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Characterization of Iron Oxide and Zinc Sulfite Nanoparticles in Atmospheric Pollution: PCA and LCF Analysis of XAS Data Using the SOLARIS ASTRA Beamline

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Atmospheric pollution from mining activities, metal production and processing has raised concerns regarding its impact on human health, particularly in relation to neurodegenerative diseases. Numerous studies have reported the presence of metal-containing nanoparticles in pollution from industrial sources worldwide, including iron and zinc nanoparticles [1,2]. Notably, research has identified iron-rich nanoparticles in urban air, with studies in Mexico City revealing their potential neurotoxic effects [3]. In Brazil, investigations have detected metal-enriched nanoparticles in railway system air pollution, highlighting the presence of iron-rich particles [4]. Despite these findings, there remains a significant gap in research regarding the presence and effects of such nanoparticles in Poland. In this study, we focus on iron oxide (magnetite) and zinc sulfide (ZnS) nanoparticles, synthesized in the laboratory to mimic those potentially emitted from smelting facilities in Poland, such as HC Miasteczko Śląskie S.A. Zinc Smelting Plant in Miasteczko Śląskie, ZGH Bolesław in Olkusz, the Oława smelter, part of the "Silesia" metallurgical plants, and iron-processing facilities such as ArcelorMittal Poland in Dąbrowa Górnicza, Celsa Huta Ostrowiec in Ostrowiec Świętokrzyski, and Huta Pokój in Ruda Śląska.

The synthesized nanoparticles were characterized using synchrotron-based X-ray absorption spectroscopy (XAS), specifically X-ray absorption near-edge structure (XANES) and extended X-ray absorption fine structure (EXAFS) analyses on ASTRA beamline at SOLARIS National Synchrotron Radiation Centre. Data were processed and analyzed to determine oxidation states, local coordination environments, and structural modifications induced by the synthesis process. Different preparation methods were compared to assess variations in their physicochemical properties. Our results suggest that the synthetic iron oxide and zinc sulfide nanoparticles share structural similarities with those found in industrial emissions, indicating their potential relevance as atmospheric pollutants. Furthermore, we investigated their interactions with proteins associated with neurodegenerative diseases, including human cystatin C (hCC) and amyloid beta, to explore possible mechanisms by which these particles may contribute to disease progression. In order to investigate the nanoparticle- mediated structural changes in the proteins, SAXS and multimodal optical spectroscopy methods were used. This study provides a basis for understanding the behavior of these materials in biological environments and their potential risks, emphasizing the importance of policy development to mitigate nanoparticle-related pollution and its associated health effects. These findings highlight the urgent need for further research into nanoparticle pollution from smelting activities in Poland, as well as its possible health implications.

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