Sanding dust from nanoparticle-containing paints: physical characterisation.

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Abstract. Increasing use of nanoparticles in different industrial applications has raised a new potential health risk to the workers as well as to the consumers. This study investigates the particle size distributions of sanding dust released from paints produced with and without engineered nanoparticles. Dust emissions from sanding painted plates were found to consist of five size modes; three modes under 1 µm and two modes around 1 and 2 µm. We observed that the sander was the only source of particles smaller than 50 nm and they dominated the number concentration spectra. Mass and surface area spectra were dominated by the 1 and 2 µm modes. Addition of nanoparticles caused only minor changes in the geometric mean diameters of the particle modes generated during sanding of two paints doped with 17 nm TiO2 and 95 nm Carbon Black nanoparticles as compared to the size modes generated during sanding a conventional reference paint. However, the number concentrations in the different size modes varied considerably in between the two NP-doped paints and the reference paint. Therefore, from a physical point of view, there may be a difference in the exposure risk during sanding surfaces covered with nanoparticle-based paints as compared to sanding conventional paints.

1. Introduction
Nanotechnology enables the design of particle-based chemicals and materials at the molecular and atomic scale. These new nanomaterial-based products have tremendous potential benefits for the society. However, nanomaterials are also associated with significant uncertainties regarding possible hazards to human health and the environment. There is evident risk of exposure to persons who produce or handle nanoparticles (NPs) in their production. The paint and lacquer industry is a potential high tonnage user of NPs. In paint and lacquers vast amounts of conventional particulate, pigments, fillers and binders are used. The new use of NPs has been aiming at developing special paint properties, e.g. water repellence, scratch resistance and improved durability. Direct or indirect nanoparticle exposure during production and application of this product group as well as during subsequent finishing and renovation may reach a large number of persons in the future [1].

Sanding painted surfaces is often one of the major activities when renovating buildings. Sanding produces a large amount of dust, and could result in an extensive exposure to NP containing dust particles or even individual nanoparticles released from the paint and lacquer matrix during sanding. Therefore, more detailed information on the particle sizes of sanding dust and whether NPs are changing the physico-chemical properties of sanding dust is needed in order to assess the potential health risks from exposure by inhalation.
In the past few years, numerous studies have investigated and discussed the potential health risks of nanomaterials [e.g. 2, 3]. Fewer studies have studied the exposure risks during handling nanoparticles [4,5,6,7,8]. There seems to be no studies available characterizing the potential exposure to nanoparticles from sanding nanoparticle-doped materials. Nevertheless, a few scientific studies have characterised the exposure to dust from sanding conventional materials in the field as well as in the laboratory. Scholz et al. [9] studied 11 job sites in order to assess the exposure to dust and lead from sanding lead-bearing paint. Total dust was sampled at 2 lpm using closed face filter cassettes. Thirty-minute total dust exposures were 1.6 (SD=2), 6.7 (SD=3.6), and 14 (SD=13) mg/m$^3$ for HEPA exhausted power sanding, manual dry sanding and uncontrolled power sanding, respectively. The lead-content in the airborne dust was generally lower than in the paint itself. For comparison, Choe et al. [10] studied the dust generation during scraping and dry machine sanding of wood, covered with leaded paint at laboratory conditions. The tests were performed in a 24.3 m$^3$ test room representing the size of a typical residential room. They measured particle concentrations with a Grimm model 1.108 optical particle counter, using data in the size range 0.4-20 µm only. Immediately after sanding there was one size mode around 3 µm and one at or below the lower size limit, 400 nm. Emission of nanosized particles from the sanding machine was not addressed. However, electrically driven sanding machines can be a prominent source for ultrafine particles in the sanding operation. Szymaczak et al. [11] reported electrical motors to be a major source of particles; especially for particles below 100 nm size. In Szymaczak's study a professional vacuum cleaner engine was used as the source of particles. The total number concentration produced by the motor operated at full power in the test room (4.2 m$^3$ with air exchange rate 0.021 m$^{-1}$) saturated rapidly at $3.0 \times 10^{11}$ particles m$^{-3}$ within 15 min of operation.

Other relevant studies include Teitsworth and Sheehan [12] who measured the effectivity of a specific shrouded tool. Personal samples of total and respirable dust were taken during grinding, sanding, trimming, and removing surplus resin. When using un-shrouded tools, the personal exposure to total or respirable dust ranged from values below the limit of detection (1.6-1.7 mg m$^{-3}$) to 50.8 mg m$^{-3}$. Carlton et al.,[13] tested a pneumatic, random orbital type sanders in a glove box during sanding of aluminium panels coated with aircraft epoxy primer and polyurethane paint, using grit size 180 and 240. No difference was found in inhalable dust generation between grit size 180 and 240.

Noteworthy, none of the previous studies have focused on a detailed characterisation of the airborne particle size distribution of dust generated by sanding painted surfaces. Complete knowledge of the particle size-distribution enables a better assessment of exposure risk and effectiveness of personal protective equipment. In this paper we characterise the airborne particle size distribution spectra generated during sanding of painted MDF plates. The sanding particles were generated in a set-up designed for simultaneous electrostatic collection of the sanding particles for subsequent physicochemical and toxicological analysis. We characterise the contribution from both the sander and paint and discuss the results in terms of number size distribution as well as surface area and mass size distribution. The presented work is generated as part of a larger project effort with the overall aim to complete a detailed physico-chemical and toxicological characterisation of NPs, which currently are in the promising candidates for use in commercial paints and lacquers, and of the dust particles generated during sanding paints produced with and without NPs.

2. Methods

2.1. Experimental set up and Instrumentation

The experiment was conducted in a 20.6 m$^3$ stainless steel human exposure chamber, which has a nominal air exchange rate 9.2 ± 0.8 h$^{-1}$ [14]. HEPA-filtering of the laboratory air assured low total background particle concentrations (<100 cm$^{-3}$). Figure 1 shows the experimental set-up, which consists of a sander unit, a sampling tube, a 0.03 m$^3$ dust reservoir made of plastic, and a commercial electrostatic precipitator (ESP), previously characterized by Sharma et al., [15], for particle sampling.
The dust particles were sampled for completion of subsequent physico-chemical and toxicological analysis.

The particle size distribution was measured from the chamber using an APS Model 3321 (Aerosol Particle Sizer, TSI Inc.), which measures the size distributions of particles from 0.542 to 19.81 µm (aerodynamic diameter). Due to the high concentrations we used a TS1 diluter model 3302A with dilution ratio of 100 to 1. An FMPS Model 3091 (Fast scanning Mobility Sizer, TSI Inc.), which measures the particle size distribution from 5.6 nm to 542 nm in 32 channels (mobility diameter), was used for sizing smaller particles. The APS and FMPS data were exported at a 10 seconds time resolution, which was sufficient to observe the relatively rapid changes in the aerosol spectra.

Sanding was performed using a commercial hand-held orbital sander (Metabo Model FSR 200 Intec) with an internal fan for dust removal. Grit size 240 sanding paper was used as recommended by the paint and lacquer manufacture. This grit size is usually applied for finishing. By using a fine grit size, we also expected an enhanced production of small particles. However, the actual enhancement is uncertain [13, 16]. Charlton et al., [13] did not observe differences in the particle size distribution using grit size 180 and 240, whereas Thorpe and Brown [16] observed an inconsistent effect of grit size on the particle size in the dust. The Metabo sander was delivered with a filter bag attached to filter exhaust air. For our purpose the filter bag was removed and the outlet modified to connect a 60 cm long and 32 mm ID flexible plastic tube after the sander to lead the dust to the dust reservoir chamber from which sampling by the APS and FMPS was performed through 10 mm, TSI Conductive Silicone Tubing. The ESP was attached at the side of the chamber sampling air through a 21 cm deep, 37 cm wide and 15 cm high tunnel made in aluminum (see Fig. 1).

![Figure 1](image)

**Figure 1.** Schematic illustration of the measurement set up.

The air-flow from the sander to the chamber and the flow from the chamber to ESP were measured with a pitot tube and a micro manometer (TT 570SV, DP Measurement UK). The volume flow to the ESP influences the cut size and collection efficiency of the ESP sampler and will be described elsewhere. The volume flow from the sander was 100 m³/hour measured at the end of the tube leading dust to the sampling chamber. The volume flow of the HEPA-filtered make-up air was 20 l/min, resulting in a 20 to 834.4 l/min ratio between the sample flow and the dilution air, which is less than 3 % of the total sampled air.

2.2. Description of the paints
For use in the large project, the Danish paint-and lacquer industry provided 13 plates, three painted with reference paints i.e. not containing NP, six painted with NPs, one lacquer with and one without NP. All the plates had a few millimeter thick layer of paint. In addition, we received two plates
covered with two different fillers. In this paper we will focus on two paints containing NPs and their reference paint, all from the same manufacturer and intended for indoor use. We denoted the NP containing paints as Paint 1 and Paint 2, respectively. According to the supplier Paint 1 contained 17 nm TiO$_2$ NP and Paint 2 contained 95 nm Carbon Black NP.

2.3. Measurement procedure
Each experiment was conducted following the same procedure. First the ventilation system in the human exposure chamber was turned on to clean the background air while measuring the particle concentrations in the chamber by the APS and FMPS. This lasted until the background concentration was less than 300 particles cm$^{-3}$. After checking the background number concentrations the instruments and sander were connected to the small sampling chamber and the size distribution from the sampling chamber was measured. The total particle concentration was always below 10 cm$^{-3}$ inside the chamber before starting the sanding experiments. Sander emissions were measured for a 2 to 3 minute period before each experiment (see spectra Fig. 2). After measuring the sander emissions some time was allowed for the total particle number concentration in the chamber dust reservoir to be reduced to background concentrations of a few hundred particles cm$^{-3}$. Then the ESP was turned on and sanding of the painted MDF plates started. Sanding was carried out for one or two minute periods until sufficient amounts of material was collected on the ESP collection plates, as assessed visually. This took 15 to 30 minutes depending on the type of paint. After sanding, all the parts from the measurement set-up were dismantled and cleaned with a vacuum cleaner.

2.4. Data-analysis
In order to evaluate the characteristics of the measured aerosol number size distributions, we fitted a multi modal log-normal distribution to the measured spectra. Fitting gave three parameters; the geometric mean diameter (GMD), the number concentration (N) and the geometric standard deviation (GSD) of each mode.

Several studies have discussed that particle parameters such as size, number concentrations and available surface area to a large extent may determine the toxicity of low-solubility particles [e.g. 3, 17]. However, the mass of the airborne particles may still be an important descriptor and is still used as a toxicological metric in characterising dose. Consequently, both the mass and surface area weighted distributions were calculated from the number size distribution assuming the particles are spherical with a density of 1 kg/m$^3$.

3. Results

3.1. Sanding machine emissions
The sanding machine emissions were checked before each sanding experiment. The continued check of particle emissions from the sander was important, as the sander was new at the start of the experiments and we wanted to control whether the sander emissions changed over time. Even-though the sander was cleaned after every experiment, some dust apparently remained from the previous experiments. Therefore, prior to each sanding experiment, the sander was allowed to run until the total number concentration and aerosol spectra were constant. Figure 2a presents the average number concentration spectrum calculated from all sander background measurements. The spectrum shows a multimodal size distribution, which will be analyzed in detail below.
Electrical motors produce both mechanical wear and spark particles. Szymaczak et al. [11] reported in their study, that spark generated particles dominated the emissions of ultrafine particles (UFP). They also conducted PIXE (proton induced X-ray analysis) analysis, which showed that Cu dominated the mass concentrations in the UFP size range. The number size distributions of the sander emissions were similar those found by Szymaczak et al. [11]. To enable a more in-depth understanding of the background emissions from the sander, the average number size distribution spectra was fitted, assuming five log-normal size distribution modes (Figure 2b). The 1st mode at 9.8 nm had 1.18e5 (6.06e4) cm\(^{-3}\), the 2nd mode at 16 nm had 1.85e5 (1.27e5) cm\(^{-3}\), the 3rd mode at 179 nm had 664.5(506) cm\(^{-3}\), the 4th mode at 904 nm had 141 (125) and the 5th mode at 1.32 (µm) had 89 (114) cm\(^{-3}\), where the numbers in parenthesis are standard deviations of the fitted data. Our measurements indicated that the particle size distribution in the sander emissions was very reproducible for particles smaller than 100 nm. In mode 3 and mode 4, the variations in particle concentrations were notably higher in between the measurements than the particle concentration variations in between mode 1 and mode 2. That is probably due to paint dust residuals inside the sander, chamber and tubes. It must be concluded that the system could not be cleaned completely in between the experiments.

3.2. Paint dust emissions

3.2.1. Number size distribution modes. Several separate size modes were observed in the particle size distribution measurements. When including sander emissions, we observed five size modes and when subtracting the sander emissions we observed three modes (Figure 3). It is clear that there is no significant particle contribution from the sanded paint under 50 nm, however both mode 3 (the smallest mode when sander emissions are subtracted) 4 and 5 also contain sander emissions.

Table 1 shows the modal concentrations and geometric mean diameters of the observed modes corrected for sander emissions. Comparison of particle emissions from the sander and from the paint dust shows that mode 3 in the paint dust has slightly smaller GMD than mode 3 in sander emissions. There is a large difference in GMD’s in modes 4 and 5. In the sander emission, mode 4 and 5 occurred at 0.90 and 1.32 µm, respectively. Sanding dust mode 4 and 5 were found at 1.02 and 2.02 µm, respectively. GMDs of the emissions from the sander and from sanding painted plates are similar. This indicates that mode 3, 4 and 5 are mixtures of sander emissions and paint dust particles. Sanding plates painted with different paints did not change sanding emission GMDs. Therefore, the size of the observed number concentration modes most likely depends in other factors such as the sander paper.
grit size and the sander engine rotation speed. The modal number concentrations in the three paints varied (see Table 1). By comparing these variations with the standard deviations calculated from the sander emissions it is evident that the emissions varied with the type of paint.

![Figure 3. Particle number concentration spectra measured during sanding: (a) with sanding machine emissions and (b) corrected for sander emissions.](image)

Table 1: Averages of the six fitting parameters obtained from the fitting procedure (geometric standard deviation is not presented): geometric mean diameter $GMD_p$ ($\mu$m), number concentration in mode $N_i$ (cm$^{-3}$). The standard deviation of each quantity is given in parentheses. Paint 1 contains TiO$_2$ and Paint 2 contains carbon black nanoparticles.

|       | $GMD_p$ ($\mu$m) | $N_1$ (cm$^{-3}$) | $GMD_p$ ($\mu$m) | $N_2$ (cm$^{-3}$) | $GMD_p$ ($\mu$m) | $N_3$ (cm$^{-3}$) |
|-------|-----------------|------------------|-----------------|------------------|-----------------|------------------|
| Ref.  | 0.140(0.05)     | 1.81*1e4(4248)   | 1.02(0.01)      | 2257(461)        | 2.02(0.06)      | 482(114)         |
| Paint 1 | 0.152(0.03)   | 1.03*1e4(740)    | 1.02(0.02)      | 3005(629)        | 1.84(0.05)      | 1182(249)        |
| Paint 2 | 0.144(0.03)   | 2.38*1e4(4000)   | 1.02(0.03)      | 3194(1119)       | 2.16(0.01)      | 599 (240)        |

3.2.2. Surface- and mass distributions. In Figure 4, the mass and surface area weighted distributions calculated from number size distributions, are presented. Figures 4a,b present distributions corrected for the sander emissions and 4c,d sander emissions are included. Figures 4a,b show that most of the mass and surface are is above 1 $\mu$m and Figures 4c,d illustrate that despite high influence in the number size distribution spectra, the sander emissions only play a minor role on mass and surface area distribution spectra.
Figure 4. Mass, and surface size distribution spectra calculated from the sanding emission number size distribution measurements. a) and b) are presented when corrected for sander emissions and c) and d) with sander emissions. For mass calculation density = 1 kg/m$^3$ was used.

4. Conclusions
The objective was to investigate if adding NPs to paints would result in emissions of free NP and/or change the particle size distribution spectra of dust produced by sanding. Dust was produced by sanding MDF plates covered with several mm of paint. Two plates were painted with NP-based paint namely with TiO$_2$ and carbon black and one plate was painted with conventional paint, which was also our reference paint. In order to evaluate the properties of the released dust, we measured the aerosol size distribution from 5.6 nm to 19.8 µm using a FMPS and an APS with 10 second time resolution. Three to five modal log-normal distributions were fitted to measured data.

The sander was a main source of particles smaller than 50 nm. Total emission number size distributions were clearly five modal. The First two modes had peaks below 20 nm and these were identified as sander emissions. Mode 3 was found at about 200 nm, which contained particles from the sander and paint dust emissions. Mode 4 and 5 were at 1 and 2 µm and they contained mostly dust released from the paints. While the number size distribution spectra were dominated by particles below 50 nm, mass and surface area distributions showed that particles above 1 µm might have an important role on these measures. Consequently, these characteristics may be important when investigating toxicity of the sanded paint dust. However, when focusing on the possible health risks caused by particles generated from sanding paint, one also has to take emissions from the sander into account when assessing the real exposure situation.
Parameters obtained from the log-normal fitting showed that the GMDs of the modes did not depend on whether NPs were present in the paints or not. The GMDs were probably more controlled by other factors of the sanding process. However, even though the positions of the modes were the same in all spectra, the modal number concentrations varied in between all three paints. Therefore NPs may have an impact to properties of the paints. It is evident that NPs released during the sanding do not occur in individual particles. Therefore accurate physical and chemical characterization is needed for obtaining more information on particle characteristics and the potential toxicity of the dust.

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