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Outi Tolvanen

Effects of Waste Treatment Technique and Quality of Waste on Bioaerosols in Finnish Waste Treatment Plants

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UNIVERSITY OF JYVÄSKYLÄ

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Editors
Jukka Särkkä
Department of Biological and Environmental Science, University of Jyväskylä
Pekka Olsbo, Marja-Leena Tynkkynen
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ABSTRACT

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The last fifteen years have seen immense changes in waste treatment in Finland. The number of landfill sites has been reduced and new waste treatment plants have been constructed; source separation of the various waste fractions has been become increasingly effective. At the same time, considerable attention has been paid to environmental factors such as odour problems.

Another important factor at waste treatment plants is the working conditions of employees. Earlier, there were numerous problems with occupational hygiene in sewage treatment plants and landfills. The present study was undertaken to determine whether serious problems with bioaerosols still exist now that there are new waste treatment techniques and waste is sorted. The concentrations of dust, microbes and endotoxins were investigated at one windrow composting site in 1993-1994 and at eight waste treatment plants in 1998-2003.

The best environment in regard to occupational hygiene was the combined drum and tunnel composting plant in Heinola. The most problematic area in the plant was the storage room (tunnel) for compost, but the concentrations of bioaerosols were low even there. At the composting plant in Hyvinkää, where the same kind of technique was in use, there were problems with bioaerosols in all working areas investigated. The same problems were encountered in dirty working areas in a drum composting plant in Oulu; in the control room number of bioaerosols was low. Conditions were worst in the dry waste treatment plant in Tampere, where viable microbes were a particular problem in the processing hall. As well, the concentrations of dust and endotoxin were occasionally increased to a level harmful to human health. The dry waste was most affected with microbes, while the treatment of wood waste caused problems with dust. In the other plants of the study, sorting and crushing of waste caused the highest concentrations of bioaerosols. The two most common air-borne fungi at every plant were *Penicillium* spp. and *Aspergillus* spp. Both fungi may cause allergy and produce harmful metabolic compounds. The aerodynamic diameter of most of the viable microbes at every plant was < 5 μm. These microbes may penetrate deep to alveoli and represent a health hazard.

This study shows that the movement of waste treatment from open fields to indoor facilities has not reduced all problems of occupational hygiene. In particular, the number of mesophilic fungi was significantly higher at indoor facilities than in the open composting field. For the determination of microbial numbers, the impactor gives better (higher) results for viable microbes than the CAMNEA method. There is a problem with the impactor, however: if the concentrations of viable microbes are very high, at a level $> 10^5$ cfu/m^3, the sampling time has to be very short, just 30 s to 1 min, and then the representativenes of the sample may suffer. Using an impactor is easy, however, and the method is cheaper than the Camnea method. There are also some problems with dust sampling, especially in winter, when static electricity interferes, sometimes even giving rise to negative results.

Key words: Bioaerosol, dust, microbes, occupational hygiene, waste treatment.

Author's address Outi Tolvanen
University of Jyväskylä
Department of Biological and Environmental Science, P.O. Box 35, FI-40014, University of Jyväskylä, Finland
E-mail: outolvan@bytl.jyu.fi
Tel: +358-14-2604234
Fax: +358-14-2602321

Supervisor Kari Hänninen
University of Jyväskylä
Department of Biological and Environmental Science, P.O. Box 35, FI-40014, University of Jyväskylä, Finland
E-mail: kahannin@bytl.jyu.fi
Tel: +358-14-2602313
Fax: +358-14-2602321

Reviewers Dr Helvi Heinonen-Tanski
University of Kuopio
Department of Environmental Sciences, P.O. Box 1627, FI-70211 Kuopio

Professor Ed Stentiford
University of Leeds, Leeds LS2 9JT, UK

Opponent Professor Jyrki Liesivuori
University of Kuopio
Department of Toxicology and Pharmacology/Finnish Institute of Occupational Health
P.O. Box 93, FI-70701 Kuopio, Finland
E-mail: Jyrki.Liesivuori@uku.fi
Tel: +358-17-201252
Fax: +358-17-201474

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This thesis is a summary and discussion of the following articles, which are referred to in the text by their Roman numerals:

I Outi Tolvanen, Kari Hänninen, Anja Veijanen & Kirsi Villberg 1998: Occupational hygiene in biowaste composting. Waste Management & Research, 16(6): 525-540.

II Outi Tolvanen 2001: Air-borne bioaerosols and noise in a dry waste treatment plant in Pietarsaari, Finland. Waste Management & Research, 19: 108-114.

III Outi Tolvanen & Kari Hänninen 2004: Occupational hygiene at a waste incineration plant. Submitted to Waste Management.

IV Outi Tolvanen 2004: Exposure to bioaerosols and noise at a Finnish dry waste treatment plant. Waste Management & Research, in press.

V Outi Tolvanen & Kari Hänninen 2004: Mechanical-biological waste treatment and the associated occupational hygiene in Finland. Submitted to Waste Management.

VI Outi Tolvanen & Kari Hänninen 2004: Occupational hygiene in two combined drum and tunnel composting plants managing source separated biowaste and sludge. Journal of Environmental Health, in press.

ABBREVIATIONS

AM	arithmetic mean
ASJ	Ab Avfallsservice Stormossen Jätehuolto Oy
cfu/m^3	colony forming unit per cubic meter of air
EU/m^3	endotoxin unit per cubic meter of air
GF	glass fibre
GM	geometric mean
HMA	Helsinki Metropolitan Area
LAL	*Limulus* amebocyte lysate
LPB	liquid packaging board
mg/m^3	milligrams per cubic meter of air
ng/m^3	nanograms per cubic meter of air
PCA	Plate Count Agar
pcs/m^3	particles per cubic meter of air
RH	relative humidity

1 INTRODUCTION

1.1 Waste treatment in Finland

Waste Act

The general aims of the Waste Act, which came into effec in 1994, are 1) to support sustainable development by promoting the sensible use of natural resources trough decrease in the formation of wastes, 2) to prevent negative health and environmental consequences of wastes, and 3) to intensify the reuse of wastes. In future, the responsibility of producers will be increased by requiring them to take into account the whole life cycle of their products and to introduce new and clean technology. Through recycling, materials can be reused before their final disposal at landfills, and their life cycle is extended. Recycling also supports the primary goal of reducing the amounts of waste to be transported to landfill.

The Waste Act calls for the treatment and utilisation of wastes. The first priority under the *obligation to treat wastes* is to reuse or recycle the material of which the waste consists. Utilisation of the energy content of the waste is the second priority, while waste combustion without energy recovery and disposing of the waste by landfilling are alternatives of last resort. In addition, the Waste Act requires use of the best, economically viable technique in the waste treatment. The *obligation to utilise wastes* requires that wastes should be utilised if this is technically possible and the costs entailed are not unreasonable relative to the disposal by other means.

Reduction in the number of landfills has been a particular goal in Finland, and the results have been good: in 1990 there were 480 landfill sites, and now there are about 140. The target for the year 2005 is about 80.

According to a study of the Finnish Environmental Centre in 1994, municipal landfill waste consisted one third (33%) of biowaste, one quarter of paper (25%) and about one fifth (20%) of board. The amount of glass was about 5%, metals 4%, textiles 2% and wood from 1 to 6%. The new Waste Act brought

Finnish regulations into harmony with those of the European Union. Since then, Finland has gradually moved towards sorting. In most municipalities, biowaste has been the first fraction to be sorted out since 2000.

Recovery and utilisation of waste fractions in Finland

Most households are required to separate their wastes into eight fractions: 1) biowaste, 2) dry waste, 3) paper and board, 4) glass, 5) metal, 6) textiles, 7) hazardous wastes and 8) used milk and juice containers. It is not unusual, however, that the dry waste fraction includes other waste fractions as well, sometimes even biowaste.

It is estimated that the theoretical accumulation of *biowaste* in Finland is 1.5 kg/resident/week. The actual accumulation of biowaste, for example in Helsinki Metropolitan Area (HMA), is 0.75 kg/resident/week, while in Jyväskylä it is 1.5 kg/resident/week. The main reason for this gap seems to be the difference in waste regulations. Regulations of HMA require source separation of kitchen biowaste only for blocks of ten flats or more, whereas in Jyväskylä every household is required to source separate the kitchen biowaste fraction. The urban biowaste is transported to waste stations and mainly composted there. Households may also compost their own biowaste or a part of it themselves.

The dry waste fraction obtained from the source separation of several fractions is expected to be relatively pure. This pre-sorted municipal (households and shops) and industrial dry waste fraction is refined into recycled energy fuel (REF) in dry waste treatment plants. Currently there are municipal treatment plants in Tampere, Pietarsaari, Hämeenlinna, Forssa and Kuusankoski. The private waste company Lassila & Tikanoja operates treatment plants in Kerava, Lahti, Lohja, Jyväskylä, Mikkeli and Valkeakoski. In addition, there are several smaller dry waste treatment plants.

About 500,000 tonnes of u*sed paper and board* is collected annually in Finland. This waste fraction is equivalent to the production of a large pulp and paper mill. The rate of collection is now 61%, but it is estimated that, with concerted efforts, an additional 100 000 tonnes could be collected, bringing the rate up to about 75%. In Germany and Austria the paper and board collection efficiency is 71%. Since the population density of Finland is about one-sixteenth that of Germany, the level of collection in Finland must be considered very good. The collection of paper is already commercially viable.

The glass recycling systems in Finland are divided into two main types: 1) refundable deposit systems and 2) collection systems.

The refundable deposit systems cover most of the glass bottles (alcoholic beverages, soft drinks) in circulation. The rate of recovery of refillable beer and soft drink bottles has been particularly high, with an average recovery of 96-98%.

The collection systems include the collection of glass waste from jars and bottles for recycling as a new raw material. About to 52,000 tonnes glass waste is collected annually. The major part of the glass waste is generated by households, hospitals and bottlers. In 1994, the recovery rate was 53%, but only 38% of the total was reused or reprocessed as raw material. Potentially, 69 to 97% of all used glass in Finland could be reused as secondary raw material in the packaging glass and glass wool industry.

The capital costs of glass recycling include investment and maintenance costs for collection bins and other facilities (refundable deposit system), transportation to intermediate depots and sorting. At present, the collection system glass is delivered to Suomen Uusiotuote Oy's treatment plant in Jokioinen, for sorting or resorting, in an automated plant, into white and coloured glass. The glass is then delivered to the local glass factory where it is melted down and processed into packaging glass or glass wool (Vuoksimaa 1996).

Scrap metal is a valuable raw material which is melted and reused in industry for manufacturing various kinds of metal products. Metal recycling requires that the metal be as pure as possible, for plastic and other impurities will put restrictions on the use. This is the reason that packaging metal is (so far) not used for making new packages. Metals can be melted, for example, and processed into construction steel. The metal ending up in landfills is mainly derived from households, the service sector (small shops and offices) and agriculture. The collection and use of scrap metal have a long tradition in Finland. The collection of scrap iron and steel has increased relatively steadily from the 1940s to 1990s.

An important source of scrap metal is cars no longer in use. There are about 250 vehicle wreckers in Finland. Sincen their main source of income is selling used spare parts, they try to acquire cars that are as new and as in good conditions as they can. After the useful parts have been retrieved, the scrap that is left is delivered one of the three places in Finland where vehicles are flattened and shredded.

Used textiles and goods are mostly sold and exchanged in several second-hand shops, antique shops and flea markets. Some larger blocks of flats maintain a recycling room, or recycling shelves built into the waste shelters. Goods and used clothing may also be recycled among friends and relatives. While "antiques" mainly comprise record discs, cassettes, books and magazines, but the spectrum of goods in second-hand shops and flea markets is much wider. Most cities also have customer-oriented recycling centres, which are managed by the Technical Service Centres of the cities and operated by private socially oriented organizations. Their responsibilities are as follows:

1) To receive clean textiles, furniture fit for resale, sports equipment, toys, books and other recyclable goods, and to sell those goods and textiles that can be reused. A free pick-up service is provided to clients in the city area.

(2) To advise and inform residents about the reuse and recycling of materials by lecturing to various groups about recycling and composting.

Hazardous wastes must deliver to special collection points for hazardous wastes. All waste management companies in Finland operate with a similar definition of hazardous wastes. *Ekokem* is a Finnish company specialised in hazardous and special waste management. Founded in 1979 and located in Riihimäki, Ekokem is owned by private chemical companies, the State of Finland and municipalities. The annual accumulation of hazardous wastes in Finland is about 100,000 tonnes. Ekokem has a special landfill for the final location of wastes that are still problematic after treatment. Ekokem also sells and hires out bins for sorting, collecting, storing and transporting of hazardous wastes, sells adhesive labels for the marking of hazardous wastes, washes liquid containers, offers laboratory services (waste, process and environmental analysis) and picks up hazardous wastes country-wide. Ekokem is not allowed to handle explosives, radioactive materials or organic mercury compounds (Heinonen 2000).

One example of successful, and cost effective waste treatment is the processing and utilisation of *liquid packaging board* (LPB) by Stora Enso in Finland. Germany generates about 160,000 tonnes of used LPB containers annually and, according to EC directives, this waste material must be recycled. Part of the waste material collected in Germany (about 70,000 tonnes) is brought to Finland for further processing by Corenso, which is a subsidiary company of Enso, the largest producer of virgin LPB in Europe. Mainly to serve the German import, in 1995 Corenso built a new pulp mill at Varkaus, with a capacity of about 70,000 tonnes/a. The Varkaus mill utilises the LPB containers as secondary raw material, along with other plastic coated carton wastes and waste corrugated board and paper.

The fibre of LPB containers is of good quality and after recovery can be manufactured into high quality products such as toilet tissue and wrapping paper as well as cardboard. Initially, plastic reject was combusted in the Varkaus power plant, but the accumulation of aluminium in the furnace entailed several shut-downs annually. A new method of treating plastic reject is to be tested: high temperature pyrolysis, which should allow the utilisation of aluminium as well.

The annual accumulation of *used electrical appliances and electronic devices* in Finland is about 100,000 tonnes. The life cycle of televisions and mobile phones is presently only a few years. As much as 95% of the material in electrical and electronic devices – mobile phones, beaters, vacuum cleaners, video recorders – can be recycled. At the moment the law allows the plastic casings of electronic devices to be transported to the landfill. However, many devices contain small amounts of various toxic substances, such as mercury and as the number of the devices is great, the total volumes may be considerable. An EU directive relative to these waste products is under consideration in Brussels.

Electrical appliances are always stripped of copper and other valuable metal parts with about 50% yield. Currently, in Finland, ways of intensifying the collection of electrical and electronic waste are being studied by various projects and by private enterprises.

The accumulation of *used car tyres* in Finland is about 2.5 million (equivalent to 30,000 tonnes). Previously the used tyres were transported to landfills where they prevent compaction and are a fire hazard. Now, tyre or car shops, service stations, tyre repair shops or re-cappers of the tyre in part are obligated to accept the used tyres without payment. In 1995, the government set a target that 90% of the used tyres in Finland should be recycled. The target was met immediately: in the first year, the accumulation was over 27,000 tonnes.

By the year 2005 an average 70% of both municipal and industrial *construction wastes* should be recovered. The most effective means to increase the quality and quantity of the waste wood recovery, and indeed the recovery of all construction waste, is through national regulations regarding sorting.

1.2 Microbes as harmful factors in waste treatment

Background

Pursuant to the Waste Act, waste treatment in Finland has been transferred from landfills and open waste treatment areas (like windrow composting) to closed waste treatment plants. Among the objectives has been to reduce harmful environmental effects such as unpleasant odours, littering and loading of landfills and to make the recycling of different waste fractions more effective. Another target has been to automate waste treatment processes as far as possible to make them less labour intensive and thus reduce the exposure of employees to harmful factors such as dust, microbes, end toxins, glucans and other metabolic product of microbes.

Most employees working with waste treatment are at some point exposed to harmful factors such as airborne particles and volatile organic compounds. Some earlier studies have shown that employees in waste treatment plants have had more stomach complaints, irritation in eyes and throat and airway symptoms than other people, and waste treatment in open fields may cause problems with occupational hygiene (Millner et al. 1980; Hänninen et al. 1993; Poulsen et al. 1995a; 1995b; Tolvanen et al. 1994; Tolvanen et al. 1998 (I); Beffa et al. 1998). Problems have also been documented in sewage and other indoor facilities treating waste (Rylander 1992; Gladding & Coggins 1997). In particular, biowaste and sludge may contain pathogens and other microbes. According to earlier studies, employees at composting plants are more exposed to bioaerosols than are other population groups (Millner 1995). Bünger et al. (1999) and Sigsgaard et al. (1999) found that employees at waste treatment facilities have increased in respiratory, gastrointestinal and skin symptoms relative to control groups. Also, in a cross-sectional study among Danish garbage and compost workers, an increased prevalence of acute gastrointestinal symptoms and mucosal and skin symptoms was observed by Sigsgaard et al. (1994). In another Danish study waste collectors were found to have excess prevalences of symptoms of nausea and diarrhoea and the gastrointestinal symptoms were most common during the summer when the waste was most malodorous (Ivens et al. 1997). Also Nielsen et al. (2000) found that exposure to microbes during the collection and handling of municipal waste is highest in summer.

Microbes are also a problem in landfills; microbe concentrations in working air in landfills may be 5-20 times as high as the background concentration (Rahkonen et al. 1987; 1990). In the studies made by Rahkonen and co-workers, it was found out that 40-60% of bacteria and 80% of fungi were able to penetrate alveoli due to their small aerodymanic size.

Sources of microbes

Microbes may be primary or secondary pathogens to humans; most secondary pathogens, including most fungi, are harmful to humans, and under unfavourable conditions may cause allergy. The most common exposure routes to microbes and dust are eyes, nose and lungs. Particle size is relevant to the development of allergic symptoms in airways; particles with aerodynamic size <10 μm mostly remain in the upper airways. Smaller particles can penetrate to windpipe and bronchus and particles < 5 μm in size may penetrate to alveoli. Most harmful are particles of aerodynamic size 1-2 μm or 0.2 μm (Terho, Haahtela & Hannuksela 1993). The motion and relative humidity of air affect the concentrations of airborne microbes; more *Aspergillus fumigatus* and *Penicillium* were released in dry indoor air (RH < 42%) than in moist air (RH >70%) (Pasanen et al. 1991). Because fungi spores are only about 0.5-50 μm in size, they float far in air; *Aspergillus fumigatus*, for example, has been reported to drift at a rate of 0.03 cm/s.

A common source of the primary pathogens encountered in waste treatment are faeces and other secretions of humans and animals, house hold waste and plant matter. Sludge contains intestinal bacteria, viruses and parasites, household waste lower amounts of the same (Boutin & Moline 1987; Golueke 1991). Extermination of all microbes is a challenge, especially during composting, where microbes are a natural part of the process and, in fact, composting does not take place in the absence of microbes. When the composting process is working normally, however, high enough temperatures can be achived that pathogens are destroyed during the process. For example, *Mycobacterium tuberculosis* causing tuberculosis is destroyed in 14 days at 65 °C, poliovirus in 30 min at 54 °C and *Salmonella* in 30 min at 60 °C (Hughes 1980). Despite this, exposure to pathogens is still possible during the management of fresh biowaste and also of other waste qualities (like dry waste from households) containing biowaste residuals. It is also important to remember that secondary pathogens may cause problems, and at least in the management of biowaste and sludge, microbes that may cause health hazards are always present.

Health hazards

A growing number of people are suffering from allergy. According to clinical estimation, about 1-2% of Finns are allergic to common airborne fungi like *Cladosporium* and *Penicillium*. Fungi *Alternaria*, *Didymella* and *Aspergillus* and thermophilic *Actinomycetes* sp. bacteria are other common microbes causing allergy (Boutin & Moline 1987; Lacey & Crook 1988; Terho et al. 1993; Madigan et al. 1997). Although a clear correlation between levels of fungi in the air and health impacts has never been established in epidemiological studies, fungi in indoor air have to be regarded as potential health hazards (Bornehag et al. 2001; Burge 2001). The extent of the health hazards depends on personal sensitivity, fungi species and strength and time of exposure. Risk to allergy is highest in atopic persons (Olver 1994; Portnoy et al. 2004). Occupational asthma occurs among employees working both indoors and outdoor. However, in outdoor work it becomes very difficult to separate occupational asthma from "normal" asthma, because many of the fungi causing allergy and asthma are normal outdoor species (Lacey & Crook 1988). It is difficult to estimate health risks at waste treatment plants, since severe infections have not been described widely for employees and mainly people suffering from immune deficiencies are at risk for more serious infections (Fischer & Dott 2003). Only a few cases of acute respiratory diseases in compost workers have been reported (Weber et al. 1993; Brown et al. 1995).

Most fungi cause irritation on mucous membrane, eyes and skin. If exposure is strong enough, as many as half of those exposed suffer symptoms such as itching, runny nose, cough, headache and fatigue. After exposure, a few percentage of people contract fungi allergy. If exposure is exceptionally strong, it may cause allergic alveolite (Haahtela & Reijula 1997). The risk to contract allergic alveolite has been associated with microbial species *A. fumigatus, A. glaucus, Penicillium, Aureobasidium pullulans, Phoma violacea, Graphium* spp., *Mucor racemosus, Fusarium basinfectum, Trichoderma* spp., *Acremonium* spp., *Thermoactinomyces vulgaris* and *T. thalpophilus* (Lockey 1974; Lacey & Crook 1988). Most alveolites are occupational diseases. Fungi concentrations as high as 10^3-10^6 cfu/m^3 have been measured at the farms of diseased farmers. Acute symptoms may occur when the fungi concentration reaches 10^8 cfu/m^3.

Aspergillosis is a disease caused by *Aspergillus fumigatus,* which occurs mostly in atopic individuals. In this disease, *A. fumigatus* grow in the mucus of the bronchus and may cause early asthmatic attack in allergic atopic individuals. It is also possible to have late asthma response and alveolite (Terho 1993; Olver 1994). Because of its many pathogenic properties, *A. fumigatus* is one of the most harmful pathogenic fungi in waste treatment. The fungus is very common in both indoor and outdoor environments and it may grow on widely different substrata such as wood, plants, paper, fabric, rubber, sludge, compost and mould (Epstein 1994). On the basis of experiments on animals, the threshold value of 10^7 – 10^8 cfu/m^3 has been proposed for *A. fumigatus* (Fogelmark et al. 1991).

As well, the metabolic products of fungi may be harmful to health; most mycotoxins are toxic to humans. Aflatoxin is carcinogenic, and trichothecene mycotoxins may cause nausea, vomiting, skin irritation and internal bleeding in addition to respiratory disorders of various kinds (Burck & Cote 1991). Numerous other toxic properties, including nephro- and hepathotoxic and tremorgenic effects have been described for mycotoxins and thus they may constitute a serious health hazard to humans (Fischer et al 1999). Gravesen et al (1994) found, that *A. versicolor* and *Penicillium expansum* can produce toxins (like patulin) on agar made from wallpaper paste. *Stachybotrys atra*, strains known to produce trichotethecenes have been isolated from building materials and also from air samples in buildings with moisture problems (Croft et al 1986; Johanning et al 1993; Johanning et al 1996). Because some mycotoxins, like patulin and trichothecenes, are volatile and may bind to aerosols, exposure can come via lungs (Rousseaux 1988). The presence of mycotoxins in bioaerosols from waste treatment plants is still largely undocumented. Mycotoxins can nevertheless be expected to be present in both living and dead spores or propagules of fungi (Fischer et al 1999). Investigations in farm workers showed that an increased exposure to dust contamined with mycotoxins can lead to hepatocellular carcinoma and mycotoxicoses of lung (Ghio & Roggli 1995). However, until now such health effects have not been observed in plants treating biowaste (Fischer et al 1999). The most common exposure route to mycotoxins may be via food; toxic mycotoxins like aflatoxin, ochratoxin and patulin have been found in nuts, vines, cereal products etc. and fungi producing these toxins include a wide range of *Penicillium* and *Aspergillus* species (Moss 2002).

B-glucans are structural cell wall polymers, present in many fungi that possess immunomodulatory activities (Brown & Gordon 2003). Both glucans and the endotoxin (lipopolysaccharide from the cell wall of gram-negative bacteria) have many toxic properties and may cause fever, headache and fatigue. The toxic properties are the same whether the microbe is dead or living (Gladding 1998). The occurrence of endotoxins correlates with a number of gram-negative bacteria. Chronic exposure to endotoxins may lead to chronic bronchitis and permanent reduction of lung function (Heederik & Douwes 1997).

Among other metabolites of microbes, also microbial volatile organic compounds (mVOC) are suggested to cause health hazards such as lethargy, headache and irritation of the eyes and mucous membranes of the nose and throat. The relevance of mVOC in working environments has not been sufficiently studied (Fischer et al. 1999; Fischer & Dott 2003) and, indeed, there is no evidence that they are toxicologically relevant (Kreja & Seidel 2002). Fischer et al. (1999) have found out that *Aspergillus fumigatus*, which is common in the composting facilities, can produce p-Mentha-6,8-diene-2-ol acetate, camphene, trans-β-farnesene, α-pinene and some terpenes; *Paecilomyces variotii* can produce δ-4-Carene, megastigma-4,6(E),8(Z)-triene, neo-allo-ocimene and β-phellandrene; *Penicillium crustosum* can produce 2-Ethylfuran, 2-ethyl-5-methylfuran and isopropyfuran. Since there are few investigations dealing with species-specific MVOCs or the quantities of these compounds in the air, it is difficult to know if a correlation exists between health effects and exposure to MVOCs (Fischer et al. 1999).

1.3 Importance of microbes in composting

Treatment of biowaste and sludge by composting is mainly a microbiological process. To understand the importance of microbes in this process it is necessary briefly to describe the composting process.

Composting can be divided into four distinct phases: 1) mesophilic, 2) thermophilic, 3) cooling and 4) maturing phase (Biddlestone & Gray 1985). The role of microbes is different in each phase.

During the mesophilic phase, the temperature of the compost rises to 25-40 ^{o}C and microbes begin to multiply rapidly; fragmentation of organic matter begins. The temperature rises and the process advances to the thermophilic phase (Hughes 1980; Biddlestone & Gray 1985; Shekhar Sharma & Johri 1992). During the thermophilic phase the compost includes a lot of thermophilic bacteria, actinomyctes and especially thermophilic fungi; pathogenic microbes are destroyed if the temperature becomes high enough (Hughes 1980). When the temperature rises to 60^{o}C, the activity of thermophilic fungi will stop, and actinomycetes and other spore-forming bacteria will continue the work of fragmentation (Biddlestone & Gray 1985; Miller 1992). Gradually reactions get slower and the temperature begin to decrease. Thermophilic fungi begin to grow once again and, together with actinomycetes, they break down long-chain polysaccharides to sugars, which are suitable for other microbes. As a result of this fragmentation process, the temperature will decrease to the level of the surrounding environment (cooling phase). Thermophilic microbes disappear and mesophilic microbes, mainly fungi, take over. At this stage, carbohydrates, fats and proteins have been broken down and the compost matter should be hygienic and more or less odourless (Hughes 1980; Biddlestone & Gray 1985).

During the cooling phase, complicated reactions occur between residual lignin, and proteins that have been liberated from dead microbes. As a result of these reactions, humus is formed and the number of microbes decreases. The maturing phase takes a few months (Biddlestone & Gray 1985) or at low temperatures, as in Finland, even a year.

Temperature is not the only factor affecting the microbial flora of composts. The pH, moisture and oxygen contents, particle size of the composting biowaste and the amount and ratio of nutrients (especially C:N) influence the appearance and activity of microbes. Optimal conditions are of great importance for the process to work properly and ensure that unpleasant odours are not formed.

Composting is not possible without microbes. Fungi are particularly important because they can degrade cellulose compounds. Cellulose is not easily decomposed, but a major source of soluble sugars and common also in composts; lignin-free cellulose is degraded by many microbes such as *Epicoccum nigrum* and *Alternaria alternata*. *Acremonium, Phialophora* and rotting fungi *Sporocybe* and *Doratomyces* degrade both cellulose and hemicellulose. Lignin, too, is resistant to decomposition; it does not absorb into cells and intracellular enzymes are unable to degrade it. Extracellular enzymes are equally ineffective. Only mesophilic fungi, especially white rot fungi, and some yeasts degrade lignin and lignocellulose effectively (Dix & Webster 1995).

As mentioned above, fungi and other microbes may represent a health hazard to employees at waste treatment plants. However, composting is not possible without microbes, which means that other solutions must be sought to avoid the problems caused by airborne microbes.

1.4 Threshold values for bioaerosols

There are no occupational threshold values for microbes. In Finland, the Ministry of Social Affairs and Health recommends that concentrations of fungi in indoor environments (residences, offices) should not exceed 500 cfu/m^3 in winter and 2500 cfu/m^3 in other seasons. The highest acceptable number of bacteria for indoor environments in all seasons is 4500 cfu/m^3 while the number of actinomycetes should be < 10 cfu/m^3. These recommended values refer to samples taken with a six-stage impactor and to mesophilic microbes. The values are not geared to health problems; if concentrations in indoor air repeatedly exceed the recommended values, it is usually a signal of moisture damage in the building. Thus, use of these values as threshold values for occupational hygiene at waste treatment plant would be a doubtful procedure. The values nevertheless provide a useful yardstick in considering the microbe levels in waste treatment plants.

There are some recommended threshold values for microbes in Scandinavia. Malmros, Sigsgaard & Bach (1992), for example, suggest that total microbe concentrations should no exceed 5000 – 10,000 cfu/m^3 and the number of gram-negative bacteria should be below 1000 cfu/m^3. Heida et al. (1995) propose that the threshold value for both fungi and bacteria could be 10,000 cfu/m^3 while the concentration of a single microbe group should not be greater than 500 cfu/m^3.

It is difficult if not impossible to state what microbe concentrations are harmful to health and what not, because different kind of microbe concentrations may elicit different symptoms depending on the exposed individual. In a study made by Flükiger, Koller & Monn (2000) it was found that the concentrations of fungi did not correlate with the concentrations of allergens in indoor environments; the amount of allergens may be much higher than the concentrations of fungi suggest.

There is no threshold value for endotoxins in Finland. The Netherlands announced in July 2001 an occupational threshold value of 200 EU/m^3 (about 12 ng/m^3) for endotoxins. After a two-year transition period the threshold value was supposed to be reduced to 50 EU/m^3 (about 3 ng/m^3) but this new value had not yet been announced. Various values had earlier been proposed as the threshold value, with proposals based on measurements in different working environments and exposure studies. A concentration >20 ng/m^3 already increases the risk for respiratory track infections (Rylander 1994). Further, a concentration of 25 ng/m^3 increases irritation, and concentrations of 100-200 ng/m^3 may cause malfunction in lungs. Clinically a significant reduction in lung function has been demonstrated with an endotoxin concentration of 300 ng/m^3; symptoms included chest pain and shortness of breath (Malmberg 1991).

The Finnish Ministry of Labour (1996) has announced a value of 5 mg/m^3 as threshold value for organic dust. This HTP_{8h}-value (HTP=haitalliseksi tunnettu pitoisuus; concentration known to be harmful) is for eight hours duration of an estimated mean concentration known to be harmful. This threshold value is relevant when it is estimated that dust exposure covers the whole working day. A value of HTP_{15min} (10 mg/m^3) is useful when the time of exposure is short. In clean working areas such as offices, the threshold value of 0.06 mg/m^3 proposed by the Indoor Society could be used (Haahtela & Reijula 1997).

1.5 Objectives of the research

In this work the numbers of viable and non-viable microbes (mesophilic and thermophilic fungi, bacteria and actinomycetes), dust and endotoxins were studied in one windrow composting field (I), two composting plants using both drum and tunnel composting technique (VI), two dry waste treatment plants (II, III), one treatment (digestion) plant for biowaste (V), one incineration plant (IV), one drum composting plant and one optical sorting plant.

The main objectives of the work were:

- to discover if the change from windrow composting in open fields to closed composting systems decreased problems with occupational hygiene (I, VI)
- to determine whether there are problems with microbes and endotoxins in dry waste treatment plants if the biowaste has been source separated (II, III)
- to identify the waste quality that causes most problems with occupational hygiene (I-VI)

- to measure concentration levels of microbes, endotoxins and dust in waste treatment plants of different type and to identify those working areas or phases that may cause problems with bioaerosols (I-VI)
- to determine the comparative efficiencies of the CAMNEA method and sampling with a six-stage impactor (Andersen sampler) in the collection of viable microbes in the working air (I-VI)
- to discover which fungi species are most common at waste treatment plants (II-VI)
- to suggest improvements to working conditions in waste treatment plants in terms of occupational hygiene.

2 MATERIALS AND METHODS

2.1 Plants treating biowaste and sludge

Windrow composting in an open field (I)

The asphalted area of the biowaste composting field at Ämmässuo landfill site in Espoo was 1 ha in 1993-1994 and the size was increased to 3 ha in 1995. Source-separated biowaste was composted in big windrows; the size of windrows varied, starting from the original 2 metres in height in spring 1993 to a height of 3 metres in autumn 1993 and 1.5 metres in summer 1994. The amount of wood chips used as bulking agent varied.

Source-separated biowaste was collected and transported at approximately one week intervals. The fresh biowaste was crushed together with bulking agent and heaped up to windrows. During the composting process, the windrows were turned to aerate and moisten them. At first the windrows were turned every third week, but starting in December 1993 they were turned every two weeks to make the aeration more efficient. From May to September 1994 the windrows were turned once a week. The different turning methods employed are described in paper I. Initially, turnings were made with a wheel loader. The windrow was unrolled, the compost bulk was moistened and the windrow was reconstructed. The sieving of the mature compost bulk was done with a sieve drum.

Windrow composting was carried out at Ämmässuo over a period of several years. Nowadays, source-separated biowaste is first composted in a tunnel composting plant and then in outdoor in windrows in the same area.

Combined drum and tunnel composting plants (VI)

Detailed descriptions of the composting plants in Heinola (Fig. 1) and Hyvinkää (Fig. 2) can be found in paper VI. The composting plant in Heinola is owned by the municipality and it operates alongside the wastewater treatment plant. The composting unit treats about 2.5 million cubic metres of sewage sludge in a year. The sludge is composted in two drums with already composted sludge and sawmill waste, typically in volume ratio 1.6:1 (sawmill waste: sludge)

From the drums the compost mass is transferred by conveyor belts to a storage room (tunnel phase) situated in the same building as the drums. From the storage room, the compost mass is transferred to windrows in an outdoor asphalted field. The transfer is done once a week with a wheel loader. The windrows are not turned during the maturing process.

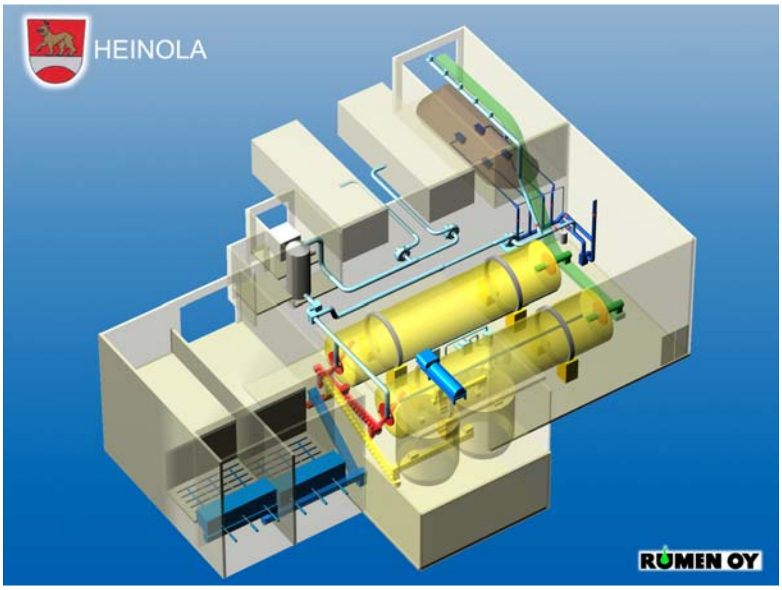

FIGURE 1 Composting plant in Heinola.

In Hyvinkää, the composting plant delivered by Rumen Ltd and owned by Hyötykapula Ltd commenced operations in summer 1998. This plant treats source separated biowaste (about 4000 t/y), sewage sludge, dry biowaste from industry and manure. The total amount of waste treated is about 20 000 t/y. Various kinds of bark and wood chips are added as bulking agent. The volume ratio has been about 1:3 (bark and chips:biowaste).

The composting process consists of four phases. 1) The mass is pre-composted in two drums with effective aeration. The target is that the temperature of the compost mass should increase to 60°C to destroy pathogens. The retention time of the mass in the drums is about 3.5 days. 2) From the drums the mass is transferred to an aerated tunnel (post-composting hall), where the delay time is about five days. 3) Maturing of the mass and intermediate storage is done in windrows in an outdoor asphalted field. The mass is windrow composted for about 1.5 months. 4) Finally, the mass is post-matured in the field for about six to twelve months. The windrows are turned once or twice during the post-maturing.

A wheel loader is used in transferring of the compost mass. The composting process in the drums is optimised with an automated control system. Process air is cleaned with an ammonia scrubber, which removes over 95% of the ammonia. The plant also has a bio-filter.

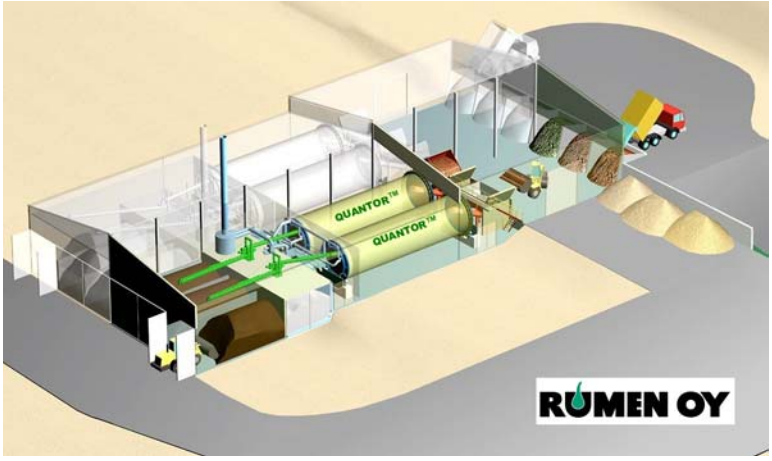

FIGURE 2 Composting plant in Hyvinkää.

Drum composting plant

The city of Oulu waste regulation source separation of kitchen biowaste at home for blocks of four flats or more. In addition to this, food shops, restaurants and cafeterias source separate their biowaste. Residents in detached houses and small row house complexes have the option to compost their biowaste in small composters on site. A separate collection bin of 140 to 240 l for biowaste must be provided at the larger residential complexes. All source-separated biowaste in Oulu (5000 t/a) is transported to the waste treatment and disposal facility at Rusko, where composting takes place in a drum composting plant. The Oulu composting plant is equipped with three drum bioreactors of 125 m^3 each. Two of them compost source-separated biowaste, while the third composts slaughterhouse waste. The retention time in the drums is one week, after which the compost is cured in windrows. The capacity of the plant is 6000 tonnes of biowaste per year. Since the biowaste is source separated it is fairly pure, which means that size reduction is the only pre-treatment required before composting. Peat is used as bulking agent.

Anaerobic digestion of biowaste (V)

A detailed description of the waste management plant of Ab Avfallsservice Stormossen Jätehuolto Oy (ASJ) is presented in paper V. The plant was founded in 1985 on the initiative of the city of Vaasa and the municipality of Mustasaari. The waste treatment facilities are located in Koivulahti, in the municipality of Mustasaari. Pre-sorted mixed waste and sewage sludge from the Vaasa area, and optically sorted wet waste from the Pietarsaari area are treated. The ASJ plant treats 25,000 tonnes of wastes annually.

The waste treatment process at the ASJ digestion plant includes two different phases: 1) mechanical treatment of waste and 2) treatment of biowaste. The waste is first crushed, and any iron is separated magnetically. Particles over 5 cm are separated out with a drum sieve, and combustible waste (paper and plastic) is mechanically separated from biowaste. This phase of the process is similar to the process in the optical sorting plant in Hämeenlinna and to the sorting and crushing process for waste at the incineration plant in Turku. This can be described as the mechanical treatment of waste. After crushing and separation, the biowaste is conveyed to a mixing chamber where it is heated and mixed and then digested for 3 to 4 weeks in a biomethanation reactor. Sewage sludge is digested in the parallel bioreactors of 1600 and 1800 m^3.

The ASJ reactors produce 2.5 million m^3/a biogas. One tonne of waste produce 100 - 160 m^3 biogas having an energy value of 500-750 kWh/t. In addition, the light material (dry waste) that is separated from the wastes is pelleted in Pietarsaari, and used to supplement black coal as a fuel.

2.2 Mechanical treatment of dry waste after source separation of biowaste (II, IV)

Ressu (IV)

Ressu, the plant in Tampere, processes three different types of waste: dry waste (mainly source-separated household waste), energy waste (mainly source-separated waste from industry and companies) and construction waste (wood). The waste types are processed alone or together. All waste streams are crushed to particle size 200 mm and transferred on a conveyor belt to metal delimiters, which remove magnetic metals. Fine aggregates and any residual biowaste are removed with a jigger screen and the waste is crushed to a particle size of 50 mm. At the end of the line the magnetic metals are again removed and the product is loaded onto trucks or is baled and wrapped in plastic for storing. The plant operates in two shifts with three employees per shift. One front loader and various other machines are used as needed.

Measurements in the plant were carried out in 1998-2000 and later in autumn 2001. Several technical modifications were made in 2000 to reduce the occupational problems in the processing hall. For example, protective casings were added to conveyor belts and local dust removal systems were improved. The aim of the measurements in 2001 was to determine whether the changes had improved occupational hygiene.

Ewapower Ltd. (II)

The dry waste treatment plant of Ewapower Ltd in Pietarsaari produces pellets from crushed dry waste. About 20,000 tonnes of pellets were produced in 1999.

The plant has been in operation since January 1998 and it has 12 employees; nine of them work with the dry waste process and three in the office. The plant runs in three shifts five days a week.

Pellets are formed from unloaded and pre-crushed dry waste under high pressure and above 100°C. The pellets are hygienic, easy to store and homogeneous. Their heating value is about 25 MJ/kg. The pellets are burned in UPM Kymmene's bark boiler in Pietarsaari.

2.3 Waste incineration (III)

The Turku waste incineration plant manages municipal waste from households and industry and produces district heat for the city of Turku. There are two incineration ovens at the plant with loading capacity of 4 t/h. In the year 2000 the plant operated for about 14,250 hours (oven I for 7050 hours and oven II for 7200 hours).

Municipal waste is emptied from lorries into the waste bunker, which is 5000 m^3 of volume. The waste is fractionated with the help of a grabbing bucket so that waste not suitable for incineration is removed and bulky objects suitable for incineration are transferred to the upper level of the waste bunker for crushing. This part of the process can be described as mechanical treatment of waste and it is similar to the sorting of waste at ASJ and at the optical sorting plant in Hämeenlinna.

The burning process has several phases. First, the burnable waste is transferred with the grabbing bucket to the feed hoppers of the incineration lines and further to the feeding tunnel. From there it is fed to the feeding grate. The grabbing bucket, and the filling and emptying of the waste bunker are controlled from the crane room.

On the feeding grate the waste dries and catches fire. The back and forth movement of the feeding grate causes the material to fall into the grate of the burning chamber. There, the main part of the waste is burned at a temperature of 1000 – 1100 °C. After that, the residual waste is transferred to the third grate (the burn out grate), where the burning is completed at a temperature slightly over 850 °C.

Combustion gases formed in the ovens are conveyed to a circulating bed heat exchanger. The heat liberated from the combustion gases is recovered into hot pressurised water and further transferred via two district heat exchangers (2 x 11 MW) to the district heating system of Turku. After heat exchange the flue gases from both burning lines are conveyed together to purification.

Sand and fly ash are removed in cyclones with two electrical filters and the mixture is pneumatically carried to the fly ash silo. The fly ash may include small amounts of metals and chlorinated hydrocarbons.

Acidic gas components of the flue gases (HCl, HF and SO_2) are removed with sprayed lime milk in the absorption reactor. After neutralising, the flue gases are fed to the channel reactor filled with activated carbon and then conveyed to the bag filter for further fractionation of the solid material. The cleaned flue gases are conveyed via fan to two chimneys.

Final products of flue gas purification are mechanically carried to a storage silo for the end products. Fly ash and the solid end products are mixed together and water and cement are added to produce a sparingly soluble solid mass. Accumulation of this solidification product is 2500 tonnes annually and it is transported to a special area of the landfill.

The slag formed during the incineration falls from the final grate to the extinguishing pool via the slag tunnel. From the extinguishing pool the slag is transferred with a conveyor belt to the slag bunker. In the year 2000 the amount of slag produced was about 10,000 tonnes. The slag is utilised for construction of the landfill.

2.4 Optical sorting of biowastes and dry wastes

The optical sorting plant in Hämeenlinna is owned by Kiertokapula Ltd. The plant has been in operation since spring 2000. The dry waste fraction and the biowaste fraction are separated in the plant according to the colour of waste bag: black bags contain biowaste and other bags dry waste. This kind of sorting can be described as mechanical treatment of waste and it is similar to the sorting of waste at ASJ and in the waste bunker of the Turku incineration plant.

Garbage trucks empty their loads to a silo. From the silo, the waste bags are transferred to three sorting lines. The bags move on the lines under cameras that have been programmed to identify black bags. A mechanical separator pushes black bags to one line and all other bags move on another line. Black bags are collected on to a transfer platform, from where they are transported to the Hyvinkää drum composting plant. Dry waste is transported to the Karanoja landfill in Hyvinkää.

The plant in Hämeenlinna operates in three sifts. Employees work in both the control room and processing hall.

2.5 Sampling

Viable, airborne microbes

In indoor facilities, airborne microbes (mesophilic and/or thermophilic fungi, bacteria, and actinomycetes) were studied with the CAMNEA method (Palmgren et al. 1986; Heldal et al. 1996; Dillon et al. 1996) and/or with the six-stage impactor in closed waste treatment plants (II-VI). At the open composting field, concentrations of mesophilic and thermophilic fungi, mesophilic bacteria and thermophilic actinomycetes were investigated with the impactor (I). In the Oulu drum composting plant and the optical sorting plant in Hämeenlinna, concentrations of thermophilic microbes were not investigated, but concentrations of viable mesophilic microbes were measured with the impactor and the total microbe concentration (both viable and dead) by the CAMNEA method.

In the CAMNEA method, samples were collected onto sterilised polycarbonate filters (Nuclepore, diameter 37 mm, pore size 0.2 μm), filter capsules, with the help of a pump (SKC 224-PCXR8) with flow rate 4 l/min (II-VI) or 1.5 l/min. Sampling time was 30 min (II-VI) or 60 min. During the sampling the cap of the filter capsule was totally removed so that the whole effective area of the filter acted as a collection surface. In measurements with the impactor, measurement times were short, ranging from 30 s to 5 min depending on the place of measurement. The flow rate of the pump was 28.3 l/min. All microbe samples were collected from the breathing zone at a height of about 1.5 m (I-VI).

All microbial samples (also endotoxin samples) were transported in cold box to laboratory. Transportation time was from 2 to 4 hours. Until treatment next day, the samples were stored in a cold room (+4 ^{o}C).

Endotoxins

Samples for study of endotoxins were collected according to the Finnish standard SFS 3860 (1988) using heat sterilised fibreglass filters (Macherey-Nagel, 85/220). The volume flow of the pump (SKC 224-PCXR8) during the sampling was 2 l/min and sampling time was 2 h. Samples were collected from the breathing zone at a height of about 1.5 m (I-VI).

Dust and fibres

Dust and fibre samples were collected from the breathing zone. Dust samples were collected according to standard SFS 3860 (1988). The samples were taken onto filters (Gelman Sciences, GN-4, number 94801, diameter 37 mm, pore size 0.8 μm). The flow rate of the pump was from 15 to 20 l/min in field measurements and 2 l/min in the measurements in the cabins (I). Sampling time ranged from 30 min to 1.5 hours (I). In measurements made in waste treatment plants, the flow rate of the pump (SKC 224-PCXR8) was 5 l/min and sampling time ranged from 60 to 80 min (II-VI).

Fibre samples were taken only at the Turku incineration plant according to the standard SFS 3868 (III). In all, 10 samples were taken: four in the waste bunker and two in other working areas. The flow rate of the pump varied between 10 and 20 l/min and sampling time was about 60 min. Samples were collected on both cellulose filters of Millipore and polycarbonate filters of Nuclepore (pore size 0.2 μm).

Measurement locations and numbers of samples

a) Windrow composting

At the open composting field at Ämmässuo samples were taken approximately 20 metres from the windrows, and background samples were collected from the edge of the field. Samples from cabins were taken from the breathing zone. All samples at the Ämmässuo field were taken down wind.

b) Closed plants treating biowaste and sludge (VI, V)

Details of the number of measurements made in Heinola and Hyvinkää are given in paper VI. Measurement locations in the composting plant in Heinola were 1) the drum composting hall, 2) the scrubber room and 3) the storage room (tunnel). In the composting plant in Hyvinkää, measurements were done 1) in the cabin of the wheel loader, 2) in the receiving hall for waste, 3) in a technical room and 4) in the post-composting hall (tunnel). In the Oulu drum composting plant, measurement locations were 1) the control room, 2) the biowaste receiving hall and 3) the drum composting hall. In Oulu, 10 impactor samples were taken from the control room and from the waste receiving hall and 11 samples from the drum composting hall. Samples were taken in years 2001-2003 and measurements were done on five different days. CAMNEA-samples were taken in four different days: six samples were taken from the control room and the drum composting hall and five samples from the receiving hall. Nine endotoxin samples were taken from the control room, eight samples from the receiving hall and ten from the drum composting hall. Samples were taken on nine different days. Eight dust samples were taken from the control room, seven samples from the receiving hall and fourteen samples from the drum composting hall. Samples were taken on eight different days.

Measurements at ASJ were made 1) during the crushing of waste and during the maintenance work in the crushing hall, 2) in the bioreactor hall during the maintenance work and when the process was operating normally and 3) in the drying house. Details of the number of measurements at each location are given in paper V.

c) Dry waste treatment plants (II, IV)

In 1998–2000, measurements locations in the Ressu dry waste treatment plant were 1) the processing hall (near the conveyor belts behind the first metal delimiter, near the jigger screen and beside the bailer) and 2) in the staff coffee room. The coffee room is located in the same building as the processing hall. In 2001, measurements were carried out 1) near the conveyor belt and 2) near the after-crusher. Measurements were done on four different days during the processing of different waste qualities: 1) wood waste + energy waste, 2) dry waste, 3) dry waste + wood waste + energy waste, and 4) dry waste + energy waste.

At Ewapower plant, measurements were made only at one location, in the hall where the waste was unloaded and crushed. All samples were taken under the conveyor belt coming from the crusher. Measurements were made when the process was operating normally and when there was no activity in the hall.

d) Incineration plant (II)

Measurement locations in the Turku incineration plant in 1998-2001 were 1) the crane room, 2) the waste bunker and 3) the oven hall (two levels) (II). Later, the management of the Turku plant decided to study occupational hygiene also in other working places in the plant to map out the risk of exposure to bioaerosols. Investigations were continued during 2001–2002 and later also in 2003 (Tolvanen 2003a; Tolvanen 2003b; Tolvanen & Hänninen 2004).

e) Optical sorting plant in Hämeenlinna

In Hämeenlinna, measurements were done on four different days in 2003–2004. Measurements were made in 1) the control room and 2) the processing hall. Two impactor samples, two CAMNEA-samples, two dust samples and two endotoxin samples per location were taken each day.

f) Camnea samples from normal outdoor and indoor air

Nine samples of indoor air and eight samples of outdoor air were taken during the summer 2003. Indoor samples were taken from four residences in Jyväskylä, an office and a corridor at the University of Jyväskylä, summer cottages at Palokka and Rautalampi and an office building in Jyväskylä. Measurements of outdoor air were made at a beach, at the shore of a lake, next to a road in the countryside, at a construction site, in a forest (two different places), and in two cityparks. Four parallel samples were taken from each location.

2.6 Analytical methodology

Airborne microbes

CAMNEA method. After sampling the filters, still in the filter capsule, were stored in a cold room over night. The next day, 6.5 ml dilution water (1 g pepton, 0.1 ml Tween 80, 1 l distilled water; autoclaved) was injected to the filter capsules. The capsule with the filter was shaken for 15 min, after which the solution from the filter capsule was removed to a test tube and the necessary dilutions (usually 10^{-1} and 10^{-2}) were made (II-VI). The diluted solutions were cultivated on four different substrates for determination of viable microbes. Substrates were, initially, both Dichloran Rose Bengal Agar (DRBC Agar) and Malt Agar for fungi, Plate Count Agar (PCA) for bacteria and both PCA and half strenght Nutrient Agar for actinomycetes (IV). Because the results on Malt Agar and DRBC Agar were of the same magnitude, the parallel use of these substrates was abandoned in 1999. In the course of the research, Nutrient Agar was found to be a poor medium for this purpose and it was no longer used after 1998.

For determining the number of mesophilic microbes, the plates were incubated at 20-25 °C. Incubation temperature of the thermophilic microbes was 40 °C in 1998. Later, temperatures of 55 °C, 50 °C, and 45 °C were tested, and 45°C was eventually chosen (II-VI). Incubation times were for fungi 7 days, for bacteria 5 days, and for actinomycetes 12-14 days.

After incubation, colonies were counted (if the number was < 300 cfu/plate) and fungi were identified. Proportions of the different genera of fungi are reported as percentages.

The total concentration of microbes (viable + dead microbes) was determined by adding to the original extraction solution (the solution from capsules after shaking) sterile 36-37% formaldehyde solution so that the final formaldehyde concentration was 1%. The sample solution (2 ml) was filtered through a polycarbonate filter (pore size 0.2, diameter 25 mm, colour black). 1 ml (II-VI) or 2 ml 0.01% acridine orange was added to the filter and left to react for 3-5 min. The colour was filtrated away and the filter was washed with 3-5 ml of sterile water (II-VI) or 2ml of sterile 0.1 M citrate buffer and 2 ml of sterile isopropanol. The filter was then dried by water suction for about 30 s and transferred to an object glass; a drop of immersion oil (Gargille non-drying immersion oil, Type B (II-VI) or Type A) was placed on the filter and the filter was covered with a cover glass. Microbes were counted with the epifluorescence microscope (magnification 1000 x). At least 400 microbes or 40 (II-VI) or 50 fields were counted. The total concentration of microbes is reported as pcs/m^3.

Six-stage impactor. Incubation temperatures were 20 °C for mesophilic and 50 °C for thermophilic microbes in 1993-1994 (measurement in open composting field) (I). Substrates and incubation times were the same as in the CAMNEA method. In measurements made at closed waste treatment plants, incubation temperatures were the same as in the CAMNEA method. After incubation, the colonies were counted and fungi were identified. The total colony counts were corrected for multiple impactions by the positive hole method (Andersen 1958) and are expressed as colony forming unit (cfu) per cubic meter of air. The number of microbes below 5 µm in their aerodynamic size was determined by calculating the percentage amounts of microbes in impactor stages 3-6 from the amount of the total microbe concentration (stages 1-6). In stage 1 microbes 4.7-7.0 µm grow, in stage 2 microbes 3.3-4.7 µm, in stage 3 microbes 2.1-3.3 µm, in stage 4 microbes 2.1-3.3 µm, in stage 5 microbes 1.1-2.1 µm and in stage 6 microbes 0.65-1.1 µm.

Temperature and relative humidity of the air were measured in conjunction with the measurements of microbes.

Endotoxins

After sampling, the filters were transferred to bottles containing sterile water. Samples were analysed at the Kuopio Regional Institute of Occupational Health by Bio Whittaker-QCL method, which relies on the use of Limulus amebocyte lysate enzyme. The concentrations are reported as ng/m^3 (I) and/or EU/m^3.

Dust and fibres

Dust filters were weighed before and after the sampling. The difference in weight gave the dust concentrations; the results are reported as mg/m^3. The fibre samples were analysed at the Kuopio Regional Institute of Occupational Health. The total content of fibres was counted with a help of a light microscope and the number of asbestos fibres with an electron microscope. Results are reported as fiber/cm^3 of air. The number of fibres was counted as all those fibres having length of at least 5 μm, maximum diameter 3 μm and ratio of length to diameter of at least 3:1 (II).

2.7 Statistical analysis

The concentrations of microbes are presented as geometric means (GM) and the concentrations of dust, fibres and endotoxins as arithmetic means (AM). Also standard deviations are presented.

The six-stage impactor divides microbes into six groups according their particle-size (aerodynamic diameter) so that microbes in stages 3-6 are smaller than 5 μm. The percentage of the number of microbes below 5 μm was calculated.

Differences in concentrations of microbes, endotoxins and dust in the different plants were examined by Student's t-test. Values of $p < 0.05$ were considered statistically significant. The same test was used to determine the differences between measurements made with the impactor and by the CAMNEA method (appearance of fungi, bacteria and actinomycetes and also *Aspergillus fumigatus*). Before test was made, logarithmic changes were made to the numbers of microbes.

To discover in which plant the situation with occupational hygiene was best or worst both, working areas in the plants were first divided into "clean" and "dirty" working areas (Table 1). "Clean" means that the bioaerosol concentrations should be low, because employees work several hours in these areas and waste is not being processed. In "dirty" working areas is treated waste. The employees usually work for only short periods of time in these areas. The results from different working places in each plant were compiled and arithmetic means (AM) for the different microbe groups and sampling methods (impactor/CAMNEA), endotoxins (II-VI) and dust were calculated (for example mesophilic fungi, sampling with impactor; AM from samples taken near the conveyor belts, near the jigger screen and beside the bailer in Ressu dry waste treatment plant). Although differences in occupational hygiene were pronounced in different working areas in the plants (both in "clean" and "dirty" areas), the mean values give a general idea of the level of occupational hygiene at the plant or in the field. On the basis of the mean values, the plats were set in two rank orders: one list for clean working areas and one for dirty working areas. Rank order was assigned for every measured parameter (except endotoxins at the open composting field; results from there were given only as ng/m^3 and elsewhere both EU/m^3 and ng/m^3 or only EU/m^3) and finally AM of points (1-8) given for each measurement locations were calculated. The plant with the largest scores has greatest problems with occupational hygiene and the plant with lowest scores least.

TABLE 1 "Clean" and "dirty" places in different waste treatment plants.

Plant	**Clean working places**	**Dirty working places**
Ämmässuo composting field	the cabin of the machines	composting field
Heinola composting plant	scrubber room	drum composting hall, tunnel
Hyvinkää composting plant	technical room, the cabin of the wheel loader	receiving hall, tunnel
Oulu drum composting plant	control room	receiving hall, drum composting hall
Digestion plant of ASJ	-	crushing of waste, bioreactor hall, drying house
Ressu dry waste treatment plant	coffee room	processing hall
Ewapower Ltd	-	crushing of waste
Turku incineration plant	crane room, oven hall	waste bunker
Optical sorting plant in Hämeenlinna	control room	processing hall

3 RESULTS

3.1 Concentrations of bioaerosols and dust during composting

Windrow composting (I)

During the treatment of windrows at Ämmässuo, the number of microbes was at times so high that the colonies grew one upon other. The concentrations of viable microbes were highest during crushing of biowaste and turning of windrows, mostly from 10^3 to 10^5 cfu/m^3 (Fig. 3). Also, in a study made in the windrow composting area in Jyväskylä, Finland, the number of fungi was higher during turning of windrows than when the windrows were not disturbed (Koivula et al. 2000). In winter, concentrations were as low as one onehundredth of those in summer. Background concentrations of fungi and mesophilic bacteria were significantly lower than microbe concentrations at the field (p-values from 0.03 to 0.006).

Endotoxin concentrations varied from 0.8 to 344.5 ng/m^3, with highest concentrations measured during crushing of biowaste and turning of windrows (Fig. 4). The threshold value of 200 EU/m^3 (about 12-25 ng/m^3) was exceeded in seven measurements of twelve in the field and in three measurements of seven in the machine cabins. The threshold value of 200 EU/m^3 was also exceeded in the windrow composting area in Jyväskylä, where endotoxin concentration during turning was 5200 EU/m^3 (Koivula et al. 2000). Background concentrations were low, from <0.8 to 5.9 ng/m^3. Dust concentrations were less than 1.3 mg/m^3 during all stages of composting and lower than at the windrow composting area in Jyväskylä, where dust concentrations ranged from 2.7 to 5.0 mg/m^3 when there was no activity at the field (Koivula et al. 2000). The concentration was highest during crushing of the biowaste with a Jenz AZ 50 machine. Background concentrations were mainly <0.01 mg/m^3 but not significantly lower than concentrations at the field (p=0.06).

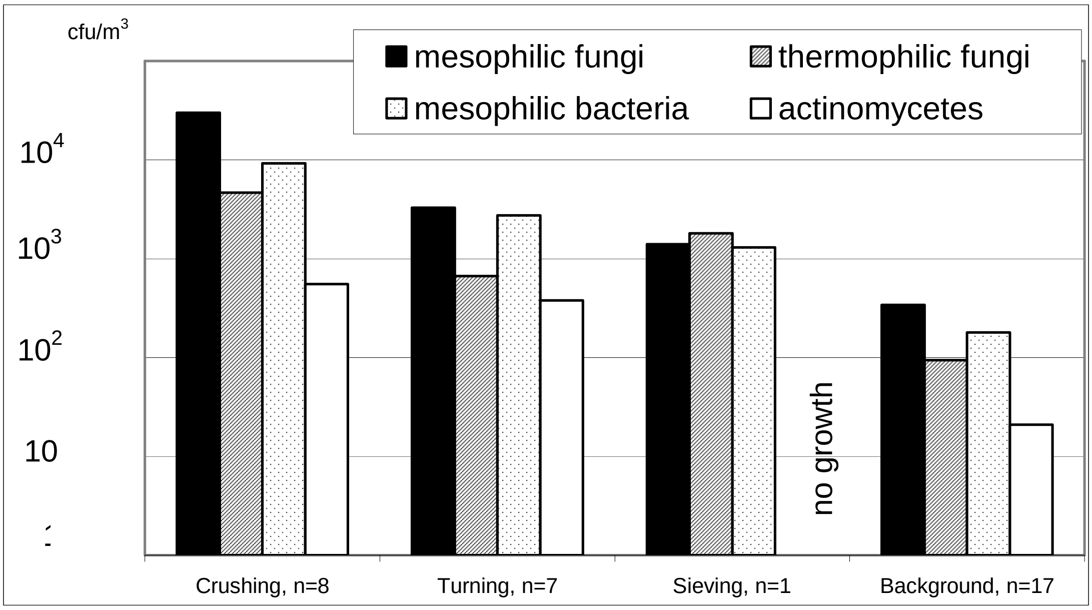

FIGURE 3 Concentrations of viable microbes (GA)(cfu/m³) during treatment of windrow composts at the Ämmässuo composting field.

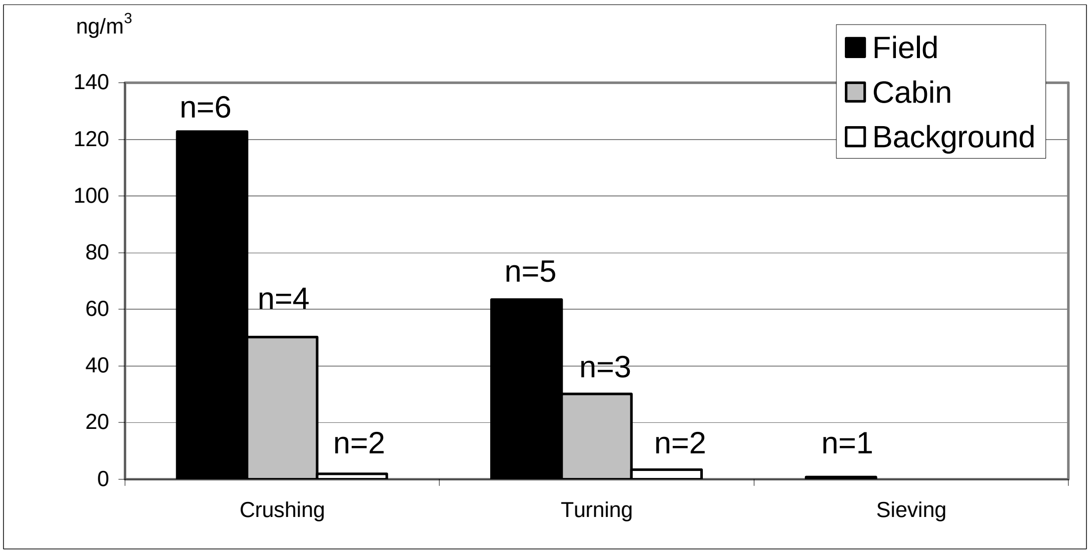

FIGURE 4 Concentrations of endotoxins (AM)(ng/m³) during treatment of windrow composts in Ämmässuo composting field.

Combined drum and tunnel composting plants (VI)

The numbers of airborne microbes and dust varied widely in the different plants treating biowaste and the various working areas. In terms of occupational hygiene, the situation was best in *Heinola* (both clean and dirty working areas), where sampling locations were aerated before measurement; numbers of microbes were mostly as low as in normal indoor air (Fig. 5), and endotoxin concentrations exceeded the threshold value of 200 EU/m³ only in one measurement made in the composting hall (Fig. 7). Most microbes were below 5 µm in aerodynamic size and the most common microbe group was mesophilic fungi.

The *Hyvinkää* composting plant had more problems with microbes and endotoxins than Heinola (Figs 6-7). In Hyvinkää, exposure to harmful levels of microbes and endotoxin is possible in the biowaste receiving hall, the technical room (which should be a relatively clean working area), the tunnel and the cabin of the wheel loader (which should also be a clean working area). During dusty working phases (for example, feeding of biowaste to drums) it is advisable to use a respirator mask (class P3). In Hyvinkää, as in all composting plants of this study, the most viable microbes were below 5 µm in aerodynamic size.

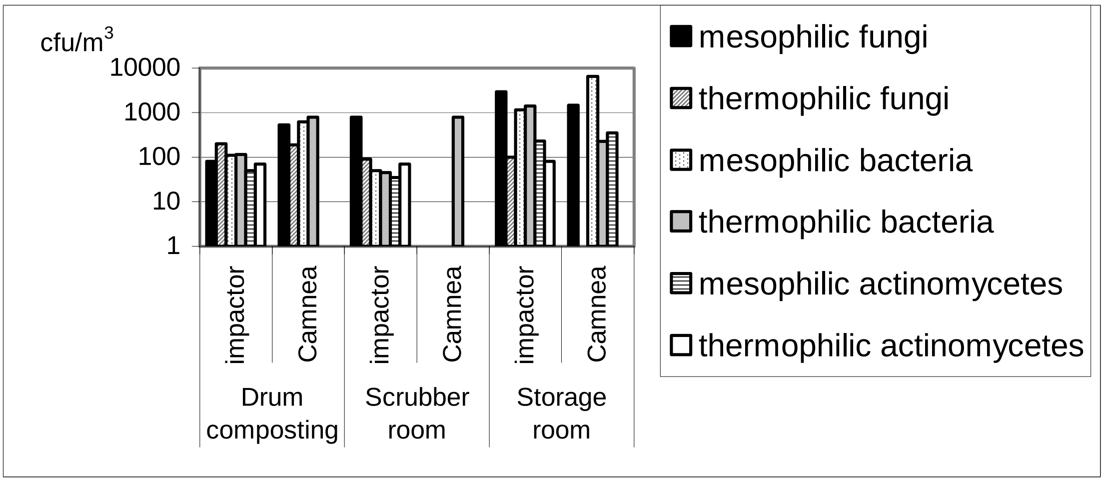

FIGURE 5 Concentrations of viable microbes (GA) (cfu/m³) in the Heinola composting plant; n from 5 to 6.

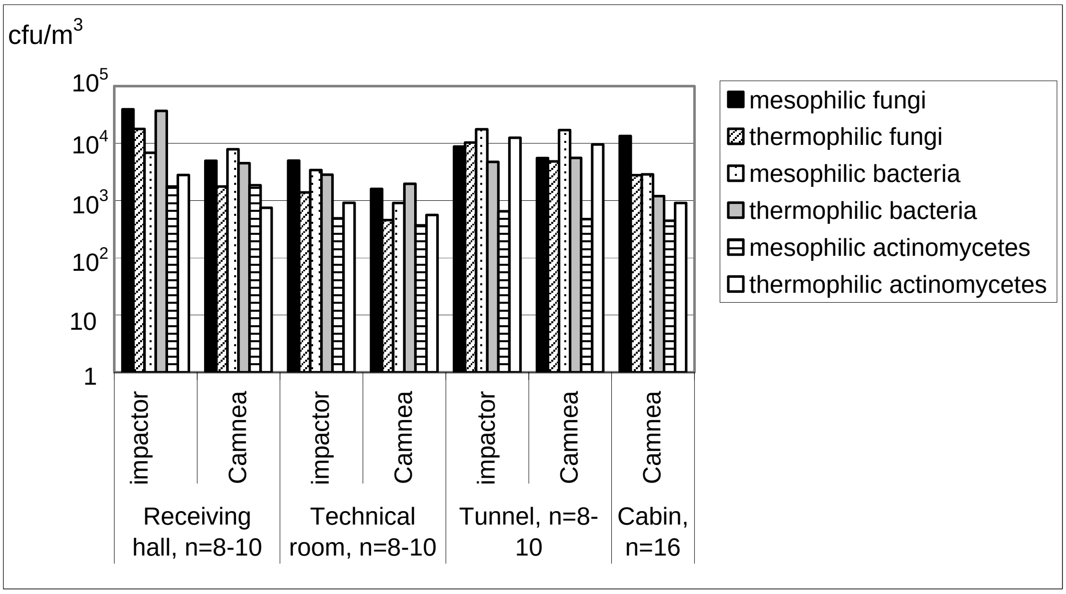

FIGURE 6 Microbe concentrations (GA) (cfu/m³) in the Hyvinkää composting plant.

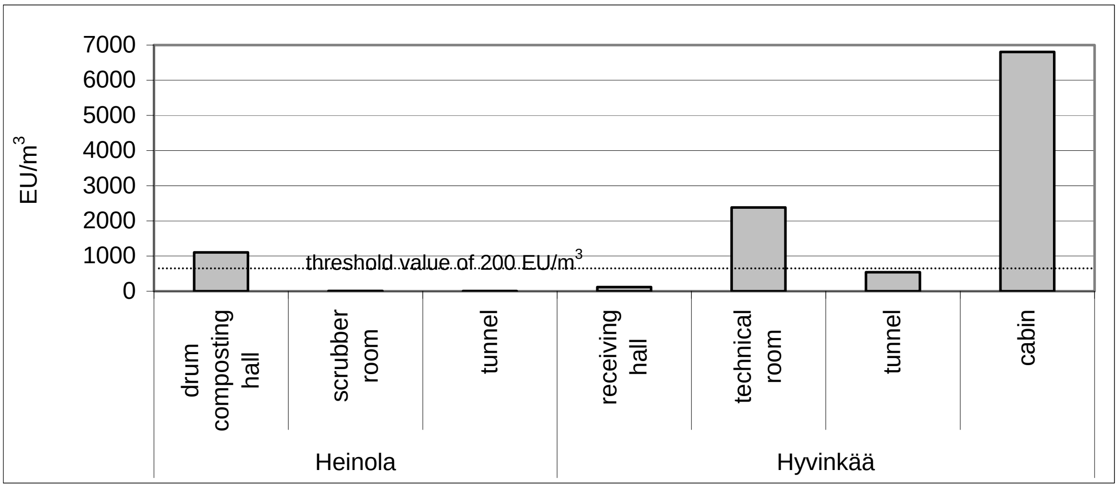

FIGURE 7 Endotoxin concentrations (AM) (EU/m³) in the composting plants in Heinola and Hyvinkää. In Heinola, n=4. In Hyvinkää, n=6 except in the cabin n=12.

Drum composting plant (Tolvanen et al. 2004)

Average concentrations of viable, mesophilic microbes in Oulu are presented in Fig. 8. The most common microbe group in Oulu was mesophilic fungi. In the control room, the number of viable microbes was low: the number of mesophilic fungi varied from 1050 to 5900 cfu/m³, the number of bacteria from 380 to 1970 cfu/m³ and the number of actinomycetes from 7 to 417 cfu/m³. In the biowaste receiving hall, the number of fungi varied from 1100 to 360 000 cfu/m³, the number of bacteria from 590 to 56 300 cfu/m³ and the number of actinomycetes from 40 to 21 000 cfu/m³. The total number of microbes (both viable and dead) in the control room ranged from 0.7 to 5.5 million pieces/m³ (GA 1.4 million pieces/m³, n=6). In the biowaste receiving hall numbers ranged from 2.2 to 192.6 million pieces/m³ (GA 21.8 million pieces/m³, n=5) and in the drum composting hall from 0.9 to 245.7 million pieces/m³ (GA 13.9 million pieces/m³, n=6).

Endotoxin concentrations in Oulu are presented in Table 2. The threshold value of 200 EU/m³ was exceeded in several measurements in the receiving hall and drum composting hall, but also once in the control room. Dust concentrations in Oulu (Table 3) were below the threshold value of 5 mg for 8 hours in all measurements.

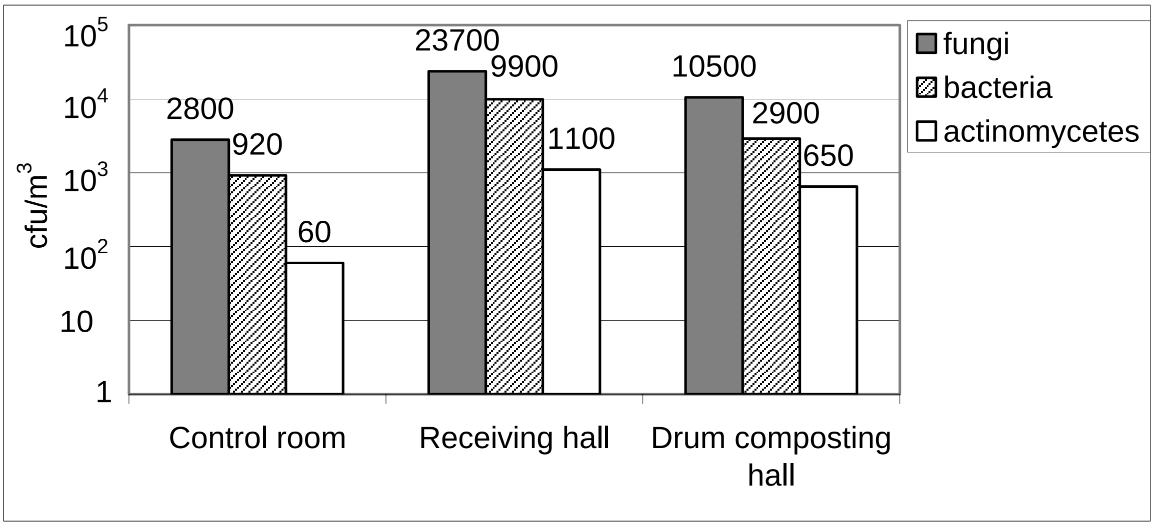

FIGURE 8 Concentrations of viable, mesophilic microbes (GA)(cfu/m³) in the drum composting plant in Oulu in 2001–2003.

TABLE 2 Endotoxin concentrations (EU/m³) in drum composting plant in Oulu in 2001-2003.

	Control room, n=9	**Receiving hall, n=8**	**Drum composting hall, n=10**
AM	101	1903	2339
min-max	0.8–870	62–8200	2–18 000

TABLE 3 Dust concentrations (mg/m³) in drum composting plant in Oulu in 2001-2003.

	Control room, n=8	**Receiving hall, n=7**	**Drum composting hall, n=14**
AM	0.6	0.5	0.6
min-max	0.5–1.0	0.1–1.3	0–2.7

Anaerobic digestion

Concentrations of microbes, dust and endotoxins were harmfully high at ASJ Stormossen during the crushing of waste, which was the mechanical part of the waste treatment process. The number of mesophilic fungi was particularly high, being on average (GA) 96,620 cfu/m³ in measurements made with the impactor (Fig. 9). The number reported in an earlier study is similar, 92,000 cfu/m³ (Liesivuori et al 1995). The number of mesophilic fungi (impactor measurements) was significantly higher during crushing than when there was no activity in the hall (p=0.00002). Concentrations of endotoxins occasionally exceeded the threshold value of 200 EU/m³.

Anaerobic digestion in the plant caused only minor problems. However, highest endotoxin concentrations were measured during maintenance work on the bioreactor: endotoxin concentrations then ranged from 2500 to 21,000 EU/m³ with an average of 10,650 EU/m³. When the process operated normally, endotoxin concentrations ranged from 4.2 to 1100 EU/m³ and were significantly lower than during maintenance (p=0.01). Also, the number of mesophilic fungi (impactor measurements) was significantly lower when the process was operating normally than during maintenance work (p=0.001).

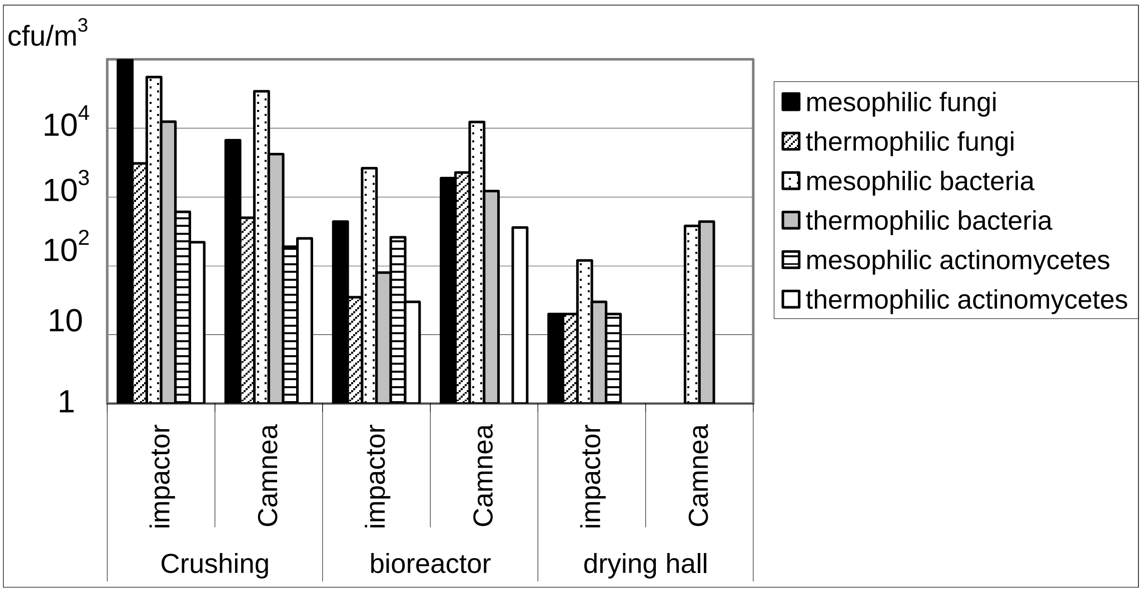

FIGURE 9 Concentrations of viable microbes (GA)(cfu/m³) at digestion plant of ASJ. During the crushing n=10 or 12, in the bioreactor n=8 or 10 and in the drying hall n=10.

3.2 Concentrations of bioaerosols and dust during treatment of dry waste (II, IV)

Concentrations of bioaerosols were harmfully high both at *Ewapower* and *Ressu,* the plants treating source-separated dry waste (Figs 10-15). Endotoxin concentrations exceeded the threshold value of 200 EU/m³ in all measurements at *Ewapower* (II) and in almost all measurements made in the *Ressu* processing hall (Fig. 17). As well, the numbers of viable microbes, especially fungi, were at a level that could be harmful to human health (Fig. 12). At the *Ressu* dry waste treatment plant, dust concentrations were occasionally over the threshold value of 5 mg/m³ (IV) and endotoxin concentrations were mostly over the threshold value of 200 EU/m³ (Fig. 16). As in the composting plants, also in dry waste treatment plants the most viable microbes were less than 5 μm in aerodymic size and able to penetrate deep in alveoli.

Some technical modifications were made in the *Ressu* processing hall in 2000-2001. For example, a conveyor belt coming from the first metal delimiter was covered. Concentrations of bacteria and actinomycetes near the conveyor belt were lower in 2002 than in earlier years, but the number of fungi was still high. Only the number of viable, mesophilic actinomycetes was significantly lower in 2001 than earlier (p=0.006). There were no significant changes in endotoxin and dust concentrations or in total microbial numbers.

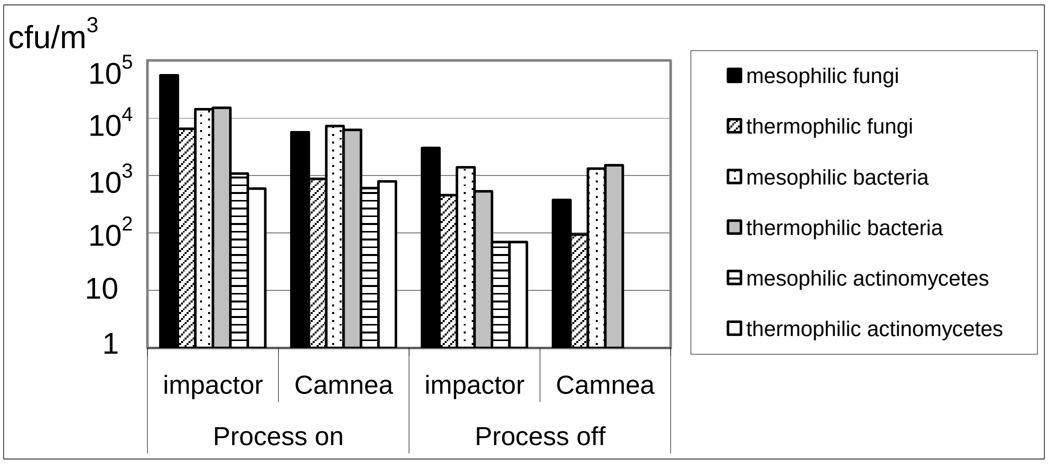

FIGURE 10 Concentrations of viable microbes in Ewapower Ltd. When the process was running, n was from 7 to 10. When the process not running, n was from 1 to 3.

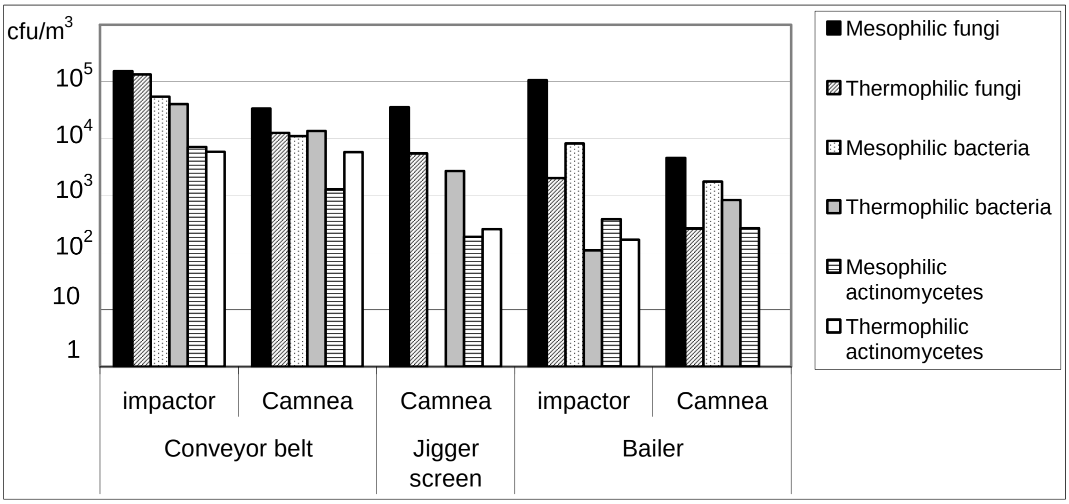

FIGURE 11 Concentration of viable microbes (GA) (cfu/m^3) in the Ressu dry waste treatment plant during treatment of dry waste. Near the conveyor belt, n=6-8, near the jigger screen n=2 and near the bailer n=4.

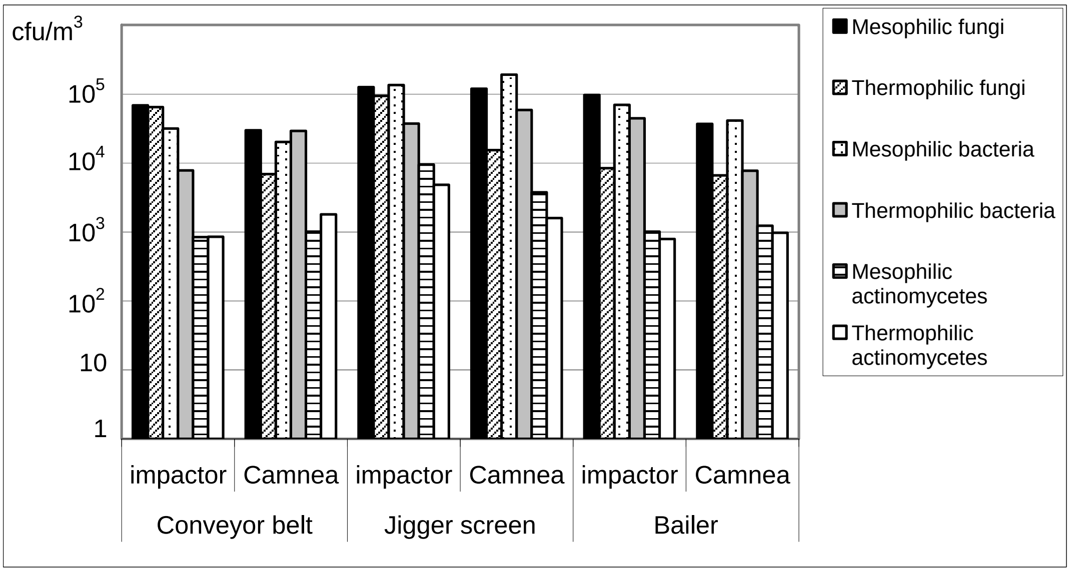

FIGURE 12 Concentrations of viable microbes (GA) (cfu/m^3) in the Ressu dry waste treatment plant during treatment of dry waste and energy waste. Near the conveyor belt, n=3-5, near the jigger screen n=2-4 and near the bailer n=1-4.

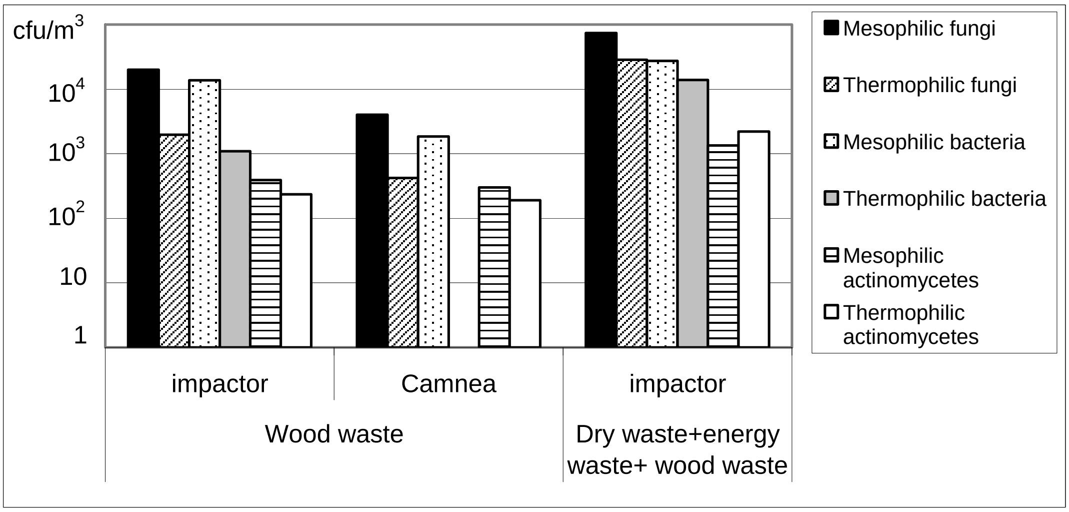

FIGURE 13 Concentrations of viable microbes (GA) (cfu/m^3) in the Ressu dry waste treatment plant near jigger screen in 1998-2000 during treatment of 1) wood waste (n=4-5) and 2) dry waste, energy waste and wood waste together (n=4).

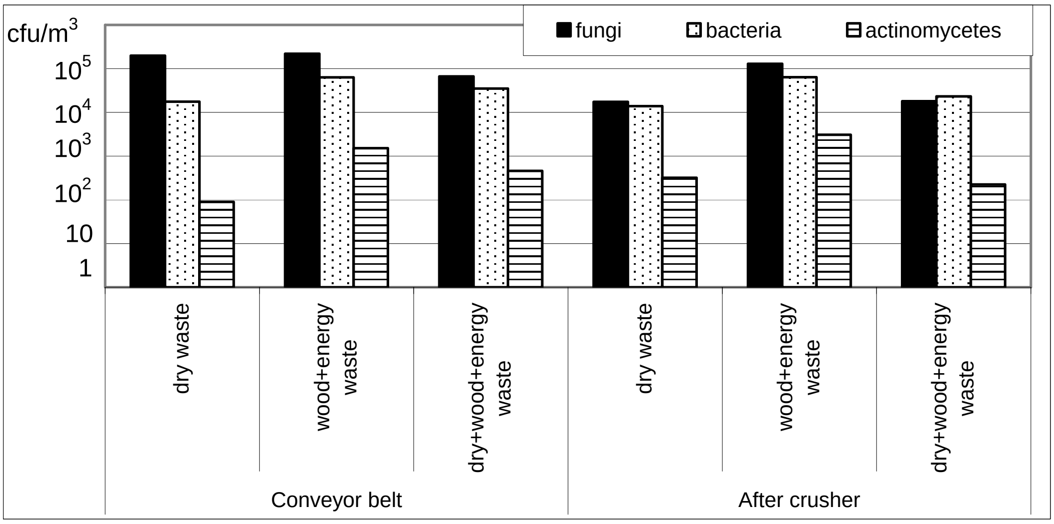

FIGURE 14 Concentrations of viable, mesophilic microbes (GA) (cfu/m^3) in the Ressu dry waste treatment plant in 2001 near the conveyor belt and after crusher; during the treatment of dry waste and dry+wood+energy waste, n=2, otherwise n=1.

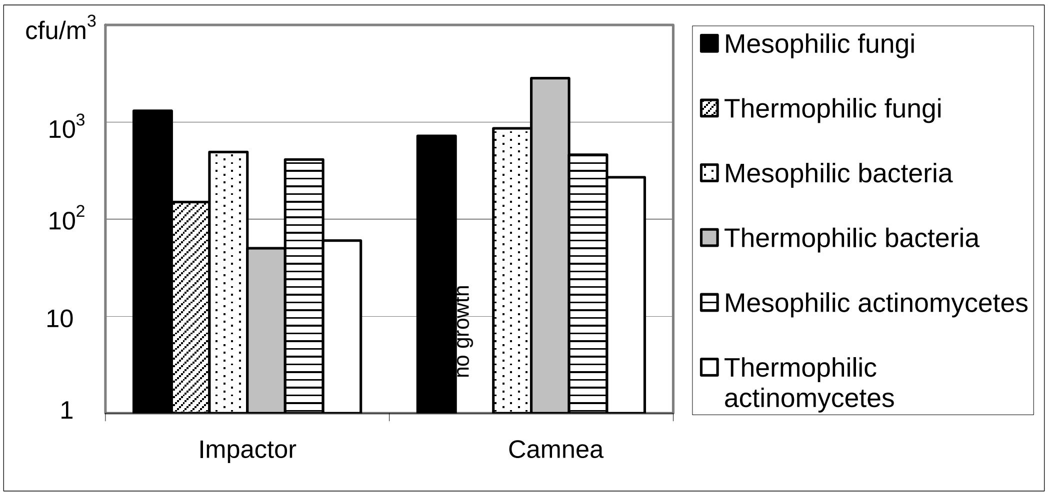

FIGURE 15 Concetrations of viable microbes (GA) (cfu/m^3) in the coffee room of the Ressu dry waste treatment plant, n=10 or 12.

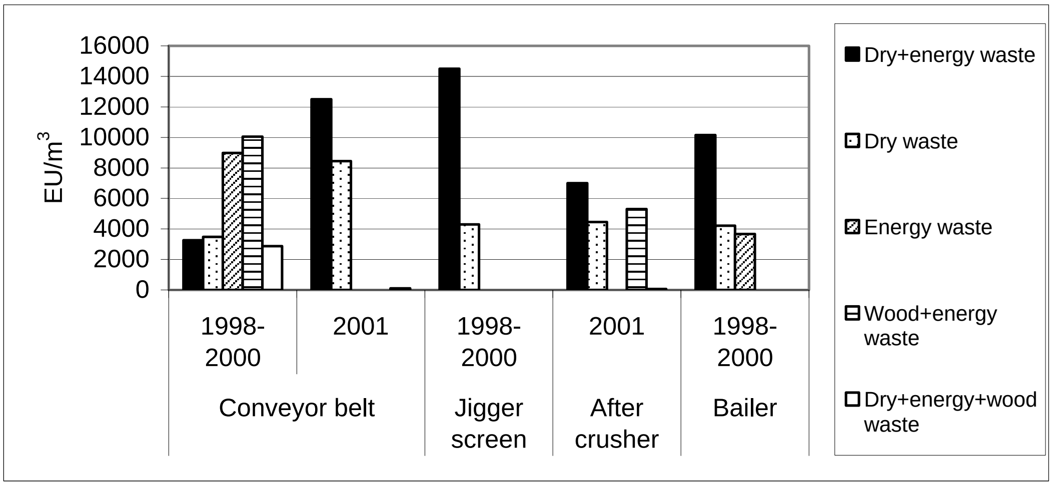

FIGURE 16 Endotoxin concentrations (AM) EU/m³ in the dry waste treatment plant Ressu. In 1998-2000 n=2-4, in 2001 n=2 or 3.

3.3 Concentrations of bioaerosols and dust at Turku incineration plant (III)

Harmfully high microbe and endotoxin concentrations (Fig. 17) were sometimes found in the waste bunker and occasionally in the oven hall of Turku incineration plant. Endotoxin concentrations in the waste bunker ranged from 16,000 to 59,000 EU/m³ with an average (AM) of 39,500 EU/m³. The concentrations of mesophilic fungi ranged from 13,920 to 221,840 cfu/m³ with an average (GA) of 118,225 cfu/m³. Concentrations in the waste bunker varied widely from one day to the next because of daily change in the quality of the waste. In the oven hall (slag pool level), endotoxin concentrations ranged from 1.8 to 1300 EU/m³ with an average of 223.4 EU/m³. In other locations endotoxin concentrations were below the threshold value of 200 EU/m³.

Microbe concentrations in several measurements in the crane room of the Turku plant were higher than they should be in an office-like working area. Later, moisture damage was found in the crane room. The damage was repaired and the ventilation of the crane room was isolated from the ventilation of the rest of the plant. After these changes the number of microbes in the crane room was at a level normal for indoor air in flats and offices.

Dust concentrations were typically low in all measurement locations and the Finnish threshold value of 5 mg/m³ (Työministeriö 1996) was exceeded only in a few measurements made in the waste bunker; the highest dust concentration was 13.7 mg/m³.

The concentration of fibres in the waste bunker was 0.014 (n=2) and just over the threshold value of 0.01 fibres/m³ (given for residences, schools etc.) (Suomen Sisäilmaston mittauspalvelu Oy 1996). In other working areas, the number of fibres varied from 0.003 to 0.005 fibres/m³ (n=1).

Later, in measurements made in 2001-2002, the situation in the waste bunker had not changed (Tolvanen 2003a). In office rooms the microbe concentrations were low: in September 2001, for example, the number of mesophilic fungi was on average (GA) 236 cfu/m^3 and in May 2002 on average 150 cfu/m^3. Likewise, concentrations of endotoxins were low and the threshold value of 200 EU/m^3 was exceeded only once, in June 2002, when the concentration was 250 EU/m^3 (Tolvanen 2003a). The measurements made in 2003 showed that dust and microbe concentrations may occasionally be high in the workshop; in May 2003 the number of mesophilic fungi ranged from 12,727 to 14,134 cfu/m^3 (n=2) and dust concentrations ranged from 4.3 to 9.3 mg/m^3 (n=2) (Tolvanen 2003b).

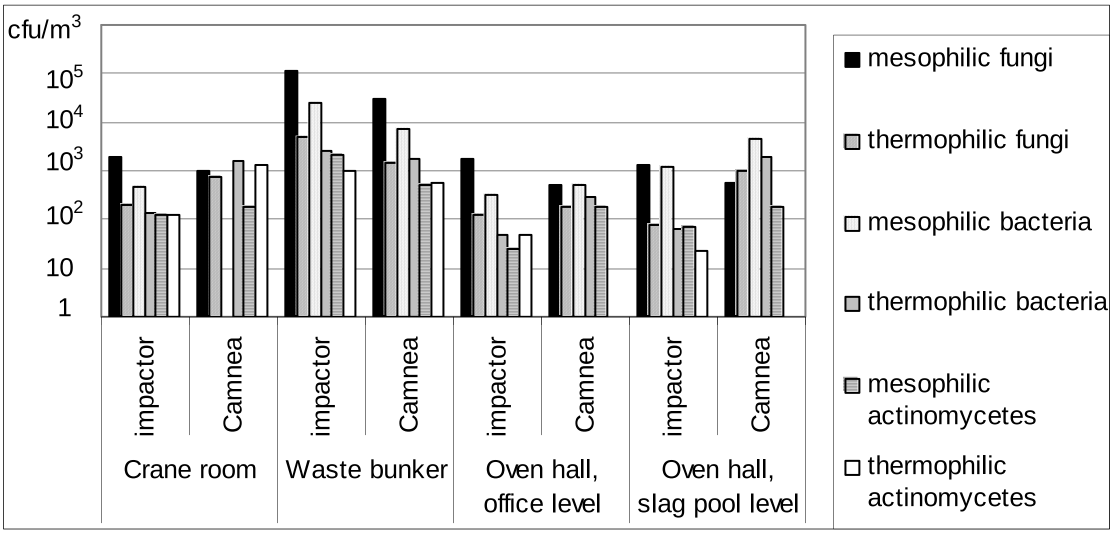

FIGURE 17 Concentrations of viable microbes (GA) (cfu/m^3) at incineration plant in Turku in 1998-2000.

3.4 Concentrations of bioaerosols and dust at an optical sorting plant

Concentrations of viable, mesophilic fungi in the Hämeenlinna optical sorting plant are presented in Fig 18. In the processing hall, the number of fungi ranged from 150,000 to 290,000 cfu/m^3, the number of bacteria from 17,300 to 220,000 cfu/m^3 and the number of actinomycetes from 140 to 2700 cfu/m^3. In the control room, which should be as clean as a normal office room, the number of fungi ranged from 1500 to 25,500 cfu/m^3, the number of bacteria from 1400 to 5900 cfu/m^3 and the number of actinomycetes from 10 to 270 cfu/m^3. On average, 82.1% of all viable microbes in the processing hall were below 5 μm in aerodynamic size. In the control room the figure was 85.2%.

Total microbe concentration was, on average (AM), 3.1 million pieces/m^3 (from 0.5 to 8.0 million pieces/m^3, n=8) in the control room and 5.1 million pieces/m^3 (from 1.1 to 15.6 million pieces/m^3, n=7) in the processing hall.

Endotoxin concentrations ranged from 0.3 to 13,000 EU/m^3 (AM 4853 EU/m^3, n=7) in the control room and from 250 to 27,000 EU/m^3 (AM 10,980 EU/m^3, n=8) in the processing hall. The threshold value was exceeded in all measurements made in the processing hall and in four measurements made in the control room. However, dust concentrations were relatively low, as in most waste management plants in this study. Dust concentration ranged from < 0.01 to 0.3 mg/m^3 (AM 0.2 mg/m^3, n=5) in the control room and from < 0.01 to 3.0 mg/m^3 (AM 1.0, n=8) in the processing hall. The threshold value of 5 mg/m^3 was not exceeded.

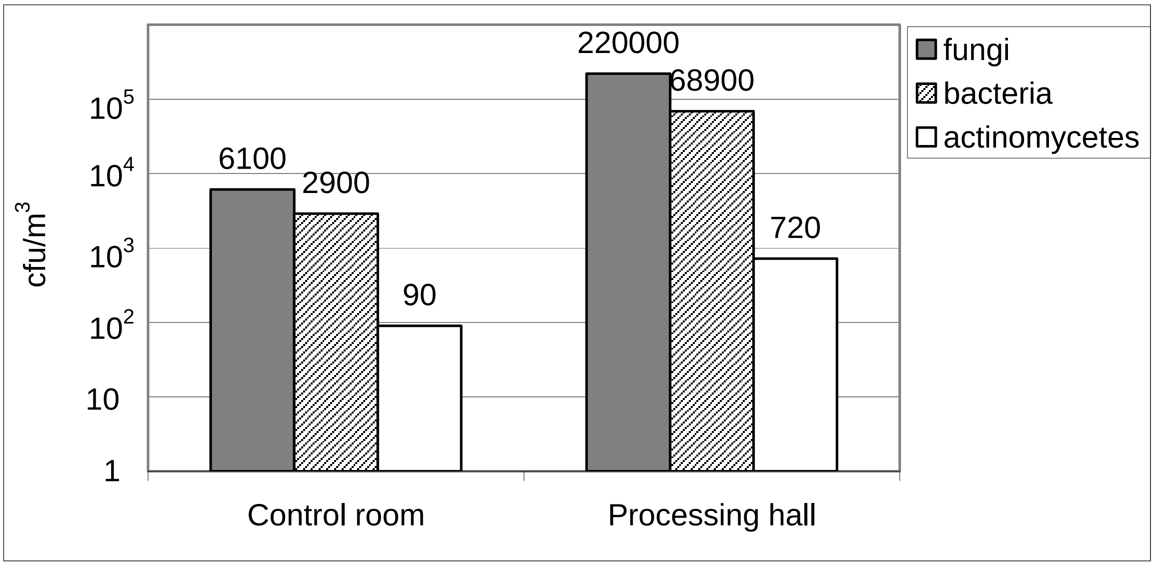

FIGURE 18 Concentrations of viable mesophilic microbes (GA) in the optical sorting plant in Hämeenlinna in 2003-2004.

Concentrations of microbes and endotoxins in Hämeenlinna were at a level that might be harmful to human health. It is advisable to use a respirator mask in the processing hall. To reduce the exposure of employees to harmful particles, it is important to avoid the transfer of airborne dust from the processing hall to the control room and social rooms.

3.5 Fungal species

The most common fungi in all plants of this study were *Penicillium* spp. and *Aspergillus* spp. Percentages of *Aspergillus fumigatus,* the most harmful pathogenic fungi at waste treatment, are presented in Table 4 (composting plants in Heinola and Hyvinkää, ASJ and Ewapower and Turku incineration plant) and in Table 5 (Ressu dry waste treatment plant). In the coffee room of the Ressu dry waste treatment plant, the percentages of *A. fumigatus* relative to all fungal species were 19.7% (impactor measurements) and 11.1% (CAMNEA method).

The percentage of *A. fumigatus* was lowest in the Heinola composting plant; in all measurement locations the percentage was < 2%. In the other plants, the percentage of *A. fumigatus* varied from 1.4 to 48.2% in impactor measurements and from 0 to 44.2% in measurements made by CAMNEA method. Mostly the percentage was about 20-40% and thus the amount of *A. fumigatus* was fairly high compared with percentages of other airborne fungi at the plants. In several plants only the number of *Penicillium* spp. was at the same level as *A. fumigatus*.

TABLE 4 Percentages (%) of *Aspergillus fumigatus* in different waste treatment plants in Finland.

	Impactor measurements	**Camnea method**
Heinola composting plant		
- drum composting hall	1.8	
- scrubber room	1.9	
- tunnel	-	
Hyvinkää composting plant		
- receiving hall	33.9	44.2
- technical room	23.5	25.0
- tunnel	44.6	43.2
- cabin of the wheel loader	no measurements	36.7
ASJ Stormossen		
- crushing of waste, process on	32.6	2.6
- crushing hall, process off	29.8	-
- Bioreactor, maintenance	-	-
- Bioreactor, normal process	18.2	no meas.
Ewapower Ltd		
- process on	31.2	30.0
- process off	30.0	-
Turku incineration plant		
- oven hall, office level	37.2	12.5
- oven hall, slag pool level	18.6	31.2
- waste bunker	23.2	15.3
- crane room	39.6	25.1

TABLE 5 Percentage of *A. fumigatus* in Ressu dry waste treatment plant during treatment of different waste qualities in 1998-2000.

	Dry waste	**Dry- + energy waste**	**Wood waste**	**Dry- + energy- + wood waste**
Conveyor belt				
- impactor	24.1	48.2	no meas.	no meas.
- CAMNEA	25.9	13.4	no meas.	no meas.
Jigger screen				
- impactor	no meas.	25.9	29.7	47.2
- CAMNEA	4.6	19.4	-	no meas.
Bailer				
- impactor	2.1	1.4	no meas.	no meas.
- CAMNEA	-	21.2	no meas.	no meas.

In the Ressu dry waste treatment plant, the percentage of *A. fumigatus* was highest near the conveyor belt when dry waste and energy waste were treated together and near the jigger screen when dry waste, energy waste and wood waste were treated together.

The numbers of other identified fungi in the Heinola and Hyvinkää composting plant, ASJ, Ewapower and Ressu dry waste treatment plants and the Turku incineration plant are presented in papers II-VI. Fungi identified in samples from the *Hämeenlinna* optical sorting plant are presented in Figs 19 and 20. On the last day of measurement, samples taken from the processing hall were so full of fungi that it was not possible to count the percentage distribution of the different species. In any event, *Aspergillus niger, Penicillium, Rhizopus* and *Cladosporium* were present. Fungi identified in the drum composting plant in Oulu are presented in Figs 21-24. The most common fungi in the working air in Oulu were *Penicillium* and *Aspergillus*.

Only mesophilic fungi were determined in Hämeenlinna and Oulu. Because *A. fumigatus* is thermophilic, the number of this fungus is not included in these results. It is probable, however, that *A. fumigatus* is common in these waste treatment plants as well.

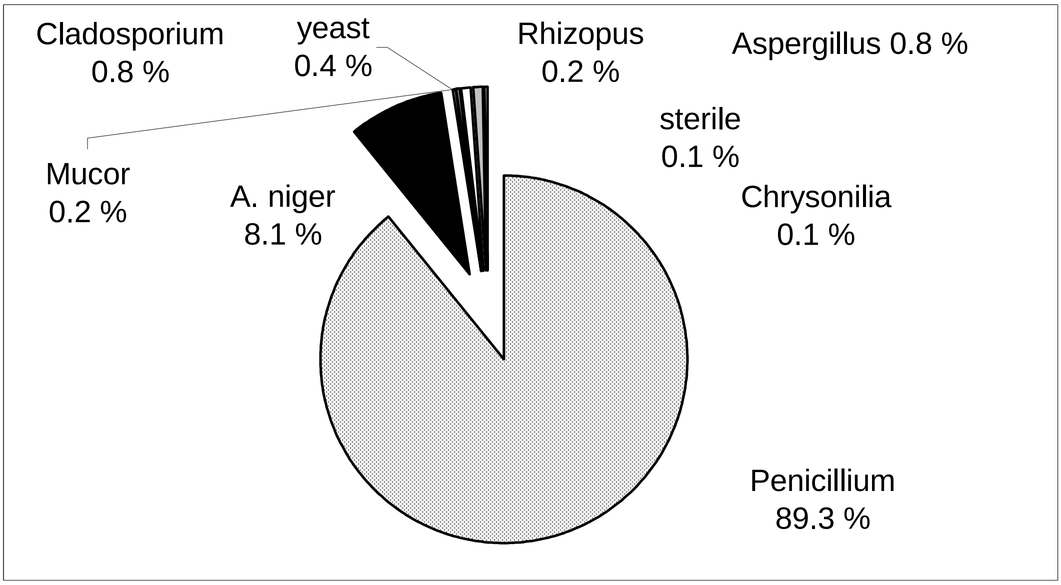

FIGURE 19 Identified fungi (% of total number of viable fungi) in the control room of the optical sorting plant in Hämeenlinna.

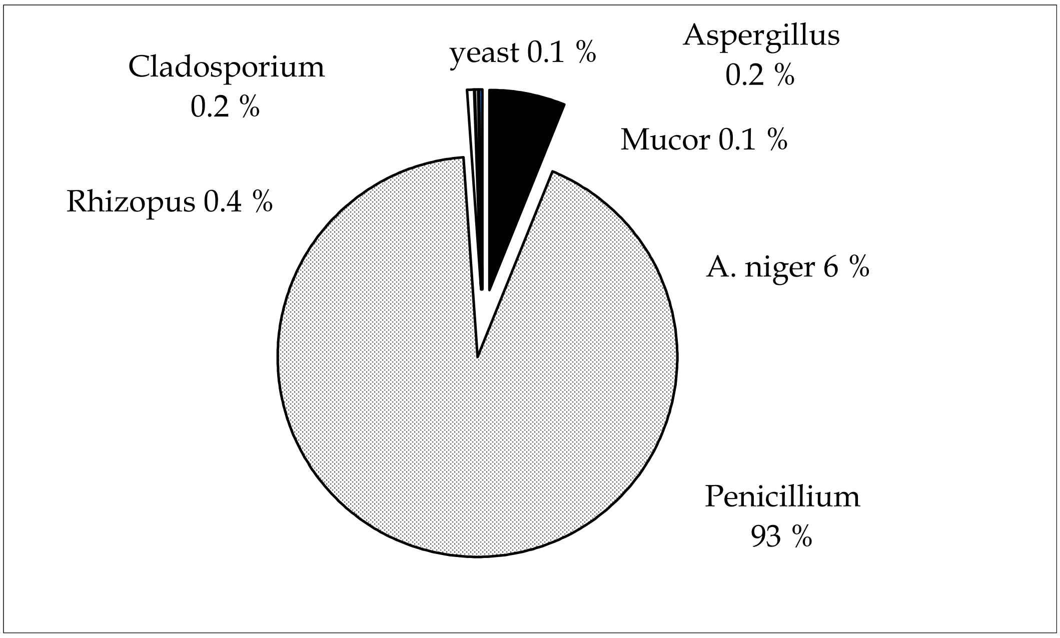

FIGURE 20 Identified fungi (% of total number of viable fungi) in the processing hall of the optical sorting plant in Hämeenlinna.

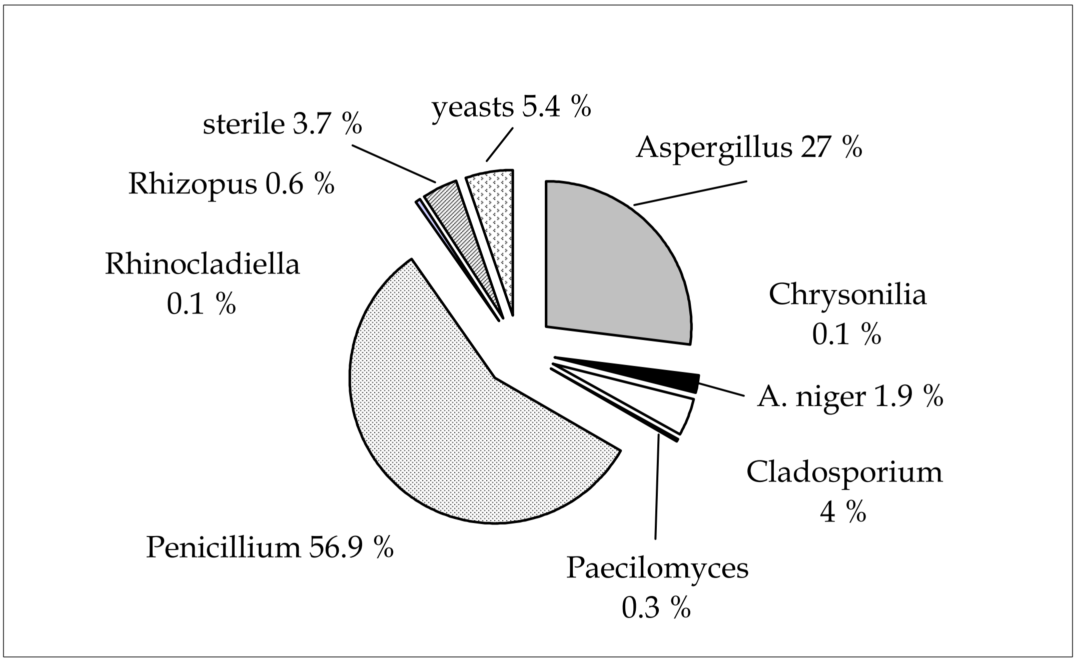

FIGURE 21 Identified fungi (% of total number of viable fungi) in the control room of the drum composting plant in Oulu.

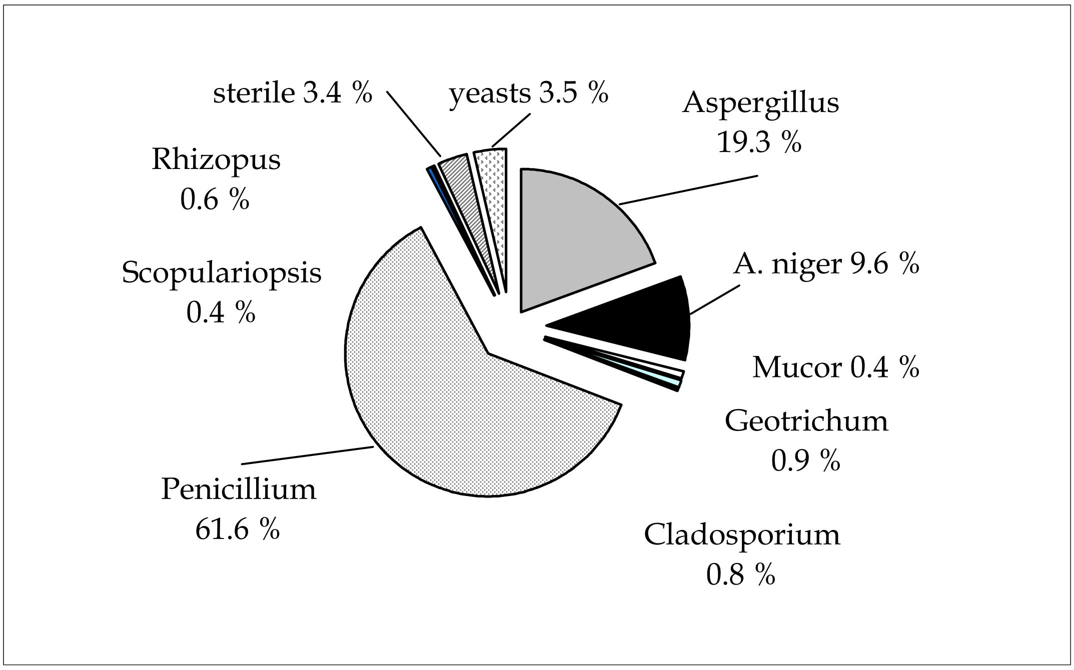

FIGURE 22 Identified fungi (% of total number of viable fungi) in the receiving hall of biowaste of drum composting plant in Oulu.

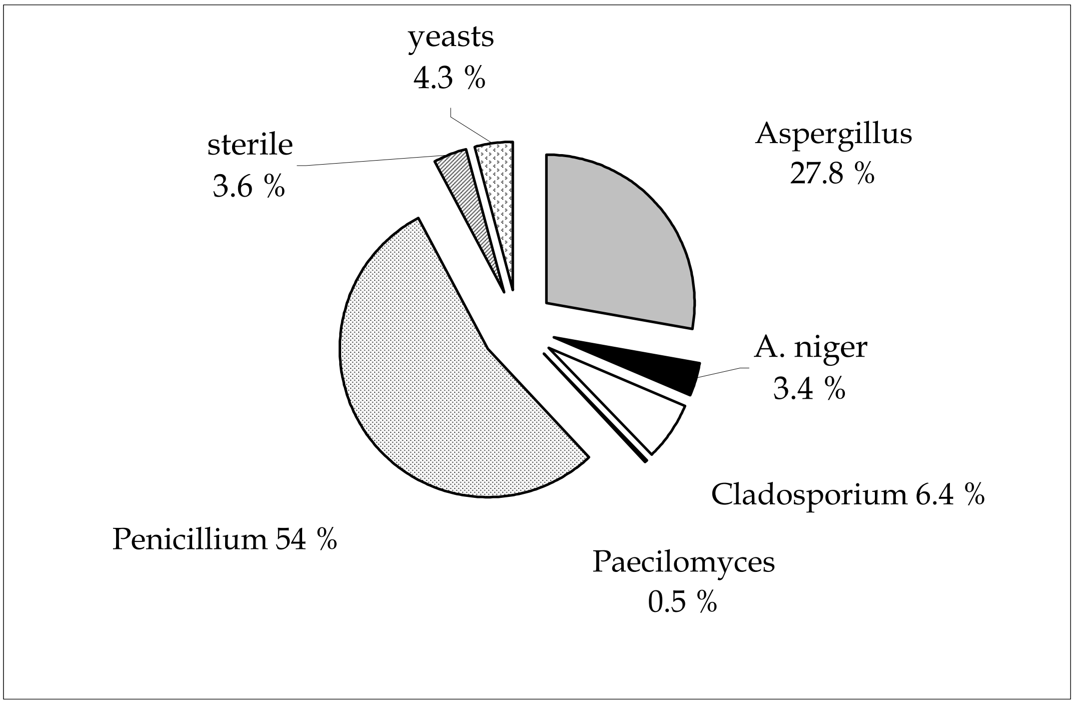

FIGURE 23 Identified fungi (% from total number of viable fungi) in the drum composting hall of drum composting plant in Oulu.

3.6 Total microbial concentrations in outdoor and indoor environments

Total microbial concentrations in different outdoor and indoor environments in summer 2003 are presented in Table 7. Measurement locations outdoors were 1) a beach, 2) countryside, next to a road, 3) a construction site, 4) a forest, 5) a forest, 6) the shore of a lake, 7) city park and 8) city park. Indoor measurement locations were 1) a residence, 2) a residence, 3) an office room at the university of Jyväskylä, 4) a residence, 5) an office building in Jyväskylä, 6) a residende, 7) a summer cottage in Palokka, 8) a summer cottage in Rautalampi and 9) the corridor of a university building.

Concentrations outdoors ranged from 1.1 to 23.8 million psc/m^3 with an average (GA) of 7.7 million psc/m^3. Indoors, microbial concentrations ranged from 1.9 to 138 million psc/m^3 with an average (GA) of 14.0 million psc/m^3.

TABLE 7 Total microbial concentrations (million psc/m^3) in outdoor and indoor environments in summer 2003 and temperature (^{o}C) and relative humidity (%) at the time of measurements.

	Outdoor			Indoor		
N.o	**Microbes**	**Temperature**	**RH-%**	**Microbes**	**Temperature**	**RH-%**
1	1.1	23.7	58	8.6	26	63
2	7.2	20.1	93	1.9	22.9	61
3	5.2	21.1	79	5.8	22.4	45
4	5.6	18.4	65	6.1	24.3	49
5	5.7	12.4	99.9	138	28.1	56
6	23.8	25.6	61	96	26.1	59
7	22.6	24.8	83	38	26.1	58
8	17.8	24.7	83	10.1	30.3	57
9				7.1	24	62

The total microbial numbers were significantly lower in the ASJ digestion plant and the optical sorting plant in Hämeenlinna than in normal indoor air ($p=0.004$ and 0.03).

4 DISCUSSION

4.1 Differences in bioaerosol and dust concentrations between plants treating similar waste

Plants treating biowaste and sludge (I, V, VI)

In the clean working areas, occupational hygiene was best at the Heinola composting plant. The concentrations of bioaerosols were also fairly low in the Oulu drum composting plant, where the clean working area investigated was the control room. The worst situations were encountered in the technical room of the Hyvinkää composting plant, in the cabin of the wheel loader at Hyvinkää, and in machine cabins in the open composting field at Ämmässuo.

The composting plants in Heinola, Hyvinkää and Oulu use more or less the same technique in waste treatment. In spite of this, there were considerable statistically significant differences between the plants. In clean working areas, *the numbers of fungi, bacteria and actinomycetes* (both mesophilic and thermophilic) in impactor measurements were significantly lower in the Heinola than in the Hyvinkää composting plant (p=0.02, 0.0004, 0.000003, 0.0001, 0.0003 and 0.000001). The numbers of fungi and numbers of actinomycetes at Heinola and Hyvinkää also differed in the results obtained by CAMNEA method (p=0.00007 and 0.004; p= 0.01 and 0.001). Numbers of mesophilic fungi and bacteria (impactor measurements) were significantly lower in the Heinola than in the Oulu drum composting plant (p=0.003 and 0.00003). Numbers of mesophilic bacteria and actinomycetes were significantly higher in the Hyvinkää composting plant than in corresponding areas in the Oulu drum composting plant (p=0.001 in both cases).

The total microbial number was significantly lower in the control room in Oulu than in the scrubber room in Heinola (p=0.01). One would expect the control room to be cleaner than the scrubber room. It is important to add, however, that the scrubber room is a place, where employees work only occasionally.

In the dirty working areas (processing of waste), the situation was worst in the Hyvinkää composting plant and best in *Heinola*. In the impactor measurements, the number of mesophilic fungi was significantly lower in Heinola than in Hyvinkää (p=0.00004) and Oulu (p=0.0005). Likewise, numbers of thermophilic fungi were significantly lower in Heinola than in Hyvinkää (p=<0.00001) and at Ämmässuo composting field (p=0.0001). Numbers of mesophilic bacteria were significantly lower in Heinola than in Hyvinkää, ASJ, Oulu and Ämmässuo (p=<0.00001, 0.02, 0.0001 and 0.005) and numbers of thermophilic bacteria were significantly lower in Heinola than in Hyvinkää (p=0.00002). Numbers of mesophilic actinomycetes were significantly lower in Heinola than in Hyvinkää (p=0.00008) and Oulu (p=0.004). And the numbers of thermophilic actinomycetes were significantly lower in Heinola than in Hyvinkää (p=<0.00001) and Ämmässuo (p=0.03).

Although bioaerosols caused the biggest problems in *Hyvinkää*, the number of mesophilic fungi was significantly lower in the dirty working areas in Hyvinkää than in the drum composting hall and the receiving hall in Oulu (p=0.002). There were differences between other plants, as well: the numbers of thermophilic fungi were significantly higher in Hyvinkää than in the ASJ digestion plant and the composting field at Ämmässuo (p=0.00005 and 0.004). Also the numbers of thermophilic bacteria and mesophilic actinomycetes were significantly higher in Hyvinkää than in ASJ (p=0.0001 and 0.00002). The number of thermophilic actinomycetes was significantly higher in Hyvinkää than in ASJ (p=< 0.000001) and Ämmässuo (p=0.00001).

Most problems with bioaerosols at the *ASJ digestion plant* occurred during the crushing of waste and the maintenance work in the bioreactor hall. Exposure of employees during these times may be brief. The numbers of mesophilic fungi were significantly higher in the ASJ digestion plant than at Ämmässuo (p=0.03), but the numbers of thermophilic fungi were lower in ASJ than at Ämmässuo (p=0.002). The number of thermophilic actinomycetes was also significantly lower at ASJ than at Ämmässuo (p=0.01). One reason for differences in the numbers of thermophilic microbes may be that the digestion process destroys thermophilic microbes more effectively than composting.

In the CAMNEA measurements, as in impactor measurements, the numbers of mesophilic and thermophilic fungi were significantly lower in the dirty working areas in *Heinola* than in Hyvinkää (p=0.00008 and < 0.000001) and higher in *Hyvinkää* than in the ASJ digestion plant (p=0.0004 and < 0.000001). Numbers of mesophilic and thermophilic bacteria were lower in Heinola than in Hyvinkää (p=0.007 and 0.000003). The number of mesophilic bacteria was lower in Hyvinkää than in the ASJ plant (p=0.004) but the number of thermophilic bacteria was higher in Hyvinkää than in the ASJ plant (p=0.004). The number of mesophilic actinomycetes was lower in Heinola than in the ASJ plant (p=0.006). The number in Hyvinkää was higher than in the ASJ plant (p=<0.000001). In the case of thermophilic actinomycetes, the number was lower in Heinola than in Hyvinkää (p=< 0.000001) and higher in Hyvinkää than in the ASJ plant (p=< 0.000001).

The total microbial number was higher in dirty working areas in Heinola and Oulu than in the ASJ plant (p=0.04 and 0.004). Also, concentrations of *endotoxins* were significantly higher in dirty working areas in Oulu than in the ASJ plant (p=0.03).

The dust concentration at *Ämmässuo* during handling of windrows was significantly higher than the background concentrations (p=0.04). Also, numbers of fungi (p=0.000005 and <0.000001), mesophilic bacteria (p=0.0001) and thermophilic actinomycetes (p=0.02) were significantly higher. Occupational hygiene was not significantly improved when the treatment of biowaste was moved from open-air composting fields to an indoor facility: bioaerorol concentrations were higher in most of the composting plants of this study than in the composting field at Ämmässuo. In terms of dirty working areas, for example, fewer occupational problems with bioaerosols were associated with the composting of biowaste in the open field than with composting in indoor facilities. Not all differences were statistically significant, however. As noted above, at the Hyvinkää plant, only the number of thermophilic actinomycetes was significantly higher than at Ämmässuo. At Heinola, concentrations of mesophilic and thermophilic fungi and mesophilic bacteria were significantly lower than at Ämmässuo. However, in the machine cabins, which should have been a clean environment, bioaerosol concentrations were almost as high as in the clean working areas in the Hyvinkää composting plant.

A different question is whether other environmental effects of windrow composting are more harmful than the effects of closed composting plants. People living in the vicinity of indoor facilities have been mostly satisfied, and the general opinion is that indoor treatment of waste is preferable to disposal at landfill sites or treatment in open fields (Alasentie 2000; Alasentie & Tolvanen 2001). Composting of biowaste in a closed plant has reduced environmental nuisances such as seagulls and unpleasant odours. If working conditions in control rooms, technical rooms and cabins of machines could be improved, treating biowaste in indoor facilities would be preferable to treating biowaste in windrows in an open field.

Comparison of the various composting plants can give only indicative results. Plants process different kinds of waste and rely on different kinds of technical solutions. More over concentrations of bioaerosols may change dramatically from one day to the next and it is impossible to know beforehand when the situation at a plant is good or bad on the sampling day and when the results are representative or not. As well, the sampling locations were different in the plants that were studied. It is clear, however, that exposure to microbes and endotoxins can also occur in indoor facilities and concentrations of bioaerosols even in supposedly clean environments may be at a level that is harmful to human health. In some cases, such as the plants in this study, a respiratory mask (class P3) is in order to reduce the exposure to microbes and endotoxins.

Plants treting dry waste (II, IV)

There were more problems with bioaerosols and dust in the *Ressu* dry waste treatment plant than in that of Ewapower Ltd. Some of the differences were statistically significant. In the dirty working areas (processing halls) *the total concentration of microbes* (p=0.004) as well as *the numbers of viable, thermophilic fungi and mesophilic bacteria* in impactor measurements were lower at Ewapower than at Ressu (p=0.04, 0.009). The number of mesophilic and thermophilic fungi in measurements made by CAMNEA method were significantly lower at Ewapower Ltd than at Ressu (p=0.0007 and 0.04). It is advisable to use a respirator mask in the processing hall of both plants when waste is being treated.

Lower endotoxin concentrations have been measured in a paper sorting plant in Denmark than in the dry waste treatment plants of Ressu and Ewapower Ltd (Breum et al 1999); concentrations ranged from 0.63 to 140 EU/m^3. In two studies made at waste treatment plants (dry waste) in the United States, endotoxin concentrations ranged from 2.8 to 72 EU/m^3 (Mahar 1999). The higher concentrations at Finnish dry waste treatment plants may be due to biowaste residuals.

4.2 Effect of waste quality and waste treatment technique on bioaerosols and dust at different kinds of plants treating different kinds of waste

4.2.1 Clean working areas

In terms of clean working areas like coffee rooms, control rooms, technical rooms and machine cabins, the occupational hygiene risk was highest at the Hyvinkää composting plant, as noted above. Conditions were best in the combined drum and tunnel composting plant treating sewage sludge from the Heinola area (VI). For clean working areas, the ranking list of the plants in this study would be (from worst to best):

1. combined drum and tunnel composting plant in Hyvinkää
2. windrow composting in open field at Ämmässuo
3. Turku incineration plant
4. Hämeenlinna optical sorting plant
5. Ressu dry waste treatment plant in Tampere
6. Oulu drum composting plant
7. combined drum and tunnel composting plant in Heinola

Dust concentrations

Dust concentrations in these plants were significantly different. Most of these results are not surprising: for example, dust concentrations were significantly higher in Hyvinkää (technical room and cabin of the wheel loader), in Oulu (control room) and in the optical sorting plant in Hämeelinna (control room) than in the coffee room at the Ressu dry waste treatment plant (p=0.003, 0.001 and 0.02). Dust concentrations were higher in the control room in Oulu that in Hämeenlinna (p=0.04).

Concentrations of endotoxins

Endotoxin concentrations were highest in Hyvinkää; the concentrations were significantly higher in Hyvinkää than in the crane room and oven hall in Turku (p=0.0001). Concentrations in Turku were also significantly lower than in the control room in Hämeenlinna (p=0.0003) and in the coffee room in Ressu (p=0.0004). Endotoxin concentrations were significantly different in Ressu and in the control room of the Oulu drum composting plant (p=0.03) and significantly different between Oulu and Hämeenlinna (p=0.03), with concentrations lower in Oulu.

Concentrations of microbes

Differences in *total microbial concentrations* were minor. The total microbial number was significantly lower in the control room in Oulu than in the control rool in Hämeenlinna or the scrubber room in Heinola (p=0.02 and 0.01).

There were some differences in *concentrations or viable microbes* between plants treating biowaste and sludge and other waste treatment plants. For example, the numbers of mesophilic fungi and bacteria (impactor measurements) were significantly lower in Heinola than in the optical sorting plant in Hämeenlinna (p=0.002 and <0.000001). Numbers of actinomycetes were lower in Heinola than in Ressu (p=0.001 and 0.003) and Hämeenlinna (p=0.02). In Hyvinkää composting plant, concentrations of fungi, both mesophilic and thermophilic, were significantly higher than in the Turku incineration plant (p=0.02 and 0.0002) and the Ressu dry waste treatment plant (p=0.02 and 0.00005). Numbers of bacteria were also higher in Hyvinkää than in Turku (p=0.001 and 0.000004) and Ressu (p=0.0009 and 0.0001). Numbers of actinomycetes, both mesophilic and thermophilic, were higher in Hyvinkää than in Turku (p=0.0007 and p=<0.000001), Hämeenlinna (p=0.003) and Ressu (p=0.01). The number of mesophilic fungi was higher in the control room in Oulu than in Ressu (p=0.01) while the number of mesophilic bacteria was lower than in the control room in Hämeenlinna (p=0.0005) and the number of mesophilic actinomycetes was lower than in Ressu (p=0.01).

In CAMNEA measurements, the number of mesophilic fungi was lower in Heinola than in Ressu (p=0.004) and Turku (p=0.0002). The number of mesophilic fungi was significantly higher in Hyvinkää than in Turku (p=0.03), and numbers of thermophilic fungi were higher in Hyvinkää than in Turku ($p=0.006$) and Ressu ($p=0.0003$). Also, the numbers of actinomycetes were higher in Hyvinkää than in Turku ($p=0.00003$ and <0.000001).

There were statistically significant differences among other plants, as well. In impactor measurements, the numbers of mesophilic fungi and bacteria were higher in Hämeenlinna than in Turku ($p=0.007$ and 0.002) and Ressu ($p=0.001$ and 0.0008). Both in impactor and CAMNEA measurements the number of actinomycetes was higher in Turku than in Ressu ($p=0.0006$ and $p=0.01$; $p=0.02$ and 0.02). In CAMNEA measurements, also the number of thermophilic fungi was higher in Turku than in Ressu ($p=0.03$).

In comparing the various clean working areas, it is important to note that even though all these places are "waste free", they are not otherwise equivalent. Cabins of the machines used in Hyvinkää and at Ämmässuo need to be very clean because an employee may spend as many as 8 hours a day in the cabin. Likewise in the control rooms and other such places the quality of indoor air needs to be good, at the same level as in residences and offices. Places like the scrubber room in Heinola, the oven hall in Turku and the technical room in Hyvinkää, on the other hand, may be allowed to be dirtier because employees do not work in these places either daily or for long periods.

4.2.2 Dirty working areas

In terms of dirty working areas, the waste treatment plant with poorest occupational hygiene was the *Ressu dry waste treatment plant* in Tampere, while that with best hygiene was the Heinola composting plant. For dirty working areas, the ranking list of all plants from worst to best is:

1. Ressu dry waste treatment plant in Tampere
2. optical sorting plant in Hämeenlinna
3. Turku incineration plant
4. combined drum and tunnel composting plant in Hyvinkää
5. dry waste treatment plant of Ewapower Ltd in Pietarsaari
6. digestion plant of ASJ Stormossen in Mustasaari / drum composting plant in Oulu
7. windrow composting in open field at Ämmässuo
8. combined drum and tunnel composting plant in Heinola.

Dust concentrations

The dust concentration was highest in the Turku incineration plant; the concentrations were significantly higher in Turku than in the Hyvinkää composting plant ($p=0.0001$), the composting field at Ämmässuo ($p=0.006$), the drum composting plant in Oulu ($p=0.002$) and the ASJ digestion plant ($p=0.0003$). Dust concentrations were also occasionally high in the Ressu dry waste treatment plant; the concentrations in the processing hall of this plant were significantly higher than the concentrations in the dirty working areas in the Hyvinkää composting plant (p=0.03) and in the ASJ digestion plant (p=0.04). The dust concentration at Ewapower Ltd was also higher than that at the ASJ digestion plant (p= 0.0008) and at Ämmässuo (p=0.002).

Dust concentrations were significantly higher in the optical sorting plant in Hämeenlinna, than in ASJ (p=0.002) and in Ämmässuo (p=0.01). It seems, then, that treatment of biowaste causes fewer problems with dust than does treatment of other waste qualities.

Concentrations of endotoxins

Endotoxin concentrations were highest in the waste bunker of the incineration plant in Turku. Concentrations were significantly higher than in the composting plants in Heinola (p=<0.000001), Hyvinkää (p=<0.000001) and Oulu (p=<0.000001) and in the ASJ digestion plant (p=<0.000001). The concentrations were also higher than in the dry waste treatment plants of Ewapower Ltd (p=0.000002) and Ressu (p=0.000004). High endotoxin concentrations were measured in the processing hall of the optical sorting plant in Hämeenlinna: the concentrations were significantly higher than in Heinola (p=0.006), Hyvinkää (p=0.0005), Oulu (p=0.002) and ASJ (p=<0.000001), but lower than in Turku (p=0.00008). Endotoxin concentrations were also harmfully high in Ressu dry waste treatment plant and higher there than in the ASJ plant (p=0.002) and in Hyvinkää (p=0.04). Endotoxin concentrations were significantly higher at the Ewapower Ltd than in Heinola (p=0.03), Hyvinkää (p=0.004) and the ASJ plant (p=0.00001). The endotoxin concentrations seem to be less of a problem in the plants treating biowaste and sludge than in the plants treating other waste qualities. However, endotoxin concentrations were also occasionally high in the composting plants and the ASJ digestion plant.

Total microbe concentrations

The highest total microbe concentrations were measured in the drum composting plant in Oulu; the concentrations were significantly higher than in ASJ (p=0.004) and the optical sorting plant in Hämeenlinna (p=0.04). The total microbial concentrations were significantly higher in Ressu dry waste treatment plant than in Hyvinkää (p=0.03), ASJ (p=0.00002) and Hämeenlinna (p=0.001). The total microbial concentration was significantly higher in the Turku incineration plant than in Hyvinkää (p=0.0004), ASJ (p=0.000002), Ewapower Ltd (p=0.00001) and Hämeenlinna (p=0.00005).

Concentrations of viable, air-borne microbes

There were many significant differences in the concentrations of viable, air-borne microbes at the different waste treatment plants. Most problems with these bioaerosols were encountered in the treatment of dry waste, but there were problems in other waste treatment plants as well.

In *impactor measurements*, the number of mesophilic fungi was highest in the optical sorting plant in Hämeenlinna. Numbers were higher than during composting in Heinola (p=<0.000001), Hyvinkää (p=0.03) and Ämmässuo (p=0.00003) and also higher than in the ASJ digestion plant (p=0.0006) and the dry waste treatment plants of Ewapower Ltd (p=0.002) and Ressu (p=0.003). In Turku, mesophilic fungi caused a problem in the waste bunker, and the fungi concentrations were higher than in the biowaste treating plants in Heinola (p=<0.00001), Hyvinkää (p=0.005) and Oulu (p=0.005) and higher than at Ämmässuo (p=0.00003) and the ASJ plant (p=0.0002). Fungi concentrations were high also in dry waste treatment plants, with the number of mesophlic fungi higher at the Ressu facility than in Heinola (p=<0.000001), Hyvinkää (p=0.0006), Oulu (p=0.0002), Ämmässuo (p=<0.000001) and ASJ (p=<0.000001). The number of these fungi was higher at the Ewapower plant than in Heinola (p=0.000007), Ämmässuo (p=0.0004) and ASJ (p=0.003). Thus, considerably more problems with mesophlic fungi were associated with the treatment of dry waste than with the treatment of biowaste.

The situation was the same with thermophilic fungi. The number of these fungi was significantly higher at the Ressu facility than in Heinola (p=<0.000001), Ämmässuo (p=0.00003), the ASJ digestion plant (p=<0.000001) and in Turku (p=0.02). The number of thermophilic fungi was higher at Ewapower than in Heinola (p=0.000003) but lower at Ewapower than at ASJ (0.0001). The number of thermophlic fungi was higher in Turku than in Heinola (p=0.00001).

The number of mesophilic bacteria was highest in the processing hall in the optical sorting plant in Hämeenlinna. The number was significantly higher than in other waste treatment plants in the study (p-values from 0.02 to <0.000001). The number of mesophilic bacteria was significantly higher in the Ressu dry waste treatment plant than in the plants treating biowaste and sludge (p-values from 0.002 to <0.000001). The number of mesophilic bacteria was higher in the ASJ digestion plant than in Turku (p= 0.02), while the numbers in Turku were higher than in Heinola (p=<0.000001), Hyvinkää (p=0.04), Oulu (p=0.01) and Ämmässuo (p=0.03). Numbers at Ewapower were higher than those at Heinola (p=0.00001).

Thermophilic bacteria were most prevalent in dirty working areas in Hyvinkää, and numbers there were significantly higher than in the Turku incineration plant (p=0.01) and the other composting plants. Numbers in the Heinola composting plant were significantly lower than those in the dry waste treatment plants of Ewapower Ltd (p=0.002) and Ressu (p=0.00005) and in the Turku incineration plant (p=0.005). The number of thermophilic bacteria was higher in the ASJ digestion plant than in Turku (p=0.04) but lower than in the Ewapower plant (p=0.008).

The number of mesophilic actinomycetes was highest in the incineration plant in Turku. The number was significantly higher than in Heinola (p=0.0003) and ASJ (p=0.00009). Likewise, numbers in the dry waste treatment plants of Ressu and Ewapower and in the optical sorting plant in Hämeenlinna were higher than in Heinola (p=0.000001, 0.004 and 0.006) and the ASJ digestion plant (p=<0.00001, 0.002 and <0.00001).

Highest concentrations of thermophilic actinomycetes were measured in the composting plant in Hyvinkää. Numbers were significantly higher than in the dry waste treatment plants of Ewapower and Ressu (p=0.00007 and 0.003) and also significantly higher than in Turku (p=0.00002). The number of thermophilic actinomycetes was higher in Ressu than in Heinola (p=0.00006) and the ASJ digestion plant (p=0.0000004). The number of these microbes in Turku was higher than the numbers in Heinola (p=0.000002) and Ämmässuo (p=0.02). Numbers of thermophilic actinomycetes were higher in the Ewapower plant than in Heinola (p=0.0003) and ASJ (p=0.0004).

Also in *measurements made by CAMNEA method*, the numbers of viable microbes were highest in the Ressu dry waste treatment plant. Numbers of fungi in the Ressu facility were significantly higher than in Heinola (p=<0.000001), Hyvinkää (p=0.00002) and ASJ (p=<0.000001). The number of thermophilic fungi was higher in Ressu than in Turku (p=0.04) and the number of fungi in Turku was higher than the number in Heinola (p=0.00003 and 0.0002), Hyvinkää (p=0.00004 and 0.03) and ASJ (p=0.0001 and 0.00007). The number of fungi at the Ewapower Ltd was higher than the number in Heinola (p=0.0009 and 0.000007) and ASJ (p=0.003 and 0.000006).

The number of mesophilic fungi was lower at Ewapower than in Turku (p=0.001) and the number of thermophlic fungi lower than in Hyvinkää (p=0.02).

The number of mesophilic bacteria was significantly lower in Heinola than in the waste treatment plants treating other waste qualities (p-values from 0.02 to 0.0002). Mesophilic bacteria were more prevalent in Hyvinkää than in Turku (p=0.03) and lower at Ewapower than at ASJ (p=0.02). The number of thermophilic bacteria was significantly higher at ASJ than in the Ressu facility (p=0.01).

Also in the CAMNEA measurements, the number of mesophlic actinomycetes was highest in the Ressu facility and significantly higher than in Heinola (p=0.005) and ASJ (p=<0.000001). The number was significantly lower at ASJ than at Ewapower (p=0.00004) and Turku (p=<0.000001).

Like the impactor method, the CAMNEA method gave the highest number of thermophlic actinomycetes for Hyvinkää. The number was significantly higher than in Turku (p=0.009), Ressu (p=0.03) and other plants treating biowaste and sludge. The concentrations of thermophlic actinomycetes were low at the ASJ facility and significantly lower than at Ewapower (p=0.0002), Turku (p=0.002) and Ressu (0.00001). The smallest numbers of thermophlic actinomycetes were measured at Heinola, and the numbers were significantly lower there than in the plants treating dry waste or burnable waste (p-values from 0.02 to 0.005).

In the study made in the *Ressu plant*, the most harmful waste fraction was the mixture of dry waste and energy waste. The mixture of dry waste, energy waste and wood waste caused fewer problems with occupational hygiene. *In* *terms of microbes*, the most harmful fraction was the dry waste (p-values in impactor measurements from 0.04 to 0.00005, and measurements made by CAMNEA method from 0.01 to 0.00002). Problems arise because the source-separated dry waste fraction includes biowaste. Microbes in the dry waste are stressed because they need moisture to multiply and, under stress, spores, especially fungal spores, are easily released into air (Jantunen et al. 1987; Rytkönen et al. 1988; Pasanen et al. 1991). Microbes were less of a problem with wood waste. The total microbial number was lowest during the treatment of wood waste and significantly lower than during the treatment of energy waste (p=0.0005).

In terms of dust, the most problematic waste type was wood waste; dust concentrations were significantly higher during the treatment of wood waste than during the treatment of other qualities of dry waste (p-values from 0.001 to <0.000001). In contrast to this, the numbers of viable microbes were significantly lower during the treatment of wood waste than other waste qualities (p-values in impactor measurements from 0.04 to 0.000007 and in measurements made by CAMNEA method from 0.004 to <0.000001).

In an earlier investigation, Wurtz and Breum (1997) noted that waste paper contaminated with organic waste contained 10-100 times as many bacteria and fungi as pure waste paper. Similarly, in Finnish dry waste treatment plants, dry waste from households may include organic waste. In the Tampere area, for example, only real estate complexes with more than five units are obliged to source-separate their biowaste. Residents in smaller complexes or single family dwellings may put their biowaste into the same container with the dry waste. Hence, about 50% of the biowaste in Tampere gets mixed with the dry waste fraction. Rules are stricter in Jyväskylä: all households are required to source-separate their biowaste and the dry waste fraction is much cleaner.

Although most people sort their waste correctly, there are nevertheless always a few who do not. Most householders also find it too time-consuming to wash all paper and plastic waste (e.g. ice-cream cartons and yoghurt containers) and thus dry waste frequently contains biowaste residues. And then there is that small group people who do not understand the importance of separating waste at all. Very probably bioaerosol concentrations in dry waste treatment plants would decrease if consumers would just take the time and effort to separate their waste correctly. Re-desing of some packaging to make it easier to clean or wash would also be of benefit.

High bioaerosol concentrations may occur in other waste management plants than dry waste plants. In all plants in this study, the microbe group causing most problems was mesophilic fungi. Similarly, in a study made by Heldal et al. (2001) fungal spores constituted the largest fraction of airborne microbes. Heldal and co-workers also found that there were no significant differences between the various collection systems for organic waste in terms of the potential of the waste to emit fungal and bacterial spores. Evidently, then, waste quality is not the most important factor when it comes to air quality in waste treatment plants. The more important factor would appear to be the technical solutions adopted at the plants.

As earlier remarked, sampling locations in the different plants were not always comparable, and the comparison of the different plants was only a very general one. It was clear, nevertheless, that exposure to high microbe concentrations is possible in incineration plants, dry waste treatment plants and composting plants alike.

Since waste always includes microbes, the exposure time becomes important. In some plants, employees have to work in dusty places only occasionally (for example the waste bunker in Turku), whereas in other plants employees have to work daily and several hours in unpleasant conditions (for example the cabin of the wheel loader in Hyvinkää).

Table 7 summarises the microbiological risks in different working areas in the Turku incineration plant (Tolvanen & Hänninen 2004). The same kind of risk assessment would be in order at other waste treatment plants.

TABLE 7 Microbiological risks in the incineration plant of Turku city.

Working place	Estimated risk	Notice
office rooms	-	measurements done
control room	-	"
workshop	**	"
receiving room for waste oil	-	no measurements
waste bunker	***	measurement done; respirator mask class P3
waste crusher	***	measurement done; respirator mask class P3
crane room	-	measurements done
oven hall	*	"
over wing of reactor	-	"
silo for fly ash	*	no measurements
silo for final product	*	"
social spaces	-	"

* = minor risk, microbe concentrations slightly over normal indoor concentrations
** = microbe concentrations may occasionally raise to level harmful to health
*** = microbe concentrations continually in the level which might cause health hazards
\- = no risk

4.3 Fungal species

The most common fungi found in this study, both in the open composting field and in indoor facilities, were *Penicillium sp*. and *Aspergillus sp*. Likewise in several previous studies *Penicillium* was identified as the most prevalent fungi in the working air in waste treatment plants (Malmros et al. 1991; Gladding & Coggins 1997). *Penicillium* species are potential mycotoxin producers. However, pathogenic species to humans such as those in *Aspergillus* (for example *A. fumigatus*) are rare in *Penicillium* (Samson & van Reenen-Hoekstra 1988).

Appearance of these fungi may indicate a high risk for employees to acquire respiratory allergic diseases or sensitisation to moulds (Fischer & Dott 2003).

In plants where the measurements included determination of thermophilic fungi, *Aspergillus fumigatus* was the most common thermophilic fungus in the working air. In general, the percentage of this fungus varied from about 20 to 40%, which means that it made a substantial contribution to the total number of air-borne fungi. This is an important result because *A. fumigatus* is one of the major fungi pathogenic to humans. *A. fumigatus* was also one of the most frequent species in the air of compost plants in the investigations of Crook et al. (1988), Fischer et al. (1999) and Koivula et al. (2000). At the open-air windrow composting field in Jyväskylä, Finland, *A. fumigatus* comprised 38% of all air-borne fungi in the air (Hänninen et al. 1999; Koivula et al. 2000). Because *A. fumigatus* is thermotolerant, it emerges especially in the thermophilic phase of composting (Samson & van Reenen-Hoekstra 1988; Götlich et al. 1999).

The metabolites of *A. fumigatus* with the highest known toxicity are gliotoxin and verruculogen. However, these toxins have not been identified among the bioaerosols found in compost facilities and they do not seem to be relevant as health hazards for employees at waste treatment plants (Fischer et al 1999).

In addition to *A. fumigatus*, also *A. niger* and many other aspergilli are potentially pathogenic to humans. *A. niger* was quite common in the waste treatment plants of this study. There are no reports to indicate that high concentration of pathogenic fungal spores would increase the risk for infection of employees with normal immune status; however, long-term exposure to fungal spores or to particles containing fungal toxins can be expected to eventually suppressor modulate the immune response in healthy people (Fischer & Dott 2003).

4.4 Reduction of exposure to bioaerosols and dust in waste treatment plants

Masks and technical solutions

Both managers and employees at Finnish waste treatment plants have been very interested in occupational hygiene and concerned about the exposure of employees to harmful factors. In most plants there was at least one working area where concentrations of bioaerosols in this study were harmfully high. Also in most working areas investigated, most microbes (> 60 %) were less than 5 μm in aerodynamic size and thus able to penetrate deep into alveoli. Use of a respirator mask is thus strongly recommended to avoid harmful exposure to microbes, dust containing harmful particles, and endotoxins. Unfortunately, employees are not always willing to use masks, which often become hot and unpleasant to use. And where masks are used, they are often used wrongly. The mask may be wrongly set on the face, for example, and polluted air may leak to the supposedly protected area. Problems also arise with the storage and maintenance of masks. It is not unusual to see a mask stored in the breast pocket of dirty overalls or simply laid down on a dusty table. Education of employees to use their masks correctly and instructions concerning them about harmful factors in the workplace are important matters. Some training has already been done at the incineration plant in Turku.

Because respirator masks are uncomfortable to use, it would be advantageous to find technical solutions for the problems with bioaerosols. In the Ressu dry waste treatment plant, technical changes in the processing hall did not reduce the problems with bioaerosols, but in the crane room of the incineration plant in Turku, for example, technical changes improved the quality of the working air considerably. According to Schlegelmilch et al. (2004), occupational problems at composting plants may be solved by capturing and treating all emission sources. At uncovered sources a point source capture of emissions should be installed to collect bioaerosols before they are emitted to air. This could be an effective way to reduce employees' exposure to bioaerosols.

Design of new plants and importance of surface and air cleaning

At least social areas, offices and control rooms in waste treatment plants should be "clean" working areas. In future, plants should be designed so that there are no direct passageways or connections between clean and dirty working areas. As was discovered in the optical sorting plant in Hämeenlinna, as well as in some other waste treatment plants, a single closed door between these working areas is not sufficient to avoid the movement of dust and microbes from processing halls to office rooms. Processing halls should be completely separate from offices and social spaces, and ventilation systems should be seprate as well, so that air cannot pass from dirty areas to clean.

The concept of carefully planned social spaces is a broad one. When employees leave the processing hall, they should be able to remove their work clothes in one changing-room, have a shower or sauna, and then go to another changing-room to dress in clean clothes. Wearing of dirty work clothes while visiting the dining room or offices should be prohibited.

Effective cleaning is another important way to reduce concentrations of bioaerosols. Boisch (2001) notes that frequent cleaning of all equipment inside buildings, as well as the interior walls, will significantly reduce both odours and concentrations of bioaerosols.

4.5 Applicability of methods to investigations of occupational hygiene at waste treatment plants

Microbial measurements

The six-stage impactor gave better results for viable microbes than the CAMNEA method; number of fungi and actinomycetes obtained with the impactor were significantly higher (p-values from 0.02 to 0.00001 and from 0.03 to 0.0002, respectively) at almost every plant. In the case of bacteria, differences between the two methods were statistically significant only in the Ressu dry waste treatment plant (mesophilic bacteria, p=0.01 and thermophilic bacteria, p=0.02) and the Hyvinkää composting plant (thermophilic bacteria, p=0.001). The impactor gave significantly higher results for *Aspergillus fumigatus* (p=0.02) as well.

Some problems are associated with the impactor. Impactor measurements are often inaccurate and sampling times at waste treatment plants usually must be short because of the high concentrations of microbes. Inaccurate but higher values are nevertheless more right than the accurate and lower results given by the CAMNEA method. The impactor is also fairly easy to use, and sampling and treatment of samples are not so time consuming as for the CAMNEA method. The impactor is thus well suited for routine measurements. The initial cost of a six-stage impactor is fairly high (about 5000 euros in 2000), but treatment of samples in the laboratory is less time consuming than treatment of samples taken by the CAMNEA method. Wüst et al. (2003) have noted the usefulness of the six-stage impactor. For example, it does not overload as quickly as the Biotest RCS-plus air sampler, which is a portable accumulator-powered sampler incorporating the principles of air centrifugation and impaction of particles. Above humidity of 50% the impactor gave significantly higher numbers of colony forming units than the RCS-plus. Both samplers can serve a useful function in airborne fungal spore sampling, however.

While the CAMNEA method is suitable for determination of the total number of microbes, using it demands experience. In particular, the counting of microbes with an epifluorescence microscope may be difficult for the beginner because there may be other particles than microbes on the counting filter and separation of microbes from other organic material is not always easy.

This study has shown that the determination of numbers of mesophilic, viable microbes gives accurate enough information about occupational hygiene in waste treatment plants in terms of microbes. However, if the numbers of *Aspergillus fumigatus* need to be known separately, it is also necessary to investigate the numbers of thermophilic fungi.

Dust measurements

The standard method (SFS 3860) for determination of dust concentrations was not good enough to reveal the real dust concentrations in working air. In winter, in particular, negative results were obtainced because of static electricity. Use of an eradicator of static electricity did not remove the problem. Null results were also common even when the occurrence of dust was evident. In future it would be important to find better methods for measuring dust. Methods should be suitable (rapid and economical) for routine measurement.

5 CONCLUSIONS

The results of this study allow the following conclusions to be drawn:

1. The move to indoor waste treatment facilities has not removed problems with occupational hygiene, not even in the management of biowaste. In every plant investigated, there were problems with bioaerosols or dust in at least one working area. The variation in levels of occupational hygiene is nevertheless great, between working areas and even at different times in the same working area (for example the processing hall of Ressu dry waste treatment plant).
2. In the determination of viable air-borne microbes, especially fungi and actinomycetes, a six-stage impactor gives significantly better results than the CAMNEA method, although the results may not always be representative because of short sampling time. Taking into account sampling time, costs of laboratory work and ease-of-use, the six-stage impactor must be considered very useful for routine measurements.
3. Most microbes at the waste treatment plants were < 5 µm in aerodymanic size and thus capable of penetrating deep into alveoli. They represent a health risk, therefore.
4. Fungi (especially mesophilic) are the most common air-borne microbes at waste treatment plants; the most common fungi in the workplace air are *Penicillium* and *Aspergillus* (including *A. fumigatus*).
5. The least hygienic working phases with wastes are the crushing and mechanical sorting of waste; bioaerosols may be a problem in the treatment of biowaste, especially the transferring or managing of fresh biowaste or compost with a wheel loader.
6. Problems with occupational hygiene are more severe at dry waste treatment plants than at composting plants, open-air windrow composting facilities, digestion plants or incineration plants. Viable, air-borne microbes are a particular problem in dry waste plants, even though dry waste should not contain biowaste, which is a favourable substrate for microbes. Source-separated dry waste from households causes the most severe microbe problems in dry waste treatment plants. Dust, rather than microbes, is a problem with wood waste.

7 In the future, waste treatment facilities need to be designed so that the exposure of employees to bioaerosols is decreased. Dusty working phases should be enclosed and dirty processing halls should be totally separated from clean ones. One way to develop safer waste treatment facilities may be to arrange seminars and training for plant designers and employees, instructing them of the harmful factors in waste treatment.

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YHTEENVETO (Summary in Finnish)

Jätteenkäsittelytekniikan ja jätelaadun vaikutus bioaerosolipitoisuuksiin suomalaisilla jätteenkäsittelylaitoksilla

Vuonna 1994 voimaan tulleen jätelain myötä Suomen jätehuolto on läpikäynyt suuria muutoksia: mm. jätteiden syntypistelajittelu on tehostunut ja kaatopaikkojen määrä vähentynyt merkittävästi. Jätteenkäsittelyprosessien tehostamiseksi ja ympäristölle aiheutuvien haittojen vähentämiseksi biojätteitä ja polttoon soveltuvaa kuivajätettä on alettu käsitellä suljetuissa jätteenkäsittelylaitoksissa. Laitoksia suunniteltaessa on hyödynnetty uusinta käytettävissä olevaa teknologiaa.

Jätteenkäsittely on useissa laitoksissa pitkälle automatisoitu. Kuitenkin, erityisesti huoltotyöt ja erilaiset ongelmatilanteet laitoksilla vaativat yhä edelleen ihmistyövoiman käyttöä. Tämän tutkimuksen tarkoituksena olikin selvittää, onko jätteiden tehostunut lajittelu ja jätemateriaalin käsittely uusissa, suljetuissa systeemeissä vähentänyt työilmaan vapautuvien ja terveydelle haitallisten bioaerosolien (mikrobit, endotoksiinit) ja orgaanisen pölyn määrää. Bioaerosoli- ja pölypitoisuuksia tutkittiin avoimella aumakompostointikentällä Espoon Ämmässuolla vuosina 1993–1994 ja kahdeksalla jätteenkäsittely-laitoksella eri puolilla Suomea vuosina 1998–2001. Elinkykyisten mikrobien pitoisuuksia tutkittiin kuusivaiheimpaktorilla sekä ns. CAMNEA-menetelmällä, jota hyödyntäen oli mahdollista selvittää myös mikrobien kokonaismäärä, ts. elävien ja kuolleiden mikrobien yhteispitoisuus. Pölypitoisuudet määritettiin standardin SFS 3860 (1988) mukaisesti. Endotoksiininäytteet kerättiin suodattimille ja analysoitiin Kuopion aluetyöterveyslaitoksella.

Tutkimuksessa mukana olleista laitoksista työhygieenisesti paras tilanne sekä puhtaissa työtiloissa (valvomot, tekniset tilat, työkoneiden hytit yms.) että likaisissa työtiloissa (tilat, joissa käsiteltiin jätettä) vallitsi *Heinolan kaupungin jätevesilietteen kompostointilaitoksella*. Laitos hyödyntää sekä rumpu- että tunnelikompostointitekniikkaa. Ongelmallisin työtila laitoksella oli tunneli, johon jäte siirretään kuljettimilla rumpukäsittelyn jälkeen odottamaan jälkikypsytystä aumoissa. Mikrobeista tunnelissa esiintyi eniten mesofiilisiä sieniä. Sienten pitoisuus keskimäärin oli kuitenkin alle 3000 cfu/m^3. Yleisimmät työilmassa esiintyneet sienet olivat *Penicillium* spp., *Aspergillus candidus* ja hiivat. Bakteeripitoisuus tunnelissa oli jopa alle Sosiaali- ja terveysministeriön asuin- ja toimistotiloille antaman suosituksen, joka on kaikkina vuodenaikoina 4500 cfu/m^3. Mikrobien kokonaispitoisuus (elävät + kuolleet mikrobit) oli keskimäärin 13 milj. kpl/m^3, muissa tutkituissa työtiloissa pitoisuus oli alhaisempi. Kaikissa tutkituissa työtiloissa aerodynaamiselta halkaisijaltaan alle 5 μm olevia mikrobeja oli > 70 % elinkykyisten mikrobien kokonaismäärästä. Endotoksiinipitoisuudet olivat yhtä mittausta lukuun ottamatta alle Alankomaissa annetun työhygieenisen raja-arvon 200 EU/m^3.

Yksi selitys alhaisiin bioaerosolipitoisuuksiin laitoksella lienee se, että ennen mittauksia laitoksen henkilökunta oli tuulettanut tutkittavia tiloja; tuuletuksesta tiedotettiin tutkijoille vasta työhygieenisten mittausten jälkeen.

Hyötykapula Oy:n kompostointilaitoksella Hyvinkäällä kompostoidaan pääasiassa biojätettä hyödyntäen sekä rumpu- että tunnelitekniikkaa. Vertailtaessa kaikkia tutkimuksessa mukana olleita laitoksia keskenään, Hyvinkään laitoksen puhtaissa työtiloissa (tekninen tila, työkoneen hytti) esiintyi eniten bioaerosolien aiheuttamia ongelmia. Myös likaisissa työtiloissa esiintyi haitallisen suuria bioaerosolipitoisuuksia. Suurimmat elinkykyisten mikrobien pitoisuudet mitattiin jätteen vastaanottohallissa jätteen syötön aikana ja tunnelissa. Vastaanottohallissa esiintyi eniten mesofiilisiä sieniä, joiden pitoisuus impaktorimittauksissa oli keskimäärin 39 300 cfu/m^3 ja CAMNEA-mittauksissa 5000 cfu/m^3. Tunnelin ilmassa esiintyi eniten mesofiilisiä bakteereja ja termofiilisiä sädesieniä. Mesofiilisten bakteerien pitoisuus oli impaktorimittauksissa keskimäärin 17 600 cfu/m^3 ja CAMNEA-mittauksissa 17 100 cfu/m^3. Tunnelissa mikrobien runsaskin esiintyminen on luonnollista ja asiaan kuuluvaa, onhan kompostointi ennen kaikkea mikrobiologinen prosessi. Mikrobien leviäminen jälkikompostointihallista muihin työtiloihin, erityisesti tunnelin vieressä sijaitsevaan tekniseen työtilaan, tulisi kuitenkin estää. Tekninen tila on erotettu ovella jälkikompostointihallista ja tilasta mitattiin ajoittain suuria mikrobipitoisuuksia.

Yleisimmät sienet laitoksen työilmassa olivat *Aspergillus fumigatus* ja *Penicillium* spp. Valtaosa mikrobeista, > 76,0 %, oli aerodynaamiselta halkaisijaltaan alle 5 μm ja siten kykeneviä tunkeutumaan alveoleihin eli keuhkorakkuloihin saakka. Kokonaismikrobipitoisuus vaihteli tutkituissa työtiloissa 1,8–10,1 milj. kpl/m^3. Keskimääräinen pitoisuus oli suurin tunnelissa. Endotoksiineille annettu raja-arvo 200 EU/m^3 ylittyi ajoittain kaikissa tutkituissa työtiloissa. Pölypitoisuudet sen sijaan olivat alle 8 tunnin HTP-arvon 5 mg/m^3.

Oulun rumpukompostointilaitoksen valvomossa työhygieeninen tilanne oli hyvä. Haitallisen suuria mikrobi- ja endotoksiinipitoisuuksia mitattiin ainoastaan rumpukompostointihallissa että jätteen vastaanottohallissa.

Biojätteen käsittelyn siirtäminen avoimilta kompostointikentiltä suljettuihin jätteenkäsittelylaitoksiin ei ole vähentänyt jätteenkäsittelyn aiheuttamia työhygieenisiä ongelmia merkittävästi. Avoimella kompostointikentällä biojätteen murskauksen ja aumojen käännön aikana bioaerosolien aiheuttamat työhygieeniset ongelmat ovatkin usein vähäisempiä kuin biojätteen käsittelystä aiheutuvat haitat suljetuissa laitoksissa. Ainoastaan Heinolassa työhygieeninen tilanne likaisissa työtiloissa oli parempi kuin Ämmässuolla.

Kaikkia laitoksia tarkasteltaessa työhygieenisesti heikoin tilanne likaisissa työtiloissa vallitsi *Pirkanmaan Jätehuolto Oy:n Tarastenjärven kuivajätteenkäsittelylaitoksella* (Ressu). Elinkykyisten mikrobien pitoisuudet olivat impaktorikeräyksessä suurimpia kuivajätteen käsittelyn aikana ensimmäisen metallinerottimen jälkeisen kuljettimen läheisyydessä sekä kuiva- ja energiajätteen yhtäaikaisen käsittelyn aikana seulalla. Alhaisimmat pitoisuudet mitattiin puujätteen käsittelyn aikana seulalla. CAMNEA-mittauksissa mikrobipitoisuus oli suurin seulalla kuiva- ja energiajätteen käsittelyn aikana. Pienimmät pitoisuudet mitattiin paalaimella kuivajätteen ja seulalla puujätteen käsittelyn aikana. Kokonaismikrobipitoisuus vaihteli prosessihallissa 5,1 milj.–140 milj. kpl/m^3. Kokonaismikrobipitoisuus oli pienin puujätteen käsittelyn aikana ja suurimmillaan kuivajätettä käsiteltäessä. Mikrobipäästöjen suhteen kuivajäte näyttäisikin olevan ongelmallisin jätejae.

Yleisimmät sienet Ressun prosessihallissa olivat *Aspergillus* spp. ja *Penicillium* spp. Aerodynaamiselta halkaisijaltaan alle 5 µm oli elinkykyisistä mikrobeista 63–85% riippuen käsiteltävästä jätelaadusta. Endotoksiinipitoisuudet ylittivät kaikissa mittauksissa raja-arvon 200 EU/m^3. Eniten endotoksiineja esiintyi seulalla kuiva- ja energiajätteen käsittelyn aikana, jolloin pitoisuus oli keskimäärin 14 500 EU/m^3. Pölypitoisuus ylitti 8 tunnin HTP-arvon seulalla kuiva- ja energiajätteen käsittelyn aikana. 15 minuutin HTP-arvo 10 mg/m^3 ylittyi puujätteen käsittelyn aikana kuljettimella ja seulalla.

Ewapower Oy:n kuivajätteen pelletointilaitoksen prosessihallissa jätteen esikäsittelyn ja murskauksen aikana esiintyi työilmassa eniten mesofiilisiä sieniä. Impaktorimittauksissa sieni-itiöpitoisuus oli keskimäärin 55 300 cfu/m^3 ja CAMNEA-mittauksissa 5600 cfu/m^3. Yleisimmät sienet työilmassa olivat *A. fumigatus* ja *Penicillium*. Bakteeripitoisuudet olivat luokkaa > 10^5 cfu/m^3 ja siten terveydelle haitallisella tasolla. Endotoksiinipitoisuus oli keskimäärin 4800 EU/m^3 eli selvästi yli työhygieenisen raja-arvon.

ASJ Stormossenin jätteenkäsittelylaitoksella mikrobeja esiintyi runsaimmin jätteen esikäsittelyn ja murskauksen aikana; yleisesti ottaen jätteen murskaus ja muu mekaaninen käsittely näyttäisivätkin olevan bioaerosolien suhteen ongelmallisimpia työvaiheita jätteiden käsittelyssä. Impaktorimittauksissa sienten pitoisuus oli ASJ:llä murskauksen aikana keskimäärin 96 600 cfu/m^3. Kuivaamossa mikrobipitoisuudet olivat alhaisia, jopa alle Sosiaali- ja terveysministeriön asuin- ja toimistotiloille antamien raja-arvosuositusten. Yleisimmät sienet laitoksen työilmassa olivat *Penicillium* ja *A. fumigatus* sekä hiivat, joita esiintyi runsaasti erityisesti kuivaamossa. Mikrobien kokonaispitoisuus eri työtiloissa vaihteli 2,2–56,7 milj. kpl/m^3. Pitoisuudet olivat suurimmillaan jätteen murskauksen aikana, jolloin myös endotoksiinipitoisuudet ylittivät raja-arvon 200 EU/m^3. Tämä raja-arvo ylittyi myös bioreaktorilla reaktorin huollon aikana.

Turun kaupungin jätteenpolttolaitoksella mikrobit olivat työhygieeninen ongelma erityisesti jätebunkkerissa, jossa mesofiilisten sienten pitoisuus oli keskimäärin impaktorimittauksissa 118 200 cfu/m^3 ja CAMNEA-mittauksissa 31 000 cfu/m^3. Yleisimmät sienet laitoksen työilmassa olivat *A. fumigatus* ja *Penicillium*. Mikrobien kokonaispitoisuus vaihteli laitoksella 0,7–150 milj. kpl/m^3 ja oli suurin jätebunkkerissa, jossa mitattiin myös korkeimmat kuitupitoisuudet. Kuitupitoisuus bunkkerissa ylitti niukasti raja-arvon 0,01 kuitua/m^3.

Pölypitoisuus ylitti ajoittain jätebunkkerissa 15 minuutin HTP-arvon 10 mg/m^3, pölypitoisuudet vaihtelivat 1-13,7 mg/m^3. Myös endotoksiinipitoisuudet ylittivät jätebunkkerissa raja-arvon: suurin mitattu endotoksiinipitoisuus oli 59 000 EU/m^3, joka ylitti raja-arvon 200 EU/m^3 lähes 400-kertaisesti. Raja-arvon ylittäviä endotoksiinipitoisuuksia mitattiin myös kuona-altaalla.

Hämeenlinnan optisen lajittelulaitoksen prosessihallissa esiintyi korkeita mikrobi- ja endotoksiinipitoisuuksia. Myös valvomossa (puhdas työtila) erityisesti endotoksiinipitoisuudet kohosivat ajoittain yli raja-arvon. Syynä lienee mikrobeja sisältävän pölyn kulkeutuminen likaisten työvaatteiden mukana prosessihallista valvomoon; käytännössä likaiset tilat oli erotettu puhtaista tiloista ainoastaan yhdellä ovella. Myös ilmanvaihto-ongelmat saattavat olla syynä valvomon kohonneisiin bioaerosolipitoisuuksiin.

Kaikilla laitoksilla niin työnjohto kuin työntekijätkin ovat olleet erittäin kiinnostuneita työolojensa kehittämisestä ja bioaerosolialtistuksen vähentämisestä. Suojainten käytössä on vielä kuitenkin parantamisen varaa; useilla laitoksilla suojaimia ei käytetä, koska ne ovat epämukavia tai sitten suojaimia ei osata käyttää ja säilyttää oikein. Jatkossa uudet laitokset tulisikin suunnitella siten, että suojainten käytön tarve vähenisi; pölyävät työvaiheet pitäisi kapseloida siten, että terveydelle haitalliset bioaerosolit eivät pääsisi leviämään työilmaan. Lisäksi likaiset työtilat tulisi eristää puhtaista toimisto- ja sosiaalitiloista siten, että lian ja pölyn kulkeutuminen prosessihalleista puhtaampiin työtiloihin olisi mahdollisimman vähäistä.

Myös mittausmenetelmät vaativat kehitystyötä; erityisesti ilman pölypitoisuuden määritystä varten olisi tärkeää saada tässä tutkimuksessa käytettyä standardimenetelmää parempi menetelmä. Elinkykyisten mikrobien pitoisuuden määrityksessä kuusi-vaihe impaktori on käyttökelpoisempi kuin CAMNEA-menetelmä huomioiden niin käyttökustannukset kuin käytön helppouskin. CAMNEA-menetelmä soveltuu ensisijaisesti mikrobien kokonaispitoisuuden (elinkykyiset + kuolleet mikrobit) määrittämiseen.

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