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HYGIENIC ASPECTS OF BIOWASTE COMPOSTING*

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Abstract: When viewing the hygienic aspects from composting plants, one has to consider not only the hygienic aspects of the product, but also the airborne hygienic aspects. This is very important regarding the microbial air pollution and possible occupational health hazards. Compared to the results of other tests performed in hospitals and offices, the composition of the air in the composting plant is heterogeneous, both in quality and quantity. Thus, special attention is needed concerning the air-particle sampling methods and the microbial investigation parameters. Our own research was done using measuring methods, which considered the complex air composition as well as the high concentration levels. The samples were extracted by the six-stage Andersen sampler. This method ensures that even extremely sensitive bacteria or moulds will survive, provided that the one-minute sampling time is respected. In addition to this, it is possible to measure microorganisms in various sizes. It was decided to take the samples only for the duration of one minute. This was done to reduce any technical incorrections and also to provide representative results. The amount of the one-minute samples was set at 30 single samples. This is based upon the German technical regulation named TRGS 402. Here the relationship between the number of samples taken and the length of sampling time is laid down when measuring hazardous substances. In all cases, three samples were simultaneously collected. Total mould and total bacterial counts covering the maximal occurring concentrations were determined. The obtained results show that in a short period of time and depending upon the heterogeneity of the input, both the bacteria and mould concentrations vary. It has been observed that an extremely high air pollution level was reached during shredding and transpositing. Through the use of statistical methods, one is able to estimate the relevance of microbial air pollution. Measuring techniques and strategies have to be adapted to the current research parameters and environmental conditions. Very large concentration differences were shown within a short period of time. Therefore measuring strategies must be able to consider this. In order to detect the average occupational hazard and in order to be able to get reproducible results, many random tests have to be taken. Resulting from the statistical comparisons, between the background concentrations and the occupational concentrations, one is able to win an objective evaluation.

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INTRODUCTION

Domestic waste as well as other refuse containing organic substances is an ideal habitat for different species of microorganisms. Therefore, it generally contains a large amount of facultative pathogens. One gram of domestic waste contains about 10^8 to 10^9 colony forming units (cfu) of total moulds plus bacteria. Compared to hospital refuse

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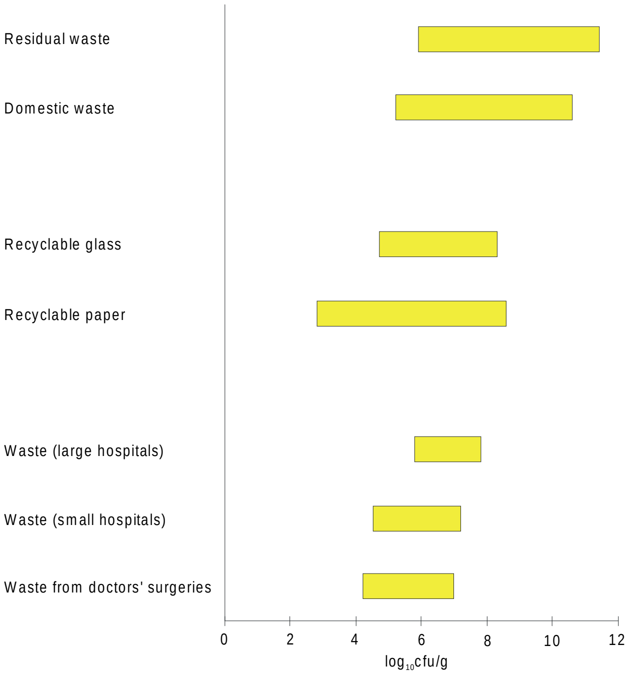

Figure 1. Total bacteria and mould counts in different waste sources. Bars indicate the observed range of concentrations specified as cfu/g.

and the microbial contamination of waste glass and waste paper the microorganism concentration levels are high, which is shown in Figure 1.

Depending on the heterogeneity of organic compounds and growth conditions the proportion of facultative pathogenic microorganisms vary. A selection of different genera, which usually can be found in domestic waste fractions, is summarized in the Table 1.

Table 1. Common microorganisms in different fractions of domestic waste.

Waste fraction	Microorganisms
Mixture of domestic waste and recyclable paper [5]	Bacteria: *Staphylococcus, Streptococcus, Acinetobacter, Enterobacter, Citrobacter, Hafnia, Klebsiella, Proteus, Salmonella, Serratia, Aeromonas, Pseudomonas, Kluyvera*
Unseparated domestic waste [1]	Bacteria: *Salmonella, Escherichia, Yersinia, Staphylococcus, Streptococcus* Viruses: Enteroviruses, Hepatitis A Virus (HAV) Moulds: Aspergilli Parasites: *Ascaris lumbricoides*
Bio-waste [30]	Bacteria: *Enterococcus, Escherichia, Pseudomonas*
Domestic waste [18]	Bacteria: *Enterobacter, Proteus, Escherichia, Pseudomonas, Klebsiella, Serratia, Citrobacter*
Recyclable glass [5]	Bacteria: *Staphylococcus, Streptococcus, Acinetobacter, Enterobacter, Citrobacter, Hafnia, Klebsiella, Proteus, Serratia, Aeromonas, Pseudomonas, Kluyvera*

The microbial diversity and the high quantity of microorganisms are not only observed at the input from waste treatment plants, but also in the air of biowaste composting plants. This is very important with regard to the microbial air pollution and the occupational health hazards, which may result therefrom.

The health conditions of people working at composting plants could be adversely affected through exposure to viable microorganisms as well as through inert particles, toxic secretions, irritating compounds and substances causing allergic reactions. Exposure to airborne particles are mainly through skin contact and inhalation. While particles smaller than 2 µm are deposited at the terminal bronchi, particles smaller than 1 µm could reach the alveoli. Generally, all microorganisms may cause health hazards especially if the individual's conditions, predisposition, immunity, and exposure situation are in an unfavourable combination. Nevertheless, the most critical factors are the continuous long-term exposure to low level concentrations and the exposure to extremely high concentrations over short periods of time.

Due to such complex hygienic conditions during the technical composting process, special attention is needed concerning the air-particle sampling methods and the microbial test specimens.

GENERAL METHODS FOR THE DETECTION OF AIRBORNE MICROORGANISMS

Selection of test specimens. As shown above, the air at composting plants is contaminated with a large variety of microorganisms. Therefore, it is impossible to focus on particular species. Alternatively, the most feasible procedure is the sampling of test specimens which summarize most of the special pathogens in one group. Some important groups are:

- total bacteria,
- total moulds,
- Gram-negative bacteria,
- fecal streptococci,
- thermophilic actinomycetes.

The groups of total bacteria and total moulds represent a wide spectrum of airborne microorganisms. In comparison, the other groups include pathogens more specifically.

Sampling and identification of selected "guide" species is not meaningful because the microorganism composition varies enormously, even during short periods of time.

Sampling methods. Concerning the heterogenous microbial composition of the air at composting plants, one must pay special attention to the sampling method. On one hand, the sampling method has to generate reproducible results. On the other hand, the method must be able to collect a wide range of microbial concentrations and different groups of microorganisms which require special environmental conditions for their survival.

At the moment different sampling methods are used, each having advantages or disadvantages depending on the individual conditions of the measurement. The

Table 2. Maximal airborne microorganism concentrations (cfu/m^3) at waste treatment plants measured by different researchers (without considering different sampling methods).

Microorganisms	Ref.	Composting plants (cfu/m^3)	Waste sorting plants (cfu/m^3)	Refuse incinerator (cfu/m^3)	Landfills (cfu/m^3)
A. fumigatus	[7]	9×10^6	5×10^3	9×10^4	1×10^5
A. niger		3×10^6	6×10^3	1×10^4	1×10^4
Mesophilic actinomycetes	[14]	1×10^5	4×10^4	2×10^4	2×10^3
Thermophilic actinomycetes		5×10^4	2.7×10^4	8.1×10^3	6×10^3
Thermoactinomyces		2×10^5	7.4×10^2	1.2×10^3	4×10^2
Total bacteria	[6]	6×10^5	4×10^4	2×10^5	7×10^4
Enterobacteria		1×10^4	1×10^1	8×10^3	5×10^3
E. coli		3×10^2	not detectable	6×10^2	3×10^2

sampling methods must guarantee that the observed results are typical of the hygienic situation. Only then can be developed actual industrial safety guidelines. In connection with this the sampling time and the amount of samples taken are important. Reducing the sampling time to below one minute is critical because irregularities on the flow of the pumps influence the results enormously.

Therefore, a technical guideline named TRGS 402 is stipulated in Germany. Here the relationship between the number of samples taken and the length of sampling time when measuring hazardous substances is specified. The regulation is based upon an eight hour working time. In practice, the number of samples which should be taken to get representative results increases when the sampling time is short. For example, when measuring only for one minute a minimum of 20 single samples should be taken at one position.

Selection of test and evaluation methods. Regarding the microbial heterogeneity of the air at composting plants, it is not sufficient to take the mean of three individual data. Our own research at sorting plants (for seperation of different materials) as well as research at composting plants show the extent of the variation to be about a factor of one hundred. This finding results from a one-hour measurement including 30 single one-minute samples at one observation point with the six-stage Andersen sampler. Because of this special problem in the branch of waste treatment, other valuation methods were needed which consider the range of variation. Only legitimate and substantial test results should be used for criticism and a valuation of the hygienic situation. Therefore, taking an adequate amount of individual random tests is essential. For example, when using a one-minute sampling time, 30 single measurements should be taken, at which three samples were collected simultaneously.

The valuation based on 30 single test data describing the airborne hygienic situation for a single group of microorganisms at one observation point could be performed using statistical methods. To test the differences between two measurement points a Mann - Whitney U test is used. The most important statistical facts of the random test could be illustrated in graphical representations called box plots. Usually we use notched box and whisker plots. This test is suitable to show graphically the distribution of the data investigated and the differences between the single observation points. In addition, confidence interval about the median can be demonstrated.

Using these methods all requirements of the guideline TRGS 402 could be met. In addition, it is possible to attain the best congruence between the data and the resulting criticism [10].

MICROBIAL AIR POLLUTION IN COMPOSTING PLANTS AND OTHER WASTE TREATMENT PLANTS

The construction of a large number of waste treatment plants, especially composting plants, requires guidelines to regulate the occupational hygiene. Therefore, a German research project was initiated to obtain data for the description of the hygienic situation at waste treatment plants. The results of this project - especially the highest measured concentration at each kind of treatment plant - are summarized in Table 2.

The highest concentrations were detected at composting plants. The data obtained depends generally on the observation point which will be illustrated in more detail.

The shown above concentrations of the total bacteria, the enterobacteria and *E. coli* were measured at the delivery hall of the waste treatment plants and at the refuse incinerator where the highest concentrations were found in the crane bridge. Upon review of the concentrations of the mesophilic and thermophilic actinomycetes as well as *Thermoactinomyces* species, the highest concentrations of each microbial group were found at different locations in different waste treatment plants. At composting plants, the highest concentrations of mesophilic actinomycetes were observed while dumping the compost. The highest concentrations of thermophilic actinomycetes were detected in the delivery hall and the highest concentrations of *Thermoactinomyces* occurred during the screening of compost. At waste sorting plants the maximal measured concentrations of

Table 3. Concentrations of airborne microorganisms at different locations in closed areas of a composting plant. Figures represent median values of 30 individual samples.

Location	Total bacteria (cfu/m^3)	Gram-negative bacteria (cfu/m^3)	Moulds (cfu/m^3)	*Aspergillus niger* (cfu/m^3)	Thermophilic actinomycetes (cfu/m^3)
Sorting cabine	1.7×10^4	8×10^2	5×10^4	8×10^3	5×10^3
Closed hall with piles	5.7×10^4	5×10^3	2.4×10^4	3×10^3	1×10^4
Shredder	5.5×10^4	6×10^2	4.4×10^4	3×10^3	4×10^3

mesophilic actinomycetes could be found at a baling press, whereas the highest concentrations of thermophilic actinomycetes and *Thermoactinomyces* could be detected in the delivery hall. During the research of landfills only resting piles were investigated for actinomycetes and *Thermoactinomyces.* The highest concentrations of aspergilli were observed at the delivery hall, in the manual refuse sorting area and in the rotting area.

In another waste sorting plant and composting plant in Baden-Württemberg (RFA) [21] the microbial air pollution was investigated. At the waste sorting plant the results for the total moulds ranged from 600 to 66,000 cfu/m^3 depending on the location and the sampling methods. The highest concentrations of total moulds were measured at the delivery hall, as well as at the waste paper press and the sorting of waste glass and waste plastics. At the biowaste composting plant the concentration of total moulds in the air of the machine hall in the manual sorting area ranged from 90,000 to 400,000 cfu/m^3 and at other locations, for example the waste paper press, from 80,000 to 200,000 cfu/m^3.

The results of concentrations for the total bacteria in the air in two sorting plants ranged from 600 to 7,200 cfu/m^3 in the presorting area and from 2,600 to 14,700 cfu/m^3 in the sorting area of plant 1. In plant 2 the concentrations of total bacteria in the air of the sorting area showed levels from 1,500 to 5,500 cfu/m^3. At this plant it was observed that the amount of the alveolar fraction increased with the mechanical treatment [12, 13].

At the different areas in a biocomposting plant we investigated the concentrations of total bacteria, Gram-negative bacteria, *A. niger*, moulds and thermophilic actinomycetes. A comparison with normal outdoor areas showed that the microbial pollution inside the closed plants was high, especially for total bacteria and moulds. The median values of the concentrations for *A. niger* and thermophilic actinomycetes are more than hundred times higher than the median values for normal outdoor areas [11] (Tab. 3).

This is also shown by the results of an investigation by Streib *et al.* [29] in a sorting plant. The concentrations for total moulds in the delivery hall were up to 690,000 cfu/m^3 and the concentrations for moulds came up to 66,000 cfu/m^3. About 90% of the bacteria were found in the fraction of fine dust which means that the particle size was less than 7 µm and more than 50% of the size of bacteria loaded particles ranged from 2 to 4.7 µm. The concentration of moulds in the composting hall was about 840,000 cfu/m^3. The concentration of total moulds in the air collected from the rotting hall after passing the biofilter was about 8,600 cfu/m^3 and the concentration of moulds 3,700 cfu/m^3. After moistening the biofilter the concentrations were on a level of normal outdoor conditions.

Our investigations at two composting plants showed that the concentrations of airborne microorganisms are at a high level at areas where the compost is shredded or otherwise handled. The highest concentrations for total bacteria and moulds, which means greater than 21,000 cfu/m^3 were found by shredding a mixture of biowaste and cuts of shrub and bushes in the outdoor area. The values were 10 times higher than in the normal outdoor air. In another composting plant the air was investigated

Table 4. Concentrations of airborne microorganisms in outdoor air at different country locations and in different seasons. Figures represent median values of 30 individual samples, and the range is given in parentheses.

Location / Season	Total bacteria (cfu/m^3)	Gram-negative bacteria (cfu/m^3)	Moulds (cfu/m^3)	*Aspergillus niger* (cfu/m^3)	Thermophilic actinomycetes (cfu/m^3)
Countryside / Summer	2×10^2 (7×10^1 - 3×10^3)	< l.d. (< l.d. - 4×10^1)	7×10^2 (1×10^2 - 4×10^3)	< l.d. (<l.d. - 7×10^1)	< l.d. (< l.d. - 1×10^2)
Mountainous region / Winter	5×10^2 (1×10^2 - 1.6×10^4)	< l.d. (< l.d. - 7×10^1)	1×10^2 (< l.d. - 7×10^3)	n.a.	n.a.
Countryside / Summer	2×10^3 (4×10^2 - 8×10^3)	n.a. n.a.	4×10^2 (1×10^2 - 4×10^3)	n.a.	n.a.
Edge of the forest / Summer	5×10^2 (4×10^1 - 8×10^3)	< l.d. (<l.d. - 2×10^2)	2×10^3 (7×10^2 - 1.1×10^4)	n.a.	n.a.

l.d.: limit of detection; n.a.: not analyzed.

Table 5. Concentrations of airborne microorganisms at different distances from an active biofilter (cfu/m^3). Figures represent median values of 30 individual samples, and the range is given in parentheses.

Location	Total bacteria (cfu/m^3)	Gram-negative bacteria (cfu/m^3)	Moulds (cfu/m^3)
On top of biofilter (old material)	6×10^3 (2×10^3 - 1.4×10^4)	<l.d. (<l.d. - 7×10^1)	3×10^3 (2×10^3 - 1.4×10^4)
25 m from biofilter (downwind)	3×10^3 (2×10^3 - 5×10^3)	< l.d. (< l.d. - 7×10^1)	6×10^3 (2×10^3 - 1.7×10^4)
40 m from biofilter (downwind)	2×10^3 (1×10^3 - 7×10^3)	< l.d. (<l.d. - 7×10^2)	1×10^3 (4×10^2 - 3×10^3)

l.d.: limit of detection.

while turning the compost consisting of 8 days old and 3 month old material in the closed rotting hall. The highest concentrations for total bacteria and moulds were found by investigating the 3 month old compost and the highest concentrations for Gram-negative bacteria by investigating the fresh 8 days old compost [9].

The results for the concentrations of microorganisms presented above, show that there are typical microbial species in different areas of waste treatment plants and also for different ages of composts and different kinds of waste. Additionally, it was observed that in the areas where dust pollution is high, or the material is dry, the microbial air pollution is consequently high.

The different phases of the composting process are characterised by the presence of different groups of microorganisms which are adapted to the specific conditions [14]. After a short lag-phase, degradation of the input material which can be easily handled by the microorganisms begins. Through the activity of the microorganisms there is an increase of temperature, along with a selection of microorganisms. The thermophilic phase is characterized by thermophilic, thermotolerant and endospore-forming microbes. A reduction in these microorganisms occurs when only difficult degradable material is left and thermophilic and thermotolerant microbes are unable to use the organic substances left as a substrate. Then mesophilic species can grow on this compost material.

Due to these results we can find Gram-negative bacteria in the fresh waste where the selection of microorganisms has not started, whereas the mesophilic or thermophilic microbial groups are typical for the different phases of reduction.

HYGIENIC ASSESSMENTS FOR THE POLLUTION OF MICROORGANISMS IN WASTE TREATMENT PLANTS

The concentration of microorganisms in the air in different locations of waste treatment plants range from several hundred to more than a few hundred thousand cfu/m³. Therefore questions arise about the health hazards of people working in these conditions. Compared to other industrial sites, concentrations of microorganisms in the air higher than 10,000 cfu/m³ will be found only in stables or caused by technical processes [2]. The microbial concentration of the normal outdoor air has a level around a few hundred cfu/m³ [24] and rarely reaches a few thousand cfu/m³ [25].

Our investigations of the normal outdoor air at different locations, during different seasons, showed that the medians are comparable, whereas the maxima of some species could exceed 10,000 cfu/m³. For instance, the concentration of several microorganisms showed maxima in summer and in forests [10] (Tab. 4).

Similar results were obtained by Fack and Philipp [6]. They found that the concentration of moulds in the normal outdoor air reached a maximum of 60,000 cfu/m³ and the concentration of aspergilli was 15,000 cfu/m³.

Looking at the results of measurements of microorganisms in normal outdoor areas, the problem of microbes being emitted to the environment from the waste treatment plants was observed. The results of our investigations obtained in summer showed that in a distance of 40 m downwind from the biofilter, which was also positioned downwind to the plant, the microbial concentrations in the air were only slightly higher than the reference measurements (Tab. 5).

Table 6. Concentrations of airborne microorganisms on a active biofilter of differently aged material (cfu/m^3). Figures represent median values of 30 individual samples, and the range is given in parentheses.

Location	Total bacteria (cfu/m^3)	Gram-negative bacteria (cfu/m^3)	Moulds (cfu/m^3)
On the top of the biofilter (new material)	7×10^3 (5×10^2 - 1.5×10^4)	< l.d. (< l.d. - 1×10^2)	3×10^3 (2×10^3 - 7×10^3)
On the top of the biofilter (old material)	6×10^3 (2×10^3 - 1.4×10^4	< l.d. (< l.d. - 7×10^1)	3×10^3 (2×10^3 - 1.4×10^4)

l.d.: limit of detection.

Table 7. Proposed occupational exposure limits in Scandinavia [26].

	Gram-negative bacteria (cfu/m^3)	Moulds (cfu/m^3)	Endotoxins (µg/m^3)
Toxic pneumonitis	10^5	10^7	1
Respiratory inflammation	10^3	10^5	0.02

In addition, we investigated the influence of the age of the biofilter material on microbial emission. The measurements were taken on a biofilter where the material was about 1 year old and on a biofilter where the material was aged 6 weeks. Considering the median values no significant differences between the concentrations of the microorganisms could be observed (Tab. 6).

A correlation between the dose and the effects in regard to frequently shown symptoms of the people working in the plants and the results of the investigations for dust, microorganisms and toxins could not be determined [23]. The reason is the great spectrum of different microorganisms which varies in the compost from plant to plant. Apart from this the composition of microorganisms changes with the age of the compost. Our investigations frequently showed that in the delivery area of a plant the microorganism species as well as their numbers can change in a short time with each new load of waste.

Investigations in Scandinavia [17, 19] showed that exposure to airborne microorganisms higher than hundred thousand cfu/m³ was the cause of different serious health problems of workers in a plant. Technical changes at the plant reducing the exposure level of the microbial air pollution led to a decrease of the problems mentioned above.

Investigations in Baden-Württemberg among 74 workers in a waste plant, comprising examination of samples from nose, hair and faeces, showed facultative pathogenic microorganisms for all samples. Obligate pathogens could not be found in any of these samples [16].

The permanent contact with viable facultative pathogenic microorganisms, their antigens and endotoxins, moulds and their toxic secretions, enzymes as well as a lot of inert particles, chemicals and substances causing inflammations and allergic reactions [8] are factors which together are responsible for the “organic dust toxic syndrome” - ODTS. This ODTS is characterized by symptoms like coughing and other influenza-like symptoms (eg. fever) as well as by inflammation of eyes, frequent infections of the respiratory tract and infections of the lungs [27].

The health risks depend not only on the conditions of environment but also on the individual conditions, especially the disposition and susceptibility of a person [4]. This is the reason for the difficulties in establishing threshold limit values for airborne microorganisms in the occupational setting. Up to now there have been no fixed international or national thresholds for airborne microorganisms especially for waste treatment plants. In Niedersachsen the recommended values from Denmark are being taken up as a part of the preventive measures [20]. The guidelines of the European Community regarding the protection of workers against biological substances [22], which also concerns waste treatment plants, consider the reduction of risks from bacteria, moulds and viruses. However, a threshold for airborne microorganisms has not yet been established.

So far, Scandinavia has recommended tentative values of acceptable thresholds for airborne microorganisms, Gram-negative bacteria, total bacteria and endotoxins [26] (Tab.7).

Comparing these values with values of concentrations of microorganisms in the different waste treatment plants shown above, it can be seen that at several locations the values would reach or exceed the thresholds for total bacteria and Gram-negative bacteria.

The question is whether these recommendations are sufficient for the protection of workers. Different persons with a disposition or allergic sensibility already have high risk levels even though concentrations are low.

It is necessary that the routine medical examinations and personal protective equipment (for example bacteria-safe mouth-nose protection) are taken seriously. Better techniques and better management could reduce the health risks to workers, even those with normal immunity levels.

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