Scanning Mobility Particle Sizer™ (SMPS™) Spectrometer

Application: Filter Test

Bibliography

2007

Japuntich, Daniel; Franklin, Luke; Pui, David; Kuehn, Thomas; Kim, Seong; Viner, Andrew, 2007, "A comparison of two nano-sized particle air filtration tests in the diameter range of 10 to 400 nanometers," *Journal of Nanoparticle Research*, **9**(1):93–107

Two different air filter test methodologies are discussed and compared for challenges in the nano-sized particle range of 10-400 nm. Included in the discussion are test procedure development, factors affecting variability and comparisons between results from the tests. One test system which gives a discrete penetration for a given particle size is the TSI 8160 Automated Filter tester (updated and commercially available now as the TSI 3160) manufactured by the TSI, Inc., Shoreview, MN. Another filter test system was developed utilizing a Scanning Mobility Particle Sizer™ (SMPS™) to sample the particle size distributions downstream and upstream of an air filter to obtain a continuous percent filter penetration versus particle size curve. Filtration test results are shown for fiberglass filter paper of intermediate filtration efficiency. Test variables affecting the results of the TSI 8160 for NaCl and dioctyl phthalate (DOP) particles are discussed, including condensation particle counter stability and the sizing of the selected particle challenges. Filter testing using a TSI 3936 SMPS sampling upstream and downstream of a filter is also shown with a discussion of test variables and the need for proper SMPS volume purging and filter penetration correction procedure. For both tests, the penetration versus particle size curves for the filter media studied follow the theoretical Brownian capture model of decreasing penetration with decreasing particle diameter down to 10 nm with no deviation. From these findings, the authors can say with reasonable confidence that there is no evidence of particle thermal rebound in the size range.

2006

Kim, Seong; Wang, Huaping; Imagawa, Masayuki; Chen, Da-Ren; Pui, David, 2006, "Experimental and Modeling Studies of the Stream-Wise Filter Vibration Effect on the Filtration Efficiency," *Aerosol Science and Technology*, **40**(6):389–395

The stream-wise vibration effect of a fibrous filter is studied experimentally and numerically for the purpose of evaluating filtration efficiency. The particle sizes range from 0.02 to 10 μm and the face velocity ranges from 3 to 10 cm/s. The vibrational peak velocity also varied from 0 to 50 cm/s. The filtration efficiency for this wide size range is obtained by combining the individual test results for fine particles (0.02 to 0.5 μm) and large particles (0.5 to 10.0 μm). For the fine particle experiment, Arizona Road Dust (ARD) test particles are generated by an atomizer after an ultrasonic process and measured by a Scanning Mobility Particle Sizer (SMPS). For the large particle experiment, the test particles are generated by a fluidized bed and measured by an Aerodynamic Particle Sizer (APS). When the particles are generated by the atomizer after ultrasonicating, the majority of the particles are in nano scale without the agglomerates on the large particle surface, while particles generated by the fluidized bed are mostly in micro-scale because many nanoparticles are agglomerated on large particle surface. The filtration efficiency increases with the vibrational peak velocity in the impaction-dominant region (D_p > 0.1 μm) and diffusion-dominant region (D_p)

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.

2001

Chen C.-C.; Chen W.-Y.; Huang S.-H.; Lin W.-Y.; Kuo Y.-M.; Jeng F.-T., 2001, "Experimental study on the loading characteristics of needlefelt filters with micrometer-sized monodisperse aerosols," *Aerosol Science and Technology*, **34**(3):262–273

In this work, three types of needlefelt filters, made of Polyester (PE), Ryton Sulfar (RS), and Polyaramid (PA), were tested to investigate the aerosol loading characteristics of fabric filters when challenged with micrometer-sized monodisperse potassium sodium tartrate (PST) particles. A fibrous filter with packing density of 9%, thickness of 0.38 mm, and fiber diameter of 5.1 μm was included for comparison. A vibrating orifice monodisperse aerosol generator was used to produce three different sizes (5, 10, and 20 μm) of PST particles for aerosol loading experiment. An ultrasonic atomizing nozzle and a TSI constant output nebulizer were used to generate polydisperse PST particles for the aerosol penetration test. The aerosol penetration of submicrometer-sized particles through the filters was measured by using a Scanning Mobility Particle Sizer. An Aerodynamic Particle Sizer was used to measure the penetration fraction of aerosol particles larger than 0.8 μm. The pressure drop across the filter was monitored by using pressure transducers, which were calibrated against an inclined manometer. Airflows of 5, 10, 20, and 30 cm/s were used to study the flow dependency. The aerosol penetration results showed that the particles larger than 3 μm did not penetrate the clean fabric filters tested in the present study. The loading curves (plots of pressure drop against sampling time) displayed three regions: an initial region of fast increase, a transition region, and a final linear region after the dust formation point. After the formation point of the dust cake, both fabric and fibrous filters shared the same slope (of the loading curves). The slope of different regions of the loading curves was determined by many factors, such as size of challenge aerosol, face velocity, surface treatment, and the compressibility of the dust cake forming on the filter. The method of final surface treatment was found to be critical to the performance of the fabric filters. In order to avoid the unnecessary rise in air resistance, the melting clumps formed during final surface treatment should be as thin and narrow as possible, just enough to support the filter bag cleaning. From the standpoint of filter quality and energy consumption, the low filtration velocity has to be adopted whenever possible, because high filtration velocity not only led to lower filter quality (in particular for submicrometer-sized particles) but also created dust cake of lower porosity, which caused an extra rise in pressure drop across the dust cake.

Huang, Sheng-Hsiu, Chen, Chih-Chieh, 2001, "Ultrafine Aerosol Penetration through Electrostatic Precipitators," *Environmental Science and Technology*, **36**(21):4625–4632

This work measures the penetration of ultrafine particles through a single-stage and a two-stage ESP as a function of particle size. Also studied herein are how parameters including particle size, rate of airflow through the ESP, and voltage of the discharging electrode affect aerosol penetration through the ESP. Monodisperse particles with sizes between 10 and 60 nm were generated as the challenge aerosols to investigate the particle charges given by an ESP. A comparison of experimental and theoretical results confirms that a partial charging regime exists when the particle diameter is several tens of nanometers. Experimental results indicated that aerosol penetration through the single- and two-stage ESPs increased significantly for particles below 20 and 50 nm, respectively. However, the exact regime depends on the parameters including airflow rate, applied voltage, and configuration of the ESP. Phenomena such as ionic flow, particle space charge, and flow turbulence may significantly affect the collection efficiency of an ESP for ultrafine particles. To achieve the same collection efficiency, it is more economical to use single-stage ESPs to collect particles less than 16 nm from the standpoint of energy consumption. However, it is more economical to use two-stage ESPs to collect particles larger than 16 nm.

1998

Chen, C.-C.; Hang, S.-H., "The effects of particle charge on the performance of a filtering facepiece," *American Industrial Hygiene Association Journal*, **59**(4):227–233

This study quantitatively determined the effect of electrostatic charge on the performance of an electret filtering facepiece. Monodisperse challenge corn oil aerosols with uniform charges were generated using a modified vibrating orifice monodisperse aerosol generator. The aerosol size distributions and concentrations upstream and downstream of an electret filter were measured using an aerodynamic particle sizer, an Aerosizer, and a scanning mobility particle sizer. The aerosol charge was measured by using an aerosol electrometer. The tested electret filter had a packing density of about 0.08, fiber size of 3 μm, and thickness of 0.75 mm. As expected, the primary filtration mechanisms for the micrometer-sized particles are interception and impaction, especially at high face velocities, while electrostatic attraction and diffusion are the filtration mechanisms for submicrometer-sized aerosol particles. The fiber charge density was estimated to be 1.35 times 10-5 coulomb per square meter. After treatment with isopropanol, most of fiber charges were removed, causing the 0.3-μm aerosol penetration to increase from 36 to 68%. The air resistance of the filter increased slightly after immersion in the isopropanol, probably due to the coating of impurities in isopropanol. The aerosol penetration decreased with increasing aerosol charge. The most penetrating aerosol size became larger as the aerosol charge increased, e.g., from 0.32 to 1.3 μm m when the aerosol charge increased from 0 to 500 elementary charges.

1994

Siag, A. M.; Tennal, K. B.; Mazumder, M. K., 1994, "Determination of fiber charge density of electret filters," *Particulate Science and Technology*, 351–355

Particle collection in electret filters is enhanced by electrostatic forces resulting from the embedded charge on the fibers of the filters. Currently, there is no simple method available for determining the charge density on the electret fibers. Since charge on the fibers can degrade with loading or during storage, a simple evaluation technique is desirable. Aerosol consisting of organic oil mist generally used for testing HEPA filters should not be used for evaluating electret filters since organic aerosol droplets rapidly degrade the electrostatic charge effect. In this study experimental measurements of penetration were made on electret filters challenged with monodisperse, polystyrene latex spheres, PLS, of known size and charge. The experimental data on penetration were used to separate the contributions of the individual collection parameters and to determine the effective density of charge on the fibers. Collection efficiency due to mechanical filtration mechanisms was measured using filters in which the electret charge had been effectively neutralized by loading the filters with an oil aerosol. Collection due to dielectrophoretic force was obtained using aerosol with zero charge. The effective charge density on the fibers was determined by comparing measurements of penetration for particles having known size and charge with the predictions of available theoretical equations. Details of this method of determining the density of charge on the fibers are described here. Experimental determinations of charge density showed reasonable agreement with the charge densities given by the manufacturers of the tested filters.

1992

Wake, D.; Brown, R.C.; Trottier, R.A.; Liu, Y., 1992, "Comparison of the Efficiency of Respirator Filters and Filtering Facepieces Against Radon Daughter Aerosols and Laboratory Generated Aerosols," *Aerosol Science*, **23**(Sl):S757–S760

Respirator filters and filtering facepieces have been tested for filtration efficiency against radon daughters in a flourspar mine. The test method involved the use of sampling filters exposed to natural radon daughters in air filtered by the test respirators. Respirators with a filtration efficiency high enough for them to be considered suitable for use against toxic dusts generally reduced radon daughter levels by 90% or more, though nuisance dust masks were ineffective. The measured penetration of radon daughters through the former types of filter correlated reasonably well with the penetration of 0.1μm neutralized monodisperse aerosol and with that of the BS4400 sodium chloride aerosol, measured in the laboratory. Test filters were exposed to radon daughters in the mine for 8 hours as a simulation of their behavior during a working shift, but their performance was not altered by this and they did not show measurable radioactivity as a result of it.

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.

Zhang, Zhiqun; Liu, Benjamin Y. H., 1992, "Experimental Study of Aerosol Filtration in the Transition Flow Regime," *Aerosol Science and Technology*, **16**(44):227–235

An experimental study was carried out to investigate the performance of fibrous filters in the transition flow regime, where the fiber radius is of the same order of magnitude as the mean free path of gas molecules. Filter media with the mean fiber diameter of 0.21-0.72 um and the packing density of 0.053-0.08 were used in this study. The transition flow conditions were achieved by reducing the gas pressure in the filter test apparatus. Experiments were performed in the pressure range of 0.1-1.0 atm using monodisperse particles of 0.04-0.45 um diameter range. The particles were generated by the electrostatic classification technique. The particulate penetration through the filter and the corresponding pressure drop were measured at face velocities ranging from 6 to 19 cm/s. Experimental results showed that the penetration decreased by three to four orders of magnitude as the pressure was reduced from 1.0 to 0.1 atm. It was found that the most penetrating particle size increased slightly as the gas pressure was reduced. The pressure drop across the filter was also found to decrease significantly as the pressure was reduced.

1990

Yu, Aoyuan, 1990, "A Simple and Reliable Testing Method for Particle-Collection Efficiency of Ultra Low Penetration Air (ULPA) Filters," *Swiss Contamination Control*, **3**:259–261

As specified in American IES Recommended Practice IES-RP-cc-001-86, Ultra Low Penetration Air (ULPA) filter is the filter having a minimum particle-collection efficiency of 99.999% for particulate diameters >0.12 um in size. And yet, the Recommended Practice does not give a detailed description of so-called <<Dual Laser Tests>> procedure. Here, the author presents a simple and reliable testing method using cold DOP as a challenge aerosol source and employing TSI Model 3071 Electrostatic Classifier and Model 3020 CNC (Condensation Nucleus Counter) to measure the efficiency of ULPA filter on 0.10 um (or0.12 um) in size. The author doesn't think the specified > 0.12 um of particle size is a necessary criterion for ULPA filter. Testing <<on 0.12 um>> particulate diameter for ULPA is a better solution, due to its good comparability and labor- and time-savings. Again, CNC does not need dilution air, and the conventional error from dilution will be avoided. The paper also makes some comments on current ULPA filter test procedures, and suggest using on <<on 0.10 um>> as a reference particle size for ULPA filters.

1987

Holton, Patricia M.; Tackett, Denise Lynne; Willeke, Klaus, 1987, "Particle Size-Dependent Leakage and Losses of Aerosols in Respirators," *American Industrial Hygiene*, **48**(10):848–854

Measuring particle size-dependent leakage into and losses inside a respirator reveals the deposition mechanisms occurring at the leak site and the flow dynamics inside the respirator. This study investigated particle size-dependent leakage and deposition within the mask by examining the leakage into the mask for different hole locations, probe locations, hole shapes, hole lengths and hole sizes. The shape of the leak has an effect on particle size-dependent leakage. Probe and leak location tests indicated that not only does the total measured leakage change but also the size-dependence of the leakage changes depending on the leak and probe locations. When the leak site is in the chin area, the clean air entering through the filters at the chin helps to carry the inward leakage into the breathing zone. Particle size-dependent leakage does occur and is due to both inertial entry losses at the leak site and within the mask, and diffusional losses within the mask and leak site. Particle size-dependent curves change shape as the hole size changes with relatively more larger particles entering through the small hole size.

Holton, Patricia M.; Willeke, Klaus, 1987, "The Effect of Aerosol Size Distribution and Measurement Method on Respirator Fit," *American Industrial Hygiene*, **48**(10):855–860

The particle size-dependent leakage into a respirator was examined by measuring the leakage of particle sizes between 0.07 to 4.4 µm through three hole sizes in a negative-pressure half-mask respirator worn by a human subject. This investigation showed that the size distribution of an aerosol test agent and the measurement method have an effect on the leakage measured in a quantitative filter test. For instance, the ratio of percent leakage measured by light scattering between test aerosols with count median diameters of 2.2 and 0.28 µm can be as large at 5:1. Likewise, the ratio of the percent leakage measured by a particle count method vs. a mass method of detection of the same polydisperse aerosol with a count medium diameter equal to 2.2 µm can be as high as 4:1. The mass leakage into a mask with a leak is also greater for an exposure aerosol with a count median diameter between 0.15 to 0.30 µm compared to exposure aerosols with larger count median diameters for aerosols with the same mass concentration.

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