LIGHTHOUSE
WORLDWIDE SOLUTIONS

Verifying Sterility

Gas Sampling in Semiconductor and Pharmaceutical Cleanrooms

Author: Jason Kelly, Applications Director

Overview

Contamination Free Manufacturing (CFM) of Integrated Circuits (ICs) and Sterile injectable pharmaceutical products has historically involved particle control and removal.

Although yield-destroying and batch destroying defects are often traced to process non-uniformities, a majority of the effort to control contamination in IC & Pharma facilities has focused on particle control.

Cleanrooms are defined by the particle concentrations in the air and designers of processing equipment strive to minimize the number of particles-per-wafer processed through the equipment or particulates found in injectable medicines.

Micro Contamination in Pharmaceutical Cleanrooms

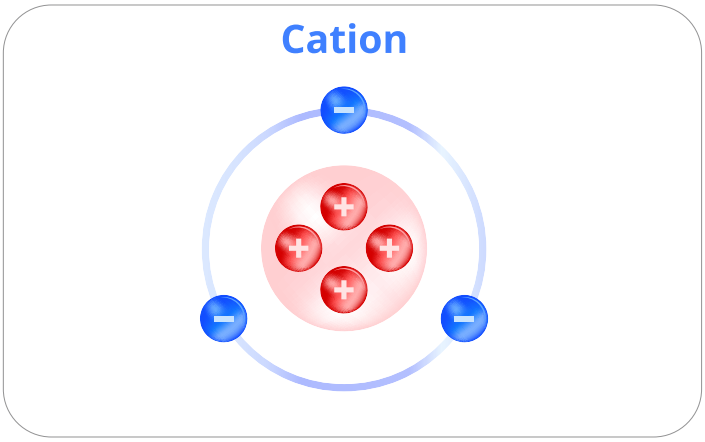
When a medication is contaminated with microorganisms like bacteria or fungus, the consequences can range from harmless to fatal. For nonsterile drugs taken orally, the effects may be less likely to be dire, as our gastrointestinal tracts provide a highly acidic, unhospitable environment that can kill most microorganisms.

However, medications that are administered intravenously or in the form of eye drops, must be completely sterile. Any contaminant can find its way directly into the bloodstream, causing sepsis or even death.

Therefore, the monitoring of particles in these pharmaceutical sterile manufacturing environments is critical to ensure patient safety and product efficacy and quality.

What are Different Types of Wafer Contamination?

Contaminants on a Si wafer's surface are just absorbed ions, elements, particles, and gases, which were acquired during the entire wafer manufacturing process. Surface contaminants can be classified into four types:



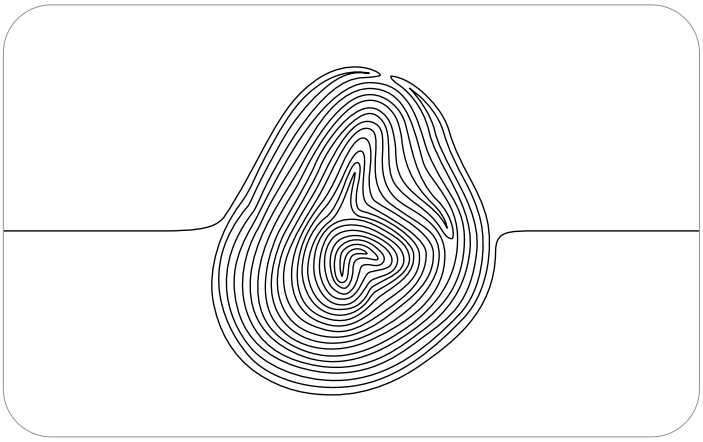
Ionic Materials

Ionic materials are composed of cations and ion that can be physically adsorbed or chemically bonded from inorganic compounds.

Examples are chlorine, sodium, and fluorine.

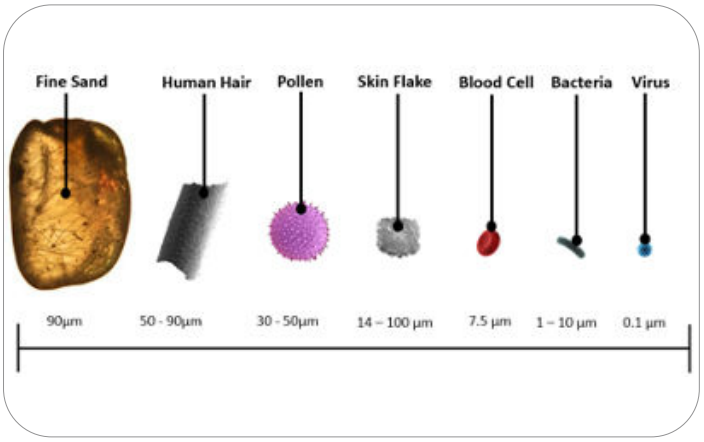
Elemental Particles

Also called atomic particles, these are made from metals such as copper and other heavy metals that can be electrochemically plated out on the surface of the semiconductor. They may also consist of dust, metal debris, fibers, and Si particles.



Molecular Compounds

Molecular compounds are films or particles of condensed organic vapors from greases, solvent residues, photoresists, fingerprints, metal oxides, hydroxides, lubricants, and other organic compounds.



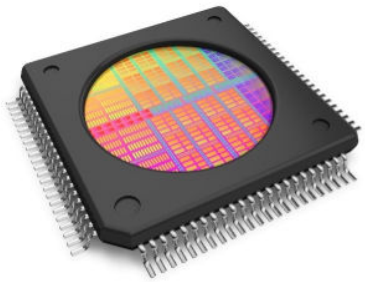
Airborne Dust

Contaminants can spawn from airborne dust during processing. It can be acquired from equipment, factory operators, wafer handling, chemical processing, film deposition, and gas piping. Moving equipment and containers for liquids are the number one carrier of particles and contaminants that can transfer on a Si wafer. On the other hand, solid materials, ambient air, gases, liquids, and chemicals don't accumulate as many particles, so they cause less particle contamination.

Sources of Semiconductor Cleanroom Contamination

Foreign Materials:

- **Fluid Impurities:** Chemicals, Gas.
- **Tools' Impurities:** Corrosion, Out-Gassing, and Handling.
- **Particles:** Suspensions within Fluids, Abrasion, Environment, Operators.



Parasitic Reactions

- Between Reactive Materials.
- Corrosion, Out-Gassing, Dissolution of Tool Parts.

Contamination Classification	Elements	Sources	Wafer Effects
Ionic Contaminant	Alkaline Na, K	• Human Pollution • Works • Chemical and Gases	• Electrical Instability Gate Oxide Leakage Retention
Ionic Contaminant	Transition Metals: Ni,Co,Fe,...	• Human Pollution • Works • Chemical and Gases • Networks-tools-processes	• Gate Oxide Integrity (GOI) degradation
Ionic Contaminant	Dopants: Al, P, In, Ga, As, B,...	• Process: Wet Processes, Implantation/Works • Material Out-Gassing • Chemical and Gases	• Shift of voltage threshold in the transistor device
Ionic Contaminant and Air Molecule Contaminant	Acids: F-, Cl-, CH3COO-, Br-, PO4--, SO4--	• Process pollution: Etch, Wet Process • Chemical Vapor Deposition (CVD) • Works • Material Out-Gassing • Traffic Pollution • Industrial Poluution	• Pad Corrosion • Aluminum Corrosion • Defectivity on Deep UV (DUV) and Mid UV (MUV) Resist • Salt Deposition on Lens, Masks, and Wafers
Ionic Contaminant and Air Molecule Contaminant	Bases: NH3 Amines	• Process pollution: Etch, Wet Processes • CVD Deposition • Works • Material Out-Gassing • Traffic Pollution • Industrial Pollution	• Footing on DUV Resist • Salt Deposition on Lens, Masks, and Wafers • Photolithography activation, especially with 193nm process
Organics	Organics	• Process Pollution: Wet process and Lithography process	• Photolithography activation, especially with 193nm process Eg: Contamination with solvent on resist
Particles	Organics	• Process Pollution: Dry Etch Polymers, Resist Strip, Wet Process • Material Out-Gassing • Chemicals and Gasses	• Gate Oxide Integrity • High Resistivity Contact • Deposition on Surface • Lens Degradation • Defectivity with Opens or Shorts on Pattern Wafers
Particles	Inorganic	• Process Pollution: Dry Etch Polymers, Resist Strip, Wet Process • Material Out-Gassing • Chemical and Gases	• Gate Oxide Integrity • High Resistivity Contact • Deposition on Surface • Lens Degradation • Defectivity with Opens or Shorts on Pattern Wafers

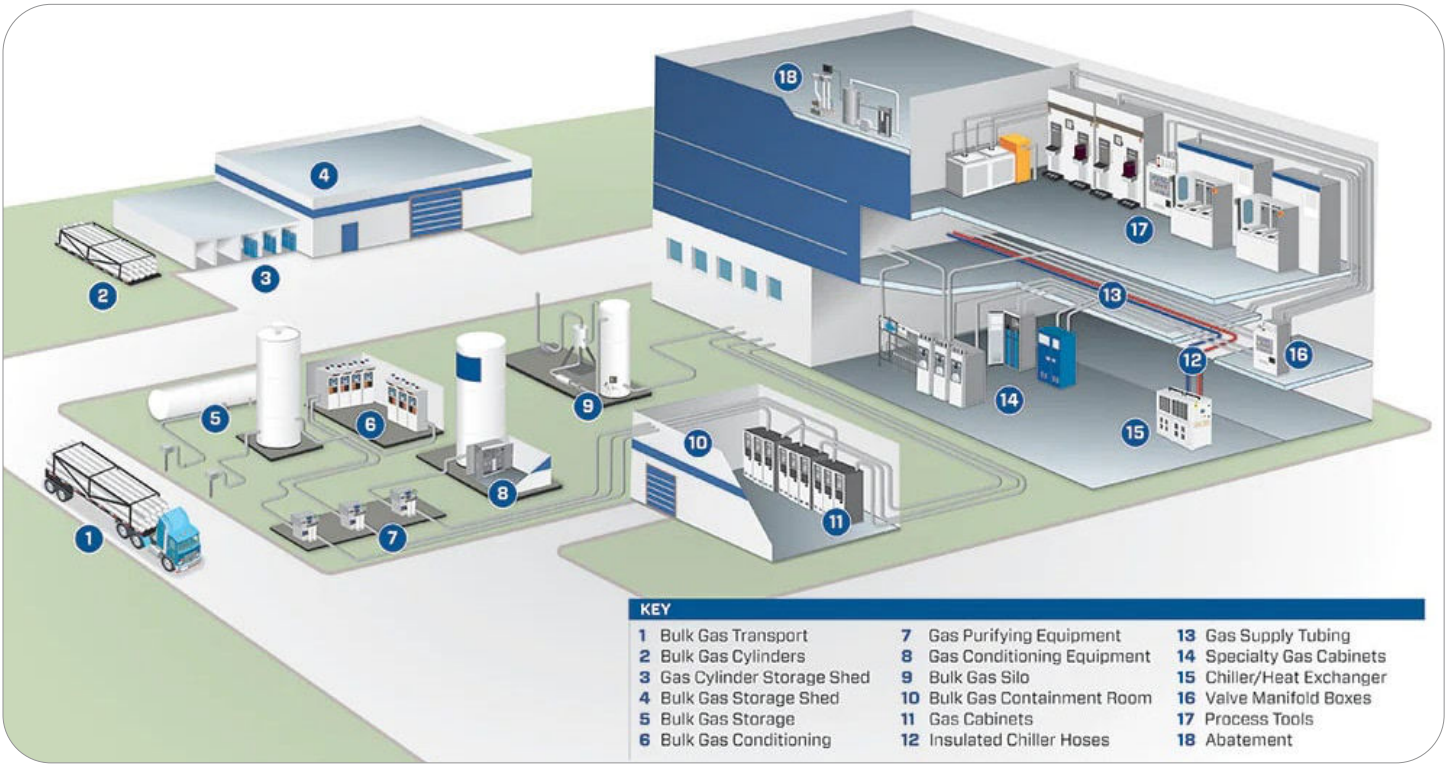


Image courtesy of asml.com

Gases in the Semiconductor Industry

In the semiconductor industry, compressed gases are essential for a wide range of processes from the fabrication of microchips to cleaning and maintenance:

Ammonia and Silane: Used in chemical vapor deposition (CVD) to produce silicon nitride and silicon films, respectively.

Argon: Used in sputtering processes to deposit thin films and in plasma etching and cleaning.

Chlorine and Boron Trichloride: Used in etching processes to create microelectronic circuits on semiconductors.

Clean Dry Air (CDA): Used for tools and machinery that require clean, moisture-free air.

Helium: Employed for cooling in various equipment and as a carrier gas for thin film deposition.

Hydrogen: Used as a reducing agent in various processes, including atmospheric annealing and epitaxial layer deposition

Nitrogen: The most widely used gas for purging and inerting, as well as for providing a clean, dry atmosphere for process and storage operations to prevent oxidation.

Oxygen: Utilized in oxidation processes to grow silicon oxide layers on wafers.

Sulfur Hexafluoride (SF_6): Commonly used as an insulating gas in electrical equipment as well as plasma etching.

Bulk gases are a significant portion of supply spend for semiconductor and display fabs. Effective supply often requires on-site production, storage, and distribution. These facilities are built concurrently with the fab, and the first qualified gas deliveries are made as soon as the fab shell is complete.

Gases in the Pharmaceutical Industry

In recent years, we have seen an increase in regulations centered around comprehensive contamination control plans. For example, the GMP Annex 1 2022 update revolves around building your cleanroom according to a risk-based contamination control plan that considers higher testing standards and levels. To stay in compliance with these ever stringent and increasing regulations, it is important to consider every factor of your contamination control plan, including monitoring compressed gases.

Compressed gases play several critical roles in the pharmaceutical industry, ranging from production processes to packaging and quality control:

Argon: Used as a protective atmosphere for the storage and packaging of pharmaceuticals to prevent oxidation.

Carbon Dioxide: Utilized in supercritical CO_2 extraction processes for pharmaceuticals, which is an efficient method for extracting active ingredients. It's also used in pH control of water used in pharmaceuticals.

Clean Dry Air (CDA): Used in pneumatic systems and for instrumentation that requires clean, moisture-free air.

Ethylene Oxide: Used for sterilizing medical products and devices.

Helium: Sometimes used for leak detection in packaging because of its small molecular size and inert properties.

Hydrogen: Employed in hydrogenation processes, which are crucial for the manufacture of many drugs.

Nitrogen: Used extensively for inerting and blanketing to protect oxygen-sensitive materials from degradation or combustion. It's also used in freeze-drying (lyophilization) processes to remove moisture from pharmaceutical products.

Oxygen: Employed in fermentation processes for aerobic bacteria and in various biosynthesis processes.

All compressed gases are one of three major categories: Liquefied, Non- Liquefied, and Dissolved Gases. Liquefied gases are gases which can become liquids when under pressure in th cylinder. Propane, nitrous oxide and carbon dioxide are examples of liquefied gases.

Compressed air is used abundantly in pharmaceutical and electronics cleanrooms. Some uses of compressed gases include: de-dusting, spray-coating tablets, over-pressurizing mixing and holding tanks, driving liquids through fill lines and filters, and operating control valves.

There are several ways in which particle contaminants can get into compressed gases:

Compressor Wear: Particles can be generated from the mechanical wear and tear of compressor components. Metal flakes or rubber from seals and gaskets can contaminate the gas as it is compressed.

Desiccant Dust: Desiccant used in drying the compressed gas can break down, leading to desiccant dust particles being carried along with the gas flow.

Handling and Transportation: Handling and transporting gas cylinders can stir up particles that may have settled or introduce new contaminants from the environment where the cylinders are stored and moved.

Improper Filtration: Inadequate filtration within the gas delivery system, or failure to properly maintain filters, can allow particles to pass through. Filters may also shed fibers or particles themselves.

Installation and Maintenance Activities: Particles can be introduced during installation or maintenance of the gas delivery system. This includes dust and debris from new piping or from maintenance tools and processes.

Intake Contamination: Particles from the ambient air can enter the gas during the initial intake process if the intake filters are inadequate or have become degraded over time.

Residual Particles from Manufacturing: Residual particles from the manufacturing process of the gas cylinders or the gas itself might not be completely removed and can contaminate the gas.

System Corrosion: Internal corrosion of the compression system and the piping can release particles into the gas stream. Moisture in the system can accelerate this corrosion, increasing the risk of contamination.

What Gas Standards are used or followed?

ISPE Good Practice Guide provides the following chart as a helpful recommendation of sampling using cleanroom specifications for compressed air plans per contaminant:

Test	Frequency / Location
Nonviable Particles	Tested every 3 months on a rotating basis for sampling locations following the central systen's final filter at predetermined locations on the horizontal piping run for each floor.
Viable Particles	Tested every 3 months on a rotating basis for sampling locations following the central system final filter and at predetermined locations on the horizontal piping run for each floor.
Dew Point (moisture)	Monitoring continuously using in-line dew point instrumentation following compressed air dryer.
Hydrocarbon (oils)	Annual sampling and testing following the coalescing filter to verify the hydrocarbon content of the compressed air system.

The International Society for Pharmaceutical Engineers (ISPE) Good Practice Guide, recommends, "in cases where the gas is entering a classified area, it is required to at least meet the room classification limits established for the cleanroom environment" (2016).

ISO Standards:

ISO 8573: This series covers the purity classes and contamination levels for particles, water, and oil in compressed air. It specifies methods for measuring contaminants and is widely used as a reference for air quality across various industries.

ISO 7396: This standard covers medical gas pipeline systems, including requirements for the supply systems for compressed medicinal gases.

ISO 12500: This series complements ISO 8573 by providing detailed methods for testing air treatment equipment used in compressed air systems, including filters and dryers. It helps in assessing the performance of equipment intended to remove contaminants such as oil aerosols, vapors, and particulates.

ASTM Standards:

ASTM G93: Standard for cleaning and testing materials used in oxygen-enriched environments, which includes guidelines for handling gases to prevent contamination.

ASTM D1945: Standard test method for analyzing natural gas by gas chromatography, which can be adapted for other compressed gases to determine their composition.

ASTM D2986: Standard practice for the evaluation of air-assay media by the monodisperse DOP (dioctyl phthalate) smoke test, useful in assessing filter performance in gas handling systems.

Compressed Gas Association (CGA) Standards:

CGA G-4.1: Pertaining to cleaning equipment for oxygen service, outlining methods for ensuring that compressed oxygen and other gases do not become contaminated.

CGA G-7: A guidebook on the proper use and handling of compressed gases, providing broad guidelines on storage, handling, and procedures for maintaining gas purity.

European Pharmacopoeia (Ph. Eur.) and United States Pharmacopeia (USP):

These pharmacopeias include standards and specifications for medical gases, detailing purity requirements, testing methods, and handling procedures to ensure safety and efficacy in pharmaceutical applications.

US FDA Guidance for Industry

Sterile Drug Products Produced by Aseptic Processing – Current Good Manufacturing Practice recommends that "compressed gas should be of appropriate purity… and it's microbiological and particle quality after filtration should be equal to or better than that of the air in the environment into which the gas is introduced."

SEMI Standards:

Specifically for the semiconductor industry, the SEMI standards cover everything from gas chemical purity to material compatibility and handling practices, ensuring that the gases do not introduce contaminants that could affect semiconductor manufacturing processes. In the semiconductor industry, the gases used in the manufacturing process are graded primarily based on their purity levels, as even minute impurities can significantly impact the quality and performance of semiconductor devices. The grading of semiconductor gases is typically divided into several categories:

Electronic Grade: This is the most common grade used in semiconductor manufacturing. Electronic grade gases are highly pure, typically 99.999% pure or better, often referred to as "Five Nines" purity. The specification might extend to even higher purity levels like 99.9999% ("Six Nines") depending on the requirements of specific applications.

Ultra-High Purity (UHP): UHP gases are a step above the standard electronic grade, required for processes where even trace amounts of contaminants could be detrimental. These gases are usually 99.9999% pure or better. UHP gases are critical for manufacturing processes like oxidation, deposition, and various etching processes, where absolute control over contaminants is necessary.

Research Grade: Research grade gases are used primarily in R&D environments where experimental processes are conducted. These gases might have specific tailored compositions and are characterized by high purity levels similar to or sometimes exceeding those of UHP gases.

Instrument Grade: Used primarily for calibration and instrumentation applications within the manufacturing process, instrument grade gases are highly reliable for ensuring the accuracy and performance of analytical equipment. They have stringent requirements for both purity and consistency.

Spec Gas (Specification Gas): Spec gases are defined by their specific compositions to meet the exact requirements of particular processes. They often have defined levels of certain dopants or contaminants that are precisely controlled to achieve the desired characteristics in a semiconductor device.

The grading of gases is supported by rigorous testing and certification processes, which include:

Particulate Count: Ensuring that the gas contains minimal solid particles, as these can clog or contaminate semiconductor tools.

Moisture Levels: Moisture is often a critical contaminant in semiconductor processes and must be controlled to extremely low levels.

> "Particulate Contamination in gases is related to a sample colume of 1cubic foot based on allowable limits at a particular size."

For example, 10/0.01 N2 mean 20 10 particles of size @0.1um for Nitrogen pipline gas (SEMI C6.6)

semi MEMBER

ISO 8573

This is the primary and most widely recognized international standard for compressed air quality. It specifies the amounts of contamination allowed in terms of particles, water, and oil in compressed air systems, and outlines methods for measuring these contaminants. ISO 8573 is divided into several parts, each focusing on different types of contaminants. This standard is often used as a benchmark for compressed gases in various applications, not just compressed air. ISO 8573 is made up of 9 parts:

ISO 8573-1: (2010)

Quality Classes: This part is the cornerstone of the standard, defining the quality classes of compressed air with respect to particles, water, and oil. Each class specifies the concentration limits for these contaminants. For instance, the classes for particulates determine the number of particles per cubic meter and are classified by their size. Similar classes exist for humidity (water content) and oil (both aerosol and vapor forms).

ISO 8573-2: (2018)

Test Methods for Oil Aerosol Content: Provides the methodologies for quantifying the amount of oil aerosol present in the compressed air.

ISO 8573-3: (1999)

Test Methods for Humidity: Outlines the methods for measuring the moisture content of compressed air, which is critical for applications where moisture can impact product quality or process efficiency.

ISO 8573-4: (2019)

Test Methods for Solid Particles: Describes the techniques used to determine the concentration and size distribution of solid particles in compressed air, essential for preventing contamination in sensitive manufacturing processes.

ISO 8573-5: (2001)

Test Methods for Oil Vapor and Organic Solvent Content: Specifies procedures for measuring the amount of oil vapor and organic solvents, which are crucial for applications requiring highly pure air, such as in pharmaceutical and food production.

ISO 8573-6: (2003)

Test Methods for Gaseous Contaminants: Provides guidelines for identifying and measuring gaseous contaminants in compressed air, including but not limited to CO, CO2, SO2, NOx, and hydrocarbons.

ISO 8573-7: (2003)

Test Method for Viable Microbiological Contaminant Content: Details the procedures for assessing the presence of viable microbiological organisms in compressed air, an important consideration for industries like pharmaceuticals and food processing where sterility is paramount.

ISO 8573-8: (2004)

Test Methods for Solid Particle Content by Particle Counting Using Optical Particle Counter: Expands on part 4 by introducing an optical particle counting method for more precise measurement of particle contamination.

ISO 8573-9: (2004)

Test Methods for Liquid Water Content: Outlines methods to measure liquid water content in compressed air, which can be critical in avoiding corrosion and ensuring the integrity of pneumatic systems.

Example of connection of compressed gas to High Pressure Diffuser to Particle Counter

Monitoring the particle count within compressed gases

ISO 8573 – Part 4:

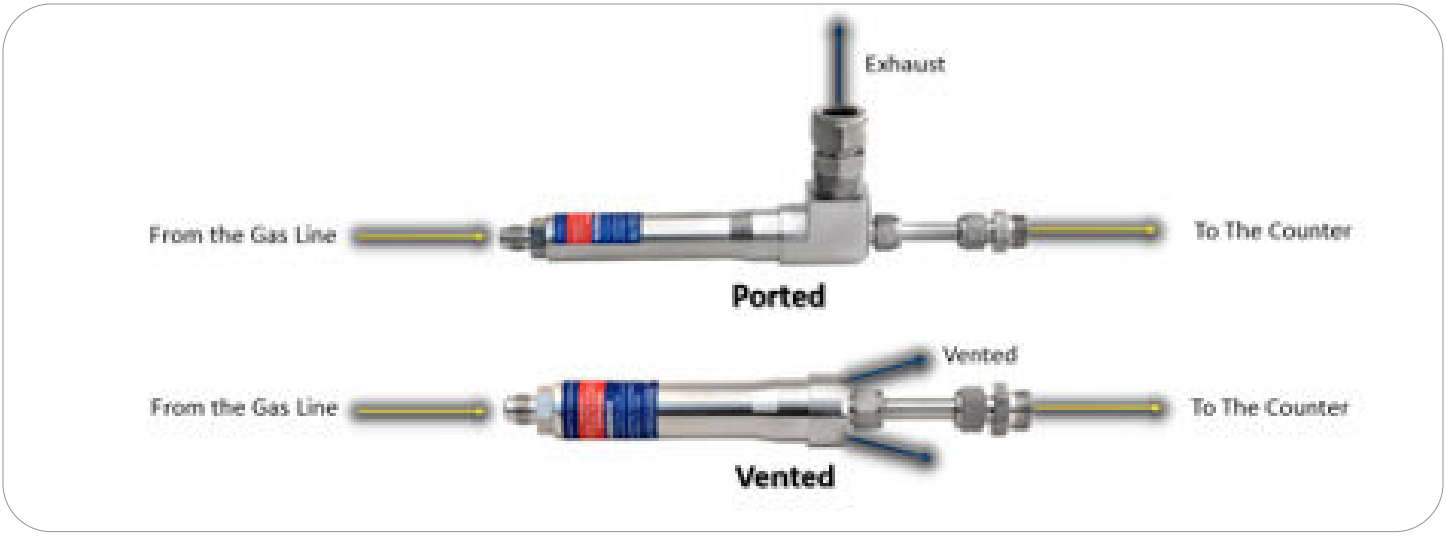
1. Provides a sampling method for compressed air.
2. A guide for choosing suitable measuring equipment to determine its particle size and concentration by number.
3. Establishes a minimum sampling volume of 1000L (1m³).
4. Use of Optical Particle Counter for testing sizes from ≥ 0.1 to ≤ 10µm.For non-viable particles a Particle Counter is used with a High Pressure Diffuser (HPD) placed inline between the gas line and the particle counter sample inlet. The HPD diffuses the high pressure gas so the flow rate of the sample is equalized. It is critical that the flow rate is maintained correctly.

Class	Maximum number of particles per m³ (see clause 5)				Particle size	Concentration
	Particle size, d µm				µm	mg/m³
	$\leqslant 0{,}10$	$0{,}10 < d \leqslant 0{,}5$	$0{,}5 < d \leqslant 1{,}0$	$1{,}0 < d \leqslant 5{,}0$		
0	As specified by the equipment user or supplier and more stringent than class 1				Not applicable	Not applicable
1	Not specified	100	1	0		
2	Not specified	100 000	1 000	10		
3	Not specified	Not specified	10 000	500		
4	Not specified	Not specified	Not specified	1 000		
5	Not specified	Not specified	Not specified	20 000		
6	Not applicable				$\leqslant 5$	$\leqslant 5$
7	Not applicable				$\leqslant 40$	$\leqslant 10$

NOTE A filtration ratio (β) related to a particle size class is the ratio between the number of particles upstream of the filter and the number of particles downstream. This can be expressed as ($\beta = 1/P$), where P is the penetration of the particles expressed as the ratio of down stream particle concentration to upstream particle concentration. The particle size class is used as an index, e.g. $\beta_{5,0} = 75$ means that the number of particles of size 10 µm (β_{10}) and larger is 75 times higher upstream of the filter than downstream.

ISO 8573 Limits for max particles per m3 from class 0 to 7

To sample compressed gas, a particle counter will need an accessory called a High Pressure Diffuser (HPD). The HPD connects the particle counter and the compressed gas line and diffuses the gas as is enters the particle counter sample inlet. If the high-pressured gas enters the particle counter sample inlet without the HPD, the sensor inside the particle counter can be damaged and the results of the testing will not be accurate.



High Pressure Diffusers:

HPD is required to reduce the pressure of the gas to be sampled to ambient such that the gas may be sampled at the instrument's standard flow rate while at the same time not introducing particulate contamination to the gas sample. In addition to the required pressure reduction, the HPD maintains isokinetic flow through to the device output to ensure that the size-distribution of any particles suspended in the gas is correct and uniform. This Particle Counter system above is suitable for monitoring gases in the Pharmaceutical Industry.

When testing dangerous gases it is important to ensure the gas is ported and exhausted away from the test environment and the operator safely. HPDs come in two forms

1. Ported for safe ventilation
2. Vented for use with atmospheric gases such as, Nitrogen, Oxygen, Argon, Carbon dioxide and other safe gases to locally vent include Helium, Nitrous Oxide and Hydrogen.

Semiconductor Applications gas monitoring down to 100nano meters

In the electronics industry there is a requirement to monitor smaller particle sizes down to 0.1µm. The most advanced setup is the High-Pressure Controller (HPC) in combination with a **Solair 1100LD** (0.1 to 5.0µm) particle counter.

Solair1100LD Laser Particle Counter with HPC gas flow controller used in semiconductor, hard disk drive and flat panel display LED industries.

Application example of Semiconductor Nitrogen gas system being monitored down to 100nm

What is Required to monitor for microbiological particles in compressed gases?

Analyzing micro burden data at point of use outlets throughout compressed air pipeline systems at a given time, acts as a window of observation into the control of the facility. Maintaining control means proper preventative maintenance, microbial monitoring scheduling and risk assessment must be appropriate for the industry being monitored. Many accreditation bodies can aid in the understanding of microbial limits and specifications, critical to specific industry needs.

Once the compressed air microbial monitoring plan is approved, a sampling procedure that provides the company with the results suitable to its limits and specifications needs to be established. This requires the use of a procedure that accurately measures and samples a specific volume of air for microbial burden analysis inside the tested compressed air system.

To monitor for viable particles an active air sampler is used with a HPD connected to the sample inlet. The other end of HPD connects to the gas line.

ISO 8573-7:2003 Compressed Air – Part 7: Test method for viable microbiological contaminant content is followed for this type of monitoring.

Microbiological Air Sampler with Gas Sampler adapter attached to monitor gas lines for microbial contamination.

The Gas Sampler is a high-performance portable gas sampling adapter for use with the **ActiveCount** microbiological air samplers

The **Active Count100H** illustrated above has a unique flow control interface that stabilizes the flow, so it is appropriate for sample measurement before the sample media is placed inside the sample head of the device.

ISO 8573 offers valuable guidelines and regulations for testing compressed gasses, a source of viable and nonviable particle contamination in cleanrooms. This is a critical portion of your contamination control plan and should not be overlooked. Either particle counters or active air samplers can be used for gas sampling, depending on your needs. **Lighthouse Worldwide Solution** offers comprehensive and industry standard-setting options for both possibilities, designed to meet your needs, abide by regulations, and keep your cleanroom clean.

For more information on monitoring for contamination in cleanroom applications visit our knowledge center for the most comprehensive library of cleanroom monitoring applications, webinars, tech papers and more:

www.golighthouse.com/en/knowledge-center/

To learn more about our environmental monitoring products, scan the QR code.

SCAN ME