

Research Papers Involving the TSI DUSTTRAK™ Aerosol Monitor

Application Note ITI-079

1. Kim, Jee Young; Magari, Shannon R.; Herrick, Robert F.; Smith, Thomas J.; Christiani, David C., Comparison of Fine Particle Measurements from a Direct-Reading Instrument and a Gravimetric Sampling Method. *Journal of Occupational and Environmental Hygiene*, **1**: 707–715 (2004)

Particulate air pollution, specifically the fine particle fraction (PM_{2.5}), has been associated with increased cardiopulmonary morbidity and mortality in general population studies. Occupational exposure to fine particulate matter can exceed ambient levels by a large factor. Due to increased interest in the health effects of particulate matter, many particle sampling methods have been developed. In this study, two such measurement methods were used simultaneously and compared. PM_{2.5} was sampled using a filter-based gravimetric sampling method and a direct-reading instrument, the TSI Inc. Model 8520 DUSTTRAK™ aerosol monitor. Both sampling methods were used to determine the PM_{2.5} exposure in a group of boilermakers exposed to welding fumes and residual fuel oil ash. The geometric mean PM_{2.5} concentration was 0.30 mg/m³ (GSD 3.25) and 0.31 mg/m³ (GSD 2.90) from the DUSTTRAK™ monitor and gravimetric method, respectively. The Spearman rank correlation coefficient for the gravimetric and DUSTTRAK™ monitor PM_{2.5} concentrations was 0.68. Linear regression models indicated that loge DUSTTRAK™ monitor PM_{2.5} concentrations significantly predicted loge gravimetric PM_{2.5} concentrations (p < 0.01). The association between loge DUSTTRAK™ monitor and loge gravimetric PM_{2.5} concentrations was found to be modified by surrogate measures for seasonal variation and type of aerosol. PM_{2.5} measurements from the DUSTTRAK™ monitor are well correlated and highly predictive of measurements from the gravimetric sampling method for the aerosols in these work environments. However, results from this study suggest that aerosol particle characteristics may affect the relationship between the gravimetric and DUSTTRAK™ monitor PM_{2.5} measurements. Recalibration of the DUSTTRAK™ monitor for the specific aerosol, as recommended by the manufacturer, may be necessary to produce valid measures of airborne particulate matter.

2. MacIntosh, David L.; Williams, Phillip L.; Yanosky, Jeff D., A comparison of two direct-reading aerosol monitors with the federal reference method for PM_{2.5} in indoor air. *Atmos. Environ.* Vol. **36** (1), pg. 107-113 (2002).

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Two types of direct-reading aerosol monitoring devices, the TSI Inc. Model 3320 Aerodynamic Particle Sizer® (APS™), and the TSI Inc. Model 8520 DUSTTRAK™ Aerosol Monitor (DUSTTRAK™ monitor), were collocated indoors with a US EPA designated Federal Reference Method (FRM) PM_{2.5} sampler, the BGI, Inc. PQ200, to assess the comparability of the sampling methods. Simultaneous 24-h samples were collected from two APS instruments, one DUSTTRAK™ monitor and one FRM sampler for 20 sample periods. The 30-min average concentrations during the 24-hour sample periods were also logged and compared for the APS and DUSTTRAK™ monitor. Statistical analysis on the mass concentrations obtained from each sampler type included paired t-tests and linear regression. The 24-h average PM_{2.5} levels from the FRM samplers were approximately normally distributed and ranged from 5.0 to 20.4 µg m⁻³ with mean and standard deviation 11.4 and 4.0 µg m⁻³, respectively. The 24-h average DUSTTRAK™ monitor levels are well correlated with FRM levels (R₂=0.859) but show significant proportional bias (beta1=2.57, p<0.0001). The 24-h average mean collocated APS levels are less highly correlated with the FRM (R₂=0.592) and do not show statistically significant proportional bias. The 30-min average levels between the two APS instruments show a high correlation (R₂=0.979) but significant proportional bias (beta1=1.31, p<0.0001). The results suggest that though the DUSTTRAK™ monitor provides precise measurements of PM_{2.5}, the accuracy of the measurements compared to the FRM can be improved through statistical adjustment. In contrast, APS PM_{2.5} measurements are less precise and less accurate compared to the FRM and therefore results from the APS should be interpreted with caution.

3. Moosmueller, H.; Arnott, W. P.; Rogers, C. F.; Bowen, J. L.; Gillies, J. A.; Pierson, W. R.; Collins, J. F.; Durbin, T. D.; Norbeck, J. M., Time Resolved Characterization of Diesel Particulate Emissions. 1. Instruments for Particle Mass Measurements. *Environ. Sci. Technol.* Vol. **35** (4), pg. 781-787 (2001).

The measurement of diesel vehicle exhaust particulate mass is currently accomplished using filter collection methods according to the Code of Federal Regulations (CFR). Such filter methods limit time resolution to a minimum of several minutes, making it impossible to study emissions during transient operating conditions. Extensive testing of five different measurement methods has demonstrated that fast response measurements of diesel exhaust particulate mass concentrations, consistent with CFR filter measurements, are feasible using existing technology. The measurement principles of choice are the real time weighing of exhaust samples as implemented in the tapered element oscillating microbalance (TEOM) and the measurement of light scattering from exhaust particles as implemented in the DUSTTRAK™ nephelometer. Each of these two instruments has distinctive strengths. The TEOM excels in the area of constant calibration, independent of vehicle. For the DUSTTRAK™ monitor, this calibration varies by vehicle. On the other hand, the DUSTTRAK™ monitor has an excellent signal-to-noise ratio, freedom from interference due to other exhaust sample properties, good time resolution, and simplicity. The strengths of the two measurement methods are complimentary, so an obvious suggestion is to integrate them. The nephelometer would obtain a fast response signal, with near real time calibration provided by the microbalance.

4. Morawska, L., He, C., Hitchins, J., Gilbert, D., Parappukaran, S., The relationship between indoor and outdoor airborne particles in the residential environment. *Atmos. Environ.* Vol. **35**, pg. 3463-3473 (2001).

The relationship between indoor and outdoor airborne particles was investigated for 16 residential houses located in a suburban area of Brisbane, Australia. The sub-micrometer particle numbers were measured using the Scanning Mobility Particle Sizer, the larger particle numbers using the Aerodynamic Particle Sizer and an approximation of PM_{2.5} was also measured using a DUSTTRAK™ monitor. The measurements were conducted for normal and minimum ventilation conditions using simultaneous and non-simultaneous measurement methods designed for the purpose of the study. Comparison of the ratios of indoor to outdoor particle concentrations revealed that while temporary values of the ratio vary in a broad range from 0.2 to 2.5 for both lower and higher ventilation conditions, average values of the ratios were very close to one regardless of ventilation conditions and of particle size range. The ratios were in the range from 0.78 to 1.07 for sub-micrometer particles,

from 0.95 to 1.0 for super-micrometer particles and from 1.01 to 1.08 for PM_{2.5} fraction. Comparison of the time series of indoor to outdoor particle concentrations shows a clear positive relationship existing for many houses under normal ventilation conditions (estimated to be about and above 2 h⁻¹, but not under minimum ventilation conditions estimated to be about and below 1 h⁻¹. These results suggest that for normal ventilation conditions, outdoor particle concentrations could be used to predict instantaneous indoor particle concentrations but not for minimum ventilation, unless air exchange rate is known, thus allowing for estimation of the delay constant.

5. Chiou, S, Tsai, C., Measurement of emission factor of road dust in a wind tunnel. *Powder Tech.*, Vol. **(118)**, pg. 10-15 (2001).

One of the critical problems in making an effective strategy to control road dust emission is to estimate the emission factor accurately. A wind tunnel was built in the laboratory to measure the emission factor of road dust under different wind acceleration conditions. Test road dusts were collected from two sites, one from the construction site where a DRAM factory was being constructed in the Science Industrial Park of Hsin-Chu (dust sample #1) and the other from an unpaved road at Nan Laio area of Hsin-Chu (dust sample #2). The dust samples were first sieved using a standard No. 325 mesh to remove particles greater than 44 μm. Thereafter, the dust samples were dried and then contained within an aluminum cell of 5 (width) × 5 (length) × 0.2 cm (depth), which was embedded in a working platform in the wind tunnel. The surface of dust samples was kept flush with the plate before testing. Test results show that the air acceleration rate affects the emission factor significantly. As the air acceleration rate is increased from 0.1 to 1.5 m/s², the emission factor is increased linearly from 1.0 to 7.0 × 10⁻⁴ kg/m² s⁻² for sample #1, and from 0.1 to 1.0 × 10⁻⁴ kg/m² s⁻² for sample #2. Test results show that the air acceleration rate has no significant effect on the threshold wind speed for re-entrainment, which was found to be 10⁻¹² m/s for sample #1, and 9-10 m/s for sample #2. While the edge effect at the surface of the dust sample has no significant effect on the threshold wind speed for re-entrainment, it increases both re-entrained dust concentration and emission factor significantly.

6. Kuhns, H., Etyemezian, V., Landwehr, D., MacDougall, C., Pitchford, M., Green, M., Testing re-entrained aerosol kinetic emissions from roads (TRAKER): a new approach to infer silt loading on roadways. *Atmos. Environ.* Vol. **35**, pg. 2815-2825 (2001).

PM₁₀ and PM_{2.5} emissions from roadways are currently estimated using the silt loading on the road surface as a surrogate for the emissions potential of road dust. While the United States Environmental Protection Agency prescribes this method in AP-42, there is considerable cost associated with silt loading measurements it is feasible to sample only a small portion of a roadway network. A new approach for measuring the concentration of suspendable PM₁₀ above road surfaces has been developed to obtain a more spatially representative estimate of a road's' potential to emit dust. The Testing Re-entrained Aerosols Kinetic Emissions from Roads (TRAKER) system uses real-time aerosol sensors mounted on a vehicle to measure the concentration of dust suspended from the road while the vehicle is in motion. When coupled with a Global Positioning System (GPS) instrument, TRAKER can be used to survey the changes in the suspendable particle reservoir due to varying road conditions over a large spatial domain.

In a recent study on paved roads in Las Vegas, the TRAKER system was compared with collocated silt loading measurements. The TRAKER system was also used to survey the relative amounts of suspendable road dust on approximately 300 miles of paved roads. The system provides a unique perspective on road dust sources and their spatial distribution. Results of this study indicated that the difference of the PM₁₀ concentrations measured behind the tire and on the hood is exponentially related to vehicle speed. This was an interesting " because current AP-42 road dust emissions estimation methods do not include vehicle speed as a factor in the emissions calculations. The experiment also demonstrated that the distribution of suspendable material on roadways is highly variable and that a large number of samples are needed to represent road dust emissions potential on an urban scale for a variety of road and activity conditions.

7. Chung, A, Chang, D.P.Y., Kleeman, M.J., Perry, K.D., Cahill, T.A., Dutcher, D., McDougall, E.M., and Stroud, K., Comparison of real-time instruments used to monitor airborne particulate matter. *J. Air and Waste Management Association*, Vol. **51**, pg.109-120 (2001).

Measurements collected using five real-time continuous airborne particle monitors were compared to measurements made using reference filter-based samplers at Bakersfield, CA, between December 2, 1998, and January 31, 1999. The purpose of this analysis was to evaluate the suitability of each instrument for use in a real-time continuous monitoring network designed to measure the mass of airborne particles with an aerodynamic diameter less than 2.5 μm ($\text{PM}_{2.5}$) under wintertime conditions in the southern San Joaquin Valley. Measurements of airborne particulate mass made with a beta attenuation monitor (BAM), an integrating nephelometer, and a continuous aerosol mass monitor (CAMM) were found to correlate well with reference measurements made with a filter-based sampler. A DUSTTRAK™ aerosol sampler overestimated airborne particle concentrations by a factor of approx. 3 throughout the study. Measurements of airborne particulate matter made with a tapered element oscillating microbalance (TEOM) were found to be lower than the reference filter-based measurements by an amount approximately equal to the concentration of NH_4NO_3 observed to be present in the airborne particles. The performance of the DUSTTRAK™ sampler and the integrating nephelometer was affected by the size distribution of airborne particulate matter. The performance of the BAM, the integrating nephelometer, the CAMM, the DUSTTRAK™ sampler, and the TEOM was not strongly affected by temperature, relative humidity, wind speed, or wind direction within the range of conditions encountered in the current study. Based on instrument performance, the BAM, the integrating nephelometer, and the CAMM appear to be suitable candidates for deployment in a real-time continuous $\text{PM}_{2.5}$ monitoring network in central California for the range of winter conditions and aerosol composition encountered during the study.

8. Lee, S. C.; Chang, M. Indoor and outdoor air quality investigation at schools in Hong Kong. *Chemosphere*, Vol. **41**(1-2), pg.109-113 (2000).

An investigation to characterize the indoor air pollutants found in air-conditioned or ventilated (ceiling fan) classrooms is presented. Indoor and outdoor air was monitored simultaneously using equipment placed 1.5 m above floor level. Air measurements were made using a Q-TRAK™ IAQ monitor (temperature, r. h. , and CO_2), a SKC formaldehyde kit, a DUSTTRAK™ monitor (respirable particulate matter, PM_{10} levels), and a portable air sampler (20 ml/min) for agar plates (total bacteria); agar plates were subsequently incubated at 32 degree C for 48 h. For determination of primary air pollutants (SO_2 , NO and NO_2), the air was sampled at 1 ml/min into Tedlar bags for laboratory analysis using a pulsed fluorescence SO_2 analyser and a chemiluminescence NO_x analyser. Results showed that all pollution parameters, with the exception of PM_{10} and CO_2 levels, complied with standards. Indoor PM_{10} and CO_2 levels typically exceeded 1 mg/m^3 and 1 ml/l, respectively. Explanations for these high levels are discussed, along with means of reducing them.

9. Ramachandran, G., Adgate, J.L., Hill, N., Sexton, K., Comparison of short-term variations (15-min averages) in outdoor and indoor $\text{PM}_{2.5}$ concentrations. *J. Air and Waste Management Association*, Vol. **50**, pg.1157-1166 (2000).

Measurements of 15-min average $\text{PM}_{2.5}$ concentrations were made with a real-time light-scattering instrument at both outdoor (central monitoring sites in three communities) and indoor (residential) locations over two seasons in the Minneapolis-St. Paul metropolitan area. These data are used to examine within-day variability of $\text{PM}_{2.5}$ concentrations indoors and outdoors, as well as matched indoor-to-outdoor (I/O) ratios. Concurrent gravimetric measurements of 24-hr average $\text{PM}_{2.5}$ concentrations were also obtained as a way to compare real-time measures with this more traditional metric. Results indicate that (1) within-day variability for both indoor and outdoor 15-min average $\text{PM}_{2.5}$ concentrations was substantial and comparable in magnitude to day-to-day variability for 24-hr average concentrations; (2) some residences exhibited substantial variability in indoor aerosol characteristics from one day to the next; (3) peak values for indoor short-term (15-min) average $\text{PM}_{2.5}$

concentrations routinely exceeded 24-hr average outdoor values by factors of 3-4; and (4) relatively strong correlations existed between indoor and outdoor PM_{2.5} concentrations for both 24-hr and 15-min averages.

10. Volckens, J., Boundy, M., Leith, D., Mist concentration measurements II: Laboratory and field evaluations. *Applied Occup. and Envir. Hyg. Journal*, Vol. **15**(4), pg. 370-379 (2000).

Sampling methods to determine occupational exposures to metalworking fluid mists are subject to bias. Light-scattering devices may respond differently to variations in particle size, shape, and refractive index. Gravimetric samplers are prone to evaporative losses of semi-volatile components. The performance of two light scattering devices, an electrostatic precipitator, and filters followed by gravimetric analysis was investigated when measuring metalworking fluid mist in laboratory and field settings. Laboratory tests with soluble oil and field tests with soluble oil, straight oil, and semi-synthetic fluid showed significant evaporative losses from filters. Light-scattering devices tended to overestimate mist concentrations when mass median diameters were less than about 2 μm and to underestimate mist concentrations when mass median diameters were larger. Filters will underestimate occupational exposures to metalworking fluid mists when semi-volatile components are present.

11. Hitchins, J., Morawska, L., Wolff, R., Gilbert, D., Concentrations of submicrometer particles from vehicle emissions near a major road. *Atmos. Environ.* Vol. **34**, pg. 51-59 (2000).

As part of a program of study to assess the exposure risks related to particulate matter in the outdoor environment, number concentrations of particles from vehicle emissions were measured at increasing distances from a major road. Particles in the size range from 0.015 to 0.697 μm were measured with the Scanning Mobility Particle Sizer™ spectrometer (SMPS™) and in the size range from 0.5 to 20 μm, with the Aerodynamic Particle Sizer® spectrometer (APS™). In addition to number concentration measurements, an approximation of PM_{2.5} fraction was obtained using a DUSTTRAK™ monitor (simple photometer). The measurements conducted at distances from the road ranging from 15 to 375 m showed, that for conditions where the wind is blowing directly from the road, the concentration of fine and ultrafine particles decay to around half of the maximum (measured at the closest point to the road) at a distance of approximately 100 – 50 m from the road. For the wind blowing parallel to the road, the reduction to half of the concentration occurs at 50 – 100 m. There is no effect on total particle number concentration at a distance greater than 15 m from the road when the wind is blowing towards the road and away from the sampling points. Total number concentrations of larger particles measured were not significantly higher than the average values for the urban environment, and decrease with distance from the road, reaching about 60% at 150 m from the road for wind from the road. PM_{2.5} levels also decrease with distance to around 75% for wind from the road and to 65% for wind parallel to the road, at a distance of 375 m.

12. Volckens, J., Boundy, M., Leith, D., and Hands, D., Oil mist concentration: A comparison of sampling methods. *American Industrial Hygiene Assoc. Journal*, Vol. **60**, pg. 684-689 (1999).

Discrepancies arise when sampling mineral oil mist using a glass fiber filter, a polyvinyl chloride filter, a polytetrafluoroethylene filter, an electrostatic precipitator, and two light-scattering devices. Most gravimetric methods show discrepancies because mist droplets, which have a high surface area, evaporate from the filters during sampling. Inconsistencies occur with light-scattering devices because these instruments are sensitive to particle size distributions, shapes, and refractive indices. Results from laboratory and field experiments show that concentrations measured using these methods vary by factors of two to five. Discrepancies were greatest when oil mist concentrations were relatively low.

13. Gunter, K.L., Sutherland, J.W., An experimental investigation in to the effect of process conditions on the mass concentration of cutting fluid mist in turning. *J. Cleaner Production*, Vol. (7), pg. 341-350 (1999).

Cutting fluid mists that are generated during machining processes represent a significant waste stream as well as a health hazard to humans. Epidemiological studies have shown a link between worker exposure to cutting fluid mist and an increase in respiratory ailments and several types of cancer, prompting closer scrutiny from several regulatory agencies. In this work, statistically designed experiments were conducted to determine the machining conditions that have the most significant effect on PM₁₀ and PM_{2.5} mass concentration levels of cutting fluid mist during a turning operation. Identification of these significant factors may lead to modifications in the machining process as a solution for minimizing cutting fluid mist, thus eliminating/reducing the need for costly mist control technology such as air filters, enclosures, and fluid additives.

14. Lehocky, A., and Williams, P. L., Comparison of respirable samplers to direct-reading real-time aerosol monitors for measuring coal dust. *American Industrial Hygiene Assoc. Journal*, Vol. 57, pg. 1013-1018 (1996).

Three types of respirable dust samplers were positioned side-by-side as area samplers within three coal-fired electric power- generating facilities. Respirable dust readings were taken using two direct-reading aerosol monitors (MIE PDM-3 Miniram and the TSI Model 8520 DUSTTRAK™ monitor) and the results compared to side-by-side respirable coal dust concentrations. Both direct-reading instruments use optical sensors for detecting dust concentrations, and in this study the air was passed through a 10-mm cyclone prior to detection. Respirable samples were collected using a 10-mm cyclone with a 5-mm PVC filter connected to a constant flow pump calibrated at 1.7 L/min. The samples were collected for fifteen 8-hr shifts over a one-month period. Respirable dust concentrations ranged from 0.23 to 10.83 mg/m³. The responses of each of the direct-reading instruments were compared to the respirable values. Neither of the two direct-reading instruments provided values that were identical to each other or the respirable samplers, but regression analyses indicated high coefficient of determination (R₂) values (0.85 and 0.94). Other statistical methods (analysis of variance, pair wise t-tests, and mixed effect models) found no significant differences (p>0.05) between the data sets for the direct-reading instruments and the respirable samples. It was concluded that the two direct-reading instruments can be used to measure respirable coal dust.

15. Influence of traffic patterns on particulate matter and polycyclic aromatic hydrocarbon concentrations in Roxbury, Massachusetts. *J Expo Anal Environ Epidemiol*, Vol. 12, pp 364-71.

Vehicle emissions have been associated with adverse health effects in multiple epidemiological studies, but the sources or constituents responsible have not been established. Characterization of vehicle-related exposures requires detailed information on spatial and temporal trends of various pollutants and the ability to predict exposures in unmonitored settings. To address these issues, in the summer of 2001 we measured continuously particle-bound polycyclic aromatic hydrocarbons (PAHs), ultrafine particles, and PM_{2.5} at a number of sites in Roxbury, a neighborhood of Boston, Massachusetts with significant diesel and gasoline-fueled traffic. We took measurements at the side of the road and at varying distances from the road, with simultaneous collection of traffic counts and meteorological conditions. Across all nine sites, median roadside concentrations were 8 ng/m³ of particle-bound PAHs (range: 4–57), 16,000 ultrafine particles/cm³ (range: 11,000-53,000), and 54 microg/m³ of PM_{2.5} as measured with a DUSTTRAK™ monitor (range: 12–86). Concentrations of all pollutants were lower at greater distances from the road, upwind, and at higher wind speeds, with greater concentration gradients for PAHs and ultrafine particles. In linear mixed effects regression models accounting for temporal autocorrelation, large diesel vehicle counts were significantly associated with roadside concentrations of PAHs (P=0.02), with a moderate association with ultrafine particles and little relation with PM_{2.5}. Although more comprehensive information would be needed for epidemiological applications, these data demonstrate significant spatial and temporal

heterogeneity for traffic-related pollutants during the summer in an urban center, with our monitoring and analytical methodology helping to inform source attribution.

16. Jamriska, M., Morawska, L., Thomas, S., He, C., Diesel Bus Emissions Measured in a Tunnel Study. *Environ. Sci. Technol.*, Vol. 38 (24), 6701-6709 (2004).

The emission factors of a bus fleet consisting of approximately 300 diesel-powered buses were measured in a tunnel study under well-controlled conditions during a 2-d monitoring campaign in Brisbane. Particle number and mass concentration levels of submicrometer particles and PM_{2.5} were monitored by SMPST[™] and DUSTTRAK[™] instruments at the tunnel's entrance and exit, respectively. Correlation between DUSTTRAK[™] monitor and TEOM response to diesel emissions was assessed, and the DUSTTRAK[™] monitor results were recalculated into TEOM equivalent data. The mean value of the number and mass emission factors was (3.11 plus or minus 2.41) x 10¹⁴ particles km⁻¹ for submicrometer particles and 583 plus or minus 451 mg km⁻¹ for PM_{2.5} (DUSTTRAK[™] monitor), respectively. TEOM PM_{2.5} equivalent emission factor was 267 plus or minus 207 mg km⁻¹. The results are in good agreement with the emission factors determined from steady-state dynamometer testing of 12 buses from the same Brisbane City bus fleet. The results indicate that when carefully designed, both approaches, the dynamometer and on-road studies, can provide comparable results, applicable for the assessment of the effect of traffic emissions on airborne particle pollution. A brief overview of emission factors determined from other on-road and dynamometer studies reported in the literature as well as with the regulatory values used for the vehicle emission inventory assessment is presented and compared with the results obtained in this study.

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