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Exploring a Novel Ultrafine Particle Counter for Utilization in Respiratory Protection Studies

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Abstract

In this study, a novel portable ultrafine particle counter developed at the University of Cincinnati was tested against a conventional condensation particle counter (CPC, TSI Inc.) for evaluating the efficiency of respiratory protection devices. The experiments were conducted with elastomeric respirators donned on a breathing manikin using combustion particles as challenge aerosols. A favorable agreement between the two data sets on the particle penetration efficiency was observed (slope ≈ 1.16, $R^2 \approx 0.99$; paired *t*-test: *p*-value = 0.91), suggesting that the new counter produced meaningful data comparable to a conventional CPC instrument.

Exposure to ultrafine (≤ 0.1 μm) particles is widespread at various workplaces. Several studies have revealed associations between ultrafine particle exposures and adverse health effects, including respiratory problems, impairment of cardiovascular function and others.[(1–3)]

Condensation particle counters (CPCs) are conventionally deployed to measure the ultrafine particle concentrations in real time. For example, the P-Trak (Model 3007, TSI Inc., St. Paul, MN) is the most commonly used CPC in occupational environments. However, commercially available CPCs are typically too bulky to serve as worker's personal exposure monitors; furthermore, their performance is generally affected by their orientation. Several attempts have been recently made to design a better instrument for real-time personal exposure assessment, including a novel ultrafine particle counter (prototype) developed at the University of Cincinnati (UC UFP counter, Figure 1).[(4,5)] The operation principle of this device, like any CPC, involves condensation on nuclei; however, the novelty of this instrument is that the condensation takes place on nano-materials entering through the input channel. After passing a PM filter (cyclone), the particles enter a non-wetting, porous, evaporation-condensation tube. Enlarged due to condensation growth, they are detected with an optical laser counter. Capillary force spontaneously generated on the surface of the non-wetting tube, prevents flooding regardless of orientation and movement. This makes the instrument particularly advantageous for field applications. Additionally, its time of response to a change in aerosol concentration is as low as approximately 0.3 seconds. The detection particle size range is 4.5 nm to >1.0 μm, which, in contrast to conventional CPCs, includes a low nano-scale. The present prototype of the UC UFP counter is portable; however, it is undergoing additional miniaturization to make the device wearable.

In this study, we examined the feasibility of using the UC UFP counter for measuring the aerosol particle penetration through an elastomeric half-mask respirator donned on a breathing manikin.[6,7] Elastomeric respirators are commonly used by firefighters and first responders. The UC UFP counter was tested against a TSI Model 3007 CPC operating side-by-side. Combustion particles (generated by burning wood, paper, or plastic) were utilized as challenge aerosols. Exposures to combustion aerosols at various workplace environments have been associated with adverse health outcomes.[2,3] More than 70% (by number) of particles in a fire-generated smoke are ultrafine.[8] The penetration values were obtained by measuring the aerosol concentrations inside and outside of the respirator. The sampled air flow was split with 0.3 L/min directed to the UC UFP counter and 0.7 L/min to the TSI CPC. The measurements were conducted for four respirator sealing conditions (unsealed, sealed at the nose area, sealed at chin and nose, fully sealed) and for three cyclic breathing flow rates (mean inspiratory flow = 30, 85, and 135 L/min) and one constant flow rate (30 L/min).

The data are presented in Figure 2. The particle penetration falls into a wide range of values: from ~0.01% to ~50%., which reflects a variety of the sealing and breathing conditions. A favorable agreement between the two data sets was observed (slope ≈ 1.16, $R^2 \approx 0.99$; paired *t*-test: *p*-value = 0.91), suggesting that the new counter produced meaningful data comparable to a conventional TSI CPC instrument and was capable of measuring in the above-mentioned wide range of parameters. We concluded that, once miniaturized to serve as a field compatible personal sampling device, the instrument can be successfully utilized for evaluating the performance of respirators directly at workplaces. Considering the data variability observed in this study (specifically two clusters at penetration levels around 0.1% and 1% as measured by the TSI CPC), a follow-up investigation is warranted to improve the sensitivity and stability of the UC UFP.

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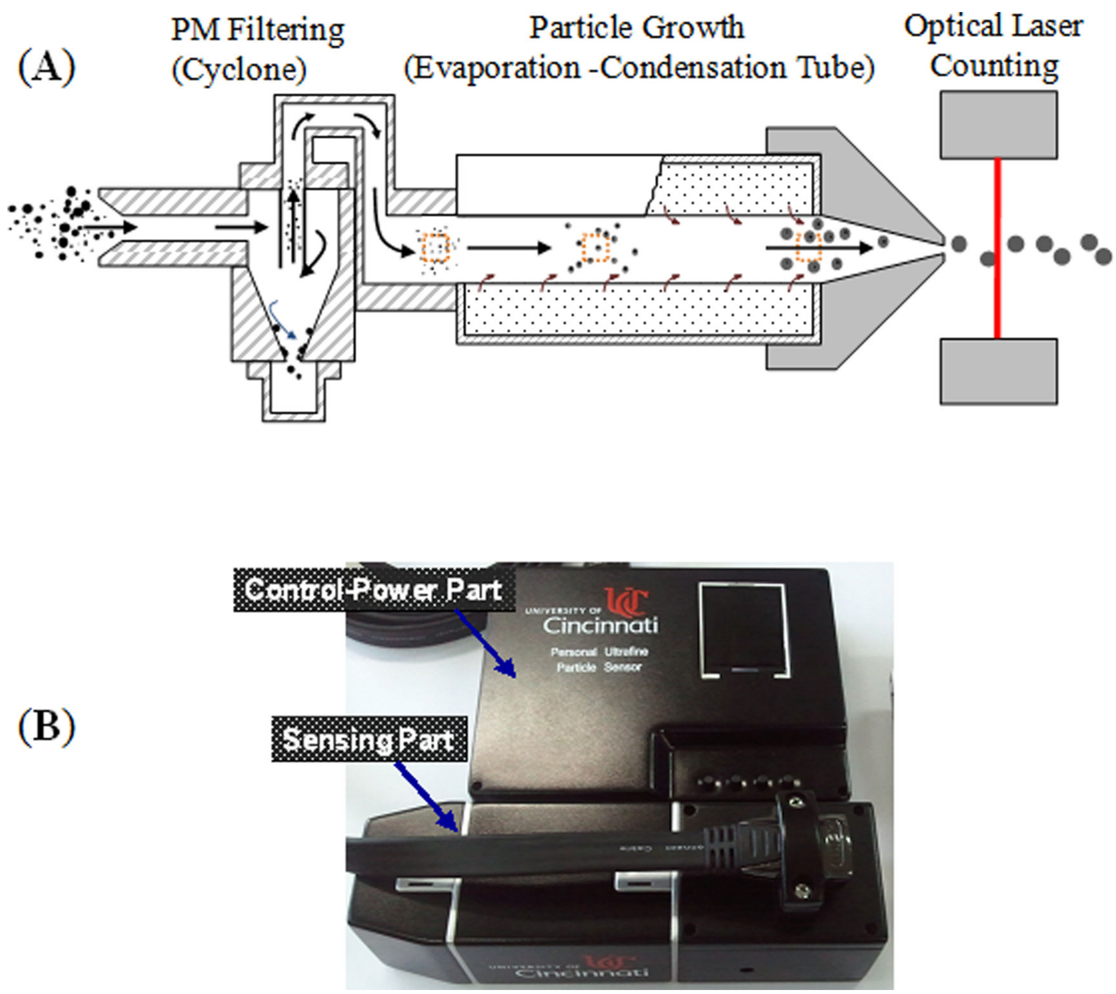

Figure 1:
The UC UFP counter: schematics of operation (A) and picture (B)

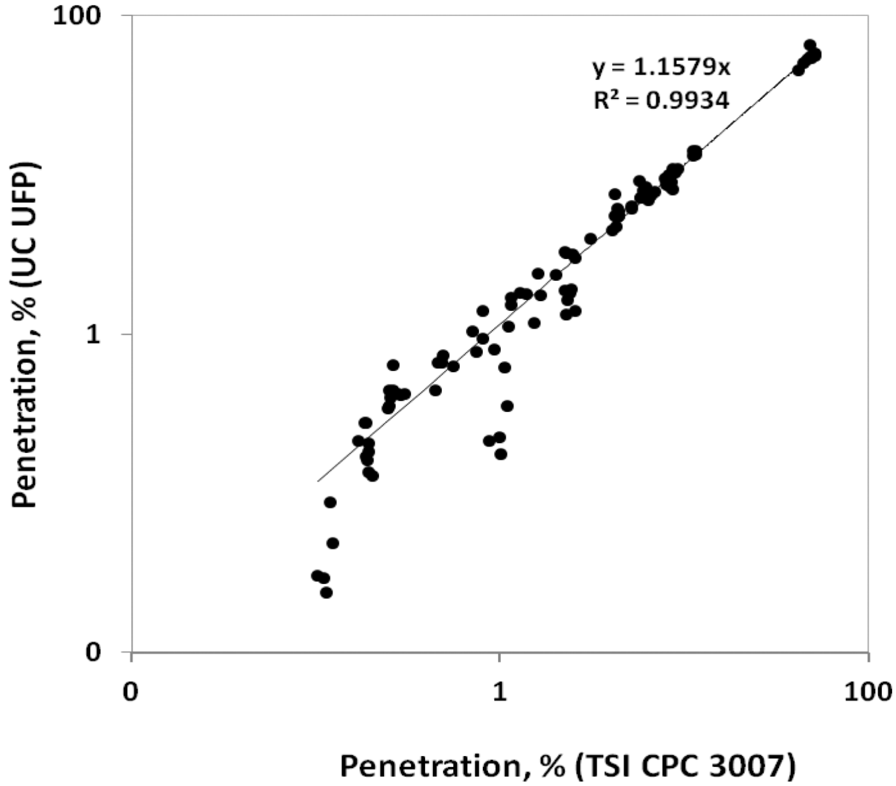

Figure 2:
The particle penetration values measured with the novel UC UFP counter versus the TSI CPC 3007