Impactor Selection Guide – Aerosol Research

INTRODUCTION

Cascade impactors are aerosol instruments designed to allow researchers to collect size-fractionated aerosol samples onto removable substrates. This permits gravimetric and chemical analysis to be conducted on differing particle size fractions. MSP is a market leader in impactors for environmental, material science, and other sampling applications.

When selecting an impactor, most researchers find that the most important considerations are: particle sizes, number of stages (size fractions), and mass detection limits (which affect impactor sample flow rate). Following these considerations, attention turns to the type of substrate, impactor pressure drop, type of pump, and rotation of impaction stages. These latter issues should also be considered, and may be of significant importance to some researchers.

Each of these parameters is discussed below, in the order of most frequent importance for researchers. As an alternative way to find the impactor that suits your needs, please see the impactor selection flow chart on p.8. Information on available accessories can be found on p. 6–7. Please contact us for additional help in selecting the right impactor for your needs.

PARTICLE SIZES AND NUMBER OF STAGES

MSP's suite of cascade impactors can collect particles with D_{50}[1] aerodynamic diameters (cutpoints) from 10 nm to 10 µm, in 3 to 13 different size fractions. The number of stages determines the size resolution of the collected samples, and consequently determines the level of detail of the data produced from the analysis of these collected samples.

The upper particle size sampled is often influenced by regulatory requirements, such as PM10[2] and PM2.5, but sometimes is solely based on the judgment of the researcher who may focus on collecting insights on PM1 and below.

Several factors can affect the selection of the smallest cutpoint. For example, the particle size of the smallest cutpoint can have a significant impact on the type and size of the pump needed to operate the impactor. If the researcher has practical or budgetary restrictions, that may affect the pump (including weight and the use of oil in a vacuum pump), the smallest cutpoint should be chosen with these restrictions in mind.

Figure 1: 120R MOUDI II Impactor: exterior (left) and interior (right).

[1] Aerodynamic Diameter at which 50% of the particles are collected onto the substrate.
[2] PM stands for Particulate Matter with the number provided representing the D_{50} cutpoint of the upper particle size sampled (i.e. PM2.5 means particles smaller than 2.5 µm).

Table 1: Non-Rotating Impactors

Simpler impactors for a variety of sizing needs. All include an after-filter.

Cutpoint Aerodynamic Diameters (µm)										
0.056	0.1	0.18	0.32	0.56	1.0	1.8	2.5	3.2	5.6	10
					X		X			X
		X	X	X	X	X		X	X	X
X	X	X	X	X	X	X		X	X	X
				X	X	X		X	X	X
		X	X	X	X	X		X	X	X
X	X	X	X	X	X	X		X	X	X

Note: All 30 L/min impactors have 47-mm diameter impaction plates, while 2 L/min models have 37-mm diameter semi-circular impaction plates.

IMPACTOR FLOW RATE AND DETECTION LIMIT OF ANALYTICAL TECHNIQUE

MSP's wide variety of impactors gives researchers significant freedom to choose a set of cutpoints that will suit their needs.

MSP's **MOUDI**[3] **series** has impactors that operate at flow rates of 2, 10, and 30 L/min. Flow rates of 30 and 10 L/min are the most commonly used for sampling 12 or 24 hour samples in rural and urban environments, while 2 L/min may be appropriate in environments with high particle concentrations, or due to other considerations (such as for personal sampling applications). A detailed description of MOUDI impactor specifications is shown in Tables 1 and 2.

In addition to the MOUDI series, the **High Flow Impactor (HFI) series** is a group of six impactors, detailed in Table 3, that operate at 100 L/min of volumetric flow. This highest flow rate is especially advantageous when sampling in clean ambient environments, where low particle concentrations will require larger sampling volumes

Figure 2: 130 High-Flow Cascade Impactor

In some cases, the questions of particle size and sampling flow rate must be considered simultaneously. For example, if the researcher intends to perform gravimetric measurements on the collected samples, collecting enough mass at the smallest particle size for the sample to be measurable may require very long sampling times. As such, the researcher's experimental design should be taken into consideration as well when choosing the smallest cutpoint.

Figure 3: 135-6 MiniMOUDI Impactor.

[3] MOUDI stands for Micro-Orifice Uniform Deposit Impactor.

Cutpoint Aerodynamic Diameters (µm)			
# of Stages	Flow Rate (L/min)	Pressure Drop (kPa)*	Model
3	30	1	100S4
8	30	10	100NR
10	30	40	110NR
6	2	1	Mini-MOUDI 135-6
8	2	10	Mini-MOUDI 135-8
10	2	40	Mini-MOUDI 135-10

*1 kPA = 10 mbar

TYPE OF SUBSTRATE

MSP's impactors can accommodate a variety of impaction substrates. The type of substrate used is dependent upon the type of offline analysis the researcher would like to perform. For ease of use, all substrates are held in place with a clamping ring on the substrate holder, and the substrate holder is easily removed from the stage due to its magnetic mount. Collected samples can be safely stored in an included sample holder for easy transport to and from the laboratory (see "Accessories").

A few notes on impaction substrates:

- For gravimetric analysis, aluminum foils are commonly used. These substrates are provided with MOUDI impactors.
- Particle bounce may occur in low-humidity environments; an anti-bounce film coating may be applied to minimize this phenomenon. A specific formulation of silicone oil spray has been tested at MSP for this purpose and is available for purchase.
- Substrate thickness should be <0.1 mm, which is the case for the most common substrates used, such as aluminum foils, thin films, and membrane filters (Teflon [polytetrafluoroethylene, PTFE], polycarbonate, nylon, and PVC).
- For researchers interested in using thicker substrates, such as quartz fiber filters, MSP has Teflon spacers available to increase the jet-to-plate distance to accommodate the thicker substrate.

The diameter of the substrate depends upon the impactor model. The majority of the impactors use 47 mm diameter substrates, but 90 mm, 75 mm, and 37 mm diameter substrates are called for in some cases. Details on substrate diameters may be found in the footnotes of Tables 1 and 2.

Table 2: MOUDI II Impactors

Versatile impactors made for a variety of applications, such as sampling in urban or rural environments, workplaces, or from laboratory experiments. All impactors have rotating stages and an after-filter.

Cutpoint Aerodynamic Diameters (µm)										
0.010	0.018	0.032	0.056	0.1	0.18	0.32	0.56	1.0	1.8	3.2
			X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	X	X

Note: all MOUDI II impactors have 47 mm diameter impaction plates, with the exception of the final three stages of the 122, which have 90 mm diameter plates.

PRESSURE DROP AND TYPE OF PUMP

Collecting particles by impaction requires a certain flow through the nozzles preceding the substrate. Smaller particle sizes require a higher pressure drop across the nozzles. With up to 2,000 nozzles per stage, MOUDI impactors are designed to keep the pressure drop to a minimum. For impactors with a smallest cutpoint stage of 56 nm (shown in Table 1), a carbon vane pump is appropriate (see “Accessories”). Impactors with stages smaller than 56 nm, however, will require the use of an oil-sealed vacuum pump in order to achieve the lower pressures needed for these lower stages; see Table 2. To successfully operate a given impactor, the capacity of the pump is determined by the impactor’s sampling flow rate and by the total pressure drop across the impactor, including the final backup filter.

For some researchers, pump and capacity and type can be a significant concern: if this is the case, the number and particle size of stages should be determined with pump considerations in mind.

STAGE ROTATION OPTIONS

As particles are collected on an impactor collection substrate, they can begin to accumulate, forming a three dimensional deposit under each nozzle. This can deteriorate impactor performance in several ways (increasing particle bounce, permitting particle re-entrainment, and possibly clogging the nozzle). To combat against these negative effects, some MOUDI impactors are available with rotating stages. When the stage is rotated relative to the nozzle plate, the impacted particles are deposited in a more uniform manner across the impaction surface. This increases the amount of particle mass that can be collected without negatively affecting impactor performance. Rotating MOUDIs have been used extensively for ambient sampling, instrument validation, and for investigating vehicle emissions, biomass burning, and other industrial processes. An applications bibliography is available from TSI Incorporated.

If the researcher would like to perform multiple off-line analyses on one sample, it is commonplace to cut the substrate material into two or four equal pieces. To facilitate the equal division of substrates for this purpose, MSP offers specially-designed nozzle plates with high-flow impactors (128-131, all non-rotating). These nozzles plates distribute the nozzles symmetrically across the stage area in four quadrants, leaving a “+”-shaped area with no deposited aerosol.

USER INTERFACE

MOUDI II impactors have a digital display touch interface that includes a programmable timer, data logging, and Ethernet communication. These features enable the researcher to:

- Define sampling time intervals. For example, a researcher could set the impactor to sample every day during morning rush hour only, or from midnight to noon.
- Create a sampling protocol from the stored data to support the quality of the sample and subsequent sample analysis. The impactor stores the measured cabinet temperature, stage pressures, and time in an evenly-spaced manner throughout the specified sampling period.
- Remotely check into the impactor to verify uptime (runtime). A convenient software tool mirrors the impactor controls to the computer screen of an internet-connected researcher and enables download of the saved data remotely.

Cutpoint Aerodynamic Diameters (µm)					
5.6	10	# of Stages	Flow Rate (L/min)	Pressure Drop (kPa)*	Model
X	X	10	30	40	MOUDI II Impactor 120R (rotating)
X	X	13	30	90	Nano-MOUDI Impactor 122R (rotating)
X	X	13	10	90	Nano-MOUDI Impactor 125R (rotating)

*1 kPA = 10 mbar

EXPERIMENTAL DESIGN / GOOD PRACTICE

Depending upon the application, a researcher may require one or more of the following:

- An active flow control system, for long sampling periods that encompass significant temperature changes. Before each sampling period, it is recommended to set the flow rate using tools like the Flow Calibrator (see "Accessories"). This procedure is usually sufficient for controlled environments, where aerosol temperatures and pressures do not vary largely over the sampling period. If, however, the sampling period is going to last longer than 24 hours, or encompass a temperature change of greater than 20°C, it is advisable to incorporate active flow control. MSP's MOUDI II Particle Sampling System 120R-120FC, is designed for this purpose (see "Accessories," and Figure 4).
- A sampling inlet for ambient sampling applications. For example omni-directional sampling inlets are typically attached to instruments or sampling lines leading to instruments.
- A large particle preseparator, if concentrations of large particles are expected to be high. This may occur in dusty environments, e.g. saw dust, when particles >10 µm are present in large amounts but sampling is focusing on smaller particles.

Table 3: High flow impactors
Sampling more material in less time. All HFI sample at 100 L/min and substrate rotation is not available.

Cutpoint Aerodynamic Diameters µm)							# of Stages	Pressure Drop (kPa)*	Model
0.25	0.4	0.8	1.0	1.4	2.5	10			
			X		X	X	3	0.6	128 HFI
X			X		X	X	4	4	129 HFI
X	X	X		X	X		5	5	130a HFI
X	X		X	X	X		5	5	130b HFI
X	X	X		X	X	X	6	5	131a HFI
X	X		X	X	X	X	6	5	131b HFI

*1 kPA = 10 mbar

It is important to keep in mind that ambient conditions such as temperature and humidity may affect impactor performance, and that sample gas composition (if corrosive) could potentially have a deleterious effect on impactor materials.

ACCESSORIES

Flow-related:

- Vacuum Pump (varies with impactor model and country, see Table 4)
- Flow Calibrator 4048
- MOUDI-II Particle Sampling System 120R-120FC (See Fig. 4)

Figure 4: MOUDI-II Particle Sampling System 120R-120FC (left)

Substrate-related:

- Substrates (47mm, Al foil, pkg 300), 0100-96-0573
- Substrates (75mm, Al foil, pkg 300), 0130-96-0575
- Substrates (90mm, Al foil, pkg 300), 0122-96-5222
- Substrates (Al foil, pkg 300 for 135), 0135-01-0014
- Glass fiber final filters, 37mm, 0135-01-5203
- Glass fiber final filters, 47mm, 0001-01-9953
- Glass fiber final filters, 90mm, 0130-01-5010
- Silicone Impaction surface spray, 0100-96-0559
- Mask for use in applying spray to substrates (comes with aluminum foil substrates)
- Silicone Lubrication Grease, 0100-96-0558
- Impaction Plates & Filter Holder (varies with impactor model, contact MSP for assistance) (See Fig. 5)

Figure 5: Impaction Plates & Filter Holder.

Software-related:

- Software for serial port data download from MOUDI II impactors (comes with MOUDI II impactors)
- Cascade Impactor Spreadsheet for simple size distribution analysis (contact MSP)

MOUDI APPLICATIONS BIBLIOGRAPHY HIGHLIGHTS

MOUDI used in Beijing, China to characterize urban aerosols

A MOUDI was used in parallel with multiple electrical-mobility based techniques to investigate the hygroscopicity of ambient aerosols in highly polluted Beijing. Samples were collected at Peking University, where some students have put facemasks on campus statues as a form of silent protest against high pollution levels (at right). Chemical analysis of MOUDI samples permitted interpretation of data gathered by the other techniques, leading to insights on how aerosol chemistry affects aerosols' response to humidity.

Citation: Meier, J., *et al*. "Hygroscopic Growth of Urban Aerosol Particles in Beijing (China) during Wintertime: A Comparison of Three Experimental Methods." *Atmospheric Chemistry and Physics* 9, no. 18 (2009): 6865–6880. *Photo credit:* http://www.hindustantimes.com/photos/world/smog-in-china/photo11-6QxhZvAfFlVaDWwu6b9NiL_photo.html?c1=10

MOUDI used in UK to sample metallic nanoparticles in ambient roadside air

Metallic nanoparticles in ambient air may represent a public health hazard, and can be generated by vehicle engines and brakes. A MOUDI was used to sample ambient air along the roadside in Birmingham, UK (at the Civic Centre, shown below) in order to collect any present metallic nanoparticles for microscopic and chemical analyses. Results demonstrated the presence of spherical metal nanoparticles, containing iron and ten other metals. Mean diameters of iron-containing particles ranged from 13.14–33.56 nm. For a recent Science magazine article on the topic of metallic nanoparticles in air, and the health risks they pose, see http://www.sciencemag.org/news/2016/09/industrial-air-pollution-leaves-magnetic-waste-brain

Citation: Sanderson, P., et *al.* "Characterisation of Iron-Rich Atmospheric Submicrometre Particles in the Roadside Environment." *Atmospheric Environment* 140 (2016): 167–175.
Photo credit: http://manchesterhistory.net/architecture/1960/civiccentre.html

MOUDI used in California, US, co-located with IMPROVE samplers and a newly-developed sampler for sampler validation

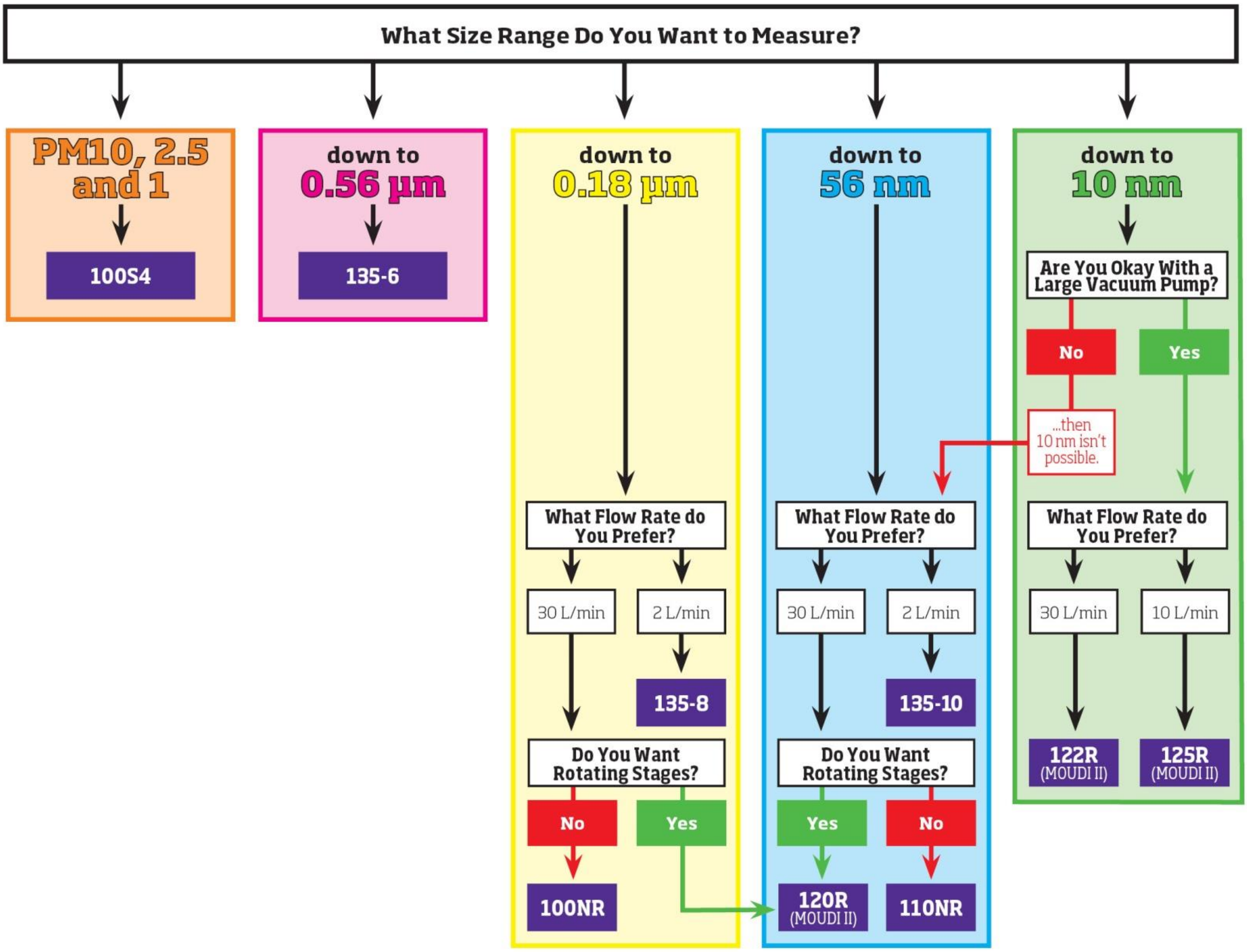
The latest design of a rotating drum impactor sampler was tested alongside a MOUDI and IMPROVE-network samplers to validate the drum impactor's performance. All instruments were co-located at the University of California at Davis (shown below), and ambient sampling was conducted during both winter and summer. Collected aerosol samples were analyzed via x-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS). The MOUDI – ICP-MS results proved to be the most repeatable of any sampler-analysis combination tested.

Citation: Venecek, M.A. *et al.* "Characterization of the 8-Stage Rotating Drum Impactor under Low Concentration Conditions." *Journal of Aerosol Science* 100 (2016): 140–154.
Photo credit: http://airquality.crocker.ucdavis.edu/improve-research/

Table 4: Vacuum Pumps for MSP Impactors

Model	Impactor	Description	Notes
0100-01-1050	100, 110	Vacuum Pump, 100/110, 110V	110V US plug
0100-01-1051	100, 110	Vacuum Pump, 100/110, 220V, EU	220V EU plug
0100-01-1052	100, 110	Vacuum Pump, 100/110, 220V, UK	220V UK plug
0100-01-0079	100S4	Vacuum Pump, 100S4, 110V	110V US plug
0120-98-1051	120R	Vacuum Pump, 120R, 110V	Used with Relay box supplied with 120R
0120-98-1050	120R	Vacuum Pump, 120R, 220V	Used with Relay box supplied with 120R
120FC	120R	Pump & Flow Controller for Model 120R	Works with 120R cabinet
0122-01-2016	122R	Vacuum Pump, 122R, 230V, EU	230V EU plug
0122-01-2011	122R	Vacuum Pump, 122R, 230V, US	230V US plug
0125-98-0100	125R	Vacuum Pump, 125R, 110V	Used with Relay box supplied with 125R
0125-98-0101	125R	Vacuum Pump, 125R, 220V	Used with Relay box supplied with 125R
0130-01-1051	128 to 131	Vacuum Pump, 128/129/130/131, 110V	110V US plug
0130-01-1050	128 to 131	Vacuum Pump, 128/129/130/131, 220V, EU	220V US plug
0130-01-1052	128 to 131	Vacuum Pump, 128/129/130/131, 220V, UK	220V UK plug
0135-01-0100	135-10	Vacuum Pump, 135-10, 110V	110V US plug
0135-01-0101	135-10	Vacuum Pump, 135-10, 220V, EU	220V US plug
0135-01-0102	135-10	135-10, 220V, UK	220V UK plug
0135-75-5007	135-6 and 135-8	Vacuum Pump, 135-6, 135-8, 110V charger	NiMH battery
0135-75-5008	135-6 and 135-8	Vacuum Pump, 135-6, 135-8, 230V charger	NiMH battery

IMPACTOR SELECTION FLOW CHART



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