



## Research paper

## Exposure to biological and chemical agents at biomass power plants



Sirpa Laitinen <sup>a,\*</sup>, Juha Laitinen <sup>a</sup>, Leena Fagernäs <sup>b</sup>, Kirsi Korpijärvi <sup>c</sup>, Leena Korpinen <sup>d</sup>, Kari Ojanen <sup>a</sup>, Marjaleena Aatamila <sup>a</sup>, Mika Jumpponen <sup>a</sup>, Hanna Koponen <sup>e</sup>, Jorma Jokiniemi <sup>e</sup>

<sup>a</sup> Finnish Institute of Occupational Health, PO Box 310, FI-70101, Kuopio, Finland

<sup>b</sup> VTT Technical Research Centre of Finland Ltd, PO Box 1000, FI-02044 VTT, Espoo, Finland

<sup>c</sup> VTT Technical Research Centre of Finland Ltd, PO Box 1603, FI-40101, Jyväskylä, Finland

<sup>d</sup> Tampere University of Technology, ELT, PO Box 692, FI-33101, Tampere, Finland

<sup>e</sup> University of Eastern Finland, PO Box 1627, FI-70211, Kuopio, Finland

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## ABSTRACT

The increasing use and production of bioenergy means that the number of employees working in this area will inevitably grow, making it ever more important to know the health and safety issues involved in the biomass supply chain. Our aim was to determine the exposure of employees to biological and chemical agents during various work tasks at different biomass-fuelled power plants in Finland. The study included technical surveys on biomass operations and occupational measurements at three CHP plants. Workers' main health risks were bacteria and fungi, which were easily spread to the air during heavy biomass processes. The exposure levels of actinobacteria, bacterial endotoxins and fungi were high, especially during the unloading of peat and wood chips. In addition, workers were exposed to mechanical irritation caused by organic dust, and chemical irritation caused by volatile organic compounds and components of diesel exhausts. Multiple exposures to these agents may simultaneously have synergistic health effects on workers' lower and upper respiratory tracts. During operations, workers were also exposed to endotoxins, actinobacteria and fungi, especially during the cleaning and handling of wood chips in silos and while working near screens or crushers. The measured concentrations exceeded the limit values proposed for these agents. The highest concentration of volatile organic compounds was found near conveyors. On the basis of these measurements, we suggested best practices for the power plants. The levels of biological agents in outdoor measurements reflected only low spreading of contaminants from power plants to the environment.

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## 1. Introduction

The use of bioenergy in Finland has increased significantly during the last decade. In 2014, the total use of wood chips in heat and power plants was about 16 TWh, which – according to the 2020 target – should be increased to 25 TWh. The use of wood fuels in multi-fuel boilers is the most central and cost-effective way to increase the use of renewable energy in the generation of heat and power. The number of employees working with bioenergy is therefore expected to grow, making it increasingly important to know about the health and safety issues involved in the biomass supply chain. The exposure of people living near heat and power

plants may also grow.

During storage, wood fuels are subject to biological and chemical reactions and decomposition caused by bacteria and fungi. A potential health hazard can be raised from airborne microspores [1]. Microbial dustiness in solid biofuels has been studied especially in Denmark [2–6]. The concentrations of microorganisms in straw and wood chip dusts were found high in rotating drum tests [2]. Correlations between endotoxins, total bacteria and fungi, and total dustiness were found significant for outdoors stored baled straw and wood chips from piles [4]. During the outdoor storage of forest residues, low volatile hydrocarbons, such as terpenes, are emitted into the air in the gas phase [7]. Also hexanal from fatty acid oxidation has been found to be an important volatile compound emitted during the storage of solid wood fuels [8].

Occupational hygiene measurements during processing of solid biofuels at power plants have been reported in a few papers

\* Corresponding author.

E-mail address: [sirpa.laitinen@ttl.fi](mailto:sirpa.laitinen@ttl.fi) (S. Laitinen).

[3,9–12]. In these studies, levels of airborne microbial components varied between the workplaces in the plants and between the plants. The personal exposure levels to endotoxin, thermophilic actinomycetes, total bacteria and total fungi at the Danish biofuel plants were high when compared with suggested exposure limits [3]. Higher concentrations of endotoxin were found at straw plants than at wood-chip plants, while the opposite was measured for a fungus called *Aspergillus fumigatus*. In a Polish study [10] at a power plant co-firing biomass with coal, the highest bacterial and fungal concentrations were determined at workplaces related to reloading, screening and biomass transport via conveyor belts to silos. The results indicated that workers are exposed to bioaerosols containing potentially pathogenic bacteria and fungi. *Aspergillus fumigatus* was found in the air at all investigated workplaces.

Inflammation but no DNA damage in mice exposed to airborne dust from a biofuel plant has been found [5]. In addition, mutagenic activity of airborne particulate matter sampled in a biomass-fuel plant has been investigated [6]. Recently, Rohr et al. [11] reviewed the literature on known and potential occupational health and safety issues related to biomass-powered electricity generation. They suggested that pre-combustion risks, including bioaerosols and biogenic organics, should be considered further. Their results from the two biomass-based power generating plants indicated that the dust concentrations can be extremely variable. Workers may be exposed to many different agents at the same time during work in biomass-burning power plants. Multiple exposure of workers depends on many things, such as the fuels and chemicals used, storage of fuels, work tasks, the usage of protective clothes and respirators, and the weather.

As in the wood-processing industry [12], bacterial and fungal components in biomass are also associated with diseases, ranging from toxic pneumonitis symptoms to severe chronic lung diseases such as asthma, chronic obstructive pulmonary disease (COPD) and allergic alveolitis [13–17]. The exposure level to micro-organisms has an impact on the occurrence of respiratory symptoms among biofuel workers [18]. Bacterial and fungal concentrations of  $>10^4$  colony-forming units per cubic meter of air (cfu m<sup>-3</sup>) should be considered a threat to workers' health [19]. For single fungal species such as thermotolerant *Aspergillus fumigatus*, a threshold limit value (TLV) of 500 cfu m<sup>-3</sup> has been suggested. Due to their higher toxicity, mycotoxin-producing and pathogenic species have to be detected specially [20]. Endotoxins may be present in small particles below 1 µm, which are present in the air of solid biofuel plants [21]. The Nordic and Dutch Expert Group [22] has concluded that adverse health effects are expected after chronic occupational exposure at approximately 90 EU m<sup>-3</sup>. Other organic and wood dust, diesel exhaust and gases from degradation processes may be

harmful, particularly vaporous and gaseous agents in biomass-fuelled power plants. The Finnish Ministry of Social Affairs and Health has established occupational exposure limit (OEL) values for these agents in Finland [23]. The Finnish Institute of Occupational Health has established a reference value of 3000 µg m<sup>-3</sup> for total volatile organic compounds (TVOC), which should not be exceeded in a good industrial environment. For high quality indoor environments, a target value of 300 µg m<sup>-3</sup> has been established.

More surveys and measurements need to be carried out to assess the occupational hazards of modern energy production that utilises renewable biomass. It is important to assess the public health effects and provide recommendations for future scenarios. The aim of the study was to clarify the health and safety issues in the context of bioenergy supply chains. The main focus of this paper was to analyse the exposure of employees to biological agents and chemical compounds during various work tasks at different biomass-fuelled power plant sites in Finland.

## 2. Materials and methods

### 2.1. Measurements at power plant sites

Occupational hygiene measurements were carried out at three biomass- and solid recovered fuel- (SRF) fuelled power plants, located in different parts of Finland, in the autumn of 2012 and the winter of 2013. The selection of the combined heat and power (CHP) plants for case studies of the measurements was mainly based on the fuel variety, but other factors such as the age of the plant were also considered (Table 1). All the case power plants received at least one of the fuels by truck: rear-unloading, full-trailer trucks or rear-tipping trucks.

The research was carried out according to the process presented in Fig. 1. We performed a technical survey on biomass operations at the selected power plants to collect background information by interviews and observations regarding the power plant, the fuels used, their delivery chains, working habits, and occupational safety and health issues.

Workers' exposure to biological and chemical agents was measured during their normal duties. The collected air samples and measurements with direct reading instruments are summarised in Table 2. The stationary sampling points were reserved for source identification and mapping out concentration levels in different working areas. The personal exposure of workers during a work task was monitored from their breathing zones. Sampling periods varied from 38 to 430 min at stationary sites and from 26 to 170 min in breathing zones. Material samples of the fuels ( $n = 23$ ) used were collected from fuel reception sites and from conveyors

**Table 1**  
Basic information on case studies' combined heat and power plants.

Power plant	A	B	C
Boiler type	BFB <sup>a</sup>	BFB <sup>a</sup>	BFB <sup>a</sup>
Power (appr.)	75 MW <sub>fuel</sub>	200 MW <sub>fuel</sub>	170 MW <sub>fuel</sub>
Age of plant	New	~10 years	Old
Fuels used	Wood fuels 100%: forest chips, used wood, whole-tree chips, stemwood chips, wood processing industry residues	Wood fuels 50%: forest chips, stumps, forest residues, sawdust Bark 20% Milled peat 25% Waste water sludge 5%	Bark and waste water sludge 50% SRF <sup>b</sup> 50%
Additives used	Elemental sulphur	None	Elemental sulphur
Flue gas cleaning	Bag filter	ESP <sup>c</sup>	ESP <sup>c</sup> + Scrubber

<sup>a</sup> Bubbling fluidized bed.

<sup>b</sup> Solid recovered fuel.

<sup>c</sup> Electrostatic precipitator.

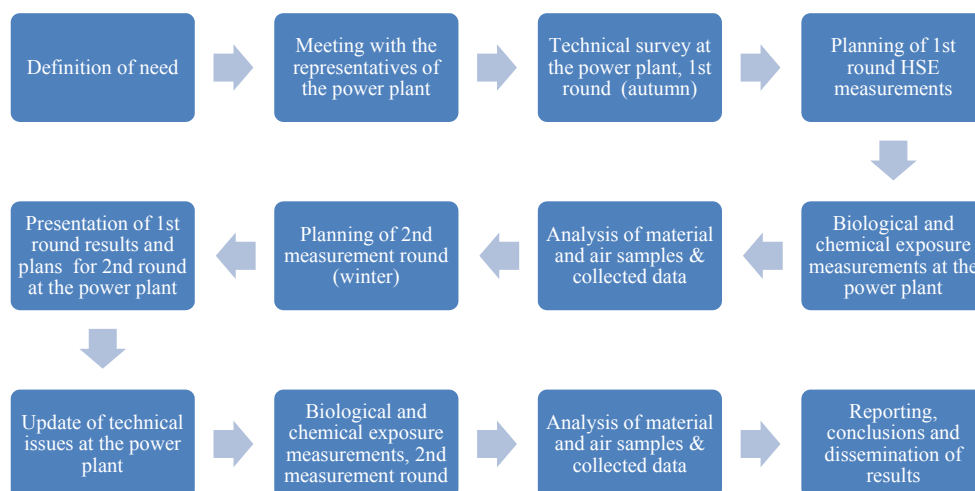


Fig. 1. Schema of research process.

Table 2

Number of collected air samples and measurements with direct reading instruments at the power plant sites.

Operation/place	Collected air samples				Direct measurements	
	Microbes	Endotoxin	Inhalable organic/inorganic dust	Other	Particles	Gases
Unloading	11	17	17	6	13	22
Processing of solid biofuels	16	18	13	26	9	21
Control room	5	5	4	3	2	0
Environmental air outdoors	11	8	0	0	0	0

before the boiler when possible. The samples were wood chips, hog fuel from stumps, bark, sawdust, thermally dried sludge, peat and SRF.

## 2.2. Analysis of biological exposure

Airborne viable bacteria and fungi were collected by open face cassettes with polycarbonate filters (0.4  $\mu\text{m}$ , Ø 37 mm, Whatman International Ltd.) at a flow rate of 2 L  $\text{min}^{-1}$  in a sample pump. Material samples for the laboratory analysis were taken directly from fuels into plastic bags according to EN 14778:2011 Solid bio-fuels (Sampling). All samples used for microbial cultivations and the analysis of endotoxins were processed within 24 h of sampling.

The viable bacteria and fungi of the samples were cultivated from 3 to 14 days on the following culture media at the temperatures specified. Mesophilic actinobacteria (*e.g.* *Streptomyces* spp.) and other bacteria were cultivated on tryptone yeast extract glucose –agar (+25 °C), mesophilic fungi on media with Rose Bengal (Hagem) and on Dichloran 18% glycerol –agar (+25 °C), thermotolerant fungi on Hagem –agar (+40 °C), and thermophilic actinobacteria on Half-strength nutrient –agar (+55 °C). After the incubation period, colonies were counted and those of actinobacteria and fungi were identified by microscopic examination of morphology. Concentrations of viable micro-organisms are expressed as (cfu  $\text{m}^{-3}$ ), and as (cfu  $\text{g}^{-1}$ ).

The detection method for endotoxins serves as a marker for the whole group of gram-negative bacteria, and indicates their presence in the sample. Inhalable endotoxins were collected into a glass fibre filter (1.0  $\mu\text{m}$ , Ø 25 mm, SKC Inc.) by an IOM Sampler at a flow rate of 2 L  $\text{min}^{-1}$ . The biologically active endotoxins in the air samples were measured using a validated kinetic chromogenic *Limulus* amebocyte lysate assay (Kinetic QCL, Lonza). The results were expressed as endotoxin units per cubic meter of air (EU  $\text{m}^{-3}$ ).

## 2.3. Analysis of exposure to particulates, vaporous and gaseous agents

The power plant operators' and truck drivers' exposure to inhalable dust was evaluated by a Millipore-filter (25 mm AAWP, pore size 0.8  $\mu\text{m}$ , Merck Millipore), using an IOM sampler (SKC) at a flow rate of 2.0 L  $\text{min}^{-1}$  [24]. Inhalable dust was also measured by the direct reading instrument SPLIT 2 (SKC). The results of the direct reading instruments were corrected gravimetrically.

X-am 5600, X-am 7000 and PAC 7000 (Dräger) direct reading instruments were used to measure concentrations of carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), oxygen (O<sub>2</sub>), nitric oxide (NO), nitrogen dioxide (NO<sub>2</sub>), ammonia, and hydrogen sulphide. Measured data was recorded on data loggers, and the recorded values represented the average values of sampling intervals from 10 s to 1 min. The gas monitor sensors for CO, CO<sub>2</sub>, NO and NO<sub>2</sub> were calibrated using calibrating gases (AGA) with known concentrations. Other sensors were calibrated in a service provided by the manufacturer of the instrument.

The VOCs were collected in Tenax TA adsorption tubes (SKC) at a flow rate of 0.1 L  $\text{min}^{-1}$ . Samples were analysed using a gas chromatograph (GC) equipped with a thermal desorption injection technique and mass selective detector [25]. Reduced sulphur compounds were collected into sample bags (Standard FlexFoil 263-20, SKC) using an evacuating sampling chamber [26]. The samples were analysed using the GC photoionisation detector technique.

## 3. Results and discussion

### 3.1. Micro-organisms in the indigenous fuels

Most of the indigenous solid fuels contained a great deal of

**Table 3**Concentrations of micro-organisms (cfu g<sup>-1</sup>) in fuel samples collected from power plants.

Fuel (N <sup>a</sup> )	Mesophilic fungi	Thermotolerant fungi	Mesophilic bacteria	Mesophilic actinobacteria	Thermophilic actinobacteria
Wood chips (6)	$9.3 \times 10^4$ – $1.5 \times 10^7$	$1.0 \times 10^3$ – $3.6 \times 10^6$	$2.5 \times 10^5$ – $2.4 \times 10^8$	$2.7 \times 10^4$ – $1.0 \times 10^6$	$<1.0 \times 10^2$ – $2.7 \times 10^4$
Hog fuel from stumps (1)	$6.8 \times 10^5$	$3.0 \times 10^4$	$1.6 \times 10^6$	$1.8 \times 10^5$	$2.0 \times 10^2$
Bark (3)	$9.3 \times 10^3$ – $5.2 \times 10^7$	$5.6 \times 10^4$ – $1.5 \times 10^6$	$4.2 \times 10^5$ – $1.6 \times 10^6$	$<1.0 \times 10^2$ – $1.8 \times 10^5$	$1.0 \times 10^2$ – $3.0 \times 10^2$
Sawdust (1)	$2.5 \times 10^5$ – $9.5 \times 10^5$	$1.5 \times 10^3$	$3.7 \times 10^7$	$<1.0 \times 10^2$	$<1.0 \times 10^2$
Thermally dried sludge (1)	$1.0 \times 10^2$ – $4.0 \times 10^2$	$<1.0 \times 10^2$	$1.4 \times 10^4$	$1.8 \times 10^3$	$<1.0 \times 10^2$
Blend of fuels (5)	$4.0 \times 10^2$ – $2.5 \times 10^7$	$1.6 \times 10^3$ – $4.0 \times 10^7$	$4.3 \times 10^4$ – $1.1 \times 10^8$	$1.8 \times 10^3$ – $5.1 \times 10^6$	$2.2 \times 10^3$ – $7.3 \times 10^4$
Peat (3)	$7.2 \times 10^4$ – $3.7 \times 10^5$	$6.0 \times 10^2$ – $3.8 \times 10^4$	$1.5 \times 10^6$ – $11 \times 10^6$	$<1.0 \times 10^2$ – $1.8 \times 10^5$	$<1.0 \times 10^2$ – $2.0 \times 10^2$
SRF (3)	$5.4 \times 10^6$ – $4.8 \times 10^7$	$5.9 \times 10^4$ – $7.1 \times 10^5$	$5.1 \times 10^7$ – $1.1 \times 10^{10}$	$<1.0 \times 10^2$ – $2.7 \times 10^4$	$<1.0 \times 10^2$ – $7.5 \times 10^6$

<sup>a</sup> Number of samples.

bacteria and fungi (Table 3). The variations in workers' exposure levels were mainly in different fuels and work tasks. The SRF fuels included the highest numbers of micro-organisms of the studied fuels, although they released lower bioaerosol and dust levels into the air than the other solid fuels. Peat, a slowly renewable biomass fuel, included smaller amounts of mesophilic bacteria than the SRF, but it caused the largest concentrations of mesophilic bacteria in working areas during the unloading of the fuel (Table 4). A majority of these bacteria are apparently gram-negative bacteria, because high concentrations of endotoxins were also detected in the breathing zones of peat drivers (Table 5). A Canadian study [27] found bacterial levels of up to  $4.8 \times 10^7$  cfu g<sup>-1</sup> in peat samples, and the presence of thermophilic bacteria was only sporadic.

Thermotolerant fungi and thermophilic actinobacteria were more abundant in the wood chip, bark and SRF fuels than in the milled peat. Mixtures of fuels also seemed to be very susceptible to microbial growth. Actinobacteria, *Aspergillus fumigatus*, *Penicillium* spp., and yeasts were the most common identified species. This may be due to the self-heating of biomass in storages, which causes a growth of these micro-organisms. When organic material with sufficient moisture content is stored for a prolonged time, micro-organisms may start to grow. Outdoor storage of solid biofuels seems to increase at least the microbial contamination of wood chips [28]. The multiplying process of micro-organisms could be prevented by drying fuel masses. One example of this in our study was the thermally dried sludge, which included only a few micro-organisms. That sludge from the waste water treatment plant of a paper mill was dried to a dry matter content of 80 w-% and then pneumatically conveyed to the boiler.

### 3.2. Workers' exposure during fuel reception

Employees were exposed to a huge amount of organic dust while unloading indigenous fuels (Fig. 2). Usually the driver has to enter the unloading room several times during the process for manual fuel sampling, opening and closing doors, and cleaning the area, which causes a great deal of variation in workers' exposure.

The inhalable dust concentrations during unloading were highest for peat and lowest for SRF (Table 5). The average inhalable dust concentrations were over 5.0 times higher than the Finnish OEL<sub>8</sub> hours for organic dust (5 mg m<sup>-3</sup>) in stationary sites for peat, wood chips and stumps. The personal measurements from truck drivers' breathing zones supported the stationary site sampling findings. However, technical preventive measures decreased drivers' average exposure levels to below the OEL<sub>8</sub> hour value in almost all cases (Table 5). The only exception was the unloading of peat, when the average inhalable dust concentration was 2.4 times higher than the OEL<sub>8</sub> hour value. The dust values measured in the unloading of forest residues and stumps were very similar to those of earlier Finnish studies [9].

Organic inhalable dust includes a great deal of bioaerosols, and therefore endotoxin levels were also the highest in the unloading of indigenous fuels (Table 5). The air concentrations of endotoxins several times exceeded the suggested limit value of 90 EU m<sup>-3</sup>, which may cause adverse health effects for workers after short- or long-term occupational exposure. Microbial concentrations during unloading were higher than 10<sup>4</sup> cfu m<sup>-3</sup>, which may be a threat to workers' health (Table 4). Bioaerosol levels measured during the unloading of fuels were higher than those in the corresponding power plants of previous studies [3,9,10]. The highest air concentrations of fungi were measured during the handling of wood chips, while the highest airborne bacterial levels were in the unloading of peat. The composition of airborne micro-organisms was similar to that identified in the biomass of the fuels.

The highest measured concentration of the TVOC during the unloading of fuels was six times the recommended reference value for good industrial air (3000 µg m<sup>-3</sup>) established by the Finnish Institute of Occupational Health (Table 6). The main VOCs in the air were α-pinene, Δ<sup>3</sup>-carene, β-pinene, limonene, and other monoterpenes (C<sub>10</sub>H<sub>16</sub>). The major part of the detected VOCs originated from pine and spruce softwood. Our findings concerning fuel reception during the unloading of biofuels supported the earlier results of fuel emissions, in which the most abundant VOCs in the air of logging residue storage were α-pinene, β-pinene and Δ<sup>3</sup>-

**Table 4**Air concentrations of micro-organisms (cfu m<sup>-3</sup>) during unloading and processing of fuels at power plants.

Operation (N <sup>a</sup> )	Mesophilic fungi	Thermotolerant fungi	Mesophilic bacteria	Mesophilic actinobacteria	Thermophilic actinobacteria
Unloading wood chips (6)	$4.5 \times 10^2$ – $1.4 \times 10^7$	$<2.3 \times 10^2$ – $1.1 \times 10^7$	$2.3 \times 10^2$ – $9.4 \times 10^5$	$4.6 \times 10^2$ – $8.9 \times 10^5$	$<1 \times 10^2$ – $1.2 \times 10^4$
Supervision room during unloading chips (2)	$2.8 \times 10^2$ – $8.8 \times 10^2$	$73$ – $1.8 \times 10^2$	$92$ – $2.2 \times 10^2$	$73$ – $92$	$<92$
Unloading stumps (1)	$3.3 \times 10^3$ – $5.7 \times 10^3$	$2.6 \times 10^2$	$2.1 \times 10^3$	$2.9 \times 10^3$	$<2.4 \times 10^2$
Unloading peat (2)	$3.7 \times 10^4$ – $1.6 \times 10^5$	$1.3 \times 10^3$ – $1.9 \times 10^3$	$3.8 \times 10^5$ – $2.3 \times 10^6$	$1.7 \times 10^4$ – $2.8 \times 10^4$	$<6.3 \times 10^2$
Unloading SRF (1)	$2.0 \times 10^4$ – $2.3 \times 10^4$	$1.9 \times 10^4$	$5.5 \times 10^3$	$9.0 \times 10^2$	$<8.3 \times 10^2$
Cabin of wheel loader during unloading SRF (2)	$<2.8 \times 10^2$ – $6.1 \times 10^2$	$<6.1 \times 10^2$	$<2.8 \times 10^2$ – $1.2 \times 10^3$	$<6.1 \times 10^2$	$<6.1 \times 10^2$
Screen, crusher (3)	$4.0 \times 10^2$ – $5.6 \times 10^4$	$5.3 \times 10^2$ – $2.0 \times 10^4$	$1.2 \times 10^2$ – $4.1 \times 10^3$	$1.1 \times 10^3$ – $2.1 \times 10^3$	$<1.2 \times 10^2$ – $3.4 \times 10^3$
Conveyor (1)	$1.5 \times 10^4$ – $1.8 \times 10^4$	$8.7 \times 10^3$	$4.7 \times 10^2$	$1.7 \times 10^3$	$3.1 \times 10^2$
Silo (2)	$8.4 \times 10^3$ – $7.0 \times 10^4$	$4.3 \times 10^3$ – $1.3 \times 10^4$	$1.2 \times 10^2$ – $6.5 \times 10^4$	$3.4 \times 10^2$ – $4.8 \times 10^4$	$<3.8 \times 10^2$

<sup>a</sup> Number of samples.

**Table 5**

Concentrations of inhalable organic dust ( $\text{mg m}^{-3}$ ) and endotoxins ( $\text{EU m}^{-3}$ ) at stationary site and in truck drivers' breathing zones during unloading of fuels at power plants.

Fuel	Reception hall ( $N^a$ )		Truck drivers' breathing zone ( $N^a$ )	
	Organic dust	Endotoxin	Organic dust	Endotoxin
Wood chips	<0.3–43 (4)	<2.8–6700 (5)	1.5 (1)	36–140 (2)
Stumps	0.5–25 (2)	450 (1)	<1.6–3.7 (3)	11–44 (3)
Peat	33–87 (2)	96 (1)	4.5–12 (2)	58–590 (2)
SRF	<1.6 (1)	16 (1)	<1.8 (2)	17–49 (2)

<sup>a</sup> Number of samples.

carene [7]. According to Edman et al. [29], the measured concentration levels of monoterpenes in pellet storage ranged from  $640 \mu\text{g m}^{-3}$  to  $28000 \mu\text{g m}^{-3}$ .

Acetone and sulphur dioxide were also detected in the air of the reception hall. Diesel gasoline contains a certain amount of sulphur, which might be responsible for sulphur dioxide emissions in trucks exhausts (Table 6). Workers' exposure to other components of diesel exhaust was also relatively high (Fig. 3). For example, during the unloading of SRF, the highest short-term concentration of nitrogen dioxide was 1.1 times higher than the  $\text{OEL}_{15 \text{ min}}$  value (6 ppm), and that of carbon monoxide was 1.3 times higher than the  $\text{OEL}_{15 \text{ min}}$  value (75 ppm). Concentrations of nitric oxide were under the  $\text{OEL}_{8 \text{ hour}}$  value of 25 ppm.

Supervision of unloading from a separate control room (Fig. 4) reduced workers' exposure to harmful agents, although in some cases it was noticed that the air flowed through the supervision hatches to the direct control room from the unloading hall. In addition, considerably lower concentrations were obtained in drivers' breathing zones in the cabins of trucks or wheel loaders. The drivers who had to go inside the halls to take fuel samples and clean the trucks, and into the unloading areas had higher exposure levels in their breathing zones than others.

During preparation of fuel samples in the laboratory, when opening of a barrel containing fuels, the inhalable dust

**Table 6**

Concentrations of total volatile organic compounds (TVOCs) and major VOCs in fuel reception hall.

Operation ( $N^a$ )	TVOC ( $\mu\text{g m}^{-3}$ )	Major VOCs	VOC concentration ( $\mu\text{g m}^{-3}$ )
Unloading of wood chips and unloading and crushing of stumps (4)	80–18000	$\alpha$ -Pinene	120–5300
		$\Delta^3$ -Carene	48–3900
		$\beta$ -Pinene	3500
		Limonene	23–2200
		Monoterpene	2000
		$\text{C}_{10}\text{H}_{16}$	
		Acetone	54
		Sulphur dioxide	45
		1-Propanol	28
		Camphene	9

<sup>a</sup> Number of samples.

concentration achieved the  $\text{OEL}_{15 \text{ minutes}}$ -value for organic dust ( $10 \text{ mg m}^{-3}$ ) in worker's breathing zone. The average inhalable dust concentration in worker's breathing zone was  $2.6 \text{ mg m}^{-3}$  during the whole working period, which was 52% of the  $\text{OEL}_{8 \text{ hours}}$ -value for organic dust.

### 3.3. Workers' exposure during processing of indigenous fuels

Stationary measurements at different locations during the processing of fuels aimed to cover all the places workers had to continuously visit. Personal samples were collected from workers who did surveillance work and walked around the power plant doing operator's tasks such as checking, cleaning and sampling during their work shift.

Crushing and screening buildings, conveyor belts, and the areas below storage silos were recognized by employees as possible exposure sites (Table 4). While the crusher and screen were processing, the concentrations of bioaerosols were high (endotoxins up to  $130 \text{ EU m}^{-3}$  and fungi up to  $56000 \text{ cfu m}^{-3}$ ). The highest short-term inhalable dust concentrations were recorded when

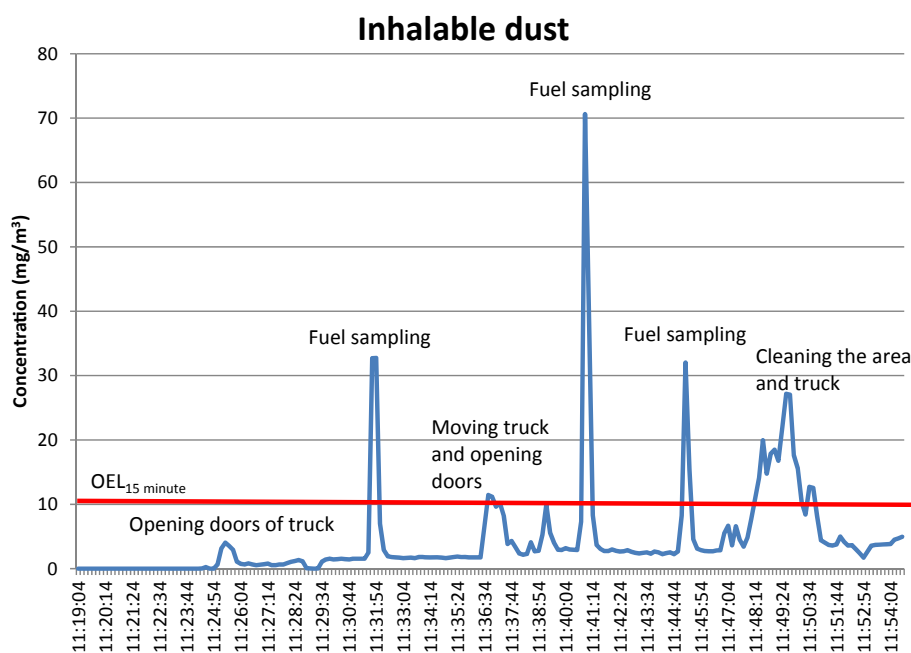
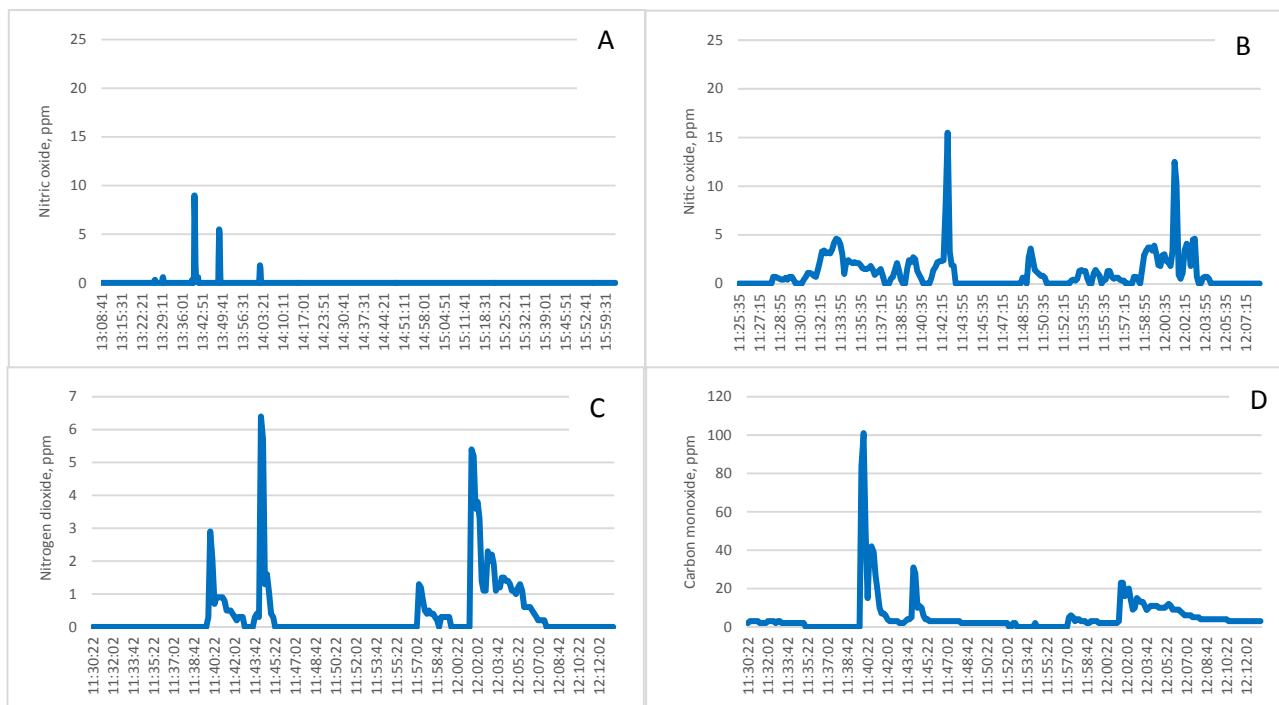


Fig. 2. Variation of organic dust concentration in drivers' breathing zones during unloading of peat.



**Fig. 3.** Concentration variation of nitric oxide (A and B), nitrogen dioxide (C) and carbon monoxide (D) at stationary sites (A, C and D) and in drivers' breathing (B) zones during unloading of biofuels.

workers had to go to the screening and crushing department of SRF: these were 1.5 times higher than the  $OEL_{15 \text{ min}}$  value for organic dust (Fig. 5). During the cleaning of SRF screens, the concentration of endotoxins was very high ( $570 \text{ EU m}^{-3}$ ) in the breathing zones of the workers. The highest average inhalable dust concentration was measured during the cleaning of screens and the changing of the sulphur sack, at  $4.3 \text{ mg m}^{-3}$ , which was 86% of the  $OEL_{8 \text{ hour}}$  value, the highest short term exposure level was 2.8 fold higher than the  $OEL_{15 \text{ min}}$ -value for organic dust, respectively (Fig. 5).



**Fig. 4.** A driver can supervise rear-unloading from a separate room through a small window.

The concentrations of reduced sulphur compounds in the heat recovery department were at a significant level and must be addressed as an occupational hazard in biomass-fired power plant processes. The average hydrogen sulphide concentrations in heat recovery were 24% of the  $OEL_{8 \text{ hour}}$  value (5 ppm), and the corresponding values for methyl mercaptan were 60% of the  $OEL_{8 \text{ hour}}$  value (0.5 ppm). A small amount (0.1 ppm) of dimethyl sulphide was also found here. The use of additives, such as sulphur or ammonium sulphate, to prevent fouling of the boiler heat transfer surfaces, to avoid the corrosion caused by alkaline chlorides from fuels, and to control air emissions, is increasing at biomass-fuelled power plants. This means that health and safety issues during these new process stages should be carefully considered. High short-term exposure to carbon monoxide in boiler rooms was also possible during malfunctions of boilers, according to the data recorded in the boiler room during the entire work shift (Fig. 5).

One surveillance operator's exposure to carbon dioxide was measured when he washed the floors near the silo department in order to determine the possible risk caused by the fermentation of biofuels. The highest measured short-term exposure level of  $\text{CO}_2$  exceeded the  $OEL_{8 \text{ hour}}$  value (5000 ppm) (Fig. 5). It was also interesting to note that during the highest carbon dioxide concentrations, oxygen concentration started to decrease, which might reflect the ability of carbon dioxide to replace oxygen in the air at already measured concentration levels. The measured decrease of oxygen concentration was not significant enough to have any effects on workers. The ratio of oxygen has to decrease to 18% before workers start to suffer [23]. Some bacteria and yeasts, especially anaerobic bacteria such as clostridia, are capable of converting a wide range of carbon sources of biomass via fermentation into chemicals and fuels such as carboxylic acids (e.g. acetic acid), acetone, butanol, and ethanol [30]. These compounds were found in the air samples taken from unloading and crushing halls, and from inside conveyors and silos, and showed the rate of the fermentation process of biofuels.

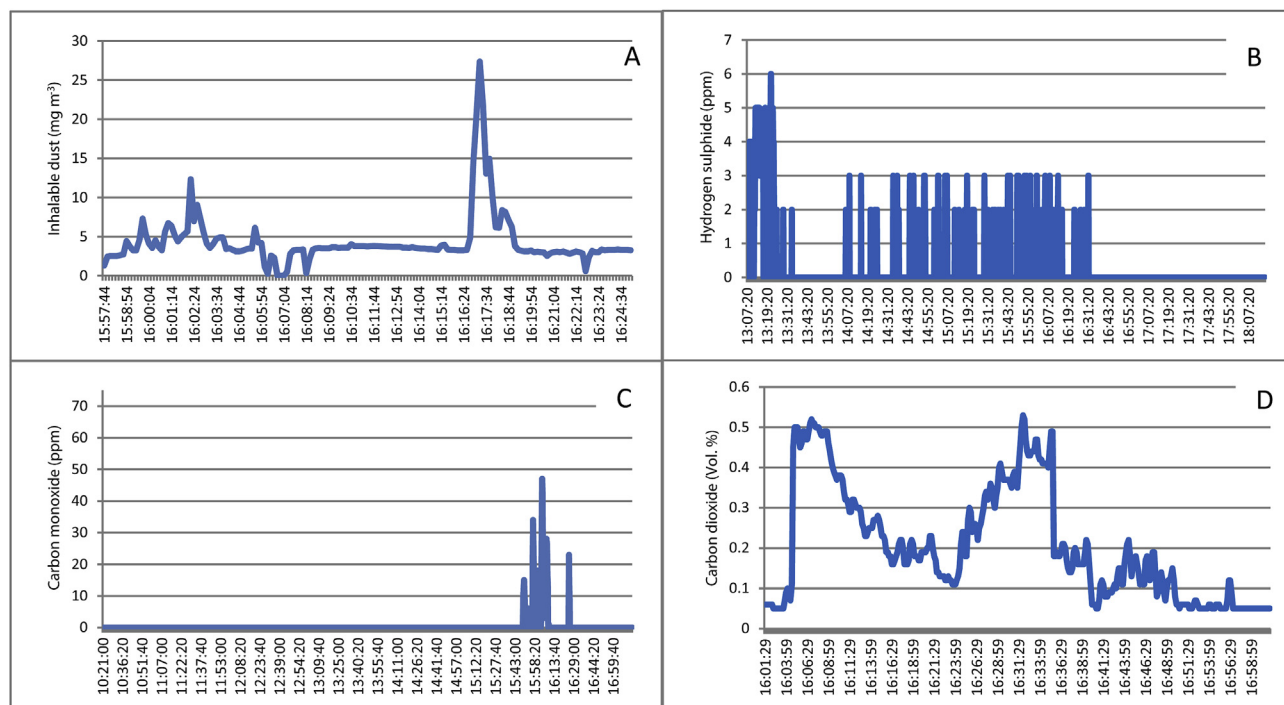


Fig. 5. Surveillance workers' exposure to organic dust (A), hydrogen sulphide (B), carbon monoxide (C) and carbon dioxide (D).

The highest TVOC concentration was measured near the conveyor of bark and sludge (Fig. 6). The measured concentration was 12 times higher than the reference value for good air quality in industry ( $3000 \mu\text{g m}^{-3}$ ). The main detected VOCs were acetic acid  $23000 \mu\text{g m}^{-3}$ , different monoterpenes  $11500 \mu\text{g m}^{-3}$ , and ethanol  $7200 \mu\text{g m}^{-3}$ . Near the bio silo, TVOC concentration was 5.3 times higher than the reference limit value, and the main VOCs were  $\Delta^3$ -carene  $3700 \mu\text{g m}^{-3}$ ,  $\alpha$ -pinene  $3600 \mu\text{g m}^{-3}$ , and  $\beta$ -pinene  $2100 \mu\text{g m}^{-3}$ . The highest average concentrations of terpenes were under 10% of the OEL<sub>8 hour</sub> value for turpentine [23]. TVOC concentrations measured in other parts of the process fulfilled the reference value for good air quality in industry.

The concentrations of bioaerosols and dust were low in the vicinity of enclosed processes. Another study of sludge drying units, in which operating dryers and conveyors were closed, found that the monitoring tasks in the dryer room were also associated with low levels of personal exposure to bioaerosols [31]. However, when

the cleaning and maintenance of the dryers and conveyors required the equipment to be opened, significantly higher task-based personal exposure levels were obtained. This was also seen in our study during maintenance work in a silo of wood chips: the concentration of endotoxins was  $310 \text{ EU m}^{-3}$  in the workers' breathing zones, and the concentrations of fungi and bacteria were  $>10^4 \text{ cfu m}^{-3}$ . In addition, during the preparation of fuel samples in the laboratory – for example, opening a barrel containing fuels – the short term inhalable dust concentration reached the OEL<sub>15 min</sub> value for organic dust ( $10 \text{ mg m}^{-3}$ ), and fungal levels were  $>10^3 \text{ cfu m}^{-3}$  in workers' breathing zones.

The levels of endotoxins, bacteria and fungi in outdoor measurements showed that only a small amount of contaminants spread from power plants to the environment. A few hundred metres away from the processing buildings, the environmental concentrations of bioaerosols were lower than in the vicinity of the power plants. The median level of mesophilic fungi was

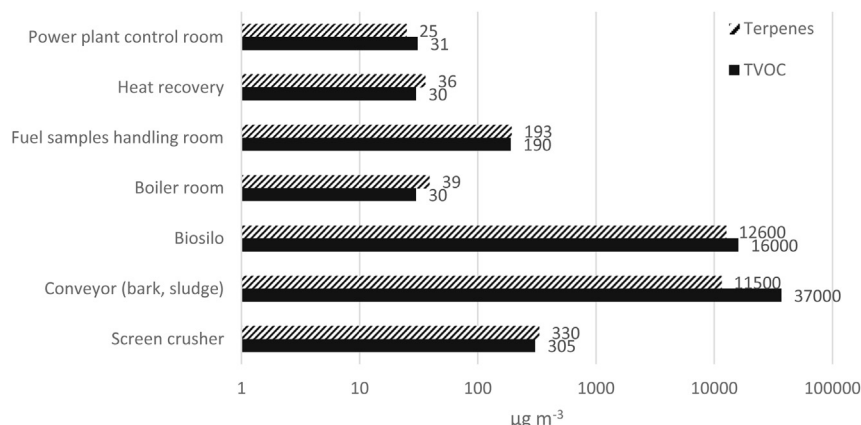


Fig. 6. Concentration of terpenes and total volatile organic compounds in different parts of power plants during processing of biofuel.

795 cfu m<sup>-3</sup> and the median concentrations of endotoxins were <2.7 EU m<sup>-3</sup>, which are normal values for micro-organisms outdoors. The results are in accordance with measurements taken by Madsen [3], where the median reference level of cfu fungi was 320 cfu m<sup>-3</sup>, and that of endotoxins 2.2 EU m<sup>-3</sup>. Especially in rainy weather, all concentrations of the microbial samples and dust samples taken from the outdoor air were low. Differences between seasons were not perceived during the study period, because the winter resembled autumn, and the temperature did not really fall significantly below zero.

#### 4. Conclusions

Using sequential technical surveys and occupational hygiene measurements at different biomass-fired power plant sites proved to be an effective method for the study. We found places and work tasks that possibly caused exposure. The occupationally harmful process steps at biofuel power plants were unloading, screening, crushing, conveying of fuels, and the handling of biomass in silos. Unloading produced a great deal of organic dust, which spread to the station area. The main occupational exposure-associated health risks for workers at biomass-fired power plants were bacteria and fungi, which easily spread to the air from indigenous fuels during heavy biomass processes. The measured exposure levels of bio-aerosols were especially high during the unloading of peat and wood chips. In addition, workers were exposed to mechanical irritation caused by organic dust, and chemical irritation caused by volatile organic compounds and components of diesel exhausts. The measured concentrations exceeded the proposed limit values for these agents. The highest concentration of volatile organic compounds was found near conveyors. The measured profile of these agents contained many metabolites of bacteria and fungi. Multiple exposures to these agents may have synergistic health effects on workers' lower and upper respiratory tracts.

More attention should be paid to health and safety issues when developing the bioenergy supply chain. The key to preventing exposure-associated respiratory impairments of workers at the biomass-fuelled power plant sites is to improve the quality of fuels. Better microbial quality also ensures higher calorific value of a solid biofuel. As a preventive technical measure, the fuel reception halls, crushers and screens could be isolated, for example, and hoods could be used in these operations. Enclosure of conveyors could also reduce the spreading of bioaerosols and other agents into the surroundings. Control rooms for the supervision of unloading fuel trucks, automated fuel sampling, and automatic cleaning systems for fuel trucks are favourable solutions for reducing truck drivers' exposure. Employee exposure should primarily be diminished by technical solutions and secondarily by the regular use of appropriate protective clothing and respirators.

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