

Scanning Mobility Particle Sizer™ (SMPS™) Spectrometer Application: Indoor Air, Exposure Monitoring, & Inhalation Toxicology

Bibliography

2007

Chang, Yu-Chen; Lee, Hsiu-Wei; Tseng, Huan-Hsiung, 2007, “The formation of incense smoke,” *Journal of Aerosol Science*, **38**(1):39-51

The formation of incense smoke generated from four different types of incense sticks, three manufactured in Taiwan and one in Japan, was investigated in a small controlled chamber. The scanning mobility particle sizer and the quartz crystal microbalance were used for particle size analyses. The count median diameter (CMD) was found to rise swiftly along the path of the incense smoke. Consequently, a representative sampling location was selected for all measurements performed thereafter. All four types of incense smoke were shown to exhibit characteristic size distributions, CMDs, and mass median aerodynamic diameters (MMADs). Electron microscopy depicted liquid and solid nature of Taiwan and Japan incense smoke, respectively. The different physical states of the particles were suspected to be a result of different smoke-generating ingredients used by different cultures. Finally, the formation mechanisms of both liquid and solid incense smoke were discussed.

Fromme, H.; Twardella, D.; Dietrich, S.; Heitmann, D.; Schierl, R.; Liebl, B.; Rüdén, H., 2007, “Particulate matter in the indoor air of classrooms—exploratory results from Munich and surrounding area,” *Atmospheric Environment*, **41**(4):854-866

Numerous epidemiological studies have demonstrated the association between particle mass (PM) concentration in outside air and the occurrence of health related problems and/or diseases. However, much less is known about indoor PM concentrations and associated health risks. In particular, data are needed on air quality in schools, since children are assumed to be more vulnerable to health hazards and spend a large part of their time in classrooms.

On this background, we evaluated indoor air quality in 64 schools in the city of Munich and a neighbouring district outside the city boundary. In winter 2004–2005 in 92 classrooms, and in summer 2005 in 75 classrooms, data on indoor air climate parameters (temperature, relative humidity), carbon dioxide (CO₂) and various dust particle fractions (PM₁₀, PM_{2.5}) were collected; for the latter both gravimetric and continuous measurements by laser aerosol spectrometer (LAS) were implemented. In the summer period, the particle number concentration (PNC), was determined using a scanning mobility particle sizer (SMPS). Additionally, data on room and building characteristics were collected by use of a standardized form. Only data collected during teaching hours were considered in analysis. For continuously measured parameters the daily median was used to describe the exposure level in a classroom.

The median indoor CO₂ concentration in a classroom was 1603 ppm in winter and 405 ppm in summer. With LAS in winter, median PM concentrations of 19.8 µg m⁻³ (PM_{2.5}) and 91.5 µg m⁻³ (PM₁₀) were observed, in summer PM concentrations were significantly reduced (median PM_{2.5}=12.7 µg m⁻³, median PM₁₀=64.9 µg m⁻³). PM_{2.5} concentrations determined by the gravimetric method were in general higher (median in winter: 36.7 µg m⁻³, median in summer: 20.2 µg m⁻³) but correlated strongly with the LAS-measured results. In explorative analysis, we identified a significant increase of LAS-measured PM_{2.5} by



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1.7 $\mu\text{g m}^{-3}$ per increase in humidity by 10%, by 0.5 $\mu\text{g m}^{-3}$ per increase in CO_2 indoor concentration by 100 ppm, and a decrease by 2.8 $\mu\text{g m}^{-3}$ in 5–7th grade classes and by 7.3 $\mu\text{g m}^{-3}$ in class 8–11 compared to 1–4th class. During the winter period, the associations were stronger regarding class level, reverse regarding humidity (a decrease by 6.4 $\mu\text{g m}^{-3}$ per increase in 10% humidity) and absent regarding CO_2 indoor concentration. The median PNC measured in 36 classrooms ranged between 2622 and 12,145 particles cm^{-3} (median: 5660 particles cm^{-3}).

The results clearly show that exposure to particulate matter in school is high. The increased PM concentrations in winter and their correlation with high CO_2 concentrations indicate that inadequate ventilation plays a major role in the establishment of poor indoor air quality. Additionally, the increased PM concentration in low level classes and in rooms with high number of pupils suggest that the physical activity of pupils, which is assumed to be more pronounced in younger children, contributes to a constant process of resuspension of sedimented particles. Further investigations are necessary to increase knowledge on predictors of PM concentration, to assess the toxic potential of indoor particles and to develop and test strategies how to ensure improved indoor air quality in schools.

2006

Destailats H.; Lunden M.M.; Singer B.C.; Coleman B.K.; Hodgson A.T.; Weschler C.J.; Nazaroff W.W., 2006, "Indoor secondary pollutants from household product emissions in the presence of ozone: A bench-scale chamber study," *Environmental Science and Technology*, **40**(14): 4421-4428

Ozone-driven chemistry is a source of indoor secondary pollutants of potential health concern. This study investigates secondary air pollutants formed from reactions between constituents of household products and ozone. Gas-phase product emissions were introduced along with ozone at constant rates into a 198-L Teflon-lined reaction chamber. Gas-phase concentrations of reactive terpenoids and oxidation products were measured. Formaldehyde was a predominant oxidation byproduct for the three studied products, with yields for most conditions of 20-30% with respect to ozone consumed. Acetaldehyde, acetone, glycolaldehyde, formic acid, and acetic acid were each also detected for two or three of the products. Immediately upon mixing of reactants, a scanning mobility particle sizer detected particle nucleation events that were followed by a significant degree of secondary particle growth. The production of secondary gaseous pollutants and particles depended primarily on the ozone level and was influenced by other parameters such as the air-exchange rate. Hydroxyl radical concentrations in the range $0.04\text{--}200 \times 10^5$ molecules/ cm^3 were determined by an indirect method. OH concentrations were observed to vary strongly with residual ozone level in the chamber, which was in the range 1-25 ppb, as is consistent with expectations from a simplified kinetic model. In a separate chamber study, we exposed the dry residue of two products to ozone and observed the formation of gas-phase and particle-phase secondary oxidation products.

2005

Chen, Chih-Chieh; Huang, Sheng-Hsiu; Kuo, Yu-Mei; Lin, Wane-Yun; Shih, Tung-Sheng; Weng, Yi-Mei, 2005, "Development of a size-selective inlet-simulating ICRP lung deposition fraction," *Aerosol Science and Technology*, **39**(5):437-443

A size-selective inlet made of polyurethane filter foam was designed and fabricated to simulate a portion of the ICRP respiratory deposition curve. A downstream aerosol measuring device then could be used to generate aerosol concentration data that represented the fraction reaching the respiratory system. This article introduces useful knowledge about porous foam penetration for particle size ranges below those reported in the previous studies. Different porosities of polyurethane foam filters were tested for aerosol penetration. Among the parameters operated in this work were (1) foam porosity (ppi), (2) filter thickness, (3) face velocity, and (4) packing density of the filter foams. Di-octyl ph-thalate was used as the test agent. A constant output atomizer and an ultrasonic atomizing nozzle were used to generate polydisperse submicrometer- and micrometer-sized particles, respectively. Aerosol concentrations and size distributions upstream and downstream of the filter foams were monitored by using a scanning mobility particle sizer (for particles with diameters smaller than 0.7 μm) and an aerodynamic particle sizer (for particles larger than 0.7 μm). The aerosol output was neutralized by a radioactive source. A lognormal-distribution curve with a mode of 0.25 μm and a GSD of 6.2 was set as the primary target curve simulating the light-work ICRP deposition model. The results showed that the most penetrating size (also referred to as collection minimum) of the filter foams decreased upon increasing the foam porosity, packing density, and face velocity. In this work, the highest foam porosity and packing density we could acquire were 100 ppi and 0.2, respectively. By adjusting the face velocity, the most penetrating size was moved to 0.25 μm , which happened to be the most penetrating size for ICRP light-work criterion. The whole aerosol penetration curve could further fit to the modified ICRP curve by adjusting the filter thickness. There are numerous ways to match the ICRP definition. This size-selective inlet becomes even more versatile if the auxiliary detector and vacuum system are operated under different flow rates to simulate light-to-heavy workloads. 19 Refs.

Gilbert, Dale; He, Congrong; Morawska, Lidia, 2005, "Particle deposition rates in residential houses," *Atmospheric Environment*, **39**(21): 3891-3899

As part of a large study investigating indoor air in residential houses in Brisbane, Australia, the purpose of this work was to quantify the particle deposition rate of size classified particles in the size range from 0.015 to 6 μm . Particle size distribution

resulting from cooking, repeated under two different ventilation conditions in 14 houses, as well as changes to particle size distribution and PM_{2.5} concentration as a function of time, were measured using a scanning mobility particle sizer (SMPS), an aerodynamic particle sizer (APS), and a DUSTTRAK. Deposition rates were determined by regression fitting of the measured size-resolved particle number and PM_{2.5} concentration decay curves, and accounting for air exchange rate. The measured deposition rates were shown to be particle size dependent and they varied from house to house. The lowest deposition rates were found for particles in the size range from 0.2 to 0.3 µm for both minimum (air exchange rate: 0.61±0.45 /h) and normal (air exchange rate: 3.00±1.23 /h) ventilation conditions. The results of statistical analysis indicated that ventilation condition (measured in terms of air exchange rate) was an important factor affecting deposition rates for particles in the size range from 0.08 to 1.0 µm, but not for particles smaller than 0.08 µm or larger than 1.0 µm. Particle coagulation was assessed to be negligible compared to the two other processes of removal: ventilation and deposition. This study of particle deposition rates, the largest conducted so far in terms of the number of residential houses investigated, demonstrated trends in deposition rates comparable with studies previously reported, usually for significantly smaller samples of houses (often only one). However, the results compare better with studies which, similarly to this study, investigated cooking as a source of particles (particle sources investigated in other studies included general activity, cleaning, artificial particles, etc). 35 Refs.

Hitchins-Loveday, Jane; Hofmann, Werner; Mengersen, Kerrie; Morawska, Lidia; Swanson, Cheryl, 2005, "Experimental study of the deposition of combustion aerosols in the human respiratory tract," *Journal of Aerosol Science*, **38**(8): 939-957

The total deposition of environmental tobacco smoke (ETS), diesel and petrol smoke in the respiratory tract of 14 non-smokers between the ages of 20 and 30 was determined experimentally. A scanning mobility particle sizer (SMPS) measuring a size range of 0.016-0.626µm was used to characterise the inhaled and exhaled aerosol during relaxed nasal breathing over a period of 10 min. The ETS, diesel, and petrol particles had average count median diameter (and geometric standard deviation) of 0.183 µm (1.7), 0.125µm (1.7), and 0.069µm (1.7), respectively. The average total number deposition of ETS was 36% (standard deviation 10%), of diesel smoke 30% (standard deviation 9%), and of petrol smoke 41% (standard deviation 8%). The analysis of the deposition patterns as a function of particle size for the three aerosols in each individual showed that there is a significant difference between each aerosol for a majority of individuals (12 out of 14). This is an important result as it indicates that differences persist regardless of inter-subject variability. 13 Refs.

Smolík, Jiří; Lazaridis, Mihalis; Moravec, Pavel; Schwarz, Jaroslav; Zaripov, Shamil; Dímal, Vladimír, 2005, "Indoor Aerosol Particle Deposition in an Empty Office," *Water, Air, and Soil Pollution*, **165**(1-4):301-312

The size- and time-resolved indoor/outdoor aerosol concentration relationships were studied experimentally in an empty office without internal particle sources. Two Scanning Mobility Particle Sizers (SMPS) and an Aerodynamic Particle Sizer (APS) sampled alternately from indoor and outdoor, together covering the size range 3–10,000 nm. The results showed that the indoor aerosol concentration depends mainly on the air exchange and deposition rates, and the outdoor concentration. At higher air exchange rates the indoor aerosol concentration approaches the outdoor one. This was observed for the accumulation mode particles. The size-dependent deposition rates were estimated using a simple aerosol dynamics experiment. It was based on equilibration of the indoor/outdoor concentrations by opening windows and analyzing the concentration decay curves after the windows were closed. For this purpose a simple mass balance model was used. The overall loss rate and the asymptotic value of indoor concentration were found by applying a non-linear least squares method on the time dependence of the indoor concentrations. The air exchange rate was estimated from the overall loss rate and the steady state values of the indoor/outdoor concentration of the accumulation mode particles.

2004

Brouwer, D.H.; Gijssbers, J.H.; Lurvink, M.W., 2004, "Personal exposure to ultrafine particles in the workplace: Exploring sampling techniques and strategies," *Annals of Occupational Hygiene*, **48**(5):439-453

Recently, toxicological and epidemiological studies on health effects related to particle exposure suggest that 'ultrafine particles' (particles with an aerodynamic diameter of <100 nm) may cause severe health effects after inhalation. Although the toxicological mechanisms for these effects have not yet been explained, it is apparent that measuring exposures against mass alone is not sufficient. It is also necessary to consider exposures against surface area and number concentration. From earlier research it was hypothesized that results on number concentration and particle distributions may vary with distance to the source, limiting the reliability of estimates of personal exposure from results which were obtained using static measurement equipment. Therefore, a workplace study was conducted to explore the performance of measurement methods in a multi-source emission scenario as part of a sampling strategy to estimate personal exposure. In addition, a laboratory study was conducted to determine possible influences of both distance to source and time course on particle number concentration and particle size distribution. In both studies different measurement equipment and techniques were used to characterize (total) particle number concentration. These included a condensation particle counter (CPC), a scanning mobility particle sizer (SMPS) and an electrical low pressure impactor

(ELPI). For the present studies CPC devices seemed to perform well for the identification of particle emission sources. The range of ultrafine particle number concentration can be detected by both SMPS and ELPI. An important advantage of the ELPI is that aerosols with ultrafine sizes can be collected for further analysis. Specific surface area of the aerosols can be estimated using gas adsorption analysis; however, with this technique ultrafine particles cannot be distinguished from particles with non-ultrafine sizes. Consequently, estimates based on samples collected from the breathing zone and scanning electron microscopic analysis may give a more reliable estimate of the specific surface area of the ultrafine particles responsible for personal exposure. The results of both the experimental and the workplace study suggest both spatial and temporal variation in total number concentration and aerosol size distribution. Therefore, the results obtained from static measurements and grab sampling should be interpreted with care as estimates of personal exposure. For evaluation of workplace exposure to ultrafine particles it is recommended that all relevant characteristics of such exposure are measured as part of a well-designed sampling strategy.

Fine, P. M.; Misra, C.; Singh, M.; Sioutas, C., 2004, "Development and Evaluation of A Compact Facility for Exposing Humans to Concentrated Ambient Ultrafine Particles," *Aerosol Science & Technology*, **38**(1):27-35

This article presents the development and evaluation of a very compact facility for exposing humans to concentrated ambient ultrafine particles ($da < 0.15 \mu\text{m}$). The human ultrafine particle concentrator (UFPC) operates at an intake flow rate of 1200 liters per minute (LPM). The concentrator is preceded by an ultrafine impactor which separates the accumulation mode from ultrafine mode particles under a very low pressure drop (1.5 kPa), a feature that is essential in enabling human inhalation studies of ultrafine concentrated ambient particulates (CAP). A key feature of the UFPC is a new cooling system, consisting of a programmable refrigerated circulator, which produces the supersaturation that is necessary to grow ultrafine PM to supermicrometer sizes so that they can be concentrated by means of conventional virtual impaction. The new cooling system allows for entirely automated operation of the UFPC. The UFPC was characterized in field experiments, in which the concentration enrichment of ultrafine particles was determined based on their number and mass concentration as well as on chemical composition including elemental carbon (EC), inorganic ions (sulfate and nitrate), and polycyclic aromatic hydrocarbons (PAH). Tests were conducted at minor-to-total flow ratios varying from 2.5-5% (hence at minor flow rates between 30-60 LPM). Measurements with the scanning mobility particle sizer (SMPS) showed a near-ideal increase in number concentrations (corresponding to the ratio of total-to-minor flow rate) of ultrafine particles after enrichment. The concentration enrichment was uniform across the entire particle diameter range of 15-660 nm. Similar results were obtained for EC and PAH concentrations (measured by an Aethalometer). Time-integrated filter-based tests, conducted to characterize the system for ultrafine PM mass and inorganic ion concentrations showed that the average enrichment factor was very close to the ideal values, indicating near-perfect collection efficiency with minimal particle losses. 21 Refs.

He, C.; Morawska, L.; Hitchins, J.; Gilbert, D., 2004, "Contribution from indoor sources to particle number and mass concentrations in residential houses," *Atmospheric Environment*, **38**(21):3405-3415

As part of a large study investigating indoor air in residential houses in Brisbane, Australia, the purpose of this work was to quantify emission characteristics of indoor particle sources in 15 houses. Submicrometer particle number and approximation of $\text{PM}_{2.5}$ concentrations were measured simultaneously for more than 48 h in the kitchen of all the houses by using a condensation particle counter (CPC) and a photometer (DUSTTRAK), respectively. In addition, characterizations of particles resulting from cooking conducted in an identical way in all the houses were measured by using a scanning mobility particle sizer (SMPS), an aerodynamic particle sizer (APS) and a DUSTTRAK. All the events of elevated particle concentrations were linked to indoor activities using house occupants diary entries, and catalogued into 21 different types of indoor activities. This enabled quantification of the effect of indoor sources on indoor particle concentrations as well as quantification of emission rates from the sources. For example, the study found that frying, grilling, stove use, toasting, cooking pizza, cooking, candle vaporizing eucalyptus oil and fan heater use, could elevate the indoor submicrometer particle number concentration levels by more than five times, while $\text{PM}_{2.5}$ concentrations could be up to 3, 30 and 90 times higher than the background levels during smoking, frying and grilling, respectively.

Kittelson, D.; Watts, W.; Johnson, J.; Remerowki, M.; Ische, E.; Oberdörster, G.; Gelein, R.; Elder, A.; Hopke, P.; Kim, E.; Zhao, W.; Zhou, L.; Jeong, C.-H., 2004, "On-Road Exposure to Highway Aerosols. 1. Aerosol and Gas Measurements," *Inhalation Toxicology*, **16**(S1):31-39

On-road experiments were conducted to determine the sensitivities of rats to real-world aerosol. This article summarizes the on-road aerosol and gas measurements and provides background information for the companion paper on the rat exposures. Measurements were carried out over 10 days, 6 h/day, driving a route from Rochester to Buffalo. Aerosol instrumentation used in this study included two scanning mobility particle sizers (SMPS) to determine the aerosol size distribution from 10 to 300 nm, 2 stand-alone condensation particle counters to determine the total aerosol number concentration, and an electrical aerosol detector to determine the aerosol length concentration. A thermal denuder (TD) was used with one of the SMPS instruments to determine the size distribution of the non-volatile fraction. Filter samples were collected and analyzed for elemental carbon, and gas analyzers measured ambient levels of CO, CO₂, and NO. Average daily total aerosol number concentration ranged from 200,000 to 560,000 particles/cm³. Past studies on urban highways have measured total number concentrations ranging between 104 and 106 particles/cm³. The average daily NO concentration ranged from 0.10 to 0.24 ppm and the corresponding CO₂ concentration

ranged from 400 to 420 ppm. The average daily geometric number mean particle size determined by the SMPS ranged from 15 to 20 nm. The TD reduced the average SMPS number concentration between 87 and 95% and the SMPS volume between 54 and 83%, suggesting that most of the particles consisted of volatile material. The TD also increased the geometric number mean diameter from 15 to 20 nm to 30 to 40 nm.

Kim, C. S.; Leith, D.; Rosati, J. A., 2003, "Monodisperse and polydisperse aerosol deposition in a packed bed," *Aerosol Science & Technology*, **37**(6):528-535

Although polydisperse aerosols in ambient and occupational settings have been associated with adverse health effects, researchers have mostly used monodisperse aerosols to investigate particle deposition in the human lung. The objective of this work was to determine whether the deposition of a series of monodisperse aerosols is reasonable to simulate the deposition of a polydisperse aerosol. A packed bed was used as an approximate surrogate to the human lung. Polydisperse and monodisperse sebacate aerosols were generated by nebulizers and a Monodisperse Aerosol Generator (MAGE), respectively. A Harvard respirator pump "inhaled" and "exhaled" aerosol through the packed bed. Complete size distributions of inhaled and exhaled aerosol were measured by an Aerodynamic Particle Sizer (APS) and a Scanning Mobility Particle Sizer (SMPS). The deposition for discrete sections of polydisperse aerosols was compared with the deposition of monodisperse aerosols. Also, the total deposition of a polydisperse aerosol was compared with the deposition of a series of monodisperse aerosols that formed the same size distribution as the polydisperse aerosol. Experiments were run with and without a charge neutralizer. With the neutralizer, no difference in deposition occurred between the discrete sections of polydisperse and monodisperse aerosols. Thus, total deposition was the same for both a polydisperse and a series of monodisperse aerosols, indicating that a series of monodisperse aerosols is reasonable to represent a polydisperse aerosol. Without a charge neutralizer, discrete sections of polydisperse aerosols with particle diameters of 3 μm or greater deposited no differently than they did with a neutralizer. However, for particle diameters of 1 μm or less, deposition of discrete sections of polydisperse aerosols was greater than that of monodisperse aerosols. Thus, total deposition was greater for polydisperse aerosols than for a series of monodisperse aerosols, indicating the need to condition aerosol with a neutralizer after the nebulization of a sebacate/alcohol solution. 21 Refs.

Rosati J.A.; Brown J.S.; Peters T.M.; Leith D.; Kim C.S., 2002, "A polydisperse aerosol inhalation system designed for human studies," *Journal of Aerosol Science*, **33**(10): 1433-1446

A polydisperse aerosol inhalation system has been developed to measure particle deposition in the lungs of human subjects. Nebulizers are used to generate aerosols with mass median aerodynamic diameters from 0.3 to 3 μm , and geometric standard deviations of 1.8-2.0. Inspired aerosol is drawn from a holding bag, passes through a sliding valve and a pneumotachograph, and enters a heated mouthpiece. Exhaled aerosol passes from the mouthpiece and pneumotachograph, through a second sliding valve and is collected in a heated sample bag. Inhalation and exhalation valves trigger automatically with change in flow direction through the pneumotachograph. Complete size distributions of inhaled and exhaled aerosol are measured by an aerodynamic particle sizer and a scanning mobility particle sizer. Fractional particle deposition of a test aerosol in the lung is determined by comparing inhaled and exhaled aerosol size fractions. Total deposition is determined from the sum of the fractional depositions. This new system precludes the need for monodisperse aerosol series to simulate polydisperse aerosol data, thus substantially reducing both study length and subject exposure.

2003

Kim, C. S.; Leith, D.; Rosati, J. A., 2003, "Monodisperse and polydisperse aerosol deposition in a packed bed," *Aerosol Science & Technology*, **37**(6):528-535

Although polydisperse aerosols in ambient and occupational settings have been associated with adverse health effects, researchers have mostly used monodisperse aerosols to investigate particle deposition in the human lung. The objective of this work was to determine whether the deposition of a series of monodisperse aerosols is reasonable to simulate the deposition of a polydisperse aerosol. A packed bed was used as an approximate surrogate to the human lung. Polydisperse and monodisperse sebacate aerosols were generated by nebulizers and a Monodisperse Aerosol Generator (MAGE), respectively. A Harvard respirator pump "inhaled" and "exhaled" aerosol through the packed bed. Complete size distributions of inhaled and exhaled aerosol were measured by an Aerodynamic Particle Sizer (APS) and a Scanning Mobility Particle Sizer (SMPS). The deposition for discrete sections of polydisperse aerosols was compared with the deposition of monodisperse aerosols. Also, the total deposition of a polydisperse aerosol was compared with the deposition of a series of monodisperse aerosols that formed the same size distribution as the polydisperse aerosol. Experiments were run with and without a charge neutralizer. With the neutralizer, no difference in deposition occurred between the discrete sections of polydisperse and monodisperse aerosols. Thus, total deposition was the same for both a polydisperse and a series of monodisperse aerosols, indicating that a series of monodisperse aerosols is reasonable to represent a polydisperse aerosol. Without a charge neutralizer, discrete sections of polydisperse aerosols with particle diameters of 3 μm or greater deposited no differently than they did with a neutralizer. However, for particle diameters of 1 μm or less, deposition of discrete sections of polydisperse aerosols was greater than that of monodisperse aerosols. Thus, total deposition was greater for polydisperse aerosols than for a series of monodisperse aerosols, indicating the need to condition aerosol with a neutralizer after the nebulization of a sebacate/alcohol solution.

Klepeis, Neil E.; Apte, Michael G.; Gundel, Lara A.; Sextro, Richard G.; Nazaroff, William W., 2003, "Determining Size-Specific Emission Factors for Environmental Tobacco Smoke Particles," *Aerosol Science & Technology*, **37**(10):780-790

Because size is a major controlling factor for indoor airborne particle behavior, human particle exposure assessments will benefit from improved knowledge of size-specific particle emissions. We report a method of inferring size-specific mass emission factors for indoor sources that makes use of an indoor aerosol dynamics model, measured particle concentration time series data, and an optimization routine. This approach provides--in addition to estimates of the emissions size distribution and integrated emission factors--estimates of deposition rate, an enhanced understanding of particle dynamics, and information about model performance. We applied the method to size-specific environmental tobacco smoke (ETS) particle concentrations measured every minute with an 8-channel optical particle counter (PMS-LASAIR; 0.1-2 μm diameters) and every 10 or 30 min with a 34-channel differential mobility particle sizer (TSI-DMPS; 0.01-1 μm diameters) after a single cigarette or cigar was machine-smoked inside a low air-exchange-rate 20 m^3 chamber. The aerosol dynamics model provided good fits to observed concentrations when using optimized values of mass emission rate and deposition rate for each particle size range as input. Small discrepancies observed in the first 1-2 h after smoking are likely due to the effect of particle evaporation, a process neglected by the model. Size-specific ETS particle emission factors were fit with log-normal distributions, yielding an average mass median diameter of 0.2 μm and an average geometric standard deviation of 2.3 with no systematic differences between cigars and cigarettes. The equivalent total particle emission rate, obtained by integrating each size distribution, was 0.2-0.7 mg/min for cigars and 0.7-0.9 mg/min for cigarettes.

Palmgren, F.; Waahlin, P.; Kildesoe, J.; Afshari, A.; Fogh, C.L., 2003, "Characterisation of particle emissions from the driving car fleet and the contribution to ambient and indoor particle concentrations," *Physics and Chemistry of the Earth, Parts A/B/C*, **28**(8):327-334

The population is mainly exposed to high air pollution concentrations in the urban environment, where motor vehicle emissions constitute the main source of fine and ultrafine particles. These particles can penetrate deep into the respiratory system, and studies indicate that the smaller the particle, the larger the health impacts. The chemical composition, surface reactivity and physical properties are also important. However, the knowledge about chemical and physical properties of particles and the temporal and spatial variability of the smallest particles is still very limited. The present study summarises the first results of a larger project with the aims to improve the knowledge. The concentration and the emissions of ultrafine particles from petrol and diesel vehicles, respectively, have been quantified using Scanning Mobility Particle Sizer of ultrafine particles in the size range 6-700 nm and routine monitoring data from urban streets and urban background in Denmark. The quantification was carried out using receptor modelling. The number size distributions of petrol and diesel emissions showed a maximum at 20-30 nm and non-traffic at about 100 nm. The contribution of ultrafine particles from diesel vehicles is dominating in streets. The same technique has been applied on PM_{10} , and about 50 percent contribution from non-traffic. The technique has also been introduced in relation to elemental and organic carbon, and the first data showed strong correlation between traffic pollution and elemental carbon. The outdoor air quality has a significant effect on indoor pollution levels, and we spend most of the time indoors. Knowledge about the influence of ambient air pollution on the concentrations in the indoor environment is therefore crucial for assessment of human health effects of traffic pollution. The results of our studies will be included in air quality models for calculation of human exposure. Preliminary results from our first campaign showed, that the deposition rate of particles in the apartment is negligible in the particle size range 100-500 nm. In the size range below 100 nm the deposition rate increases with decreasing particle diameter to a value of approximately 1/h at 10 nm. The penetration efficiency shows a maximum of 60 percent at 100 nm. More detailed studies of exchange of particles in outdoor/indoor air and the transformation are planned to take place during three next campaigns.

Stephenson, D; Seshadri, G; Veranth, J M, 2003 "Workplace exposure to submicron particle mass and number concentrations from manual arc welding of carbon steel," *AIHA Journal*, **64**:516-521

Particle emissions from manual shielded metal arc welding of carbon steel were sampled in a typical industrial maintenance and metal fabrication workplace environment. Particle number measurements over the size range from 14 nm to 10 μm using a scanning mobility particle sizer and an optical particle counter showed that welding produced an approximately lognormal particle mode with a 120 nm count median and a geometric standard deviation of 2.07. This study produced welding particle number concentrations on the order of $2 \times 10^5/\text{cm}^3$ in the building air 8.5 m away from the welding. Workplace exposure samples were below the current 8-hour American Conference of Governmental Industrial Hygienists mass concentration threshold limit value of 5 mg/m^3 . Submicron particles comprised 80% of the total aerosol mass collected by a cascade impactor during welding. The concentration of larger particles was indistinguishable from indoor background. Microscopy showed that the welding emissions are dominated by clusters formed from <0.1 μm primary spheres. These data on the particles resulting from aerosol transformation by natural dilution inside an industrial building can be compared with laboratory-scale studies of welding particulate. The particle number characteristics observed in this study are significant because toxicological hypotheses suggest that number or surface area may be a better metric than mass when evaluating the health effects of fine particles.

2002

Hitchins, J.; Morawska, L.; Gilbert, D.; Jamriska, M., 2002, "Dispersion of particles from vehicle emissions around high- and low-rise buildings," *Indoor Air*, **12**(1):64-71

Understanding the distribution of outdoor pollutants around a building envelope, generated by sources located in its vicinity, is important when choosing the location of building ventilation system intakes, as well as for quantifying the exposure of people living or working in the building. A systematic experimental characterisation of the number concentration of submicrometre particles was undertaken around the envelope of six buildings (both low- and high-rise) at different distances from a road (the main pollution source). The concentrations were measured using two TSI Scanning Mobility Particle Sizing. PM_{2.5} concentrations were also monitored around the low-rise buildings using two TSI DUSTTRAKS. For the three high rise buildings the concentration of fine and ultra-fine particles decreased in most cases to about 50-60% from the approximate ground level readings (between heights of 0 to 6 m), to full building height (from 24 to 33 m above the ground). Measurements of submicrometre particle number concentrations as well as PM_{2.5} fraction in the envelope around low-rise isolated buildings did not show any significant trends from the front to the rear of the building. The sensitivity of PM_{2.5} measurements to a small number of larger particles, possibly from sources other than vehicle emissions, was observed.

Sarnat, J. A.; Coull, B. A.; Koutrakis, P.; Long, C. M.; Schwartz, J.; Suh, H. H., 2002, "Using sulfur as a tracer of outdoor fine particulate matter," *Environmental Science & Technology*, **36**(24):5305-5314

Six homes in the metropolitan Boston area were sampled between 6 and 12 consecutive days for indoor and outdoor particle volume and mass concentrations, particle elemental concentrations, and air exchange rates (AERs). Indoor/outdoor (I/O) ratios of nighttime (i.e., particle nonindoor source periods) sulfur, PM_{2.5} and the specific particle size intervals were used to provide estimates of the effective penetration efficiency. Mixed models and graphical displays were used to assess the ability of the I/O ratios for sulfur to estimate corresponding I/O ratios for PM_{2.5} and the various particle sizes. Results from this analysis showed that particulate sulfur compounds were primarily of outdoor origin and behaved in a manner that was representative of total PM_{2.5} in Boston, MA. These findings support the conclusion that sulfur can be used as a suitable tracer of outdoor PM_{2.5} for the homes sampled in this study. Sulfur was more representative of particles of similar size (0.06–0.5 μm), providing evidence that the size composition of total PM_{2.5} is an important characteristic affecting the robustness of sulfur-based estimation methods.

2001

Morawska, L.; He, Congrong; Hitchins, J.; Gilbert, D.; Parappukkaran, S., 2001, "The relationship between indoor and outdoor airborne particles in the residential environment," *Atmospheric Environment*, **35**(20):3463-3473

The relationship between indoor and outdoor airborne particles was investigated for 16 residential houses located in a suburban area of Brisbane, Australia. The submicrometer particle numbers were measured using the Scanning Mobility Particle Sizer, the larger particle numbers using the Aerodynamic Particle Sizer and an approximation of PM_{2.5} was also measured using a DUSTTRAK. The measurements were conducted for normal and minimum ventilation conditions using simultaneous and non-simultaneous measurement methods designed for the purpose of the study. Comparison of the ratios of indoor to outdoor particle concentrations revealed that while temporary values of the ratio vary in a broad range from 0.2 to 2.5 for both lower and higher ventilation conditions, average values of the ratios were very close to one regardless of ventilation conditions and of particle size range. The ratios were in the range from 0.78 to 1.07 for submicrometer particles, from 0.95 to 1.0 for supermicrometer particles and from 1.01 to 1.08 for PM_{2.5} fraction. Comparison of the time series of indoor to outdoor particle concentrations shows a clear positive relationship existing for many houses under normal ventilation conditions (estimated to be about and above 2h⁻¹, but not under minimum ventilation conditions (estimated to be about and below 1h⁻¹). These results suggest that for normal ventilation conditions, outdoor particle concentrations could be used to predict instantaneous indoor particle concentrations but not for minimum ventilation, unless air exchange rate is known, thus allowing for estimation of the "delay constant".

Osunsanya, T.; Prescott, G.; Seaton, A., 2001, "Acute respiratory effects of particles: mass or number?" *Occupational and Environmental Medicine*, **58**(3):154-159

To determine whether associations might be found, in patients with chronic airflow obstruction, between symptoms, peak flow rate (PEF), and particle mass and numbers, and to assess which measure was most closely associated with changes in health. Epidemiological studies have shown associations between particulate air pollution and cardiovascular and respiratory disease, and it has been proposed that these may be mediated by particles of nm size (ultrafine). Relations were investigated between symptom scores, PEF, and bronchodilator use in 44 patients aged ≥50 years with chronic obstructive pulmonary disease, and daily measurements of both mass of ambient particles of aerodynamic diameter less than 10 μm (PM₁₀) and numbers of ultrafine particles (<100 nm), allowing for meteorological variables. Symptom scores, bronchodilator use, and PEF were recorded daily for 3 months. Counts of ultrafine particles were made by the TSI model 3934 scanning mobility particle sizer (SMPS) and PM₁₀ measurements by the tapered element oscillating microbalance (TEOM). Ultrafine particle counts indoors and outdoors were significantly correlated, those indoors being about half of those outdoors. No associations were found between actual PEF and PM₁₀ or ultrafine particles. However, there was a 19% increase in the rate of 10% decrements in daytime PEF with increases in PM₁₀ from 10 to 20 μg/m³ which was of borderline significance (p=0.05). A change in PM₁₀ from 10 to 20 μg/m³ was

significantly associated with a 14% increase in the rate of high scores of shortness of breath ($p=0.003$). A similar change in PM_{10} as a moving average of the same day and 2 previous days was associated with a 31% increase in the rate of high scores for cough ($p=0.02$). Cough symptoms were also associated with lower temperatures ($p=0.02$). Higher use of medicines was also associated with higher PM_{10} , but the increases were very small in clinical terms. Evidence was not found to support the hypothesis that the component of particulate pollution responsible for effects on respiratory symptoms or function resides in the fraction below 100 nm diameter. The consistent associations between symptoms and PM_{10} suggest that a contribution of the coarser fraction should not be dismissed. Further studies will be needed before the conclusions of this specific project may be generalised.

2000

Abt, E.; Suh, H. H.; Catalano, P.; Koutrakis, P., 2000, "Relative contribution of outdoor and indoor particle sources to indoor concentrations," *Environmental Science and Technology*, **34**(17):3579-3587

The effect of indoor particle sources on indoor particle size distributions and concentrations was previously investigated using real-time indoor and outdoor particle size distribution data collected in four homes in Boston in 1996. These data demonstrated the importance of indoor sources (i.e., cooking, cleaning, and movement of people) and air exchange rates on observed indoor concentrations. As part of the continued analyses of these data, a simple physical model was used to determine the source emission and infiltration rates for specific particle sizes. Decay rates were also estimated. Cooking, cleaning, and indoor work (characterized by movement of people) significantly increased $PM_{(0.7-10)}$ concentrations by 0.27, 0.27, and 0.25 $\mu m^3 cm^{-3} min^{-1}$, respectively. Cooking was the only variable significantly associated with generation of particles less than 0.5 μm in diameter. Outdoor particles (0.02-0.5 and 0.7-10 μm) were found to contribute significantly to indoor particle levels. Effective penetration efficiencies ranged from 0.38 to 0.94 for 0.02-0.5 μm particles and from 0.12 to 0.53 for 0.7-10 μm particles. Estimates for 0.7-10 μm particles decreased with increasing particle size, reflecting the influence of deposition losses from gravitational settling. The real-time particle size distribution data in conjunction with time-activity information provides valuable information on the origin and fate of indoor particles.

Chang, Y. C.; Tseng, H. H.; Hong, G. I.; Wang, K. T., 2000, "Measurement of smoke properties of incenses made in three countries," *Journal of Aerosol Science*, **31**(S1):S488-S489

Smoke properties of incenses made in different countries are investigated. The system used consists of a flow control/conditioning console, a smoke chamber (0.035 m^3), an electrical resistance type of ignition control unit, and particle measuring instrumentation. The results showed that the smoke properties such as CMD and $MMAD_{50}$ were very similar for all three incense samples. The maximum total mass and the total number concentrations differ from each other. 3 Refs.

Ristovski, Z. D.; Tass, I.; Morawska, L.; Saxby, W., 2000, "Investigation into the emission of fine particles, formaldehyde, oxides of nitrogen and carbon monoxide from natural gas heaters," *Journal of Aerosol Science*, **31**(S1):S490-S491

The range of concentration levels of submicrometer particles, formaldehyde (HCHO), oxides of nitrogen (NO_x), and carbon monoxide (CO) that arises from the standard operation of four typical flueless natural gas heaters are investigated. The results showed that both fine particle mass and number emission rates are low and the mass ones are close to 0.046 ng/J . This showed that the emission of particles during the combustion of natural gas in domestic heaters do not contribute to the indoor particle concentration. Natural gas heaters are a larger contributor of organic compounds such as formaldehyde and NO_2 .

Wallace L., 2000, "Real-Time Monitoring of Particles, PAH, and CO in an Occupied Townhouse," *Applied Occupational and Environmental Hygiene*, **15**(1):39-47

Beginning in October 1996, indoor and sometimes outdoor air at an occupied house in a suburban area of Virginia has been monitored continuously for particles, PAH, and CO. Two Climet monitors have been used to count particles in six size ranges between 0.3 and $> 10 \mu m$, with 1-minute averages being collected every 5 minutes. Two Ecochem PAH monitors have been used to sample for particle-bound PAHs once every minute. Also, two Langan CO monitor-data loggers have measured CO once each minute while logging the PAH data. Two Aethalometers measure black carbon. A single Scanning Mobility Particle Sizer (SMPS) measures ultrafine particles. The pairs of monitors are set up either to provide an indoor/outdoor or an upstairs office/downstairs kitchen comparison. Air exchange is occasionally measured using a Bruel & Kjaer 1302 SF6 monitor, as a parameter necessary for estimating deposition rates for particles and PAH. Results from the first 16 months of monitoring (10M observations) include: neighborhood woodburning and morning rush hour traffic are the most important sources of PAH and black carbon outdoors; candles, matches, incense, and frying, sauteeing, broiling, deep-frying, and stir-frying are additional important indoor sources of PM. One citronella candle was an extremely powerful PAH source. Neither woodburning nor vehicles appears to be an important source of particles indoors, but frying, grilling, and sauteeing are extremely strong indoor sources, together with combustion events such as use of matches and candles. Physical movement was an important source of coarse but not fine particles. Use of the gas stove for extended periods of time led to increased CO concentrations—vehicles and woodburning were relatively minor sources in comparison. The gas oven, gas burners, and electric toaster oven were important sources of ultrafine particles ($< 0.1 \mu m$). A source-proximity effect was noted, with the kitchen monitor reading two to five times

higher than the upstairs monitor for particles from kitchen events, while the upstairs monitor often read higher than the kitchen monitor for events caused by physical activity alone.

1999

Morawska, L.; Barron, W.; Hitchins, J., 1999, "Experimental deposition of environmental tobacco smoke submicrometer particulate matter in the human respiratory tract," *American Industrial Hygiene Association Journal*, **60**(3):334-339

Measurements of 15 nonsmokers and 3 smokers breathing environmental tobacco smoke (ETS), were conducted to study particle deposition within the human respiratory tract. The subjects inhaled ETS of count median diameter (CMD) of about 0.2 μm and geometric standard deviation (GSD) of 1.7. The particle size distribution in the submicrometer range in the inhaled and exhaled air from the subjects was measured using a Scanning Mobility Particle Sizer (SMPS). A deposition of 56.0 plus or minus 15.9% was observed for nonsmokers while breathing ETS through the nose and 48.7 plus or minus 11.6% while breathing ETS through the mouth. One individual tested four times gave an average deposition of 57.4 plus or minus 11.5%, providing an indication of intra-individual variation. Such a variation is expected since the breathing rate was not controlled in order that an indication of the deposition experienced on a day-to-day basis could be obtained. For nonsmokers the deposition while breathing through the mouth was lower than through the nose and the variability within the measurements was also lower for mouth breathing. The latter could be due to the variation in individual size and shape of the nasal passage. Smokers had, on average, a higher rate of deposition but also a higher inter-individual variability making it difficult to draw conclusions with respect to the affect of smoking on ETS particle deposition. The average deposition of the three smokers was 65.3 plus or minus 24.1% for nasal breathing and 66.1 plus or minus 17.6% for mouth breathing.

1998

Walton, W. Henry; Vincent, James H., 1998, "Aerosol Instrumentation in Occupational Hygiene: An Historical Perspective," *Aerosol Science and Technology*, **28**(5)417-438

Occupational hygiene has always been very influential in aerosol science - and vice versa. This paper gives an historical overview of this interaction, in particular how aerosol measurement instrumentation has evolved for the measurement of workers' exposures to aerosols in the occupational setting. It shows how health-related criteria for aerosol measurement have shifted from ones based on airborne particulate mass to ones based on particle count concentration, and then back again, depending on the aerosol science knowledge that was available at the time. It also draws the distinction between instrumentation based on time weighted-average sampling and direct-reading measurement, and the factors that govern how the choice of type of measuring instrument was made in the past, the way it is made now, and the way it might be made in the future.

1997

Morawska, L.; Jamriska, M.; Bofinger, N. D., 1997, "Size characteristics and ageing of the environmental tobacco smoke," *Science of the Total Environment*, **196**(1):43-55

The work presented here is a study of the behaviour of the particulate phase of ETS under controlled laboratory conditions and in real indoor environments with the aim of providing information for assessment of human exposure to ETS. This paper reports investigations of the size distribution of ETS and changes to the distribution with time under a range of environmental conditions. Measurements were performed using two instruments, the Scanning Mobility Particle Sizer and the Aerodynamic Particle Sizer, which enabled the determination of the precise locations of ETS peaks at frequent short time intervals. While total particle concentrations or changes in concentrations are not specific markers of ETS, peaks related to ETS in the spectral distribution of atmospheric particles, for a properly designed experiment, are. The presence and locations of these peaks are characteristic of ETS in indoor environments and are clearly distinguishable from the background particle distribution. It is demonstrated that an initial ETS size distribution in an indoor environment about 10 min after generation by a human smoker has a major peak in the submicron range between 60 and 90 nm. The location of the peak does not depend on the relative humidity, but does depend on the way the cigarette is smoked. An increase in particle size in the range of 20 to 50%, takes place in the first 30 to 60 min after ETS generation and then remains unchanged for the duration of the experiment. A decrease in particle size (shrinkage) was not observed during these experiments.

1996

Spanne, M.; Olsson, B. O.; Gudmundsson, A.; Bohgard, M., 1996, "Characteristics of particle emissions at paint manufacturing," *Journal of Aerosol Science*, **27**(S1):S437-S438

The handling of pigments and powders in paint manufacturing cause emissions of airborne particles. A great variety of substances occur. Previous studies of simulations of pouring of pigments, which occur in small scale weighing procedures, showed typically bimodal size distribution including a sub-micron and a super-micron mode. The objective of the study was to

get detailed knowledge on the relation between different source processes (depending on production technology, equipment and the manual handling routines) and aerosol characteristics. Super-micron particles were continuously measured with a time-of-flight instrument (Aerodynamic Particle Sizer, APS TSI Inc.) and sub-micron particles with an electric mobility spectrometer (Scanning Mobility Particle Sizer, SMPS TSI Inc.). In addition filter sampling techniques for standardized work-place sampling (so-called total dust filter cassettes, a cyclone sampler for respirable dust an IOM-samplers for inhalable dust) have been used for idealized exposure/are measurements using a rotating mannequin as a carrier of these samplers. The filters were analyzed gravimetrically and with Particle Induced X-ray Emission Analysis.

1994

Lin, Rong-Hwa; Wang, Chrong-Reen; Li, Chih-Shan, 1994, "Size Distributions and Lung Deposition of Submicrometer Particles from Metered Dose Inhalers," *Environment International*, **20**(2):161-167

The size distributions of the submicrometer particles generated from ten metered dose inhalers (MDIs) were determined by a high resolution particle sizer, which could measure the particles in the size range of 0.01 μm to 1 μm . The particle sizer contains a differential mobility analyzer (TSI 3071) and a condensation particle counter (TSI 3022). The median diameters ranged from 0.06–0.10 μm with a geometric standard deviation of 2. In addition, the surface median diameters and volume median diameters were found to be 0.30 μm and 0.45 μm , respectively. Moreover, none of the size distributions of the generated submicrometer particles fits log-normal distributions. The deposition probabilities of the submicrometer particles in the airways were evaluated. It was observed that the average deposition percentages of the particles in the alveolar, tracheobronchial, and extrathoracic regions are 32%, 4%, and 4%, respectively. Understanding the deposition of submicrometer particles from MDIs should benefit the clinical practice in inhalation therapy.

1995

Wampler, David A.; Miller-Leiden, Shelly; Nazaroff, William W.; Gadgil, Ashok J.; Litvak, Andres; Mahanama, K.R.R.; Nematollahi, Matty, 1995, "Effectiveness of smokeless ashtrays," *Air and Waste Management Association*, **45**:494-500

Most environmental tobacco smoke (ETS) issues from the tips of smoldering cigarettes between puffs. Smokeless ashtrays are designed to reduce ETS exposure by removing particulate and/or gas-phase contaminants from this plume. This paper describes an experimental investigation of the effectiveness of four smokeless ashtrays: two commercial devices and two prototypes constructed by the authors. In the basic experimental protocol, one or more cigarettes was permitted to smolder in a room. Particulate or gas-phase pollutant concentrations were measured in the room air over time. Device effectiveness was determined by comparing pollutant concentrations with the device in use to those obtained with no control device. A lung deposition model was applied to further interpret device effectiveness for particle removal. The commercial ashtrays were found to be substantially ineffective in removing ETS particles because of the use of low-quality filter media and/or the failure to draw the smoke through the filter. A prototype ashtray using HEPA filter material achieved better than 90% particle removal efficiency. Gas-phase pollutant removal was tested for only one prototype smokeless ashtray, which employed filters containing activated carbon and activated alumina. Removal efficiencies for the 18 gas-phase compounds measured (above the detection limit) were in the range of 70 to 95%.

1993

Li, Chih-Shan; Lin, Wen-Hai; Jenq, Fu-Tein, 1993, "Characterization of Outdoor Submicron Particles and Selected Combustion Sources of Indoor Particles," *Atmospheric Environment*, **27B**(4):413-424

Environmental tobacco smoke, mosquito-coil smoke, and joss stick smoke are the major indoor combustion sources in Asian countries. Field evaluations of the size distributions of outdoor submicron particles and selected combustion sources of indoor particles were conducted in an apartment in Taipei urban area. The size distributions of submicron aerosols were determined by a high resolution particle sizer, which could measure the particles in the size range of 0.017-0.886 μm . The particle sizer contains a differential mobility analyser (TSI 3071) and a condensation particle counter (TSI 3022). The number concentrations of the indoor and outdoor submicron particles varied from 14,000 to 150,000 cm^{-3} and from 10,000 to 45,000 cm^{-3} , respectively. The changes of the size distributions and the number concentrations of submicron aerosols before, during, and after the aerosol generations were compared. The average number median diameters of environmental tobacco smoke, smoldering cigarettes, mosquito-coil smoke, joss stick smoke, the indoor typical conditions, and the outdoor typical conditions were 0.090, 0.085, 0.094, 0.084, 0.091 and 0.054 μm respectively. Regarding the surface area-weighted size distributions, the average surface median diameters of these conditions were 0.229, 0.219, 0.282, 0.188, 0.224 and 0.221 μm , respectively. In addition, the average volume median diameters were 0.338, 0.332, 0.398, 0.289, 0.330 and 0.340 μm , respectively. These indoor combustion sources did generate a significant number of the ultrafine and submicron particle which have higher deposition probabilities in the respiratory tract. Further health evaluations of the submicron particles from these combustion sources are needed.

1992

Li, Wei; Montassier, N.; Hopke, P. K., 1992, "A System to Measure the Hygroscopicity of Aerosol Particles," *Aerosol Science and Technology*, **17**(11):25-35

An aerosol conditioner (wetted wall reactor) was modified to mimic the conditions inside the human respiratory tract, i.e., relative humidity >99% and 37°C. By combining the wetted wall reactor with tandem differential mobility analyzer, a system was developed to study the hygroscopic properties of aerosols in submicrometer range. This paper describes the system, and the results of system tests using three compounds of known composition, NaCl, (NH₄)₂SO₄ and (NH₄)HSO₄ are presented.

TSI Incorporated – 500 Cardigan Road, Shoreview, MN 55126 U.S.A

USA	Tel: +1 800 874 2811	E-mail: particle@tsi.com	Website: www.tsi.com
UK	Tel: +44 149 4 459200	E-mail: tsiuk@tsi.com	Website: www.tsiinc.co.uk
France	Tel: +33 491 11 87 64	E-mail: tsifrance@tsi.com	Website: www.tsiinc.fr
Germany	Tel: +49 241 523030	E-mail: tsigmbh@tsi.com	Website: www.tsiinc.de
India	Tel: +91 80 41132470	E-mail: tsi-india@tsi.com	
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