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EFFECTS OF SALT-AEROSOLS FROM A GRADIERWERK ON INHALATION THERAPY AND AMBIENT AEROSOLS

AUSWIRKUNGEN VON SALZAEROSOLEN EINES GRADIERWERKES AUF INHALATIONSTHERAPIE UND UMGEBUNGSAEROSOLE

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Abstract

This paper examines the effects of salt aerosol production at a Gradierwerk (GW) facility in Bad Reichenhall, Germany. The sampling campaign concentrated on the particle number concentration below 500 nm suspended in air. Sampling sites directly at the GW and at certain distances were chosen to investigate the effects of the salt aerosols on inhalation therapy and on the ambient aerosol inventory. 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.

Keywords: Gradierwerk, salt aerosol, inhalation spa, lung deposition

Zusammenfassung

Diese Arbeit zeigt die Untersuchung von Effekten der Salzaerosolinhalation an einem Gradierwerk in Bad Reichenhall, BRD. Die Untersuchungen konzentrierten sich auf einen Messbereich der suspendierten Partikelanzahl von unter 500 nm. Um einen therapeutischen Effekt und einen Einfluss auf die Umgebungsaerosole zu erkennen, wurde sowohl direkt am GW als auch in Abständen davon gemessen. Ein Vergleich des Aerosolbestandes wurde bei Nichtbetrieb des GW ermittelt. Die erhaltenen Daten wurden in einem stochastischen Lungendepositionsmodell verwendet, welches eine höhere Gesamtdeposition und eine erhöhte Ablagerung in der Alveolarregion bei Nichtbetrieb des GW zeigt. Dies weist direkt auf den therapeutischen Nutzen der Sole-Inhalation durch reduzierte Lungendeposition und erhöhtes Clearance hin. Die Ergebnisse zeigen auch einen Filtereffekt im ultrafeinen

Bereich, welcher die Abgaspartikel vom nahen Straßenverkehr in der Umgebungsluft zu reduzieren scheint.

Schlüsselwörter: Gradierwerk, Salzaerosole, Kur, Lungendeposition

Objectives

The primary objectives of this study were (i) to examine the particle size distribution originating from a Gradierwerk (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 to ease respiratory difficulties. The site of investigation is located in the city center of Bad Reichenhall, Germany. 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 through the twigs onto the leeward side of the wall, where people walk along for therapeutic inhalation.

Figure 1: Arial view of the GW located in Bad Reichenhall (modified after Google Earth)

Materials and Methods

On three days with similar weather conditions, aerosol measurements were made at the GW and in the surrounding park. On 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.

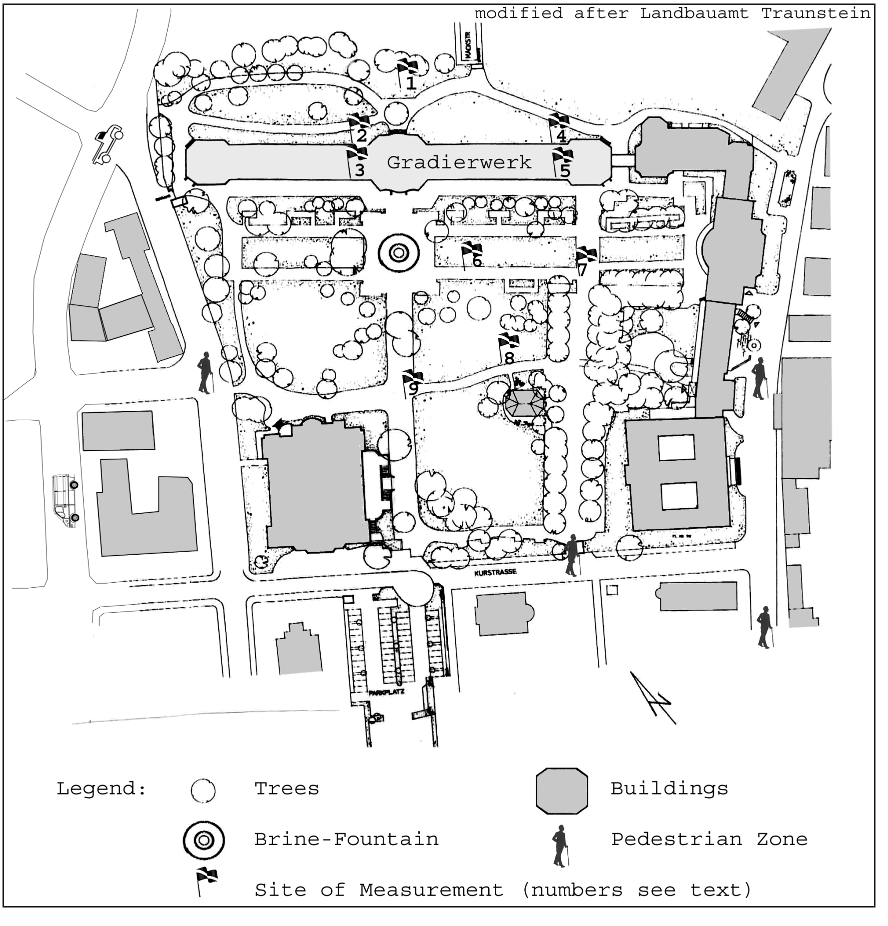

Figure 2: Schematic site map showing the measurement points in reference to the GW.

For the on-site measurements, an SMPS (Scanning Mobility Particle Sizer) and an OPC (Optical Particle Counter) were used to monitor the particle size inventory ranging from 5.5 nm to 6.5 µm in total. The SMPS is a mobile continuous nanoparticle counter, which combines a CPC (Condensation Nucleus Counter, Grimm model # 5.403) and a DMA (Direct Mobility Analyzer „Vienna-Type“, Grimm model # 5.500, sheath air flow 3.0 L/min). The OPC (Grimm Model # 1106) was used to extend the observation range from the SMPS up to 6.5 µm. During measurements with the SMPS and OPC system it was found that the sampled measurement range exceeded our relevant observation window. Follow-up measurements were then performed using the SMPS with the DMA only.

To better understand the formation of the agglomeration peak during the on-site measurements, a laboratory experiment was conducted, which simulated "real-world" conditions. An aluminum container with a total air-capacity of 1.1 m^3, a pneumatic driven nebulizer (analog to the TSI Portable Atomizer, Model # 3079), 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.

Table 1: Description of measurement sites: on-site measurements (day 1-3) constitute averages of at least 3 consecutive scans, whereas laboratory chamber experiments (day 4-6) were used to create time series of up to 40 scans.

Day of Measurement	GW on/off	Site of Measurements (RH [%] / T [ºC] averages)								
		1	2	3	4	5	6	7	8	9
Day 1: May 4	on	48/25	65/22	70/22	61/22	72/21		70/21	47/23	
Day 2: July 11	on	44/29		72/24			50/24	71/23		46/26
Day 3: Aug. 2	off	46/24	64/19	65/20			56/24	45/21		45/23
Day 4: Aug. 8	Chamber exp.	20-30 / 22								
Day 5: Aug. 9	Chamber exp.	40-50 / 22								
Day 6: Aug. 10	Chamber exp.	60-80 / 22								

On site micro-climatic temperature and humidity levels were recorded with the handheld Testoterm 6010 model. Meso-scale climatic data, such as wind direction and wind speed were obtained from the nearby weather monitoring station at Salzburg Airport as well as from Deutscher Wetter Dienst (DWD, German Weather Service) to verify the micro-climatic data gathered on-site. According to prevailing wind patterns, a roof-top mounted detection device routes the brine in such a way as to sprinkle only that side of the GW that does face direct wind exposure.

Table 2: Meso-scale climatic data during measurement hours: average values of wind speed [km/h] from Salzburg Airport, Beaufort Number from DWD and wind direction [º], where 0º is north. Based on data from Salzburg Airport and DWD.

Day of Measurement	Wind Speed [Bft] Bad Reichenhall	Wind Speed [km/h] Salzburg Airport	Wind Direction [º] Salzburg Airport
Day 1: May 4, 2006	3	15	30
Day 2: July 11, 2006	3	20	40
Day 3: August 2, 2006	3	22	110

A stochastic lung model originally developed by KOBLINGER and HOFMANN (1990) and HOFMANN and KOBLINGER (1990) 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, whereas deposition probabilities are computed by deterministic formulae. Further details about the airway geometry selection, the random path of particles through this geometry and the methods of aerosol deposition calculation in conductive and respiratory airways during a full breathing cycle can be found in the original publications (HOFMANN & KOBLINGER 1990, KOBLINGER & HOFMANN,1990). This particle deposition model enables the computation of total, regional (bronchial and alveolar) and differential (individual airway generations) deposition in the human adult lung.

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 (fig.3). 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 (fig. 4). 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.

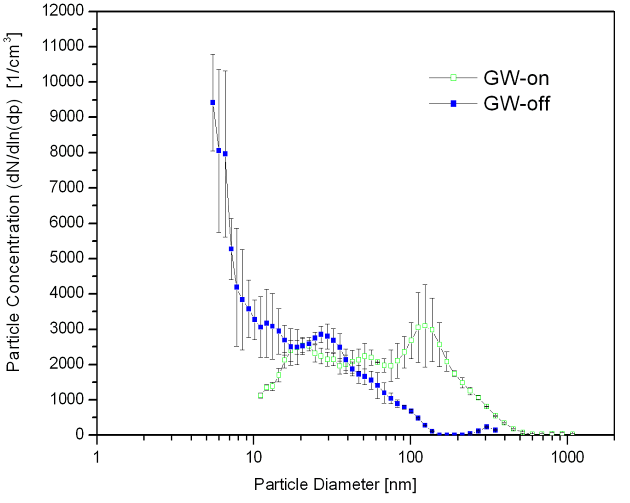

Figure 3: Differences in particle size distributions during on/off cycles at the lee sides of the GW, representing a 3-scan average with standard deviation.

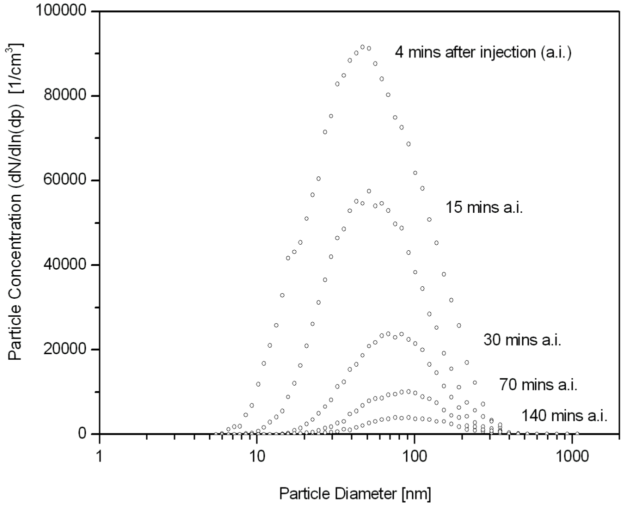

Figure 4: Chamber experiments (SMPS with DMA): brine aerosol generated from GW, nebulized for 3 minutes under controlled temperature and humidity conditions.

Feeding the SMPS-data set into the Stochastic lung model produces various deposition graphs (fig. 5). 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 (ASGHARIAN 2004).

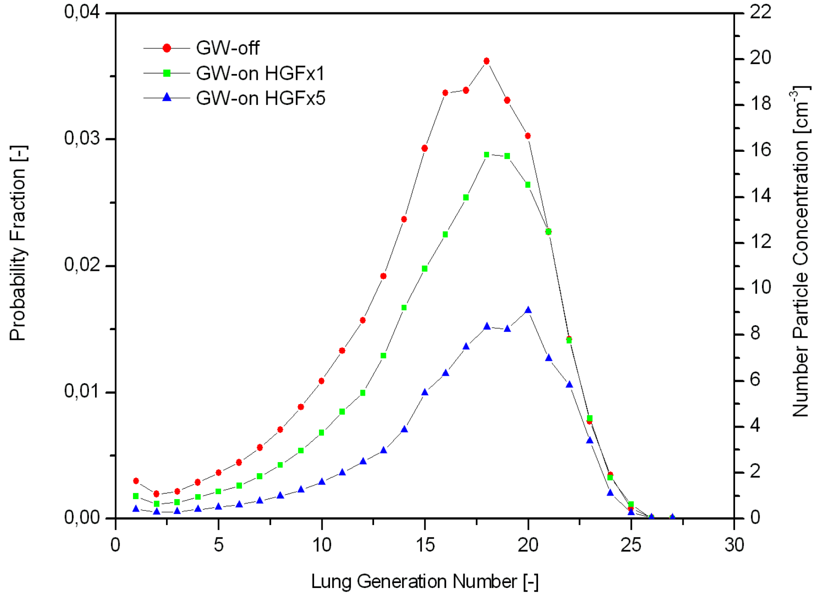

Figure 5: Modeling differential and total particle deposition in the lung, using the Monte Carlo code IDEAL. Plotted are three individual simulations and for various Hygroscopic Growth Factors (HGF).

Discussion

The obvious aerosol emissions by the GW are documented by the measurements taken on day 1 and 2. A distinct peak at around 100 nm is clearly seen, the NaCl-peak. This peak is absent on day 3, when the GW was turned off (fig. 3). In order to verify the emission peak at around 100 nm and to associate it with the nebulized brine, a lab-experiment was performed to correlate this assumption (fig. 4). The results neatly fit with field observations: the aerosol peak at around 100 nm does indeed correspond to the accumulated aerosol fraction emitted by the GW as seen at days 1 and 2. This is also supported by the fact that on day 3, when the GW was turned off, no characteristic NaCl-peak could be measured.

In addition to the occurrence of the salt-aerosol peak, there is a filtering effect in the ultrafine particle size regime. This unexpected finding of our investigation can be seen on days 1 and 2, when the GW was in operation and where small amounts of these aerosols (5 to <100 nm) were observed. These aerosols most likely originated from nearby road traffic as wind conditions on the measured days corresponded with the location of the main road through Bad Reichenhall. This proposed filtering effect is supported by the measurement conducted on day 3, which revealed a drastic increase of airborne particles in the observed size range. The absence of the particle load in the ultrafine size range persisted throughout the measurements when the GW was switched on. It reemerged only during the measurements when the GW was turned off. 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 (PARTS & LUTS 2005).

While particle deposition due to sedimentation and impaction is a predominant phenomenon of particles in the size range from 500 to 1000 nm, 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 (HOFMANN 2003). According to the human lung model published by YEH and SCHUM (1980), airway generations 1 to 15 can be assigned to the tracheo-bronchial region, while all generations beyond generation 15 belong to the pulmonary or alveolar region. Hence, 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 (DONALDSON ET AL. 1988).

Particle deposition calculations for the measured size distributions were carried out with and without hygroscopic growth (fig. 5). 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 (VOGT et al., 2001) 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. A further reduction of the total lung deposition by a factor of about 2 is achieved by introducing a HGF of 5 for the emitted brine aerosol. According to HEYDER et al. (2004), such a HGF is reasonable as the relative humidity levels in the human lungs are found to be 99.95%, which corresponds to a growth factor that fluctuates between 4.2 and 5.2 (for convenience we used a standard HGF of 5).

Conclusions

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 (DAVISKAS 1996). Besides the therapeutic effects of salty aerosols, the air next to the GW contains a smaller particle burden in the ultrafine spectrum, which contributes to the overall benefit of the GW. Therefore, the ability of the GW to reduce the amount of nano-particles in the ambient air is an additional advantage to the therapeutic applications of brine inhalation. Due to its specific construction, the GW appears to act as an artificial waterfall (PARTS & LUTS 2005). The influence of the waterfall effect at GW facilities, especially the production and interaction of aerosol ions, should be further investigated.

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