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Improved Particle Counting Accuracy in Manifold Monitoring

Abstract

Many particle counter users are unaware that – during traditional manifold sampling – the monitor undercounts the ambient particle concentration. Because of the additional vacuum created by the manifold pump, the particle concentration is substantially lower in the air sampled than in the ambient cleanroom air. Unless the system adjusts appropriately, this lower-than-expected particle density causes a 7 – 17% under-reporting of particle concentrations.

Figure 1. AM II 16 Aerosol Manifold system

Historically, different particle counters have used different methods of compensating for this undercounting. To date, none of these compensation techniques have resulted in truly accurate numbers; some have lead to additional errors, such as particle mis-sizing, which in turn caused 40% underreporting in the first channel.

Particle Measuring Systems has now developed a system where these counting errors are automatically eliminated. When used with the Aerosol Manifold II, the Lasair II/III's proprietary system for pressure monitoring and flow control makes it possible for the first time to correctly normalize the raw counts and calculate accurate cleanroom particle concentrations.

Introduction

The Lasair® III is the latest generation of aerosol particle counter from Particle Measuring Systems. The Aerosol Manifold II is designed to work with the Lasair III and the Lasair II, under the control of Particle Measuring Systems facility monitoring software (Facility Net or Pharmaceutical Net). This paper reviews the measurement errors inherent in manifold monitoring, then explains the patented pressure measurement and normalization techniques that PMS uses to eliminate these problems.

Figure 2. Lasair II 110 particle counter.

Figure 3. Lasair III 310C particle counter.

Particle Undercounting in Manifold Systems

In traditional manifold systems a powerful pump pulls air simultaneously from as many as 32 different monitoring locations; each location can be as far as 125 ft. away. This large cumulative length of tubing, plus the volume of air being moved, requires the pump to create a strong vacuum. Thus, when the particle counter in turn must sample air from the manifold, it also must operate at a vacuum; the counter no longer draws air at room pressure (as it would if no manifold were being used).

This increased vacuum (i.e., lower pressure) in the particle counter causes an error in the measurement of ambient particle concentration. A 1.0 CFM particle counter is designed to generate a 1.0 CFM flow at a constant velocity at the sample inlet pressure. In standalone (non-manifold) use, the sample inlet pressure is essentially the same as the atmospheric pressure, so the unit maintains a 1.0 CFM flow, plus or minus its nominal tolerance (e.g., 5%).

With a manifold attached, however, the entire system operates at a lower than ambient pressure; this is due to the vacuum required to pull air through the long lengths of manifold tubing. As a result, the 1.0 CF sampled at the inlet will have a lower concentration of particles than observed in 1.0 CF of ambient air (see Figure 4). Thus, the particle count per cubic foot with a manifold will be proportionately lower than if sampled directly from the ambient air.

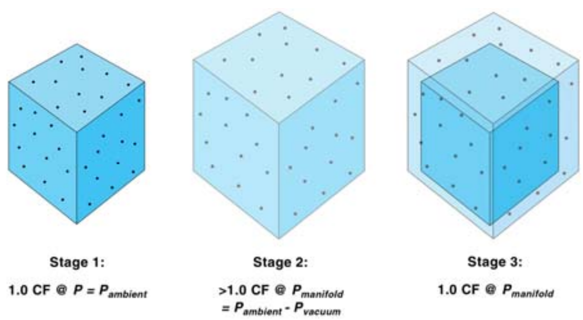

Figure 4. Impact of manifold vacuum on particle concentration.

- **Stage 1**:
  1.0 CF sample of ambient air has a defined particle concentration.
- **Stage 2**:
  Once this sample enters the manifold tubing, the vacuum created by the manifold pump causes the sample to expand; particles are dispersed over a larger volume.
- **Stage 3**:
  When the counter now samples its 1.0 CF of manifold air at the sample inlet pressure, the particle concentration is lower than in the ambient air.

To provide truly accurate results, the manifold system must compensate for this change in pressure. To understand how the Lasair II/III compensation system works, it is helpful first to review its pressure measurement system.

Pressure Measurement in the LASAIR II/III

The Lasair II/III uses a new, patented pressure measurement system to avoid the undercounting problems traditionally associated with the use of a manifold. At the heart of the system are three separate pressure transducers:

1) The first pressure transducer monitors the pressure inside the sample inlet. This sensor allows the Lasair II/III to measure and correct for the vacuum caused by the manifold pump.

2) A differential pressure sensor measures the difference between the pressures before and after the sample cell. The Lasair II/III uses this information to regulate the flow rate and velocity through the sample chamber.

3) A third pressure transducer measures the ambient atmospheric pressure.

Figure 5 shows the pressure sensor system the Lasair II/III uses to detect and compensate for flow anomalies.

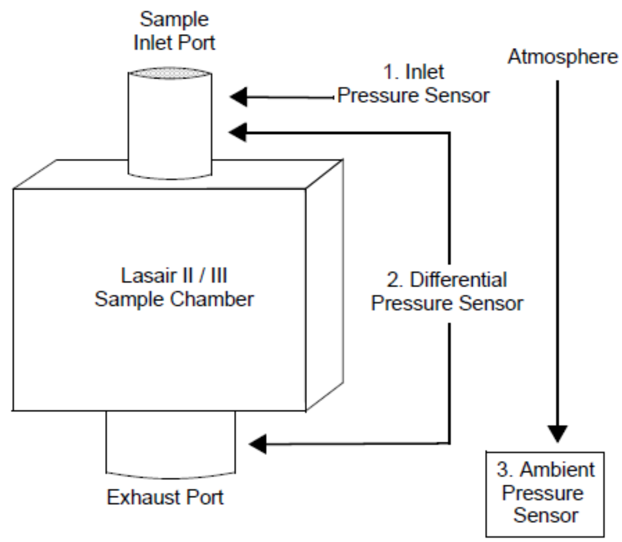

Figure 5. LASAIR II/III Pressure Sensor System.

Concentration Correction Factor with the LASAIR II/III

Airflow in the Lasair II/III is servo-controlled using the data from the sample inlet and the differential pressure sensors. This information is used to adjust the Lasair II/III blower/pump to generate a 1.0 CFM flow rate at a constant velocity at the sample inlet pressure. In normal sampling, this sample inlet pressure is approximately the same pressure as in the cleanroom. As seen in Section 2.0, however, when using a manifold, the air at the inlet is at a partial vacuum with respect to cleanroom air. Thus, the 1.0 CF sampled has a lower particle concentration than 1.0 CF of ambient cleanroom air.

To correct for this phenomenon, the Lasair II/III calculates the equivalent ambient volume sampled (instead of the nominal 1.0 CF). This is done by multiplying the measured sample volume times the ratio of the density of the air at the inlet to the density of ambient cleanroom air:

(1) Equivalent Ambient Sample Volume (CF) = Measured Volume*Inlet Density/Ambient Density, which can be simplified to:

(1a) Equivalent Ambient Volume (CF) = Measured Volume*Inlet Pressure/Ambient Pressure.

Example: Calculating Equivalent Ambient Volume

Background:

Manifolds draw about 25” to 50” H_2O (or 6.2 to 12.4kPa) of vacuum

Atmosphere at sea level is approximately 101.3kPa.

#1) What is the equivalent ambient sample volume at 25” H_2O of vacuum (at sea level)?

1.0 CF * (101.3kPa – 6.2kPa) / 101.3kPa = 0.939 CF.

#2) What is the equivalent ambient sample volume at 50” H_2O of vacuum (at sea level)?

1.0 CF * (101.3kPa – 12.4kPa) / 101.3kPa = 0.878 CF.

Normalizing Counts in Facility Net (or Pharmaceutical Net)

Once the equivalent ambient sample volume has been calculated, the raw particle counts can be correctly normalized:

(2) Normalized particle count (N/CF) = Observed particle count/Equivalent ambient sample volume, which is equivalent to:

(2b) Normalized particle count (N/CF) = Observed particle count * Ambient pressure/Inlet pressure.

In the Lasair II/III manifold system, both raw counts and equivalent ambient sample volumes are communicated to Facility Net (or Pharmaceutical Net), which then performs the normalization calculations. (For example, for an equivalent sample volume of 0.93, the normalization factor would be 1.0/0.93 = 1.075.) If desired, the raw counts are still available.

Correction/Normalization Table

Table 1 provides the equivalent ambient sample volumes (compared to the nominal 1.0 CF sample volume) for a wide range of manifold operating conditions. Notice that the equivalent sample volume may need correction for altitude as well as for manifold vacuum.

Table 1. Equivalent Ambient Sample Volume (CF) in Manifold Systems

Altitude (ft)	**Manifold Vacuum (inches of H_2O)**					
	30	**35**	**40**	**45**	**50**	**55**
0	0.93	0.91	0.90	0.89	0.88	0.86
1000	0.92	0.91	0.90	0.88	0.87	0.86
2000	0.92	0.91	0.89	0.88	0.87	0.85
3000	0.92	0.90	0.89	0.87	0.86	0.85
4000	0.91	0.90	0.88	0.87	0.85	0.84
5000	0.91	0.89	0.88	0.86	0.85	0.83

As can be seen, when using a manifold system, the equivalent ambient volume sampled typically will be only 83 – 93% of the 1.0 CF that the particle counter sampled. Systems that fail to compensate will under-count particle concentrations by 7 – 17%.

Shortcomings of Alternative Compensation Techniques

Over the years, particle counter users have employed a variety of techniques for compensating for this undercounting phenomenon. The most common has been, upon installation, to increase the pump speed so the equivalent ambient volume is closer to the nominal 1.0 CFM.

As another alternative, a few manufacturers have tried using a mass flow controller to servo-control the pump. Such controllers automatically increase the volume flow to ensure that the particle counter samples the target mass. Thus, the same mass is sampled as in 1.0 CFM of ambient air.

Unfortunately, both of these techniques require increasing the velocity through the sample chamber. This causes two problems: First, increasing the velocity causes the traditional particle counter to lose its calibration, to the point that it no longer meets JIS specifications. Second, increasing the sample velocity also causes a new type of problem, particle-sizing errors:

Counters determine particle size by evaluating the shape of the pulse a particle generates as it passes through the laser beam; the shape recognition algorithms used to accomplish this are set during calibration. If, however, the same particle passes through the beam more quickly, the pulse is smaller; this results in some percentage of the particles being misclassified as belonging to a smaller size channel. In the smallest size channel, some particles will not be counted at all.

Thus, increasing the sample velocity reduces the counting efficiency. Moreover, where before one could calculate the degree of undercounting (see Sections 4 & 5), now the size of the error becomes very complicated to predict.

Figure 6 illustrates particle-sizing errors caused by increasing the sample velocity in a manifold system. This graph shows three separate tests run on a Lasair II-325 connected to the Aerosol Manifold II via a 125’ sample line. The first bar illustrates counting losses (in 0.3 µm particles at 50” H2O pressure) when the sample velocity was increased to achieve an equivalent ambient flow rate of 1.0 CFM. Note that the counts dropped to under 60% of those seen by the reference unit. While these data reflect the first channel, the higher channels also were impacted.

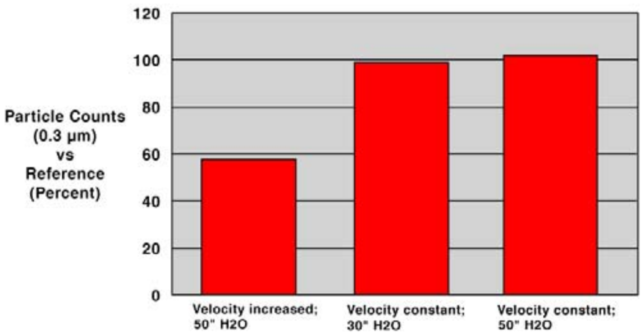

Figure 6. Particle sizing errors due to increased sample velocity.

In the next two bars on Figure 6, normal sample velocity was maintained so that the unit drew its normal 1.0 CFM at constant velocity at the sample inlet pressure. For these cases the normal counting efficiency was maintained; counts were approximately 100% of those seen by the reference unit.

The Lasair II/III system avoids these under-sizing errors, as well as the original undercounting errors. It avoids under sizing errors by maintaining the same sample velocity throughout. It then uses Facility Net (or Pharmaceutical Net) to correctly normalize the data to eliminate undercounting errors (see Sections 2.0, 5.0, and 6.0).

Conclusions

The powerful vacuum of the manifold pump causes the particle concentration of the sample to be lower than the particle concentration of ambient cleanroom air. Unless the system compensates properly, this lower concentration results in a corresponding under-reporting – typically under-counting by 7 – 17%.

Previous manifold sampling systems have either ignored this error, or have used some compensation system. Until now, none of these compensation techniques have produced truly accurate counts. In part, this is because most have been based upon increasing the sample velocity; this in turn has generated particle under-sizing errors, which also resulted in as much as 40% under-reporting in the first channel.

The Lasair II/III offers the only manifold system that corrects for both of these issues. Using data from the patented pressure-sensor system, the Lasair II/III calculates the pressure-corrected, equivalent ambient sample volumes, and then sends Facility Net (or Pharmaceutical Net) the normalization factors required to produce accurate measurements.

1/23/2012