Product Performance Evaluation Guide

Canāree, IPS

Background Information

All Piera devices are individually calibrated in a controlled environment against an US EPA approved FEM (GRIMM EDM180) using standardized calibration aerosol. Devices are only shipped to customers upon successful completion of the entire calibration process including QA to ensure that the device performs within the specification stated on the datasheet.

A sensor is expected to report accurate particle count data based on aerosol samples collected from a localized area around the sensor itself in real time, and any instantaneous discrepancies in data between multiple sensors are acceptable as long as their overall average readings over a period of time are within specifications in case of non-dynamic environment.

In a dynamic environment where aerosol concentration rapidly changes, or concentration uniformity is not guaranteed due to ambient airflow and generation of aerosol particle, it has to be assumed that the sensor data is accurately representing the actual condition around the sensor. Many unquantifiable factors can affect possible device-to-device variance beyond specifications during such dynamic environments.

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1. Understanding Particle Counters

1.1 Myths and Facts

Light scattering optical aerosol particle counters are designed to count and size airborne particles in real-time. The best results occur in controlled environments. Users tend to expect this type of equipment to tumble out absolute results however, it is crucial to understand the underlying operating principle of the device, its benefits, and limitations in order to understand the relevance of the data generated and to put the operation of particle counters in context. No measurement is absolute, all is relative to the measuring technique, and algorithm employed.

Almost all real-life particles are non-uniform in structure, essentially a mixture of various heterogeneous, polydisperse matters with wide range of sizes, shapes and chemical compositions that directly affect their optical characteristics. This therefore poses the question of how to qualify the size? Particle counters size and count particles by matching a signal response generated by the contaminant particle to an optical equivalent size of monodisperse particles with known physical characteristics such as polystyrene latex spheres (PSL) or nebulized potassium chloride (KCl) solution. This is a standard approach of particle sizing. The instrument is adjusted for each reference particle size used and a calibration curve generated within the instrument. The sizing response from real-life particles is therefore referenced by the instrument as an equivalent to a perfectly spherical latex sphere and counted in one particular size range (or channel). Size/number distribution reported by an instrument should therefore, never be treated as absolute, as there are a number of variables operating i.e. physical properties, refractive index, orientation etc., that will play a part in the size indicated (and therefore the size channel in which the particle is counted).

1.2 Operation Principle of Light Scattering Particle Counters

Light scattering particle counting is a glorified expression of utilizing a light source to illuminate the particles. Air is usually sampled with a fan or a vacuum pump. As entrained particles in the air pass through the laser beam, the laser light interacts with particles and is scattered. The term ‘scattering’ means that the light undergoes a directional change. This change occurs in all directions: forwards, backwards and sideways. A single or multiple photo-detector(s) convert the burst of photon energy from particles into a pulse of electrical energy. In essence, it is not counting particles, but rather counting quantized energies originated by scattered photons.

There may also be a degree of absorption when a percentage of the light energy is retained by the particle and in some instances effects such as phosphorescence may occur from some particles’ types. Therefore, the whole term ‘scattering’ is made up of different physical properties relating to light, and the interaction of light and particles.

The interaction of light and particles therefore depends upon the particle composition, its refractive index and the difference between that particle and the background medium. In operation, the instrument compares the response it is getting from the particle signal to the calibration curve generated with latex spheres. What the instrument is actually doing is comparing the response from the interaction of that particle and the laser light and then relating that, not to some irregular particle of unknown morphology, but to reference particles whether PSL or KCl, in a background of air through a proprietary algorithm.

1.3 Summary

The Instrument itself is not counting and sizing particles, it is counting and sizing photon energies and relating them to a similar response from reference particles in the air. It is also advised to be aware of the fact that such characterization of photon energies depends not only on the chemical/physical attributes of particles but also a device’s sizing algorithm. While it is true that these devices allow users to take instantaneous samples and get a very good real-time indication as to the loading of particles in a room or localized area around devices, it should not cloud the user's appreciation of how the instruments operate and the actual meaning of the data that is generated, which can be quite different from manufacturer to another.

2. Simple Field Testing

2.1 Field Testing Guide

Place multiple sensors in close proximity in a sealed container, run them simultaneously for at least an hour before taking the average of each size bin reading from the sensors and compare.

You may try injecting particles into the system before or in the middle of an experiment but be sure to give enough time for particles to be evenly distributed, and analyze data obtained from a relatively stable period after all the particles are properly mixed. To ensure particles are well-mixed, fans may be used at low speed. This section of the document is only intended for stable condition testing.

Be sure to position the devices so that the air inlets are facing the same direction to minimize device-to-device interference.

If the data from the sensors differ significantly from each other then you may have a hardware problem. Contact Piera Systems for support.

2.2 Pre-test Checklist

	Yes	No
1. Are there any obstacles interfering with the sensor air path?	☐	☐
2. Are the sensors adequately powered via stable power source? (If using battery pack, make sure it is fully charged)	☐	☐
3. Is there any sensor making excessive noise?	☐	☐
4. Is the evaluation chamber free from any kind of disturbance?	☐	☐
5. Have you taken necessary steps to ensure concentration uniformity?	☐	☐
6. Are there any particulate sources that affect the chamber condition?	☐	☐
7. Are all sensor air inlets aligned, facing the same direction?	☐	☐
8. Have you set the unit of output consistently across the sensors?	☐	☐

2.3 Post-test Checklist

	Yes	No
1. Has there been any incident that could disrupt the test environment? (moving, walking nearby if the chamber is not completely sealed)	☐	☐
2. The particle concentration level within the chamber was between 20 #/L and 100,000 #/L?	☐	☐
3. The mass concentration level within the chamber was at least 5ug/m^3?	☐	☐
4. Has there been any change of power source or sensor reboot?	☐	☐
5. Any obstacles near air inlets of the sensors found after the evaluation?	☐	☐
6. Have you successfully retrieved all data from the sensors?	☐	☐

If any of the questioned above were answered "No," then the test needs to be repeated.

2.4 Data Analysis

Average of particle count data for each bin over the duration of test period should be calculated. Check if the result is approximately within the datasheet specifications for perfective conditions. Fit a linear regression curve to particle count for each bin and make sure that the overall change of concentration is within ±15%.

Note: the simple field testing is not intended for validating the specifications of the sensor itself. Please go to section 3. Performance Evaluation Protocol for in-depth testing.

3. Performance Evaluation Protocol

Performance testing should be conducted in a carefully controlled environment to evaluate Piera sensors. A test chamber, reference particle (either PSL or KCl) generator, one or more reference instruments (GRIMM 11D or EDM180) are recommended for proper evaluation.

Note: Low-cost nephelometric and spectroscopic particulate sensing devices including Piera devices that utilize laser or infrared light sources without internal temperature and relative humidity control mechanism are susceptible to error depending on test conditions. Ambient air flow, and location of DUT (Device Under Test) within a testing environment can also affect sensor readings, and therefore a precise test chamber constructed to minimize such effects should be used in order to correctly evaluate Piera devices. It should also be acknowledged that particulate mass data can differ from reference devices depending on the nature of particles present during evaluation due to the variance in particle density and non-uniform particle concentration within the test chamber.

3.1 Test Conditions

Temperature: 18°C – 28°C
Relative humidity (RH): 40% – 70%.
Use polydisperse KCl dissolved in distilled water. Test particle size distribution should be in range specified in Table 1.

KCl Test Particle Size and Distribution	Value
Count Mean Diameter (um)	0.3 – 0.6
Geometric Standard Deviation (σ_g)	1.5 – 2.3

Table 1. Test particle (KCl) size and distribution.

Minimum Mass Concentration (ug/m^3)	Particle Bin (Optically Equivalent)	Maximum Mass Concentration (ug/m^3)
20	$PM10_{oe}$	300
8	$PM2.5_{oe}$	100
5	$PM1.0_{oe}$	90

Table 2. Test particle maximum and minimum mass concentration limit.

Note: KCl particle size changes if RH is 80% or more. Density of KCl is 1.989 g/cm^3.

3.2 Equipment

1. A light-scattering single particle counter (reference device)
   - Calibrated according to ISO 21501-4 within a year prior to an IPS device evaluation.
   - Should have 0.3um lower detection limit, with 1.0um, 2.5um and 10um particle channel output. 3 or more channels should be dedicated to 1.0um or lower size bins; at least 2 channels in between 1.0um – 2.5um, and 3 or more channels for the range 2.5um – 10um.
2. A test aerosol generator (atomizer) and a particle mixing chamber
   - Should have capability to generate particles specified in the Test Condition.
3. A diffusion dryer (control humidity of the generated particles)
4. A neutralizer (to ensure the particles are electrically neutral)
5. A duct type test chamber
   - Should not be susceptible for changing its volume or shape, constructed with non-static materials, and air-tight. At least 1m^3, less than 8m^3 in volume is recommended.
6. A fan (for mixing up particles within the test chamber)
7. Temperature and RH measurement devices
8. HEPA filter
9. Piera device(s)

   Air purifier (Optional: to control the particle concentration within the chamber)

3.3 Test environment Setup

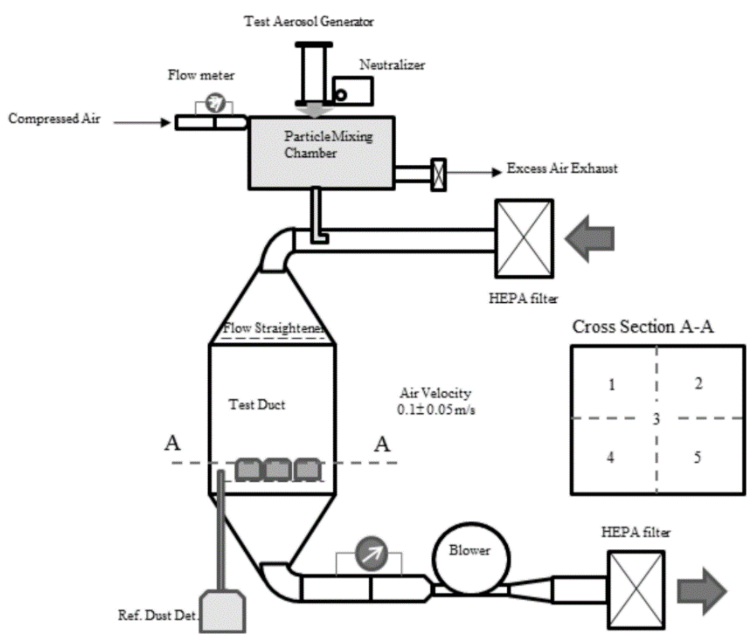

Figure 1. Sample test equipment setup.

1. Setup a test environment according to Figure. 1. It is recommended to have an exhaust vent on the bottom of the test chamber.

2. Locate DUT in the center of the test chamber. Recommended maximum number of DUTs tested simultaneously is four.
3. The air inlet of the reference device should be leveled with the air inlet of DUT. The air inlet of reference device should be 5cm away from DUT's air inlet, and the length of reference device's sampling tube should not exceed 30cm. Stainless steel is recommended material for the tube.

   Note: In a low Reynolds number pressure driven flow of neutrally buoyant particles, there is usually an irreversible dispersion of the particles and a net flux towards the central core resulting in a high concentration region there and low concentration near the walls.

4. Do not obstruct the IPS air inlet and outlet during testing.
5. The DUT should be exposed to the test environment directly, without a cover or enclosure.
6. In case more than one DUT are to be tested simultaneously, ensure that the air inlets are all facing the same direction as the reference device's air inlet.
7. The sum of all projected area of DUT within the test chamber should be less than 5% of the cross section of the chamber. The projected area of the reference device itself should also be included in the sum if the device is located within the test chamber.
8. The particle concentrations at locations specified in Figure 1 "Cross Section A-A" are within 15% of their mean concentration.

3.4 Procedure

1. Circulate filtered clean air through the test chamber prior testing.
2. Generate test particles and inject it to the particle mixing chamber, and set initial particle mass concentration above the maximum specified in Table 2.
3. Stop particle generation, and inject the mixture to the test chamber. A fan may be used to stir the air within the test chamber. The speed should be controlled so that the flow rate is limited to 0.1±0.05m/s within the chamber at any time. Downward air flow direction is recommended.
4. The chamber fan should be turned off and must wait for at least 5 minutes before start taking data from all devices.
5. Turn on the air purifier to gradually decrease particle concentration level within the chamber. This is an optional step in order to expediate the testing. Testing in an undisturbed condition, without a purifier can also be done.
6. Collect data for at least 600 seconds – or until the mass concentration within the test chamber reaches the minimum concentration level specified in Table 2.
7. Ensure that at least 30 data points are recorded before the mass concentration within the test chamber reaches the minimum concentration level specified in Table 2.
8. Record temperature and relative humidity during the testing.
9. Properly clean out the test chamber with filtered air.