$PM_{2.5}$ hygroscopic behaviour characterization through an electrical conductivity method

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1. Introduction

Particulate matter (PM) hygroscopicity affects the light wavelength scattering because of the increase of particle size, the chemistry of the particles through multiphase reactions, the ability to act as cloud condensation nuclei and has important effects on the Earth's radiative forcing [1,2]. In addition, PM deposition on printed circuit boards can produce electrochemical corrosion and cause the 'failure' of Data Center information technologies (ITs) [3]. In particular to avoid PM deposition and atmospheric corrosion, Data Center spend 35-50% of their energy consumes to continuously cool IT equipment in a closed-loop system. Recently Ferrero et al. [4] have showed that using Direct Free-Cooling system Data Center could save about 7.4 MWh for each kW of installed IT and corrosion risk can minimize considering PM deliquescence and crystallization processes.
PM-induced corrosion occurs when water-soluble particles were subjected to transition phase – from solid to aqueous – and become electrically conductive. This happens once air conditions reach the particle deliquescence relative humidity (DRH) and return not conductive once particle crystallization relative humidity (CRH) is reached. The latest point happens at lower RH values than which DRH [5]. Considering DRH and CRH in design of Data Center in Po Valley appears fundamental taking into account inorganic ion fraction [4] which represents about 45% of $PM_{2.5}$ and about 90-95% of this percentage consists in NO_3^-, SO_4^{2-} and NH_4^+ [6]. ASHRAE (American Society of Heating , Refrigerating and Air-conditioning Engineers) proposed a not standardizable system to characterize PM-induced corrosion and the hygroscopic fraction transition phase hysteresis cycle is not considered because of the lack of the crystallization processes study.
Thus, to characterize PM hygroscopic behaviour in Po Valley, $PM_{2.5}$ samples where exposed to different RH conditions in an Aerosol Exposure Chamber (AEC) and an innovative method was applied to determine DRH of environmental $PM_{2.5}$ samples through electrical resistance measurements as was shown by Yang et al. [7]. In addition, the same method was improved to determine CRH too.

2. Methods

$PM_{2.5}$ hygroscopicity was studied using an AEC, specifically designed for this purpose. Electrical conductivity method was used to characterize environmental $PM_{2.5}$ DRH and CRH ranges.

2.1. Aerosols sampling

24 environmental $PM_{2.5}$ samples were collected in Torre Sarca site (TS: 45°31'19"N, 9°12'46"E), located on the northern side of Milan, using the FAI-Hydra dual channel low-volume sampler (2.3 m^3 h^{-1}, time sampling 24 h, PTFE filters, ∅=47 mm).

2.2. Aerosol Exposure Chamber (AEC)

A 1 m^3 volume hermetically isolated chamber – called AEC – was designed to let electrical resistance measurements. $PM_{2.5}$ samples were housed in round PTFE frames and blocked by two copper electrodes (far-between 5.0 mm) linked to an external multimeter (see section 2.3). Indoor-air conditions were monitored by a thermo-hygrometric sensor (DMA672, LSI-Lastem) with 1 s time resolution. Internal RH was controlled through an evaporation system using ultra-pure water (Milli-Q) and dehydration was carried out using pure air (Aria Zero, Sapio S.r.l.). Experiments were accomplished at different RH steps between 20% and 95%.

2.3. Conductivity measurements

Aerosols DRH and CRH were determined starting from the measure of electrical conductivity in function of RH inside the AEC. As reported by Yang et al. (2002) [7] the conductivity method shows an appreciable reliability for the insensibility to deviations of the mixture composition from the eutonic value. Electrical resistance was measured through an HP 3421A Data Acquisition Module (resistance range: 300Ω – 30MΩ). DRH and CRH regions were evaluated as RH ranges within $PM_{2.5}$ samples show a dramatic variation of their conductivity value, thus the gradient method was applied to this parameter.

3. Results

$PM_{2.5}$ electrical conductivity measurements show marked hysteresis behaviour during indoor AEC air humidification and dehydration (Fig.1).

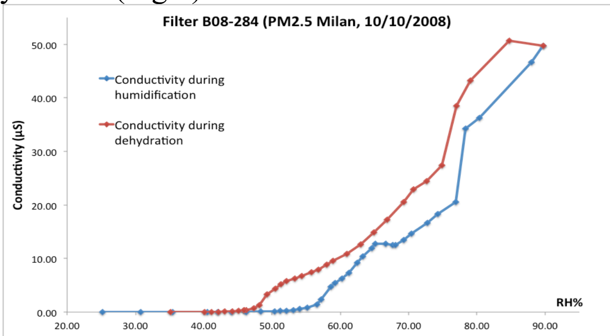

Fig. 1 – Aerosol conductivity curve during indoor AEC air humidification and dehumidification.

As Fig.1 shows, at the same RH values where it can be observed an electrical conductivity strong increase during humidification stage, aerosol conductivity is higher during dehydration stage. This hysteresis cycle influences the RH values of DRH and CRH, which were evaluated through a gradient method and transition regions were characterized. Every conductivity curves show that deliquescence occurs at higher RH values than crystallization. In particularly, $PM_{2.5}$ samples point out an averaged DRH of 60.33±0.74% RH while average CRH occurs at 48.13±0.64%. Deliquescence and crystallization range can also be considered: results show that the first transition starts at 56.76±0.94% and ends at 64±0.94% while crystallization starts at 50.00±0.56% and ends at 45.71±0.69%.

4. Conclusions

Deliquescence and crystallization relative humidity (DRH and CRH, respectively) were characterized for 24 environmental $PM_{2.5}$ samples collected in Milan site through the electrical conductivity determination in function of different RH air conditions. Conductivity curves had showed hysteresis behaviour during humidification and dehydration cycles confirming, as in literature is, that DRH occurs always at higher RH values than CRH. In fact, experimental data pointed out an averaged DRH of 60.33±0.74% and CRH of 48.13±0.64% RH.

These data were then compared with ASHRAE limits suggested to avoid the risk of electrical circuitry's corrosion occurrence using a Direct Free-Cooling system to remove heat in Data Center indoor air. The results showed that "recommended" (RH<60%) limits not protect circuits from atmospheric corrosion caused by deliquescent particles deposition. In addition, ASHRAE not consider aerosol history and underestimates the importance of crystallization conditions.

References

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