Respiratory Tract Deposition of Particles from Biomass Combustion

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Abstract. The respiratory tract deposition of particles from two types of biomass combustion was measured for 10 healthy subjects. The aerosol was extensively characterised. Model calculations of the deposition were made based on the particle properties. The results show that particle water absorption has substantial impact on deposition. The particles from biomass combustion obtained a size in the respiratory tract at which the deposition probability is close to its minimum.

1. Introduction

There is an ongoing discussion about the relative importance of particle number, surface and mass concentration in health effects of an aerosol. Air quality guidelines usually regulate the mass concentration. It is possible that the differences in health effects of various aerosols could be partly explained by a potentially large variation in the respiratory tract deposited dose of the particles. In this study the respiratory tract deposition has been measured and calculated for particles from biomass combustion. A full report of the study is published elsewhere (Löndahl et al. 2008 [1]).

Smoke from biomass combustion is one of the major environmental threats to human health – especially in the poor part of the world (Lopez et al. 2006 [2]). It is also of increasing interest in search for renewable fuel to reach a sustainable development. One key parameter to fully understand the health effects of the particles is to estimate their probability to deposit in the lungs.

Biomass combustion particles are often hygroscopic and will thus change size in the lungs by absorption of water vapor. The relative humidity (RH) in the lungs is estimated to 99.5%. The common dose models do not usually take particle water absorption into account. Hence they need to be modified in order to make a correct estimate of the deposition biomass combustion particles. To
The respiratory tract deposition of particles from biomass combustion was measured for healthy human subjects with a novel instrument named RESPI (Löndahl et al. 2006 [3]). Data fulfilling our quality assurance protocol was obtained for 10 subjects (4f/6m). A modern residential wood pellet burner fired with a typical softwood pellet fuel was used for generating the emissions. Two entirely different operation conditions were applied: 1) efficient “complete” combustion at high load (~10 kWfuel) with an intensive/turbulent and hot (900-1100°C) flame and 2) low temperature (600-800°C) incomplete combustion at ~5 kWfuel simulating “wood smoke” by burning moist fuel with reduced air/fuel mixing. The combustion aerosols were cooled and diluted using a three stage dilution system. In addition the deposition was measured for nebulised hydrophobic DEHS-oil particles.

Biomass particles usually contain a large fraction of salts and therefore grow by absorption of water in a humid environment such as the respiratory tract. Thus, deposition is expected to change. To verify this, growth by water absorption was measured at 90% relative humidity (RH) with an H-TDMA. Based on these data and on the measured chemical composition, the particle hygroscopic growth factors at the RH prevailing in the lung were estimated. Thereby, the well-established ICRP dose model (ICRP Publication 66 1995 [4]) could be adjusted for particle water absorption. This was done in order to show consistency between measured deposition and theory.

3. Results and Discussion
There were considerable differences in deposition between the three studied aerosols (Figure 1). Average tidal volume for the 10 subjects was 0.68 ± 0.18 L and breathing frequency 12.4 ± 2.1 min⁻¹. The measured deposition fraction (DF) of the particles emitted from efficient combustion had a minimum around 60-70 nm. For particles from low temperature combustion the minimum was stretched out from 60-300 nm. On average, 21%–24% of the number, surface and mass of the inhaled particles were deposited for both studied biomass combustion aerosols. The DF for the reference oil was higher but similar in shape to the deposition estimated from the common ICRP model (Figure 4).

![Figure 1. Measured respiratory tract deposition of particles from two types of biomass combustion (efficient and low temperature) and the deposition of hydrophobic reference particles.](image-url)
The two biomass combustion aerosols had different size distributions, chemical composition and ability to absorb water – properties of fundamental importance for the respiratory tract deposition (Figure 2 and 3). Figure 2 shows the hygroscopic growth factor measured at 90% (left) and extrapolated to 99.5% RH (right). Figure 3 shows how this growth changes the size distribution in the lungs at 99.5% RH. The efficient combustion aerosol had a number concentration of $1.46 \pm 0.06 \times 10^5$ cm$^{-3}$, a count median mobility diameter, CMD, of 81 nm and a geometric standard deviation, $\sigma_g$, of 1.5. The low temperature combustion aerosol had a number concentration of $3.8 \pm 1.2 \times 10^4$ cm$^{-3}$, CMD of 137 nm and $\sigma_g$ of 1.8. PM$_1$ samples of efficient combustion particles consisted by mass to 96% of soluble alkali salts, primarily K$_2$SO$_4$, KCl and K$_2$CO$_3$. The soluble volume fraction of KCl was 0.51, as derived from the HTDMA measurements. The fraction of K$_2$SO$_4$, which was only partly in solution at 90% RH, was 0.38 according to the chemical analysis. The increase in hygroscopic growth caused by inclusion of K$_2$SO$_4$ as it goes into solution at higher RH is shown in Figure 3 (right). The total carbon content was <1%. In contrast, the particles from low temperature combustion were more complex and consisted of 85% carbonaceous material (organic compounds and soot) and 14% alkali salts. The fraction of insoluble material in these particles, calculated from the HTDMA data, increased with size and particles above 400 nm were nearly hydrophobic.

![Figure 2](image1.png)

**Figure 2.** The size-dependent particle growth factor (Gf) measured at 90% RH (left) and extrapolated to 99.5% RH (right).

![Figure 3](image2.png)

**Figure 3.** The particle number size distributions of the two biomass combustion aerosols at dry conditions and at 99.5% RH.
The experimentally determined DF agreed largely with the predicted DF when hygroscopic growth was incorporated in the model calculations (Figure 1 and 4). The modeled DF curve was shifted to the left towards smaller dry diameters, for both combustion aerosols, although most significantly for the efficient combustion due to higher growth factors. For instance, the “measured” growth factor for 100 nm particles from efficient combustion was 4.1 (Figure 3). Hence, these particles were assumed to grow to a size of 410 nm in the respiratory tract and thus deposit with the same probability as hydrophobic 410 nm particles.

![Figure 4. The deposition fraction according to the ICRP model after adjustment for particle water absorption.](image)

4. Conclusion
This study experimentally verifies that the ability of real-world particles to absorb water sometimes substantially alter the deposition in the respiratory tract. This has previously only been shown by theoretical calculations and a limited number of experiments whereof most with NaCl particles. The majority of the particles from the two studied and completely different types of biomass combustion aerosols obtain a size in the respiratory tract (after water up-take) which coincides with the minimum in deposition probability. This was evident from both the measurements on human subjects and from model calculations, where particle characteristics were included. The respiratory tract deposited fraction of particles did thus become low (0.21-0.24) compared to what could be expected from for example traffic exhaust particles which are both smaller in size and more hydrophobic.

References
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