2U.1

On-Road and Laboratory Evaluations of Cabin Air Filters using Integral Number and Surface Area Concentration Monitors. CHAOLONG QI, Nick Stanley, David Y. H. Pui, University of Minnesota.

In recent years, a rapidly increasing number of vehicles are equipped with cabin air filters (CAF) to enhance the air quality in vehicle's cabin. In this study, we evaluated the performance of a cabin air filter in both laboratory and on-road tests using integral number and surface area concentration monitors.

The laboratory tests showed that the most penetrating particles size (MMPS) for the tested CAF is in 200-300 nm range. Considering that the majority of the particles under the on-road condition are smaller than 300 nm, it is necessary to extend the current CAF test standard (ISO 11155-1) to smaller particles. The on-road test results from Condensation Particle Counter (CPC) and Nanoparticle Surface Area Monitor (NSAM) are consistent with each other. The capture efficiencies for on-road particles in both nucleation and accumulation modes can be measured and distinguished, and the results agree well with the laboratory tests. On the average, about 60-70% of the road particles can be removed by the CAF under evaluation.

After turning on the recirculation air in the vehicle, the particle concentration inside the cabin decays exponentially and can reach a concentration lower than that in a normal office because particles are continuously captured by the CAF in the recirculation air. A simple model was developed to describe the concentration decay and the modeling results fit the test data well for each ventilation flowrate. Average particle capture efficiency and particle generation rate inside the cabin for different ventilation flowrates can be achieved from the fitting parameters. The majority of the particles in the recirculation air are in the MMPS range. And the capture efficiency calculated from the model agrees well with the laboratory tests.

2U.2

Filter Performance Under The Liquid-Coated Particle Loading. TA-CHIH HSIAO, Da-Ren Chen, Washington University in St. Louis.

The filter performance when loaded with liquid-coated particle has been experimentally studied. Liquid-coated particles are widely observed in the real world. The loading behavior of filters (e.g., filter pressure drop v.s. loaded particle mass) for liquid-coated particles might be different from those for the cases of loading purely solid or liquid particles. None of previous studies addressed the coated particle loading issues.

To systematically perform such a study we developed a liquid-coated particle generation system, in which monodisperse solid core particles mix with the vapor of coating liquid under the well-controlled temperature environment. By varying the core particle size and the coating liquid thickness, coated particles of fixed sizes and different liquid volume percentage were produced. In this study the overall coated particle size was kept around 400 nm. The generated coated particles were loaded on the high-efficiency fiber glass filter media. Sodium chloride particle is used as the core material. Two different liquids, dioctyl sebacate (DOS) and glycerol, were coated on the core particles. The selection of two liquids was to study the viscosity and surface tension effects on the filter loading curve. The result shows in general the loading behavior of liquid-coated particle transits from that of loading pure solid particle to that of loading pure liquid particles as the liquid volume percentage increases. The transition between two limiting cases, however, is different for particles coated with DOS and glycerol due to their different viscosity and surface tension. The transition details will be presented and discussed in AAAR 2007.

2U.3

Investigation of Multi-layer Nanofiber Filters. JING WANG, Seong Chan Kim, Yue Bai and David Pui, University of Minnesota.

Filter media composed of multiple layers of nanofibers and a backer made of micro-meter fibers are studied. SEM images of the nanofiber layers reveal a wide distribution of the fiber size, from 50 nm to 800 nm. Filtration tests are carried out for three samples A, B and C. Sample A has the thickest nanofiber layers and sample C has the thinnest nanofiber layers. The filter media are challenged with monodisperse NaCl particles and pressure drop and penetration are measured. The size of the testing NaCl particles ranges from 30 nm to 300 nm. The most penetrating particle size for the three samples is found to be 90 nm. The pressure drop increases and the penetration decreases as the nanofiber layers become thicker. The figure of merit, which represents the ratio of the filtration efficiency to pressure drop, is then computed. All the three nanofiber filters show higher figure of merit than the bare backer, indicating that nanofibers can improve the filter quality. Sample A and B show similar figure of merit, even though sample A has much thicker nanofiber layers. It is because when too many nanofibers are added, the increase of pressure drop offsets the benefits on filtration efficiency. The results indicate that optimization of the nanofiber fraction is an important problem in composite filter design.

A numerical model is developed to simulate nanofibers with a wide size distribution. The fibers are randomly packed into a filter with specified solidity. Particle capture due to interception, inertial impaction and diffusion are computed. The slip condition is used on fiber surfaces. The pressure drop can be overestimated by 30% and the penetration can be 2 — 3 times higher if the slip condition is not considered. The results from the numerical model are in fair agreement with experimental results.

2U.4

Numerical Analysis of Fluid Flow in Pulse-Jet Cleaning for Pleated Filter Bag. KYOUNGSOO LIM , Youngok Park, Junghwan Lim, Korea Institute of Energy Research.

A pleated filter bag has many advantages such as lower pressure drop and longer pulsing interval than a round filter bag because of its low filtration velocity and large filtration area at the same flow rate and space. However, the pleated filter bag shows the different performance according to pleated height and shape, filter media depth and physical characteristics, the number of pleated valley, and so on. Especially, these parameters have a great effect on filter cleaning efficiency. Sometimes, the pleated filter bag has insufficient cleaning efficiency due to narrow pleated filter valley. Thus, it is very important to understand the flow field or pressure profile in the pleated filter bag when the filter cleaning is going on.

In this study, a numerical simulation on the fluid flow of pulse-jet cleaning for pleated filter bag was conducted to examine the effects of the pulsing air on pleated filter surface. The pleated filter has a length of 1000 mm, an inner diameter of 65 mm, an outer diameter of 135 mm, and 30 pleated valleys with a pleated height of 25 mm. Its filtration velocity is 1.0 m/min and the pulsing pressure from a nozzle diameter of 8 mm is 3~7 bar.

The numerical simulations yielded the velocity and pressure profiles in pleated filter bag and showed the transmission and travel of pulsing jet flow with elapsed pulsing time. The pulsing-jet air transmitted the highest pressure to the upper part of filter surface and the lowest pressure to the part between the middle and bottom of filter.

2U.5

Evaluation of air filtration system including a diffusion pre-charger and a medium filter for removal of nano particles.
JAE-HONG PARK, Yee-Kyeong Jung, Jeong-Hoon Byeon, Ki-Young Yoon, Jungho Hwang, Yonsei University.

An air filtration system including a diffusion pre-charger and a medium filter was designed and tested for removal of nano particles. The corona type pre-charger was installed on the top and bottom wall of test duct, which was diffusion charging section, in this study. Nano particles were passed through the diffusion charging section, and then charged by generated ions from pre-charger. Medium filter which made of electret polymer fibers, was used to capture charged particles from diffusion charging section. We evaluated removal efficiencies of nano particles, based on the number concentration. Test particles were 10-100nm sized NaCl particles which were generated by electric furnace. The face velocity of the air flow was varied from 0.5 to 1.0m/s. Number concentration of test particles were measured by scanning mobility particle sizer (SMPS). And Ozone monitor was used for monitoring ozone, which were inherently produced by pre-charger. [The authors acknowledge the financial support from the Seoul R&BD program (Grant no. 2006-8-1842).]

2U.6

Electrostatic Control of Particulate Emissions from Diesel-Powered Machinery.
ALI FARNOUD, Alfredo Juan Armendariz, Southern Methodist University.

Diesel engines are more efficient than gasoline engines but high emissions of soot are a concern in both the environmental and occupational setting. Experimental and recently commercialized diesel particulate mechanical filters can cause considerable fuel penalty, are prone to thermal fracture, and are not applicable for a wide variety of non-road mobile and machinery applications. Electrostatic precipitators have been used by utilities and heavy industry for nearly a century but they have not been successfully miniaturized for use on mobile sources and machinery. The objective of this study was to investigate the removal efficiency and optimized the performance of a small-scale electrostatic precipitator for diesel exhaust particulate control on a diesel-powered electric generator. The exterior dimensions of the ESP were 32 x 22 x 21 cm and the collection plates were 25 x 15 cm. The ESP was designed for easy adjustments of plates and wire positions, wire types, and total plate area. Tests were performed at both positive and negative corona polarities. Mass control efficiency measurements were made by sampling particles on to Teflon-coated fibrous filters, two different particle counters, a CPC and a nephalometer, were used to determine coarse particle (<500 nano-meters) and fine particle (15nm<dp<500nm) number collection efficiencies. Results show that that ESP was able to reduce mass emissions by 90%, and reduce coarse number emissions by 75%, and fine particle emissions by 65%.

2U.7

Measurements of Bipolar Aerosol Charge Fractions of Initially Neutral 70 nm Particles for Various Neutralizers with Different Ion Sources and Geometries over a Range of Source Strengths and Flowrates. CHUNGMAN KIM, Mark R. Stolzenburg, Peter H. McMurry, University of Minnesota; Xiaoliang Wang, Stanley L. Kaufman, Gilmore Sem, TSI Inc.; Hiromu Sakurai, National Institute of Advanced Industrial Science and Technology (AIST), Japan.

The aim of these measurements was to study the effects of neutralizer activity and aerosol residence time on charge fraction. We used the tandem differential mobility analyzer (TDMA) technique to measure the bipolar fractions of singly- and doubly-charged 70 nm particles. Particle concentrations were maintained at a relatively low level to ensure that no ion depletion occurred. Test flowrates ranged from 0.3 to 5 L/min for most neutralizer configurations with some measurements at higher flowrates for a few selected neutralizers.

The neutralizer types studied included:
- TSI Models 3077/3077A and 3012/3012A Krypton-85 neutralizers of varying activities
- Tokyo Dylec Corp. Americium-241 neutralizer
- Univ. of Minn. Particle Technology Lab Polonium-210 neutralizer with varying activities
- Aerosol Dynamics Inc. Polonium-210 neutralizer with varying activities
- Sokken surface-discharge microplasma aerosol charger.

The results show a fall off in charging efficiency for some neutralizers as either flowrate increases or activity decreases. Based on this data a goal of this work is provide neutralizer users with guidelines for neutralizer selection to bring neutral aerosols to a stationary charge state. This includes upper limits on flows and lower limits on activities depending on the type of neutralizer used.

Several additional observations were made in the course of these measurements. Measured charge fractions frequently differed from those given by Wiedensohler (1988). Also, measured charge fractions varied to some degree with the composition of the challenge aerosol. These observations may be a result of ion properties differing from those assumed by Wiedensohler and/or varying depending on the aerosol atomized and the solvent used.

Wiedensohler, A. (1988). An approximation of the bipolar charge distribution for particles in the submicron size range. J. Aerosol Sci., 19, 387-389.

8C.1

Investigation of Thermal Rebound below 20 nm and under elevated temperature up to 420 K. WEON GYU SHIN, Kenjiro Iida, David Y.H. Pui, University of Minnesota.

Nanoparticles are building block of nanomaterials and produced in large quantity. They may pose a health risk to workers because of increased toxicity due to the large specific surface area for nanoparticles. Nanoparticles are believed to be collected with increasing efficiency with decreasing particle size by Brownian deposition. This was demonstrated by several recent papers under room temperature condition (Kim et al., 2006). However, as mean thermal speed increases with increasing temperature or decreasing particle size, thermal rebound is more likely to occur.

This paper experimentally investigates the filtration efficiency of a model filter, i.e., a screen type mesh at both room temperature and different elevated temperatures in the size range below 20 nm. We performed experiments down to 2.5 nm under both room and elevated temperatures and also down to 1.2 nm under room temperature using an ethylene glycol based laminar flow condensation particle counter. Silver particles in the size range from 2.5 to 20 nm and NaCl particles in the size range from 1.2 to 3.4 nm were used as test materials. In order to have sufficient concentrations for filter testing, a unipolar charger (Chen and Pui, 1999) was used to increase the charged fraction of nanoparticles, especially in the size range below 3 nm. Experimental results are compared with a classical theory for the filtration with screen type mesh by Cheng and Yeh (1980). The experimental results agree well with the theory down to 2.5 nm at room temperature and even elevated temperatures up to 350 K. However, it was observed that thermal rebound occurs below 3.0 nm at elevated temperatures and also below 1.5 nm at room temperature condition.

8C.2

Fundamental Electrical Properties of a Small-Scale Electrostatic Precipitator. ALI FARNOUD, Alfredo Juan Armendariz, Southern Methodist University.

Full-scale industrial electrostatic precipitators (ESPs) have been widely used for a century but they have not been miniaturized for use in mobile sources and machinery. There are growing experimental and commercial applications of small-scale ESPs. The objective of this work was to determine the fundamental electrostatic properties of small-scale ESPs. A DC-powered, wire-plate electrostatic precipitator was designed and constructed for this work, with variable geometry internal components. Adjustments were easily made to plate-to-plate and wire-to-plate distances, wire numbers and types, and total plate areas between tests. The exterior dimensions of the ESP were 32 x 22 x 21 cm, and the collection plates were 25 x 15 cm. Onset voltages, sparkover voltages, and voltage-current relationships were obtained for plate-to-plate distances from 1.5 to 2.5 cm, and for wire diameters from 0.125 to 0.5 mm. Experimental data were compared with theoretical electrostatic predictions. The results indicated that some electrostatic properties, like the differences in current production between positive and negative corona operation, and the general parabolic trend in voltage-current, were consistent between small-scale units and predictions using large-scale experience. However, many important differences were found between observed and predicted onset and sparkover voltages and current production. A new electrostatic model was developed to more accurately predicting voltage-current behavior in small-scale ESP's.

8C.3

Inactivation Potential of Filter Immobilized Airborne Mammalian and Avian Viruses in Weak Electric Fields. Raydel Mair, Paul A. Rota, Centers for Disease Control and Prevention, Peter McKinney, Strion Air Corporation, Ralph A. Tripp, S. Mark Thompkins, Dept of Infectious Diseases, College of Veterinary Medicine, University of Georgia, MARK HERNANDEZ, Department of Civil, Environmental and Architectural Engineering, University of Colorado at Boulder.

Electric field irradiation has been successfully applied for microbe disinfection by the food industry, and its application for controlling airborne infectious diseases (bioaerosols) has been gaining increased attention. Weak electric field irradiation was investigated for its potential to inactivate wild type human and avian influenza, as well as vaccine strains of measles and pox viruses. Timed series experiments were performed by immobilizing known quantities of pure infectious viruses on coarse virgin fiberglass air filter media. The filters hosting these microorganisms were exposed to a defined electric field, through a symmetric corona discharge array (c.a. 190 KV /m; 50 micro-A / sq.m). The titer of infectious virus, immobilized on these filters before and after electric field exposure, was measured monitored by using a standard plaque assay or by in situ staining to detect infectious foci.

Electric field exposures caused a significant drop in the recovery of infectious virions from fiberglass filter media as judged by logarithmic declines in plaque-forming units or infectious foci. When controlled for aging and velocity-induced desiccation effects, the application of a weak electric field across glass fiber filter media hosting otherwise infectious virions appeared to cause denaturation such that they could no longer be recovered as infectious microbiological agents. In static pilot filtration systems maintained at 20oC and a relative humidity of 40%, electric/ionization field exposure resulted in the following inactivation responses with respect to otherwise identical controls: measles (vaccine strain) 99.99% in 90 min; vaccina virus (MVAT7) 99.9% in 18 hr; wild-type human influenza virus 99% in 200 min; wild-type avian influenza avian 99.9% in 200 min. Results suggest that weak electric fields used to enhance the efficiency of coarse low-pressure drop filters may be an effective engineering technology for rapidly inactivating and/or destroying pathogenic viral agents in and on fiberglass and other polymeric media.

8C.4

Investigation of Aerosol Penetration through Individual Protective Equipment in Elevated Wind Conditions.

MICHAEL A. HILL, Suresh Dhaniyala, Clarkson University; Terence A. Ghee, Jonathan Kaufman, NAVAIR.

Performance of individual protective equipment (IPE) designed to protect an individual from harmful airborne substances has yet to be characterized when the individual is exposed to high wind conditions. Based on permeability, high wind causes air flow through the IPE fabric, making aerosol filtration efficiency an important design characteristic. Aerosol filtration efficiency in elevated wind conditions (above 10 mph) was studied. Filtration performance was measured using both benchtop filter-holder as well as wind tunnel tests. Benchtop tests consisted of measuring particle concentration upstream and downstream of the fabric placed in a filter holder. Tests were run at varying face velocities ranging from 0.06m/s to 0.4m/s. Wind tunnel tests were performed at constant fabric face velocity, with varying wind speeds ranging from 10mi/hr to 80mi/hr. A particle injection technique was developed for seeding the wind-tunnel at these ranges of velocities with uniform concentrations. Particles of several different densities and sizes ranging from 60nm to 2 microns were used in the tunnel and filter test setups. Initial test results show that particle penetrations increase with increasing wind speed for a constant face velocity. Also, the wind effect on particle penetration is seen to be most visible for particles of higher density. A theoretical model correlating filtration efficiency and design variables such as fiber diameter was created using data from penetration tests and electron microscope analysis of the IPE fabric. The wind-tunnel test procedure and penetration results for varying test conditions will be presented.

8C.5

Performance of facepiece respirator filters against bioaerosols.

SERGEY A. GRINSHPUN, Robert Eninger, Takeshi Honda, Atin Adhikari, Tiina Reponen, University of Cincinnati.

Since the certified filtering facepiece respirators generally provide better protection than health-care masks, the former have been widely recommended for use in case of major outbreaks of diseases caused by airborne bio-agents. However, the data about penetration of aerosolized bio-agents through the respirator filters are not always available. Some of the smallest bioaerosol particles of concern, such as viruses as well as bacterial and fungal fragments, fall into the ultrafine size range, for which the efficiency of respirators is not well-characterized. In this study, we measured the penetration of particles through respirator filters while the respirator was sealed on a breathing manikin and challenged with bioaerosols. The experiments were performed at inhalation flow rates of 30, 85 and 150 L/min with certified respirators representing different types, such as N95, N99, N100, P95, P100, FFP-2, and FFP-3. This study was exclusively focused on the filter performance, and, therefore, no faceseal leakage effect was included in this testing. The aerosol concentrations inside and outside the respirator filter were measured in real-time, size-selectively using a Wide-Range Particle Spectrometer (MSP Corp., USA). In addition, the penetration of viable microorganisms was determined by collecting bioaerosol samples outside and inside the respirator donned on the breathing manikin. These samples were analyzed by culture-based colony or plaque forming unit enumeration. The experiments revealed that, for some respirators, the filter collection efficiency could drop below the threshold level, for which it was certified. This was most clearly shown for MS2 virions in the size range of about 30 to 70 nm. Theoretical analysis confirmed that the shift of the most penetrating particle size towards nano-sized particles is attributed to the electret filter media, which is conventionally utilized in high-efficiency respirators.