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Effect of therapeutic salt aerosols on ambient particle concentrations, size distributions and related lung deposition

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Abstract

This research examined the effects of salt aerosols on inhalation therapy and the ambient aerosol inventory at a Gradierwerk (GW) facility in Bad Reichenhall, Germany. The sampling campaign concentrated on the suspended particle number concentration below 500 nm, sampling sites directly at the GW and at certain distances to the facility. For comparison, measurements were also made while the GW was turned off. Factoring the aerosol data into a stochastic lung deposition model showed a higher total deposition as well as a slightly higher deposition in the alveolar region for the day the GW was turned off. This directly illustrates the therapeutic benefit of the brine inhalation by reducing lung deposition and increasing clearance. The data also reveal a filtering effect in the ultrafine particle range when the GW was in function, which seems to reduce the amount of aerosols originating from the nearby traffic.

Fig. 1: Photo of the investigation site; path for therapeutic inhalation

Introduction

The primary objectives of this study were (i) to examine the particle size distribution originating from a GW inhalation spa, and (ii) its effect on ambient aerosol size distributions and the visitors of the GW. The GW is a covered open-air saltwater inhalation facility, where people with respiratory problems seek relief. The site of investigation is located in the city center of Bad Reichenhall. Almost 400,000 liters of alpine saltwater trickle down every day through a 13 meter high wall made up of around 100,000 bundles of hawthorn and blackthorn twigs. The salt water is running down on the windward side of the GW, allowing the wind to press the brine-aerosol through the twigs onto the leeward side of the wall, where people walk along for therapeutic inhalation.

Fig. 2: Drawing of the research site and surroundings

Methods

On three days with similar weather conditions, aerosol measurements were made at the GW and in the surrounding park. During two of these days, the facility was operating. In order to obtain background data, a third set of measurements was performed when the facility was turned off. A couple of measurement sites were chosen to obtain a realistic picture of the particle distribution across the surroundings of the GW.

For the on-site measurements, an SMPS was used to monitor the particle size inventory ranging from 5.5 nm to 1080 nm in total. The SMPS is a mobile continuous nanoparticle counter, which combines a CPC and a DMA.

To better understand the formation of the agglomeration peak during the on-site measurements, a lab-experiment was conducted. An aluminum container with a total air-capacity of 1.1 m^3, a pneumatic driven nebulizer, a humidifier and a built-in fan were used to simulate on-site conditions in Bad Reichenhall. Under controlled humidity and temperature conditions, HEPA-filtered air was used to spray brine from the GW during a time interval of 3 minutes into the chamber. A stochastic lung model originally developed by Koblinger and Hofmann [1] and Hofmann and Koblinger [2] was applied to the collected data to investigate the fate of inhaled particles. In this model, the geometry of the airways along the path of an inhaled particle is selected randomly using the Monte Carlo code IDEAL-2, whereas deposition probabilities are computed by deterministic formulae.

Results

During days 1 and 2 of the GW in operation, the particle distribution exhibits a peak concentration around 100 nm, which can be seen at all measurement sites. This peak is absent in data sets obtained on day 3 when the GW was turned off; instead much higher particle concentrations can be observed in the ultrafine size range.

The chamber experiment shows a significant NaCl-peak, which is leveling out over time by shifting towards a particle size range of about 100 nm. At first, a peak around 45 nm was produced during an initial injection period of 3 minutes. Over a time span of 170 minutes, this peak shifted to the characteristic accumulation peak at around 100 nm as observed under real-world conditions at the GW.

Feeding the SMPS-data set into the Stochastic Lung Model produces various deposition graphs. Total deposition in the lungs varies from almost 60%, when applying the data sets obtained when the GW was turned off, to 20% when considering brine nebulization with a final HGF (Hygroscopic Growth Factor) for NaCl-aerosols of 5 [3].

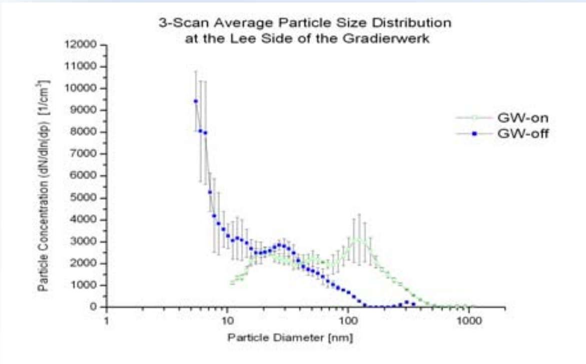

Fig. 3: Differences in particle size distributions during on/off cycles at the lee side of the GW, representing a 3-scan average with standard deviation

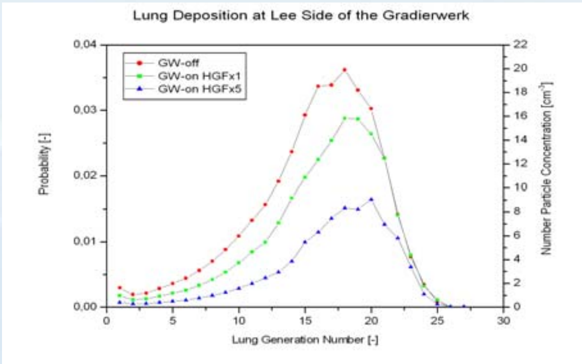

Fig. 4: Modelling differential and total particle deposition using the Monte Carlo code IDEAL-2. Plotted are three individual simulations and for various HGF.

Conclusion

This study has shown that there is a filtering effect in the ultrafine particle size regime. This unexpected finding of our investigation can be seen on days when the GW was in operation. This may be linked to the "waterfall effect", i.e. the formation of nanometer-sized charged aerosols and their growth in the lower atmosphere are important processes involved in climate changes and health effects [4].

The ultrafine range from 5 to 500 nm is primarily affected by diffusion and particle coagulation. Thus deposition in the deeper lungs is associated with particles smaller than 500 nm [5]. Airway generations beyond 15 belong to the pulmonary or alveolar region [6]. We can conclude that the alveolar deposition, especially from hydrophobic particles, such as urban traffic exhaust, tends to increasingly deposit in the higher generation airways (alveolar region), and to a lesser extent in the bronchial region, where ciliary motion can translocate deposited particles towards the trachea (mucociliary clearance). It has been proposed that alveolar deposition is associated with increased cardio-circulatory problems, as the immune system is the primary organ to remove entrapped particles therein [7].

Particle deposition calculations for the measured size distributions were carried out with and without HGF. This is of particular importance as exhaust aerosols, especially from urban traffic, are largely hydrophobic. However, this does not imply that oxidized exhaust particles do not show hygroscopic growth to a certain extent [8]. Applying the scanned particle spectrum when the GW was turned off revealed a significantly higher pulmonary deposition originating from urban traffic in all airway generations when compared with those sets of data where HGF was larger than 1. Re-running the model with the spectral data when the GW was in operation, the total pulmonary deposition decreased by almost a third.

The results of the lung model show clearly the benefit of inhaling the salty air by reducing the particle deposition as well as increased mucociliary clearance induced by the inhalation of the salt-aerosols [9]. Besides the therapeutic effects of salty aerosols, the air next to the GW contains a smaller particle burden in the ultrafine spectrum. Due to its specific construction, the GW appears to act as an artificial waterfall.

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