The role of aerosol chemistry and hygroscopicity in preventing corrosion and saving energy in green data centers

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1. Introduction

A large global usage of electricity (~27% in Western Europe and ~2% worldwide) is due to industrial data centers (DC) (Shehabi, 2009) where a high density of information technology (IT: computers for data storage, global networks, etc.) is present and results in substantial room and IT heating (Greenberg et al., 2006). As a result, the energy consumption of a DC due to air conditioning (AC) alone is ~35-50% of the whole DC (Shehabi et al., 2008). This turns into economic and environmental costs (greenhouse gas emissions) whose needs of reduction push towards innovative technologies. A Direct Free Cooling (DFC) system could answer this need using outside air to directly cool the IT (Shehabi et al., 2008). Even attractive, this approach involves the risk to introduce outdoor aerosol which can deposit on electronic circuitry and damage them depending on its hydration level. An aerosol hydration in fact allows the dissociation of the water-soluble ionic fraction causing bridging and corrosion (ASHRAE, 2011; Shehabi et al., 2008).

Thus, to deal with the aforementioned risk, modelled and measured aerosol hygroscopicity, as a function of aerosol chemistry, were used in this study to prevent aerosol hydration (thus corrosion) and save energy in a DC, created for the Italian Oil and Gas Company (Eni) (5200 m^2 of IT installed) specifically optimizing the DC's DFC (thermodynamic limits and indoor aerosol levels).

2. Methods

2.1 Sampling site

The investigated DC is under construction and located at Sannazzaro de' Burgondi (SdB, Po Valley; 5200 m^2 of IT installed, 30 MW; $8 \cdot 10^6$ m^3 h^{-1} of cooling air; www.eni.com/green-data-center/it_IT/pages/home.shtml) (Ferrero et al., 2013). PM_1 and $PM_{2.5}$ were sampled (4 hours; FAI-Hydra sampler; 2.3 m^3 h^{-1}, PTFE filters, Ø=47 mm) during spring and summer 2010. Meteorogical parameters and "wet" and "dry" aerosol size distributions (Tandem OPC system: TOPCs, 2 GRIMM 1.107) were also investigated; they allowed to asses the aerosol hydration (Khlystov et al., 2005) at SdB.

2.1 Aerosol chemistry

PM samples were chemically analyzed by means of ion chromatography (IC, Dionex ICS-90 and ICS-2000). Water soluble ions were extracted in ultrapure water (Milli-Q) in an ultrasonic bath (SOLTEC SONICA®). Cations (Na^+, NH_4^+, K^+, Mg^{2+} and Ca^{2+} determined by Ion Pac CS12A-5 μm column, using methansulfonic acid as eluent) and anions (Cl^-, NO_3^-, SO_4^{2-}), together with mono and dicarboxylic acids (formiate, acetate, propionate, oxalate, malonate, succinate, glutarate analysed by Ion Pac AS11A-5 μm column using KOH) were analyzed.

2.2 Aerosol hygroscopicity

2.2.1. Measurements in the Aerosol Exposure Chamber

Aerosol hygroscopicity was studied on a subset of 15 $PM_{2.5}$ samples by means of conductivity measurements as a function of the relative humidity (RH) in an Aerosol Exposure Chamber (AEC; 1 m^3) specifically designed for this purpose. In the AEC PM samples are housed over PTFE supports, provided with a pair of electrodes each. RH varied with 1% step by means of ultrapure water (Milli-Q) evaporation. Conductivity measurements were carried out at 25°C (the IT cooling set-point within the DC) using the Hewlett-Packard 3421A acquisition module. T and RH were monitored using LSI-Lastem sensors.

2.2.2. Modeling: E-AIM and ISORROPIA

The chemical analysis of PM samples were used to calculate the aerosol deliquescence relative humidity (DRH), using both the Extended-Aerosol Inorganic Model (E-AIM; a state-of-the-art thermodynamic model for the H^+-NH_4^+-SO_4^{2-}-NO_3^--carboxylic acids-H_2O aerosol system Clegg et al., 1998; Pathak et al., 2004) and the ISORROPIA model (Fountoukis and Nenes, 2007).
Models output were validated throughout results obtained in the AEC and by the use of the TOPCs system

3. Results and discussion

Aerosol chemistry evidenced a NO_3^-, $SO_4^=$, NH_4^+ dominated system (90-95% of the whole ions). The ionic balance of acids and bases was calculated: the condition of all PM_x was close to neutrality and only a small amount of H^+ were not neutralized (~5%). Neutral conditions are important for the use of a DFC system: they avoid the presence of corrosive acidic species which also are known to lowering the DRH.
Moreover, aerosol chemistry was used to model the DRH by means of E-AIM and ISORROPIA models. They were first validated through a comparison with measured DRH values in AEC on a 15 $PM_{2.5}$ subset samples. Considering the whole $PM_{2.5}$ subset, the averaged DRHs estimated via E-AIM and ISORROPIA were 62.9±2.0% and 61.5±0.9%, respectively. They agree with the values measured using the AEC: 61.7±1.4%. Moreover, the modelled hydration curves were also validated using $TOPC_s$ (R^2>0.95).
Therefore, modelled DRH_s values over the all PM_1 and $PM_{2.5}$ samples collected at SdB were used to optimize the DFC operating cycle.
The average modelled DRH for PM_1 was 61.2±1.1% (spring), and 68.4±1.4% (summer), while in the case of $PM_{2.5}$ it was 60.8±0.7% (spring) and 62.4±0.9% (summer). DRH values were lower during spring due to a NO_3^- predominance (17-20% of PM_x mass), while SO_4^{2-} was dominant during summer (10-18% of PM_x mass). Therefore, considering the mean standard deviation associated to each averaged DRH, reported values were found to be slightly higher than 60% allowing to choose 60% of RH as the upper limit for the DFC operating cycle to prevent deliquescence and thus the corrosive effects of the aerosol.
Considering this limit, the energy consumption of the DC was estimated. For this purpose a finite state dynamic discrete model was applied basing on the total time when outdoor thermodynamic conditions allowed DFC operation. An annual energy saving of 81% was estimated, compared to traditional AC data centers. This turns into an estimated saving of 7.4 MWh for each kW of IT. In terms of environment savings, considering a CO_2 emission factor of 362 gCO_2 kWh^{-1} (European Environment Agency, EEA: http://www.eea.europa.eu/) t of CO_2 not emitted were estimated: an emission savings for each kW of IT of 2.7 t of CO_2 (80 kt the entire DC) was found (Ferrero et al., 2013).

4. Conclusions

This work reports results regarding both measured and modelled aerosol hygroscopicity in relation to aerosol chemistry in the Po Valley. These data were applied to prevent aerosol corrosion and to save energy in a DC under construction for the Italian Oil and Gas Company. The DFC operating cycle was thus optimized and the energy consumption of the DC was investigated revealing an energy saving of 81% compared to traditional AC cooling systems.

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