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The magnetic properties of indoor dust fractions as markers of air pollution inside buildings

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ABSTRACT

The distribution of indoor dust into size fractions can be a convenient way to characterize the pollution in apartments located in the city center and suburbs. Magnetic properties revealed that concentration of magnetic particles increases with decreasing granulometric size. The coarse- and medium-grained dust from the suburbs show the higher concentration of magnetic particles than the same fractions from the city center. The finer-grained fractions from the center contain more magnetic particles than the dust from suburbs. The coarse-grained dust contains mixture of single-domain to multi-domain magnetite. Magnetite and metallic iron are present in the medium- and fine-grained fractions. In these fractions, the metallic Fe contributes to the relatively high values of magnetic susceptibility and saturation magnetization, and affecting the values of hysteresis parameters and ratios. The medium-grained fraction is dominated by shaving-shape particles containing metallic iron or/and traffic-related elements as Ca–Mg–Si–Ti–K–Al–Ba. Spherules of very diverse surface morphologies (orange-peel, hexagonal-pattern, thread-like and druse-like), were observed in fine-grained fraction of indoor dust. Magnetic mineralogy, metallic iron affects the values of coercivity and remanence causing the shift of ratios hysteresis parameters towards region characteristic for MD grains of magnetite in the Day–Dunlop plot.

1. Introduction

In recent years, indoor air quality is studied due to the fact that people spend an average more than 90% of their time in indoor environments (homes/apartments, offices, schools, etc.; [7]).

In the absence of major indoor sources, the level of indoor air pollution is directly linked to particulate matter suspended in the outdoor atmosphere. This assumption has been confirmed by the study of the ratio of indoor-to-outdoor concentration particles of several traffic related sources, of the particle size distribution spectra and of the kind of pollutants inside and outside of buildings [5,12,15–17,24,36].

Magnetometry is one of the most effective, fast and low cost methods for the qualitative estimation and characterization of the environmental pollution (soil, sediments, air). Magnetic methods are based on the general assumption that there is a link between the magnetic fraction and the pollutants in the dust from waste products, industrial activities, vehicle traffic etc.

Magnetic analyses have been carried out for the examination of the pollution in urban and industrial areas by measuring the magnetic properties of street dust settled on roads [2,21,22,33,38,39,41,42], ice [1], airborne particles captured on vegetation [29,30] and particle matter suspended in atmospheric air [4,14,32,34]. These studies have been focused on the magnetic properties, morphologies, sources of pollution and indication of the correlation between concentration dependent magnetic parameters (magnetic susceptibility and magnetization) and the content of toxic metals and other trace elements. With the same methods, it is possible to study household dust, which reflects the degree of indoor air contamination. However, there are only a few works [13,18,19,25] that undertake the study of indoor dust. Ref. [19] examined the magnetic characteristics of the pair indoor–outdoor dust. Halsall [16], found a linear correlation between the total concentration of polycyclic-aromatic-hydrocarbons and the magnetic parameters, thus reflecting the pollution in outdoor and indoor air.

Górka-Kostrubiec [13] presented the study of magnetic properties of household dust involving about 200 apartments in various locations in Warsaw (Poland), which were affected by different sources of external pollution and neglecting the industrial impact. The results revealed two sets of dust, different in mineralogy and magnetic properties. Two different slopes in the linear regression between the magnetic susceptibility and the concentrations of toxic metals and trace elements were found.

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The aim of the present study is to show the differences and the similarities of specific granulometric fractions of indoor dust collected in the city center and in the suburbs of Warsaw. As the magnetic parameters reflect the concentration, mineralogy and grain size of magnetic particles, magnetometry was used to describe different granulometric fraction of household dust. Recognition of morphology and chemical composition of the magnetic particles has been carried out using scanning electron microscope and energy dispersive X-ray spectrometer.

It was assumed that in the absence of relevant indoor sources, the magnetic properties of individual fractions of indoor dust reflect the penetration of particles from anthropogenic and/or natural outdoor sources to the interior of apartments [26]. Because of size and mass of the particles, the coarse-grained dust could be track-in into the inside on footwear of residents and paws of pets. The fine-grained fraction could mainly contain the airborne particles suspended in the atmosphere, which probably penetrate into the apartments through the natural and/or mechanical ventilation. On the basis of morphology and the distinct chemical composition of the individual fractions, it is possible to indirectly reveal the origin of the source of pollution. For example, Ca and Mg elements are components of detergents additives added to common engine oil. As Monaci [30] suggested, the positive correlations of Ca/Fe and Mg/Fe show that their possible source is vehicle traffic. Furthermore, Ni and V elements are derived mainly from the fossil fuel emissions, Ba is a common component in automobile break pads and Cr, Mn, Pb and Zn are currently the main metallic pollution emitted by motor vehicles.

2. Material and methods

Dust samples were taken from the first level of private apartments located in the city center with heavy traffic (labeled O-2) and in the suburbs (labeled B-14) of Warsaw, (Poland). The samples were collected in the same time period, between April and May, 2012. Detailed information about road traffic and habits of the residents (cigarette smoking, home heating, animals, etc.) was known. Both apartments are very similar; they are on the ground floor and they have the similar area (about 100 m^2). The site O-2 is in the center area of the city close to medium traffic roads (cars, trams). The apartment (like most buildings in the city) is connected to the central heating system from the power plant. The site B-14 is situated in a clean residential quarter of suburbs within about 10 km of the city center. In this district, all the buildings use individual heating systems. The apartment is close to the crossroad with medium traffic (cars and buses) in rush-hours (morning and early evening). The significant indoor pollution sources, such as smoking, fireplace, pets and activities of residents are similar in both apartments.

The dust was collected over the course of one month using vacuum cleaners with multi-layer bags. It should be clarified that the cleaning of both floor and furniture surface of the apartment was equivalent to collecting the dust samples. The powders were selected from the bags and mechanically sieved using the laboratory shaker with a standard sieve set. Initially, the dust was sieved through a mesh with 1 mm openings, this fraction was labeled as "All" and it was the material chosen for further grain size distribution. In the next cycle of sieving the following fractions of grains were obtained: diameter between 1 and 0.5 mm (fraction "0.5"), between 0.5 and 0.25 mm (fraction "0.25"), between 0.25 and 0.1 mm (fraction "0.1"), between 0.1 and 0.071 mm (fraction "0.071") and less than 0071 mm (fraction "<0.071").

The low-field magnetic susceptibility (χ) was measured at two frequencies (976 Hz and 15600 Hz) of magnetic field using the Multi-Function-Kappabridge (AGICO). The frequency-dependence of magnetic susceptibility (χ_{fd}) was calculated from the susceptibility measured at low and high frequencies. The anhysteretic remanent susceptibility (χ_{arm}) was acquired at 100 mT of AF field and 100 μT of DC field using the device LDA-3 (AGICO), and was measured by SQUID magnetometer (2G Enterprises, USA).

The saturation of the remanent magnetization (M_{rs}), saturation magnetization (M_s), coercivity of remanence (B_{cr}) and coercivity (B_c) were determined from the hysteresis loops and the curves of DC back-field application using vibrating sample magnetometer (VSM Molspin, Great Britain). The hysteresis parameters: M_s and M_{rs} as well asχ, and χ_{arm} were normalized on the unit mass.

The temperature-dependence of magnetic susceptibility κ(T) was measured by the Multi-Function-Kappabridge coupled with the CS-3 high-temperature furnace.

To characterize the morphology and shape of magnetic particles the direct observations of Scanning Electron Microscopy (SEM) were carried out. The chemical composition of magnetic extract was determined by the Energy Dispersive X-ray Spectroscopy analysis (EDS). The magnetic extract of dust was separated using a neodymium hand magnet.

3. Results

3.1. Thermomagnetic analyses

The variation of magnetic susceptibility *vs* temperature for three granulometric fractions ("0.5", "0.1", "<0.071") from both sites is shown in Fig. 1. For each fraction, the curves κ(T) show an estimated Curie temperature around 580 °C, in the usual range for magnetite. The small shift of the Curie point towards lower values can be associated with nonstoichiometric magnetite particles. Sagnotti [35] explained this behavior assuming the hypothesis of non-stoichiometric composition, because the Fe_3O_4 particles can include a number of substitution ions in the lattice.

The κ(T) curves revealed that the individual fractions have different magnetic mineralogy. For the medium and finer fractions, the heating curves show a susceptibility decrease at 575 °C; then, the decrease continues, with a different shape or slope, for temperatures up to 700 °C, the highest possible with CS3 furnace. The magnetic susceptibility of the medium fraction does not reach a relatively low value even at 700 °C. This may indicate the presence of a high temperature ferromagnetic phase, likely pure iron, for which $T_c = 770$ °C. During cooling, the susceptibility decreases until the start of the reverse transformation for magnetite at ~575 °C. It suggests that the chemical reactions (oxidation), starting at high temperatures, transform pure iron into magnetite, still paramagnetic at these temperatures. For the finest-grained fraction, the heating between 600 and 700 °C causes the decrease in susceptibility to a very low value; during cooling, the susceptibility does not changes up to the Curie temperature of the reverse transformation for magnetite. It indicates that a part of the ferromagnetic particles become paramagnetic close to a temperature of 700 °C.

3.2. Magnetic parameters depending on the concentration of the magnetic particles

Fig. 2 shows the histograms of the values of the magnetic parameters classified for different granulometric fractions of O-2 and B-14 samples; the same values are reported in Table 1. All the parameters which depend on the concentration of the magnetic particles (χ, χ_{arm}, M_s, M_{rs}) show the same trend with decreasing grain size. A general increase of the concentration dependent magnetic parameters with decreasing grain-size is observed (Fig. 2a–d). For example, for O-2, the susceptibility of the finest fraction is about eight-times higher than the coarsest fraction. For