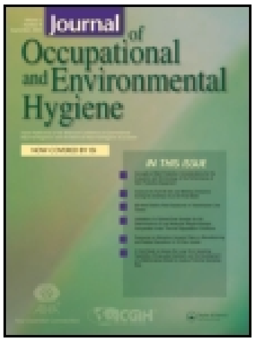

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Evaluation of IOM Personal Sampler at Different Flow Rates

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The Institute of Occupational Medicine (IOM) personal sampler is usually operated at a flow rate of 2.0 L/min, the rate at which it was designed and calibrated, for sampling the inhalable mass fraction of airborne particles in occupational environments. In an environment of low aerosol concentrations only small amounts of material are collected, and that may not be sufficient for analysis. Recently, a new sampling pump with a flow rate up to 15 L/min became available for personal samplers, with the potential of operating at higher flow rates. The flow rate of a Leland Legacy sampling pump, which operates at high flow rates, was evaluated and calibrated, and its maximum flow was found to be 10.6 L/min. IOM samplers were placed on a mannequin, and sampling was conducted in a large aerosol wind tunnel at wind speeds of 0.56 and 2.22 m/s. Monodisperse aerosols of oleic acid tagged with sodium fluorescein in the size range of 2 to 100 μm were used in the test. The IOM samplers were operated at flow rates of 2.0 and 10.6 L/min. Results showed that the IOM samplers mounted in the front of the mannequin had a higher sampling efficiency than those mounted at the side and back, regardless of the wind speed and flow rate. For the wind speed of 0.56 m/s, the direction-averaged (the average value of all orientations facing the wind direction) sampling efficiency of the samplers operated at 2.0 L/min was slightly higher than that of 10.6 L/min. For the wind speed of 2.22 m/s, the sampling efficiencies at both flow rates were similar for particles <60 μm. The results also show that the IOM's sampling efficiency at these two different flow rates follows the inhalable mass curve for particles in the size range of 2 to 20 μm. The test results indicate that the IOM sampler can be used at higher flow rates.

Keywords flow rate, IOM, personal sampler

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INTRODUCTION

The Institute of Occupational Medicine (IOM) personal sampler(1) is one of the most commonly used samplers to estimate the personal exposure of workers to airborne particles in the workplace. It is designed to collect inhalable particle matter (IPM) at a flow rate of 2 L/min. IPM, defined as the fraction of ambient airborne particles that are deposited in the respiratory tract, is one of three size-selective criteria.(2–4) It is used to assess the exposure to airborne particles that could cause damage anywhere in the human respiratory tract, including the nasal or oral region, regardless of sampler orientation with respect to wind direction.

The IOM sampler's performance in wind tunnel tests has shown that the sampling efficiency is a function of particle size, wind speed, and wind direction.(5–7) The sampling efficiency, in general, decreases as the wind speed increases.(6,7) In the wind speed range of 0.4 to 1.6 m/s, the IOM sampler's direction-averaged sampling efficiency follows closely with the IPM curve.(6,7) When comparing its sampling efficiency with other commercially available inhalable personal samplers under the same test conditions, the IOM sampler's performance emerged as the best reference instrument for collecting inhalable airborne particles.(8)

In a recent study, the IOM sampler was used to collect aerosols in an environment with low aerosol concentrations.(9) However, when it was operated at the designed flow rate of 2.0 L/min, sometimes it could not collect sufficient material for chemical analysis. New personal sampling pumps make it possible to operate a personal sampler at a rate up to 15 L/min, which increases the amount of material collected on the IOM sampler. To determine if the IOM sampler's performance at a higher sampling flow rate is similar to that of the designed flow rate, it was evaluated at a higher flow rate in a wind tunnel using a Leland Legacy sampling pump (SKC Inc., Eighty Four, Pa.). The sampling efficiency as a function of wind speed and flow rate was investigated.

MATERIALS AND METHODS

Wind Tunnel

All measurements were made in a wind tunnel inside a 4.3 × 3.7 × 3.6-meter test room.(10) The wind tunnel consists of an 11-meter-long circular duct with a diameter of 1.83 m; a stationary air blender (Blender Products, Inc. Denver, Colo.), which creates mixing; a flow straightener; a test chamber; and a blower (Figure 1).

Incoming air filtered by a high-efficiency particulate air (HEPA) filter is drawn from the specially designed test room into the open-loop flow and exhausted to the same room. The blower used for the wind tunnel (IAP, Inc., Phillips, Wis.) has a capacity of 1100 m^3/min at 1.25 kPa static pressure. The wind velocity in the wind tunnel can be adjusted from 0.5 to 8.0 m/s

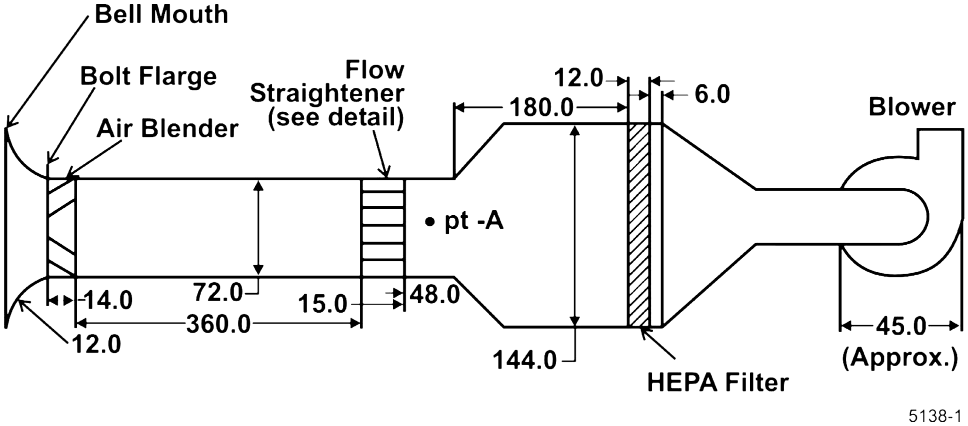

FIGURE 1. Schematic of wind tunnel with measurements in inches. Adapted from Figure 1 of Cheng et al.(10)

by changing the speed of the blower motor. The wind tunnel was calibrated according to U.S Environmental Protection Agency (EPA)(11) and American National Standards Institute (ANSI) standards.(12) The coefficient of variation (COV) of the wind speeds measured in the middle two-thirds of the test section was found to be less than 5% for all of those wind speeds within the range specified by the EPA and ANSI N13.1, i.e., 10% over the middle two-thirds of the cross-sectional area.

The uniformity of the aerosol concentration in the test section was measured using a 10-μm test aerosol. The COVs of the aerosol concentration were 7.5, 9.1, and 7.5% for wind speeds of 0.56, 2.2, and 6.6 m/s, respectively. The calibration details were described previously in Cheng et al.(10)

Test Aerosols

The vibrating orifice monodisperse aerosol generator (VOAG; model 3050; TSI, Inc., St. Paul, Minn.) was placed immediately outside the wind tunnel entrance. The air with monodisperse, sodium-fluorescein-tagged oleic acid aerosols generated by the VOAG traveled through the length of the wind tunnel and the flow straightener to dampen the turbulence before entering the test chamber. Particles in the size of 4 to 100 μm were used in the study. A pressurized tank was used as liquid feeding system instead of the syringe pump to provide a steady, continuous liquid of oleic acid/sodium fluorescein dissolved in ethanol to the generator.

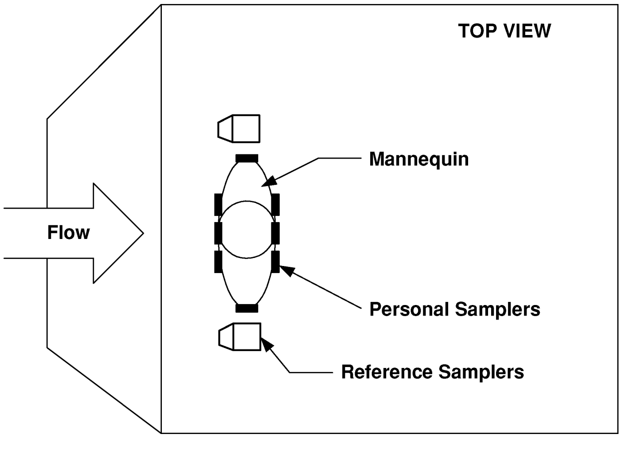

FIGURE 2. The position of mannequin, personal samplers, and reference samplers in the test chamber

The test aerosol size was determined by an aerodynamic particle sizer (APS, model 3310A; TSI Inc.) for particles smaller than 20 μm. Because the APS cannot measure particles larger than 20 μm, these particles were collected by impacting them on a glass slide coated with a fluorocarbon surfactant (Type K, 0.2%; William F. Nye Inc., New Bedford, Mass.). Their size was measured with an optical microscope (Olympus BH-2; Olympus Optical Co., Tokyo, Japan).

Personal Sampler

Eight IOM personal samplers were mounted on a full-size mannequin (170 cm) at a height of 150 cm. Three samplers were mounted at the chest of the mannequin, three on the back, and two at the sides (Figure 2), similar to the test configuration used in other studies of personal samplers.(5,13) Twenty-five-millimeter cellulose filters (Type 41; Whatman, Inc., Florham Park, N.J.) were used in the test. The sampler was operated at a flow rate of 2.0 L/min, and a high flow rate was obtained during the pump test with wind speeds of 0.56 and 2.22 m/s.

Pump Performance Test

Five Leland Legacy sampling pumps were randomly picked for the test. The pumps' flow rates with and without IOM filter load were tested with a Gilian Gilibrator (model 1860-B; Sensidyne, LP, Clearwater, Fla.) at high altitude in Albuquerque, New Mexico (0.82 atm), and at sea level in Corpus Christi, Texas. Five pumps were randomly picked for the test. Each flow rate given by the Gilibrator was an average of five readings. This test gave the actual flow rate as a function of the setting flow rate at different altitudes with the filter load.

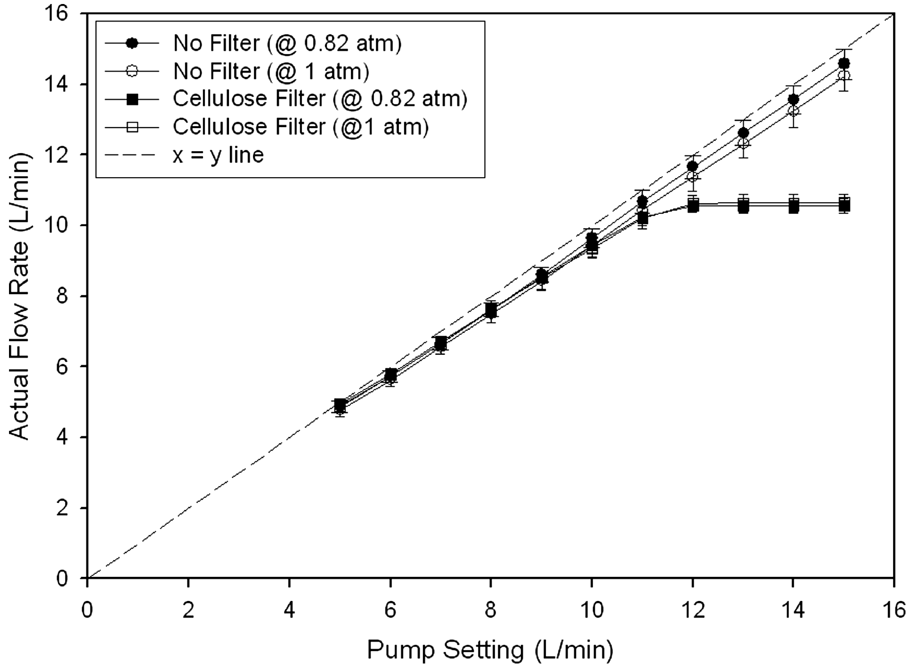

FIGURE 3. Actual flow rate as a function of setting flow rate at different altitudes with and without filters

Test Protocol

Two filter samplers with appropriate isokinetic inlets for velocities of 0.56 and 2.2 m/s were used as reference samplers to collect the aerosol concentration at the test section. The isokinetic samplers were located on each side of the mannequin and operated at a flow rate of 68 m^3/hr and controlled by a Venturi orifice downstream of the filter (model G10557PM10; Thermo Andersen, Smyrna, Ga.). The test aerosols were collected on a 20 × 25.4-cm glass fiber filter. After each test, the isokinetic nozzles were rinsed with a solution consisting of 50% isopropyl alcohol and 50% distilled water (v/v) to recover any analytical tracer from the internal walls. The filters from the reference samplers and IOM samplers were placed in the solution with 50% isopropyl alcohol and 50% distilled water (v/v) to elute the fluorescent tracer.

The concentration of fluorescent tracer in the solution was measured with a fluorometer (model 450; Sequoia-Turner Corp., Mountain View, Calif.). The fluorescent tracer

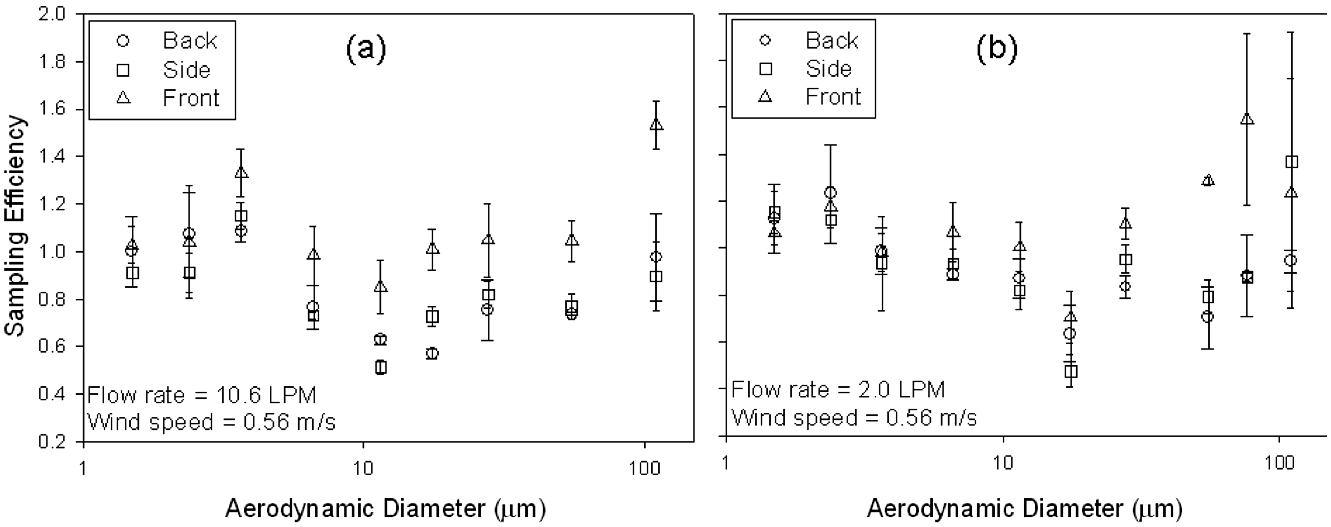

FIGURE 4. Personal sampler sampling efficiencies for 10.6 L/min (a) and 2.0 L/min (b) at the wind speed of 0.56 m/s as a function of particle size

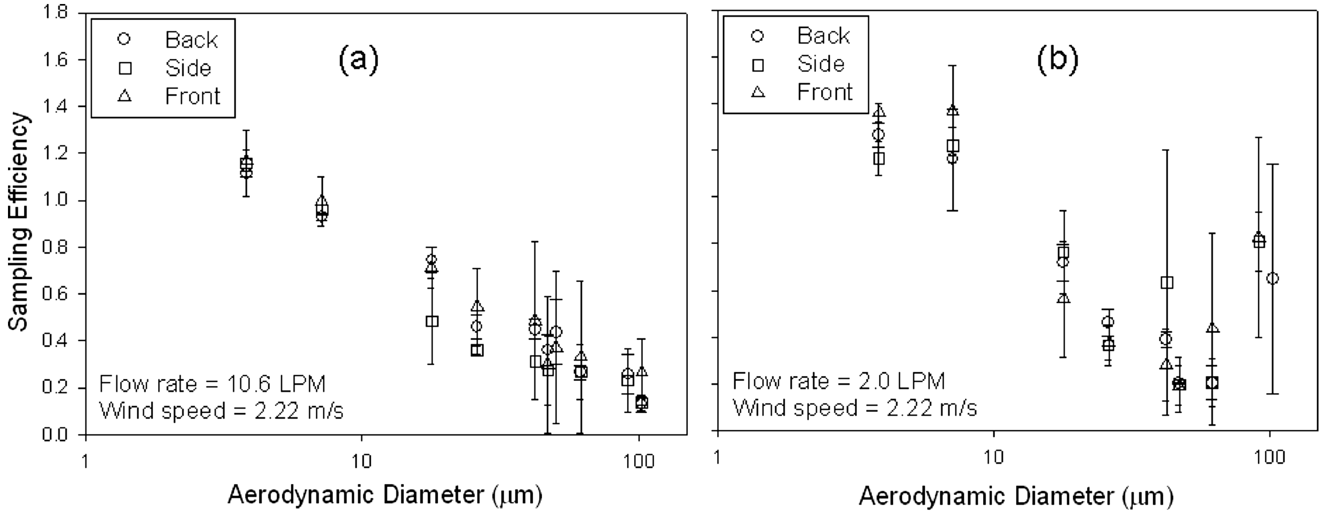

FIGURE 5. Personal sampler sampling efficiencies for 10.6 L/min (a) and 2.0 L/min (b) at the wind speed of 2.22 m/s as a function of particle size

concentration was calculated by taking the sampling flow rate, sampling time, and dilution factor into account. The sampling efficiency was obtained by dividing the fluorescent tracer concentration measured by the test sampler by the fluorescent tracer concentration measured by the reference sampler.

RESULTS AND DISCUSSION

Figure 3 shows the measured flow rate of the Leland Legacy pump at different atmospheric pressures. The measured flow rate of the pump agreed with the indicated flow rate without filter loading at all flow rate ranges and at the two altitudes. However, the actual flow rate reached a maximum level of 10.6 L/min at both atmospheric pressures when the pump was set to 11 L/min and higher with a cellulose filter loaded. This maximum flow rate of 10.6 L/min was used in the personal sampler performance test. It shows the Leland Legacy sampling pump's indicated flow rate is good only when there is a minimum pressure drop. The actual flow rate of the Leland Legacy pump is a function of the flow resistance of the sampling device and the collection substrate. The Leland Legacy pump must be flow calibrated when used with a different device and/or collection substrate.

The sampling efficiency as a function of particle size at a wind speed of 0.56 m/s is shown in Figure 4 for the flow rates of 2.0 L/min (Figure 4a) and 10.6 L/min (Figure 4b). Figure 4

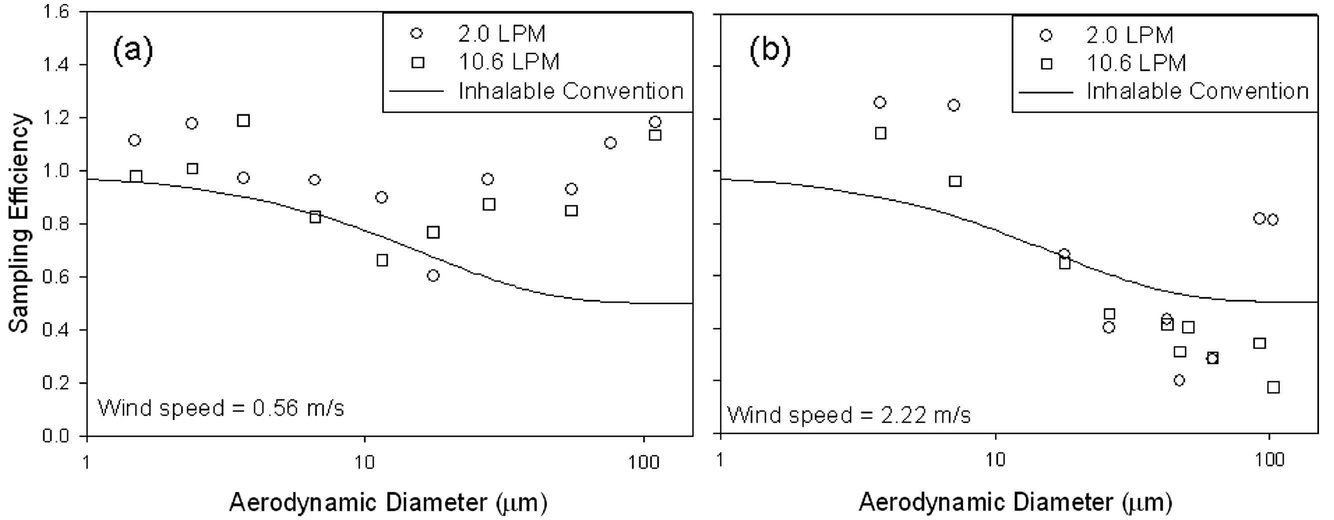

FIGURE 6. Comparison of two operating flow rates at the wind speed of 0.56 m/s (a) and 2.22 m/s (b) regardless of the sampler inlet orientation

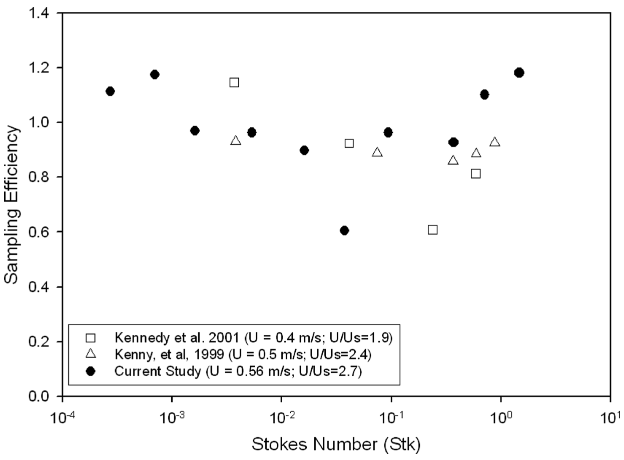

FIGURE 7. Personal sampler sampling efficiency compared with reported data as a function of Stokes number at low wind speed

also shows the sampling efficiencies with the sampler inlets positioned at 0°, 90°, and 180^o to the wind. During sampling, a flow stream has to bend around the mannequin to get into the samplers at the sides and back. However, the particles in the stream are not collected by the sampler because of inertia. Therefore, the sampling efficiency, especially for large particles, was higher when the sampler inlet faced directly into the wind. This result also agreed with other studies reported in the literature.(5,13–15)

Figure 5 shows similar information at the high wind speed of 2.22 m/s. Figure 5a shows that the sampling efficiency decreases as the aerodynamic particle size increases when the IOM sampler is operated at 10.6 L/min. Figure 5b shows a similar trend for the case of 2.0 L/min, except that for particle sizes between 90 and 100 μm the sampling efficiency increases, perhaps due to the subisokinetic condition. Again, in most cases, the sampling efficiency was higher when the sampler was worn on the front of the mannequin.

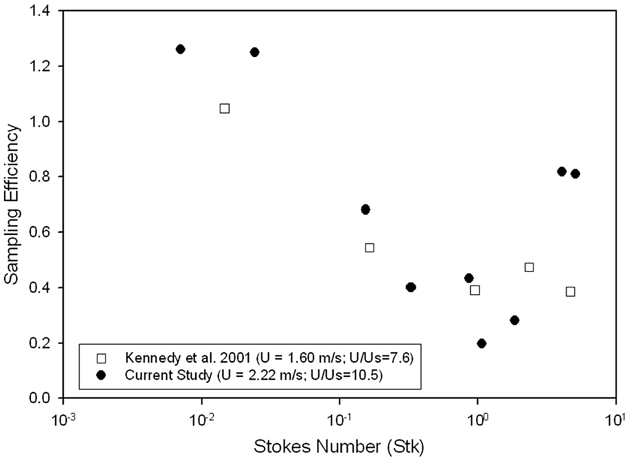

FIGURE 8. Personal sampler sampling efficiency compared with reported data as a function of Stokes number at high wind speed

Figure 6 compares the direction-averaged sampling efficiency of the IOM at two sampling flow rates. Figure 6a shows that the sampling efficiencies for both flow rates are similar at the wind speed of 0.56 m/s, but there is a slightly higher efficiency for the 2-L/min sampling flow rate as compared with that of 10.6 L/min. Figure 6b shows that at the wind speed of 2.22 m/s, sampling efficiencies for both flow rates are similar except for very large particles of 80 and 100 μm. These results indicate that the IOM sampler can be operated at the higher flow rate of 10.6 L/min and has a similar sampling efficiency as that obtained for the designed flow rate of 2 L/min.

The sampling efficiency can be described as a function of several dimensionless parameters, such as Stokes number (*Stk*), the ratio of free-stream velocity (U) to the velocity through the sampler orifice (U_s), and the ratio of sampler orifice width (δ) to sampler width (D).(16–18) Figures 7 and 8 compare the IOM sampling efficiencies reported in the literature.(6,13) All these data were obtained using mannequins in wind tunnels and were direction-averaged sampling efficiencies at a flow rate of 2 L/min. The sampling efficiency was plotted as a function of *Stk* defined as $d_{ae}^2 \gamma U/18\eta\delta$, where d_{ae} is the particle aerodynamic diameter, γ is the density of pure water, and η is the viscosity of air.(19)

Figure 7 shows the IOM efficiency as a function of *Stk* at a low wind speed between 0.4 to 0.56 m/s and U/U_s between 1.9 to 2.7. As shown in the figure, the sampling efficiency decreases to a minimum of approximately 0.6 at a *Stk* of 0.1 and then increases as the *Stk* increases. The results indicate that the sampling efficiency of a personal sampler is a complex phenomenon influenced by the inertial effects of the particle, the ratio of wind speed and sampling velocity, and flow pattern around the mannequin.(20) Two effects compete for the sampling efficiency. The inertial effects from increasing the particle size and wind speed result in increased sampling efficiency, whereas the flow pattern around the body tends to reduce it.(6,15) The combined test results shown in Figure 7 indicated that at a wind speed of approximately 0.5 m/s, the inertial effect of the particles is dominant, resulting in increased sampling efficiency for $Stk > 0.1$.

Figure 8 compares the current study with results reported in the literature at a high wind speed (between 1.6 to 2.2 m/s) and U/U_s between 7.6 to 10.5.(6) The sampling efficiency decreases to a low value between 0.2 and 0.3 at a *Stk* of approximately 1 and then increases as the *Stk* increases. This indicates that at a higher wind speed, the flow pattern effect (which reduces the sampling efficiency) is dominant at a higher *Stk* up to 1. Figures 7 and 8 also show that these test results for these two wind speeds are in good agreement with reported data obtained under similar conditions.

CONCLUSIONS

The data show that the Leland Legacy sampling pump's flow rate may not be accurate when the pump is used in conjunction with a filter or other sampler. Calibrating the flow rate when this sampling pump is connected to a sampler is critical. In this study, the IOM personal sampler was tested at a maximum flow rate of 10.6 L/min by varying the Leland Legacy sampling pump's orientation and testing it at two wind speeds. The sampling efficiencies at the 2-L/min flow rate also were compared. The sampling efficiency was affected by the sampler inlet's orientation in the wind and the wind speed. At a low wind speed of 0.56 m/s, the direction-averaged sampling efficiencies for both flow rates have a similar trend, but there is a slightly higher efficiency for the 2-L/min sampling flow rate as compared with that of 10.6 L/min. At the high wind speed of 2.2 m/s the sampling efficiencies for both flow rates are similar, except for very large particles of 80 and 100 μm.

Test results show that the IOM can be operated at the high sampling flow rate of 10.6 L/min, and that this sampling efficiency is similar to but slightly lower than that for the 2.0-L/min flow rate.

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