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Peak exposures to main components of ash and gaseous diesel exhausts in closed and open ash loading stations at biomass-fuelled power plants

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HIGHLIGHTS

- Health risks caused by crystalline silica compounds were found in FA and BA.
- Air concentrations of dust, SiO_2, Cr, Mn, Ni and nitric NO were high during loading.
- Synergistic health effects on upper and lower respiratory system are possible.
- Technical measures and PPEs are essential for the safe loading of ash.

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ABSTRACT

Fly and bottom ashes are collected at power plants to reduce the environmental effects of energy production. However, handling the ashes causes health problems for operators, maintenance workers and truck drivers at the power plants. Hence, we evaluated ash loaders' peak inhalation exposures to the chemical components of ash and diesel exhausts in open and closed ash loading stations at biomass-fuelled combined heat and power plants. We also carried out chemical and morphological analyses of the ashes to evaluate their health hazard potential in order to find practical technical measures to reduce workers' exposure. On the basis of X-ray diffraction analyses, the main respirable crystalline ash compounds were SiO_2, $CaSO_4$, CaO, $Ca_2Al_2SiO_7$, NaCl and $Ca_3Al_2O_6$ in the fly ashes and SiO_2, $KAlSi_3O_8$, $NaAlSi_3O_8$ and $Ca_2Al_2SiO_7$ in the bottom ashes. The short-term exposure levels of respirable crystalline silica, inhalable inorganic dust, Cr, Mn, Ni and nitric oxide exceeded their Finnish eight hours occupational exposure limit values in the closed ash loading station. According to our observations, more attention should be paid to the ash-moistening process, the use of tank trucks instead of open cassette flatbed trucks, and the sealing of the loading line from the silo to the truck which would prevent spreading the ash into the air. The idling time of diesel trucks should also be limited, and ash loading stations should be equipped with exhaust gas ventilators. If working conditions make it impossible to keep to the OEL values, workers must use respirators and protect their eyes and skin.

1. Introduction

Fly and bottom ashes are collected at power plants to reduce the environmental effect of energy production. In general, combustion technology and the flue gas cleaning system determine the basic

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characteristics of ashes and form the basis of ash management. The properties and therefore behaviour of ashes are also highly dependent on the fuels used and the prevailing combustion conditions. The coarser bottom ash is collected from the bottom of a combustion chamber and fine fly ash is separated from flue gases by electrostatic precipitators or fabric filters. The fly ash fraction is largest in fluidized bed boilers, usually 80–90% of the total generated ash. Fly ash can be unloaded from ash silos in either moistened or dry form, depending on how it is to be delivered and its end use. The moistening of ash effectively diminishes ash dusting. Biomass ashes that are used as forest fertilizers are usually unloaded and transferred in dry form, and moistened in a separate granulation process by an entrepreneur.

The handling of ashes poses problems for operators and maintenance workers in power plants such as their high exposures to inhalable dust and metals (Jumpponen et al., 2014). The loading of ashes causes peak exposures for truck drivers and the workers who recycle the ashes. Bottom and fly ash contains many inorganic chemical agents such as heavy metals and crystalline silica, to which workers may be exposed. Fine fly ash particles are mainly formed from alkali metal compounds, for example the alkali salts of potassium, sodium sulphates, chlorides and carbonates (Bølling et al., 2009). In addition to alkali salts, the coarse particle fraction includes Ca, Mg, Al, Fe and several other metals in the form of oxides, silicates, carbonates, sulphates and phosphates, depending on the fuel used and possible additives used in the combustion processes (Tissari et al., 2008; Sippula et al., 2009a, 2009b).

Bottom ash consists mainly of the coarse fraction of particulate matter, and is partially the same matter as coarse fly ash, which originates from the mineral matter present in the fuel (van Loo & Koppejan 2008). Thus, the typical bottom ash components in biomass combustion processes are, for example, Ca, Mg, Fe, Mn, and Al, in the form of silicates, phosphates, carbonates, and sulphates (Tissari et al., 2008). Awareness of the composition of the ash provides valuable information for workers' occupational risk assessments. In addition, the composition of the ash might also indicate its potential to dissolve into the sweat and gastric fluids of workers, causing dermal and oral exposure to heavy metals (Pöykiö et al., 2012). Earlier studies have found maintenance workers' potential inhalation exposure to be very high. During ash removal or maintenance tasks in biomass- and recycled fuel-fired power plants, the average air concentrations of Mn, Al, As and Pb have been found to be over or very close to occupational exposure limit values (OEL) (Jumpponen et al., 2014). Reported health effects after simultaneous exposure to multiple metals have varied from irritation of the upper respiratory tract to damage to the central nervous system, resulting in mutagenic effects (Shukla and Singhal, 1984; Mani et al., 2007; Celik et al., 2007; Garcon et al., 2007; Halatek et al., 2009; Walton, 2011a,b). In addition, ash loaders might be exposed to respirable crystalline silica originating from soil contaminated stumps and from the sand of fluidized bed boilers. Exposure to respirable crystalline silica can cause silicosis. Silicosis is normally associated with long-term exposure, but symptoms of acute silicosis may also develop shortly after exposure to high concentrations. Silicotic workers may be at a higher risk of lung cancer than workers who do not have silicosis (Kreiss and Zhen, 1996; Miller et al., 1998; NIOSH, 2002). Due to above mentioned findings, the International Agency for Research on Cancer (IARC) has classified respirable crystalline silica as carcinogenic to humans (WHO, 1997). Strong epidemiological evidence also supports the association between long-term exposure to crystalline silica and severe health effects, e.g. chronic obstructive pulmonary diseases (COPD), cardiovascular disease and rheumatoid arthritis (Chen et al., 2012; Calvert et al., 2003; Preller et al., 2010; Sauni et al., 2012; Zhou et al., 2014, Hochgatterer et al., 2013).

Idling of trucks during the ash loading process may also expose workers to components of diesel exhaust such as nitric oxide, nitrogen dioxide, carbon monoxide and fine soot (elemental carbon) particles (Zaebst et al., 1991, Gao et al., 2016, 2017a, 2017b). IARC has classified diesel engine exhausts as carcinogenic to humans (Group 1) on the basis of sufficient evidence that exposure is associated with an increased risk of lung cancer (IARC, 2012). Exposure to diesel exhausts can also cause inflammation of the lungs, which may aggravate chronic respiratory symptoms and increase the frequency and intensity of asthma attacks. Nitrogen oxides on the other hand can damage lung tissue, lower the body's resistance to respiratory infection and worsen chronic lung diseases such as asthma (Sydbom et al., 2001). As in the case of crystalline silica, high short-term exposures to diesel exhausts also seem to induce more alterations in lung tissues than low long-term exposures (Kobayashi et al., 1997; Nikasinovica et al., 2004; Ghio et al., 2012).

This study evaluated ash loaders' rarely studied possible inhalation peak exposures to the chemical components of ash and diesel exhausts in open and closed ash loading stations at biomass-fired power plants. By combining several chemical and morphological analyses of the ashes, we determined the major chemical compounds and trace metals in the ashes, and evaluated their potential to expose workers through the inhalation system. Ashes' potential to dissolve into the saliva or gastric fluids and thus cause exposure through the dermal and oral exposure routes were also discussed. The final goal of the study was to find the best practices for reducing workers' exposure in ash loading stations.

2. Materials and methods

2.1. Sampling procedures

Air and material samples were collected from three Finnish combined heat and power (CHP) plants. All the plants were bubbling fluidized bed boilers (BFB), and their power capacities varied from 75 to 200 MW_{fuel}. New Power Plant A used 100% of wood fuels. For example, forest chips, used wood, whole tree chips, wood industry residues, and fly ashes were collected using a bag filter. Old Power Plant B was fuelled by wood fuels together with bark, milled peat and waste water sludge, and ESP was used for fly ash separation. Solid recovered fuel (SRF) and bark, together with wastewater sludge, were combusted in old Plant C, which had an ESP and a wet scrubber for flue gas cleaning. Plants A and C used elemental sulphur as an additive to control the corrosion, fouling and air emissions.

Air samples were taken from stationary sampling sites near workers' working areas from open and closed ash loading stations. Material fly ashes were taken from ash silos, depending on the sampling possibilities at the power plants. Bottom ashes were sampled from the bottom ash containers of the power plants.

2.2. Procedure for fly and bottom ash sample sieving

The material samples were sieved for the analyses, to remove particles larger than the respirable fraction (<10 μm), in order to reflect better health effects of ashes during inhalation. Bottom ash (BA) samples were first sieved with a 4 mm sieve to remove the biggest particles. Sample (BA) A was not analysed, because it consisted entirely of the large particle size class. All fly ash (FA) and bottom ash samples were then sieved using a 45 μm sieve (Retsch AS200 sieving machine with metal wire sieves) and further with a 10 μm sieve (HK Technologies Ultrasonic sieving machine with stainless steel/nickel wire sieves).