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EXPOSURE TO AIRBORNE MICROORGANISMS AND VOLATILE ORGANIC COMPOUNDS IN DIFFERENT TYPES OF WASTE HANDLING

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Abstract: Occupational exposure of workers to airborne microorganisms and volatile organic compounds (VOC) in different types of waste treatment situations was examined during summer time. Microorganisms were collected as stationary samples using a six-stage Andersen impactor, while for VOCs both personal and stationary sampling was conducted. The exposure at the waste handling facility was considerably greater than at landfill sites or in waste collection. The concentrations of viable fungi were maximally 10^5 cfu/m^3, and the concentrations of both total culturable bacteria and Gram-negative bacteria exceeded the proposed occupational exposure limit values (OELV), being 10^4 and 10^3 cfu/m^3, respectively. Exposure to VOCs in the waste handling facility was three times higher than at the landfill sites, being at highest 3000 μg/m^3, considered to be the limit for discomfort. The use of personal protective equipment at work, thorough hand washing and changing clothes after the work shift are strongly recommended in the waste handling facility and the landfill sites.

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INTRODUCTION

In Finland, 3.1 million tons of municipal waste are produced annually; 30 % of this is produced by consumers, meaning that each individual produces an average of 200 kg of municipal waste every year. The rest of the municipal waste load is produced by shops, offices, small-scale industrial enterprises, and construction sites [18].

This municipal waste load is traditionally dumped into landfill sites. There are 498 working landfill areas in Finland [8]. During the past two decades, there has been growing pressure to recycle the waste or to use the energy content of the refuse by burning it. This, however, requires sorting of the waste, and several pilot projects to sort the domestic waste have therefore been started.

Regardless of whether or not the waste is presorted, it must be handled in some way in order to use it for burning or for production of natural gas. This usually requires special facilities built for this purpose. Only a few of such waste handling facilities have so far been built in Finland.

In Denmark, several waste handling plants were built at the end of the 1980s and experiences were not satisfactory from the occupational health point of view. The workers reported shortcomings in ergonomics, as well as subjective symptoms of draught and cold [15, 16]. Further investigations revealed cases of bronchial asthma and organic dust toxic

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syndrome (ODTS) [20]. In one of the waste handling plants built in 1986, eight workers out of 15 suffered from eye and throat irritation, cough and fever, and the diagnoses were bronchial asthma or chronic bronchitis. The symptoms were related to high particulate levels containing bacteria and endotoxins [17]. Although the concentrations of airborne microorganisms were lower in the resource recovery plants compared to those found in agriculture [20] the provisional Dutch guideline of 10^4 cfu/m^3 (colony forming unit) for bacterial and fungal concentrations in total was exceeded [11, 17]. Clark *et al.* [6] reported that at a compost plant where the material was processed, the concentration of *Aspergillus fumigatus* was at maximum 10^6 cfu/m^3, but the numbers of Gram-negative bacteria were usually lower.

At Finnish landfills, there is usually a checking station where the waste trucks are received and refuse is registered. After registration, the refuse is unloaded under supervision and the equipment operator spreads and compacts the refuse. Presorted domestic biowaste, raw sludge and digested sewage sludge are composted separately within the landfill area.

Rahkonen and Ettola [22] concluded that the concentrations of fungi and mesophilic bacteria at the landfills were 2-30 times higher than the background concentrations. Further, concentrations of Gram-negative bacteria exceeded the suggested occupational exposure limit value (OELV) of 10^3 cfu/m^3 [17]. Compost windrows can cause occupational hazards when turned. The concentrations of bacteria and fungi exceeded 10^2-10^5 cfu/m^3 during turning [12].

According to Heida *et al.* [11] the concentrations of volatile organic compounds in the composting facility are below Dutch occupational exposure limit values, and adverse health effects of exposure to various organic compounds are thus not very likely. The workers at waste handling plants complain about bad odours, and Mølhave *et al.* [19] have shown that even low air concentrations of volatile organic compounds can cause irritation of the eyes, nose and throat.

Gaseous emissions from landfill sites and their effect on the environment were studied by Luning and Tent [14]. They stated that gaseous emissions of methane, nitrogen oxides, sulphur dioxide and halogenated hydrocarbons from landfill areas contribute significantly to the greenhouse effect. Twenty six selected volatile organic compounds measured at several landfill areas in New Jersey, USA, were found to be in excess of urban background levels [10].

In Finland, the gaseous emissions from landfills are examined from samples taken from tubes inserted in the fills. Assmuth and Kalevi [2] found chloromethanes and volatile aromatics in concentrations well above background levels. According to them, carbon tetrachloride, dichloromethane, toluene and benzene pose the most severe toxicological risks. However, Ettala *et al.* [7] estimated that emissions of methane and chlorinated compounds were well below the occupational exposure limit values. These two studies demonstrate variations between the landfill areas in concentrations of volatile organic compounds.

The aim of this study was to compare exposure in different waste treatment situations and to assess the occupational health risks of waste handling. We examined occupational exposure to microorganisms and volatile organic compounds of three groups of waste workers, i.e. in waste collection, at landfill sites, and in the resource recovery plant.

MATERIALS AND METHODS

Work situations sampled

Waste collection. Two workers from a private waste collection company were chosen to participate in the study after surveying the work practice. The workers used rear loading compaction vehicles, and during the sampling period they collected mixed household waste from 50–90 bulk storage containers (volume 1 m^3) in up to 30 different locations, where the frequency of waste collection is twice a week. With one of the workers two sampling periods were executed and one sampling period with the other. The number of microorganism samples collected in three different locations was nine, five of them were samples of xerophilic fungi and four samples of total bacteria. The microorganisms were collected as near to the worker's working area as possible as he was emptying containers. Eight control samples (four of xerophilic fungi and four of total bacteria) were collected just before the worker started to collect municipal waste for the first time. Eight separate VOC samples from the worker's breathing zone were taken during these periods. No control sample was taken for VOCs.

Landfill areas. At both of the landfill areas participating in the study, two workers supervised the unloading and spread and compacted the refuse. Both landfills accept domestic and building refuse, excess soil and small amounts of special refuse such as slaughter refuse, sewage sludge and industrial refuse. The amounts of waste handled were 64,000–75,000 tons per year. Sampling of microorganisms and VOCs from these two landfill sites was conducted twice at each site. The total number of both xerophilic fungi and total bacteria samples was 16 and the number of control samples was five for both xerophilic fungi and total bacteria. The sampling was executed as near as possible to the site the refuse was unloaded and compacted. Sixteen VOC samples were collected during these four sampling periods. Four of them were personal samples and three area samples served as background control samples. Both microorganism and VOC control samples were taken at the site about 50–200 meters upwind from the place waste was handled.

Resource recovery plant. The resource recovery plant handles 55,000 tons of presorted household waste and sludge per year. The waste was dumped into a pit in the waste processing room from where a conveyor belt took it to a mechanical shredder. If the waste was dry, mainly plastics, paper and cardboard, it was taken to the traditional landfill site after being shredded. Wet waste was taken on a conveyor belt to a separate bioreactor building where it was fermented to produce natural gas. Two of the workers operated the mechanical shredding from the control room or next to the pit, and one of the workers was situated in the fermentation tank building.

Two different sampling periods were conducted at the resource recovery plant. Samples were taken from the waste processing room, control room and from the bioreactor building. In addition, control samples were taken at the site about 50–200 m upwind from the place where waste was handled. The sampling was most extensive in the waste processing room where four samples of each for xerophilic fungi, total bacteria and Gram-negative bacteria were collected. An additional two samples for analysis of each group of microorganisms were collected from the waste processing room at the time the mechanical shredder was malfunctioning. Two samples of each for xerophilic fungi, total bacteria and Gram-negative bacteria were collected in the control room and in the bioreactor building. Three stationary and two personal VOC samples were collected in the waste processing room while the amount of stationary samples in the control room and in the bioreactor building were two and four, respectively. Two VOC control samples were taken at the site about 50–200 m upwind from the place waste was handled.

None of the waste handling sites had organized training in good working habits for the workers, and none of the workers used any protective equipment.

All the sampling periods were performed during summer time.

Methods of sampling and analysis

Sampling of microorganisms. Viable airborne fungi and bacteria were sampled with a six-stage Andersen impactor (model 10-800; Andersen Inc.) calibrated at an airflow rate of 28.3 l/min. Xerophilic viable fungi were collected on dichloran glycerol agar (DG18; Oxoid). Total viable bacteria were collected on R2A agar (Difco), and eosin methylene blue agar (EMB Difco) was used as a selective culture medium for viable Gram-negative bacteria. Gram-negative bacteria were collected only at the resource recovery plant.

The Andersen impactor was situated about 1.5 m above the ground as close as possible to the worker's working area. The control samples were taken some 100 m upwind from the place where waste was handled. In the case of truck drivers, the control samples were taken at the site once in a workshift just before collecting the dumpsters for the first time. The sampling time varied from 1–10 min.

Analysis of microorganisms. The plates of DG18 agar were incubated at 25ºC for 7 days. The plates for total bacteria count (R2A) were incubated at 20ºC for 7 days and EMB agar plates at 37ºC for 2 days. After incubation, the colonies were counted and the results were corrected by the positive-hole correction method [1]. The results are expressed as colony-forming units per m^3 of air (cfu/m^3). Fungal genera were identified with a light microscope and Gram-negative bacteria were identified after Gram staining by API 20E (for enterobacteria) and API 20 NE (for non-enterobacteria) test kits.

Sampling of volatile organic compounds. For collection of volatile organic compounds an adsorbent tube (length, 157 mm; outer diameter, 6 mm) filled with 150-200 mg of organic porous polymer adsorbent Tenax TA (60-80 mesh; Ohio Valley Specialty Chemical) was used. Before sampling, the Tenax tubes were purified for 6–8 hours or overnight at 300ºC under helium (AGA) flow of 20 ml/min. A glass fibre filter (Gelman Instrument Company) mounted in an open-faced three-piece cassette was used to prevent particles from entering the Tenax adsorbent. A personal air sampler (SKC 226-35; SKC Inc.) was used for sampling at the rate of 50 ml/min. The pump was calibrated by an airflow calibrator (Gilibrator, Gilian). In the stationary sampling of VOCs the Tenax tubes were located about 1.5 m above ground as close as possible to the workers. Stationary sampling was not done in the case of compactor truck drivers. In the personal sampling of VOCs, the Tenax tubes were located as close to the worker's breathing zone as possible. The blank samples were taken some 100 m away upwind from the place where waste was handled; in the case of truck drivers blank samples were not taken. The sampling time varied from 30–240 min.

Analysis of volatile organic compounds. The compounds trapped on the adsorbent were thermally desorbed with a thermal desorption injector (Chrompack Thermal Desorption Cold Trap Injector) [24]. The desorption temperature was 250ºC and the desorption time 10 min. The desorption gas was helium (20 ml/min). After desorption, the volatile compounds were concentrated in a cold trap (Chrompack WCOT Fused Silica CP-SIL 5 CB, film thickness, 5.0 µm; inner diameter, 0.53 mm) where the temperature was maintained at -120ºC with liquid nitrogen. The concentrated compounds were injected onto the column by the carrier gas by heating the trap to 200ºC for 2 min. Between the injector and the column there was an interface where the temperature was maintained at 200ºC. The gas chromatographic separation of VOCs was carried out by an HP 5890 gas chromatograph, using a fused silica capillary column (HP-1; 50 m by 0.20 mm [inner diameter]; Hewlett Packard) coated with cross-linked methyl silicone and a film thickness of 0.5 µm. The gas chromatographic temperature program was as follows: initial temperature 40ºC followed by a temperature rise of 10ºC/min up to 60ºC. After this first step, the temperature was increased by 1.5ºC/min up to 180ºC followed by an increase of 20ºC/min up to 280ºC/min. For identification of volatile compounds, a mass selective detector (HP 5971; Hewlett Packard) was used after the gas

Table 1. Concentrations of viable airborne fungi and bacteria in waste collection, at landfill sites and in the resource recovery plant (cfu/m^3).

	Xerophilic fungi			Total bacteria			Gram-negative bacteria[a]		
Sample	n	Median	Range	n	Median	Range	n	Median	Range
Background	12	100	14-580	11	110	18-1,500	2	7	0-14
Waste collection	5	1,200	70-23,000	4	1,700	35-4,500	-	-	-
Landfill sites	16	970	70-27,000	16	9,000	70-58,000	-	-	-
Resource recovery plant									
Waste processing room	4	112,000	64,000-121,000	4	150,000	47,000-165,000	4	65,000	23,000-139,000
No processing[b]	2	4,200	2,500-5,800	2	7,200	6,800-7,600	2	2,300	600-4,000
Control room	2	3,300	2,400-4,200	2	7,800	2,100-14,000	2	1,100	350-1,900
Bioreactor building	2	1,600	1,600-1,640	2	3,200	2,700-3,600	2	200	70-330

n = number of samples, [a]sampled only at the resource recovery plant, [b]mechanical shredder malfunctioning or there was no refuse to process

chromatographic separation. The temperature of the ion source was 280ºC and 70 eV was used as electron energy. The detector was used in the scan mode and ions from m/z 40 to m/z 400 were scanned. The volatile organic compounds were quantified as equivalents of toluene (Merck, > 99.5%) and a reference standard library (NIST) was used for identification of the compounds. When available, reference compounds were used as certification of identification of volatiles. Reference compounds and toluene standards were diluted to methanol and the dilution was spiked on to Tenax adsorbent. 1 litre of air was then pumped through the spiked adsorbent tube. The concentrations of volatile organic compounds are given as µg/m^3.

Statistical analysis. Mann-Whitney U nonparametric test was used to test the statistical significance of results.

RESULTS

Microorganisms. The airborne concentrations of viable fungi and bacteria in waste collection, at landfill sites and in the waste handling facility are presented in Table 1. The median concentration of fungi (1.12 × 10^5 cfu/m^3) was 100 times higher in the waste processing room at the resource recovery plant than in waste collection and at landfill sites where the median concentrations of fungi were modest, 1.2 and 0.97 × 10^3 cfu/m^3, respectively. The differences in concentrations between the waste processing room and waste collection and landfill sites are statistically significant with p-values $p < 0.014$ and $p < 0.002$, respectively. The concentration of bacteria was 15 times higher ($p < 0.005$) at the resource recovery plant than at the landfill sites and both total culturable bacteria and Gram-negative bacteria concentrations in the waste processing room exceeded the proposed occupational exposure limit values. It is noteworthy that the concentrations of fungi and bacteria in the bioreactor building were low, probably due to the closed fermentation tanks, while the microorganism concentrations were higher in the control room, regardless of the isolation and separate ventilation of this room.

The most abundant genera of fungi were *Aspergillus*, *Penicillium*, *Cladosporium*, *Acremonium* and *Fusarium*. In the genus *Aspergillus*, *A. fumigatus* and *A. niger* were the most abundant species. Other identified genera of fungi were *Alternaria*, *Aureobasidium*, *Botrytis*, *Geotrichum*, *Humicola*, *Hyalodendron*, *Monilia*, *Mucor*, *Paecilomyces*, *Rhizopus* and *Ulocladium*. The following Gram-negative genera were identified with API test kits: *Achromobacter*, *Acinetobacter*, *Aeromonas*, *Enterobacter*, *Escherichia*, *Hafnia*, *Klebsiella*, *Pseudomonas*, *Serratia* and *Yersinia*.

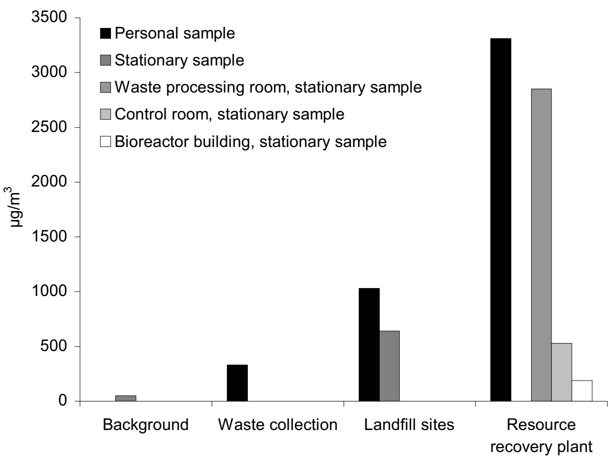

Figure 1. Concentrations of volatile organic compounds in waste collection, at landfill sites and in a waste handling facility. Concentrations are presented as medians.

Volatile organic compounds. The concentrations of volatile organic compounds during waste collection, at landfill sites and at the waste handling facility are presented in Figure 1. The concentrations of VOCs during the mechanical shredding of waste were three times higher ($p < 0.009$) in the waste processing room at the resource recovery plant (2850 µg/m^3) than at landfill sites (640 µg/m^3). Workers exposure to VOCs during waste collection was only modest (330 µg/m^3), and the pattern of VOCs suggested that most of the VOCs originated from the exhaust fumes of the vehicle rather than from the waste. Exposure to VOCs in the control room of the waste handling facility (530 µg/m^3) was greater than the exposure during waste collection, although not statistically significant ($p < 0.192$). When the mechanical shredding was temporarily stopped due to the shortage of refuse, or due to malfunctioning of the machine, the concentrations of VOCs and microorganisms were markedly reduced. During breaks, the median concentration of VOCs in the waste processing room was 550 µg/m^3 (n = 2). In the control room during the break the concentration of VOCs was 180 µg/m^3 (n = 1). Altogether 250 compounds were identified from the samples taken during waste handling. The following groups of compounds were found: aliphatic branched and unbranched hydrocarbons, cyclic hydrocarbons, aromatic hydrocarbons, esters, ethers, organic acids, aldehydes, ketones, alcohols, heterocyclic compounds, polyaromatic hydrocarbons, chlorinated hydrocarbons and sulphuric compounds.

DISCUSSION AND CONCLUSIONS

The occupational exposure to microorganisms and volatile organic compounds of three groups of waste workers, i.e. in waste collection, at landfill sites and in the resource recovery plant, was considerably different. The exposure in waste collection was generally low, but it is possible that while opening a waste container the worker can be exposed to high levels of microorganisms and VOCs for a short period of time. In addition, the physically demanding work carried out at a high speed results in a pulmonary ventilation of 25-40 l/min instead of the normal 6 l/min. At high pulmonary ventilation, particles may travel further down into the respiratory tract, thus inducing an irritative reaction [21]. When interviewed during the sampling period, the workers did not consider exposure to microorganisms and VOCs as the greatest inconvenience of their work. Instead, they stated that the handling of heavy waste bags, bins and containers, together with poor accessibility to the waste, causes many musculoskeletal problems.

The concentrations of fungi and bacteria at the landfill sites were 10^3-10^4 cfu/m^3 and similar to those measured by Rahkonen and Ettala [22]. The concentrations of microorganisms and VOCs are dependent on the quality of the refuse and the weather conditions, especially in Finland where temperatures vary from +25ºC in summer time to -25ºC in winter. This study was conducted in the summer time which was supposed to be the worst when considering a possible exposure to microorganisms and VOCs. The workers experienced extreme weather conditions to be far more crucial to their health than the exposure to microorganisms and VOCs.

The maximum exposure to microorganisms and VOCs was observed in the waste processing room at the resource recovery plant. The concentrations of fungi and bacteria were 10^4-10^5 cfu/m^3, which exceeded the concentrations measured by Malmros *et al.* [17] at a Danish garbage sorting plant. The concentrations of total culturable bacteria and Gram-negative bacteria were clearly above the suggested occupational exposure limit values [23]. The high levels of microorganisms and VOCs can be explained by the facts that the conveyor belt was open, the ventilation system seemed to be inefficient, and wet refuse fell off the belt and accumulated in many parts of the plant. The exposure of the workers in the bioreactor building was minor due to the use of closed fermentation tanks. The concentrations of microorganisms and VOCs in the control room were high, 10^3 cfu/m^3 and 530 µg/m^3, respectively. The concentrations of the bacteria exceeded the suggested occupational exposure limit, and the workers' exposure to VOCs was greater than that of the workers in waste collection.

The workers in the waste processing room stated that they suffered occasionally from eye and upper respiratory tract irritation, whereas the worker in the bioreactor building did not experience any health effects caused by the work. This is in good agreement with the results of Hansen *et al.* [9].

Most of the fungi found in this study belonged to the genera *Aspergillus* and *Penicillium,* which are known, e.g. for their potential to irritate the upper respiratory tract [3, 4]. The identified Gram-negative bacteria, found in waste handling also by Rahkonen and Ettala [22] and Clark *et al.* [6] are common in soil and water. High concentrations of endotoxins, toxic lipopolysaccharide components of Gram-negative bacteria, have been reported in waste handling [17, 20]. Endotoxins may cause fever, eye inflammation and fatigue in exposed workers [5, 13]. It can be assumed that also the endotoxin concentrations were high at the sites of the resource recovery plant where high concentrations of Gram-negative bacteria were measured.

The occupational exposure limit values for most of the organic compounds in air in Finland are in the range of 10^1-10^3 mg/m^3. In this study, the sum of dozens of VOCs in a sample was maximally 4.7 mg/m^3. Some VOCs are not adsorped by Tenax and therefore the VOC results are at least, to some extent, underestimations of true values. Although it can be concluded that the concentration of any single volatile compound did not exceed the Finnish occupational exposure limit value, the reactions of single workers to total VOC concentrations varied. The following classification of total VOC concentrations by Mølhave *et al.* [19] was suggested: Comfort range (< 200 µg/m^3), symptoms might occur within the range (200-3,000 µg/m^3), discomfort range (3,000-25,000 µg/m^3), and toxic range (> 25,000 µg/m^3). Thus, the VOC concentrations in the ambient air of the waste treatment workers were either in the multifactorial or discomfort range.

The workers at the resource recovery plant had the highest levels of exposure to both microorganisms and VOCs. At the landfill sites, the exposure to bacteria and VOCs was higher than in waste collection, where the exposure was only modest. Both microorganism and VOC exposure may cause various symptoms of the airways, and even cases of occupational diseases have been reported [4]. The mechanisms by which this exposure causes diseases are still largely unknown, but it is evident that exposure to these agents should be minimized.

Safe working habits are vitally important in waste management, especially for avoiding adverse health effects in waste handling. The use of personal protective equipment, thorough hand washing, and changing of clothes after the workshift, must be emphasized. The teaching of safe working habits is most crucial in the resource recovery plant where the waste handling occurs inside closed buildings. In addition, the ventilation of the control room in the resource recovery plant should be efficient enough to remove the impurities from the air.

In conclusion, despite the small amount of samples and apparent underestimation of VOC concentrations, the present results show that the exposure of workers to microorganisms and VOCs may be high in waste handling. These data are necessary for occupational health care personnel who organize health surveillance and instruct workers on the potential health effects of their work.

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