Examining the Drying Process

Drying parts may seem like a straight-forward process, but there are variables to consider...

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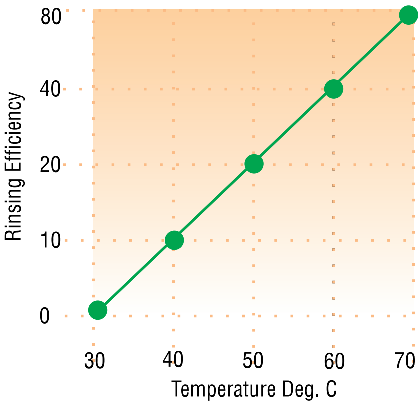
Drying rinse water from parts is usually the last consideration in the cleaning process. Drying may seem like a straight-forward process, but it is not. An unclear understanding of water vaporization leads to difficulties in implementing drying processes. Vaporization of the top layer is almost instant, however, the lower levels remain in a liquid state.

Another critical factor in the drying process is the poor thermal conductivity of water. Water cannot effectively conduct thermal energy from a heated substrate to the upper molecular layers of the water. Ineffective thermal transfer means that heating wet objects may not assure that the drying rate will increase.

Also, the strength of water on the surface should not be underestimated. The boundary layer effect will slow air flow over an objects' surface, slowing vaporization. Porous surfaces, or those that are effectively wetted due to high surface tension, can be difficult to dry.

Liquid inside small through or blind holes can be difficult to remove as well. The area is small compared to the volume of moisture. In some applications, moisture can be vaporized, but still remain entrapped. Water vapor recondenses in the cavity when the assembly returns to ambient temperature. Water trapped in grooves, cracks or between adjacent surfaces is difficult to remove using just about any drying method.

Staining and water spots are serious issues. These "drying defects" are invariably traced to the rinse water and



1. TEMPERATURE vs. Rinsing Efficiency

the speed at which water is removed from the surface. Faster drying results in fewer stains and water spots.

Water spots are caused by salts in the rinse water. Common culprits are sodium, calcium and manganese. The best rinsing is achieved using 18 megohm deionized water. Rinsing is also more effective if the water is heated.

Rinse waters contain dilute amounts of cleaning solution and contaminants. Evaporation concentrates the contaminants in the rinse water. There is an electron charge imbalance between the rinse waters and impurities, causing contaminants to congregate at the perimeter of a water droplet.

Where stain prevention is critical, an aqueous cleaning bath between the final plating bath and the first rinse bath may solve contamination defects. Aqueous materials that strip plating salts, organic materials and amino substances are helpful.

Thermal/Vacuum Drying can eliminate many problems encountered when drying complex parts. The process dries water from critical surfaces such as semi-conductor components, electrical contacts and electronic parts. It differs from conventional vacuum drying because it quickly removes high volumes of water.

Wet objects are placed in a vacuum chamber equipped with special heaters. A vacuum is applied to the chamber causing rapid conversion of water to water vapor, which is removed from the chamber. Oxidation is minimized because of the lack of oxygen in the chamber.

A controller in the computer system detects the point when all moisture has been removed from the products. The system automatically shuts down and is then ready for the next batch of devices.

The thermal/vacuum process rapidly evacuates moisture trapped in blind holes. Although a cavity may appear full of water, small amounts of air are present as well. When atmospheric pressure is reduced in the vacuum, the air rapidly and explosively expands, forcing water out of the cavity (Fig. 2).

Thermal/vacuum drying can remove one pound of water from 20 lbs of gold plated seal lids in less than 10 min. In another test, 3.2 lbs of water were removed from 28 lbs of plated crystal cans in less than 15 min.

The systems are compact. A typical unit consumes 45 amps of 240 AC, single-phase power.

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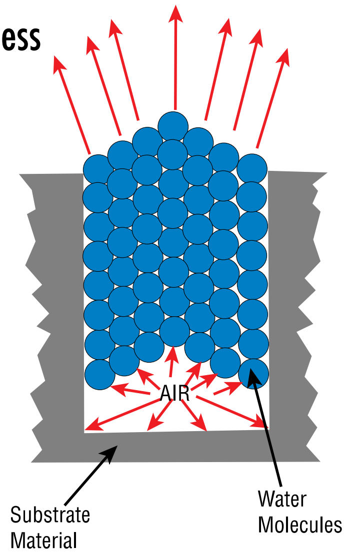
Vacuum Bake-Out Drying also uses a vacuum to vaporize water. The process is effective in removing small amounts of water in the area of 10 to 100 ppm. Its power and space requirements are similar to thermal/vacuum drying equipment. Typically, vacuum bake-out equipment has no rotary capability. Typical drying cycles are longer the thermal/vacuum drying processes. This technology is usually used for drying semi-conductor wafers.

Perfluorinated Displacement Drying. In this process, wet parts are



2. EXPLOSIVE EXPULSION of entrapped water

TABLE I—Comparison of Common Drying Processes and Equipment

Process	Mechanism	Common Applications	Operation	Part Size
Thermal/ Vacuum	Computer controlled vacuum and thermal vaporization	A, B, C	D, E, F	G, H, I
Vacuum Bake-Out	Vacuum vaporization	C	D, E, F	G
Perfluorinated Displacement	Water floated away by heavier solution	B, C	D, E, F	G
Alcohol Adsorption	Adsorption of water by alcohol	B, C	D, E, F	G, H
Convection Oven	Forced thermal evaporation	A, B	D, E, F	G, H, I
Air Knife	Heated laminar air flow forces gross water from the surface and promotes vaporation	C	F	G, H, I
Centrifugal Spinning	Mechanically forces water displacement	A, B	D, E	G, H

A = General, Non-critical Applications; B = Critical Applications; C = Medical, Semiconductor, Aerospace, Super Critical Applications; D = Manual; E = Semi-automated; F = Fully automated; G = Small; H= Medium; I = Large; J = Very Low Quantity; K = Low Quantity; L = Medium Quantity; M = High Quantity; N = Simple; O = Flat Panel; P = Complex; R = Very Slow; S = Slow; T = Medium; U = Fast; W = Poor; X = Better; Y = Good; Z = Very Good; AA = Very Low; BB = Low; CC = Medium; DD = High.

immersed in a bath of perfluorinated solvent. The fluid is much heavier than water. The water floats to the top of the tank where it is drained off and discarded. New equipment and modifications of existing CFC-displacement drying equipment are expensive. The material price is high and the drying rate is slow.

Production testing shows that a 45 min perfluorinate displacement drying process is required for a given batch of products that require only 10 min in a vacuum dryer.

Alcohol Adsorption Drying. Wet parts are immersed in a bath of alcohol. Water is adsorbed or "captured" inside the interstitial spaces in the molecular structure of alcohol. Adsorption continues until there are no spaces left in the alcohol. This is referred to as saturation, which is reached rapidly.

Process control is difficult. This method also has some serious safety concerns (fire) as well as the problem of legal disposal of saturated alcohol. The process is best suited to applications where there is only minimal moisture to remove.

Conventional Drying Ovens draw cooler ambient air into the oven where

Quantity of Water	Object Complexity	Process Speed	Control	Equipment Cost	Operating Cost
J, K, L, M	N, O, P, Q	U	Z	CC, DD	BB
J	P, Q	T	X	CC, DD	BB
J, K	N, O, P, Q	T	X	DD	DD
J, K	N, O, P, Q	T	X	BB	CC
K, L, M	N, O	T	X	CC	CC
K, L	O	T	Y	CC, DD	DD
K, L, M	N, O	T	X	CC	BB

it is heated and travels upward through the interior. The moving air vaporizes wetted films. The vapor-laden air continues out of the oven, thereby extracting the water vapor. This process is slow and generates rust rapidly. This method also uses a lot of energy and floor space. Water entrapped in the blind holes is difficult to extract. The process is frequently used for general drying of relatively simple large objects where oxide formation and production speeds are not important.

Hot-Air-Knife Drying is typically a conveyorized drying process where the wet product is passed under a series of laminar-air-flow nozzles that use temperature and air movement to carry away vaporized water. This process is most suited to large quantities of similar panel-like products.

This method depends on the consistent orientation of the wet surfaces to the hot-air knives. It is not effective for removing water from blind holes. The most effective use of hot air knives is removing moisture from flat panels such as printed circuit boards or metal sheets.

Centrifugal Drying. In this process, wet parts are placed in a cylindrical basket that is spun at various speeds. Centrifugal force is applied to the water. The G-force flings water away from the parts.

In some applications heating is included to encourage vaporization. The process is not completely effective in removing liquid trapped in holes. However, the equipment is relatively inexpensive and compact. Systems are frequently used to remove water from products such as nuts and bolts.

Compressed Gas Blow-Off Drying uses manually directed nozzles to force gross amounts of water from a part. The remaining moisture is allowed to vaporize in ambient air. This is a slow process with high labor costs and low equipment expenses.

Contaminants can be transferred to surfaces when normal compressed air is used, if the air is not filtered and clean.

Ambient Air Drying allows water to naturally evaporate into the plant air. It is slow and prone to form oxides. There is no equipment or consumable material costs. This method is the least desirable technique and is used on large to extremely large objects that are not harmed by oxides and do not need to dry quickly.

The rinsing and drying process must be jointly addressed. Many drying defects are caused by inadequate or improper rinsing. There is a variety of techniques available for removing water from cleaned parts. Each of these is suited for specific applications. There is no one technique for moisture removal. Selecting the appropriate drying method must be based on the level of dryness you need, the complexity of the part and the production rate required. **PF**