Modular Impactors — Accurate, Simple-to-operate, and Cost-effective Environmental PM Samplers

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Abstract

The EPA has defined PM2.5, PM10, and PM Coarse to monitor environmental exposure to particulate matter. Despite the PM2.5 and PM10 definition being somewhat different from the respirable, thoracic, and inhalable fractions defined by ACGIH, monitoring environmental PM provides important information leading to better assessment of overall worker exposure to particulate matter.

This study presents a series of new inertial impactors developed to monitor exposure to PM2.5, PM10, and PM Coarse. The impactors feature modular construction that includes an inlet, outlet, and filter cassette with incorporated support for an impaction substrate. To achieve optimal impactor performance, an oiled porous plastic support disk is recommended for use as the disposable impaction substrate.

The impactors were calibrated in the laboratory using an Aerodynamic Particle Sizer APS 3320. Data indicate good agreement with PM2.5 and PM10 as defined by EPA for both personal and area impactors. Field data obtained in different environmental conditions reveal good agreement between the newly developed modular IMPACT PM10 Impactor, and a collocated MiniVol Sampler (Airmetrics, Inc.) and FH 62 C14 Continuous Ambient PM Monitor (Thermo Andersen).

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Inertial Impactor Design Theory

Particle-laden air enters the impactor through the inlet nozzles. Larger particles with enough inertia deviate from the airstream lines and impact on the impaction plate while smaller particles follow the airstream lines around the impaction plate and collect on the filter (Figure 1). Impactor cut-off size can be adjusted by changing air velocity (particle velocity) inside the acceleration nozzle. An increase of particle velocity inside the nozzle will lead to collection of smaller particles due to an increase of their inertia. In contrast, the size of particles able to follow the airstream lines will increase with decreased velocity.

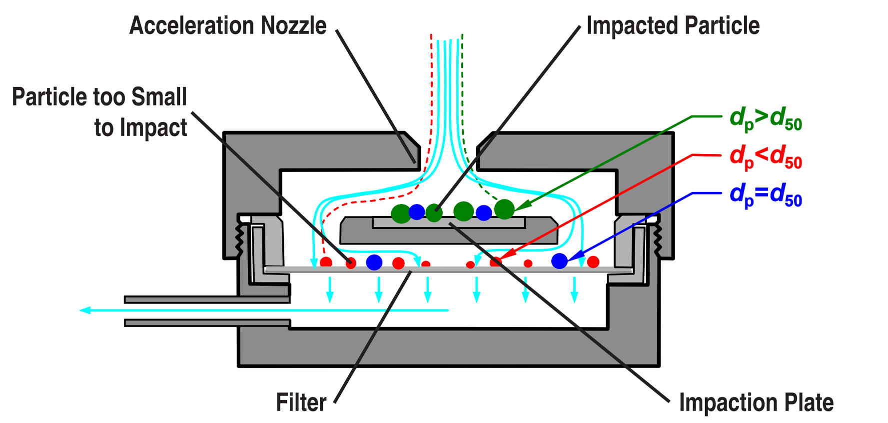

Figure 1. Schematic of inertial impactor

Performance of an inertial impactor is defined in terms of 50% cut-off size, d_{50}; 50% of particles with d_{50} penetrate through the impactor and another 50% are collected. d_{50} can be calculated using the following formula (Rader and Marple 1985):

$$d_{50} = \sqrt{\frac{9\mu W Stk_{50}}{\rho_p V_o C}}$$

Formula 1

where μ is air viscosity, W is the width or diameter of the impactor nozzle, Stk_{50} is the Stokes number corresponding to a 50% particle cut-off, ρ_p is the particle density, V_o is average air velocity in the nozzle, and C is the size-dependent Cunningham slip correction factor. Stk_{50} depends on the Reynolds number of the flow through the nozzle, Re, jet-to-plate distance, S, and impactor nozzle throat length, T.

Modular Impactor Design

The new modular impactors (U.S. Patent No. 7,334,453) are comprised of two modules: a housing and a particle collecting assembly. The inlet attaches to the outlet by screwing the two parts together and the particle collecting assembly is housed inside (Figure 2A). Particle-laden air enters the impactor through the inlet nozzles. Larger particles collect on the impaction substrate while smaller ones follow the airstream lines through the annular opening around the impaction substrate and collect on the filter. An oiled porous plastic support disk is recommended for use as the disposable impaction substrate to achieve optimal impactor performance. After sampling, the impactor inlet is unscrewed from the outlet and the particle collecting assembly (filter cassette with incorporated collection substrate) is readily available for quick replacement of the filter and impaction substrate. In addition to a single-stage impactor, a multiple-stage sampler can be assembled using similar modules (Figure 2B). The two-stage impactor featuring a PM10 inlet as Stage 1 and a PM2.5 impactor as Stage 2 will collect PM Coarse and PM2.5 simultaneously. The modular impactor design was applied to build samplers for personal and area sampling. Formula 1 was employed to determine the size and number of nozzles for each particular impactor. Personal Modular Impactors (PMI) operate at a 3.0 L/min flow rate and use a 37-mm filter and 25-mm impaction substrate (Figure 3). PMI 2.5 has four nozzles with a 1.5-mm diameter each. There are eight 2.8-mm diameter nozzles in the PMI 10. The IMPACT Samplers (Figure 4) operate at a flow rate of 10.0 L/min, are designed for area sampling, and employ a 47-mm filter and 37-mm impaction substrate. IMPACT 2.5 has eight 1.8-mm diameter nozzles and IMPACT 10 features eight nozzles with a diameter of 4.3-mm each. The IMPACT Sampler together with a battery operated pump form a compact, portable, and simple-to-operate particle sampling system known as the Deployable Particulate Sampler or DPS (Figure 5).

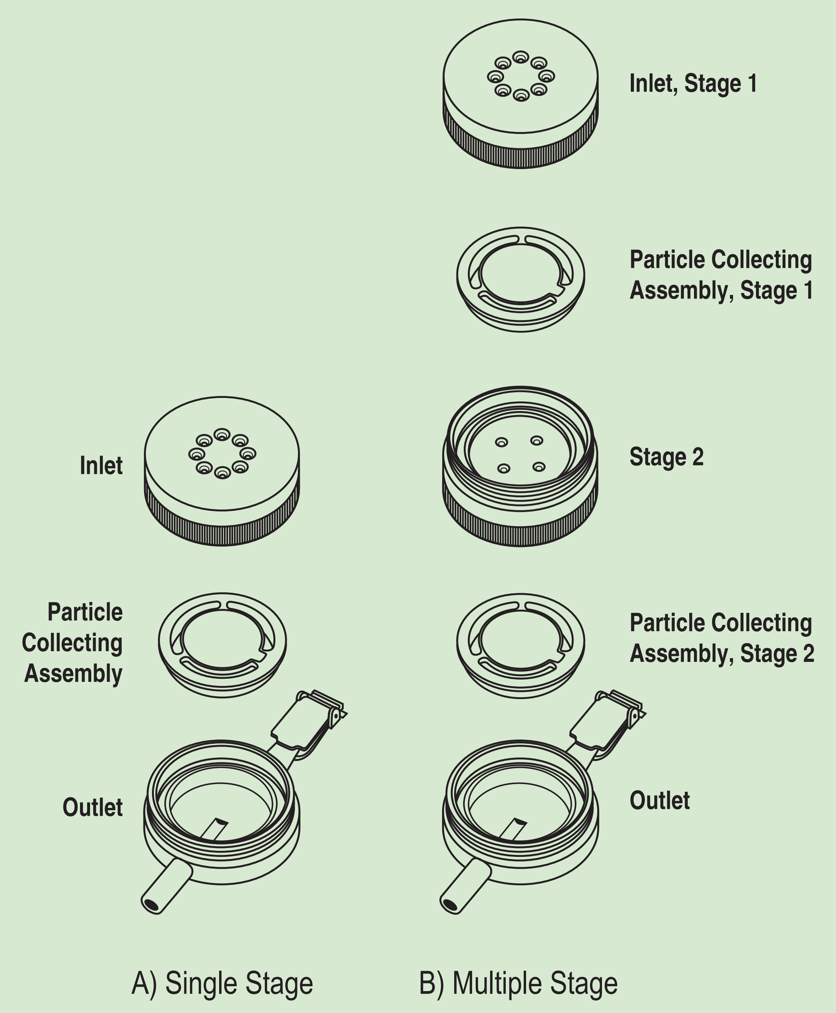

Figure 2. Modular impactor design

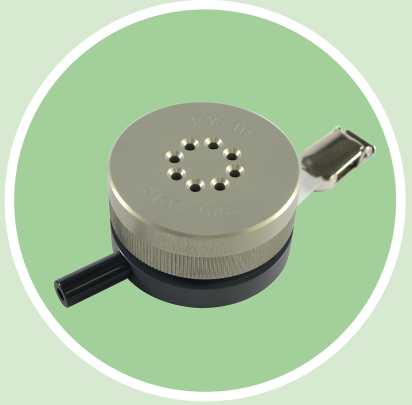

Figure 3. Personal Modular Impactor (PMI)

Figure 4. IMPACT Sampler

Figure 5. Deployable Particulate Sampler (DPS)

Test Methods

The newly developed impactors were calibrated in an aerosol test chamber (Figure 6) using an APS 3320 (TSI Inc.). Field tests included comparison of the 2-hour ambient PM10 concentration from a collocated DPS System (SKC Inc.), MiniVol Sampler (Airmetrics, Inc.), and FH 62 C14 Continuous Ambient PM Monitor (Thermo Andersen). Three series of field tests were performed in different geographical locations and ambient conditions.

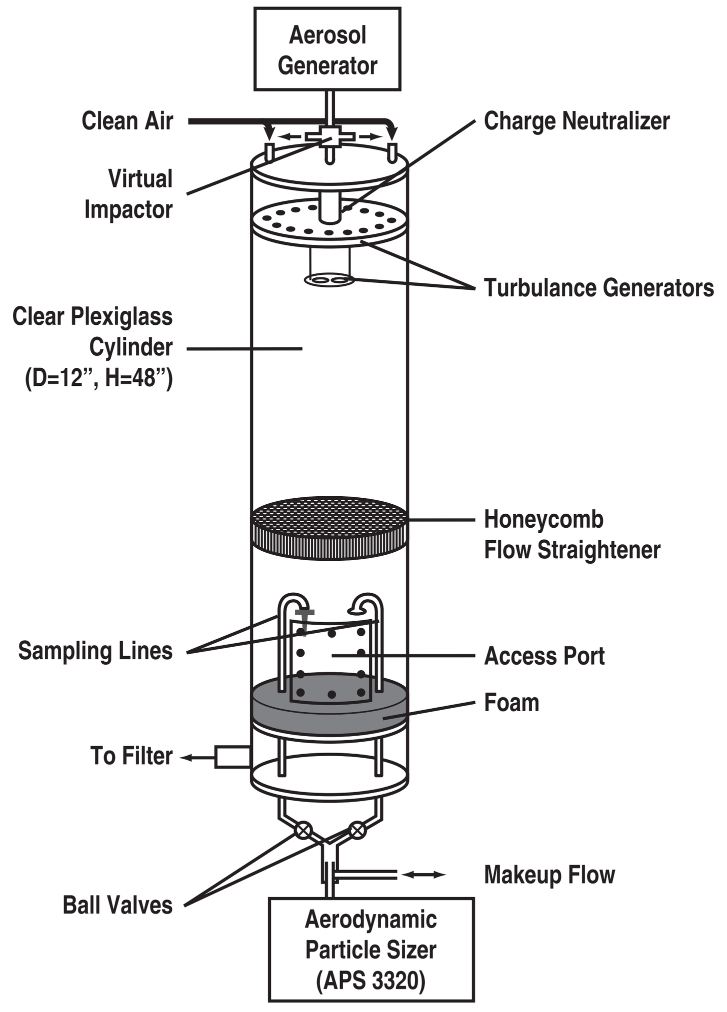

Figure 6. Schematic of aerosol test chamber

Performance of Newly Developed Modular Impactors

Figure 7 shows the sampling efficiency of the newly developed modular impactors measured in the test chamber. As shown, both PM2.5 samplers, 3.0 L/min and 10.0 L/min versions, follow closely EPA's PM2.5 curve. The sampling efficiency curves of the PM10 impactors are somewhat sharper than the PM10 curve defined by EPA. Nevertheless, side-by-side comparison of the IMPACT PM10 Sampler with the performance of a collocated MiniVol Sampler and FH 62 C14 Continuous Ambient PM Monitor show good agreement between data obtained with all of these samplers (Figure 8).

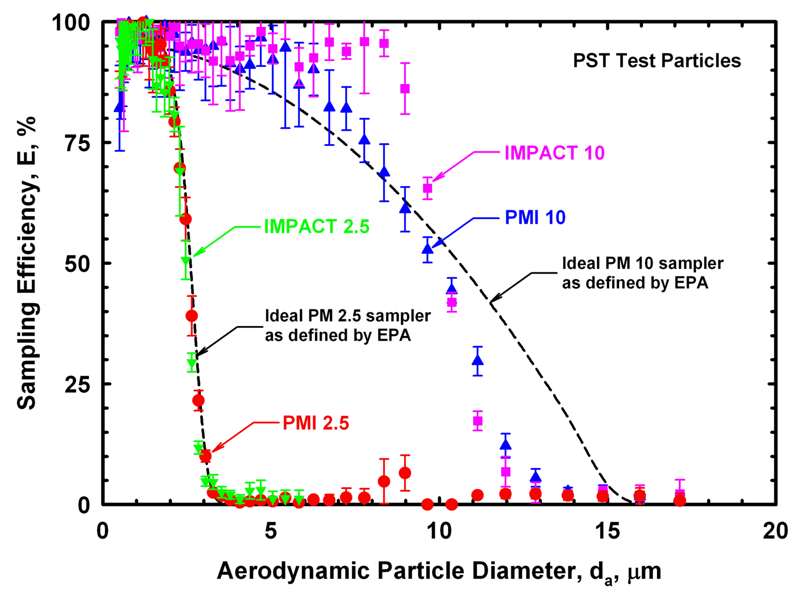

Figure 7. Sampling efficiency of new modular impactors

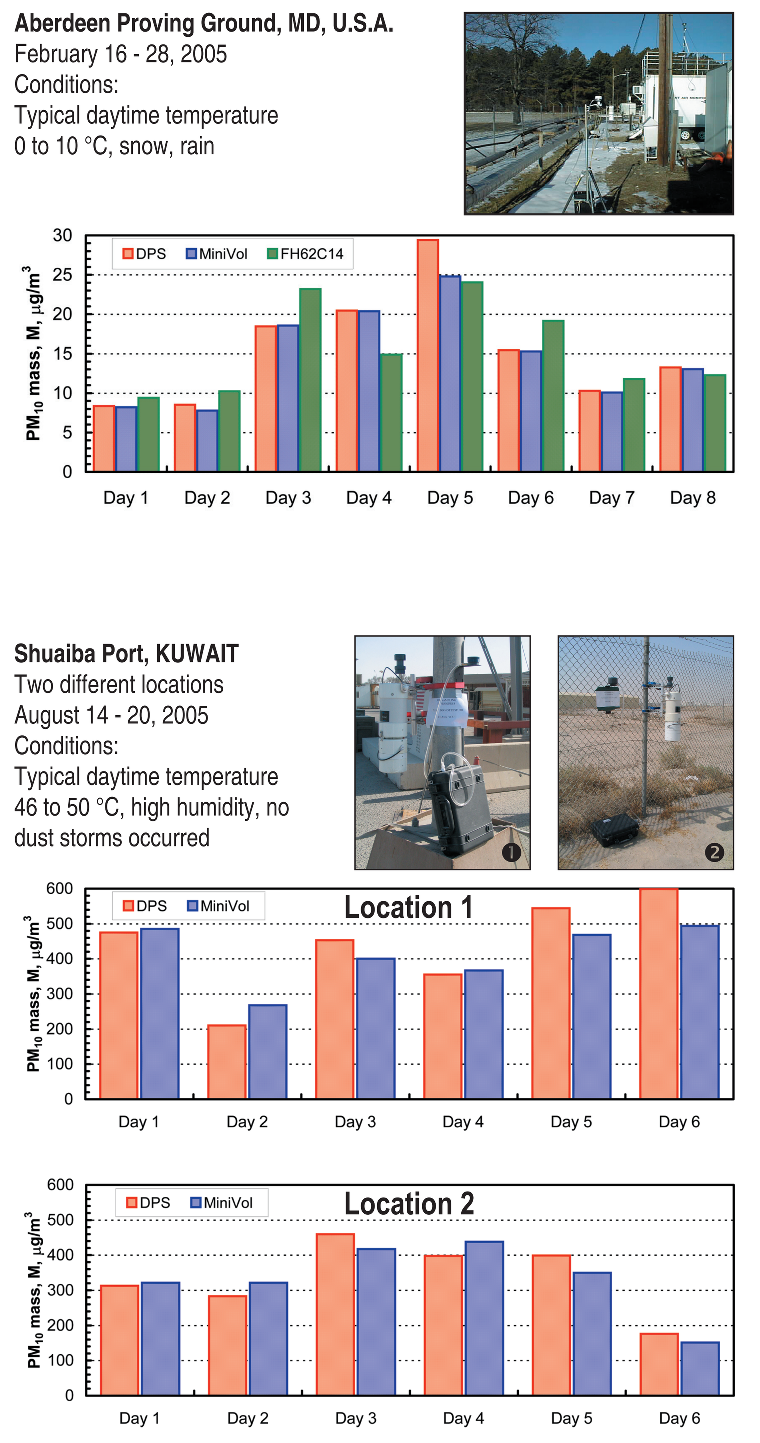

Figure 8. Comparison of IMPACT PM10 (in DPS System) with MiniVol Sampler and FH 62 C14 Monitor

Conclusion

A series of new inertial impactors were developed, manufactured, and tested. The modular design of the new impactors has been proven to provide an accurate, simple-to-operate, and economical solution for monitoring exposure to PM2.5, PM10, and PM Coarse.

Reference — Rader, D.J. and Marple, V.A. (1985). Effects of Ultra-Stokesian Drag and Particle Interception on Impaction Characteristics. *Aerosol Sci. Techno.* 4:141-156.