

Desiccator Storage: The Missing Link in the Manufacturing Chain

Manufacturers understand the need to control moisture, static, and particulates at every critical processing stage. Unfortunately, however, they often limit comprehensive environmental safeguards to discrete manufacturing operations. The fact is that sensitive materials – integrated circuits (ICs), components for high voltage systems, pharmaceutical solids, medical products, and others – are vulnerable to degradation or destruction at virtually every moment, and especially during extended periods of storage between these operations. This damage often results from chemical reactions that can be avoided entirely if materials remain in the dry, inert environment provided by a desiccator.

Desiccators not only safeguard against defects caused by particles, static, and chemical vapors (including moisture), but also offer features – including data management, space efficiency, documentation, and security – designed to meet critical requirements in a wide range of industries.

Humidity Control

Because its effects are not immediately apparent, moisture is one of the most insidious environmental hazards. Sensitive materials stored at an unacceptably high humidity level may not

show signs of degradation until after a “dwell time” that can last for weeks or months, when consequences are much more serious. Imagine an aircraft’s high voltage ignition system failing because humidity exposure during manufacturing compromised a key component, or a chemotherapy treatment rendered ineffective because moisture has decreased the drug potency.

One notorious, and too familiar, example of moisture related damage is the “popcorn” effect that occurs during reflow soldering of IC packages (**Figure 1**). Although the vast majority of ICs are packaged in plastic encapsulants (because they are cheaper than ceramic ones), manufacturers are often unaware of the consequences of using hygroscopic materials in a solder reflow process. Moisture absorbed into the package vaporizes

during the rapid heating and generates pressure along metal-to-plastic contact regions. Differences between the coefficients of thermal expansion of the two materials can cause loss of adhesion, swelling, and cracking.

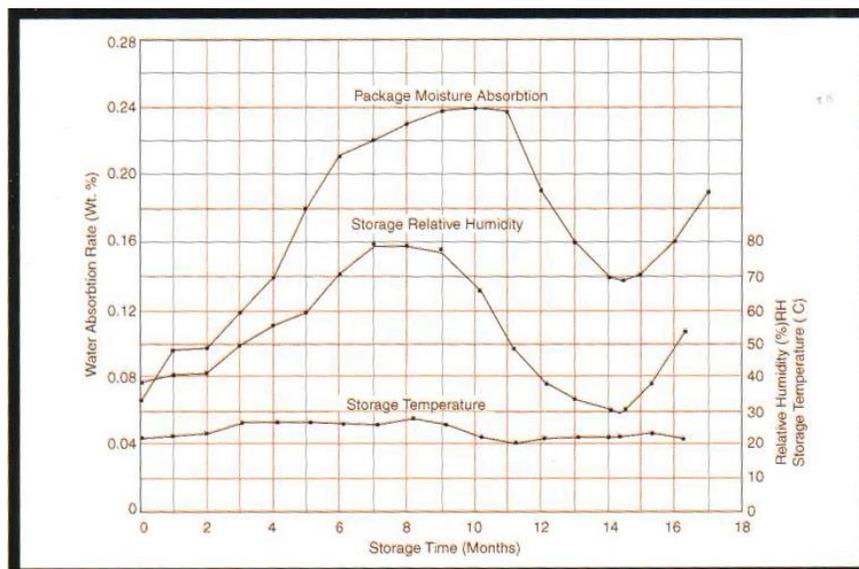


Figure 1: Fluctuations in humidity levels during storage correlate directly to moisture absorption rates of plastic encapsulant.¹

In the best-case scenario, a loud, audible “pop” signals the problem, and testing confirms a deterioration of electrical function. In the worst-case, but more

common, scenario, the damage is not immediately detectable, and the “walking wounded” ICs pass through several subsequent processing steps – and are delivered to the customer – before the inevitable electrical failure occurs. Because moisture absorption, and with it the likelihood of part failure, is directly related to the duration of exposure, dry storage is an obvious solution to this problem.

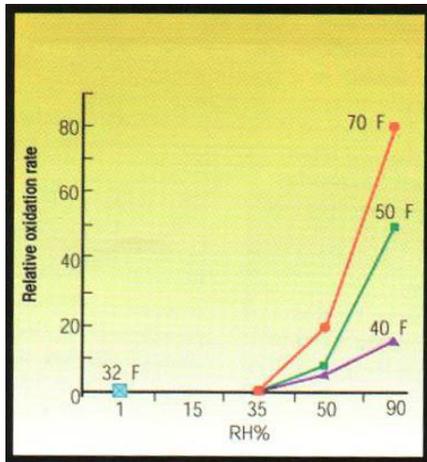


Figure 2. Relative oxidation rates, shown as a function of humidity and temperature

Moisture-related damage is also common in package bonding. If the IC packages have been in inventory for more than six months but inadequately protected against

moisture, leads will oxidize to a point where the solderability is materially affected and the board yields will drop (Figure 2).

Worst of all, the harsh mathematical reality of compounding failure rates in PCB (Printed Circuit Board) assembly transforms relatively low failure

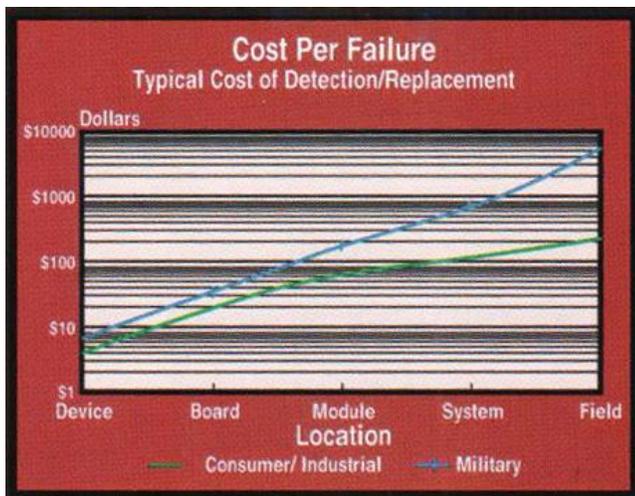


Figure 3

rates among PCB-bound packages into significant failure levels by the time these packages are mounted. As shown on the board yield charts (Figures 3 and 4), assuming a typical complexity of 150 parts, 15% of boards will fail and require costly reworks if only one in a thousand packages (1000 PPM) failed during board assembly. With board complexity and competitive yield thresholds on a sharp increase, manufacturers must control moisture exposure at every turn in the processing cycle in order to keep failure levels below this 1000 PPM standard.

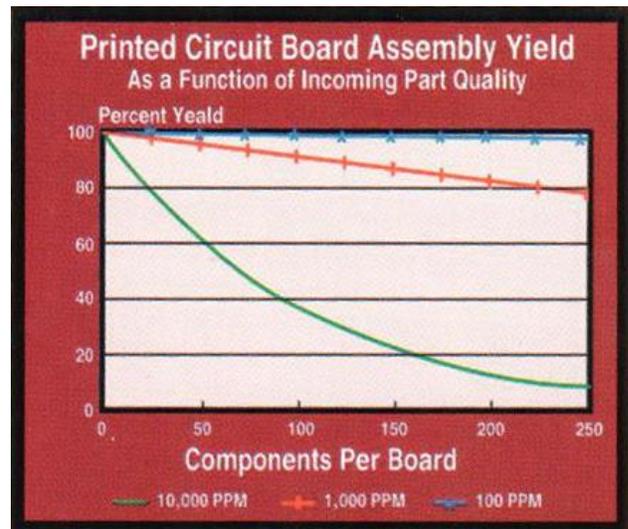


Figure 4. Yield chart of a typical (assumed) 15% failure rate.

Moisture also poses significant risks in other industries. High humidity rates facilitate the growth of mold, bacteria, and other microbes, making it an important environmental concern in pharmaceutical, biomedical, medical device manufacturing, and food processing applications. Biotechnology research that requires controlled moisture removal from DNA samples after protein synthesis also requires low-humidity storage facilities.

To minimize these problems in the clean manufacturing industries, RH must be monitored and controlled carefully during every period of storage. The specific humidity requirement of the part or material being contained is the single most important consideration when choosing a desiccator system. For example, products

composed of copper foil, such as batteries, must be stored at a humidity level of less than 5% RH to prevent minute, barely detectable degrees of oxidation that can nonetheless ruin processing operations.

In pharmaceutical applications, the product must be kept dry in order to prevent degrading chemical reactions. Lab refrigerators can dry to only approximately 30% RH, a level insufficient to prevent deterioration. A desiccator, however, can automatically maintain the very dry conditions (10% RH or less) to ensure product integrity.

Nitrogen Purging: An Efficient Alternative

While regenerating or disposable desiccants are often used to control the level of RH in a minienvironment, nitrogen purging is the most efficient method of maintaining very low humidity levels. Desiccant-based dry storage systems – often involving dual-tower designs for simultaneous on-line drying and off-line regeneration – are effective for low-volume applications, but they cannot provide the precisely regulated low dew points required in more and more critical manufacturing applications. Typically, they are also expensive to operate because they require built-in heaters to bake the moisture out of the desiccating medium. Failure of any system component can lead to a rapid rise in the desiccator humidity level.

Furthermore, these systems typically require close monitoring to ensure that the incoming gas flow remains adequate to lower the internal dew point as the silica medium nears its maximum effective adsorption point (the point at which it has adsorbed between 5-25% of its own weight in water). Adsorption effectiveness varies widely both with temperature and ambient RH. In difficult applications, calling for very low humidity thresholds at high ambient humidity levels, a desiccant may actually desorb – contributing to, rather than solving, the moisture problem.

A nitrogen-purge system eliminates these problems. Pure nitrogen is the standard medium

for contamination-free storage (as well as for many process operations) because of its low dew point, which makes it an ideal storage medium in moisture-sensitive applications, and because it can be isolated and purified relatively inexpensively. In addition, nitrogen is typically cleaner than filtered air. By introducing measured amounts of dry nitrogen into an air-tight enclosure, a well-designed control system continuously displaces moisture-laden air. Nitrogen, which has a lower specific gravity than air, is introduced into the upper section of the desiccator, and water vapor is purged out of the bottom through a bleed/check valve. This nitrogen purge must be continuously maintained in order to counteract the hygroscopic characteristics of the plastic typically used in desiccator fabrication.

This simple setup works great in theory, but real-world circumstances can greatly compromise the effectiveness of a flowmeter-based nitrogen delivery system. The single greatest problem confronting storage facility management is the need to access stored components. The moment an access door is opened, a momentary negative pressure draws air laden with moisture and particles into the controlled environment. In a relatively high ambient-humidity environment, this backfill can expose parts to significant amounts of moisture, which must be rapidly flushed from the system before it can be absorbed by material surfaces.

This requirement exposes the central dilemma of a simple flow-regulating setup: if you set the flowmeter to compensate for this backfill with a high-flow purge, you run the risk of overpressurizing the system when doors are closed. Seals eventually fail, and cabinets can even explode. Equipping an enclosure with an adequate number of bleed valves can relieve this pressure but leads to nitrogen waste when doors are closed. In a confined or poorly ventilated storage facility, this continuous, high-flow purging can even raise the percentage of nitrogen in the

air to unsafe levels. Other factors, including fluctuations in ambient humidity levels and differences in cabinet sizes and conditions, only complicate the chore of maintain a carefully regulated low-moisture environment.

Cut Recovery Time, Increase Shelf Life

Fortunately, nitrogen-purge systems are available today with integrated, automated nitrogen control capabilities that solve these problems, offering relatively low-cost ways to increase component yields and boost profitability. These systems make use of advanced gas-flow engineering to reduce system recovery time (the time necessary to restore an acceptable internal humidity level after an access door has been open). One system, for example, incorporates a pressure regulator, gauge, flowmeter, and a variable flow mechanism, allowing it to maintain a low-level, economical positive pressure during normal operation, but automatically increases the nitrogen flow when an access door is opened to prevent contamination inflow. When the door is closed, the system provides the high flow for a set time, in order to flush out any trapped air, and then re-established an economical low-level purge, making this flexible system (**Figure 5**) appropriate for storing frequently accessed materials.

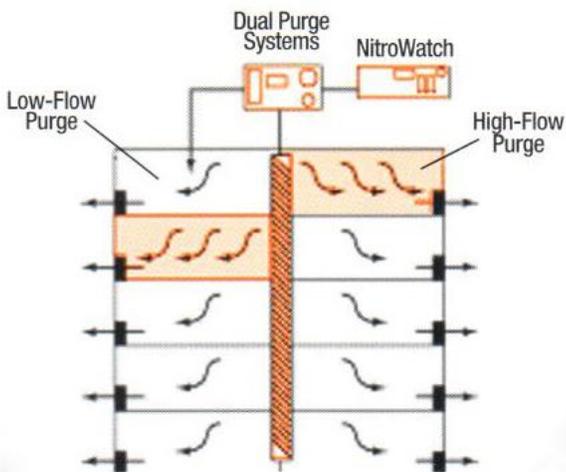


Figure 5. A "Smart" multiplexed nitrogen control system automatically maintains a separate RH level in each chamber, directing a high-flow purge only where it is needed and only for as long as needed to restore the %RH set point.

Teamed with a monitoring system that can maintain a sub ambient internal RH level down to 0% RH for each chamber of an enclosure independently, the flow will be automatically activated when an adjustable threshold is exceeded. By improving the efficiency of the nitrogen purge and moisture removal, a multiplexed gas control system also helps to compensate for the hygroscopic characteristics of the desiccator material, such as Plexiglas, static-dissipative PVC, and other polymers that allow moisture to pass through the enclosure walls. For this reason, ambient humidity is another factor to consider when specifying a storage system, for a desiccator in a humid location will require more nitrogen purging than one located in a dry environment. Because each chamber of a multiplexed system is controlled individually, nitrogen usage is minimized and RH setpoint recovery times are greatly reduced.

Particle Control

The most widely discussed type of yield-busting contamination is, of course, particles. In microelectronics and semiconductor processing especially, manufacturers have become aware of the critical need to control smaller and smaller particle sizes in order to maximize yields of components with submicron geometries.

Particle control inside the minienvironment can be achieved through a combination of strategies. First, close attention must be paid to the component materials and fabrication techniques:

- Electropolished stainless steel is the material of choice of metal components subject to heavy use.
- Dissipative plastics are preferable to acrylic because they eliminate static charges that attract and hold particles to a desiccator surface.
- Gasket materials are non-corrosive, non-outgassing, and exceptionally resilient. New methods of mechanically attaching gasket materials to stainless steel reinforcement

frames eliminates the use of adhesives, which can eventually react with the gasket material and compromise sealing effectiveness.

High capacity desiccator systems can be specified with integral filter/blower modules, which can maintain cleaner-than-Class 1 particle conditions by recirculating the process gas through HEPA or ULPA filters with efficiencies as high as 99.999% measured at 0.12 µm particles.

ESD Protection

While the dry environment of a desiccator protects products from moisture damage, it also increases the potential for electrostatic discharge (ESD). ESD damage occurs when the static charge differential between two materials exceeds the field strength of the insulating material.

As shown in **Table 1 and Figure 6**, the relative level of ESD voltage generated increases as the RH decreases. Thus, the typical amount of voltage generated in handling a polyethylene bag will increase from 600 volts at 80% RH to over 20,000 volts at 20% RH.

Even minute discharges are sufficient to destroy ICs and other microelectronic devices. In pharmaceutical applications involving fine powders, static charges pose a different problem: chemical powders literally cling to a charged surface, compromising the effectiveness of mixing

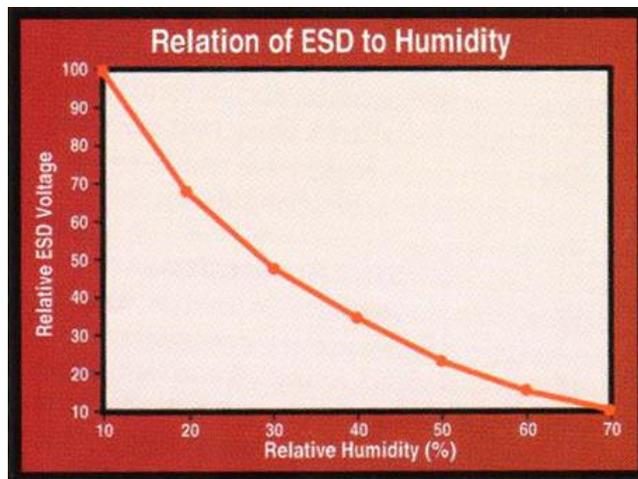


Figure 6. Low humidity levels are associated with increased ESD voltages, pointing to the need for effective static-control measures inside a desiccator.

and packaging operations. Similar problems exist with very fine membranes, foils, thin papers, and ultra light plastics.

This is why any nitrogen-purged desiccator should incorporate static-control provisions. For the storage of conductive parts, a grounded chamber with electrically conductive storage shelves is essential. All storage systems should be equipped with a ground continuity indicator/alarm, and provisions should be made to discharge an operator before parts are accessed (either by means of grounded wrist straps or, more conveniently, grounded cabinet latches).

Another method of safeguarding stored materials against ESD makes use of the concept of the “Faraday Cage,” i.e., that any volume enclosed by a conductor will be completely shielded from electric fields. A Faraday enclosure places the hermetically sealed, nitrogen-purged desiccator environment between stainless steel plates. By keeping the cage grounded and at zero potential, a Faraday desiccator environment safeguards stored products against ESD, even in the presence of strong electric fields (**Photo 1**).

	Low humidity (20%)	High humidity (80%)
1. Walking across synthetic carpet	35 KV	1.5 KV
2. Handling polyethylene bag	20 KV	600 V
3. Sitting on foam cushion	18 KV	1.5 KV
4. Sliding plastic box on carpet	18 KV	1.5 KV
5. Heat-shrinkable film on PC board	16 KV	3 KV
6. Pulling mylar tape from PC board	12 KV	1.5 KV
7. Walking across vinyl floor	12 KV	250 V
8. Triggering plastic solder-sucker	8 KV	1 KV

Table 1



Photo 1. The Faraccator™ uses the principle of the Faraday Cage to shield components against ESD.

Static-dissipative polymers provide further ESD protection. Although topical anti-static treatments are available, such coatings offer neither the durability nor the uniform surface resistivity of plastics featuring solvent-welded dissipative layers. Static-dissipative PVC is especially effective in this regard because it offers full visibility of stored components and resists a broad range of chemicals. Static-dissipative PVC also makes it easy to wipe down a desiccator cabinet, since it eliminates the attractive surface charges that seize air-borne particles. Both external and internal walls of a static-dissipative desiccator should have a surface resistivity in the range of 10^6 to 10^8 ohms/sq cm, even when exposed to light abrasion.

These static-control measures are effective at shielding stored parts from external fields or dissipating charges on conductive materials. Nonconductive parts, however, require the neutralizing effect of ionizing equipment. Static neutralization is especially important in processes involving plastic component packages that build

up charges as they are handled, or charged plastic films that attract and hold contaminants. An effective ionizing system automatically generates a balanced charge of positive and negative ions, which are emitted through nozzles placed inside the desiccator in such a way that incoming nitrogen flow disperses them throughout the storage area. This design requires a plenum wall at the rear of the cabinet, which optimizes the uniformity of nitrogen flow and hence ion distribution.

Additional Benefits

Remote/centralized monitoring and control.

While desiccators minimize the danger of moisture, particle, and static contamination, a number of innovations, including remote data monitoring, address other concerns specific to clean manufacturing facilities. Such remote monitoring, display, and processing capabilities include the ability to receive and then transfer humidity, temperature, and particle data over a serial interface for processing or documentation of storage conditions at a number of locations, and even to provide remote warning alarms if set points for humidity, temperature, or flow are exceeded.

Optimization of space. Desiccators enhance production efficiency in a number of other ways. Strategic installation of a pass-through desiccator can optimize the use of floor space by dividing a working area or allowing pass-through access through a cleanroom wall (**Photo 2**).

Security. Desiccators providing security from tampering or theft are also available, with a number of options available to suit different security requirements. One such unit houses a nitrogen-purged desiccator inside a locked enclosure. System software documents each entry into the inner shell of the desiccator. The outer shell, constructed of steel, resembles a standard filing cabinet, with a full-length, lockbar mechanism.



Photo 2. Pass-through desiccators optimize floor space, allowing parts access into a cleanroom or division of a workspace.

The highest level of security is provided by placing a desiccator within a safe, surrounded by a 4-in. steel wall and locked by a combination lock and triple-action security boltwork. When locked, steel rods secure the top, bottom and both sides of the dual swing-action, and reinforced access doors making it impossible to open even if the outer hinges are removed. The combination lock can be reset on site to ensure maximum security.

Boeing engineer Jitu Gaglani attests to the benefits of using desiccators. More than 100 are used at Boeing's facilities to protect microelectronics against ionic contamination, moisture, and corrosion. Gaglani notes that the use of desiccators also prevents components from becoming lost or incorrectly identified; components that look alike, but have different functions, are stored in separate, labeled drawers within the desiccator.

The Bottom Line: Low-Cost Versatility

The rapidly escalating cost of microcircuit manufacturing, not to mention the often astronomical expenses associated with reworking or scrapping failed packages, makes the initial investment in a desiccator storage system absolutely crucial if low-humidity storage correlates to appreciable increase in yield. When the competitive stakes are high, the consequences of unreliable humidity control become prohibitively costly. Any cost-benefit analysis must also take into account the savings in nitrogen provided by more efficient systems, as well as the savings in labor costs associated with monitoring and adjusting less sophisticated storage systems, or of managing the alternatives to low-humidity storage (vacuum sealing and resealing, oven baking to remove moisture, etc.).

For such applications, these innovations in storage system design clearly overcome significant drawbacks of flowmeter-regulated or desiccant-charged cabinets while preserving the economy and convenience of a fully visible, easy-access storage cabinet. Best of all, the newest systems can extend the shelf lives of stored materials – and thereby improve yields to profitable levels – much more effectively than other storage methods. In short, the desiccator, while still a relatively simple storage concept, has gone high tech and manufacturers in many industries would do well to take notice.

Reference:

1. Nicolaou, Chris. "Plastic Package Failure Modes," *Surface Mount Technology*, November 1992, pp. 45-50.