg O_2/l	18,000-68,000	35,000
K+ mg/l	5,000-14,000	5,341
Mg2+ mg/l	100-1,000	250
Ca2+ mg/l	100-700	450
Na+ mg/l	150-1,500	570
Ptotal mg/l	80-260	120
Stotal mg/l	100-450	270
N org. mg/l	250-800	580
NH4 mg/l	400-1,100	650
NO3 mg/l	1.7-25.0	15
Ntotal mg/l	503-2,085	1,140
Cl mg/l	1,000-5,000	2,670
pH-Value	5.7-10.3	8
Zn µg/l	1,000-8,000	< 0.1
Pb µg/l	10-200	< 0.1
Cr µg/l	10-200	< 0.1
Cd µg/l	10-140	0.1
Cu µg/l	10-300	0.4
Ni µg/l	70-2,600	2.8
Aldrin ng/l	< 0.1	4.6
Dieldrin ng/l	< 0.1	< 1
Endrin ng/l	< 0.1	
Heptaclor ng/l	< 0.1-0.2	
Sum HCH ng/l	< 0.1--2	
Sum DDX ng/l	< 1-20	
Sum PCB ng/l	< 1-49	
Sum PAK ng/l	< 1	

Tab. 5.20: Contamination of leachate and condensation in biowaste composting (according to [9])

Process Step	Sample)1	Compost age [d]	BSB5 [mg/l]	CSB [mg/l]	pH [-]	KCl)² [g/l]	Nitrate [mg/l]	Ammonium [mg/l]	Depositable materials [mg/l]
Rotting Box	L	0-5	7,050	15,150	7.1	8.4	-	-	8.0
Rotting Box	L	7	2,340	6,230	8.1	4.3	3	-	1.5
Rotting Drum	C	0-7	60	1,720	8.8	2.6	-	-	-
Rotting Drum	C	0-7	300	2,370	7.9	1.2	-	-	-
Windrow after Box	L	0-49	150-2,070	1,140-3,780	6.6-9.0	1.6-	6-36	-	0.3-3.4
Windrow after Drum	L	0-56	80-2,000	780-2,160)³	7.1)³-7.8	7.7	0-4)³	-	0.3-2.0
Windrow Direct	L	0-47	150-39,000	1,120-67,000	5.5-8.0	1.1-2.9	-	-	1.2-25.0
Suction-ventilated Windrow			4,400	66,810	6.3	0.9-20.2	34	92	
Rotting Reactor			3,300-7,050	6,200-15,100	7.1-8.1		0-3	-	
Compression-ventilated Windrow (Row Decomposition) [38]	L	0-21	17,300	30,700	7.5		1.3	1300	-
Biofilter Condensation	C		6-300	1,700-2,400	7.9-8.8	6.4	0	400	
Comparison [13]	L	-	4,020-32,800	8,700-57,000	5.0-9.7	0.8-34.4	-	-	0.0-7.0

)[1] L: = Leachate, C: = Condensation ;)² Calculated ;)³ Compost age 22 d

In open land windrows an increase in the precipitation-dependent leachate was observed in conjunction with increasing windrow age, which is caused by the amount of vaporisation due to decreasing windrow temperatures.

Frequent turning, which improves the structure and with it the ability to retain water, in connection with higher vaporisation rates reduces the leachate outflow significantly.

As a result of the mechanical loading of the decomposition material caused by the movement more cell water is set free in dynamic decomposition systems (rotary drum). Depending on the structure and dwell time of the decomposition material in the system up 3.3 l/Mg (dwell time 26h) has been recorded.

In static preliminary decomposition systems (rotting box) amounts of leachate in the range of approx. 30 l/Mg as well as condensation measurements of 50-100 l/Mg (high air exchange value) are stated. The quality of the leachate with reference to the organic load is better than in nonventilated windrow processes due to the high aeration rate. (see also *Table 5.20*)

The ranges according to company data for leachate and condensation measurements are stated in *Table 5.21*.

Tab. 5.21: Amounts of leachate and condensation in different rotting processes [29]

Process	Leachate [l/Mg]	Condensation [l/Mg]
Drum processing	0-30	No data
Boxes/containers	60-100	30-300
Windrow composting	10-60	35-170
Row/Tunnel Compost-ing	0-20	30-100
Briquettes	0	150

The amounts of condensation are hereby extremely dependant on the aeration rate, addition of heat from the exhaust air and the air management (air guidance, exhaust air purification).

5.10.4 Treatment of Waste Water From Composting Plants

Prerequisite for direct induction is the compliance with the requirements of §7a WHG. Along the same lines the requirements for waste water from biowaste composting plants according to §1 Nr.10 of the AbwHerkV depending on the level of current technology should be fulfilled. Usually the requirements for landfill leachate (attachment 51) should be fulfilled.

Hereby the relevant values for composting are:

- BSB_5 : 20mg/l
- CSB: 200mg/l
- NH4-N: 50mg/l

These values can not be achieved from composting. Therefore pre-treatment is always necessary for direct induction.

For induction into public canalisation the following should be observed:

- Indirect induction directives (state-level)
- Municipal ordinance legislation (basis ATV worksheet 115)

According to the partial current principle anchored in §7a WHG, which states that the partially or non-removable substances in the partial current in central sewage treatment plants has to be removed before mixing, as well as in compliance with §7a Abs.3 WHG, which means that CSB (>400 mg/l) as well as ammonium nitrate (>50 or 200 mg/l) make pre-treatment of the leachate necessary.

In open windrow processing leachate recycling is not allowed by the "TA-Luft" (Technical Instructions for Air Purification). In encapsulated processing (containers, boxes, windrows, tunnels etc.) it is beneficial to recycle the leachate as much as possible with reference to minimisation. Hereby the odour potential of the leachate may possibly be reduced by coarse desludging.

An increase in the salt content of the compost due to leachate/condensation recycling has not yet been proven in practical operation [16]. In order to avoid regermination in the decomposition area, which no longer achieves the necessary temperatures for decontamination (e.g. in the last phase of intensive decomposition), it should be observed that leachate not be used to moisturise.

Operational difficulties can be caused by clogging of the nozzles in the watering aggregates.

Despite recycling of water from processing, waste water often occurs that has to be treated otherwise.

The following possibilities for waste water treatment are given:

- Purification process in the composting plant (expensive)
- Joint treatment along with landfill leachate in landfill leachate purification plants
- Induction into the municipal sewage treatment plant (special regulation)
- Land treatment (only in special cases)

Figure 5.37 shows an example for a waste water schema for a composting plant.

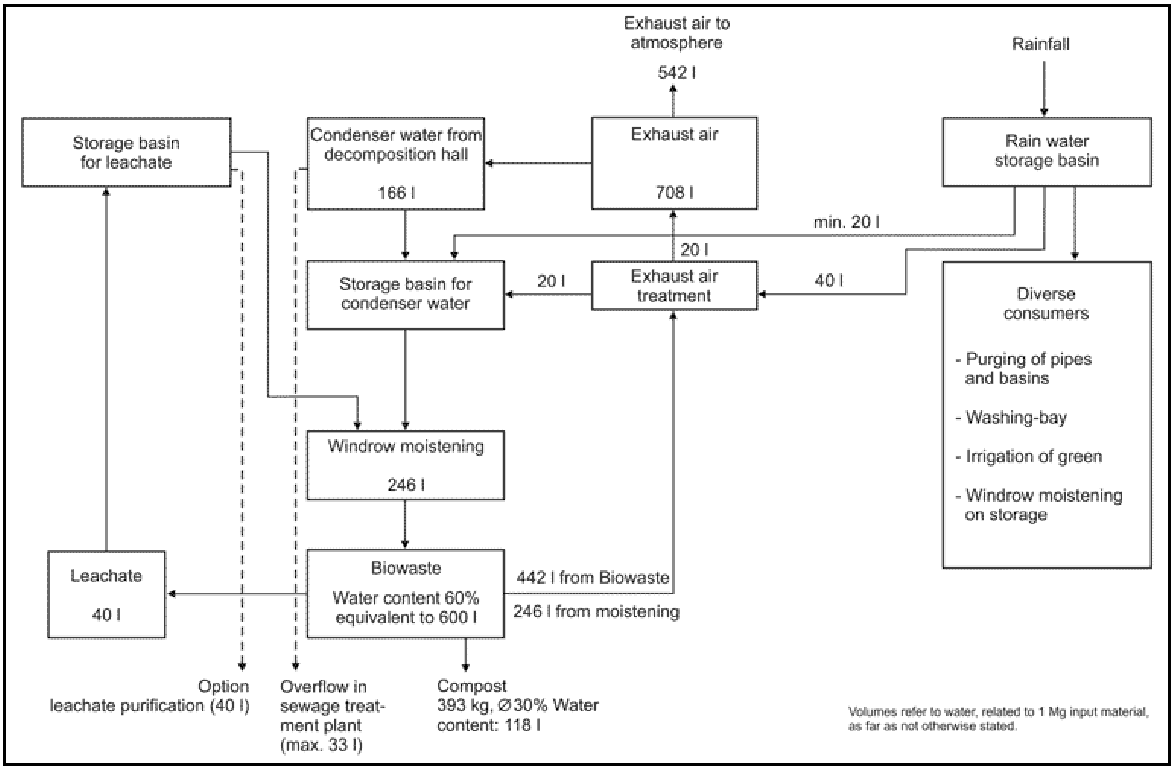

Fig. 5.37: Process and waste water schema of a composting plant, (encapsulated windrow composting) (according to [20]

5.11 Mass Balance

The mass balance of a composting plant with coarse treatment, intensive decomposition and fine decomposition is shown in *Figure 5.38* based on an example.

In the field the mass balance of a plant is influenced by:

- Input material (water content, organic substance content, foreign material content)
- Treatment technique in the coarse and fine treatment (size reduction, screening, foreign

material removal)

- Operation of the decomposition (degrading of organic substance, watering and dewatering)

The fundamental mass reduction - related to the input, takes place by decomposition losses, which are in the range of approx. 60%; hereby the water that is discharged through the exhaust air (from the water content of the decomposition material) accounts for the largest portion at approx. 40-45%. The degradation of organic substance, which should be assumed at 50-60%, reduces the mass by approx. 15%. This decomposition loss is made up mostly of carbon dioxide and water.

The water added to the decomposition is discharged to the full extent as a part of the balanced process.

Approx. 5 % is residue from sorting, sighting, and Fe removal; approx. 10-15% of the fed biowaste can be refed into the system as bulking agents.

As such about one-fourth of the input material remains for use as matured compost.

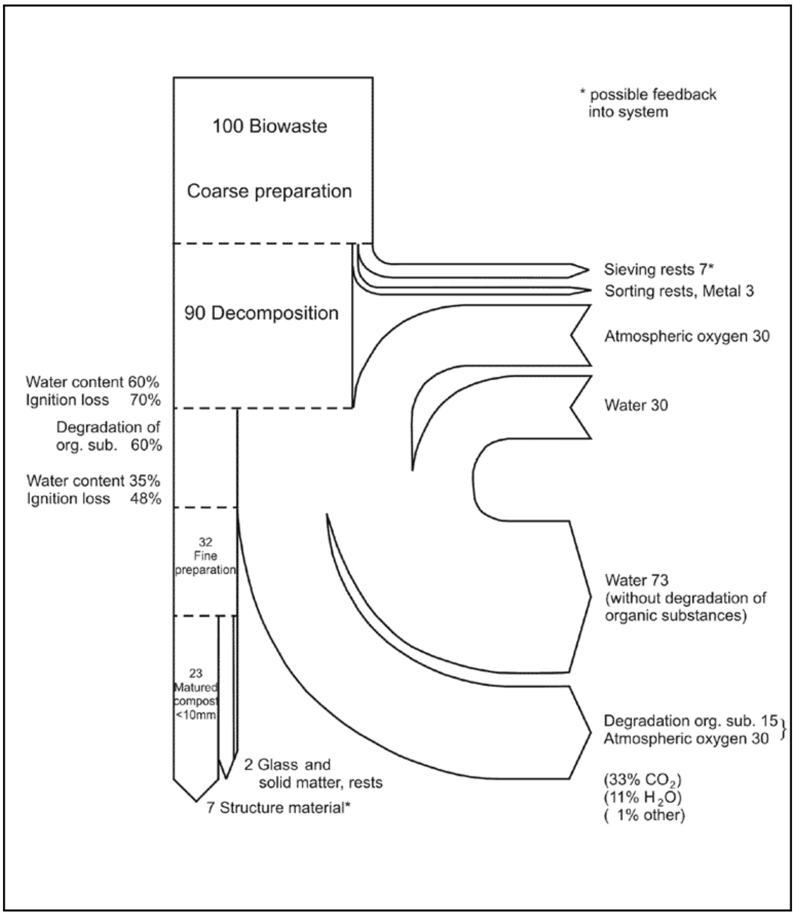

Fig. 5.38: Mass balance of a composting plant

5.12 Cost Structures of Biowaste Composting

Fundamentally, a general, non-project-specific indication of investment and operational costs is only possible within a widely-expanded framework since aside from boundary conditions (see below) the cost structures are significantly influenced by the technical development, the competition situation, firm politics and the economic situation (e.g. inflation). Under the assumption of equal boundary conditions it is, however, possible to indicate the costs with consideration for the mentioned unclear variables.

One should differentiate between investment and operational costs (with or without capital costs). The investment costs of biowaste composting plants should principally be structured according to DIN 276, whereby modifications are sensible due to the high processing technique portion. Thus, it can be divided into seven cost groups:

Tab. 5.22: Cost Groups According to DIN 276 [9]

Reference Number	Cost Group
100	Real estate
200	Adaptation and integration
300	Building - construction
400	Building - technical units
500	Outside facilities
600	Equipment and artwork
700	Additional building costs

The largest portion of the cost is for building construction and technical units with a total of 70 - 80 %. In building construction there is further classification into the operational units, e.g. delivery, treatment, decomposition (exhaust air purification), storage, social buildings. Aside from the division according to operational units the technical equipment can be further itemised into the mechanical and electrical portions (potentially additional MSR).

In addition, the necessary vehicles (front-end loader, lorry) and containers should also be taken into consideration.

The investment costs are hereby especially dependant on the following factors:

- Plant throughput
- Plant technology (level of automation, implemented aggregates, aggregate standard)
- Emission protection measures (enclosure, ventilation technology, exhaust air purification and discharge (chimney))
- Building standard (architectural design and detail construction, material selection, easy service and maintenance)
- Infrastructure of the location (supply pipes, traffic accessibility, potential use of existing facilities (e.g. landfill with infrastructure facilities))
- Building soil situation (ground water state, allowable soil compression, topography)

The specific treatment costs (e.g. €/a, €/Mg) result from the

- Investment-related costs
- Operation-related costs
- Yields
- Diverse other costs

The investment-related costs, which are calculated as annuity, are linearly dependant on the investment costs and are influenced by

- Financing (interest rate)
- Tax exempt period for the investments (e.g. building 15-25 years, machinery approx. 8-12 years, vehicles etc. 5-8 years).

Out of this annuities are calculated with an appointed interest rate of 6 % (see *Table 5.23*).

Tab. 5.23: Annuities for Biowaste Composting Plants (e.g. Rate of Interest 6%)

Building:	10.3% -7.8%
Machinery:	16.1% -11.9%
Vehicles:	23.7% - 16.1%

Approaches are represented for cost estimation of the operation-related costs based on an example in *Table 5.24*. It should be noted that these are to be adapted to the respective regional cost level.

Tab. 5.24: Example for Approaches for Cost Estimation of Operational Costs (Values in Mg Input-related)

Personnel Costs	30,000 - 40,000 €/employee
Wear and Repair Costs	0.5 - 1.5% of the building investments
	3.0 - 5.0% of the machine investments
	5.0 - 10% of the vehicle and equipment investments
Equipment and Energy Costs:	
Electrical Energy	0.1 - 0.2 €/kWh or 20 - 40 kWh/Mg
Fuel (Diesel)	1.1 - 1.3 €/l or 2 - 6 l/Mg
Water, Waste Water	2 - 5 €/m³ 0.1 - 0.5 m³/Mg
Other Equipment, Analyses Costs	0.2 - 1 €/Mg
Administrative Costs	5 - 20% of the personnel costs
Insurance and Taxes	1 - 2% of the investment costs
Residue Disposal	70 - 200 €/Mg waste

Potential yields for compost, valuable matter (metals) should not be taken into general consideration since they depend on the market situation and have to be calculated along with marketing work. The cost savings and the yields from the use of heat energy (e.g. from the exhaust air) can be conceptionalised with consideration for the necessary investments for this purpose.

Different miscellaneous costs, just as concepts for risk and profit, VAT etc., depend on the selected form of operation and should be considered in operational forms under civil law. Due to different calculation fundamentals these costs do not necessarily appear in civil law calculation in the form of higher operational costs.

The range of specific investment and operational costs can be stated based on the evaluation of company offers, implemented plants and citations. Hereby integration costs, land costs etc. have not been included in the calculation. The range of the specific investment costs of small plants is very large.

While the investment costs for open plants (windrow composting) with simple coarse and fine treatment (screening) lie in the range of approx. 100 - 00 €/Mg, they lie at 400 - 700 €/Mg for plants with a throughput capacity of approx. 6000 Mg/a with encapsulated preliminary decomposition systems and roofed maturation phase. In plants with this throughput capacity and complete encapsulation investment costs of 800 - 1000 €/Mg can be expected. Plants with an average capacity of 10,000 -15,000 Mg/a, which have been realised manifold, lie between 500 and 900 €/Mg. With increasing throughput capacity the specific investment costs are significantly lower since money can be saved by multiple shift operation and due to larger dimensioning of aggregates. (see *Figure 5.39*)

It should be observed that, especially with the modular-like constructed plants, no linear connection exists between specific investments costs and throughput capacity, but rather a jump in investment costs occurs with the respective necessity of an additional module. While windrow processing is often used in plants smaller than 6000 Mg/a (often decentralised, agriculturally-operated small plants), in the plants with between 6000 and 20,000 Mg/a nearly all of the described processes in *Chapter 5.2 Technical Composting Systems* are implemented. Plants with significant more than 20,000 Mg/a usually work with commercial turning equipment and decomposition systems.

Accordingly, the specific total costs result based on the input material. These are around 70 - 150 €/Mg in simple plants, while in the plants in the range from 10,000 Mg/a the costs are between 90 to 240 €, depending on the constructive technical complexity. In larger plants with approx. 20,000 Mg/a the specific cost fluctuate between 90 € (open windrow process) to 150 €/Mg (encapsulated process), while in plants with significantly more than 30,000 Mg/a, which have only been realised to a small extent, the specific costs lie in the range of 90 - 120 €/Mg. (see *Figure 5.40*)

The portion of the capital costs in the specific operational costs is generally in the range of 50 - 65%, the personnel cost portion at 10 - 15%.

Generally, it should be considered that the low total costs are usually a sign of simple mechanical equipment and low demands on emission control, as well as simpler building constructions. A direct comparison between the dependency of the costs on the implemented intensive decomposition system is not available, especially for the most commonly used plants with a throughput of 10,000 to 25.000 Mg/a.

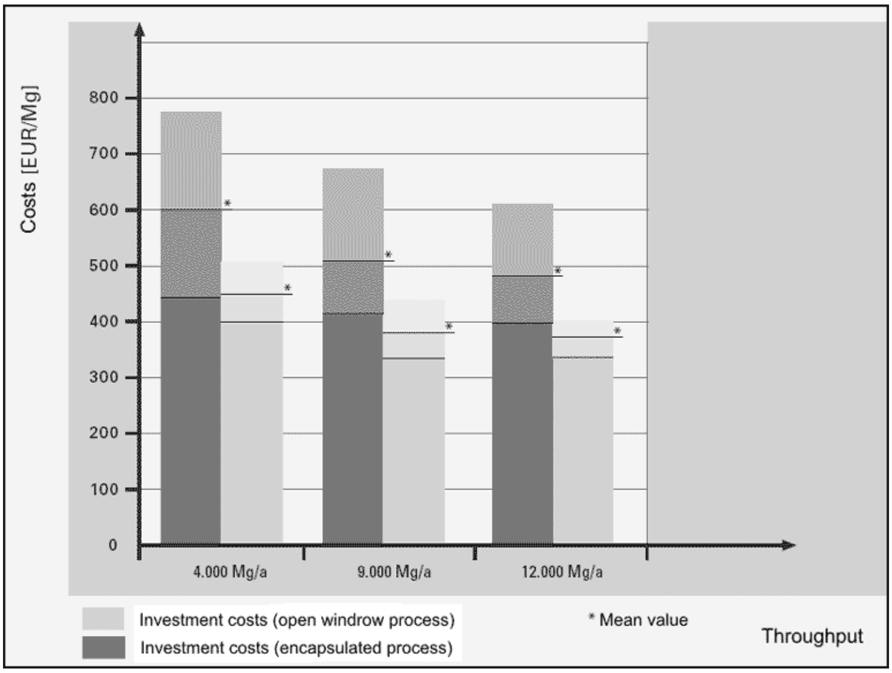

Fig. 5.39: Specific investment costs of composting plants [€/Mg*a]

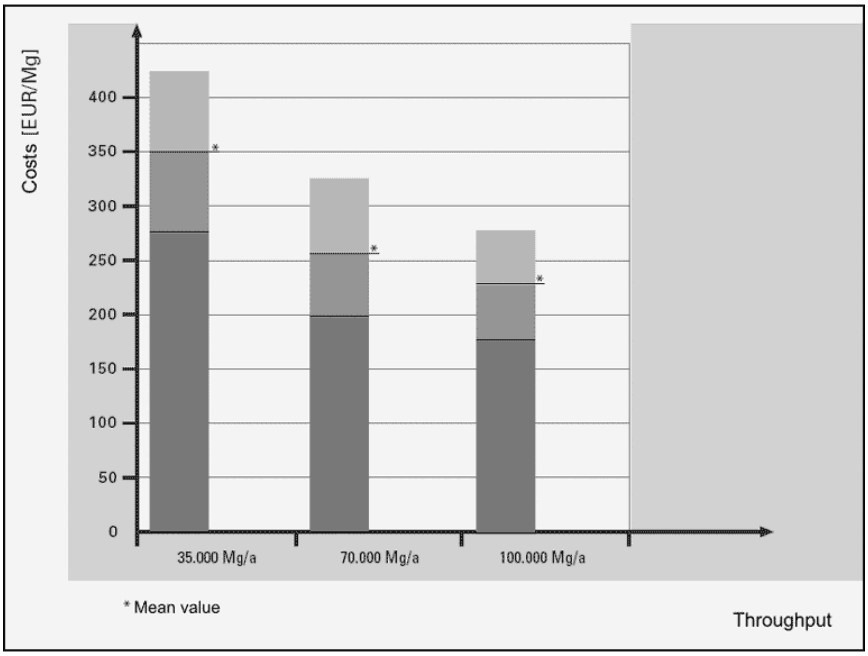

Fig. 5.40: Specific total costs of composting plants [€/Mg]