Brechtel Manufacturing Incorporated

Model 8100 Pumped Counterflow Virtual Impactor Manual

Version 2.0

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1 Introduction

This manual includes technical information describing the BMI Model 8100 Pumped Counterflow Virtual Impactor (PCVI). The purpose of the impactor is to separate and concentrate particles larger than a certain size, termed the cut size, from smaller particles within an air sample flow. The original design of the PCVI was based on the work by Boulter et. al., *Aerosol Science and Technology*, 40:969-976, 2006. The BMI Model 8100 PCVI has been designed and manufactured for nominal 50% cut size aerodynamic diameters (D50) between about 0.3 and 3 μm , and input air sample flow rates between 6 and 17 lpm. Concentration factors between 5 and 20 have been realized in the PCVI. The 50% cut size corresponds to the particle size where one-half of the particles are collected into the receiving orifice of the sample outlet flow while the remaining particles pass radially outward through the PCVI body. Particles smaller than the cut size are removed with an efficiency exceeding 99.9%. The cut-size of the impactor depends on the particle Stokes number, which depends on the air velocity through the inlet nozzle, the square of the particle diameter, particle density, the viscosity of air, the diameter of the jet, and the Cunningham slip correction factor. Through the pressure and temperature dependence of the air viscosity and the Cunningham slip correction, the cut-size depends on the pressure and temperature operating conditions of the impactor.

In 2011, BMI redesigned the PCVI based on new work published by Kulkarni et al., *Aerosol Science and Technology*, 45:382-392, 2011. The throat length of the nozzle was increased to permit improved velocity profile development and the lead-in angle to the reduced throat diameter was decreased to reduce particle impaction and improve flow development. BMI also implemented a gradual diameter increase on the outlet flow channel to avoid sharp steps that would produce eddies and subsequent particle impaction. Another significant improvement implemented in 2011 was a counter-clockwise oriented pumped flow profile to reduce particle deposition in the pumped flow region. This design improvement was suggested by G. Kulkarni (personal communication) based on fluid modeling. The original angled mating surfaces were replaced by a guide pin alignment design to facilitate more repeatable, high-precision alignment.

This manual should be read in its entirety. It is important that items shown in BOLDFACE are understood - they describe key user responsibilities when operating the instrument.

2 Installation

The impactor attaches to a user-supplied flow control system via six compression fittings (see figures 1 and 2). The sample inlet flow is drawn into the unit through the 1/8" diameter metal tubing at the top. The vacuum pumped excess flow is drawn from the two 1/4" outside diameter tubes oriented tangentially to the body. The compressed air counterflow input is delivered into the body through the two 1/4" outside diameter tubes that point radially inward toward the center of the body. The sample outlet flow is drawn from the body through the 1/4" outside diameter tube sticking downward from the base of the body

The impactor has been fabricated using an ultra-high vacuum brazing process that produces extraordinarily clean metal surfaces and also slightly anneals the stainless steel material. Care must be taken to avoid bending or overly stressing the air inlet and exit tubes when tightening the swagelock or other fittings or attaching flexible tubing. The tubing can be bent during installation if unduly stressed. **Over-tightening compression fittings will cause the sample flow tubes to become distorted and eventually result in leaks.**

The PCVI is constructed from several pieces that are sealed by O-rings and held together with four long bolts. The alignment of the various pieces is critical to the proper operation

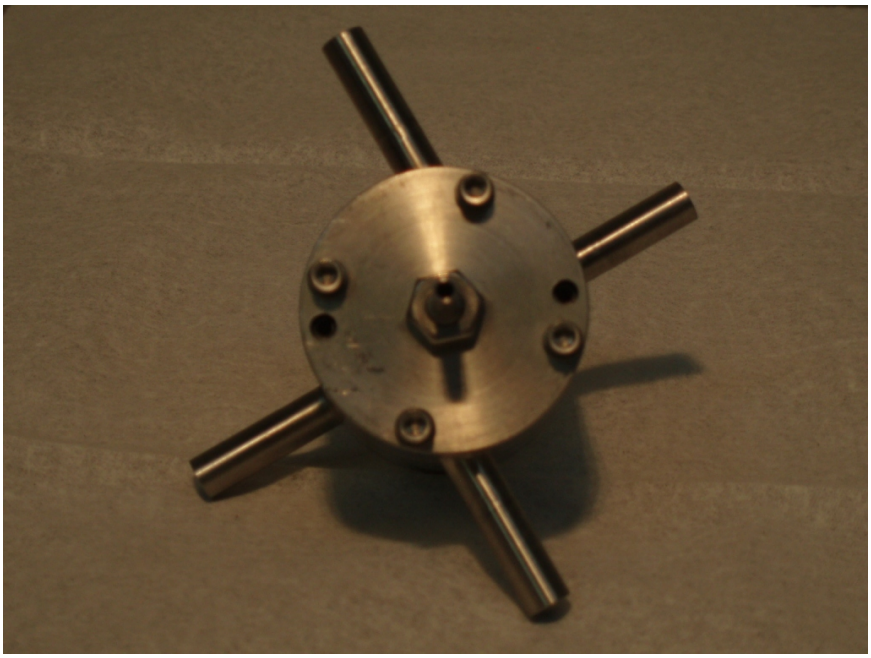

Figure 1: Top view of the BMI Model 8100 PCVI showing the small nozzle sample entrance tube and nozzle lock nut. The tangential orientation of the two tubes for the pumped flow leaving the PCVI can be seen and are distinguished from the add flow tubes that point radially in to the PCVI body.

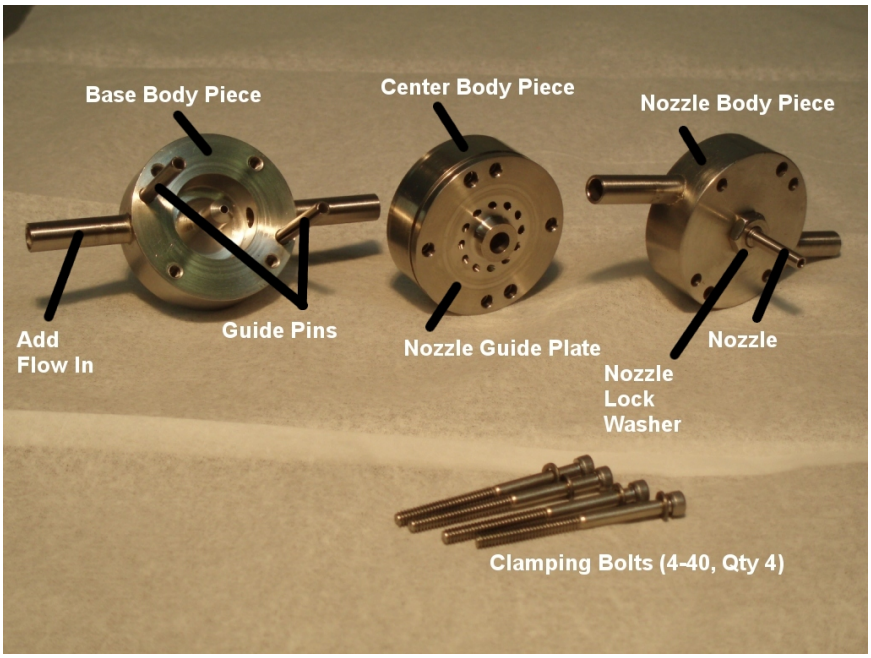

Figure 2: Photo of the disassembled PCVI showing the base with guide pins on the left, the center body piece in the middle, and the entrance nozzle body piece on the right hand side. Also shown are the four bolts used to hold the body pieces together and compress the O-rings between each body piece.

of unit. Alignment is established by the two precision roll pins that have been pressed into the base of the PCVI and the precision guide holes that are machined in each body piece that slide over the guide pins. **Due to the tight tolerance on the alignment, the guide pins can become cocked within the guide holes during assembly of the PCVI. When this occurs, carefully align the body component with the guide pins and slide gently to engage it.** Do not force any of the body components over the guide pins, doing so will distort the alignment. Make sure the O-rings have been installed with a small amount of O-ring grease before assembling the body.

The user should rigidly mount the PCVI body to a table-top or laboratory benchtop in an orientation that satisfies the particular measurement need. Install the PCVI so it can be easily disassembled for cleaning.

Other photos for reference purposes are shown below in figures 3 and 4.

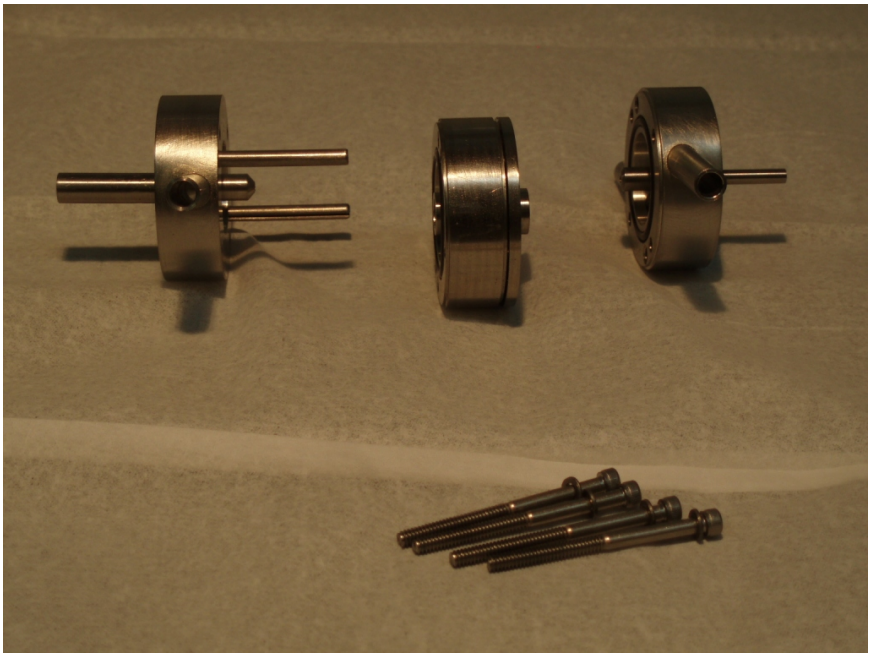

Figure 3: Photo of the disassembled PCVI showing the base with guide pins on the left, the center body piece with nozzle guide plate in the middle, and the entrance nozzle body piece on the right hand side. Also shown are the four bolts used to hold the body pieces together and compress the O-rings between each body piece.

3 Operation

Operation of the impactor involves simply supplying the add flow rate, drawing the pumped flow rate, and drawing the desired sample outlet flow rate from the bottom of the body. A representative flow system setup is shown in figure 5. Typically, two or three off-the-shelf mass flow controllers are used to maintain the desired air flow rates. The sample inlet flow is determined by the difference between the sum of the pumped and sample outlet flows and the add flow. See table 1 for a summary of operating conditions and resulting particle cut sizes. It is the user's responsibility to provide the necessary vacuum pump and compressor, as well

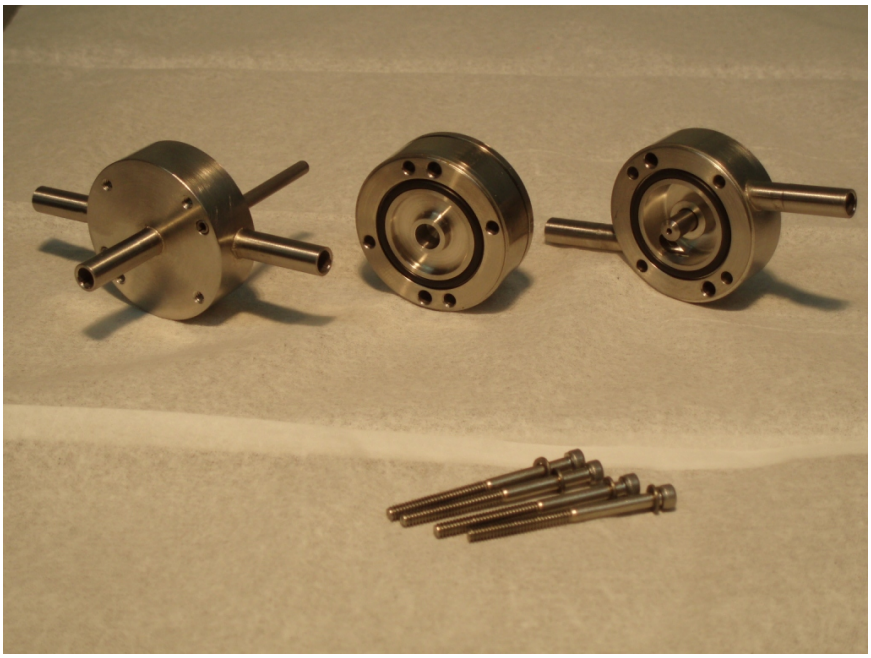

Figure 4: Photo of the disassembled PCVI showing the base with guide pins on the left, the center body piece with nozzle guide plate in the middle, and the entrance nozzle body piece on the right hand side. Also shown are the four bolts used to hold the body pieces together and compress the O-rings between each body piece.

as to draw and control the necessary flows. Verify that the impactor installation is leak free by operating the impactor with a HEPA filter upstream and a CPC or other particle detector downstream to verify that no artifact counts are recorded. All impactors are leak checked under high vacuum conditions at BMI prior to shipment. The loading within the PCVI body must be monitored by visual inspection and the pumped flow chamber cleaned to prevent clogging of the jets. The required frequency of cleaning will depend on the particulate mass loadings during sampling and it is the users responsibility to clean the PCVI when needed.

One technique for monitoring the likelihood of clogging as a result of particle deposition in the pumped flow chamber is to measure the pressure difference between the sample flow outlet and the pumped flow outlet. An increase in observed pressure drop with time normally indicates the onset of jet clogging. It is the users responsibility to provide the pressure drop measurement. If the pressure drop across the impactor will not be monitored, then the total pressure within the pumped flow exit line could be monitored to identify when the pressure drops due to clogging.

Table 1: Summary of operating conditions for the PCVI. All flows in lpm, pressure reported in hPa. Add flow is defined as counterflow plus sample out flow. Results shown are taken from Boulter et al. reference.

Sample In Flow	Sample Out Flow	Add Flow	Pressure	Dia Cut Size (μm)
12.4	2.8	5.2	50	0.28
17.0	0.75	5.0	270	0.98
11.3	0.68	5.0	395	1.30
6.8	0.68	2.5	695	1.88
6.6	0.68	4.5	731	2.83

4 Disassembly of the PCVI

Follow these steps to disassemble the impactor for cleaning and inspection:

1. Remove four bolts holding body together.
2. Carefully pull nozzle body piece (reference 2) away from remainder of body, sliding it off the guide pins.
3. Slide the center body piece and nozzle guide plate along the guide pins to remove them from body.
4. Take care when sliding any of the body pieces along the guide pins so that the piece does not stick. Keep the piece perpendicular to the guide pins and move it slowly without tremendous force.
5. If necessary, remove the lock nut locking the nozzle to the nozzle body piece and unscrew the nozzle from the nozzle body piece.
6. DO NOT REMOVE SPRING GUIDE PINS from body base piece! They are permanently installed to the base of the PCVI.

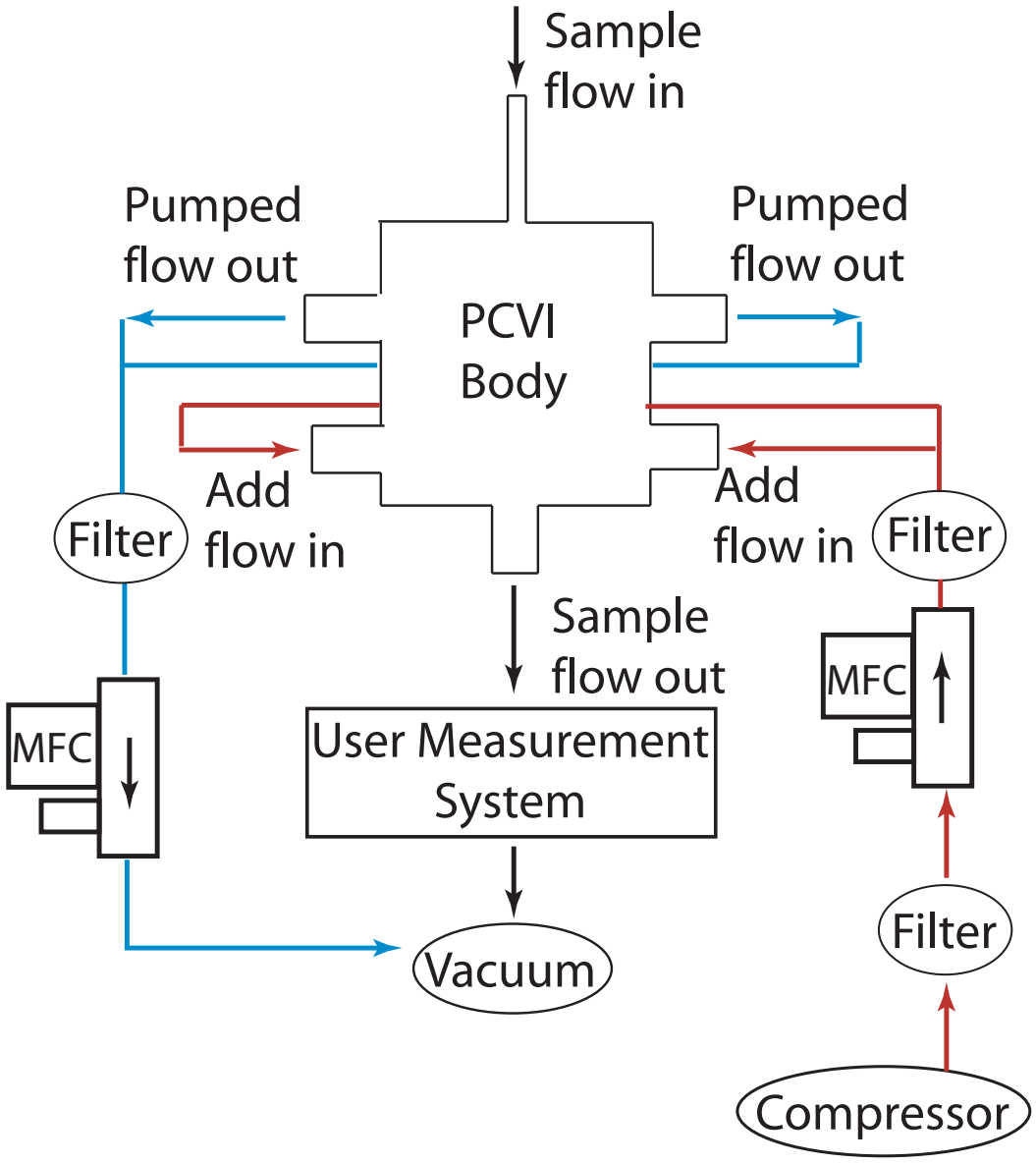

Figure 5: Schematic of the typical flow control setup for the Model 8100 PCVI showing the sample inlet flow at the top of the schematic, pumped flow drawn from the unit by a user supplied mass flow controller (MFC) and vacuum pump, the HEPA-filtered add flow supplied to the unit using a user supplied compressor and MFC, and the sample outlet flow controlled by the user's measurement system.

5 Assembly of the PCVI

Follow these steps to assemble the impactor:

1. Clean the nozzle with ultrapure water and methanol and apply a small amount of O-ring grease to the O-ring inside the nozzle guide plate (O-ring size is -009).

2. Clean all body piece O-rings (O-ring size -020), and apply a small amount of grease to each.

3. Screw nozzle into nozzle body piece inserting the 1/8" outside diameter end of the nozzle into the face of the nozzle body piece that faces into the PCVI body.

4. Hold nozzle guide plate against nozzle body piece without O-ring installed between guide plate and body piece and adjust position of nozzle to match contour of nozzle guide plate.

5. Install lock nut to secure position of nozzle in nozzle body piece.

6. Install center body piece with O-ring in place over spring guide pins so it rests against body base piece.

7. Install nozzle guide plate over spring guide pins.

8. Install nozzle body piece over spring guide pins.

9. Take care when sliding along guide pins that the pieces do not stick. Keep the pieces perpendicular to the guide pins and move slowly without tremendous force.

10. Install and tighten four 4-40 bolts to hold body together. Apply a small amount of lubricant to the bolts.

11. install a HEPA filter on the sample inlet, cap add and pump flow ports, and draw flow with a CPC through outlet port to leak check unit.