Water-based Condensation Particle Counters (WCPCs)

Design & Characterization

2006

Erickson, Kathy; Liu, Wei; Osmondson, Brian; Oberreit, Derek R.; Schiesher, Nathaniel; Quant, Frederick, 2006, "Performance Characterization of a Compact Water-Based Condensation Particle Counter (TSI Model 3781)," *International Aerosol Conference 2006*, St. Paul, MN, USA, September 10–15, 2006

Condensation particle counters (CPCs) have been used for decades as the most effective and reliable method to measure number concentration of ultrafine airborne particles. Setting up a measurement network with research-grade CPCs can be expensive. A compact water-based CPC (TSI model 3781 WCPC) designed for long-term monitoring is the newest addition to the CPC family. This WCPC features small size, low cost, and light weight (<3kg). This 3781 is ideal for indoor air monitoring using multiple units since water is the working fluid and it is inexpensive. It is also suitable for outdoor applications as well.

Similar to other WCPCs, the 3781 uses a cooled saturator and a heated condenser to enlarge particles into water droplets which are then measured optically. This unique technique (technology from Aerosol Dynamics, US patent no. 6,712,881) makes use of the higher mass diffusivity of water vapor compared to the thermal diffusivity of air to supersaturate the sample stream and grow particles by condensation. The 3781 has an aerosol flow rate of 0.12 L/min with an additional 0.48 L/min bypass flow at the inlet to minimize particle diffusion losses. It operates in single particle count mode with a live-time coincidence correction.

In this study, the 3781 counting efficiency curves were measured for particles of several different materials, and the effect of test aerosol purity will be discussed. Response time, linearity, and zero count performance were also characterized. Household nanoparticle exposure data will be presented.

Hering, Susanne V.; Lewis, Gregory S.; Quant, Fred R.; Oberreit, Derek R., 2006, "A Micro-Environmental, Water-Based, Condensation Particle Counter" Poster, *2006 International Aerosol Conference*, St. Paul, MN, September 10–15, 2006

Concentrations of ultra-fine particles inside homes and offices and schools are influenced by both indoor and outdoor sources, as well as building ventilation and proximity to roadways. Because people spend the majority of their time indoors, monitoring of these micro-environments is important in the assessment of community exposures. A portable condensation particle counter would enable the assessment of these occupied spaces, and could prove useful in mapping of the global concentrations of ultra-fine particles. Water-based condensation particle counting approach is an attractive approach for these applications. The elimination of butanol reduces operating costs, and allows monitoring in areas where toxicity is of concern. Laminar flow water-based condensation particle counting was introduced in 2003. The first instrument (TSI-3785) detects particles as small as 5 nm (Hering et al, 2005). Subsequent efforts have led to an instrument with detection of particles as small as 3 nm (TSI-3786). Reported here is the new, micro-environmental, condensation particle counter (ME-WCPC). This instrument is based on the same principal as the prior laminar-flow water-based counters, but it has a smaller aerosol sampling rate to better enable measurements at the high concentrations often found in ambient air.

Liu, Wei; Kaufman, Stanley L.; Osmondson, Brian L.; Sem, Gilmore J.; Quant, Frederick R.; Oberreit, Derek R. 2006, "Water-based Condensation Particle Counters for Environmental Monitoring of Ultrafine Particles," *Journal of Air and Waste Management Association*, **56(4):**444-455

TSI Inc. (Shoreview, MN) has introduced three new water-based condensation particle counters (WCPCS) that were designed to detect airborne particles larger than 2.5 nm (model 3786), 5 nm (model 3785), and either 10 or 20 nm (model 3782). These WCPCs are well suited for real-time, environmental monitoring of number concentration of airborne ultrafine particles. Their unique design incorporates the use of water as the working fluid instead of alcohol. Water is odor free, readily available, and eliminates the problem of water condensation and absorption into alcohol working fluids during operation in humid environments. In this study, the performance of three TSI WCPCs was characterized for several aerosol compositions, including sucrose, salt (NaCl), dioctyl sebacate (DOS), dioctyl phthalate (DOP), emery oil (poly-alphaolefin), silver, impurity residue particles, and ambient aerosol particles. All particles were size selected using a nano differential mobility analyzer (nano-DMA; model 3085, TSI Inc.) to create monodisperse challenge aerosols. The challenge aerosol was mixed uniformly with clean makeup flow and split into a WCPC and a reference instrument to determine the counting efficiency of the WCPC. For the model 3785 WCPC, the D50 (i.e., the particle diameter with 50% counting efficiency) was determined to be 3.1 nm for salt particles, 4.7 nm for sucrose and ambient particles, 5.6 nm for silver particles, and ┌ 50 nm for ultrapure oil particles. The sensitivity to oil droplets increased dramatically (D50, 10 nm) when the oil was slightly contaminated. The D50 of model 3786 ultra- fine water-based CPC (UWCPC) was 2.4 nm for impurity residue particles. The D50 of the model 3782 WCPC was 10.8 (with a nominal setting of 10 nm) or 19.8 nm (with a nominal setting of 20 nm) for sucrose particles. All three WCPCs have response times of less than 2 or 3 sec and are therefore able to detect fast-changing events.

Mordas, G.; Kulmala, M.; Petäjä, T.; Hämeri, K., 2006, "Calibration of the Ultra-fine Water-based Condensation Particle Counter TSI3786," *2006 International Aerosol Conference*, St. Paul, MN, September 10–15, 2006

A number concentration of aerosol particles of nucleation mode are measured using condensation particle counters (CPCs). A working principle of CPCs consists of three consecutive processes: supersaturating aerosol-laden air with vapor of a working fluid, growth of the particles by condensation of the supersatured vapors and optical detection of the particles after their growth. The CPCs are classified according to the technique that is used in creating the supersaturation (McMurry, 2000). Widely used commercial CPCs (TSI3010, TSI3022, TSI3025, TSI3007) are conductive cooling instruments and all these instruments use alcohol to create the supersaturation. At last year, a new commercial instrument with a new supersaturation creating technique was produced. New unique design of the CPC allows use water as a working fluid. First produced water-based CPC (TSI3785) was described and investigated by Hering et al. (2005) and Mordas et al. (2006) to detect ultrafine aerosol particles. The WCPC has been later modified by manufacturers and a new ultrafine water-based CPC TSI3786 was constructed. UWCPC is a thermally diffusive, continuous, laminar-flow laminar CPC. The condensational growth of the particles is achieved by heating of the aerosol flow in a wetted growth tube. Due to the fact that mass diffusivity of water is higher than thermal diffusivity of air, a supersaturated area is generated inside the growth tube. Thus, the created supersaturated conditions allow promote a condensational growth of passed particles. The diffusion losses of ultrafine particles are minimized by transporting an aerosol flow to the growth tube through a special capillary and focusing it in the centerline of the growth tube. In this study, the performance characteristics of newly developed ultrafine water-based condensation particle counter (TSI3786) are examined. The effect of temperature differences i.e. the degree of supersaturation obtained inside the instrument and resulting effects to the particle detection efficiency are experimentally determined. Additionally, the effect of chemical composition of particles on detection efficiency was investigated. The measurements were conducted for silver, ammonium sulphate and sodium chloride particles. Also, the UWCP was compared with commercial widely used CPCs (TSI3025, TSI3010, TSI3007, and TSI3785).

Petäjä, T.; Mordas, G.; Manninen, H.; Aalto, P. P.; Hämeri, K.; Kulmala, M., 2006, "Detection Efficiency of a Water-Based TSI Condensation Particle Counter 3785," *Aerosol Science & Technology*, **40(12)**:1090-1097

In this article we present observations on the detection efficiency of a recently developed TSI 3785 Water Condensation Particle Counter (WCPC). The instrument relies on activation of sampled particles by water condensation. The supersaturation is generated by directing a saturated airflow into a "growth tube," in which the mass transfer of water vapor is faster than heat transfer. This results in supersaturated conditions with respect to water vapor in the centerline of a "growth tube." In this study, the cut-off diameter, that is, the size, where 50% of the sampled particles are successfully activated, varied from 4 to 14 nm for silver particles as a function of temperature difference between the saturator and the growth tube. The solubility of the sampled particles to water played an important role in the detection efficiency. Cut-off diameters for ammonium sulphate and sodium chloride particles were 5.1 and 3.6–3.8 nm, respectively at nominal operation conditions. Corresponding cut-off diameter for hydrophobic silver particles was 5.8 nm.

Stolzenburg, Mark R.; Iida, Kenjiro; McMurry, Peter H.; Smith, James N.; Keady, Patricia B.; Hering, Susanne, V., 2006, "Field Evaluation of a Water-Based Ultrafine Condensation Particle Counter," Poster *2006 International Aerosol Conference*, St. Paul, MN September 10–15, 2006

Detection of particles with diameters below 5 nm is important to understanding new particle formation in the atmosphere. Additionally, reliable monitoring of all ultrafine particles, defined loosely as those with diameters below 100nm, is important to assessing the contributions of ultrafine particle sources such as combustion, and the potential health risks associated with this size fraction. The recently introduced ultrafine water-based condensation particle counter (UWCPC) is an attractive approach for monitoring particle number concentration because it eliminates the need for toxic and costly working fluids. Additionally, the aerosol sampling rate (5cm3/s) is higher by a factor of 10 than the butanol ultrafine condensation particle counter (UCPC), providing improved counting statistics for measurements downstream of a mobility size selector. The question addressed in this paper is the size-dependent measurement efficiency of the UWCPC for ambient aerosols, and its comparability to butanol-based instruments under field conditions. These field tests are motivated by laboratory observations with single-component aerosols which show a greater dependence of the instrument response on aerosol composition than has been noted for the butanol-based instruments.

2005

Attoui, MB; de la Mora, J. Fernadez, 2005, "On the Detection Limit of Hydrophilic Particles by a Water CPC," Presentation, 2005 European Aerosol Conference, Ghent, Belgium, August 28–September 2, 2005

The water-based condensation particle counter (WCPC) concept of Hering et al. (2004) has been turned by Quant Technologies into two commercial instruments. A first WCPC model was characterized by Kaufman and colleagues at the 2004 meeting of the AAAR. As expected from water's small Kelvin diameter at its critical supersaturation for homogenous nucleation (Magnusson et al.), they noted a low size detection limit. This advantage is, however, offset by a surprising inability to detect hydrophobic particles. Quant's second WCPC model achieves a higher supersaturation than his first WCPC, and has a lower size detection limit (saturator 283K, growth tube 338K and optic 338K0. It will be tested here with hydrophilic nanoparticle of polyethylene glycol (PEG).

Biswas, Subhasis; Fine, Philip M.; Geller, Michael D.; Hering, Susanne V.; Sioutas, Constantinos, 2005, "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 (W-CPC) 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 W-CPC/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).

Hering, S., Keady, P.B.; Stolzenburg, M.R.; Fernandez, A.E.; Miguel, A. H.; Quant, F.R.; Oberreit, D.R., 2005, "Response of Water-Based Condensation Particle Counters to Ambient and Vehicular Particulate Matter", Presentation, *2005 European Aerosol Conference*, Ghent, Belgium, August 28–September 2, 2005

Concerns regarding the health effects of ultra-fine particles and particulate emission from vehicular traffic is motivating the measurement of these particles in ambient air. Water-based condensation particle counting is an attractive approach for monitoring particle number concentration because it eliminates the need for toxic and costly working fluids.
Reported here is the response of a laminar-flow water-based condensation particle counter (WCPC) to ambient and vehicular traffic aerosols. The WCPC is a continuous, thermally diffusive instrument that enlarges particles by water condensation to enable them to be counted by optical means. The WCPC uses a "growth tube" technology that explicitly takes into account the high diffusivity of water vapor wherein the supersaturation necessary for particle activation and growth is produced in a wetted tube whose walls are warmer than the entering flow.

Hering, S. V.; Quant, F. R., 2005, "Two New Water-Based Condensation Particle Counters," Presentation, *American Geophysical Union*, Fall Meeting, San Francisco, CA, December 5–9, 2005

Described here are two new, thermally-diffusive, water-based condensation particle counters (WCPC) for determination of aerosol number concentrations. One of these, the TSI Model 3786 ultrafine WCPC, detects particles as small as 2.5 nm at an aerosol flow rate of 300 cm3/min. The second is a not-yet-commercialized, compact, 12-volt instrument (ME-WCPC) weighing 2.5 kg with a lower size limit of 5 nm, and an upper concentration limit in single-count mode of ~10E7cm-3. In contrast to the cold-walled condensers of the older butanol-based particle counters, these WCPCs use a warm, wet-walled "growth tube" that explicitly takes into account the high diffusivity of water vapor. Because the mass diffusivity of water vapor exceeds the thermal diffusivity of air, the flux of water vapor to the centerline is faster than the heat flux from the walls, thereby producing the supersaturation necessary for particle activation and growth. An obvious advantage of the WCPCs over the butanol-based particle counters is the elimination of odor, toxicity and waste disposal issues with the use of butanol. Reported is the field evaluation of the ultrafine- and ME-WCPCs, with comparison to the more well-established butanol-based TSI Model 3010 and 3025 counters. A passive flow system provided a 9:1 dilution of ambient air for the TSI 3010 in order to stay within an acceptable concentration range for that instrument. Equivalency of aerosol sampling rates for all instruments was evaluated through comparison of counting efficiency for near-monodisperse aerosols at with diameters ranging from 50 to 200 nm. Over four weeks of measurements the ultrafine WCPC reported 6% higher concentrations than the ultrafine butanol Model 3025 counter, consistent with the slightly lower size cutoff of the ultrafine WCPC. Concentrations from the ME-WCPC units were higher than for the 10nm cutpoint TSI 3010, but lower than for the 3 nm cutpoint TSI 3025 ultrafine. For all comparisons, the correlation coefficient R>0.97

Hering, Susanne V., Stolzenurg, Mark R., 2005, "A Method for Particle Size Amplification by Water Condensation in a Laminar, Thermally-Diffusive Flow," *Aerosol Science & Technology*, **39(5)**:428-436

A new method is presented for the enlargement of particle size through condensation of water vapor in a laminar, thermally diffusive flow. The method involves the introduction of an air flow at temperature T_i into a wet-walled tube at a temperature $T_w > T_i$. This approach yields higher supersaturation values than either mixing or cold-walled condensers when operating between the same temperature extremes. Model results for the saturation profiles within the condensing region show that the peak supersaturations are reached along the centerline of the flow, and that the activation efficiency curves are steeper for large temperature differences when the cutpoint diameter is smaller. Experiments conducted with three types of aerosol, oleic acid (a water-insoluble oil), a mixture of oxalic acid and sulfate, and with ambient laboratory aerosol confirmed that condensational growth is achieved with this approach, although experimental cutpoints are somewhat higher than predicted for wettable particles.

Hering, Susanne V.; Stolzenurg, Mark R.; Quant, Frederick R.; Keady, Patricia B.; Oberreit, Derek, 2005, "A Fast-Response, Nanaoparticle Water-Based Condensation Counter," Presentation, the Particulate Matter Supersite program and Related Studies, *An International Specialty Conference sponsored by the American Association for Aerosol Research*, Atlanta, GA, February 7–11, 2005

A thermally diffusive, laminar-flow, water-based condensation particle counter (WCPC) has been developed to measure number concentrations for nanometer and ultrafine particles. Particles are enlarged by water condensation in a laminar flow using a "growth tube" technology that explicitly takes into account the high diffusivity of water vapor. The supersaturation necessary for particle activation and growth is produced in a warm wet-walled condenser. Because the mass diffusivity of water vapor exceeds the thermal diffusivity of air, the flux of water vapor to the centerline is faster than the heat flux from the walls. The first version of this instrument has an unsheathed sample flow of 1 L/min and saturator and condenser temperatures of 20C and 60C respectively. Its lower cutpoint, defined as the particle size detected with an efficiency of 50^ is 4.5nm for non-hydrophobic aerosols, including salts, organic acids and ambient aerosols. Reported here is a second, nanoparticle version of the instrument. The nano-WCPC utilizes a 50% sheath flow with an aerosol flow of 0.3 L/min, and saturator and condenser temperatures of 10C and 70C respectively. Tests with ambient, tunnel and laboratory generated aerosols show that the effective cutpoint is approximately 2.7nm. The time response is approximately 300mn excluding the flow-enduced lag. The relatively high aerosol sampling rate yields significantly better counting statistics, allowing much faster size distribution scans than previously possible.

Hering, Susanne V.; Stolzenurg, Mark R.; Quant, Frederick R.; Oberreit, Derek, Keady, Patricia B.; 2005, "A Laminar-Flow, Water-Based Condensation Particle Counter (WCPC)," *Aerosol Science & Technology*, **39(7)**:659-672

A new water-based condensation particle counter (WCPC) is presented. The WCPC is a thermally diffusive, laminar flow instrument. Condensational enlargement is achieved through the introduction of a saturated airflow into a "growth tube" with wetted walls held at a temperature higher than that of the entering flow. An unsheathed, 1 L/min instrument utilizing this principle has been evaluated with various aerosols. The particle size detected with an efficiency of 50% is at or below 4.8 nm for particles sampled from vehicular emissions or ambient air, and for various laboratory-generated inorganic salts. The cut point is higher for the organic materials tested, ranging from 8 nm to 30 nm depending on the compound and purity level. An empirically determined dead-time correction factor is applied to the coincidence correction, which allows extension of the single-count mode to higher concentrations. The counting efficiencies for 80 nm oil and salt aerosols are equal, and above 97% for concentrations approaching 10^5 cm^{-3}. When subject to a step-function change in input concentration the time required to attain 90% of the final value, including a 0.5 s lag, is 1.3 s. The corresponding exponential time constant is 0.35 s. The WCPC evaluated here is marketed as the TSI Model 3785.

Hering, S., M.R. Stolzenburg, F.R. Quant, D.R. Oberreit and P.B. Keady, “A Nano-Particle, Water-Based Condensation Particle Counter", Presentation, *24th Annual AAAR Conference*, Austin TX, October 17–21, 2005

A thermally diffusive, laminar-flow, water-based condensation particle counter (WCPC) has been developed to measure number concentrations for nanometer and ultrafine particles. Particles are enlarged by water condensation in a laminar flow using a “growth tube” technology that explicitly takes into account the high diffusivity of water vapor. The supersaturation necessary for particle activation and growth is produced in a warm wet-walled condenser. Because the mass diffusivity of water vapor exceeds the thermal diffusivity of air, the flux of water vapor to the centerline is faster than the heat flux from the walls. The first version of this instrument has an unsheathed sample flow of 1 L/min and saturator and condenser temperatures of 20^{o}C and 60^{o}C respectively. It’s lower cutpoint, defined as the particle size detected with an efficiency of 50% is below 5nm for non-hydrophobic aerosols, including salts, organic acids and ambient aerosols.

Reported here is a second nanoparticle version of the instrument. The nano-WCPC utilizes a 50% sheath flow with an aerosol flow of 0.3 L/min., and saturator and condenser temperatures of 12^{o}C and 75^{o}C respectively. Tests with ambient, tunnel and laboratory generated aerosols show that the effective cutpoint is below 3 nm. The time response is characterized by an exponential time constant of 0.2 sec. The relatively high aerosol sampling rate yields significantly better counting statistics, allowing much faster size distribution scans than previously possible. A dead time correction factor allows single particle counting to 100,000 cm^{-3}. Comparison to traditional, butanol-based instruments under field conditions will be presented.

2004

Hering, Susanne V., Olga Hogrefe, G. Garland Lala and Kenneth L Demerjian. “Field Evaluation of a Laminar-Flow, Water-Based Condensation Particle Counter,” Poster, *American Association for Aerosol Research 2004 Annual Conference*, Atlanta, GA, October 4–8, 2004

A newly developed, laminar flow, water-based condensation particle counter (WCPC) was evaluated under field conditions during a three-week field campaign in New York City. The WCPC utilizes a “growth tube” technology that enables the enlargement of particles by water condensation in a laminar, thermally diffusive flow. The instrument tested, the Quant-400, is the prototype of the commercial version (TSI-3785). It operates at a sample flow of 1 L/min and is not sheathed. Saturator and condenser temperatures were set at 20C and 60C, respectively. Field measurements were made at Queens College, in January 2004, as part of the New York Supersite Study. Total ambient particle number concentrations were compared to a collocated butanol-based condensation particle counter (TSI-3022). On one day, the WCPC was placed downstream of a nano-differential mobility analyzer, with collocated measurements with an ultrafine condensation particle counter, the TSI-3025. The WCPC agreed to within 2% on average of the TSI-3022 when concentration data are derived from single particle counting. Pooled standard deviation for five-minute averaged data was 4%. Agreement was not as good, nor as consistent, at ambient concentrations about 65,000 cm^{-3}, when the WCPC values were derived from total scattering from the “cloud” of particles. When placed downstream of the nano-differential mobility analyzer, the WCPC concentrations were generally within the statistical error of those reported by the TSI-3025 over the entire size range from 5 nm to 100 nm.

Hering, Susanne V; Stolzenburg, Mark R., 2004, “Continuous, laminar flow water-based particle condensation device and method,” US Patent # 6,712,881, March 30, 2004

An apparatus and method for producing a diffusive, continuous laminar flow for particle growth via condensation of vapors with a mass diffusivity near or higher than the thermal diffusivity of the surrounding gas. In an exemplary embodiment, the method uses the condensation of water vapor onto particles suspended in air.

Hering, Susanne V.; Stolzenurg, Mark R.; Quant, Frederick R.; Oberreit, Derek, 2004 “A Laminar-Flow, Water-Based Condensation Particle Counter,” Presentation, *American Association for Aerosol Research 2004 Annual Conference*, Atlanta, GA, October 4–8, 2004

A thermally diffusive, water-based condensation particle counter (WCPC) has been developed to measure airborne particle number concentrations in the size range about approximately 6nm. Particles are enlarged by water condensation in a laminar flow using a “growth tube” technology that explicitly takes into account the high diffusivity of water vapor. Traditional laminar-flow condensation particle counters do not work well with water because water vapor diffuses too rapidly and does not reach the necessary supersaturation within the cold-wall condenser region. In contrast, the WCPC employs a warm, wet-walled condenser. Because the mass diffusivity of water vapor exceeds the thermal diffusivity of air, the flux of water vapor to the centerline is faster than the heat flux from the walls. This difference produces a maximum in the water vapor supersaturation along the centerline of the flow. Theoretical modeling indicates that cutpoints as small as 2nm could be achieved with this approach. A commercial prototype utilizing an unsheathed sample flow of 1 L/min, was tested with laboratory-generated sodium chloride, ammonium nitrate, oleic acid and dioctyl sebbacate aerosols. Particle were generated by atomization, neutralized using a Po-210 source, classified with a nano-DMA, and detected with a TSI 3025 ultrafine condensation particle counter and aerosol electrometer in parallel with the WCPC. The lower curpoint, defined as the particle size detected with an efficiency of 50% is 6.5nm for oleic acid aerosol, 6nm for ammonium nitrate, and below 5nm for sodium chloride. For pure doctyl sebacate the cutpoint is above 30nm, but the cutpoint drops to near 10nm when a trace of sodium chloride is added. For monodisperse fractions of ambient aerosols, the response of the WCPC was comparable to the TSI 3024 ultrafine CPC for particle diameters above 6nm.

Liu, W, Kaufman, Stan L.; Sem, Gil J.; Quant, Fred R., 2004 "Material Effects on Threshold Counting Efficiency of TSI Model 3785 Water-based Condensation Particle Counter," Poster, *American Association for Aerosol Research 2004 Annual Conference*, Atlanta, GA, October 2004

The TSI Model 3785 water-based condensation particle counter (WCPC) offers rapid number concentration measurements of airborne ultra-fine particles. Its unique design allows this instrument to use water as its condensing fluid. Water is non-toxic, odor-free, non-contamination, and inherently eliminates the water condensation problem seen with alcohols in a humid environment. These advantages make it important to fully characterize its performance in comparison with standard butanol condensation particle counters. One critical aspect of such a counter's performance is its material dependence, i.e., the effect of the material of particles on its threshold response. From the performance of the early General Electric water-based condensation particle detectors it is known that for a water-based particle counter, there will be a difference in response to hydrophobic and hydrophilic materials. The threshold behavior of the WCPC was measured in this study, for particles of several different materials including sucrose, emery oil, DOS, DOP, and sliver. Sucrose and oil particles were generated using an electrospray (TSI 3480), and silver particles were generated using a tube oven. Monodisperse particles were selected with a nano DMA. The particle counts of the water-based CPC and a TSI 3022 CPC were compared to the readings of an electrometer (TSI 3068A) to obtain counting efficiencies. The D50 cut point, i.e., the size with a 50% counting efficiency, of the WCPC is 4.7nm for sucrose. The D50 cut points for pure oil particles are much larger (>50nm) and are different for different types of oils.

Quant, Frederick R.; Oberreit, Derek; Stolzenburg. Mark R., 2004 "Increasing the Single Particle Counting Range of a Condensation Particle Counter," Poster, *American Association for Aerosol Research 2004 Annual Conference*, Atlanta, GA, October 2004

Since the development of continuous-flow condensation particle counters (CPC), the ability to count single particles has been applied as a technique to infer the particle concentration of aerosols. Single particle counting operation is desirable as a means of measuring particle concentrations because it relies on fundamental parameters: the number count of high signal-to-noise particle events, time, and flow rate. The presence of a particle in the viewing volume causes a period in which no additional particles can be detected (dead-time). For increasing particle concentrations, statistical particle coincidence in the detection volume increases. Since these coincident particles are not measured, the concentration accuracy decreases with increasing concentration. This typically defines the upper concentration limit of the CPC or the point at which the instrument switches to a photometric mode of operation. The photometric concentration reported by a CPC is based on a calibrated conversion of photodetector signal to particle concentration. These calibrations are not trivial to perform or easily verified. The coincidence corrections including corrections for counter dead-time have been used for many years to extend the single particle counting range of a CPC. Corrections of less than a factor of two have been performed in real-time on some commercial CPCs. This work demonstrates the application of dead-time measurement to extend the usable range of the single particle counting mode of a CPC. Precise measurement of dead-time along with the application of correction factors allows a further extension of the single particle counting range of a CPC. The real-time single particle counting range of a CPC was extended to conditions where the resulting dead-times exceeded 80% of the sample period.

2003

Hering, Susanne V., Stolzenburg, Mark R.; Quant, Frederick R.; Oberreit, Derek, 2003, "A Continuous, Laminar Flow, Water-based Condensation Particle Counter," Poster, *American Association for Aerosol Research 2003 Annual Conference*, Anaheim, CA, October 2003

Airborne particle number concentrations are measured using condensation particle counters (CPCs) that enlarge particles through condensation so they may be detected by optical means. Most common are continuous, laminar-flow CPCs that use an alcohol, such as butanol, as the condensing vapor. These thermally diffusive CPCs rely on the low diffusivity of the condensing alcohol vapor to produce the necessary supersaturation within the condenser region. They do not work well with water because water vapor diffuses too quickly. Reported here is a new, laminar-flow, water-based condensation particle counter (WCPC). The WCPC uses a novel "growth tube" technology that explicitly take into account the nigh diffusivity of water vapor (patent pending). In contrast to the traditional instrument, the condensing region of the WCPC employs warm, wetted walls. Because the mass diffusivity of water vapor exceeds the thermal diffusivity of air, the flux of water vapor to the centerline is faster than the heat flux from the walls. This difference produces a maximum supersaturation along the centerline of the flow. Theoretical modeling indicates that the cutpoints as small as 2nm could be achieved with this approach. A pair of prototype instruments,

operating at a sample flow of 1 L/min, have been constructed and tested. Comparison is made to a butanol-based CPC (TSI 3010) for monodisperse fractions of ambient aerosol, and for laboratory-generated monodisperse aerosol of dioctyl sebacate, ammonium sulfate, and dioctyl sebacate mixed with 0.2% ammonium sulfate. Above 30nm the data are strongly correlated (R^2>0.99) with a slope =1.0 for each of these four aerosol types. Below 20nm the WCPC is more efficient than the 3010 for ambient aerosol, for ammonium sulfate and for dioctyl sebacate mixed with 0.2% ammonium sulfate, but less efficient for the pure organic, dioctyl sebacate. The WCPC response time is of the order of 1 s.

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