## OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

## DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

## FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

## CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

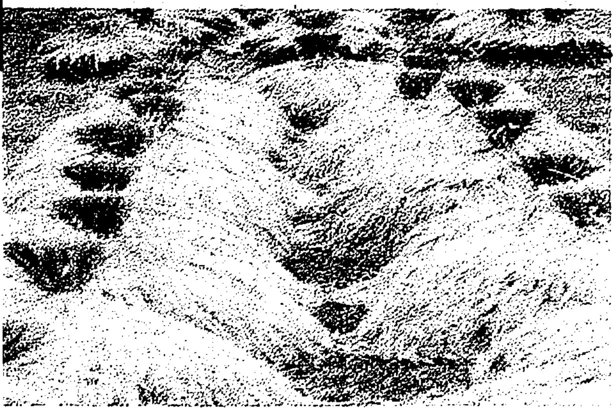
UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

22248

**United Nations Industrial Development Organization**

*Cleaner Production and Environmental Management Branch*
*Sectoral Support and Environmental Sustainable Division*

# COMPOSTING



## A TECHNOLOGICAL ASSESSMENT

---

*United Nations Industrial Development Organization*
*Vienna International Centre*
*A-1400 Vienna*
*Austria*
*Tel: 0043 1 26026 3883*
*FAX: 0043 1 26026 6819*

# OVERVIEW

This document has been prepared by Roberta De Palma, a UNIDO associate expert, and has been reviewed by Dr. S. Piccinini director of the Environment and Energy department of the Italian Research Institute C.R.P.A., Centro Ricerche Produzioni Animali *(see appendix 'A')*.

All technical and economic information contained within this document, which relates to composting practice, is based upon the European experience in this specific sector, over the course of the last twenty years. It should further be noted that all the examples referred to in this document, relating to market opportunity, investment and operational costs of a composting plant are based on the European experience, they must, therefore, be adapted to the socio-economic reality of each specific country.

The prime objective of this document is to 'Raise Awareness' of composting technology, in both developing and transitional countries, as a sustainable practice to facilitate the recovery of organic matter, especially from urban solid waste.

The operational parameters of the composting process, are described, as well as their influence on processing time and on compost quality. The analysis and evaluation of the different composting technologies, currently in use, has been carried out in order to define the criteria which should be used in the decision making process. These criteria should be employed when selecting the best available technology, according to the type of organic waste, and the initial cost-benefit analysis. Collection systems for organic waste, and the market for compost have been investigated in order to analyse all the aspects related to the effectiveness and efficiency of composting practices.

Finally, there is a case study. The subject of this case study is a composting plant for 15,000 ton/year of organic waste. The technical input for design parameters and financial analysis is examined in some detail.

# Table of Contents

## 1. Scientific Background

Composting is a bio-oxidative process leading to a highly stabilised organic product, which may then contribute directly to soil conditioning and fertility. Compared to other processes (fermentation and anaerobiosis), composting allows a fast, simple and safe approach to bulk treatment of organic waste. It also produces fewer odours, and develops a thermophilic stage, which decreases the concentration of animal and plant pathogens in the mass. On the other hand, fermentation and anaerobiosis leads to products that will undergo further stabilisation (bio-oxidation) when exposed to air. For urban and industrial composting of organic residues, maximum process efficiency is required. This in turn is a reflection of our ability to successfully manage the microbial population growth and activity. Main factors, which need to be optimised and controlled are oxygen, supply to the mass, moisture and temperature control, C/N ratio, balance of nutrients and pH.

Fast diffusion and proper succession of the microbial populations, as required in the different stages, are essential. Generally, substratum composition (carbon, nutrients, pH, moisture) and, therefore, microbial metabolism tend to become limiting factors when processing urban, agricultural and industrial waste. Process programming and plant design must also take into account the specific limitations in dealing with different organic material. Management of the process of composting must take into account the vale of the end product as well as compatibility with plant cultivation. Production with phytotoxic metabolites characterises the intermediate phases of organic matter degradation and may be used as a parameter to assess the degree of stabilisation of the process. Use of organic soil conditioners in agriculture involves different products in relation to the required degree of stabilisation, according to specified needs, as well as other considerations such as cost and energy conservation.

## 2. Introduction

Composting as a means of waste disposal is increasingly used on a world-wide basis. The concept of organic matter recovery for use in agriculture is becoming more popular than either of the alternative methods, i.e., landfill or incineration. This is due largely to the fact that composting not only permits energy recovery from waste, but also guarantees disposal of the most highly polluting fraction of waste: biodegradable organic matter. As an added bonus, it also reduces the quantities of waste to landfill, thus effectively helping to protect the environment.

Though composting is undoubtedly an ecologically valid system it should not be underrated in the area of agronomy. Composting provides large amounts of organic matter for agriculture, which can then be used to replace organic matter lost every year through normal, accepted agricultural practices.

- ⇨ In Europe, where some farmland has been in the process of depletion for more than two thousand years, the problem of restoration of organic matter is becoming increasingly urgent.
- ⇨ Desertification problems, which have an impact felt largely by African countries, are generating a growing market for compost product.

Organic matter in soil is one of the fundamental necessities for biological fertility and when its content falls below certain level there is no turning back the process of what is known as "desertification".

## 2.1 Why Composting ?

Several different kinds of waste contain large amounts of organic matter which can be beneficially used in the agricultural process, these are:

- ⇨ Solid urban waste
- ⇨ Sewage sludge
- ⇨ Agricultural waste
- ⇨ Food factory waste
- ⇨ Some types of industrial waste

Some of these types of waste require careful separation of organic matter from inert material *(for example: glass, plastic, and metals.).* Moreover, all require size reduction and chemical-biological conditioning before being considered suitable for use in agriculture. The organic fraction of wastes is heterogeneous and if introduced fresh into the soil, will undergo a rapid process of transformation by the soil micro-flora. Composting radically transforms the various organic substances; it mineralises the simpler and easily assailable and humidifies more complex compounds. Mature compost is made up of fairly homogeneous organic matter with high molecular weight components and, hence, is more stable. Addition of fresh organic matter to the soil is to be avoided since it results in a deleterious change in the ecosystem in which the crop is developing.

Once the organic matter is placed in the soil, if it is not partially humidified, it will be degraded by the micro-flora resulting in a production of intermediate metabolites, which are not compatible with normal plant growth. Other disadvantages are competition for nitrogen between micro-organisms and roots, a high carbon/nitrogen (C/N), and the production of ammonia in the soil. Composting is therefore a way of obtaining a stable product from biological oxidative transformation, similar to that which naturally occurs in the soil.

## 2.2 Theoretical Considerations on Composting

When discussing composting, a careful distinction must be made between questions regarding the plant and those concerning the process itself. By plant we mean the system's machinery, buildings and equipment used for composting. By process we mean the correct application of the biological transformation with optimisation of all the parameters and conditioning factors. The principles underlying composting are quite simple. They must, however, be scrupulously respected during composting if the quality and the stability of the final product are to be guaranteed. In the past, some industrial plants have been constructed with no consideration given to those principles; this inevitably has resulted in low quality and unstable composts appearing on the market.

In order to build consumer confidence and ensure future market growth in the demand for high quality compost, it is essential to improve the analysis and quality control techniques used to gain official certification for the product. Clearly understood legal and commercial definitions for the certification phase should be constructed.

## 3. Operational Parameters

From the point of view of the process itself, the term 'optimum conditions' can be defined as "producing good quality compost in as short a time as possible". This result can only be obtained if the entire process is carried out with all the parameters controlling that process, performing at optimal levels. Optimisation of these parameters is largely dependant upon the system in use. These parameters will vary according to whether the process is carried out in windrows or in a reactor and whether air flow is sucked or blown. For this reason it is not possible to define the ideal condition of the raw material without considering the composting system to be adopted. The following is an analysis of the principal factors that control composting.

## 3. 1 Composition Of The Mass

The preparation of organic matter for composting is, at present, carried out in two ways:

1. Mechanical preparation
2. Combined biological and mechanical preparation

Mechanical processes involve size reduction by shredding, followed by separation of inert material by screening, dynamic separation, airflow separation, electromagnetic separation, etc.

In combined biological-mechanical processes, waste is placed in biological reactors for a few *(1-3)* days, where the process of biological decomposition begins, together with mechanical size reduction. After this phase in the reactor, the biodegradable organic fraction has undergone drastic conditioning; it emerges macerated and broken down so that separation of inert material is easily effected mechanically. Furthermore, the organic fraction has undergone microbial attack and so is better conditioned for the following process of composting. In addition to reduction to optimum size, it is more homogeneous and is uniformly invaded by micro-organisms. This means that the physical and chemical characteristics of matter for composting can vary according to the preparation to which it has been subjected. Organic matter for composting is composed of solids, water and gas, with a constant interchange between the three fractions. Solid matter consists of ash, inert material and biodegradable material containing water. The individual relationships among these components are extremely important for the evolution of the process and the quality of the end product. These parameters can vary within a limited range if the process is to proceed correctly (see [7]).

Microbial transformation of the organic fraction into compost is essentially an aerobic oxidative process. This means that the surface to volume ratio of the particles has a direct influence on the manner and the speed of degradation; the air water ratio in the particle inter-space is equally important. Water and oxygen are indispensable for microbial activity and when the proportion is lower than the critical level, microbial metabolism and respiration slow down and stop; this means that the composting process slows or stops too.

## 3. 2 Aeration Of The Mass

The air contained in the inter-spaces of the composting mass at the beginning of microbial oxidative activity varies in composition. The carbon dioxide content gradually increases and the oxygen level falls. The average $CO_2 + O_2$ content inside the mass is about 20 %; oxygen concentration varies from 15-20% and carbon dioxide from 0.5 to 5%. When the oxygen content falls below this level, anaerobic micro-organisms begin to exceed aerobic ones. Transformation and anaerobic respiration processes take over. It is obvious, therefore, that the micro-organism must have a constant supply of fresh air if they are to maintain their metabolic activities unaltered. In composting, oxygen is not only necessary for aerobic metabolism and respiration of micro-organism, but also for oxidising the various organic molecules present in the mass.

One of the main functions of aeration is that of supplying oxygen so that a low level does not limit the process. There exists, therefore, a direct relationship between oxygen consumption and temperature. Temperatures, which enhance microbial activity, are in the range 28-55° C, with highest consumption of oxygen.

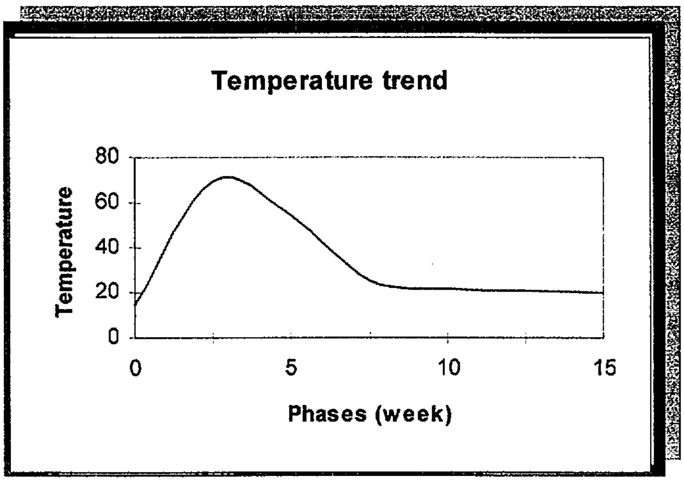
## 3.3 Temperature

High temperatures result from biological activity: heat liberated through respiration of micro-organisms decomposing organic matter builds up within the pile since dispersion is low due to the natural insulation of solid urban waste. Excessively high temperatures inhibit growth in most of the micro-organisms present, thus slowing down decomposition of organic matter. Only a few species of thermophilic sporigenous bacteria show metabolic activity above 70°: *Bacillus stearothermophilus, Bacillus subtilis, Clostridium,* and non-spore forming bacteria, gram-negative, aerobic: genus *Thermus*.

For rapid composting, high temperatures over prolonged periods of time, must be avoided. An initial thermophilic phase may be useful in controlling thermosensitive pathogens.

Using forced ventilation throughout the process solves the problem of high temperature. Its advantage is that evaporative cooling is induced in the region of the pile that is most highly insulated and heat is carried to the outer layers. Another important feature in controlling temperature is the use of a temperature-controlling unit responding to a temperature sensor placed in the pile. A ceiling temperature is established in which aeration time is automatically regulated by heat output

*Fig. 1 The temperature trend during the composting process.*



## 3. 4 Moisture

Aerobic decomposition can take place only if the moisture content of the organic matter is in the range of 40-70%. During the maturation phase, the temperature is increasing and as a consequence, the moisture content of the compost declines.

Moisture content and aeration are closely interrelated in terms of displacement of air in the interstices by water, promotion of aggregation and lowering of the structural strength of the material. Optimal moisture content in composting varies and essentially depends on the physical state and size of the particles and on the composting system used. Too little moisture means early dehydration of the pile, which arrests the biological process giving physically stable, but biologically unstable compost. Too much moisture interferes with the aeration by clogging the pores.

## 3. 5 Carbon/Nitrogen Ratio

The final value of the C/N ratio of good mature compost to be used in agriculture is around 15. To obtain this value it is necessary to start with an organic matter, which has a C/N ratio of around 25-30. This is equivalent to an excess of carbon, which will be used by the bacteria for energetic purpose and will be given back in the form of $CO_2$ and $H_2O$ during the process. If the process of composting is progressing correctly, the nitrogen will not be consumed and as a result, will form part of the end product.

Low C/N ratios will slow decomposition and increase nitrogen loss. If the initial C/N ratio is greater than 35, the micro-organisms must go through many lifecycles, oxidising off the excess carbon until a more suitable C/N ratio for their metabolism is reached. Low values would lead to a nitrogen loss through ammonia volatilisation especially at high pH and high temperature values. After extensive experiments (see [7]) on composting it was demonstrated that the general optimum C/N ratio was 25 in the starting material; higher values slowed the rate of decomposition, lower ones resulted in nitrogen loss.

## 3. 6 pH Level

Generally, organic matter with a high range of pH values *(from 3 to 11)* can be composted. However, optimum values are within the range of pH 5.5 to 8.0. Bacteria prefer a nearly neutral pH, while fungi develop better in a fairly acid environment.

In practice, the pH in a pile cannot easily be changed. Generally, the pH begins to drop during the initial stages of the composting process, as a direct consequence of the activity of acid-forming bacteria that break down complex carbonaceous material to organic acid intermediates. High values of pH in the starting material, in association with high temperatures, can cause a loss of nitrogen through volatilisation of ammonia.

## 4. Composting Technology

Composting is a microbial reaction of mineralisation and partial humidification of organic substances which, under optimum conditions, takes place within a month. It is very difficult to decrease this time since it is not possible for composting to take place in a few days. Composting time depends on the biological cycles of the micro-organism involved, environmental factors and genetic constitution of micro-organisms condition their replication time. Although environmental factors may be improved, genetic limits remain. The end products are completely dependant upon whether conditions are aerobic or anaerobic. Composting requires that the process be mostly aerobic so that organic matter is partially mineralised and humidified.

To make composting suitable for organic waste requires three fundamental points to be met:

1. Brevity of the process and low energy consumption
2. To guarantee a standard end-product, not only safe for agriculture uses, but also satisfactory in terms of the fertilising value
3. Hygienic safety of end products

Composting must be controlled in order to guarantee low costs and high quality end products. This has resulted in the emergence of several different kinds of practical composting systems. The aim of all of these systems is basically the same: creating the best condition for the process.

In the composting process, the main factor that can be influenced by technology, and around which designs are developed, is the availability of oxygen. With respect to design, the equipment for providing aeration ranges from the relatively simple to the very complex. This range leads to the generalised classification of compost technology *(as depicted in Fig. 1).* In practical terms the important point is how the systems compare with respect to effectiveness in accomplishing aeration, and even more importantly, how they meet the objectives, i.e., producing high quality compost in as short a time as possible.

An important means of co-ordinating the process is the movement of the bio-mass and its height: the periodic movement of the bio-mass is important for recreation of "loosening" of the material necessary for the diffusion of air throughout the mass.

A mass of composting material can be aerated by either or both of the following two methods:

⇨ Turning
⇨ Forced aeration

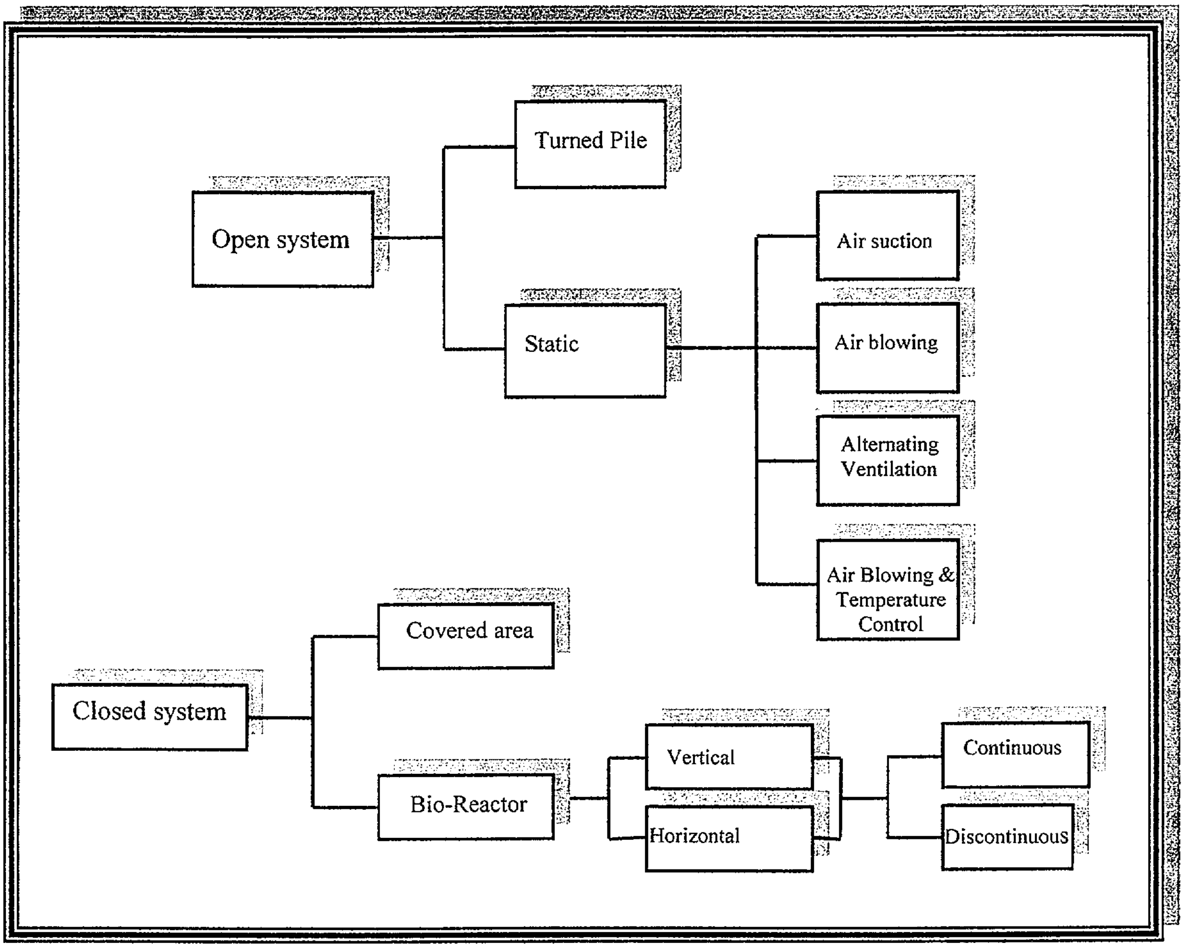
Turning can be done manually or with special machines. Composting systems, which are identified with this activity, are commonly known as either "static" or "dynamic".

The movement of the bio-mass becomes increasingly more important when:

1. The porosity of the matter decreases
2. The moisture content increases (obstructs the diffusion of oxygen*)*
3. The putrescence matter content is high (which results in an accelerate consumption of oxygen)

The main features of both "open" and "closed" systems are as depicted below.

*Fig. 1 - Composting technology classification.*



## 4.1 Open Systems

In an open system the organic matter is piled up in uncovered areas. The pile can be horizontal, triangular or with a trapezoidal section, and has height ranges of between 2 and 3 metres. Different aeration systems are available according to the principle of static or dynamic movement of the organic matter.

### 4.1.1 Turned Pile

Pile turning, though widely used because of its simplicity, has its limits.

- ⇨ Turning oxygenates the pile only periodically. Since the optimal level of oxygen must be kept constant to enhance biological oxidation, interrupted aeration may be unsuitable.
- ⇨ Pile turning always requires more space, whether the piles in turning are moved laterally or with special machines, which leave the pile in the same place. In the second method, the pile must not be too high for the machine to turn it. Periodic turning, for disease control and containment reasons, is not completely satisfactory. During the final stages of composting, when the material is nearly dry, dust containing large quantities of *aspergillus fumigatus* spores is released into the air.

### 4.1.2 Static Pile

The idea of aerating a static composting pile by forced air permits us to evaluate the exact amount of oxygen to be given and enables the control of other important parameters such as moisture and temperature. It also has the advantage of low costs, smaller floor areas required, and there is no periodic turning of piles with all its disadvantages.

Ventilation of piles can be done in several ways:
- ◆ Air suction
- ◆ Air blowing
- ◆ Alternating ventilation (blowing and suction)
- ◆ Air blowing in conjunction with temperature control

The suction system has been widely adopted in the USA. With this system, airflow of about 0.2 cubic meters/min/tonne at the blower inlet is sufficient to provide an oxygen concentration of 15%. In order to reduce the problem caused by odours, the air can be passed through a small filter pile of mature compost.

The process, which is based on blowing and temperature control, uses a temperature controller located in the pile. This temperature controller receives and interprets a continuous signal. When the signal indicates that the temperature has risen above the set point, the controller activates the blower until ventilation decreases the pile temperature.

This system has two main advantages:

1. Blowing enhances evaporation giving a low moisture end product and guaranteeing high stability.
2. Automatic temperature control avoids long periods of high temperature (> 60° C).

Since most micro-organisms involved in composting do not survive at temperatures above 60° C, it is advisable that this temperature should not be reached in composting so that microbial activity is at maximum efficiency. This is often true for fungi which are strongly inhibited at high temperatures, These are useful in degrading cellulose and lignin. High temperature are highly selective towards the micro-flora; very few bacteria survive above 70° C. The result is that the composting process is arrested until the temperature falls and micro-organisms can recolonise the mass.

High temperatures have a positive effect in reducing pathogens. For this reason several processes include an initial phase of suction composting which permits the temperature to rise for few days; the air stream is then inverted, in conjunction with temperature control, and the process continues.

## 4.2 Closed Systems

The process takes place in bordered areas *(container, bioreactor, or tunnel)* or in covered areas *(barns)* in order to ensure better control of the process parameters *(due to the independence from weather conditions and due to the management of odour emission).*

### 4.2.1 Vertical Reactors

These reactors, generally over 4-m high, can be:

- “Continuous”, composting material in one large mass
- “Discontinuous”, mass arranged on different floors

Discontinuous vertical reactors contain, on different levels, piles no higher than 2 or 3 m and, therefore, have no disadvantages apart from the high cost of the plant and maintenance.

Continuous vertical reactors, may contain one single mass up to 9 m high, the process is extremely difficult to control; uniform oxygen cannot be obtained even when blowing from beneath is used. Since volume of air per unit surface area must be proportional to the height of the pile, the lower part of the mass is over-ventilated with excessive cooling and drying. Upper layers are insufficiently aerated; as air passes through the composting mass, it changes composition losing oxygen and acquiring carbon dioxide. For this reason, forced ventilation in reactors and in windrows is not suitable for heights over 3 m. Continuous vertical reactors may also be difficult to manage if the discharging mechanisms break down or need maintenance and repair. Manual discharge of 1000-2000 cubic meter reactors is rather difficult.

### 4.2.2 Horizontal Reactors (tunnel)

Generally pre-selected organic matter (separated from inert material) is used in these reactors and the process requires from 15-30 days. Material inside these reactors may be static or periodically turned and piles should not be higher then three meters. In these reactors air is nearly always blown from the bottom. Some include temperature control in addition to blowing. If this equipment is used correctly, it combines the advantages of both open and closed systems, giving better control over the process and resulting odours. The same principles as those for vertical reactors apply to this type: operational simplicity and low cost, otherwise they are not suitable.

## 5. Criteria for Choosing The Best Available Composting Technology

The choice of the most suitable technology is directly related to the composition of the organic matter to be composted. We can classify the organic matter into two distinct classes:

1. Biomasses with low putrescent matter *(e.g. ligno-cellulose scrap from wood industry or from maintenance of green urban area).*
2. Biomasses with high putrescent matter *(organic fraction of urban solid waste, sludge and scraps from agri-industries).*

The composting process related to organic matrix with high putrescence matter is characterised by two phases:

| | |
|---|---|
| First phase: | commonly known as "active composting time" (ACT): during this period the oxygen consumption of the biomass is very high. |
| Second phase: | commonly known as "curing" during this phase the process is much slower and needs less oxygen. |

The first phase is very sensitive to the process condition. This means that for this type of organic matter, a closed system is more suitable, at least during the ACT *(Active Composting Time)* phase. A closed system can guarantee a high degree of control over the process. A further justification is in the area of release of odour into the environment; this has most impact during the ACT phase. Using a closed system makes it possible to reduce the impact of odour and pathogens in the environment, this is achieved by making use of several methods that will be explained in the following section.

Conversely, open systems are suitable for the composting of an organic matrix with a low content of putrescent matter and a high content of ligno-cellulose material (60-70%). *(For this type of matrix the ACT phase is less intensive and the odour production may not be a priority).*

In a similar way, it is possible to evaluate when it is advisable to use either a static system or a dynamic system.

- ♦ Static systems are based on the idea that moving the mass during the process produces a thermal block to the bacterial activity and can disturb the micro-ecology of the mass.
- ♦ Dynamic systems are more flexible systems and are suitable for all types of organic matter, especially when the composition of the biomass is not stable.

## 5. 1 Composting Plant For Low Putrescent Organic Matter (green scrap)

This type of composting site is designed for an organic matrix, which contains green scrap in the minimum percentage range of 60-70%, and the remaining part of the putrescent organic matter as the fraction selected from urban solid waste. The plant can use open technology as an extensive system. Usually the open area is entirely paved and drained, with harvesting of rainwater, which is collected and stored in special containers, to be used later, during the process of reintegration of the moisture content of the biomass.

The composting yard is organised as follows:

- ⇨ An initial area for weighing the materials
- ⇨ An area for stocking the different material

While the ligno-cellulose matter can be stored for long period *(e.g. one year)*, the putrescence matter is immediately mixed processed, in order to avoid any possibility of anaerobic and non hygienic conditions occurring *(e.g. presence of mice or other animals)*.

### 5.1.1 Process Life-Cycle

The life-cycle of the process can be described as follows:

- The cutting up and mixing of the different organic fractions.
- The compost is then prepared in a special pile.
- The compost is now ready to start the aerobic oxidation guaranteed by the porosity of the substratum and assisted by periodic turning *(the frequency is inversely proportional to the amount of the material and the frequency is once each 2-8 weeks)*. The dimensions of the pile are very critical in order to guarantee a good absorption of rainwater. The best option is a trapezoidal section with a base of 8-12 m and a height of 2-3 m. This type of pile, also realises a saving in the region of 30% of the surface required from the triangular section.
- The curing period which takes 2-3 months.
- The compost now needs to be refined *(moisture control or mixed with peat)* according to the required quality of the end-product.
- The compost can now be put into bags to receive a higher added value, ready for the market.

The technology required for these types of composting plants is very simple and their management does not require any specific expertise.

In order to realise good quality compost, the most important factor is related to the quality of the organic fraction derived from urban solid waste; it is essential that the content of heavy metal is very low and that contamination from inert materials and plastic is minimal. This means that it is necessary to process the organic matrix, which has already, been selected at source.

## 5.2 Composting Plant for High Putrescence Organic Matter (selected matrix)

The selected organic matrixes for this type of composting plant could came from the following areas:

⇨ Organic fraction separately collected from urban solid waste, e.g. food market scraps, restaurant and tourism activity scraps.
⇨ High putrescent matter from agro-industries, e.g., slaughterhouse waste, fruit and vegetables scraps, etc.

In the first instance, it is necessary to mix this organic matter with a bulking agent *(waste from wood industry, straw, or wastepaper)*, which may not be available.

- In instances where this bulking agent is not available, it is better to choose a dynamic system, which can help to redistribute the oxygen in the biomass and to avoid anaerobic phenomena occurring.
- In instances where the bulking material is available, a static system using a forced ventilation system is also suitable.

The pre-treatments of the organic matrixes consist of an initial sifting and a magnetic separation to recover iron.

The biological process is mainly composed of two phases:

1. ACT intensive phase in a "closed system" for a period of 10-30 days, with forced ventilation, high air flow, tuning up systems and collection and treatment of odour emission.
2. Curing phase, eventually in "open system" for 30-90 days characterised by low airflow and low frequency of turning up of the mass.

See Fig. 2 for a graphical description of the process.

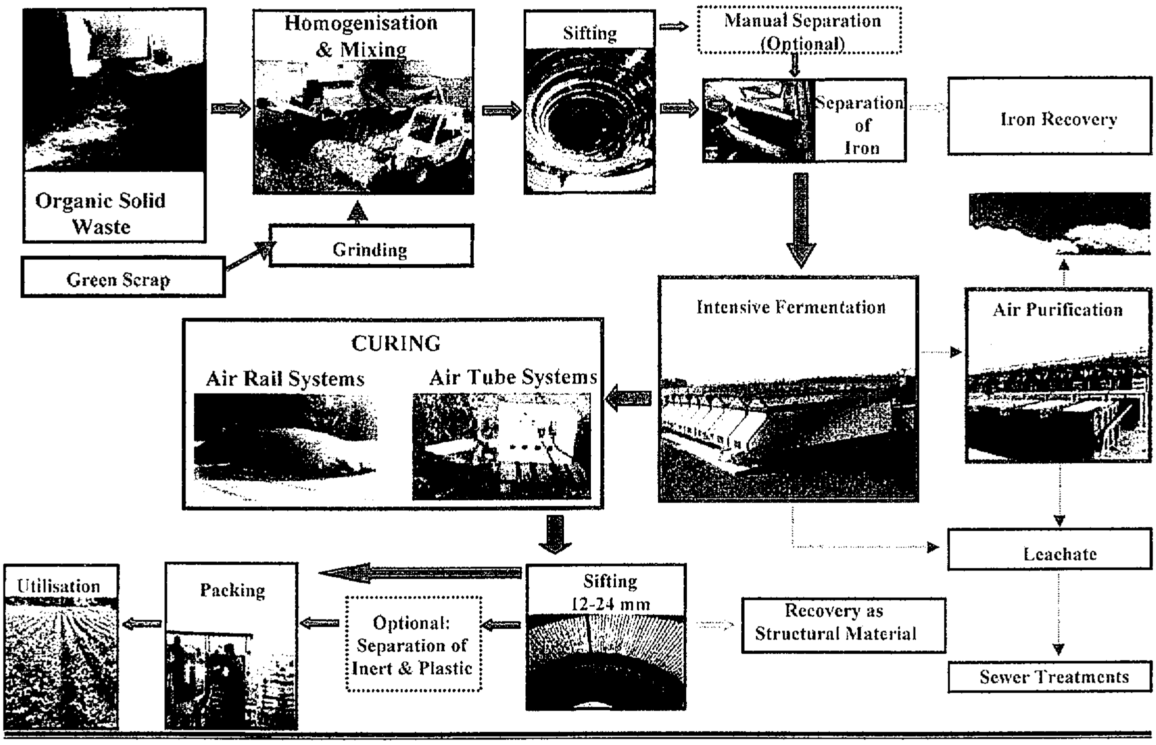


**Fig. 2 - Composting Technology for Organic Selected Matter** *(high putrescent content)*

### 5.2.1 Odour Emission Treatments

One of the main environmental impacts of composting plants is the potentially offensive smell resulting from the processing of waste materials.

The unpleasant odour, can be significantly reduced by using one of two different process types, these are as follows:

1. Abatement treatments
2. Dispersion technology

The systems used to disperse the odours produced during the biological transformation are as follows:

1. High stack used to release exhausted air into the higher atmosphere
2. High speed of air emission
3. Pre-dilution of exhausted air with fresh air prior to the emission

The abatement treatment mostly frequently employed in Europe, is bio-filtration. It consists of a biological oxidation of the odour molecule, by micro-organisms which are able to oxidise molecules which have been absorbed by a filter. The filter consists of a compost layer, wood scrap or a biologically active peat layer. The efficiency of this type of filter is very high, 95% for a volume of 100-200 N $m^3/h$ of air treated for each $m^2$ of bio-filter. The minimum suggested time of residence of the air in the bio-filter is 30 seconds, and the recommended height is 1-2 meters.

If the filter is cleaned and regularly maintained/serviced, this efficiency remains almost constant for a period of 2-3 years.

## 5.3 Composting Plant For Organic Matter From Bulk Urban Solid Waste

When the organic matter present in the urban solid waste is not selected at source through a separate collection, the composting process is different from those seen in previous cases. The contamination, due to the presence of plastic, paper, glass and metals *(which generally constitute the bulk of urban waste)* requires an initial separating out stage using a series of mechanical sieves,. The efficiency of separation depends on the type of material. However, a certain amount of contamination will still be present in the final product.

From a technological point of view, the equipment required is more complex than in the case of pre-selected organic matrix. The cycle of separation can start with an initial grinding of the bulk waste followed by a magnetic separation of iron and by pre-oxidation *(1- week)*.

The sequence of the treatments is depicted in Fig. 3 and is as follows:

- Sifting to separate contaminants *(especially plastic)*.
- Intensive oxidation phase *(2 weeks)* in a closed system.
- Ballistic separation of the inert and glass.
- Curing in an open system *(5 weeks)*.

The initial grinding of the waste can be omitted at the beginning *(it can make the separating out of glass and plastic more difficult)*. Moreover grinding causes breakage of batteries *(a common constituent of urban solid waste)* and the consequent spread of hazardous heavy metals in the waste. For these reasons, it is better, in some cases, to grind the waste after an initial sifting and separation of the main contaminant material has taken place.

The final quality of the compost that can be obtained in this way is generally not very high. This type of compost retains a high level of contamination and is best avoided for agriculture use. However, there are alternative potential uses; for example, it can be used as landfill.

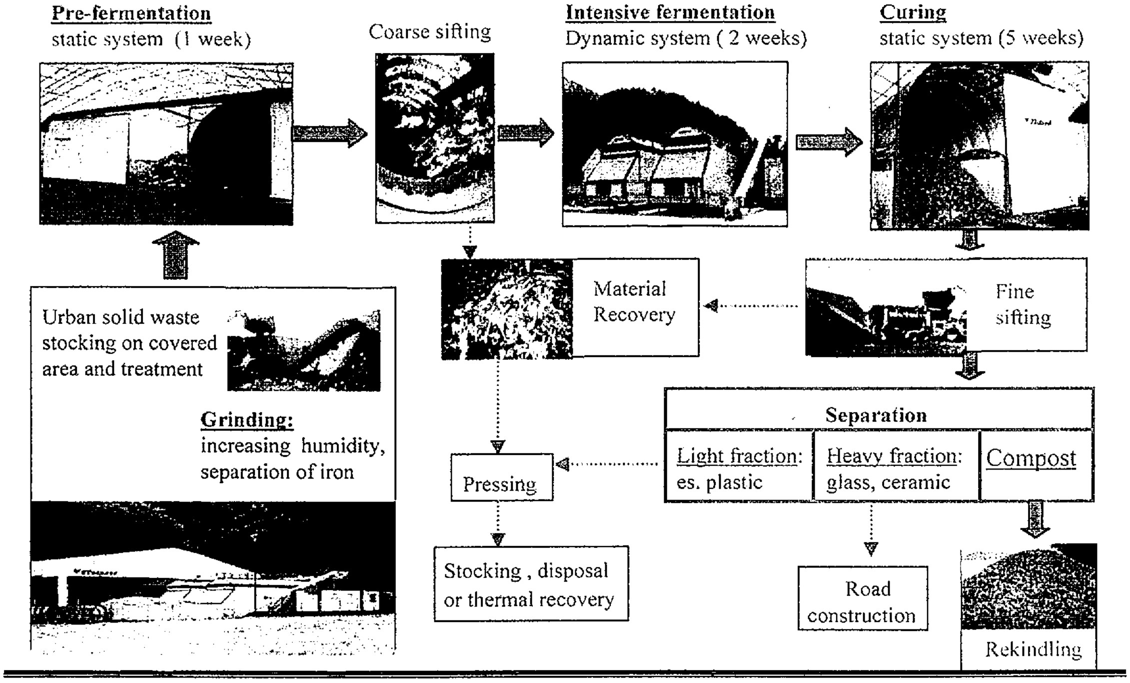


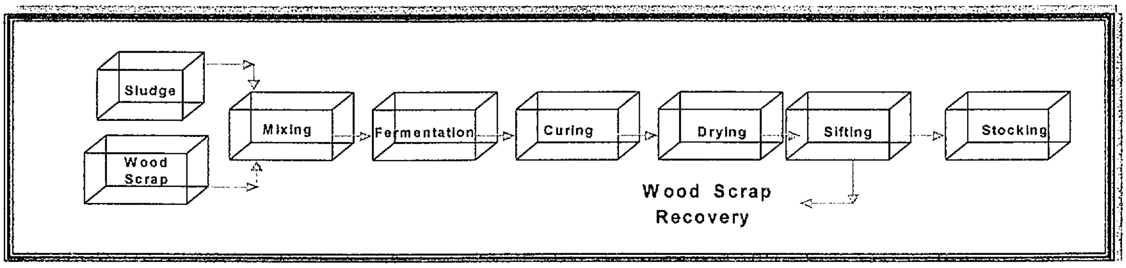
**Fig. 3 - Composting technology for bulk Urban Solid Waste**

## 5.4 Composting Technology For Sludge

The practicality of composting sludge is heavily dependant upon its origin/source. Sludge originating from some agro-industries, paper industries and urban sewers are rich in organic constituents.

It is necessary to mix the sludge with ligno-cellulose scraps to obtain the right moisture content, a good C/N ratio, and the best aeration condition for the aerobic composting process. The technology for this composting site could be open or closed depending on the investment opportunity *(the open system is much cheaper then the closed one).*

*Fig. 4 Depicts a Block scheme process for sludge mixed with wood scrap.*

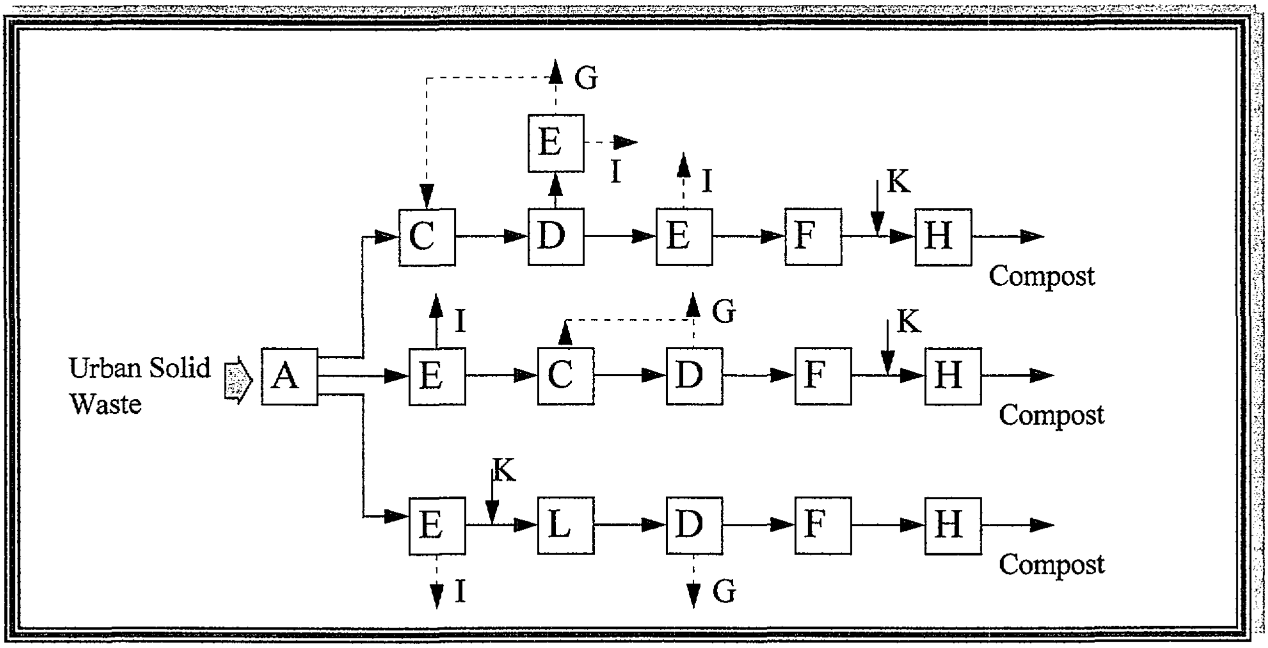


As an alternately to ligno-cellulose scraps, the sludge can be co-composted with the urban solid waste. This option is feasible employing the same technology used for urban solid waste, with the introduction of a mixer to mix the two different type of waste together. The sludge must already be digested and dehydrated *(8-10 % solid suspended)* before being mixed with the urban solid waste. The sequence of treatments can be different, depending on whether there is a pre-oxidation phase or iron separation.

Fig. 5 depicts three different options for sludge composting technology for use with urban solid waste. The advantages of co-composting with urban solid waste are as follows:

- ⇨ Increase of moisture content in the urban solid waste
- ⇨ Increase of N ratio in the final compost and enhanced potential to produce good quality compost for agriculture use
- ⇨ Avoidance of expensive sludge treatments

*Fig. 5. Depicts co-composting of sludge with urban solid waste: three different technical options*



Legend:
A = Stocking; C = Grinding; D = Sifting; E = Iron separation;
F = Refining; G = Scraps; H = Natural fermentation ; I = Iron recovery ; K = Sludge input; L = Pre - fermentation

## 6. Organic Matter Collection From Urban Solid Waste

The most important factor in the whole composting process is the necessity to use good quality organic matter. This must be selected at the source, following an efficient separating out process. It is relatively simple to organise the collection of organic matter from agro-industries or for sludge. However, it is more difficult to organise the collection of separated organic matter from urban solid waste.

The separated collection in urban areas can be organised in two different ways:

1. Door to door collection
2. Collection using rubbish skips

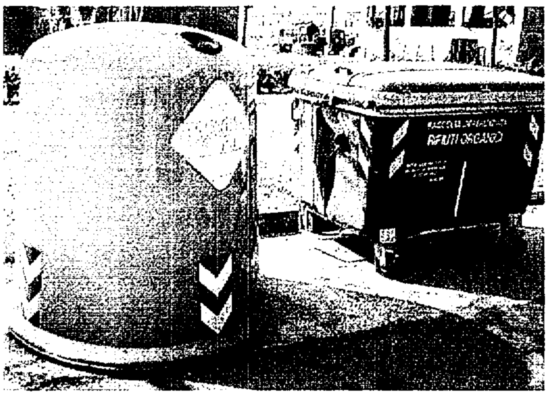
Door to door collection uses existing local authority refuse collection services. Households use two different bags for waste: in one is placed the domestic organic waste; and in the other is placed non-organic waste. Wastepaper and glass is collected separately. The local authority collects the separate bags in alternate weeks: the result is that domestic organic waste is collected regularly, once every two weeks. The advantages of this method of collection are the good quality of organic matter collected. In a European country, Italy for example, the collection cost of organic and non-organic waste, including the separate collection of glass and wastepaper, *(final treatment and disposal are not included)* is around 30 US$ per inhabitant per year. This data reflects the Italian per person production and composition of waste figures which are approximately 450 kg per year of which 130 kg per inhabitant per year is organic waste.

The second option, 'collection through rubbish skips' has a capacity of approximately 1500-1700 litres, of which approximately 600-900kg is of organic waste. This option is less expensive than the previous one, but it has some major disadvantages. These are largely due to the placement of these rubbish skips in urban areas; because of the inconvenience of carrying organic waste to these locations, participation from households is reduced, resulting in a reduction in the quality and quantity of the organic waste collected.

The collection of organic matter from selected users, such as, restaurants, food markets and canteens represents a relevant proportion of the total of all organic urban waste. It can be collected from the premises, or through the allocation of rubbish skips, for the sole use of those premises. Usually the quality of the organic matter collected from selected users is better then that collected from the whole urban area. The quantity of organic matter collected solely from selected users, could justify the starting of a composting plant.

All the above information is based upon European standards and organic matter production (around 30% of total urban solid waste). It is evident, that the collection system selected must be adapted to the conditions in the country. For example, where the percentage of organic matter in the urban solid waste is very high *(60-80 %)*, a separate collection for organic matter may not be a realistic solution. In this case the organic matter could be collected with the other waste and separated from the contaminants later on.

*The picture below shows common examples of 'collection using rubbish skips'.*



## 7. Compost Market

The market demand for compost exists and it is increasing. As a result of the restrictive environmental requirements set in place by governments, the demand is limited to high quality compost *(low heavy metal concentration and inert matter*). It is very difficult to obtain good quality compost from bulk urban solid waste, even if the required complex and expensive technology is available to produce it. The technology and the management required, to produce high quality compost from selected organic matter, either from urban solid waste or from agri-industrial scrap and sludge mixed with green scrap, has already been consolidated. Potential applications for this compost are related to its life span:

- Fresh compost: has a maximum life span of two months. It can be used in vineyards, fruit and vegetables cultivation according to the rich content of organic matter;

- Stabilised compost: has a life span of between 2 and 6 months. It can be used in cereal and forage cultivation prior to sowing;

- Cured compost: has a life span of 6-24 months, and can be used in root crop cultivation, floriculture and in plant nurseries.

The market value of compost depends on its capacity to act as a successful substitute for natural products like peat or animal manure, already used in agriculture.

An interesting opportunity to add value to the product is to mix it with peat in accordance with the required agronomy performance. This type of mixed soil is of higher quality and can be sold at a higher price.

A very important factor, and one that is relevant to the feasibility of any composting plant, is one of transport cost. Before building a plant it is necessary to evaluate the distance between the producer of organic matter and its potential users, in order to include this cost in the ultimate selling price. Clearly, if the transportation costs are high then it may not be possible to sell the end product at a competitive price.

## 8. Organisational Aspects and Institutional Structure

The composting plant must have a well-defined strategy/business plan that has resulted from a thorough and exhaustive analysis, in order to maximise the opportunities for success. The following is a generalisation of the stages that must be gone through:

- ⇨ First and foremost, establish if a market demand for compost exists in that area.
- ⇨ Ensure that an accurate assessment of the availability of organic matter, to be composted, has been undertaken. This is necessary in order to know both the quality and the quantity of raw material available on the market and hence, the quality and the quantity of the final product.
- ⇨ A long-term strategy/business plan together with continuous monitoring of the compost market.
- ⇨ Continuous monitoring of the availability and quality of organic matter suitable for composting.
- ⇨ A marketing strategy aimed at promoting the product, and stabilising the market price.

To reach these goals it is necessary to include in the strategy/business plan two "structures" and two "actions".

The two structures are as follows:

1. The setting up of a recognised quality assurance system.
2. The setting up of a research and development centre, which should also be responsible for informing the public.

The two actions are as follows:
1. The creation of a centre where the producers of compost and potential users could meet regularly to discuss requirements future development etc.
2. To encourage the increasing use of compost in the public sector.

Different agreements must be reached between the producers of compost and the local authorities in order to define the competence, the supply of organic matter and prices.

A consortium should be created, to take care of marketing aspects and carry out other support activities. For example, the consortium could promote the image of compost to specialised users, either through the creation of an information network or workshop and fair. On-site public demonstrations would be much appreciated by the potential users; in order to demonstrate the doses and the modality required. At the very least, a data bank to store all the information regarding the production of organic waste, should be created.

A laboratory for chemical analysis on compost samples must also be created in order to investigate the quality parameters and to guarantee the stated characteristics of the product.

## 9. Compost Production Costs

The costs associated with the production of compost are divided between investment and operational costs.

Operational costs include the cost of the land, the cost of energy required by the process (kWh), administrative costs, treatment residual recovery, and the costs of personnel.

General costs vary according to the treatment technology being used. In this section comparisons will be made between some of the main technology processes for organic selected matter from urban solid waste (VGF = Vegetable, Garden, Fruit) mostly used in Europe, according to a Dutch survey *(November 1994, 'Nederlandse andernening voor enerergie en milieu', Haskoning Royal Dutch Consulting Engineers and Architects).* The composting plants analysed have been grouped into five categories according to the type of process:

1. Biocontainer
2. Covered area
3. Vertical reactor
4. Open system
5. Tunnel

For each of these categories there exists different types of technology. Table. 2 shows, for each group, the range of variability of the investment and management unit costs, the energy consumption, the surface area required for the plant, time of biological transformation of the organic matter, and the total amount of compost produced. These values refer to a fixed size of composting plant equal to 50,000 tonnes of VGF per year.

*Table 2 - Range of variability of the project parameters for a composting capacity of 50,000 t VGF year: different composting processes are compared.*

| | **Measure unit** | **Composting Process (capacity 50,000 VGF / year)** | | | | |
|---|---|---|---|---|---|---|
| | | **Biocontainer** | **Covered Area** | **Vertical reactor** | **Open System** | **Tunnel** |
| Surface | $m^2$ | 16,000 | 16,000 - 35,000 | 9,000 | 35,000 | 4,500 - 13,700 |
| Operational cost | US$/ t VGF | 54 | 38 - 61 | 41 | 37 | 30 - 44 |
| Investment cost | US$/ t VGF | 253 | 188 - 329 | 180 | 205 | 137 - 213 |
| Time process | days | 70 | 56 - 84 | 42 | 77 | 28 - 49 |
| Compost produced | t/ t VGF | 0.45 | 0.33 - 0.39 | 0.45 | 0.43 | 0.37 - 0.52 |
| Energy consumption | kWh/ t VGF | 20 | 35- 45 | 70 | 20 | 32 - 45 |

Increasing the size of the plant results in the general unit costs of waste decreasing. This means that to be feasible, a composting plant must have a minimum size. Too small and plants are unable to pay back their initial investment costs.

The general costs analysed in Table. 2 are relevant to the whole plant and are suitable for European countries. If the composting plant is designed in a developing or in transition country, the cost analysis must be reviewed and adjusted accordingly. If the investment costs cannot vary in any significant way, the operational costs will be, in all probability, very different. This is reasonable if we consider, for example, that land, electrical energy, fuel, cement and personnel costs are usually lower in developing countries than in European countries.

## 10. Case Study

In this section a small scale composting plant is described, in order to analyse the surface floor space required, the type of machinery required, the investment costs and the operational costs.

This plant can treat 15,000 tonnes per year of organic waste, of which 10,000 tonnes come from selected urban solid waste, and 5,000 tonnes are green scraps.

*Table 3 – Types of waste and quantity, density and volume values per year.*

| Type of waste | Quantity (ton per year) | Density ($ton/m^3$) | Volume ($m^3$ per year) |
|---|---|---|---|
| Organic fraction of urban solid waste | 10,000 | 0.7 | 14286 |
| Green scraps (ground) | 5,000 | 0.45 | 1111 |

The process phases are schematised in the Fig. 6. The organic fraction of urban solid waste is collected separately in order to increase the quality of the final product. In this case, an initial sifting of the organic matter is not required, with the exception of an initial visual and manual control. After delivery, the organic waste is stored in a shed and mixed with the green scraps during the course of the following one or two days. The green scraps can be stored in an open area prior to grinding.

The biological process takes place in 30 days in a shed where periodical turning of the mass (8 turning per cycle) is done by a shovel or by a turning machine. The curing phase ends in 60 days and takes place in a covered area. Even during the curing phase, 4 turnings of the mass are necessary. Finally the compost is sifted *(10-40 mm)* and stored in a separate shed. The surface areas required for each phase of the process are given in table 4.

The mass balance of the process depends on the size of the final sifting: if the final particle size of the compost is around 12-15 mm the profit on the initial organic mass is around 23 % in weight. For the considered composting plant, out of the initial 15,000-tonnes of organic matter per year, it is possible to obtain 3,400 tonnes of compost.

*Fig. 6 - A case study: composting process flow sheet*

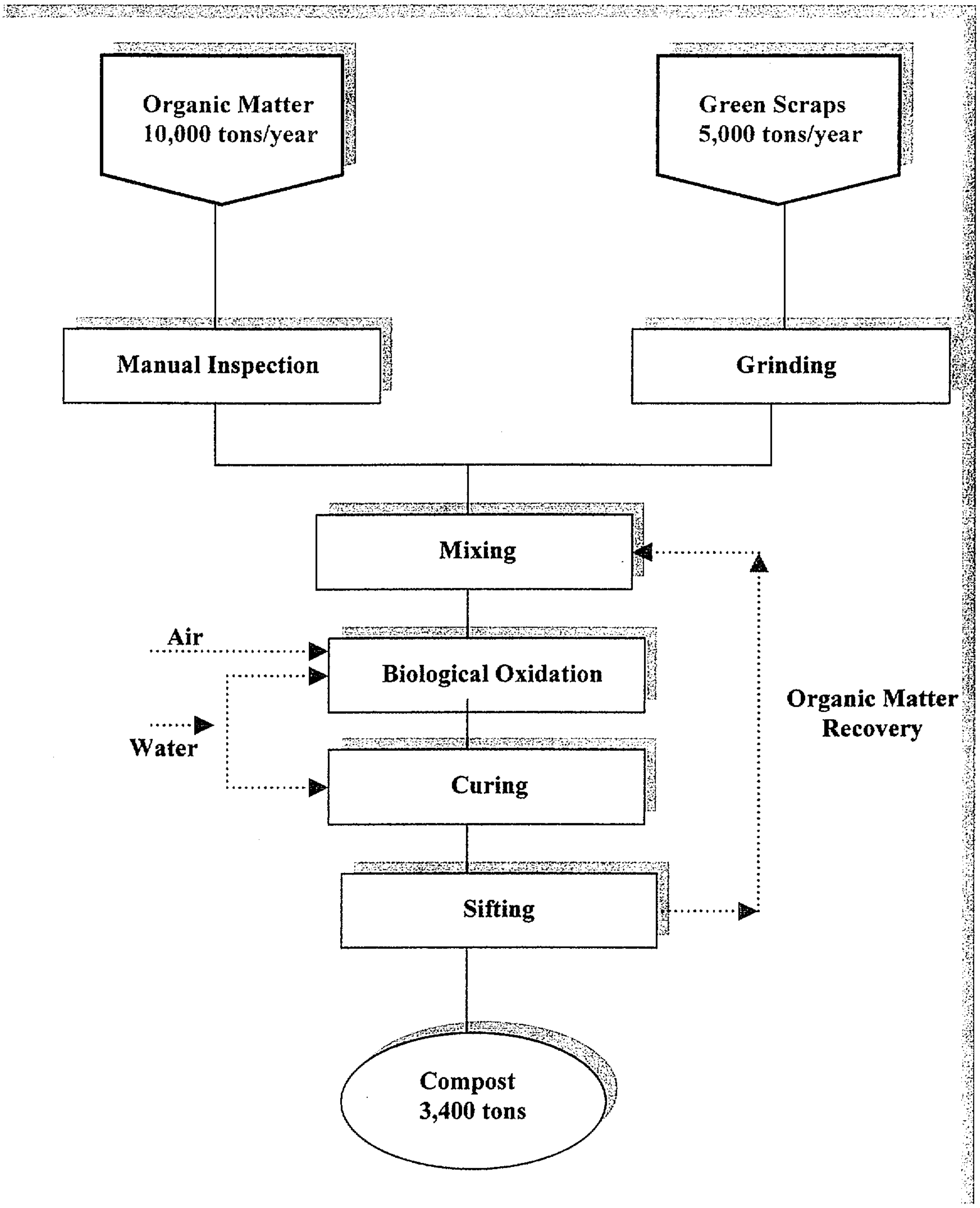


*Table 4 – Process phases and the surface area required for each.*

| **Process Phases** | **Surface required ($m^2$)** | |
|---|---|---|
| 1. Conferment, stocking and mixing: | | |
| a) organic fraction from Urban waste | shed | 200 |
| b) green scraps | open area | 1,360 |
| 2. Biological phase: | | |
| biological oxidation | shed | 2,052 |
| curing | covered area | 2,172 |
| 3. Sifting and stocking | shed | 780 |
| Total | | 6,564 |
| Internal viability (+ 30 %) | | 8,533 |

Special consideration must be given to the treatment of the exhausted air coming from the biological oxidation and from the storage shed of the organic matter. If the odour impact is considered a priority at the site where the plant is operating *(e.g. high population density area)* it will be necessary to design a biofilter. The technical parameters to consider are the value of specific flow of air to treat per square meter of biofilter (100-200 $m^3$ /h per $m^2$), the high of the biofilter and the capacity of the fans.

The investment costs including both the civil and infrastructure works and the Electro-mechanical machinery are summarised in Table 5.

*Table 5 – Investment cost per phase.*

| | **Investment** | **Costs** | | |
|---|---|---|---|---|
| | **Description** | **Unit cost** | **Quantity** | **Total cost** |
| **Infrastructure** | Lay-by, streets, squares, sewer | 42 US$ / m$^2$ | 8,533 m$^2$ | 358,386 US$ |
| **Services** | Office, weighting machine | | 20 m$^2$ | 11,200 US$<br>33,350 US$ |
| **Stocking/ bio-oxidation of organic matter** | Shed | 250 US$ /m$^2$ | 2,252 m$^2$ | 563,000 US$ |
| **Curing area** | covered area | 111 US$ /m$^2$ | 2,172 m$^2$ | 241,350 US$ |
| **Stocking of green scrap** | open area | 36 US$ / m$^2$ | 1,360 m$^2$ | 49,150 US$ |
| **Stocking and sifting** | Shed | 110 US$ / m$^2$ | 780 m$^2$ | 85,000 US$ |
| **Wiring** | P.I. 250 kW | | | 138,900 US$ |
| **Air treatment system** | biofilter, + 2 fans 35 kW + 2 fans 22 kW | | | 123,350 US$ |
| **Machines** | n. 1 grinder,<br>n.1 tractor,<br>n.1 shovel<br>n.1 sifter<br>n.1turning machine | P=180 kW<br>P= 100 kW<br>P= 100 kW<br>P= 60 kW | | 138,900 US$<br>36,100 US$<br>83,350 US$<br>111,110 US$ |
| **TOTAL** | | | **US$** | **1,973,146** |

The operational costs *(see Table 6)* have been evaluated with the following assumption:

- Personnel costs: manager of the plant US$ 55,500 per year, technical workers US$ 27,800 per year and machinery maintenance US$ 33,350 per year.
- Cost of electric energy: US$ 0.1 per kW
- Maintenance and assurance: 5% of the Electro-mechanical installation costs

*Table6 –Breakdown of operational costs.*

| Operational costs | (US$) |
|---|---|
| Personal (1manager, 2 technical workers, 1machinery maintainer) | 144,500 |
| Energy consumption (electricity and fuel) | 92,700 |
| Maintenance | 31,585 |

## 11. Conclusion

The quantity of organic waste increases every year and disposal problems increase accordingly.

Many traditional disposal systems, still in use, are not sufficiently safe either ecologically or hygienically. Ecological factors and energy conservation oblige us to be increasingly careful about waste disposal. Composting biodegradable organic waste is one of the best solutions to these problems, because it guarantees complete disposal of waste and allows efficient recovery of energy in the form of organic fertiliser to be used in agriculture.

Different composting technologies are available and must be selected accurately, according to the type of organic waste available, to the quality of the end product required and to the prevailing environmental conditions. In order to avoid irreversible pollution of agricultural land, every possible precaution must be taken from the outset:

- Avoid spreading on land, non-biodegradable toxic compounds, such as heavy metals, pesticides, plastic, etc.
- Good quality stabilised compost must be supplied to agriculture to prevent damage to growing crops.
- Compost must be free from pathogens before use in agriculture.
- Guidelines and legislation in this field must be developed and introduced to define standards of quality for compost.

The case study, analysed in section 10, provides useful information regarding the feasibility of a composting plant. The technological options selected for the case study are quite simple and are suitable for composting treatment in any developing or transitional country. The investment costs of such a plant in a developing country must be reviewed according to the different costs of cement, of electrical energy and fuel and labour costs. The machinery costs must be increased in order to compensate for the transportation costs *(plus 10-15 %)*. The case study illustrated can be considered as a starting point for designing a pilot composting plant in a developing country.

## Acknowledgements

The author wishes to express her gratitude to the following individuals and organisations who provided her with technical information, support and encouragement during the research and writing stages of this document development:

United Nation Industrial Development Organisation "UNIDO" - Cleaner Production and Environmental Management Branch "SES/PEM", in particular Mr. Z. Csizer, Director SES/PEM, and Prof., Doc. Michael Moore, Senior Technical Adviser;

Centro Ricerche Produzioni Animali "C.R.P.A.", Reggio Emilia Italy, in particular Dr. S. Piccinini, director of Environmental Division.

## Glossary of Terms

*The following is a list of words or terms that appear in the text of this document. The meaning of each word, or term, is shown alongside it. These meanings are not intended to represent a definitive explanation of those words or terms, but rather an explanation of the meaning within the context of this document.*

| *Word/Term:* | *Meaning:* |
|---|---|
| **Anaerobic** | living processes that do not require the presence of oxygen. |
| **Biomass** | the total mass of living organisms. |
| **Bio-oxidation** | reactions carried out by living organism in which oxygen combines chemically with other substances. |
| **Fermentation** | a chemical change induced by a living organism, which involves the decomposition of sugars and starches, to ethanol and carbon dioxide. |
| **Fungi** | heterotrophic, eukaryotic organisms reproducing by spores |
| **Metabolites** | an intermediate substance produced and used in the processes in living cell or organism. |
| **Micro-flora** | bacteria. |
| **Mineralisation** | the decomposition in soils of organic matter by micro-organisms with the realise of mineral elements as inorganic ions. |
| **Pathogens** | micro-organisms which cause disease within other organisms. |
| **Phytotoxic** | a substance toxic to plant. |
| **Stabilisation** | a process that tends to keep compounds or mixtures from changing their form or chemical nature. |
| **Thermophilic** | a biological process that is optimal at elevated temperatures. |
| **Thermo-sensitive** | processes which are sensitive to temperature change. |
| **VGF** | Vegetable, Garden, Fruit - North European terminology to define the organic fraction of urban solid waste. |

# Bibliography

***Books:***

[1] *"Ingegneria della Trasformazione in compost",* IERAD Institut Europeen pour une politique integree des Ressources, de l'Amenagement et du Developpement, C.I.P.A. editor, 1994

[2] *"Composting of agricultural and other wastes", various authors,* Elsevier Applied Science Publishers, *1984, ISBN 0-85334-357-8*

[3] *"Progettazione e Gestione di Impianti di Compostaggio", Atti del 3° corso Nazionale di Perfezionamento C.R.P.A"-Consorzio Compostatori Italiano CIC,* Reggio Emilia, May 1999

***Journals and Papers:***

[4] *"Annuario del compost di qualita'",* supplemento *ad ACER 2/1996* anno 12°, March/April

[5] *"Quaderni dell'Ambiente Urbano: Compostaggio a quali condizioni",* Atti del convegno Regione Puglia, 1999

[6] *"Sistemi e tecnologie di Compostaggio: il processo ed I presidi ambientali",* Centemero, M., Favoino, E., Italian National Conference *Ricicla,* Rimini 1997

[7] *"Technological aspects of composting including modelling and microbiology",* de Bertaoldi, M., Vallini,G., Pera, A., Istituto di Microbiologia Agraria Universita' di Pisa, Italy, 1984

[8] *"Conversion techniques for VGF biowaste",* NOVEM Nederlandse anderneming voor energie en milieu, Haskoning Royal Duch consulting engineers and architects, 1992

## *APPENDIX "A"*

### *C.R.P.A. - "Centro Ricerche Produzioni Animali"*

**Activities:**
The Research Centre for Animal Production (C.R.P.A.) was founded as a public institute in 1971 with the specific task of co-ordinating research and extension service programs on animal production in the Region of Emilia-Romagna. In the first years of its activities the Centre has been mainly occupied with the co-ordination of regional funds for university research on behalf of the regional Government. During the eighties the Centre started to expand its activities carrying out research program itself. The major part of finance for research comes from the regional Government of Emilia-Romagna, but the Centre obtains an increasing flow of research funds from national authorities like the Ministry of Agriculture, the Ministry of Environment, the National Research Council (CNR) and the Italian Agency for Alternative Energy (ENEA). Currently EU funded research is being carried out in collaboration with other European research centres.

The Centre carries out applied research directed at farming and the food industry. Research results are currently being disseminated by means of national agricultural reviews and leaflets.

C.R.P.A. is involved in consultancy and advisory activities for the Regional Ministry of the Environment of Emilia-Romagna for the application of environmental legislation.

The Centre is organised in 7 research units:

1. *Environment-Energy*
2. *Agronomy*
3. *Software development*
4. *Animal Housing*
5. *Agricultural Machinery*
6. *Animal Production*
7. *Economics*

The research activities of C.R.P.A. on waste management and energy saving themes concern the following aspects:

- *Anaerobic digestion*
- *Odour reduction in slurry*
- *Land-spreading equipment*
- *Energy use and saving in animal production*
- *Utilisation of manure and sewage on land*
- *Fertiliser value of manure: qualitative and quantitative measurements and assessments methods.*
- *Organic waste composting*
- *Solid-liquid separation*
- *Ammonia emission*
- *Animal manure composting*

**Cleaner Production and Environmental Management Branch**
**P.O. Box 400**
**A-1400 Vienna, Austria**
**Tel: 0043-1-26026- 3883**
**FAX: 0043-1 26026-6819**

**Printed in Austria**
**V.99-85865-August-1999-120**

**UNIDO publication**
**Sales No. UNIDO.99.8.E**
**ID/SER.0/24**