MAKING ACCURATE MASS DISTRIBUTION MEASUREMENTS WITH TSI'S MODEL 140 REAL-TIME QCM-MOUDI™ IMPACTOR: BEST PRACTICES

APPLICATION NOTE QCM-MOUDI-001 (A4)

Contents

What Does the Real-Time QCM-MOUDI™ Impactor Offer?

The Model 140 Quartz Crystal Microbalance (QCM) MOUDI™ Impactor is a unique instrument that allows users to perform real-time, size-segregated, mass concentration measurements for solid particles smaller than 2.5 µm. Mass measurements are made using a first-principles technique (i.e., Quartz Crystal Microbalance), which means that no assumptions are needed regarding optical properties, density, or shape factor of the collected particles. This first-principles technique means that calibration of the QCM crystals is not required.

As with any research-grade instrument, care must be taken to ensure that the QCM-MOUDI™ impactor has the conditions it needs to fulfill its ability for providing highly accurate, real-time mass concentration data. This "Best Practices" document describes how to determine what accessories you may need, what settings you should use, and what maintenance schedule you should follow to ensure that you are gathering the most accurate data.

What Accessories do I Need?

Since the applications for QCM-MOUDI™ impactor vary widely, the list of required accessories can vary significantly too. To determine which of the accessories described below you will need to ensure optimum performance and data accuracy for your particular application, it will be important to know the following about the aerosol you intend to sample:

- Expected PM2.5 mass concentration (<25, 25–100, >100 μg/m^3)
- Expected temperature
- Expected % relative humidity or dew point temperature

Read below to learn how each of these environmental conditions influences the need for certain accessories.

Sampling Inlet

Ambient Monitoring Applications

For all ambient monitoring applications, the QCM-MOUDI™ impactor will require the use of a TSP or PM10 sampling inlet (the PM10 inlet will cut at approximately 12.9 μm if operated at 10 L/min). This inlet should feature a 1.25" OD down tube, a 1.25" to 3/8" reducer, and a 3/8" sampling tube that connects directly to the QCM-MOUDI™ inlet. Figure 1 shows an example of such an inlet system.

Figure 1: Sampling inlet for QCM-MOUDI™ impactor.

All Other Applications

Aside from the ambient monitoring described above, other applications will often require the sampled air to be transported through some tubing to the instrument inlet. When designing or installing this inlet line, keep the following things in mind:

Bends and Orientation

A straight-down path is optimal to minimize losses of larger particles. If bends in the tubing cannot be avoided, make them as few and as gentle (i.e. large radius of curvature) as possible.

Overall Length

Generally speaking, shorter transport tubing is preferable, to reduce losses to the tubing walls.

Tubing Composition

Conductive tubing will minimize the loss of particles due to electrostatics.

Pre-Drying

While the relative humidity of the sampled air may be below 100%, it is possible for the humidity to reach 100% if the sampled air is quite warm and it cools *en route* to the QCM-MOUDI™ impactor. This leads to water condensation in the sampling line, which is detrimental to data quality. This problem may occur when using the instrument for ambient sampling in tropical or sub-tropical climates, and may also occur in temperate climates during the hot weather season. In such a case, it is very important to remove this excess water from the sampled air before it reaches the instrument.

To determine whether your sampling conditions would require this additional drying step, assess whether at any time during your sampling campaign, the dew point of the sampled air would exceed the temperature of the air *as it enters the instrument.* As a guideline, you may use the temperature of the room where the instrument is as the lowest acceptable dew point of the sampled air. If the dew point would exceed this temperature, condensation will occur before the sampled air enters the instrument, resulting in erroneous mass measurements. Online humidity calculators may be helpful in this regard; one such calculator can be found at http://andrew.rsmas.miami.edu/bmcnoldy/Humidity.html.

To avoid this circumstance it is advisable to install an additional Nafion® dryer upstream of the QCM-MOUDI™ inlet. The dryer must be operated with a counter flow of 10 L/min of filtered room air at low pressure (<35 kPa abs or >20" Hg vacuum) to provide the driving potential to dry the incoming sampled aerosol.

Figure 2: Large-diameter Nafion® dryer, recommended for sampling from hot and humid environments. Recommended length of 48" (1.2 m) for maximum drying capacity.

Pre-Dilution

The QCM-MOUDI™ impactor is highly sensitive to mass, being able to detect 50 ng on a single stage and to measure up to about 150 μg of solid particles with a linear response. This upper mass limit means that it may be necessary to dilute the sampled aerosol before entering the QCM-MOUDI™ inlet. The necessity of pre-dilution depends upon two factors: PM.5 concentration and the length of the total sampling time.

For ambient sampling campaigns that will sample for 24 hours or more without interruption, pre-dilution is recommended for conditions where PM2.5 > 30 μg/m³. If a diluter is not installed under these conditions, the QCM crystals will need to be cleaned more frequently. The use of the diluter at high PM mass concentrations will also help to reduce the cleaning frequency of the nozzle plates in the impactor.

A simple type of diluter (TSI Model 3332, 10 L/min, 10:1) is shown in Figure 3. In this diluter the flow is driven by the sampling instrument and it is internally divided in two streams that are designed to maintain the designed dilution ratio. This diluter can be easily installed upstream of the QCM-MOUDI™ impactor to provide a fixed 10:1 dilution ratio.

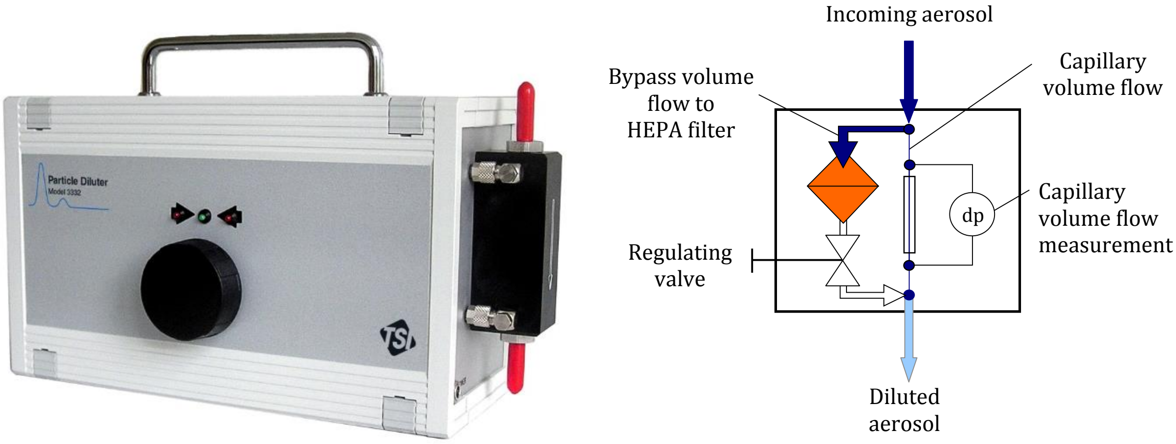

Figure 3: The bypass diluter - Model 3332 - that can be used with the QCM-MOUDI™ impactor. (*right*) the diluter design allows the particle-containing flow to travel straight through the diluter, minimizing losses due to impaction or diffusion.

Instrument Enclosure

In order to ensure that the instrument itself is not exposed to direct rain, snow, wind or solar radiation, or to temperatures outside its specified range of 15–30 °C, the QCM-MOUDI™ impactor must be installed in a climate-controlled room. Stability of the room temperature within a couple of degrees Celsius will improve the accuracy of the mass measurements since the crystals have a slight temperature dependence. This recommendation does not apply to the sampled air but to the temperature of the room where the instrument cabinet is installed.

What Settings Do I Use?

Selecting the Sample Interval for Data Collection

Why is this Choice Important?

One of the choices a QCM-MOUDI™ impactor user makes before starting data collection is deciding how often to record data. While the raw, 1 Hz data can be saved (see the checkbox labeled "Save Raw Data" in Figure 4), it is highly advisable to select a sample interval that is suitable for the application because manually processing 1 Hz data into a usable interval is labor-intensive.

Sample interval options included in the QCM-MOUDI™ impactor are 10 seconds, 1 min, 5 min, 30 min, and 60 min, as shown in Figure 2 in the "Sample Interval" drop-down menu. While all of those options are available, some may not all be suitable for your particular conditions.

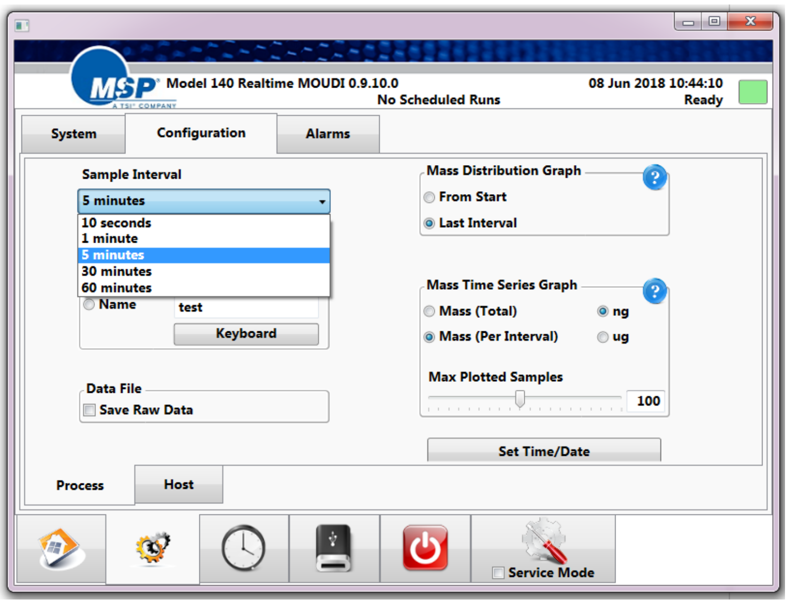

Figure 4: Screenshot of the configuration screen in the QCM-MOUDI™ impactor onboard software. Different sample intervals can be selected easily.

For example, collecting data with a short sample interval in a very clean environment would not produce high-quality data because the mass collected within the short sample interval may fall below the limit of detection of the quartz crystal microbalances. The goal, then, is to have the sample interval long enough to ensure adequate mass collection, but short enough to provide meaningful time-resolved data.

How Do I Choose the Best Sampling Interval for my Application?

The recommended sample interval is influenced by:

- The PM2.5 concentration of the sampled air (measured in $\mu g/m^3$)
- The sensitivity of a single stage (50 ng)
- The number of stages in the instrument (6)
- The design inlet flow rate of the instrument (10 L/min)

To address all of these considerations, the following formula may be used to determine the minimum sample interval for a given PM2.5 concentration:

$$t_{interval} = \frac{150}{PM2.5} \qquad \text{(Eq. 1)}$$

where:

$t_{interval}$ = the minimum recommended sample interval, in minutes.

PM2.5 = the PM2.5 concentration (in $\mu g/m^3$) presented to the instrument inlet. If pre-dilution is performed, the PM2.5 level after dilution should be used.

After determining the minimum sample interval for your application, select the next larger sampling interval from the list of available values. For example if the PM2.5 is around 10 $\mu g/m^3$, the equation above would suggest a 15-minute sampling interval. Since 15 minutes is not listed, select the next larger sampling interval of 30 minutes. In this case using a 5-minute sampling interval may result in mass measurements with more variability (signal noise).

Total Sampling Time

Why is This Choice Important?

The total sampling time is the time from when data collection is started to when it is stopped. Ideally, this is also the frequency at which the quartz crystals are cleaned (see "Cleaning the Crystals," below).

The primary factor that determines how long the total sampling time can be is the amount of deposited mass each stage can collect before its sensitivity is reduced. At this point, the stage needs to be cleaned of the deposited particles, so sampling must be stopped. Figure 5 shows a picture of a quartz crystal impaction plate loaded with sampled particles.

Each quartz crystal has a maximum recommended load of 150 µg. When the entire stack is considered as a whole, it is recommended to clean all of the stages once the entire stack has accumulated approximately 450 µg.

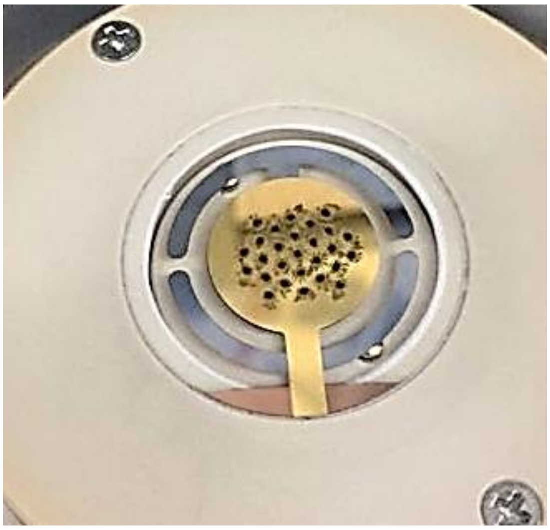

Figure 5: QCM-MOUDI™ impaction plate with collected particles.

How Do I Choose the Optimum Total Sampling Time for My Application?

Monitoring via the Front Screen

Since the particle concentration will vary with time, and the collected mass is distributed (often unevenly distributed) among all six impactor stages, it is always recommended to monitor the mass collected at each stage in order to stop the sampling when one of the stages reaches 150 μg.

The software embedded on the QCM-MOUDI™ impactor allows you to see a live measurement of the mass collected on each of the six stages, as well as the total mass collected across the entire stack, within a given sampling period (assuming the measurement starts with clean crystals). This enables you to monitor the loading of the QCM stages to more accurately determine the appropriate interval for cleaning the crystals. For more information on cleaning the crystals, see the next section, below.

Estimating the Total Sampling Time

While monitoring the instrument front screen is the most informed way to determine the total sampling time, it is useful to be able to estimate this in advance. To do so, you must know the approximate PM 2.5 mass concentration that will be sampled by the instrument.

For example, if the PM2.5 concentration is about 15 μg/m³, the impactor is collecting 15 μg/m³ x 0.01 m³/min =0.15 μg/min, or 216 μg/day. Using the guideline value of 450 μg mentioned previously, the QCM-MOUDI™ impactor could be run for a total sampling time of about 50 hours.

Table 1: Estimated cleaning frequencies for several PM2.5 concentrations.

PM2.5 concentration*	Estimated total sampling time (= cleaning frequency)
5 μg/m³	150 hours
15 μg/m³	50 hours
25 μg/m³	30 hours
50 μg/m³	15 hours
100 μg/m³	7.5 hours

*PM2.5 concentration in the sampled air. If pre-dilution is used, the concentration after the pre-dilution should be used for estimating the cleaning frequency.

You can estimate the appropriate total sampling time for your application using either Table 1 or Equation 2 (where PM2.5 is entered with units of μg/m³).

$$Total\ sampling\ time\ (h) = cleaning\ frequency = \frac{750}{PM2.5} \qquad (Eq.\ 2)$$

Please note that if pre-dilution is used as described above, then the diluted concentration should be used when making this estimation.

How Frequently Will the Instrument Need Maintenance?

Maintenance procedures for the QCM-MOUDI™ impactor including cleaning the crystals, refilling the distilled water bottle, cleaning the impactor nozzle plates, and replacing the final filter are all described below. Further details can be found in the operating manual of the QCM-MOUDI™ impactor.

Cleaning the Crystals

The convenience of the QCM-MOUDI™ impactor's real-time measurements can make it easy to forget that these measurements are made possible by conventional inertial impaction. As with any other cascade impactor, particles are accumulating within the QCM-MOUDI™ impactor, and this accumulation means that cleaning is necessary.

Since the sampled particles deposit on the QCM crystals, cleaning these crystals is the most common cleaning procedure. Cleaning frequency depends upon the PM2.5 mass concentration of the sampled air. Please see the section above on "Total Sampling Time" for further details.

The cleaning procedure itself is easy; to clean all six stages and get back to data collection takes less than 30 minutes, including instrument warm-up. The easiest way to clean the QCM crystals is to gently wipe them with a lens paper (for example, Fisherbrand #11-996) that has been wetted with a few drops of isopropyl alcohol. Crystals can be easily scratched by regular cotton swabs so these are not recommended. Refer to the QCM-MOUDI™ impactor manual for more details on the cleaning procedure.

Refilling the Distilled Water Bottle

The QCM-MOUDI™ impactor requires a continuous source of clean, distilled water for the humidity conditioner inside the instrument cabinet. Therefore, the 1-L water bottle must be always refilled before it runs low. The water consumption is dependent on the relative humidity of the sampled aerosol, but a good guideline is to refill the water bottle every 48 hours when running the instrument continuously.

It is strongly recommended that only distilled water be used in the QCM-MOUDI™ impactor. The use of ultra-pure DI water is not recommended, as it can affect the internal components of the plumbing system. Likewise, the use of tap water will damage the Nafion® membranes inside the instrument. For these reasons, only regular distilled water is recommended.

Cleaning Impactor Nozzle Plates

While the crystals need to be cleaned most often, the nozzles plates that precede each of the crystals also need to be cleaned periodically. How frequently the nozzle plates need to be cleaned depends upon the PM concentration of the sampled aerosol.

The nozzle plates can be easily removed for cleaning, and full cleaning instructions are provided in the operating manual. If the normal cleaning procedure does not remove all particle deposits from the nozzles, sonicating the nozzle plate(s) for a few minutes is advised.

Replacing the Final Filter

The impactor base has a 47 mm filter holder that can be used to collect particles smaller than 45 nm on a standard 47 mm air sampling filter (i.e. glass or quartz fiber). If the mass collected on this filter needs to be quantified with a laboratory microbalance, this filter should be removed and replaced after each sampling period. In most air sampling applications this filter will collect negligible amounts of mass compared with the mass collected on the impaction stages, so if these particles will not be analyzed the same final filter could be used several times.

References

Model 140 Real-Time QCM-MOUDI™ Impactor Operating Manual.

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