DEVELOPMENT OF A DICHOTOMOUS SLIT NOZZLE VIRTUAL IMPACTOR

Yiming Ding* and Petros Koutrakis

Department of Environmental Health, Harvard School of Public Health, 665 Huntington Ave., Boston, MA 02115, U.S.A

(Received 30 July 1999; revised and accepted 21 March 2000)

Abstract—A high-volume slit nozzle virtual impactor has been developed to collect fine and coarse particles. The size cut-off and particle loss characteristics of the developed slit virtual impactor agree well with those of the 16.7 l min⁻¹ commercially available dichotomous sampler. The effects of various flow and physical design parameters on the collection of both fine and coarse particles have been investigated. The results of these tests indicated that many of the theoretical principles established for round nozzle virtual impactors can be successfully applied to slit nozzle virtual impactors. However, the effects of the flow volume and Reynolds number (Re) on the cut-off behavior and particle losses are more pronounced for slit virtual impactors. The impactor’s particle size cutpoint decreased as the total inlet flow and Re increased. For Re < 7000, particle losses increased with particle size. For Re of about 7000, particle losses exhibited a maximum near the 50% cutpoint, which is typical in round nozzle virtual impactors. For Re > 7000, losses of fine particles were significant, while coarse particle losses were low. Changes in the minor-to-total flow ratio and collection slit width also affected particle losses.

INTRODUCTION

Human health effects associated with exposure to airborne particulate matter include increased mortality and respiratory and cardiovascular morbidity (Pope et al., 1995; Schwartz and Morris, 1995). Particles with aerodynamic diameter less than 10 μm (PM₁₀) can enter the respiratory system, and thus they can have an impact on respiratory health. Inhalable particles are usually classified into two categories: coarse (particle aerodynamic diameter between 2.5 and 10 μm) and fine (particle aerodynamic diameter ≤ 2.5 μm). Although recent epidemiological studies (Pope and Dockery, 1992, Pope et al., 1995; Dockery and Pope, 1994) have demonstrated strong associations between morbidity and mortality and PM₁₀, the relative contributions of the coarse and fine particle fractions to these effects is not currently understood. Therefore, it is expected that future toxicological and epidemiological studies will investigate the relative toxicity of fine and coarse particle fractions of PM₁₀ (NRC, 1998).

A number of sample collectors have been developed to classify particles according to their aerodynamic size. They include cyclones, centrifuges, and impactors (Chow, 1995). Among these techniques, round nozzle virtual impactors have been mostly used for particle collection because of their sharp cut-off characteristics and small internal particle losses. These virtual impactors have been extensively studied (Hassan et al., 1979; Marple and Chien, 1980). For example, the successfully developed dichotomous sampler (Loo and Cork, 1988) has been widely used in many field studies (Dzubay and Stevens, 1975; Lewis and Macias, 1980; Spengler and Thurston, 1983). This sampler has a flow rate of only 16.7 l min⁻¹. Although it is possible to increase the sampling flow by increasing the nozzle diameter, this can result in a dramatic increase in the pressure drop across the impactor. To overcome this problem, a multi-nozzle virtual impactor was developed by Marple et al. (1990). However, the use of multiple nozzles requires minimization of jet interaction and
strict nozzle alignment (Fang et al., 1991). Thus, if high sampling volumes are desired (e.g. 1000 l min\(^{-1}\)), a large number of nozzles are required, which can be costly.

The objective of the study is to design and evaluate a slit nozzle virtual impactor to separate the coarse and fine particle fractions of PM\(_{10}\). The inlet flow can be adjusted to any desirable flow rate. Although two-dimensional slit nozzle virtual impactors have been studied before (Ravenhall et al., 1978; Forney et al., 1982), these previously developed rectangular slit virtual nozzle impactors were not axisymmetric, and thus the steepness of the particle collection efficiency curve is not as good as that of round jets. In this paper we present the development of a slit nozzle virtual impactor with axisymmetric geometries that operates at a small pressure drop and exhibits a sharp cut-off efficiency curve with low particle losses.

METHODS

The slit virtual impactor

The slit nozzle virtual impactor is shown in Fig. 1. Sample air enters through the acceleration nozzle at a flow of \(Q_0\). Particles larger than the impactor size cutpoint have enough momentum to cross the air streamlines and enter the collection probe, whereas particles smaller than the cutpoint size make an almost 90° turn and follow the deflected streamlines into the major flow \((Q_M)\) channel. The separated large particles are kept airborne within a relatively small fraction of air flow \((Q_m/Q_0)\) which passes into the collection probe, constituting the minor flow \((Q_m)\).

The flow field in a virtual impactor is mainly determined by the Reynolds number

\[
Re = \frac{\rho W_a V_0}{\mu} = \frac{\rho Q_0}{\mu L},
\]

(1)

where \(\rho\) and \(\mu\) are the air density and dynamic viscosity, respectively, \(W_a\) is the acceleration slit width, \(V_0\) is the jet velocity, \(Q_0\) is the total inlet flow rate, and \(L\) is the slit length. Previous studies by Marple and Chien (1980) and Forney et al. (1982) have shown that particle losses in a virtual impactor are minimized for the Reynolds number in the range 500–1600. A slit virtual impactor can also be characterized using the Stokes number \((St)\) in the same way as a round jet virtual impactor. The Stokes number for slit virtual nozzle impactor can be defined as (Masuda and Nakasita, 1988)

\[
St = \frac{\rho C_d d_p^2 V_0}{9 \mu W_a} = \frac{\rho C_d d_p^2 Q_0}{9 \mu LW_a},
\]

(2)

![Fig. 1. Schematic of the slit virtual impactor.](image)
where $\rho_p$ is the particle density, $C_c$ is the slip correction factor, and $d_p$ is the particle diameter. $St$ is a dimensionless parameter and, for a given set of impactor parameters, the $St^{1/2}$ is a measure of the impactor particle size cut-off. Some theoretical studies have reported that the $St^{1/2}$ at the 50% cutpoint remains relatively constant over a wide range of operating conditions for a given virtual impactor configuration and for a given minor-to-total flow ratio (Marple and Chien, 1980; Ravenhall et al., 1982; Chen et al., 1986).

**Test apparatus**

The system used for generating coarse particles is shown in Fig. 2. Aqueous suspensions of 1% (by weight) hollow glass spheres (density of 1.1 g ml$^{-1}$ and nominal size distribution of 2–20 μm, Polysciences, Washington, PA) were aerosolized using a pocket nebulizer (Retec X-70/N) with filtered room air at a jet pressure of 7.5 psi. A relatively stable aerosol flow with both constant particle concentration and size distribution was achieved as follows: (a) an external reservoir containing 200–400 ml of the aqueous suspension of hollow glass spheres was continuously mixed with a magnetic stirrer; (b) the suspension was transferred (by gravity) through a narrow diameter pvc plastic tubing (with a high enough velocity to prevent settling of the particles onto the tubing wall) from the external reservoir.
to the nebulizer reservoir; (c) a steady flow of clean air was bubbled through the suspension in the nebulizer reservoir to achieve a good mixing; and (d) a fraction of the suspension in the nebulizer reservoir was continuously drained off (with slight vacuum) in order to keep the level in the nebulizer reservoir constant (this also minimized the effects of water evaporation, which normally would increase the concentration of suspended particles with time).

The flow of particles coming out of the nebulizer was about 3 l min$^{-1}$. A plastic bottle (300 ml) was placed after the nebulizer to trap large liquid droplets. Subsequently, the nebulized aerosol was mixed with filtered room air at the top of a rectangular duct which was placed upstream of the inlet to the slit nozzle virtual impactor. The duct (internal dimensions 6 × 20 × 120 cm) was used to mix the aerosol with filtered air and to achieve laminar flow before the aerosol was introduced into the test system (Fig. 2). Both the minor flow and major flow of the slit nozzle virtual impactor were connected to pumps with mass flowmeters in-line to monitor the flow rates.

The particle number concentration as a function of particle size was measured using an isokinetic probe with a flow of 5 l min$^{-1}$ connected to an Aerodynamic Particle Sizer (APS, TSI Model 3310). The probe was alternately attached to the duct (upstream), the minor flow, and the major flow, with at least two tests at each point for each experiment. The pressure drop in both the minor and major channels was monitored using Magnehelic gauges.

The particle collection efficiency of the slit nozzle virtual impactor for each size fraction was calculated as the ratio of the number concentration of particles in the minor flow to the sum of the particle number concentrations in the major and minor flows. The internal particle loss of the system for each size fraction, $\text{PM}_{\text{loss}}$, was determined by comparing the particle number concentration measured in major and minor flows with that measured in duct flow:

$$\text{PM}_{\text{loss}} = \frac{C_m Q_m + C_M Q_M}{C_D Q_0} \times 100\%,$$

where $C_D$, $C_m$, and $C_M$ are particle number concentrations determined by the APS in the duct, minor, and major flow, respectively, and $Q_0$, $Q_m$, and $Q_M$ are the total flow, minor flow, and major flow, respectively.

RESULTS AND DISCUSSION

The virtual impactor performance depends on the flow parameters, such as the Reynolds number (Re) and minor-to-total flow ratio ($Q_m/Q_0$ or $r$), and on the physical design parameters, such as $W_c/W_a$ and $S/W_a$ ratios (see Fig. 1: $W_a$ is the acceleration slit width, $W_c$ is the collection slit width; and $S$ is the distance between the acceleration and collection slits). To evaluate the effects of different parameters on the performance of the impactor, a basic configuration with a specific design was tested initially. Subsequent impactor performance tests were conducted by changing one parameter at a time.

Basic configuration

The basic configuration had an acceleration slit width ($W_a$) of 0.305 cm, the same as the jet diameter of the commercially available dichotomous impactor (Loo and Cork, 1988). The acceleration slit depth ($l$, Fig. 1a) was 0.330 cm, and the slit width of the collection probe ($W_c$) was 0.427 cm. Both the acceleration and collection slits had a length ($L$) of 0.762 cm. The gap ($S$) between the two slit nozzles was 0.457 cm (1.5 times $W_a$). The total flow was 50 l min$^{-1}$ with a minor-to-total flow ratio of 10%, similar to that of the dichotomous sampler. The corresponding major flow pressure drop across the slit nozzle virtual impactor was 4.1 inch of water or 1.02 KPa, a value very close to that of the dichotomous sampler (4.4 in of water). The minor flow pressure drop was 0.01 KPa (0.03 in of water).
Figure 3 shows the particle collection efficiency and the internal particle loss as a function of particle size. For comparison, the performance of the 16.71 min⁻¹ dichotomous sampler is also shown in solid lines. The results for the two samplers are in excellent agreement, which is expected since the two samplers have similar Reynolds numbers (approximately 7500), Stokes numbers, and major flow pressure drop values. This suggests that the theoretical principles established for round jet virtual impactors are applicable to slit nozzle virtual impactors. As expected, losses of the slit nozzle virtual impactor are the greatest for particle sizes near the cutpoint (about 23% for 2.5 μm particles) and decrease rapidly for both smaller and larger particles. Considering that typical ambient particles have a bimodal size distribution with a minimum occurring between 2.0 and 3.0 μm, only a small fraction of the total particle mass would be lost for ambient applications. For example, according to Marple et al. (1990), the high-volume virtual impactor (HVVI) with 37% particle losses near its cutpoint size had an integrated fine particle losses of less than 1%. Note, however, that the particle losses for the dichotomous sampler (Fig. 3) showed increases for particles larger than 6 μm. The slit nozzle virtual impactor showed a similar pattern, but for particles above 9 μm.

**Effect of Reynolds number**

The effect of Reynolds number (Re) on the impactor performance was investigated. The design parameters were the same as for the basic configuration, and the minor-to-total flow ratio (r) was kept at 10%. As shown in Table 1, five different total flow rates (Q₀) were tested: 10, 30, 50, 80, and 100 l min⁻¹ with corresponding Re values of 1500, 4400, 7300, 12000, and 15000, respectively. The collection efficiency curves and particle losses for the different Re values are shown in Figs. 4 and 5, respectively.

The collection efficiency curves become steeper and the cutpoint size decreases as Re increases. The effect of Re value on the cut-off characteristics is more significant than that predicted by theoretical studies. A previous computer modeling study (Marple and Chien, 1980) indicated that the collection efficiency curves were almost identical for various Reynolds numbers (Re = 1-15 000), while greater slopes of the penetration flow streamlines were demonstrated for larger Re values. The increased particle collection efficiency at a higher Re value may be a direct consequence of the decrease in particle size cutpoint. The size cutpoint decreases from 5.8 μm at Re = 1500 to 1.8 μm at Re = 15 000. However, the
Table 1. Summary of the parametric tests

<table>
<thead>
<tr>
<th>$W_x$ (cm)</th>
<th>$W_z$ (cm)</th>
<th>$L$ (cm)</th>
<th>$Q_0$ (l min$^{-1}$)</th>
<th>$r$ (%)</th>
<th>$Re$</th>
<th>$\Delta P_{\text{Major}}$ (KPa)</th>
<th>$\Delta P_{\text{Minor}}$ (KPa)</th>
<th>$d_p$ ($\mu$m)</th>
<th>$St^{1/2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.305</td>
<td>0.427</td>
<td>0.762</td>
<td>10</td>
<td>10</td>
<td>1500</td>
<td>0.04</td>
<td>0.00</td>
<td>5.8</td>
<td>0.69</td>
</tr>
<tr>
<td>0.305</td>
<td>0.427</td>
<td>0.762</td>
<td>30</td>
<td>10</td>
<td>4400</td>
<td>0.35</td>
<td>0.00</td>
<td>3.5</td>
<td>0.71</td>
</tr>
<tr>
<td>0.305</td>
<td>0.427</td>
<td>0.762</td>
<td>50</td>
<td>10</td>
<td>7300</td>
<td>1.02</td>
<td>0.01</td>
<td>2.5</td>
<td>0.68</td>
</tr>
<tr>
<td>0.305</td>
<td>0.427</td>
<td>0.762</td>
<td>80</td>
<td>10</td>
<td>12,000</td>
<td>2.74</td>
<td>0.01</td>
<td>2.1</td>
<td>0.70</td>
</tr>
<tr>
<td>0.305</td>
<td>0.427</td>
<td>0.762</td>
<td>100</td>
<td>10</td>
<td>15,000</td>
<td>4.11</td>
<td>0.02</td>
<td>1.8</td>
<td>0.68</td>
</tr>
<tr>
<td>0.305</td>
<td>0.427</td>
<td>0.762</td>
<td>50</td>
<td>5</td>
<td>7300</td>
<td>1.02</td>
<td>0.00</td>
<td>3.1</td>
<td>0.81</td>
</tr>
<tr>
<td>0.305</td>
<td>0.427</td>
<td>0.762</td>
<td>50</td>
<td>15</td>
<td>7300</td>
<td>1.02</td>
<td>0.01</td>
<td>2.2</td>
<td>0.58</td>
</tr>
<tr>
<td>0.305</td>
<td>0.427</td>
<td>0.762</td>
<td>50</td>
<td>20</td>
<td>7300</td>
<td>1.02</td>
<td>0.02</td>
<td>1.8</td>
<td>0.47</td>
</tr>
<tr>
<td>0.305</td>
<td>0.356</td>
<td>0.762</td>
<td>50</td>
<td>5</td>
<td>7300</td>
<td>1.02</td>
<td>0.00</td>
<td>3.1</td>
<td>0.81</td>
</tr>
<tr>
<td>0.305</td>
<td>0.356</td>
<td>0.762</td>
<td>50</td>
<td>7</td>
<td>7300</td>
<td>1.02</td>
<td>0.01</td>
<td>2.8</td>
<td>0.73</td>
</tr>
<tr>
<td>0.305</td>
<td>0.356</td>
<td>0.762</td>
<td>50</td>
<td>10</td>
<td>7300</td>
<td>1.02</td>
<td>0.01</td>
<td>2.5</td>
<td>0.68</td>
</tr>
<tr>
<td>0.305</td>
<td>0.356</td>
<td>0.762</td>
<td>50</td>
<td>12</td>
<td>7300</td>
<td>1.02</td>
<td>0.34</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>0.305</td>
<td>0.508</td>
<td>0.762</td>
<td>50</td>
<td>10</td>
<td>7300</td>
<td>1.02</td>
<td>0.39</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* Non-applicable, there is no detectable particle separation due to turbulence.

Fig. 4. Effect of Re on the collection efficiency of the slit virtual impactor.

St$^{1/2}$ value does not change significantly and remains in a narrow range of 0.68–0.71 (see Table 1). This is in agreement with results observed for round jet virtual impactors (Loo and Cork, 1988). Sioutas et al. (1994a) reported a relatively smaller St$^{1/2}$ value for a low cutpoint slit nozzle virtual impactor (ranging from 0.48 to 0.55).

Figure 5 shows the relationship between particle losses and Reynolds number (Re). To simplify the discussion, we examine particle losses in two size ranges: (a) below 2.5 $\mu$m (fine particles) and (b) above 2.5 $\mu$m (coarse particles). In the region below 2.5 $\mu$m, particle losses are low for Re values below 5000, while for higher Re values losses are considerably higher. The particle loss curve for Re = 15000 does not even exhibit the typical maximum in the cutpoint range (1.8 $\mu$m). Examination of the impactor components following testing showed that fine particles were primarily lost on the backside of the acceleration slit and on the walls of the cavity chamber in the major flow. This is expected since an increase in Re will cause an increase in flow instability and generate turbulence around the acceleration nozzle and inside the major flow channel. Such flow instabilities and particle losses in the gap between the acceleration and collection slits at high Re numbers were observed previously (Masuda and Nakasita, 1988; Loo and Cork, 1988). The sharp increase of fine particle losses in the major flow explains why the collection efficiency curves show a small bump in the fine particle range for Re values greater than 10000, as illustrated in Fig. 4.
Above 2.5 μm, the coarse particle losses are higher for low Re values. For Re = 4400, while the particle loss curve in Fig. 5 exhibits a small peak near the cutpoint (3.5 μm), the particle losses are much higher for particles above 5 μm. For Re = 1500, the internal losses of coarse particles are high and increase steadily in the size range from 1.5 to 7 μm without exhibiting a maximum near the cutpoint (5.8 μm). Previous studies of slit nozzle virtual impactors have also demonstrated a steady increase of particle losses without showing a maximum near the cutpoint for Re values under 3000 (Forney et al., 1982; Sioutas et al., 1994a,b). Examination of the impactor components following testing showed that coarse particle losses were mostly observed on the walls of the collection probe and the receiving tubing directly after the collection probe. It is of interest to note that coarse particle losses are totally eliminated at a higher Re (total flow above 80 L min⁻¹). At a higher jet velocity, coarse particles can penetrate deeper into the collection probe without reattaching to the side walls of the collection probe and the receiving tubing.

Effect of minor-to-total flow ratio (r)

Using the basic configuration, the slit nozzle virtual impactor was tested at a total flow of 50 L min⁻¹ for four different r values: 5, 10, 15, and 20%. Figures 6 and 7 show the collection efficiency and particle loss results, respectively. As expected, the efficiency curves become less steep and the size cutpoint decreases from 3.1 to 1.8 μm as the r value increases from 5 to 20%. Unlike the effect of increasing Re, the increase of r leads to a decrease in the 50% cutpoint St¹/² (see Table 1), mainly due to the higher contamination of the minor flow by fine particles at higher ratios. Since the minimum collection efficiency of any particle size is equal to the minor-to-total flow ratio, r, the collection efficiency curves in Fig. 6 do not reach zero for particles below the cutpoint. Fig. 7 suggests that particle losses near the cutpoint increase as the r value decreases. Furthermore, a high minor-to-total flow ratio causes a rapid increase in coarse particle losses near 10 μm, possibly due to the induced turbulence in the collection probe.

Effect of Wc/Wa

In addition to the basic configuration (Wc = 0.305 cm and Wc/Wa = 1.4), two other collection slits were also built with Wc values of 0.356 and 0.508 cm, with Wc/Wa ratios of 1.2 and 1.7, respectively. The value of S was kept the same and the total flow was
maintained at 50 l min⁻¹ for all tests. For the lower \( W_c/W_a \) ratio, the slit nozzle virtual impactor was tested under four minor-to-total flow ratios: 5, 7, 10, and 20%. The most striking result of decreasing the collection slit width is the dramatic increase in particle losses as shown in Fig. 8 as compared to the basic configuration in Fig. 7. A smaller collection slit seems to especially have problems with coarse particle collection at a higher minor-to-total flow ratio. As the minor-to-total flow ratio increases, the coarse particle losses continue to increase. When \( r \) reaches 12%, the increased minor flow causes strong turbulence in the slit nozzle virtual impactor and particle losses leap up for all particle sizes.
Fig. 8. Effect of $Q_m/Q_0$ ($r$) on the particle losses of the slit virtual impactor with $W_e/W_s = 1.2$ and $Q_0 = 50 \text{ l min}^{-1}$.

Fig. 9. Effect of $W_e/W_s$ on the particle losses of the slit virtual impactor at a total flow of $50 \text{ l min}^{-1}$.

Figure 9 directly shows the effect of different collection probe size ($W_e$) on particle losses at a 10% minor-to-total flow ratio and a total flow rate of 50 l min$^{-1}$. The basic configuration ($W_e/W_s = 1.4$) exhibits the lowest particle losses. As described above, a smaller collection slit causes increased coarse particle losses while the fine particle losses are similar to those of the basic configuration. However, a larger collection slit ($W_e/W_s = 1.7$) has much higher particle losses for a wide range of particle sizes. This is because the enlarged...
collection slit provides sufficient space for many streamlines to make an almost complete U-turn, which results in significant losses on both the collection probe and the backside of the acceleration slit (Loo and Cork, 1988). Previous flow visualization experiments for slit nozzle virtual impactors (Forney et al., 1982; Masuda and Nakasita, 1988) have also demonstrated the formation of turbulent eddies in a large collection probe. The flow instabilities are caused by the reduction of the flow velocity and the abrupt pressure recovery in the enlarged collection probe. Therefore, the optimum $W_c/W_s$ ratio should be close to that of the original basic configuration, about 1.4.

Optimization of major and minor flow pressure drops

The pressure drop across the virtual impactor is an important factor to be considered in designing a virtual impactor. According to Bernoulli’s equation (Marple et al., 1990), the pressure drop across a nozzle is proportional to the square of the average velocity in the nozzle ($V_0^2$). As a result, the major flow pressure drop of a given slit nozzle virtual impactor is determined by the inlet flow,

$$\Delta P_{\text{Major}} \propto Q_0^2.$$  \hfill (4)

A similar relationship was found for our experiment. Table 1 shows the $\Delta P_{\text{Major}}$ results for different values of $Q_0$. The major flow pressure drop of the slit nozzle virtual impactor ($W_s = 0.305$ cm) is generally low; the $\Delta P_{\text{Major}}$ is only 16.5 in of water or 4.11 kPa for even the highest flow tested ($Q_0 = 100$ l min$^{-1}$). As shown in Fig. 5, a higher inlet flow ($Q_0$) and, therefore, a higher $\Delta P_{\text{Major}}$ led to higher losses of fine particles due to an increased Reynolds number. But the losses of coarse particles were reduced at higher $Q_0$ values because coarse particles may gain more momentum and penetrate deeper into the collection probe under a higher major flow pressure drop.

Table 1 indicates that for the basic impactor configuration, $W_c = 0.427$ cm and $W_c/W_s = 1.4$, the minor flow pressure drop of the slit nozzle virtual impactor is extremely small (0.00 to 0.02 kPa). The minor flow pressure drop increases slightly as the total inlet flow and the minor-to-total flow ratio increase.

On the other hand, a larger collection slit ($W_c = 0.508$ and $W_c/W_s = 1.7$) does not decrease the minor flow pressure drop either even though the total flow rate is kept the same ($Q_0 = 50$ l min$^{-1}$). Surprisingly, a much higher minor flow pressure drop (0.59 kPa, Table 1) was observed for $r = 10\%$. The increased minor flow pressure drop may be ascribed to the occurrence of pressure recovery in the collection probe as the space in the collection probe is large enough for flow reversal to occur.

CONCLUSIONS

A dichotomous slit nozzle virtual impactor has been developed and evaluated for fine and coarse particle collection. The performance of a rectangular nozzle can be quite similar to that of a round nozzle. For a slit length of 0.762 cm, the developed impactor operates at a flow rate approximately three times that of the dichotomous sampler. Both the Re number and minor-to-total flow ratio ($r$) influence the particle size cutpoint and collection efficiency curve, but only $r$ affects the 50% cut-off St$^{1/2}$ value. The effect of Re on particle losses is significant. For the separation of coarse and fine particle fractions, an intermediate value of Re (about 7000) should be chosen to minimize both fine and coarse particle losses. However, if only collection of coarse particles is of interest, a higher Re value with a higher major
pressure drop should be selected to reduce coarse particle losses. Increasing the minor-to-total flow ratio decreases the particle losses near the impactor cutpoint.

The width of the collection slit is an important parameter that can affect the performance of a slit nozzle virtual impactor. If the collection slit is too wide \( (W_c/W_a = 1.7) \), turbulence in the collection probe can take place due to flow reversal and pressure recovery. In contrast, if the collection slit is too narrow \( (W_c/W_a = 1.2) \), especially with a large \( r \) value, the particle losses above the impactor cutpoint can be substantial. Furthermore, for the narrow collection slit, there is an upper limit for the minor-to-minor flow ratio. As \( r \) increases slightly above 10%, the turbulence in the minor flow can cause an abrupt increase in both the minor flow pressure drop and the overall particle losses.

Acknowledgements—Appreciation is given to Stephen T. Ferguson and Mike Wolfson of the Harvard School of Public Health. The development of the slit nozzle virtual impactor was supported by EPRI under contract WO3253-06. Also funding was provided by the EPA/Harvard Center on Ambient Particle Health Effects (Grant # R827353-01-0).

REFERENCES


