Atmospheric Environment 193 (2018) 101–108

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Human exposure to airborne particles during wood processing

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ARTICLE INFO

Keywords:
Wood dust
PM_{10}
Ultrafine particle
Workplace exposure
Aerosol dosimetry

ABSTRACT

Wood processing has been known to emit a large amount of inhalable wood dust, but the emissions of particles with diameters smaller than 10 µm and ultrafine particles (UFP, particles with diameters smaller than 100 nm), as well as their exposure levels, remain unclear. The present study measured the particle profiles from 5.6 nm to 10 µm from wood processing in a pilot plant and in the wood industry, respectively. Large increase of particle number concentrations (PNC) was observed during pilot scale refinery, flaking, cross hammer mill, chipping and sawing, but not during sieving, drying, gluing and pressing, when comparing with background PNC. In the wood industry (one sawmill and one wood-based panel factory), we observed high PNCs, and in some production sites (chipping, MDF form station, MDF press station) high particle mass concentrations (PMCs). Human respiratory tract deposition modelling showed that the deposition of the particle surface area in the size range of 0.3–10 µm was mainly in the extrathoracic region, and the particle surface area in the size range of 5.6–560 nm was mainly deposited in the alveolar interstitial. Exposure of a few minutes when processing wood in the pilot plant can lead to a high particle dose. The particle dose for an 8-h exposure in the wood industry was much higher than urban background exposure scenarios, in some workplaces by a factor of about 50–100. This study gives first evidence that wood processing could emit a large number of UPF and particles < 10 µm. Our results indicate that the current mass-based occupational exposure limit for wood dust is not able to reveal the high exposure to UFP and particles < 10 µm.

1. Introduction

In the wood processing industry, the exposure to wood dust is one of the major potential health threats to workers. Epidemiological studies have shown that exposure to wood dust is associated with nasal and sinonasal cancers (Alonso-Sardon et al., 2015). Consequently, the International Agency for Research on Cancer (IARC) classified wood dust as a group 1 human carcinogen (IARC, 1995). In the European Union, the occupational exposure limit value for hardwood dust is 5 mg/m^3 (Council Directive, 2004). This limit value was used to protect workers from exposure to wood dust as a carcinogen.

Wood dust also causes many respiratory and dermal symptoms. Early studies on the association between wood dust exposure and respiratory diseases were published in 1940s (Ordman, 1949a, 1949b), where allergic asthma was attributed to wood dust exposure. Evidence continued to accumulate regarding the health effects of wood dust (Alwis, 1998; Enarson and Chan-Yeung, 1990; Hessel et al., 1995). Alwis (1998) summarized four main non-carcinogenic respiratory health effects including 1) allergic respiratory effects such as asthma (Douwes et al., 2001; Schlunssen et al., 2012); 2) non-allergic respiratory effects including reduced lung function and chronic bronchitis (Hessel et al., 1995; Noertjojo et al., 1996; Whitehead et al., 1981a); 3) sinonasal effects (Holmstrom and Wilhelmsson, 1988; Wilhelmsson and Lundh, 1984) and 4) lung fibrosis (Hubbard et al., 1996; Scott et al., 1990). Obviously, wood dust influences both upper and lower respiratory tracts, and causes many non-carcinogenic respiratory diseases, which affects the wellbeing of non-protected wood industry workers.

A number of studies carried out so far focused on the exposure to inhalable wood dust, which is defined as the dust that can be inhaled by nose or mouth (Alwis et al., 1999; Demers et al., 2000; Kauppinen et al., 2006; Magagnotti et al., 2013; Rongo et al., 2004; Saejiw et al., 2009; Scarselli et al., 2008; Scheeper et al., 1995; Teschke et al., 1999). The inhalable wood dust consists of particles with a diameter smaller than 100 µm (ACGIH, 2005). Several studies demonstrated that the majority of inhalable wood dust mass is in the size range of > 10 µm (Chung

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https://doi.org/10.1016/j.atmosenv.2018.08.064
Received 20 March 2018; Received in revised form 30 August 2018; Accepted 31 August 2018
Available online 01 September 2018
1352-2310/

et al., 2000; Pisaniello et al., 1991; Whitehead et al., 1981b), which deposits almost exclusively in the extra-thoracic region (including nose, mouth, larynx and pharynx), and is most relevant to nasal diseases. On the other hand, PM_{10} or $PM_{2.5}$, (defined as particles with an aerodynamic diameter smaller than 10 μm, or 2.5 μm, respectively) is able to penetrate deeper in the respiratory tracts, including bronchial, bronchioles and the gas exchange region of the pulmonary alveoli. Moreover, the ultrafine particles (UFP, particles with a diameter smaller than 100 nm) can penetrate into the alveolar region, and enter the blood circulation system (Oberdörster et al., 2005).

These small particles (particles < 10 μm and UFP) contribute a small fraction to the inhalable wood dust mass concentration, and are therefore neglected largely when focusing on the inhalable wood dust. In this regard, the extensively studied exposure to inhalable wood dust, may not provide the most relevant information for assessing the risk of wood dust in the lower respiratory tract. The determination and characterization of particles in the sub-10 μm size range is needed for a risk assessment of wood dust in the lower respiratory regions.

The particle number concentration (PNC) is commonly used when describing the UFP, however, from a toxicological point of view, the more health relevant dose metric is the particle surface area (Brown et al., 2001; Schmid and Stoeger, 2016). Therefore, when evaluating the particle exposure, particle surface area should be investigated as well, since it may provide a more comparable exposure metric with other studies.

Traditional wood and furniture industries, where most previous measurement campaigns occurred, mainly deal with mechanical processing of wood like cutting, sawing, joinery and sanding. However, the worldwide production of wood-based panel products has increased rapidly, and was doubled since 2000 (http://www.fao.org/faostat/en/#data/FO). The wood-based panel industry uses different procedures than sawmills and furniture factories, including chipping, refinery and thermo-press, sanding etc. More information on the wood-based panel production could be found in Kasal et al. (2015). Studies focused on the physical characteristics of aerosol particles and exposure levels in the wood-based panel industry are scarce. Consequently, it is one of our aims to expand the knowledge in this area.

In the wood industry, the use of coniferous wood is dominant. However, in the past years, the forestry and environmental policy in Germany favored the cultivation of hardwood and mixed forest, thus reduced the coniferous wood supply. The wood industry is facing increasing pressure on the coniferous wood supply and increasing prices. An alternative is the substitution of coniferous wood by hardwood, which has been little utilized so far. It is expected that the proportion of hardwood as raw material in the wood industry will increase in the future. As a result, we selected three common hardwoods (birch, oak and beech), and one type of coniferous wood (pine) in the processing, with a particular focus on the hardwoods emission.

When considering the open questions discussed above the aim of the present study is twofold: 1) to measure the particle profiles during the processing of wood, and 2) to characterize the workplace exposure to particle and the deposition in human respiratory tracts.

2. Materials and methods

2.1. Wood processing and measurement sites

2.1.1. Pilot plant

The measurements were carried out in the pilot plant at the Fraunhofer WKI, in a sawmill, and a wood-based panel factory, respectively. The pilot plant consists of two enclosed production halls, A and B, where several machines are installed (see Figure S3). Hall A has a dimension of 30 m × 10 m × 7 m (L × W × H), and was used for sawing, flaking, cross hammer mill, chipping and sieving. Hall B has a size of 35 m × 15 m × 7 m (L × W × H). The processings including drying, refinery, gluing and pressing were carried out in Hall B.

Particles were measured in the pilot plant for processing including sawing, flaking, cross hammer mill, chipping, sieving, drying, refinery, as well as gluing, forming and pressing. Four common woods of birch, oak, beech and pine were processed. Three types of wood board (medium density fiber board (MDF), oriented strand board (OSB) and particle board) were produced from each wood type. During a processing cycle, the particle instruments were placed next to the production site at a distance of about 1.5 m. It was chosen to represent the exposure situation of the machine operator. The online particle measurement was started before the processing to obtain the particle background concentration. Four types of woods were processed one after another. There was a break between processing each wood, which allows the emitted particles to disperse and the concentrations to decrease. When the processing finished, the instruments kept measuring for 30 min or until the concentrations decreased to the similar level as background concentration. A detailed protocol was kept recording the sequences of processes (start, processing, end, break, cleaning etc.) and any other activities that may influence the particle concentrations. The pilot scale wood processing may reflect the situations in a carpentry or in a DIY workshop.

2.1.2. Sawmill

The measurements in the sawmill were carried out in two production sites, one head saw and one band saw. The head sawing hall is an enclosed production hall, but there are curtains separating the hall from outdoor environment (Figure S4-A). A door was frequently opened during head sawing. Two measurements were carried out in the head sawing hall, for sawing oak and beech, respectively. The round woods are fed to the head saw, where they are cut into boards. The wood boards are examined and sorted by a worker. At first, the measurements were conducted near the head saw (measurement location 1) and then moved to the worker who sorts the wood boards (measurement location 2). The band sawing hall was a half-open production hall (Figure S4-B). The measurement location was next to the band saw, and near the open side of the production hall. One measurement was carried out in the band sawing hall when sawing beech.

2.1.3. Wood-based panel factory

In the wood-based panel factory, we carried out the measurements at five production sites including wood chipping, refinery hall, MDF form station, MDF press station, and MDF sanding & cutting station. The particle background concentrations were measured only in the chipping hall. In other sites, background concentrations cannot be measured, as the production was continuously running.

2.1.3.1. Chipping. The woods were chipped in the chipping hall (see Figure S5-A). Instruments were placed in front of the wood transfer line and about 3 m away from the chipper. The processing started with beech, followed by pine boards and finally ash. The chipping speed was about 40 tons of woods per hour. The door of the production hall was closed when chipping beech, and opened when chipping pine boards and ash. The mean temperature and relative humidity (RH) were 11.5 °C and 68.4% during the measurement.

2.1.3.2. Refinery hall. The measurement site was located in the center of the refinery hall, about 3 m away from the refinery (Figure S5-B). The mean temperature and RH during the measurement were 24.9 °C and 34.7%, respectively.

2.1.3.3. MDF form station. It is in the enclosed MDF production hall (see Figure S5-C). At the MDF form station, wood fibers which have been premixed with adhesives are formed in the desired mat. The measurement location was about 5 m in front of the form station. The mean temperature and RH were 36.4 °C and 13.5%, respectively.

2.1.3.4. MDF press station. The wood fiber mat was pressed under high