## Technical Note No. 065
## Use and Limitations of Low-Cost PM Sensors in Air Quality Measurements

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### Summary:

This Technical Note provides guidance for using low-cost particulate matter (PM) Sensors in air quality measurements and recognizing their limitations. This Tech Note applies to the following 2B Tech instruments that use these sensors: AQLite (standard) Air Monitoring Packages and Personal Air Monitors (PAM).

### Tools/Materials Needed:

none

### Introduction

Recently there has been an enormous surge in interest in the application of low-cost sensors to conduct measurements of air pollutants by educators, citizen scientists and groups interested in air pollution levels within their own communities. Indeed, it is now recognized that sensors can fill important gaps that are virtually impossible to fill with conventional or even miniaturized instrumentation because of their low cost, small size, and ease of deployment. However, the limitations of sensors must be recognized and care must be taken to obtain reliable results. 2B Tech incorporates several low-cost sensors in our AQLite measurement platform and our Personal Air Monitor (PAM, previously offered by 2B Tech). In this Tech Note, we will focus on low-cost PM (Particulate Matter) sensors that are based on the technique of optical particle counting (OPC). Our Tech Note 066 focuses on electrochemical sensors.

### Practical Recommendations for the Use of Low-Cost PM sensors

The low-cost PM sensor that 2B Tech is currently using in our AQLites and our more recent PAM is the Plantower PMS7003. Older models of our PAMs used the Plantower PMS5003, which is the sensor used in the popular Purple Air PA-II PM monitor. Since the PA-II PM monitor has such widespread use, many of the recommendations presented here were originally derived from studies involving the PMS5003 sensor; however, we have found that they equally apply to the newer PMS7003. This PM sensor outputs values for $PM_1$, $PM_{2.5}$, and $PM_{10}$, which are mass concentrations (in µg/m$^3$) for particles having diameters less than 1, 2.5, or 10 µm, respectively.

(1) Plantower $PM_{2.5}$ values have been shown to correlate well with established reference PM techniques; however, the raw $PM_{2.5}$ output of the Plantower is typically a factor of 1.2 to 2.0 larger than $PM_{2.5}$ measured by reference methods (see Barkjohn et al., 2021a for example). As the sensor response depends upon local aerosol composition, one should "calibrate" the Plantower $PM_{2.5}$ response to the average local aerosol mix by co-locating it with an established reference PM method for a few days to weeks. A correction factor can then be derived from this intercomparison to be applied to future sensor $PM_{2.5}$ data. Make sure to include $PM_{2.5}$ concentrations ≥ 5 µg/m$^3$. Ideally, this comparison should be done a few times per year to account for possible seasonal changes in the aerosol mix.

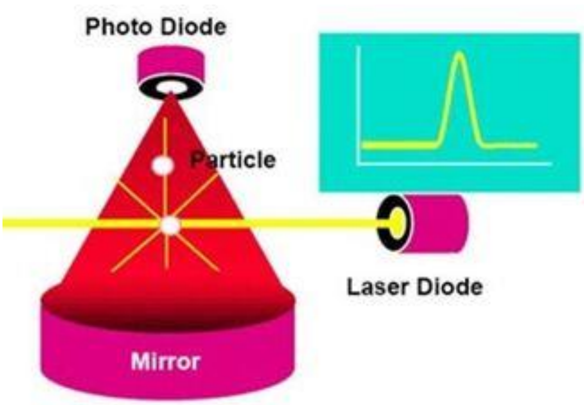
(2) Although Plantower $PM_{2.5}$ measurements show good correlation with reference methods, the same cannot be said of the $PM_{10}$ output. This appears to be due to a combination of issues

that impact their measurement of larger particles (see Ouimette et al., 2024). Therefore, *these sensors currently have not been shown to provide reliable measurements of* $PM_{10}$.

(3) At high relative humidity (RH > 70%), water can coalesce on particulates and increase their size and mass. At 2B Tech, we do not automatically apply humidity corrections to data from our low-cost PM sensors. However, accompanying humidity measurements can be used to correct PM measurements during post-processing of data (see next section for more details).

## Further Understanding of Low-Cost Particulate Matter (PM) Sensors

The Plantower PM sensors operate on the principle of Optical Particle Counting (OPC). Low-cost optical particle counters (OPCs) were originally developed for monitoring particulates in




indoor HVAC systems. Only recently have air quality scientists realized that they often correlate well with ambient $PM_{2.5}$. All OPCs (low-cost or otherwise) operate by illuminating a flow of air typically with a small laser diode. As a particle flows through the laser light path, it can scatter light, producing a pulse of light that is detected by a photo diode (see Figure to left). The intensity of the light pulse increases with the size of the particle. The recorded light pulses are counted and binned by intensity (i.e., particle size) over some time period (typically a few seconds). From these binned counts, the sampling air flow rate, and an assumed particle density and shape, the mass density (µg/m$^3$) of the particulates can be calculated.

The light intensity vs. particle size calibration in an OPC is typically determined using particles that have well-defined chemical composition, size, and shape (usually spherical). However, ambient aerosols are not well-defined – they are highly variable in both chemical composition and shape, which leads to several complicating issues:

(1) A particle's chemical composition affects its refractive index, which, in turn, determines the way a particulate scatters or absorbs light. For example, smoke from a fire can either appear black (actively flaming) or white (smoldering) depending upon how hot the fire is burning. You see this difference because of changes in the chemical composition (and therefore the refractive indices) of the smoke particulates. Differing refractive indices alter how the light is scattered or absorbed, which then determines what light reaches one's eyes. In a similar fashion, particulates of varying composition will also scatter light differently in an optical particle counter.

(2) To compute PM mass density (µg/m$^3$) from particle counts it is necessary to assume both a particulate shape and density. The shape is required to determine the volume of a particle whereas the density (units of mass/volume) is then used to convert that particulate volume to particulate mass. Both of these assumptions are complicated by the facts that ambient aerosols do not have uniform shapes and nor chemical composition (as discussed above) which determines aerosol density.

These properties of ambient aerosols are why an *in situ* field calibration versus reference PM instrumentation is necessary to derive a correction factor (sometimes referred to as a K-factor) to tune the OPC mass calculations to the local aerosol mix. It should be noted that this correction factor is needed for all OPC instruments, not just the low-cost PM sensors. Reference PM instrumentation that are certified by the US-EPA include gravimetric Federal reference methods (FRM, typically filter collection, followed by weighing of the particulate mass) or a gravimetrically calibrated equivalent method (FEM). Lastly, although this *in situ* calibration is reasonably robust, sudden changes in aerosol composition (for example, a wildfire smoke event) can alter sensor response and temporarily lead to incorrect PM mass concentrations.

Issues that relate primarily to low-cost PM sensors (and the Plantower specifically) include poor response to $PM_{10}$ and the impact of humidity on the measured PM. $PM_{10}$ is typically underestimated by a significant amount and often shows poor correlations with reference methods. A recent study (Ouimette et al., 2024) has suggested that inhomogeneities in the light source of Plantower sensors can lead to incorrect sizing of particles as they become larger than about 1 µm in diameter. Along with other known difficulties associated with larger particulates (such as efficient sampling into the sensor and impaction on walls within the sensor), this leads to underestimation of the mass contribution from larger aerosols. Although further studies on the response of larger particles in low-cost PM OPCs are warranted, currently $PM_{10}$ measurements from these sensors (and in particular, the Plantower) should be viewed with skepticism.

High relative humidity (RH > 70%) causes water to coalesce on airborne particulates, increasing their size and mass, as well as altering their refractive index. Typical PM reference methods and higher-cost OPCs operate by controlling the incoming RH; reducing it to ~ 25-50% RH to prevent this water uptake. However, humidity control is typically impractical with low-cost PM sensors due to the expense and larger power requirements. Therefore, many studies have developed algorithms to correct low-cost $PM_{2.5}$ sensor data for humidity (e.g., Zheng et al., 2018, Barkjohn et al., 2021a and 2021b). Some of these corrections are more theoretically based, while others are strictly derived empirically from field data. As these humidity correction algorithms are an evolving science (Patel et al., 2024), we currently have opted *not* to automatically apply any PM humidity-based corrections. The accompanying humidity measurements in the AQLite or PAM can be used during data processing to derive corrections based on any user-preferred method. *Note - when using these humidity correction algorithms from the literature, one should be aware that there is typically a term included in these equations that accounts for the in situ "calibration" as described in Recommendation (1)*.

## References: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