Describing the Diffusion and Distribution of Airborne Nanoparticulates (NPs) and Ultrafine Particulates (UFPs) - Investigation of Size, Composition and Concentration in a Metallurgy and Smelting Plant by Scanning Electron Microscopy (SEM)

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Abstract:

Airborne nanoparticles have long been a human health concern, with epidemiological studies linking increased mortality and health problems. This study investigates the nature and evolution of dust particles within a unit for mining and mineral recycling, focusing on a metallurgical plant producing iron and aluminum ingots. It characterizes the particles in the air and investigates the significance of their chemical composition and size. Samples have been collected from different areas of a mining plant and have been analyzed by means of scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS).

The results show a high concentration of metallic particles near the thermal mining area and a decrease in concentration towards other areas. The SEM shows particles of irregular size and distribution. The diameter of spherical particles ranges from 12 nm to more than 5500 nm. Microanalysis (EDX) data indicate the presence of iron oxide ($Fe2O3$) nanoparticles with oxygen and iron as major components. The larger nanoparticles show compounds adhering to their surface, indicating that they are composed of a core of iron and oxygen. It is likely that other chemical elements such as copper, aluminum, and carbon are incorporated to form many large nanoparticles.

This research provides valuable insight into occupational health and safety measures to mitigate potential health risks associated with exposure to these nanoparticles by shedding light on the formation and distribution of airborne nanoparticles in a foundry environment.

Keywords: Nanoparticles, Airborne, Ultrafine particles, Scanning Electron Microscope, Workspace healthy, Foundry, Energy-dispersive X-ray spectroscopy (EDS).

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Introduction

Effects of airborne nanoparticles on human health have been a source of worry for many years. Indeed, epidemiological studies have connected airborne particles to a rise in cardiovascular [1-3], pulmonary [4, 5], and neurological [6] disease incidence and mortality.

Many workers are exposed to a variety of nano-metrically small particles. Differentiating between man-made nanoparticles (NP) and ultrafine particles (UFP) from industrial, human, and natural sources is a standard practice in occupational hygiene. Several writers have thoroughly studied the NP and UFP toxicities [6–10]. Additionally, research indicates that NPs are typically more harmful than the same chemical size [11, 12].

This study takes into account a unit for the mining and recycling of minerals, focusing on a metallurgical plant that produces ingots of iron and aluminum. Samples were collected in numerous workshops during the course of work. Particles were collected during the casting and grinding processes after various minerals were recycled by melting and separating the various components.

For the determination of the exposure of the workers, analytical methods often use representative sampling methods [13, 14]. This approach uses energy dispersive X-ray spectroscopy (EDS) and scanning electron microscopy (SEM).

Experimental:

- Description of the foundry:

It involves a large workshop of 50 meters long and 90 meters wide, equipped with a furnace comprising fans for the dust removal.

- The Elemental Analysis

A Quanta 250 Scanning Electron Microscope was used to examine the samples in powder form. Moreover, to highlight the topography of the corrosion product studied, several high-resolution images were taken in different areas and at different magnifications, ranging from 2000 to 10000 times.

- The following parameters have been selected for the analysis;
- Pressure mode: High vacuum (> $1.03\ 10^{-4}$ Pascal)
- Primary electron beam: 15Kv
- Electron beam size (spot): 2.5 and 3
- Secondary electron detector: Everhart Thornley Detector ETD ()
- Working distance (WD): 8 mm

- Magnification: from 2000x to 100000x
- Sample Analysis by Energy Dispersion X-Ray (EDX)
- The samples' morphology and the chemical composition are illustrated in the images resulting from the Scanning Electron Microscope (SEM) analysis coupled with the EDX.

Results and discussion

The data on the concentration of PFUs and NPs in the air were collected during the normal working hours (i.e. from 8 am to 4 pm) when the operation of the furnace was intensive.

Accordingly, the analysis was based on two variables in order to study the dispersion of the nanoparticles and NPs generated by the iron liquefaction and alloying processes:

The distribution according to the size of the dust particles.

- The distribution according to the chemical composition of the dust particles.

A high concentration of metallic particles was found near the first area of the furnace in the different samples and in the study of the three workshop areas. This level is moderate near the separator area and relatively low near the settling and distribution area. As shown in Figure 1(a), this preliminary study established a baseline for the distribution of metal particle concentrations of UFPs and NPs in the unit for mining and mineral recycling. By introducing processes that require other elements, the elemental distribution is shown in Fig. 1(b) (separation region) and will be very important at high concentrations. Furthermore, the concentration of some metallic elements has been altered significantly.

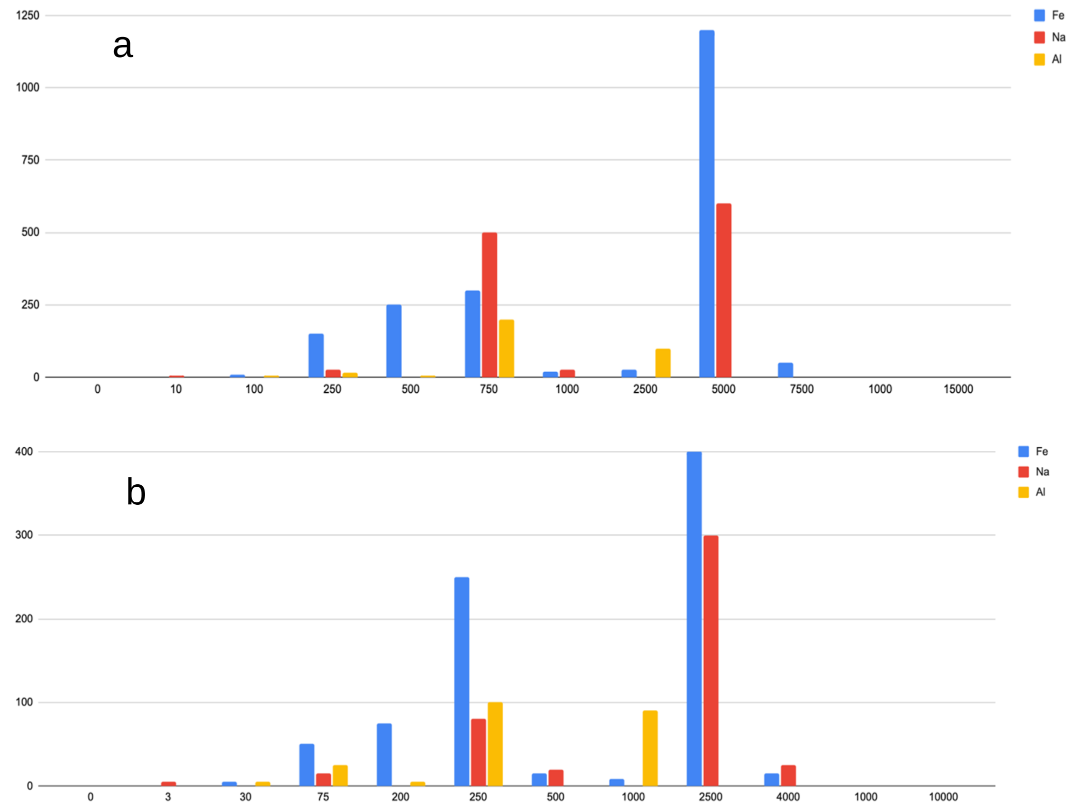

Figure 1: Distribution of mineral materials according to work areas

-SEM examination

From the first view in the SEM with a magnification of (a) x60000 at 2500kv, the distribution of airborne particles in the form of glomeruli of regular spherical size up to 6.6 µm in diameter can be observed. In addition, the presence of objects of irregular size can also be seen. Note that only spherical objects are considered in this research.

Figure 2 shows an irregular distribution of PFU and NP from 1 nm to over 2500 nm in diameter.

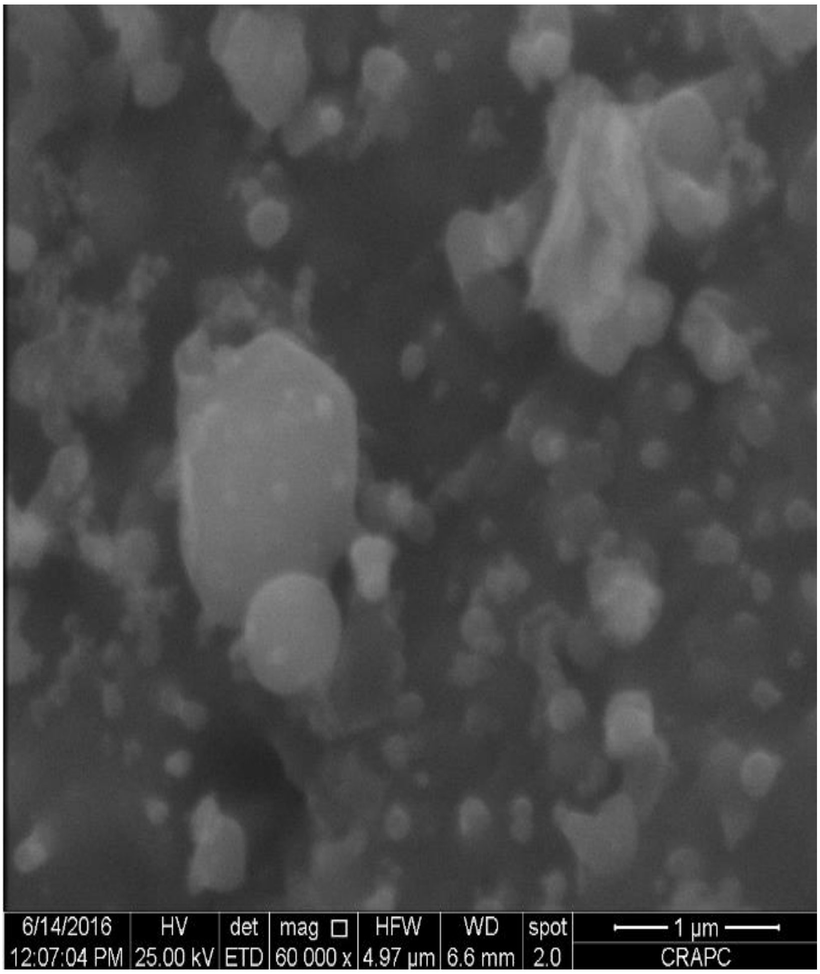

Figure 2: SEM images of the powder at different magnifications x60000 at 2500kv.

The image in Figure 3 is shown at a low level of magnification in which spherical particles of a variety of sizes and diameters can be seen. One can see particles of different shapes, including micron particles, which are the finest grains of sand. However, the large spherical particles with smaller particles deposited on their surfaces, which are sub-assemblies of nanoparticles, are the most important to note, especially in Figure 4.

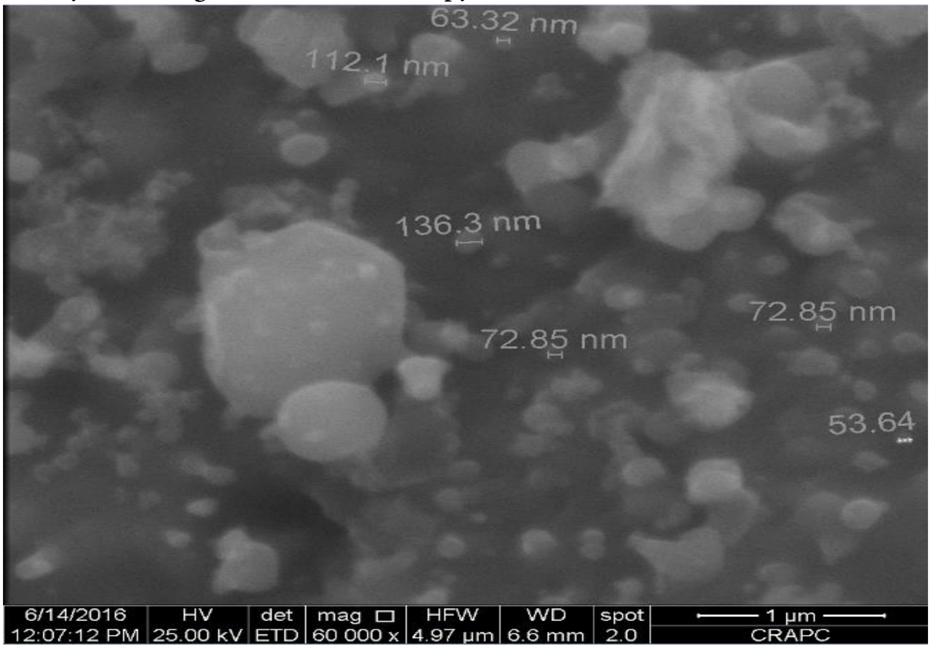

Figure 3: spherical particles of various sizes and diameters.

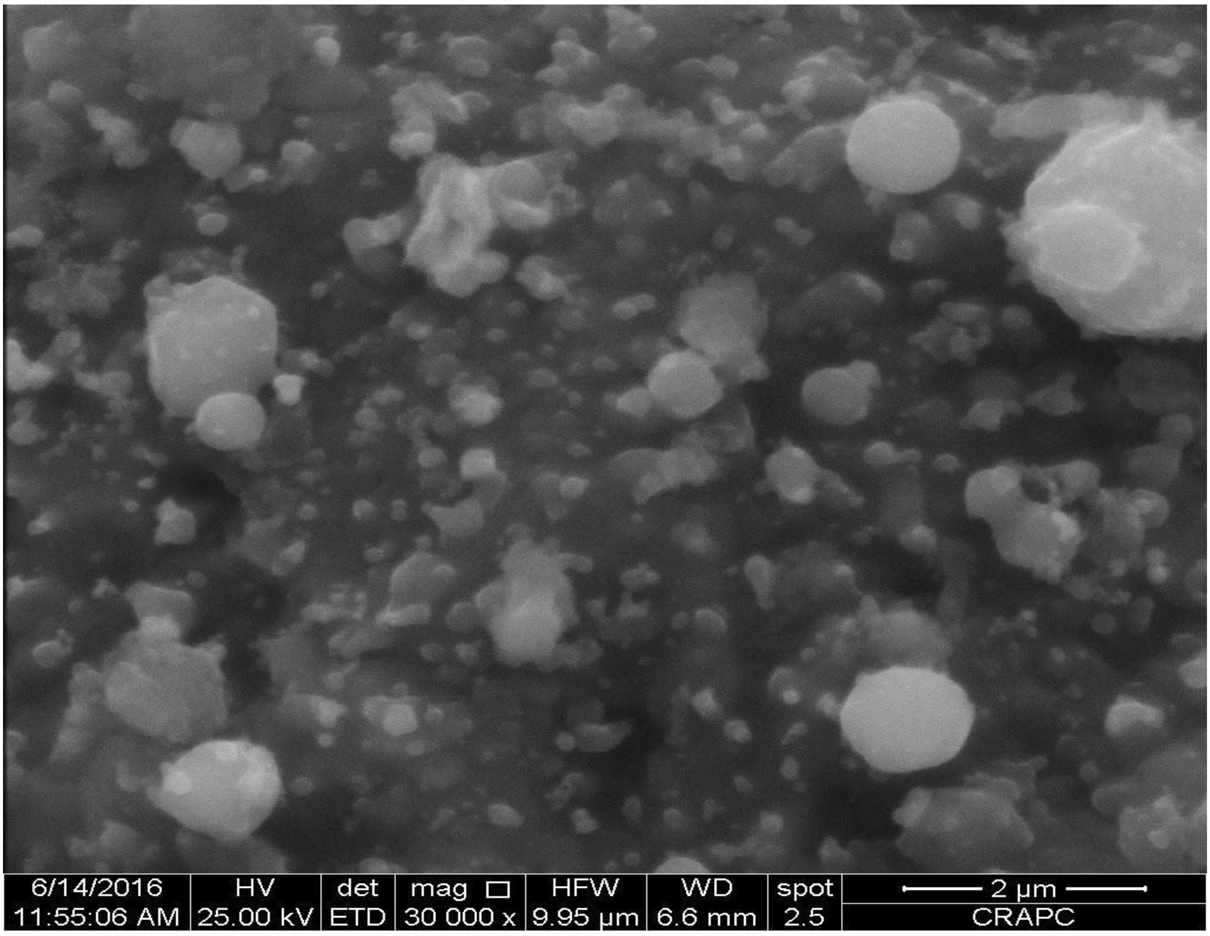

Figure 4: Morphology of metal powders observed by scanning electron microscopy in secondary electron mode are spherical particles and agglomerates of various size, ranging from 10 to 589 nm.

Comparing the images, shows that in Figure 3 and Figure 4, the small nanoparticles are homogeneous, while the large nanoparticles are clearly visible. Therefore, some bodies such as the small nanoparticles can be seen adhering to their outer surface (Figure 3 & 4). It is also obvious that the NPs are condensing on each other to form aggregates of NPs with large volume or micro-NPs that are relatively large in size compared to the NPs.

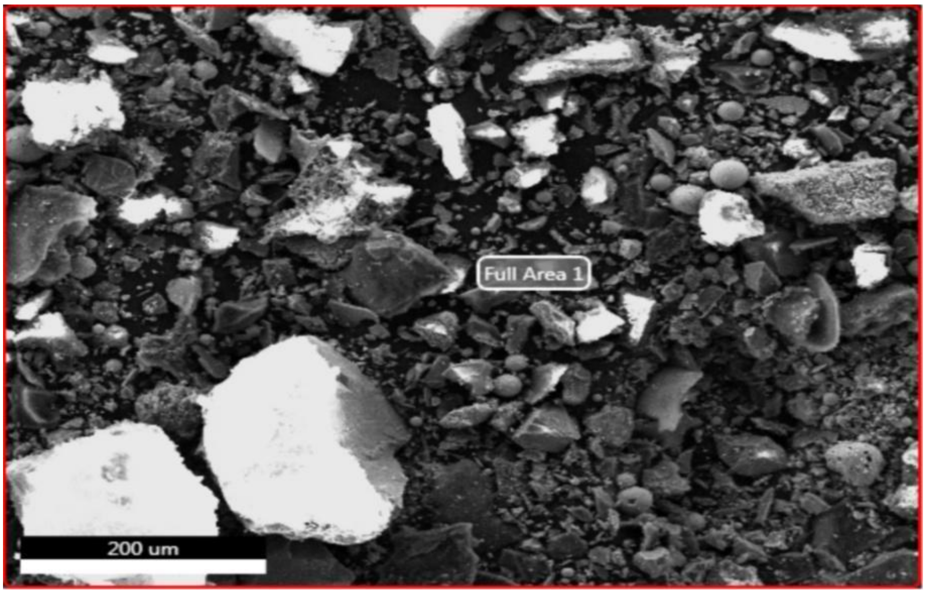

Figure 5: SEM-EDS image to obtain spectra in the selected areas (points)

A micro-analyzer (EDX) is installed in the scanning electron microscope. The latter collects the photons released by the primary electron beam. The x-ray detector can determine the photons' energy. In addition, data describing the chemical type of the atom is obtained by analyzing these beams. Figures 5-6 provide examples of particle collection.

The following observations can be made from the established analysis:

A scanning electron microscope is equipped with a microanalyser (EDX). The latter collects the photons that are released by the primary beam of electrons. The energy of the photons can be determined with an X-ray detector. Analysis of these beams also provides data describing an atom's chemical nature. Examples of particle capture are shown in Figure 6.

From the appropriate analysis, the following observations can be made:

EDX data for nanoparticles below 150 nm (EDS spot) highlight the concentration of chemical constituents in several microregions, indicating oxygen (O), iron (Fe), manganese (Mg), aluminum (AL), potassium (K) atoms, etc.). etc.

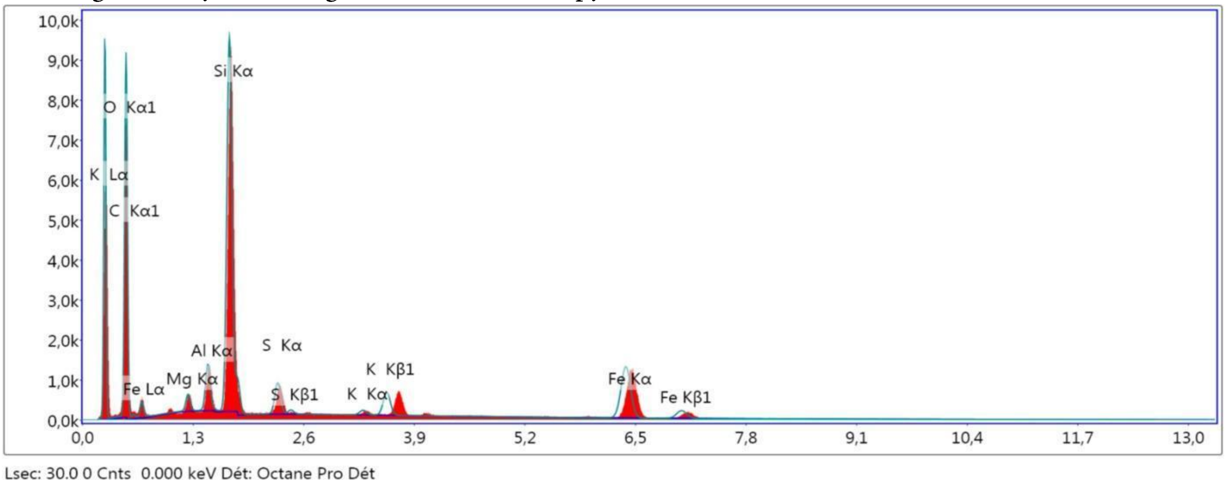

Figure 6: EDX spectrum of the powder on the EDS Spot4 area

Elément	% de masse	% atomique
C K	43.82	56.80
O K	34.63	33.70
Mg K	0.58	0.37
Al K	1.31	0.76
Si K	9.69	5.37
S K	0.96	0.47
K K	0.20	0.08
Fe K	8.80	2.45

Table 1: Quantitative results obtained by the SEM-EDS on the overall analysis of the sample

Conclusion

In conclusion, this paper highlights the concern surrounding the effects of airborne nanoparticles on human health, particularly in occupational settings. Epidemiological studies have linked airborne particles to increased mortality and the incidence of various diseases, including cardiovascular, pulmonary, and neurological conditions. The differentiation between man-made nanoparticles (NP) and ultrafine particles (UFP) from different sources is crucial in understanding their toxicities, with NPs generally proving to be more harmful than particles of the same chemical size.

The study focused on a metallurgical plant producing iron and aluminum ingots, where samples were collected from various workshops during different processes. Analytical methods using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) were employed to determine workers' exposure to nanoparticles.

The results demonstrated significant variations in airborne particle concentrations within different areas of the plant. High concentrations of metallic particles were found near the furnace, decreasing in other zones. SEM examination revealed irregularly sized particles, including spherical ones ranging from 1 nm to over 2500 nm in diameter.

This research contributes to our understanding of airborne nanoparticles' distribution and composition in a metallurgical environment, shedding light on potential health risks for workers. The findings emphasize the importance of implementing safety measures and monitoring systems to protect workers' health and well-being in industries where exposure to nanoparticles is prevalent. Further investigations and ongoing research are essential to fully comprehend the implications of airborne nanoparticles on human health and to develop appropriate strategies for risk management and mitigation.

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