Desiccator Cabinets and Cleanrooms

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When laboratory scientists and chemists speak of "desiccators," they are typically referring to small glass jars that provide economical long-term storage of small quantities of a pre-dried sample or hygroscopic chemical reagent in a general laboratory setting. Glass desiccators may also be used for cooling down a substance that was heated up in a crucible or beaker.

Glass desiccators, however, pose a significant contamination hazard inside of a cleanroom. Further, they cannot maintain the extremely low relative humidity levels required for critical moisture-sensitive devices (MSDs). Semiconductor, medical device, and even pharmaceutical manufacturing processes often require precisely controlled low-humidity storage of MSDs inside a cleanroom because that they are also susceptible to either particle or biological contamination. As we shall see, only specialized desiccator cabinets are suited to this task.

Glass and vacuum desiccators: Inexpensive, but costly The simplest desiccator is a glass jar with a desiccant powder (such as calcium chloride or silica gel) layered on the bottom. A metal tray or ceramic disk provides a small platform for the sample, and the desiccator is sealed using silicone grease. Desiccants create a drying effect through adsorption, a chemical or mechanical process that draws moisture out of the air and retains it. Once the desiccant reaches its saturation point, it can no longer provide moisture protection. In the case of indicating silica silicate gel or anhydrous calcium sulfate, this saturation point is easily identified through a blue-to-pink color change. In order to regain its adsorptive capability, the desiccant must be regenerated through a heating cycle (of 100 C for up to 24 hours, for calcium sulfate) that bakes out moisture. In the simplest desiccators, this regeneration process requires that laboratory personnel replace the saturated desiccant inside the chamber with regenerated material.

This manual handling not only interrupts processing but also makes glass desiccators ill-suited for cleanroom use. The manual manipulation of desiccant typically contributes to airborne contaminant load since most desiccants shed particles, and operator activity itself generates particles. Furthermore, glass desiccators typically provide insufficient drying of critical moisture-sensitive samples due to the inherent limitations of desiccants; most can hold only up to 35 percent of their weight in water and only small quantities will fit within the typical laboratory desiccator.

The vacuum desiccator, a derivative of the glass jar desiccator, offers an alternative to using loose desiccant materials. Applying vacuum to a desiccator jar can effectively dry samples as long as they’re not susceptible to damage in a vacuum environment. However, vacuum desiccators require the addition of a vacuum pump, which contributes noise and contaminants to the cleanroom.

Thus, these simple desiccators are best suited for a general lab setting. Life science researchers and chemists who utilize a glass desiccator typically do not require the particle-free, aseptic conditions of a cleanroom for their research. The use of desiccant powders and greases would immediately contaminate a critical environment.

Desiccant-based dry cabinets

Desiccant-based systems use one of two designs: static and dynamic. A static desiccator (e.g., a glass jar) requires manual regeneration of the desiccant, which as we’ve seen involves breaking the seal of the desiccator and transporting the desiccant to an oven, an inherently dirty process. A dynamic desiccator automatically regenerates the desiccant as it nears saturation, typically using a built-in heating element to evaporate the moisture.

The most common dynamic desiccator is the desiccant-based dry cabinet. Dry cabinets offer greater storage capacities and controlled RH levels, typically achieved by alternating between two desiccant modules that cycle in and out of the airflow circuit, one providing moisture adsorption and the other undergoing regeneration via an integral heating module and fan.

Although these systems are more complex and expensive than traditional desiccators, they do provide low relative humidity monitoring and even set point control required in more critical applications. A large dry cabinet, for example, lends itself well to long-term bulk storage of microelectronic components and moisture-sensitive optical devices. Perhaps the greatest advantage of an automated desiccant-based desiccator cabinet is the elimination of the manual maintenance associated with removing and restoring saturated desiccant. The quick access via doors and low maintenance avoid the processing slow-downs associated with simpler glass or vacuum desiccators.

While a desiccant dry cabinet features enhanced capabilities, its design also limits suitability for the most stringent cleanroom environments. A dry cabinet works by circulating moisture-laden air over the desiccant bed while the desiccant progressively lowers the relative humidity. Because fans can cause particles emanating from the desiccant to enter the airflow, particle-sensitive samples could be exposed to both particle and microbial contamination, which can then enter the cleanroom. A HEPA-filtration system can be introduced to capture these contaminants, but this measure adds complexity to the system and compromises drying efficacy since the filter introduces additional moisture load. Furthermore, the airflow generated by the heated drying mechanism can cause turbulence outside of the cabinet and disrupt the laminar flow that is essential to the cleanroom environment, and expelled heat and water vapor can likewise disrupt cleanroom conditions. Due to the extremely low particle counts necessary for ISO 5 cleanrooms, a desiccant dry cabinet would most likely be placed outside of the cleanroom and serve primarily for long-term storage.

The nitrogen-purged cleanroom desiccator cabinet When choosing the appropriate humidity-controlled storage environment for a cleanroom, the desiccator cabinet should meet a specific set of environmental criteria that influence particle generation, laminar airflow, temperature, and humidity.

All surfaces should be non-shedding and as flat and smooth as possible, free of cracks and crevices, to facilitate frequent cleanings. Any direct metal-on-metal or metal-on-plastic scraping — as, for example, occurs when rotary latches engage inside surfaces — should be avoided. The materials used to construct the cabinet should withstand repeated use of disinfectants without degradation that could lead to cracks or chips. In most critical applications, conductive or static-dissipative materials are required, both for protection of samples sensitive to electrostatic discharge (ESD), and also to minimize aggregation of surface charges that can generate particle attraction. In short, the atmosphere within the cabinet must be able to meet the same standards of cleanliness as the outside environment without disrupting the laminar airflow.

For a cleaner alternative to desiccant-based systems, a nitrogen-purged system can provide superior RH control, with automated set points well below 5 percent RH, without the inherent drawbacks of the desiccant cabinets noted above. Clean, dry nitrogen gas provides the ideal desiccating medium. It contributes no particles and, in a cabinet that features an effective airflow design, rapidly dilutes and displaces moist air in the chamber to maintain an inert environment for materials such as chemicals or pharmaceutical compounds that are sensitive to humidity and other chemical vapors.

A variable-purge system minimizes nitrogen expense and disruption of external laminar flow by maintaining a low flow when the desiccator environment is below the specified set point level and a high flow only when a door opens or humidity spikes above the set point level. Use of high-precision RH sensors, combined with this variable-purge design and effective airflow engineering, minimizes humidity recovery times (and hence moisture exposure) while conserving nitrogen.

ISO 5-compatible construction

A well-designed cleanroom desiccator is composed of materials that meet contamination requirements. Stainless steel (304 or 316) is the preferred material, and electropolishing removes iron and other impurities in the stainless steel surface, resulting in ultra-smooth surfaces rich in chromium and nickel that won't shed particles. Any plastic should include durable static-dissipative characteristics to prevent ESD and static attraction. Doors should avoid use of adhesive weather strip-style gaskets that can outgas chemical vapors and tend to slip and lose sealing ability under constant exposure to a dry environment; mechanically attached, one-piece elastomer gaskets avoid these problems. Hardware, including shelves, latches, and hinges, should use all-stainless steel construction to avoid flaking and subsequent corrosion common with plated components.

Expanding applications

Traditionally, nitrogen-purged desiccators were commonly found in the semiconductor industry, where defect rates rose with even slight exposure to moisture in the air. Moisture exposure oxidizes the microscopic connections of an integrated circuit, leading to latent defects that are extremely difficult to detect and may not become visible until chips are packaged in more expensive assemblies. Electronic components are also threatened by moisture's ability to diffuse through most plastics, including the plastic packaging that supposedly protects the device.

If a plastic component is exposed to the ambient humidity for a long time, the plastic will absorb enough moisture to cause failures due to warping, cracking, and delamination when the component heats up. As technology improves and electronic parts become thinner, moisture will penetrate the thin plastic encapsulation and reach the critical circuitry with less exposure time. These effects are exacerbated when production takes place in high-humidity climates, as the greater differences in relative humidity speed up the diffusion process. As the use of ROHS-compliant solder spreads, the incidence of moisture-related failures will increase because of the higher temperatures involved in the reflow process. Each of these hazards can be mitigated by providing the proper dry environment for storing components during production and packaging.

In a more recent development, medical device manufacturing also demands a high level of contamination control during the production of sterile devices. In the case of the evolving bioabsorbable polymer industry, nitrogen-purged desiccators offer the optimum combination of dry and sterile environments. Bioabsorbable polymers are plastic-like chemical compounds that will break down and safely absorb into the human body. These polymers are injection molded to form a wide range of implanted medical devices such as cardiovascular stents, orthopedic plates and screws, dental scaffolding, and suture anchors for surgery. These devices perform vital bodily functions or provide structural support for injured areas, eliminating the need to later remove the supporting device at high cost and risk of infection. However, the devices made with bioabsorbable polymers, as well as the raw material itself, undergo hydrolytic degradation when exposed to moisture, which can significantly limit the shelf life of these medical devices. The normal methods of removing moisture cannot be applied, because “baking” often distorts the device’s delicate features and vacuum packaging is still susceptible to moisture diffusion. In order to avoid compromising the sterility of the bioabsorbable device, the best approach would be to vacuum package the devices and place them within a nitrogen-purged desiccator cabinet to ensure that only the highest quality product reaches the patient.

All of these processes typically require cleanroom processing, and — due both to their greater cleanliness and more efficient humidity control — nitrogen-purged desiccators provide a solution that is ultimately most cost-effective. Although these cabinets require a supply of high-quality, clean nitrogen that may not be readily available in some facilities. The spread of low-cost nitrogen generators, which isolate and filter nitrogen from feed air, are making nitrogen desiccators a viable alternative in even small production facilities.

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This article appeared in the January/February 2016 *[2] issue of* Controlled Environments.

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