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2005

# A SET-UP FOR FIELD STUDIES OF RESPIRATORY DEPOSITION IN HUMANS

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## *Introduction*

It has been estimated that airborne particles in ambient air (e.g. PM10 and PM2.5) leads to a loss of 6.4 million years of healthy life annually in the world (WHO 2003). The corresponding estimate for Europe is 750,000 years (WHO 2002; Ezzati et al. 2002) and for Sweden 2,500 years (Forsberg et al. 2005). It has been suggested that fine and ultrafine particles, especially from combustion sources, have a stronger association with adverse health effects than larger particles (Donaldson et al. 2001). The biological mechanisms by which particles affect health at moderate levels in the industrialised world are not fully understood. Susceptible sub-groups such as people with pre-existing respiratory or cardiovascular diseases, elderly and children have been identified.

In 1881, Tyndall made the first observation of aerosol particle deposition in the respiratory system. The probability of an inhaled particle to be deposited in the human airways depends on its size, shape and chemical composition as well as on the breathing pattern and airway geometry of the inhaling person. The term “respiratory deposition” refers to the mean probability for an inhaled particle to be deposited in the respiratory system. Most knowledge of respiratory deposition comes from measurements of particle concentration in inhaled and exhaled air using monodisperse hydrophobic particles in healthy young test-persons. There are surprisingly few experimental data available for ambient particles and ultrafine particles in general. In addition there are only few experimental data for ultrafine particle deposition in susceptible sub-groups (Chalupa et al. 2004). To fill this gap there is a need for experimental methods with which large groups can be studied in various environments e.g. at the low concentrations often encountered for ambient particles. An important parameter rarely taken into account is the hygroscopic growth into solution droplets that occurs in the respiratory tract for soluble species

The aim of this work was to develop and characterise a fast respiratory deposition method suitable for field measurements in humans. The method should have well-documented accuracy and allow fast measurements (less than 15 min).

## *Respiratory Deposition Method*

The system can be divided into three main parts: aerosol generation, breathing system and measurement system. The two latter parts are shown in figure 1.

**Aerosol Generation**

Two different sources of aerosol were used, hygroscopic sodium chloride and hydrpophobic di-ethyl-hexyl-sebacate (DEHS). Polydisperse aerosol was generated with a nebuliser (Model 3076, TSI Inc., US), sodium chloride from a distilled water solution with 1% salt and DEHS from an ethanol solution with 0.1% DEHS, which resulted in a dried aerosol with a number geometric mean diameter (GMD) of 50-80 nm. In experiments involving human test persons the wet aerosol from the nebuliser passed a single nozzle impactor with a cut-off diameter of 0.7 μm. This reduced the mass concentration by a factor of 5-10. The ethanol was subsequently adsorbed in two active charcoal denuders. The aerosols were diluted with particle free air in a 1 m3 box in order to decrease the RH below 30% and achieve the desired number concentrations (50,000-430,000 cm-3). Typically a particle concentration of 90,000 cm-3 was chosen. The arrangement of the system is shown in Figure 1. It basically consists of a mouthpiece, two tanks made of stainless steel connected by a T-shaped brass piece with two one-way valves, an automatic two-way valve, a drier and a particle spectrometer. When a human test-person inhales, air is drawn actively from the larger tank for “inhaled” air. Inhaled and exhaled air is separated by two one-way valves (Lip membrane, Laerdal medical, Norway), of the “duck-bill” type, which opens with minimal flow obstruction. The valves are made of silicon rubber, but were covered with a 50 nm thick layer of gold applied with vacuum deposition (Auto 306, Edwards, UK) to decrease losses by electrostatic deposition. The exhaled aerosol enters a smaller tank that is heated to 38-40 °C to prevent condensation. Both the inhalation tank and the exhalation tank are thus open to the surrounding atmosphere and operate at pressures near ambient. The breathing continues until a sufficient number of particles are counted to

calculate the deposition, normally between 10 and 20 minutes depending on the aerosol concentration. A pressure transducer (PasCal 100, Hoffrichter, Germany) connected to a pneumotachograph (Type 1, Dr. Fenyves und Gut, Germany) is used to register the exhaled flow-rate and breathing frequency. Temperature and RH are measured in the aerosol sampling lines just after exit from the two tanks using capacitive sensors (Hygroclip S, Rotronic, Switzerland).

**Measurement System**

In both systems the aerosol concentration is measured in the reservoirs for inhaled and exhaled air. The sampling location is chosen with a computer controlled two-way valve (Solenoid Valve, type 330, Bürkert, Germany). The aerosol is dried with a 48" Nafion single tube drier (MD-070, Perma Pure, NJ, USA), which reduces the RH to below 25%. Measurement of the particle size distribution was made with a scanning mobility particle sizer consisting of a differential mobility analyser (DMA, Model 3071, TSI Inc., US) and a condensation particle counter (CPC, Model 3010, TSI Inc., US). The DMA is operated in a closed loop set-up with a diffusion drier (Model 3062, TSI Inc., US) in the sheath flow to reduce the RH in the DMA to below 5%. Temperature and RH is measured after the nafion drier and in the DMA sheath flow loop.

A computer program (written in LabVIEW 7.1) was constructed in order to control the particle spectrometer, record the breathing pattern, control valves and sensors and continuously calculate the respiratory deposition.

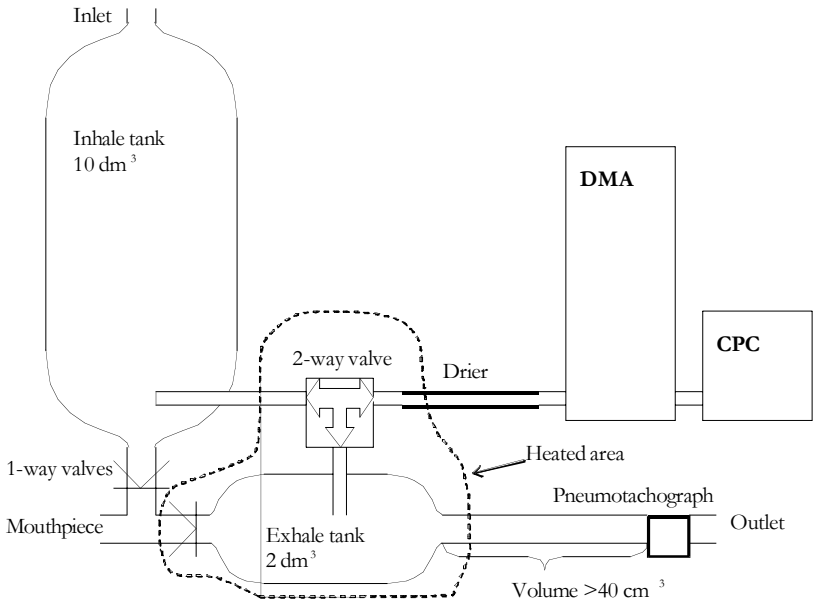



Figure 1. Schematic figure of the flow-through system

**Method Characterisation**

The flow-through method was characterised with reference to losses in the breathing system usıng a sınus wave pıston-type breath sımultor. When determining respiratory deposition, corrections must be made for particle losses in the equipment, DFequip.

$$DF_{human}(d_{p,i}) = 1 - \frac{C_{ex}(d_{p,i})}{C_{in}(d_{p,i}) \cdot (1 - DF_{equip}(d_{p,i}))} \quad (1)$$

Where dp,i is the particle diameter in size-channel i and Cin and Cex denote the particle concentration in the inhaled and exhaled samples.

**Experiments with human test-persons**

The main part of the validation experiments were performed in one healthy male test-person (26 years old) to minimise physiological variations. The test-person followed suggested (square wave) breathing patterns on a computer screen.

To estimate the precision of the method, NaCl aerosol was inhaled in three “identical” experiments (on the same day) with breathing frequency 10 ± 0.1 min-1, minute volume 10 ± 0.1 L/min. The measurement time was 15 minutes for each of these sessions.
To validate the sensitivity of the method, deposition of NaCl was compared for three different breathing patterns, 6 ± 0.5 min-1, 10 ± 1 min-1 and 15 ± 1 min-1. Hydrophobic DEHS particles were inhaled at 10 ± 1 min-1 and 10 ± 1 L/min.

The experiments were performed at a concentration of 100,000 cm-3. The inhaled mass concentration in experiments with human test-persons was below 100 µg/m3 as determined with combined measurements with an APS 3321 and the SMPS.
Modelling respiratory deposition

Respiratory deposition predicted with the ICRP 66 model (ICRP, 1994) was calculated for a healthy male, breathing through the mouth at 10 L/min with frequencies 6, 10 and 15 min-1. Hygroscopic growth was incorporated in the model by assuming RH=99.5% throughout the respiratory tract and immediate growth to the equilibrium size.

## *Results*

After covering the one way valves with gold, the deposited number fraction ın the system decreased with up to a factor of two and is below 6% for 20 nm particles and approximately 1% for 100-300 nm.
The respiratory deposition determined with the system was found highly repeatable in identical experiments with a single test-person (Figure 2). The method is clearly sensitive enough to distinguish between the three different breathing patterns in single experiments (Figure 3). The variations are in relatively good agreement with the ICRP model. Figure 4 illustrates the difference in deposition between hygroscopic NaCl particles and hydrophobic DEHS particles. The agreement with the ICRP-model is relatively good, indicating that the RH is close to 99.5% in regions of the respiratory tract where particles were deposited.

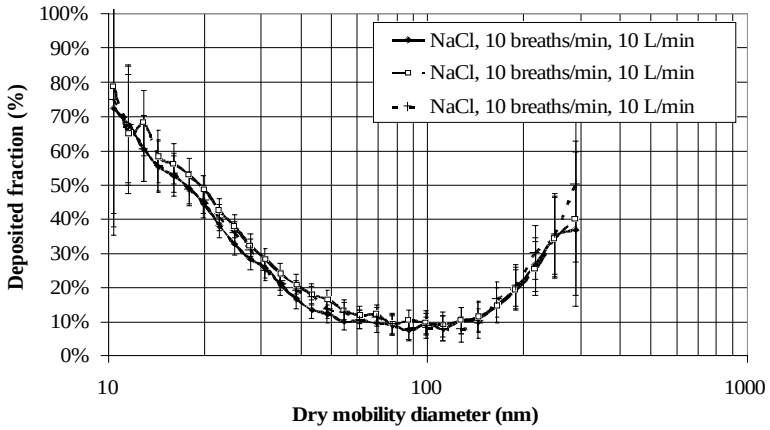



Figure 2. Respiratory deposition of NaCl for a single test-person in three identical experiments. Breathing frequency, 10 min-1, minute volume 10 L/min Error bars show a 95% confidence interval due to counting statistics.

## *Discussion and Conclusions*

The flow-through system performed favourable in experiments with hygroscopic aerosols in human test-persons. The precision of the method investigated with “identical” experiments with semi-controlled breathing patterns resulted in variations below 5% (DF = x ± 5%) for the main part of the size interval. The method is sensitive enough to quantify differences between breathing patterns and

Figure 3. Respiratory deposition of NaCl in a single test-person. Single measurements with breathing frequencies of 6, 10 and 15 min-1 and an average flow-rate of 10 L/min.

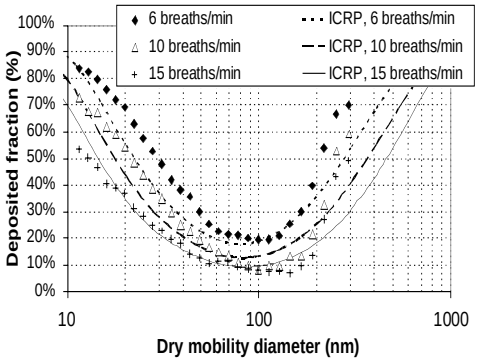
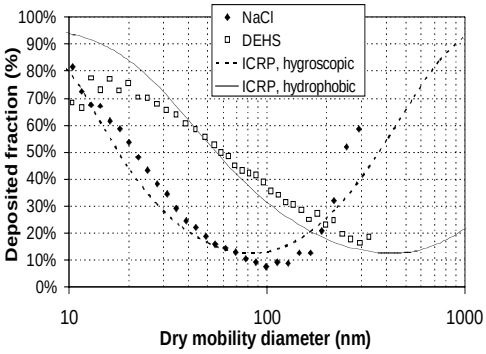



Figure 4. Respiratory deposition of hygroscopic NaCl particles and hydrophobic DEHS particles in a single test-person. Breathing frequency 10 min-1, minute volume 10 L/min.




differences between hygroscopic and hydrophobic aerosols. Respiratory deposition increased for all particle sizes for decreasing breathing frequency since the deposition efficiency of both diffusion and sedimentation increases with residence time. Our results with NaCl and DEHS and comparisons with the ICRP model shows that the hygroscopic particles deposit as if grown to their equilibrium sizes at RH=99.0-99.5.

In conclusion, the method offers a fast and relatively simple way to determine respiratory deposition in human test persons. The method performed well in precision and sensitivity tests. We plan to use the described method on larger groups of test-persons with varying respiratory status in various environments, including street canyon, fresh wood smoke and indoor aerosols.

Acknowledgements

This study was supported by The Building and its Indoor Environment, a research school at Lund University. The Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS) and the Swedish National Air-pollution Programme (SNAP, Swedish EPA).

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