SCANNING MOBILITY PARTICLE SIZER™ (SMPS™) SPECTROMETER

BIBLIOGRAPHY

APPLICATION: INSTRUMENT CHARACTERIZATION

2006

Zhu, Yifang; Yu, Nu; Kuhn, Thomas; Hinds, William, 2006, "Field Comparison of P-TRAK and Condensation Particle Counters," *Aerosol Science and Technology*, **40**(6):422–430

The P-TRAK ultrafine particle counter is a portable version of a condensation particle counter (CPC). Both instruments detect particle number concentrations in real time but have different detection limits. The P-TRAK has been widely used for indoor air quality evaluation and aerosol research. However, there is very limited information about the reliability and precision of this instrument and its comparability with other similar instruments. The purpose of this study was to compare a P-TRAK ultrafine particle counter with a standard CPC and evaluate its applicability to ambient air monitoring. This study was carried out near the Interstate 405 freeway (I-405) in Los Angeles. Measurements were made at increasing distances from the freeway on both sides at night as well as inside and outside of two 2-bedroom apartments located near the freeway. A CPC and a Scanning Mobility Particle Sizer (SMPS) were collocated with two P-TRAK s and measurement results compared. In general, higher correlations were observed between P-TRAK and CPC data for indoor measurements than outdoor. The highest P-TRAK and CPC correlation (r 2 = 0.9385) was detected inside Apartment 2, which is located farther away from the freeway than Apartment 1. The poorest correlation occurred at 30 m downwind from the freeway. In that case, the P-TRAK reported about 25% of ultrafine particle concentration that CPC did. A sigmoid (S-shape) function was fitted to observed P-TRAK to CPC ratios and geometric mean diameters of the corresponding ultrafine particle size distributions. Overall, we concluded the P-TRAK worked reasonably well when sampled indoor air. However, it has significant limitations in detecting freshly emitted ultrafine particles from vehicles. The P-TRAK underestimated ultrafine particles especially for particles smaller than its activation size which was found to be approximately 250–30 nm. Caution must be given in interpreting data collected by P-TRAK monitors near combustion sources.

2005

Asbach, C.; Fissan, H.; Kuhlbusch, T.A.J., 2005, "Investigation on the gas particle separation efficiency of the gas particle partitioner," *Atmospheric Environment*, **39**(40)

A gas particle partitioner (GPP, US patent 6,761,752 B2) that allows highly efficient separation of gas and particles with no effect on the thermodynamic conditions and substantially no change of the composition of the gas has been developed. The GPP is a coaxial arrangement with inner and outer electrode. It utilizes a corona discharge to electrically charge the particles and a strong electric field in a separate unit to take them out of the sample flow. Several measures were taken to minimize an effect of the corona discharge on the gas composition. The GPP is designed such that when switched on, the sample flow is particle free, whereas when switched off, the sample flow contains a representative sample of the aerosol. The GPP as described in this manuscript was designed to meet the requirements for precise artifact correction with particle mass concentration monitors, such as the TEOM. This paper focuses on the gas particle separation efficiency of the instrument. The separation efficiency was determined for both, (ultra-) fine and coarse particles. The (ultra-) fine particles were generated with diameters ranging from 18 to 255 nm of polystyrene latex particles and their size distributions measured with a Scanning Mobility Particle Sizer (SMPS). Coarse particles with diameters between 4.5 and 10.7 µm were generated from a sodium chloride solution and characterized with an Aerodynamic Particle Sizer (APS) and a tapered element oscillating microbalance (TEOM). The investigations showed that the separation efficiency was very near 100% for all particles with diameters larger than 25 nm, whereas it decreased for smaller diameters. Particles of size 18 nm were separated from the gas flow with an efficiency of approximately 97%. Along with near 100% separation efficiency, the additional gas concentrations were 42 ppbV for O_3 and 15 ppbV for NO_2. 13 Refs.

Biswas, Subhasis; Fine, Philip M.; Geller, Michael D.; Hering, Susanne V.; Sioutas, 2005, Constantinos "Performance Evaluation of a Recently Developed Water-Based Condensation Particle Counter," *Aerosol Science & Technology*, **39**(5):419–427

This study provides an intercomparison of the performance of a newly developed water-based condensation particle counter (WCPC) and a more widely used butanol-based CPC (TSI 3022A). Four test aerosols (ammonium nitrate, ammonium sulfate, adipic acid, and glutaric acid) were generated and tested in the laboratory before the instruments were deployed at four field locations (USC/downtown LA, I-710 Freeway, Pacific coast, and Los Angeles International Airport). Both instruments sampled the same incoming aerosol. Selected experiments utilized a differential mobility analyzer to select a particle size upstream of the CPCs. Evaluation of performance was based on the response of the instruments to varying particle composition, concentrations, and size. The results indicated good correlation between the two CPCs, with R^2 values ranging from 0.74–0.99. Good agreement was found between the two instruments for particle concentrations between 0 and 40,000 particles/cm^3, with WCPC/TSI 3022A ratios between 0.8 and 1.2. Due to differences in the photometric mode calibration of these instruments, the ratio drops to 0.6–0.8 between 40,000–100,000 particles/cm^3. However, the ratio rises again for lab aerosols above 100,000 particles/cm^3 to 1.0–1.1. Results of this evaluation show that the W-CPC is a reliable particle– counting technology for particle concentrations encountered downstream of a DMA as well as in some ambient environments (< 40,000 particles/cm^3).

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.

Girshick, S.L.; Hafiz, J.; Heberlein, J.; McMurry, P.H.; Mukherjee, R.; Renault, T.; Wang, X., 2005 "System for in situ characterization of nanoparticles synthesized in a thermal plasma process," *Plasma Chemistry and Plasma Processing*, **25**(5):439–453

We have designed a particle diagnostic system that is able to measure particle size and charge distributions from low stagnation pressure and high temperature (2000-4000 K) environments in near real time. This system utilizes a sampling probe interfaced to an ejector to draw aerosol from the low pressure chamber. Particle size and charge distributions are measured with a scanning mobility particle sizer. A hypersonic impactor is mounted in parallel with the scanning mobility particle sizer to collect particles for off-line microscopic analysis. This diagnostic system has been used to measure size and charge distributions of nanoparticles (Si, Ti, Si-Ti-N, etc.) synthesized with our thermal plasma reactor. We found that the mean particle size increases with operating pressure and reactant flow rates. We also found that most particles from our reactor are neutral for particles smaller than 20 nm, and that the numbers of positively and negatively charged particles are approximately equal. Inc. 33 Refs.

Lee, D.; Park, K.; Zachariah, M.R., 2005, "Determination of the size distribution of polydisperse nanoparticles with single-particle mass spectrometry: The role of ion kinetic energy," *Aerosol Science and Technology*, **39**(2):162–169

We develop a method to determine size and size distribution (30–150 nm) of polydisperse nanoparticles using a laser ablation/ionization time-of-flight single-particle mass spectrometer that extends the work first described by Reents and Ge. We found a composition independent "power law" dependence between the total peak area and original particle volume that enables one to determine particle volume directly from a particles mass spectrum. This power-law relationship suggests that some ions ablated and ionized from a particle are selectively lost during transport from the laser ablation/ionization region to the detector. A numerical calculation of ion trajectories shows that ion loss is highly dependent on the initial kinetic energy of ions. We show that the size-dependent energetic ions formed by the laser-particle interaction lead to power-law relationship between the cube root of peak area and particle diameter. The results demonstrate that particle size distributions measured with the mass spectrometer are in good agreement with those measured with a scanning mobility particle sizer.

Lipsky, Eric M.; Robinson, Allen L., 2005, "Design and evaluation of a portable dilution sampling system for measuring fine particle emissions from combustion systems," *Aerosol Science and Technology*, **39**(6):542–553

The size and complexity of current dilution samplers is a major barrier to more wide-spread application of these systems for source characterization. A new, more portable dilution sampler has been designed to provide measurements consistent with the widely cited Caltech dilution sampler. Intercomparison experiments were performed using a diesel engine and wood stove to evaluate the comparability of the new design with a sampler based on the Caltech design. These experiments involved simultaneous operation of multiple dilution samplers from the same source. Filter based measurements included PM2.5 mass, organic carbon, and elemental carbon emissions. Particle size distributions in the range from 10-480 nm were measured using a scanning mobility particle sizer.

The filter-based and integrated-total volume measurements made with the two designs are in good agreement. For example, the average relative bias between the two samplers of PM2.5 mass emission rate measured with Teflon filters is 1%. Nucleation was intermittently observed in the sampler based on the Caltech design, but rarely observed in the new design. Significant discrepancies in total number emissions between the two samplers occurred during periods of nucleation. Experiments were also conducted to examine the effects of residence time on the diluted emissions. No changes in the filter-based or integrated volume measurements were observed with an additional 40-s residence time, indicating that phase equilibrium is established in the 2.5 s of residence time provided by the dilution tunnel. This conclusion is consistent with theoretical analysis. These results provide new insight into the effects of dilution sampling on measurements of fine particle emissions, providing important data for the ongoing effort of the EPA and ASTM to define a standardized dilution sampling methodology for characterizing emissions from stationary combustion sources. 20 Refs.

Riebel, Ulrich; Stommel, Yves Gorat, 2005, "A corona-discharge-based aerosol neutralizer designed for use with the SMPS-system", *Journal of Electrostatics*, **63**(6–10):917–921

The widely used scanning mobility particle sizer (SMPS) for measuring submicron particles uses radioactivity to charge aerosol particles to a known charge distribution. Because of numerous restrictions and safety issues concerning radioactive sources, corona-discharge-based neutralizers are an attractive alternative. The newly developed electrical neutralizer consists of an aerosol chamber with an AC electrical discharge. Combining small residence times, high ion concentrations, small electric field strengths, discharge in the aerosol chamber itself and an automatic regulation of the ion input results in a very effective neutralizing device. Experiments with an initially uncharged aerosol have shown that charging of submicron particles to the bipolar equilibrium charge distribution was possible for volumetric flow rates of up to 1.5 L/min and concentrations of at least 5 x 10^6 1/cm^3. Particle loss (>@3 nm) and particle production (>@3 nm) were not observed. 9 Refs.

Taishi, Tsuyoshi; Koyama, Tetsuji; Kwon, Soon-Bark; Seto, Takafumi; Sakurai, Hiromu, 2005, "New Measurement System of Nanoparticles in the Automobile Exhaust Gas," *JSAE Technical Paper No. 20055680, JSAE Autumn Conference*, Sept. 28–30, 2005, Toyoko, Japan

The aerosol measurement techniques such as scanning mobility particle sizer (SMPS) are one of major methods to evaluate the size distribution of diesel nanoparticles. The charge distribution is important to reduce data from mobility distribution to size distribution. The radioactive sources as aerosol charge neutralizer has been widely used, however, the limit of ion generation rate and the difficulty in handling especially at outdoor measurement remained as problem. In this presentation, we developed a new measurement system for diesel nanoparticles using the microplasma aerosol charger. Characteristics and performance of the system for diesel nanoparticle measurement were reported.

Yoon, Young Jun; Cheevers, Sinead; Jennings, S. Gerard; O'Dowd, Colin D.,2005, "Performance of a venturi dilution chamber for sampling 3–20 nm," *Journal of Aerosol Science*, **36**(4):535–540

The transmission efficiency of a venturi mixing and dilution system was investigated with laboratory generated aerosol by comparison of two condensation particle counters (CPCs). The transmission efficiency exceeded 95% for particle sizes between 3 and 20 nm. The use of the diluter system is demonstrated through comparison with total concentrations derived from a nano-scanning mobility particle sizer (nSMPS) applied to measuring a rapidly changing atmospheric nucleation mode. The study indicates that the diluted-CPC sampler can resolve rapidly changing, and more intense peaks in excess of 10^6 cm^{-3}, which are otherwise missing or under-sampled by the nSMPS.

2004

Chakrabarti, B.; Singh, M.; Sioutas, C., 2004, "Development of a near-continuous monitor for measurement of the Sub-150 nm PM mass concentration," *Aerosol Science & Technology*, **38**(S1):239–252

Population exposures to ambient particulate matter (PM) have recently received considerable attention due to the association between ambient particle concentrations and mortality. Recent toxicological studies suggest that ultrafine PM (diameter <100 nm) may be responsible for the observed health effects. However, even though ultrafine mass concentrations vary drastically over short time scales in the atmosphere, no monitor currently measures ultrafine PM mass continuously. The need for monitors that can perform ultrafine particle concentration measurement in shorter time intervals is of paramount importance to environmental health, as such a monitor can lead to substantial improvements in population exposure assessment to ambient ultrafine PM. In this study, a modified BAM (Beta Attenuation Monitor) is employed to measure near-ultrafine (i..e.., <0.15 µm or $PM_{0.15}$) particulate mass concentration. The BAM is preceded by a 0.15 µm cutpoint impactor, which is designed to have very low pressure drop. The BAM is operated in a 2 h cycle at a downwind receptor site in the Los Angeles Basin in Claremont. Among the other instruments colocated with the BAM are scanning mobility particle sizer (SMPS), an aerodynamic particle sizer (APS), and a Micro-Orifice Uniform Deposit Impactor (MOUDI). Our results indicate that the $PM_{0.15}$ mass concentrations obtained by means of the modified BAM and MOUDI are in excellent agreement. The $PM_{0.15}$ SMPS-to-BAM concentration ratio is generally smaller than 1 and follows a rather distinct diurnal profile, with a maximum towards the middle of the day and minima during the early morning and nighttime periods, presumably due to the classification of fractal-structured ultrafine particles in the accumulation mode by the SMPS. The lack of correlation between $PM_{2.5}$ and $PM_{0.15}$ mass concentrations further corroborates the need for developing monitors such as the modified BAM for the documentation of the short-term variation of ultrafine mass measurements. 24 Refs.

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 µm). 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.

Johnson, Tim; Caldow, Robert; Poecher, Arndt; Mirme, A.; Kittelson, David, 2004, "A new electrical mobility particle sizer spectrometer for engine exhaust particle measurements," *SAE 2004 World Congress and Exhibition*, March 8–11, 2004, Detroit, Michigan, USA

Electrical mobility has a long history as a tool for measuring the particle size of engine exhaust emissions. This paper gives a review of these methods as well as more current methods for making exhaust particle measurements. Each of the methods discussed has a limitation especially for making fast (sub-second) measurements. A new instrument is discussed that has been developed by TSI based on a technique developed over the last two decades by the University of Tartu - Estonia. A description of the instrument, the Engine Exhaust Particle Sizer™ (EEPS™), is given as well as engine dynamometer data showing a comparison between the current standards for engine exhaust measurements, the Scanning Mobility Particle Sizing (SMPS™) system and the Condensation Particle Counter (CPC). The EEPS compares favorably with the SMPS and CPC while providing sub-second response.

Ludwig, Chr.; Mohr, M., 2004, "On-Line Characterization of Aerosols Formed in a Jet Flow Condenser for Analytical Applications," *Paul Scherrer Institut Scientific Report 2003*, Volume **V**

With a jet flow condenser (JFC) aerosol particles can be generated from gases containing high boiling substances. This can be used for transferring these substances from the hot carrier gas into an analytical device. In this study we have investigated the particle number size distribution (NSD) produced in two JFCs with different geometry. Experiments were performed with elemental zinc as a model substance. Zinc has been volatilised in a tubular furnace and the particles generated in the JFC were characterized on-line by a Scanning Mobility Particle Sizer (SMPS).

2003

Chen, C.-C.; Huang, S.-H., 2003, "Loading characteristics of a miniature wire-plate electrostatic precipitator," *Aerosol Science & Technology*, **37**(2):109–121

In this work, in order to investigate the particle loading effects on the performance of an electrostatic precipitator (ESP), simultaneous measurements of the dust cake thickness accumulated on the collection plates, ESP's collection efficiency, corona discharge characteristics, and ozone concentration were conducted experimentally. A laboratory scale single stage wire-plate ESP was used for the aerosol loading test. Two kinds of particulate matter, cement and aluminum oxide (Al[2]O[3]), were generated by using a Palas Powder Disperser. A displacement meter was used to monitor the dust cake thickness accumulated on the collection plates. A scanning mobility particle sizer was used to measure the particle size distribution and number concentration upstream and downstream of the ESP. Ozone generated by the ESP was sampled 20 cm downstream of the ESP exit and measured with an ozone analyzer. The Dioctyl Phthalate (DOP) was also used as a liquid challenge agent in order to investigate the loading effects of liquid particles on the ESP performance. The results showed that when challenged with cement particles, the ion current decreased with increasing dust cake thickness under a constant electrical field strength. Moreover, the collection efficiency and ozone generated by corona discharge decreased as the loading test progressed. For example, when the dust layer was about 5 mm in thickness, the output current and the ozone concentration decreased about 33 and 44%, respectively, and the collection efficiency (300 nm particle) decreased about 4% at a fixed electrical field strength of -4.2 kV/cm. However, the ion current increased as aluminum oxide particles deposited on the collection plates. The increase in ozone concentration and aerosol penetration was mainly due to the occurrence of back corona, evidenced by the existence of the caves on the surface of the dust layers. In the case of testing with cement particles, the ion current rises after about 20 min of loading test and then decreases with time, while ozone concentration increases synchronously.

Johnson, T; Caldow, R; Poecher, A; Mirme, A; Kittelson, D, 2003, "An Engine Exhaust Particle Sizer™ spectrometer for transient emission particle measurements," *9th Diesel Engine Emissions Reduction (DEER) Workshop 2003*, Newport, RI (US), 08/24/2003—08/28/2003

There has been increased interest in obtaining size distribution data during transient engine operation where both particle size and total number concentrations can change dramatically. Traditionally, the measurement of particle emissions from vehicles has been a compromise based on choosing between the conflicting needs of high time resolution or high particle size resolution for a particular measurement. Currently the most common technique for measuring submicrometer particle sizes is the Scanning Mobility Particle Sizer (SMPS™) system. The SMPS system gives high size resolution but requires an aerosol to be stable over a long time period to make a particle size distribution measurement. A Condensation Particle Counter (CPC) is commonly used for fast time response measurements but is limited to measuring total concentration only. This paper describes a new instrument, the Engine Exhaust Particle Sizer™ (EEPS™) spectrometer, which has high time resolution and a reasonable size resolution. The EEPS was designed specifically for measuring engine exhaust and, like the SMPS system, uses a measurement based on electrical mobility. Particles entering the instrument are charged to a predictable level, then passed through an annular space where they are repelled outward by the voltage from a central column. When the particles reach electrodes on the outer cylindrical (a column of rings), they create a current that is measured by an electrometer on one or more of the rings. The electrometer currents are measured multiple times per second to give high time resolution. A sophisticated real-time inversion algorithm converts the currents to particle size and concentration for immediate display.

Lapuerta, M; Armas, O; Gomez, A, 2003, “Diesel particle size distribution estimation from digital image analysis,” *Aerosol Science and Technology*, **37**:369–381

One of the most serious problems associated with Diesel engines is pollutant emissions, especially nitrogen oxides and particulate matter. However, although current emissions standards in Europe and America with regard to light vehicles and heavy duty engines refer to the particulate limit in mass units, there has been increasing concern of late to know the size and number of particles emitted by engines. This interest has been promoted by the latest studies about the harmful effects of particles on health and is enhanced by recent changes in internal combustion engine technology. This study is focused on the implementation of a method to determine the particle size distribution that could be appropriate for the current methodology of vehicle certification in Europe. This method uses an automated Digital Image Analysis Algorithm (DIAA) to determine particle size trends from Scanning Electron Microscope (SEM) images of filters charged in a partial dilution system used for measuring specific particulate emissions. The experimental work was performed on a stationary electric generation direct injection Diesel engine with 0.5 MW (671 hp) rated power, which is considered as a typical engine in middle power industries. Particulate size distributions obtained using DIAA were compared with distributions obtained using an Optical Particle Counter (OC) and a Scanning Mobility Particle Sizer (SMPS), the latter currently considered as the most reliable technique. Although the number concentration detected by this method does not represent the real flowing particle concentration, the algorithm gives a fair reproduction of the trends observed with on-line techniques (SMPS and OC) when the engine load is varied.

Singh, M.; Misra, C.; Sioutas, C., 2003, “Field evaluation of a personal cascade impactor sampler (PCIS),” *Atmospheric Environment*, **37**(34):4781–4793

This paper presents the field evaluation of a personal cascade impactor sampler (PCIS). PCIS is a miniaturized cascade impactor, consisting of four impaction stages, followed by an after-filter. Particles are separated in the following aerodynamic particle diameter ranges: <0.25, 0.25-0.5, 0.5-1.0, 1.0- 2.5 and 2.5-10 micro m. The PCIS operates at a flow rate of 9 liters per minute (l/min) using a very high efficiency, battery-operated light pump at a pressure drop of 11 in H sub 2O (2.7 kPa). For field evaluation, the PCIS was collocated with other samplers including the micro-orifice uniform deposit impactor (MOUDI), scanning mobility particle sizer (SMPS) and aerodynamic particle sizer (APS) in Los Angeles and Claremont, CA. PCIS and MOUDI agree very well for coarse particulate matter (PM) ($PM_{2.5-10}$) mass concentrations. The fine PM ($PM_{2.5}$) mass as measured by PCIS is in excellent agreement with SMPS-APS measurement (1.02 times) and slightly higher (1.1 times) than the MOUDI measurements. Time-integrated (size fractionated) $PM_{2.5}$ mass, inorganic ions (nitrate and sulfate), elemental carbon (EC) and organic carbon (OC) concentrations obtained with PCIS and MOUDI were found to be in very good agreement with few differences in the <0.25 micro m size fraction, especially for OC and nitrate measurements. Near-continuous and size fractionated $PM_{2.5}$ nitrate and total carbon measurements by PCIS and MOUDI using the ADI and Sunset labs monitors are in close agreement for all size fractions, indicating that any differences between MOUDI and PCIS measurements for time-integrated data might be due to artifacts associated with long-term sampling and not to differences in individual cut-points. The performance of the PCIS was also evaluated in wind tunnel tests at wind speeds up to 8 km/h. These tests showed that particle sampling efficiency and separation characteristics of the PCIS are unaffected by the wind speeds for particles up to 10 micro m in aerodynamic diameter.

2002

Chen, C.-C.; Huang, S.-H.; Kuo, Y.-M.; Wu, C.-H., 2002, “Aerosol penetration through silica gel tubes,” *Aerosol Science & Technology*, **36**(4):457–468

Silica gel is commonly used by industrial hygienists to collect gases and vapors in the work place, in particular air contaminants with high polarity. The collected air pollutants are then treated and analyzed to identify their type and to determine the concentration using various methods and instrumentations. In addition to collection of gaseous pollutants, the silica gel tubes are also used for acid mist collection according to the listed official analytical methods (e.g., NIOSH method 7903 and OSHA method ID-165SG). However, the filtration characteristics of silica gel tubes have not been thoroughly investigated. A constant output aerosol generator and an ultrasonic atomizing nozzle were used to generate submicrometer-sized and micrometer-sized aerosol particles, respectively. A scanning mobility particle sizer and an aerodynamic particle sizer were used to measure particles smaller and larger than 0.6 µm, respectively. Potassium sodium tartrate and dioctylphthalate were used as the solid and liquid test agents, respectively. Two types of SKC silica gel tubes (Cat No. 226-10 and 226-10-03) were examined for aerosol penetration, air resistance, and loading characteristics. The results show that the aerosol penetration through the silica gel tubes could be as high as 80% at the penetration maximum (or collection minimum) under the normal sampling flow of 0.5 L/min, well within the inertial impaction dominated region. Two glass wool plugs and one urethane plug between sorbent sections and at the back end of the SKC 226-10 contributed about 22% of the total air resistance, and the remaining 78% of the air resistance was caused by the silica gel. When the filtration efficiency by these separators was deduced, the aerosol penetration at the most penetrating size was as high as 90%. The aerosol penetration increased and the penetration curve shifted to a smaller particle size as the sampling flow increased. However, this increase in aerosol penetration of particles smaller than the penetration maximum reached a maximum and then decreased as the sampling flow was increased beyond 1.5 L/min (equivalent filtration velocity of 93 cm/s), a clear evidence of inertial impaction surpassing the diffusion deposition. As a result, the use of silica gel tubes for acid mist collection may not be appropriate if the behavior of the complete aerosol size distribution is not considered as part of the assessment of these devices. 17 Refs.

2001

Abbey, E.; Petersen, E.; Rickard, M.; Traum, M.; Welle, R., 2001, “A new shock-tube facility for studying combustion phenomena in mixtures containing condensed species,” *Proceedings of the National Heat Transfer Conference*, **1**:947–955

Two shock tubes at The Aerospace Corporation have been refurbished for the study of fundamental processes related to the formation and reaction of solid and liquid aerosols at elevated temperatures. One shock tube is intended for the study of powdered aerosols and other condensed-phase species, while the second tube is designed for die study of gas-phase reactants. Recent upgrades and additions include a new high-vacuum system, an optimized velocity-detection scheme, a computer-based data acquisition system, and new techniques and procedures for handling experiments involving gas/powder mixtures. Diagnostic techniques include laser extinction for particle volume fraction and size, optical pyrometry for particle temperature, laser-light

scattering for particle size and number density, temporally and spectrally resolved emission from gas-phase species, and a Scanning Mobility Particle Sizer. Details on the setup and operation of the shock tube and diagnostics for the study of heterogeneous combustion processes are given, and sample results are presented. 24 Refs.

2000

Robert M. G.; Peter O. W., 2000, "Laser-induced incandescence and elastic-scattering measurements of particulate-matter volume fraction changes during passage through a dilution tunnel," *Report, Sandia National Labs*. 11 page(s), Report No. SAND2000-8736C

Modern diesel engines produce far less mass of particulate matter than their predecessors, but this advance has been achieved at the expense of a significant increase in the number of sub-micron sized particles. This change in soot morphology has created the need for new instrumentation capable of measuring small volumes and sizes of particulate matter in a reasonable period of time, and preferably in real-time. Laser-induced incandescence and laser elastic scattering are complementary techniques suitable for this task. Optical measurements are presented for a diesel engine exhaust and compared with measurements performed using a Scanning Mobility Particle Sizer. This study investigates the effects of exhaust dilution and temperature control of the sampling system. It is also shown that laser-induced vaporization of low temperature volatile material is a potentially valuable technique for measuring the volatile component of exhaust particulate matter.

1999

Kaufman, S. L.; Caldow, R.; Dorman, F. D.; Irwin, K. D.; Poecher, A., 1999, "Conversion efficiency of the TSI Model 3480 electrospray aerosol generator using sucrose," *Journal of Aerosol Science*, **30**(S1):S373–S374

In this study, measurements of the overall conversion efficiency from solute to aerosol for the Model 3480 Electrospray Aerosol Generator (EAG) were carried out to learn whether further increases in aerosol yield would be possible. The measurements enabled to determine the size-distribution and concentration of the aerosol. Data was obtained with which to estimate the aerosol concentrations provided by the EAG. 3 Refs.

1998

Hilton, M.; Black, J. D., 1998, "Detection of soot particles in gas turbine engine combustion gases using non intrusive FTIR spectroscopy," *Proceedings of Society of Photo-Optical Instrumentation Engineers*, Bellingham, WA, 3493:20–31

Fourier Transform IR (FTIR) spectroscopy for making non-intrusive measurements of gas turbine exhaust gases and laser-induced incandescence (LII) for measuring soot content are being evaluated in EU Brite EuRam project AEROJET. Soot concentrations in modern air-engine exhausts are very low (typically less than 0.2 mg/cu m) with mean particle sizes less than 100 nm. The standard extractive filter paper soot measurement gives results expressed in terms of SAE smoke number, typically less than 10 SAE for modern engines. IR studies of exhaust gases from a modified air engine that produces high levels of particulates showed a broadband baseline shift caused by soot which depended on engine running conditions. Higher levels of particulates were studied in the exhaust of a small liquid kerosene fuelled combustor sector rig using an FTIR spectrometer. The IR broadband background that depends on both soot particle size and number density was compared to combustion efficiency. Preliminary results showed that for smoke numbers less than 5, broadband emission increased as combustion efficiency decreased and unburnt hydrocarbon content increased. Results obtained at the same running conditions using LII, soot measured in an extracted sample using an optical obscuration smoke meter, particle size distributions using a Scanning Mobility Particle Sizer (SMPS), and FTIR spectrometer measurements are compared.

Li, Y.-T.; Koropchak, J. A., 1998, "Investigations of particle characteristics and carrier effects on particle beam LC-MS," *Instrumentation Science & Technology*, **26**(4):389–407

We investigated the characteristics of the particles resulting from a thermospray nebulizer and two different desolvation systems for particle beam liquid chromatography-mass spectrometry (PB-LC-MS). The particle size distributions and shapes/morphologies were characterized using a Scanning Mobility Particle Sizer (SMPS) and high resolution transmission electron microscopes (HRTEM), respectively. The carrier effects of ammonium acetate were evaluated with these particle characteristics and the PB-LC-ITMS responses. The addition of ammonium acetate changed the particle size distributions and shapes/morphologies, and also significantly increased the analyte transmission efficiency in both the SMPS and the PB LC-ITMS. However, ammonium acetate did not cause increases in particle sizes and particle size decreases were even observed in some cases. The observed particle shapes and morphologies were different for caffeine and 3,3 prime -dimethoxybenzidine, and also depended on the desolvation methods. These results were interpreted to be due to the combined carrier effects of fragmenting large aerosols, increasing analyte solubility, and neutralizing the charged particles. The fragmentation of large aerosol particles via the addition of the semivolatile carrier was also hypothesized as a major process reducing the gravitational loss of aerosols and increasing the analyte transport efficiency. In the other set of experiments based on UV absorption, the mass balance of caffeine was evaluated. Both the SMPS and the mass balance data suggested that the porous membrane desolvation system could discriminate the small particles which, at least in part, resulted in the poor analyte transmission efficiency and nonlinear calibration behaviors of PB LC-MS. (Author abstract) 31 Refs.

1997

Chen, D.-R.; Pui, D. Y. H., 1997, "Experimental investigation of scaling laws for electrospraying: Dielectric constant effect," *Aerosol Science & Technology*, **27**(3):367–380

Experiments were performed to investigate the effect of liquid dielectric constant on existing scaling laws for the electrospraying process. The variations of the droplet size and the emitted current were measured as a function of the dielectric constant for the

electrospray operating in the cone-jet mode. Eight different solvents with dielectric constants, κ, ranging from 12.5 to 182 were tested. The residue particle size distributions were measured using a TSI scanning mobility particle sizer, (SMPS). The produced liquid droplet sizes were then calculated from the known solution concentrations. The results show that: (1) For the produced droplet size, D[d], experimental data are in agreement with the scaling law (G(κ) = 1.66 κ[-] [1/6]) proposed by Gañán-Calvo et al. (1994) for solvents with high dielectric constants. The derivation in low dielectric constant cases may be that the assumption of Gañán-Calvo (1994) on the characteristic length may not hold for the present system; (2) for the emitted current, I, experimental data deviate from those given by Fernández de la Mora and Loscertales (1994) except for the case of benzyl alcohol. The difference may be partially explained by the use of different electrolytes. A larger deviation is found in comparing with the equation, f(κ) = 6.46κ[1/4], provided by Gañán-Calvo et al. (1994). The reasons may be due to the inapplicable characteristic length assumption and the role of ion drifting current in the total emitted current. Based on the experimental data collected, some problems are pointed out regarding the criteria proposed in the previous studies for predicting the minimum liquid feed rate. A formula is given based on these data to estimate the maximum feed rate and to explain the observations reported in Chen et al. (1995).

1992

Ylatalo, Sampo I.; Kauppinen, Esko I.; Hautanen, Jukka; Joutsensaari, Jorma; Ahonen, Petri; Lind, Terttaliisa M.; Jokiniemi, Jorma K.; Kilpelainen, Markku, 1992, "On the Determination of Electrostatic Precipator Efficiency by Differential Mobility Analyzer," *Aerosol Science*, **23**(S1):S795–S798

In order to determine penetration curve of the electrostatic precipitator (ESP) as a function of aerosol particle diameter in the range of 10-1000 nm measurement series were carried out in real scale power plant conditions. Differential mobility particle sizing (DMPS) system was used to measure the particle mobility distributions before and after ESP. MICRON-algorithm (constrained regularization) was used to invert mobility distributions to the corresponding number distributions. Penetration curve was calculated from the measured number distributions.

1991

Adachi, Motoaki; Romay, Francisco J.; Pui, David Y. H., 1991, "High-Efficiency Unipolar Aerosol Charger Using a Radioactive Alpha Source," *Journal of Aerosol Science*, **23**(2):123–127

A new design of a unipolar charger has been developed. The charger consists of a radioactive source placed between two screen electrodes enclosed by a Plexiglass tube. The electric field in the charger is aligned with aerosol flow. The new charger is capable of charging ultrafine aerosols efficiently and with low particle losses. The charger was evaluated thoroughly both theoretically and experimentally. The basic equations for the charging process in this charger were numerically solved for monodisperse, ultrafine aerosols under various operating conditions. From the calculation results, the particle charge level and loss rate within the charger were found to depend on two dimensionless parameters defined in the paper. In the experiment, the particle charge level and penetration rate were measured for particle sizes of 10-30 nm, operating voltages of 3-9 kV, flow rates of carrier gas of 2-5.21 min^-1, and pressures of 0.46 and 1 atm. The experimental results which were obtained under similar conditions estimated by the dimensionless parameters were found to agree with the theoretical predictions. The charger gave a unit charge to 50% of the 10 nm diameter particles with 20% particle losses. The charger was found to work also under low pressure as a high-efficiency charger.

Kauppinen, Esko I., 1991, "On the Determination of Continuous Submicron Liquid Aerosol Size Distributions with Low Pressure Impactors," *Aerosol Science and Technology*, **16**(3):171

The aspects associated with the determination of continuous submicron aerosol size distributions using multijet low pressure impactors have been studied. Multiple sets of error free and noisy simulated data sets have been inverted and impactors have been compared with the differential mobility particle size analyses (DMA) method using well defined, laboratory generated liquid oleic acid aerosols tagged with ammonium fluorescein. Impactors included in this study were the Berner-type impactor HAUKE 25.015 (BLPI), modified University of Washington Mark 5 impactor (KLPI) and the impactor designed at the University of Florida (LLPI), as described by Hillamo and Kauppinen (1991), Kauppinen and Hillamo (1989) and Vanderpool et al. (1990), respectively. The inversion of simulated error free impactor data (i.e., data with perfect kernel functions) for unimodal submicron aerosols with small (2.5%) stage mass error estimate yields results very close to input distributions, when the method based on constrained regularization (Wolfenbarger and Seinfeld, 1990, 1991) is used in the inversion. When the error estimate is increased, inverted spectra are flattened. However, the remain clearly unimodal. When normally distributed random error is added to the data and the error estimate for each data point equals to the standard deviation of the random error, the fraction of bi- and trimodal inverted spectra increases with increasing the random error level and the asymmetricity of the kernel functions. When the random error level and data error estimates are equal to or smaller than 10%, inverted spectra are mainly unimodal close to input distribution for both error free and noisy data. The inversion of impactor data from the detailed laboratory experiments (i.e., the data with real kernel functions) indicate, that only BLPI kernel functions are accurate enough to yield unimodal distributions close to those measured with DMA. When the stage mass error estimate is increased beyond the stage mass determination error, unimodal spectra also for KLPI and LLPI are found. The decrease of the BLPI stage mass error estimate below the experimental error increase the agreement with DMA results. In most cases the error estimate for BLPI stage masses can be decreased to 2.5%, indicating the validity of both BLPI submicron kernel functions and fluorometric method used to determine stage mass concentrations.