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A magnetic approach for understanding the impact of Covid-19 lockdown on PM_{10} in Rome, Italy(*)

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Summary. — The magnetic properties of PM_{10} daily filters collected in Rome and Latium region during and after the Covid-19 lockdown (9 March–18 May 2020) were compared for outlining the impact of the mobility restrictions on airborne particulate matter. In urban traffic sites, the average PM_{10} concentration levels did not significantly change after the end of the lockdown, when vehicular traffic returned to its usual levels. Conversely, the average magnetic susceptibility of PM_{10} daily filters approximately doubled after the lockdown, pinpointing the increase of metallic emissions related to vehicular traffic. The magnetic fraction of PM_{10} near urban traffic sites was dominated by magnetite-like minerals mainly arising from brakes emissions.

1. – Introduction

The Covid-19 lockdown provided a unique experiment for assessing the impact of human activities on anthropic emissions. The reduction of PM_{10} concentration was uncertain: in Rome, its decrease was estimated about just the 9–12% with respect to the same period in 2019 [1], despite the drop of vehicular traffic, up to −78%. This article is an abridged and revised overview of [1], where the magnetic properties of PM_{10} filters were investigated for comparing the traffic-related metallic fraction of the filters collected in Rome during and after the lockdown. In fact, PM can show remarkable magnetic properties arising from magnetite-like ferrimagnetic particles, often associated with heavy metal [2]. The magnetic properties of PM may arise from exhaust emissions related to industry or vehicles, as well as from non-exhaust abrasion dusts from brakes, that represent the main source of urban magnetic PM [3, 4].

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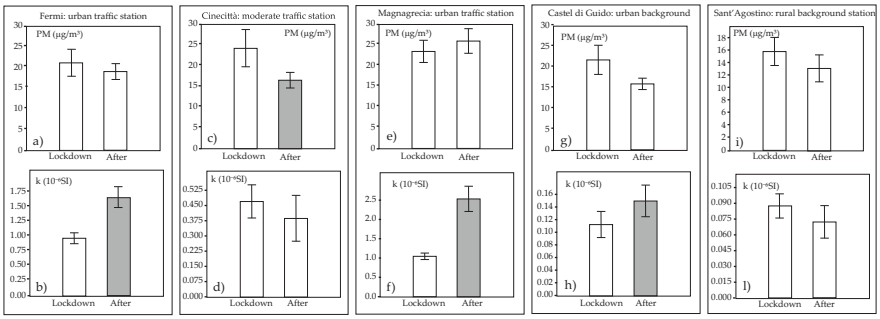

Fig. 1. – Bar-charts and standard error of average PM_{10} concentration and volume magnetic susceptibility (k) of daily filters from Rome and Latium region: bars of the same color indicate no significant difference at 95% during and after the lockdown: modified from [1].

2. – Methods

2˙1. *Location and sampling*. – PM_{10} filters were collected at five stations in the Latium region: Fermi and Magnagrecia are busy traffic stations, Cinecittà is a moderate traffic station located in the courtyard of a school in a secondary road. Castel di Guido and Sant'Agostino represent suburban and rural background stations, the second one in a coastal locality 60 km far from Rome.

In Fermi, PM_{10} filters were collected for most of the lockdown period (23 March – 18 May 2020), soon after the end of the measures (19 May – 14 June 2020) and nine months later (7 March – 15 April 2021). In Cinecittà, the collection of the lockdown PM filters continued in the 20 May – 14 June 2020 period. Magnagrecia was sampled from 26 March to 11 May 2020, with shorter time series later available in 2020 and 2021. Background stations' filters were collected from 29 March to 14 June 2020.

2˙2. *Magnetic measurements*. – A comprehensive description of the laboratory methodologies is reported in [1]. The low-field magnetic susceptibility of PM_{10} filters was measured using a AGICO KLY-5 meter. The hysteresis properties —coercive force (Bc), coercivity of remanence (Bcr), saturation remanent magnetization (Mrs) and saturation magnetization (Ms)— were measured with a Micromag 3900 magnetometer. The domain state and magnetic grain-size of the samples were compared to theoretical magnetite according to the hysteresis ratios Mrs/Ms *vs.* Bcr/Bc in the "Day plot" [5], where the mean domain state of a sample is deduced with respect to the single domain (SD), pseudosingle domain (PSD), and multidomain (MD) zones therein demarcated. First-order reversal curves, FORCs [6], were measured using the Lakeshore 8604 magnetometer; FORC diagrams are useful for delineating the distributions of the interaction field (Bu) and coercivity in samples, in order to distinguish between SD, MD and PSD behaviors. Upon verification that magnetite-like minerals dominated the magnetic mineralogy of the filters, the magnetite weight percentage fraction (wt%), with respect to the total mass of PM_{10}, was calculated dividing Ms for the saturation magnetization of pure magnetite.

3. – Results and discussions

3˙1. *Urban traffic stations: Fermi and Magnagrecia*. – The bar-charts of average PM_{10} concentrations and k values, during and after the lockdown, are shown in fig. 1, according to the statistical approach described in [1]. Fermi and Magnagrecia urban traffic stations showed robust similarities: on average, PM_{10} concentration was not significantly different during and after the lockdown, at 95% confidence level (fig. 1(a), (e)). Conversely, after the lockdown, k significantly increased (fig. 1(b), (f)).

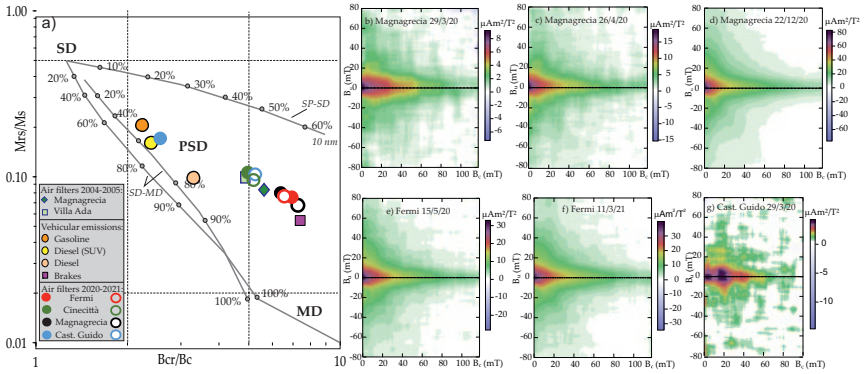

Fig. 2. – (a) Bi-logarithmic "Day plot" for Fermi, Cinecittà, Magnagrecia and Castel di Guido, station averaged. Closed circles are during lockdown, open circles afterwards. Also reported: mean values for 2004–2005 air filters, fuel exhausts and brake dusts [7]. The SD (single domain), PSD (pseudo-single domain) and MD (multidomain) fields and the theorethical mixing trends for pure magnetite particles (SP, superparamagnetic) are from [5]. FORC diagrams for Magnagrecia (b) and Castel di Guido (g) during the Caucasian dusts event; Magnagrecia (c) during and after (d) the lockdown; (e) Fermi during Saharian event and (f) after the lockdown. Modified from [1].

The linear correlation k *vs.* PM_{10} changed between lockdown and afterwards, switching from no correlation ($p = 0.93$ and $p = 0.80$) to significant correlation ($p < 0.01$) for Fermi and Magnagrecia, respectively. After the lockdown, k significantly represented the PM_{10} concentration levels, that were therefore linked to the restored high levels of vehicular emissions. In Magnagrecia, the wt% of magnetite spanned from 0.2 to 3.5%, thus implying that extreme changes in traffic-related magnetic emissions may be masked by a variation of less than a single digit in PM_{10} concentration levels. PM_{10} concentration data alone did not efficiently record the major traffic increase after the end of the lockdown, that was properly highlighted by magnetic analyses.

3˙2. *Low traffic and backgrounds stations: Cinecittà, Castel di Guido and Sant'Agostino*. – In Cinecittà station, the average k values were considerably lower with respect to Fermi and Magnagrecia, reflecting the different urban setting. Even lower magnetic susceptibility values were measured at the suburban background station of Castel di Guido and at the rural background of Sant'Agostino. Cinecittà and Sant'Agostino showed no significant difference during and after the lockdown for k (fig. 1(d), (l)), with PM_{10} concentration significantly decreasing in Cinecittà station after the lockdown (fig. 1(c)). Castel di Guido showed a significant increase of k after the lockdown (fig. 1(h)), under unsignificant variations of PM_{10} concentration (fig. 1(g)). Sant'Agostino constituted the most proper background station, being completely unaffected by the lockdown and the traffic conditions, as also confirmed by the unvaried correlation between k and PM_{10} [1].

3˙3. *Magnetic mineralogy for the analysys of PM_{10} sources*. – The hysteresis properties were analyzed on selected filters. In fig. 2, the filters were compared, at site mean level, to the average data obtained in 2004 and 2005 in Magnagrecia and Villa Ada urban park, and to fuel and brakes emissions sampled in cars' exhaust pipes and wheel rims [7]. The filters from Fermi and Magnagrecia, during and after the lockdown, were very close to the former Magnagrecia and "brake" points, in conformity with the magnetic biomonitoring observations in Milan, where brake abrasion was pinpointed as the main source of urban PM [3]. The points from Cinecittà, during and after the lockdown, coincided in the

central part of the plot, overlapping the urban background of [7]. The position of the Castel di Guido point, during the lockdown, was remarkably different, falling in the upper PSD region of the Day plot. After the lockdown, the Castel di Guido filters overlapped the Cinecittà points, thus approaching the moderate urban traffic conditions. A selection of FORC diagrams is shown in fig. 2(b)–(g): the processing parameters are listed in [1], where the smoothing factors were underestimated with respect to their actual values, ranging from 6 to 10.

Except Castel di Guido, MD features prevailed; during the exogenous dusts atmospheric event of 29 March 2020, the FORC of Castel di Guido highlighted a SD component peaking at 20 mT, that is also present in Magnagrecia on the same day (fig. 2(b), (g)). This component might be associated to local natural sources or to a magnetic signature of the Caucasian event occurring between 26 and 30 March. Conversely, the FORC diagram of Fermi on 15 May 2020 seems not affected by a Saharian dusts event (fig. 1(e)). FORC diagrams closely resembled those for brakes reported in [3] and [7], in coherence with the considerations made after the Day plot: brakes' emissions dominate the magnetic properties of PM_{10} in traffic urban sites, with minor magnetic components related to local or exogenous natural sources and, possibly, fuel emissions.

4. – Conclusions

A detailed study of the magnetic properties of PM_{10} filters collected during and after the lockdown was carried out in Rome, to assess the impact of the COVID-19 restrictions on the traffic-related fraction of particulate matter; the main findings are:

1) In traffic urban sites, the average PM_{10} concentration did not significantly change after the end of the lockdown, despite traffic raised up to high levels; conversely, the average magnetic susceptibility of PM_{10} filters approximately doubled.

2) In the moderate traffic urban station and in the rural background site, the magnetic susceptibility of PM_{10} filters was unaffected by the lockdown.

3) In urban traffic stations, the magnetic mineralogy of PM_{10} filters was dominated by magnetite-like minerals arising from brakes emissions.

4) Magnetic susceptibility is diagnostic of important variations of traffic conditions that are not evident from PM_{10} concentration data alone.

This study highlights that a significant reduction of vehicular brake wear emissions is highly demanded in traffic urban contexts, where they currently constitute one of the most severe sources of environmental pollution.

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