Boost Throughput and Reduce Energy Costs with Solvent Drying

Mike Jones
MicroCare Corp., New Britain, CT

Many surface finishing processes involve aqueous cleaning or a thorough rinsing with deionized (DI) water. Cleaning is performed with the goal of removing contamination that might degrade a subsequent process or as a finishing step, to ensure a bright, contamination-free surface ready to be shipped out the door. One historical challenge has been the persistent difficulty of quickly, completely and consistently removing residual water from cleaned components. Residual water causes problems with water spots, “halos” and imperfections in follow-on processes. In effect, the water used to clean the parts also becomes a contaminate itself.

Is this a major problem? Evidence would suggest it is. Drying is a major manufacturing step in the finishing of almost every metal component and sub-assembly after aqueous cleaning or rinsing. There also are similar problems in the world of photonics, optics, ceramics and high-end plastic products. Specific industries include the manufacture of liquid crystal displays, jewelry, medical devices, fuel injection systems, microswitches, electronic assemblies, plated parts, semiconductors, precision bearings, mirrors and lenses.

Drying Limitations

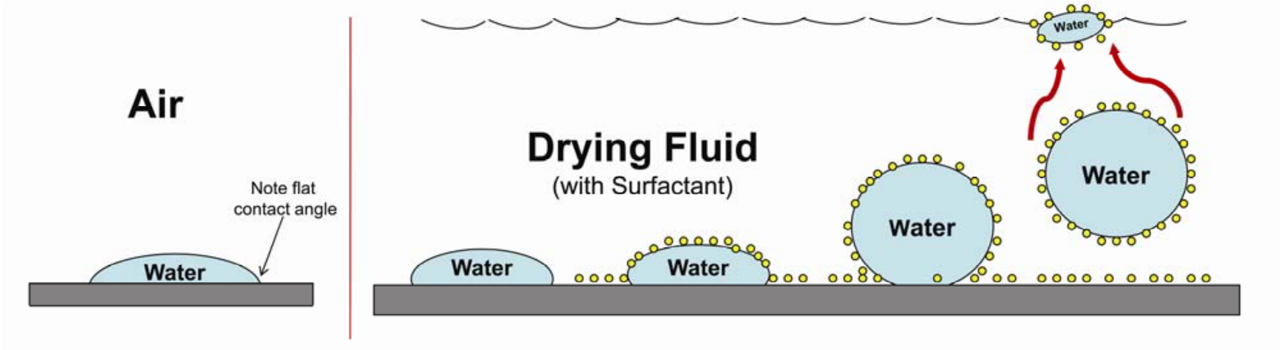
There are four popular methods to remove water. All of these choices have substantial costs and limitations.

Evaporative drying (either baking in an oven or using infrared lights) generally often will leave a residue of non-volatile material that was suspended or dissolved in the water, which defeats the whole point of cleaning in the first place. It is a slow process so throughput is hampered. The energy requirements are high which makes it expensive. Many parts also are heat-sensitive, which renders the process unsuitable.

Because of their ability to handle high throughput, the most common option is a *turbo-blower* or “*air knife*.” These systems require a large footprint in an already congested facility. They are very noisy and relatively violent, making them unsuitable for lightweight or fragile parts. Regardless of the volume of air, tiny parts and/or complex shapes can still trap water in recesses that an air knife will never find. So air knives often are used in concert with evaporative drying to ensure a thorough result, further driving up energy costs.

The two other popular choices are *centrifugal drying* and *media drying*. Centrifugal drying is highly effective in removing gross amounts of water but the position of the parts in the dryer can affect results; deep wells or blind apertures are difficult to dry. Delicate surfaces could be damaged so the process is suitable only for durable pieces. Often a slight water film usually remains which must be removed by other means.

Media drying uses a porous medium, such as sawdust or corncobs, to absorb the water. The media then must be disposed or dried through evaporation. Often the parts must then be further processed to remove dust or other residues deposited by the absorbent media.



This illustration highlights the effect of a solvent/surfactant immersion on a droplet of water. When the droplet is exposed to air, it has a relatively flat "contact angle" or "wetting angle" due to the surface tension of the water. But, when immersed in the drying fluid, the heavier fluid works its way around the droplet, lifting it from the surface of the part. The surfactant (represented by the yellow dots) breaks down the surface tension of the water and minimizes any electrostatic bonds, allowing the water to be lifted off the substrate by the dense solvent. Eventually, the water floats to the surface of the drying fluid where it is easily removed by mechanical processes.

Most readers, who are using some form of aqueous cleaning, probably are dealing with one or more of these drying systems today in their facilities. The best thing that can be said about these drying answers is that they are adequate most of the time. But there is a better answer, one that is safe, quiet, fast, extremely consistent and highly affordable. It's called "solvent drying."

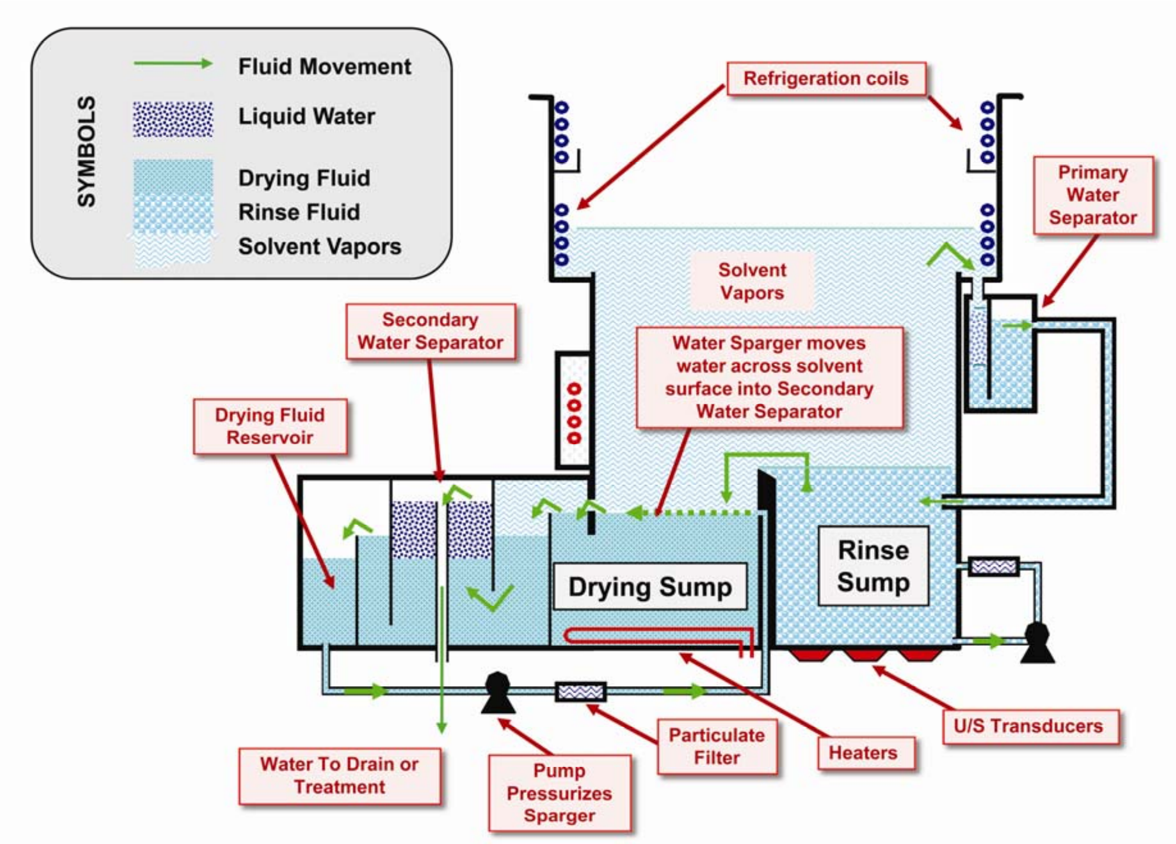
Solvent Drying

Years ago, in the days of "Freon" and similar cleaners, "solvent drying" or "dewatering" was often the process of choice for precision drying. It is still widely used today in Europe and other locations where the cleaning requirements are demanding, or the quality requirements are high, or energy is expensive. It is most common in the plating industry, but also widely used in the coating and treatment of plastic, metals, mirrors, lenses, crystals and ceramics. The method is particularly useful where specific reflective and refractive properties must be maintained.

The displacement drying process requires special fluids with an unusual combination of characteristics: they must be nonflammable, not miscible with water, have a low boiling point, a high specific gravity, low surface tension, low viscosity and a low "latent heat of vaporization." Importantly, the high specific gravity allows the heavy, dense drying fluid to surround water droplets and release them from the surface of the parts. The low surface tension and low viscosity allows the solvent to get into tiny nooks and apertures to remove any water.

The latent heat of vaporization indicates the ease with which a liquid evaporates. Unlike water, a good drying agent such as "HFC 43-10" dries almost instantly and cannot be trapped in tiny holes or blind vias. Table 1 compares these metrics between three drying solvents and the water being removed.

This combination of favorable chemical characteristics is the major reason for the dry, spot-free condition of parts emerging from a solvent drying system.



A modern, high-throughput drying system strongly resembles the vapor degreaser technology upon which it is based. However, the water-removal features are greatly expanded in a drying system. The parts are dried in a class vapor degreaser system using the "rinse sump" the "drying sump" and the vapor area, all on the right side of the schematic. (Typically the parts are moved using a basket-and-hoist system, which is not shown here for simplicity.) The whole left side of the system is dedicated to removing the excess water. It begins with a "sparging" system which blows any residual water across the surface of the solvent and into several weirs which trap it in the water separator system. Gradually, the water is collected in the secondary water separator and flows to drain. A small portion of the water acts as a "cap" on top of the drying fluid to prevent excess solvent losses. The whole system uses the inherent characteristics of the drying fluid and water to easily dry the parts and remove the water.

TABLE 1

CHARACTERISTICS AFFECTING SOLVENT DRYING EFFICIENCY *(in Alphabetical Order)*

Fluid	Surface Tension (Lower is better)	Viscosity (cP) (Lower is better)	Spec Gravity (Higher is better)	Latent Heat (cal/g) (Lower is better)
CFC-113 (Freon®)[1]	17.3	0.68	1.56	63.1
HFC-43-10 (Vertrel®)[2]	14.1	0.67	1.580	31.0
Isopropyl Alcohol (IPA)[3]	22.10	1.06	0.81	167.7
Water	72.80	1.00	1.000	543.0

Notes: (1) CFC-113, often called "Freon," "Arklone" or "Genesolv" was a popular drying agent until the 1980s. It was a suspected ozone-depleting substance and has been phased-out globally under the Montreal Protocol. (2) HFC-43-10 is the ozone-safe, nonflammable material used in DuPont drying agents, which are the most widely used world-wide today. (3) IPA is a constituent of some drying solvents, but cannot dry as a stand-alone material due to the flammability risks. It is included here as a reference point because its handling is a familiar reference for most engineers and technicians.

So it is clear that the very chemical nature of water makes it very difficult to remove efficiently from complex surfaces. The solvent drying process, with its unique chemical characteristics, actually uses Mother Nature to dry the parts rather than brute force. This makes solvent drying highly efficient and reliable.

It's worth mentioning that solvent drying actually requires two similar (but not identical) fluids. The first is the drying agent. This consists of the solvent plus a slight proportion of a hydrophobic surfactant additive to enhance the displacement of the water. It is used only for the initial charge of the system (and in small quantities for make-up).

The second material is a rinsing fluid. Its sole purpose is to rinse away any residual surfactant from the drying fluid that may be on the parts. Both fluids are nonflammable and are compatible with most plastics, ceramics, elastomers, metals, and other materials.

An alternative drying process is called "absorption drying." Absorption drying requires a different type of fluid, similar to those above but with an interesting twist. Absorption drying requires a solvent that *is* miscible with water. In this process, the water is not displaced so much as it is actually absorbed into the drying solvent hygroscopically. The water then is removed from the drying agent with a gravimetric water separator. This process often is preferred when a "coating" process immediately follows the drying process. The popular DuPont solvent, HFC 43 – 10, when mixed with hygroscopic isopropyl alcohol provides a nonflammable solvent that will remove water from intricate parts by dissolving the water in the alcohol.

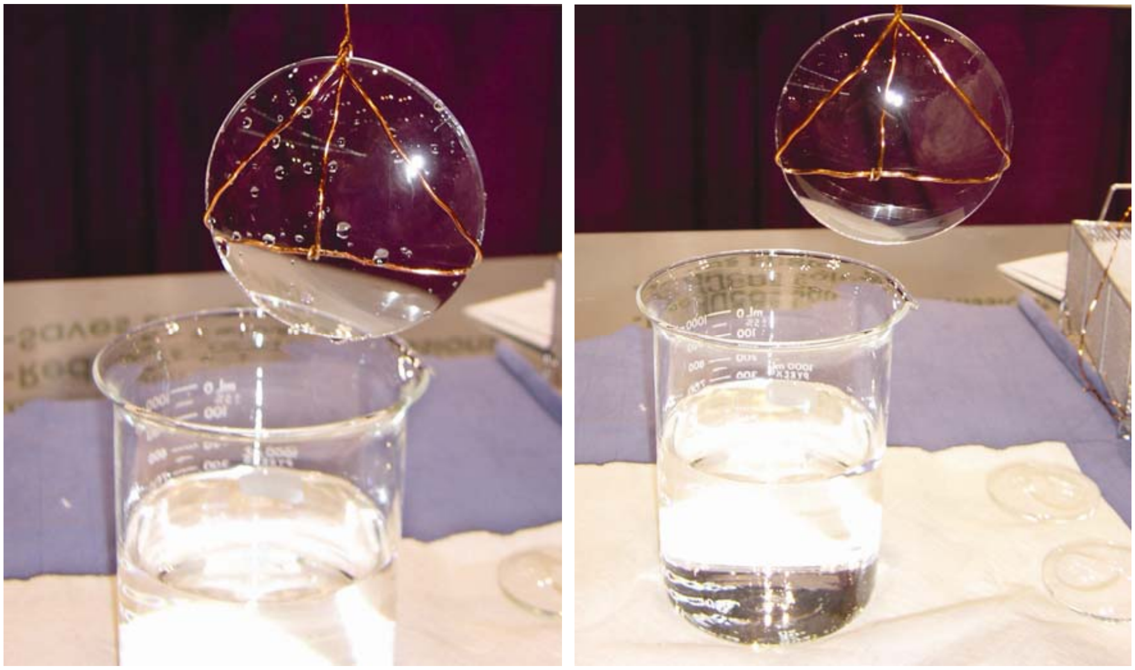
Process Details

As mentioned above, displacement drying floats the displaced water off the parts. Typically, a technician will place the parts in open-mesh basket and lower the basket into the drying chamber containing the displacement fluid. A brief immersion is sufficient to dislodge the water, depending on the size, configuration and other characteristics of the parts. The total time parts spend in the drying process would be typically a minute in the drying sump, and a total drying process time of perhaps 8-10 minutes. It is this speed and the reliability of the drying process that boosts throughput so substantially.

Once a water-covered part is immersed in the drying fluid, the inherent chemical properties of the solvent enable it to penetrate beneath the water droplets. The droplets are buoyant because the solvent is denser than water and not miscible with it. This lifts the droplets away from the surface of the part and they rise to the surface of the drying tank. Figure 1 shows how the drying fluid lifts droplets from surfaces.

The water flows across the surface of the heavier solvent just as oil floats on top of water. It is "sparged" with solvent jets into a water separator and then to drain. Meanwhile, the parts are removed from the drying fluid and passed through one or more cascading baths of a rinsing fluid to remove any residual surfactant from the surfaces. After a brief drying phase the parts are removed from the system. At this point they are dry, at room temperature, spot-free and ready for further processing. Figure 2 shows a simplified schematic of a solvent drying system.

The beauty of displacement drying is that the low surface tension and low viscosity makes it easy to dry parts completely, removing water even from tiny apertures, cracks and crevices. The only time drying cannot occur is if water is trapped in inverted cup-like cavities. Agitation of the basket avoids this problem. When possible, it is important to orient the parts so any apertures are pointing upward, so released water can float up to the surface of the bath; some users have baskets that gently tumble or rotate to provide automatic agitation and proper orientation. (Another application for absorption drying, as opposed to displacement drying, is when the parts cannot be tumbled. Absorption drying will remove the water from parts of any shape or configuration.)



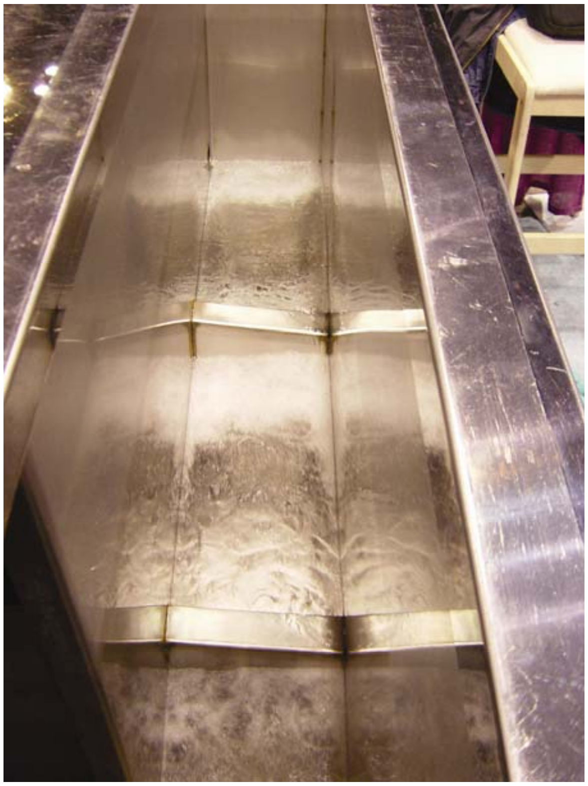
This simple demo shows the efficiency and speed of solvent drying. In the photo on the left, a simple glass lens is speckled with water droplets, representing the residues of some hypothetical manufacturing process. If these droplets were left to dry by themselves, water spots would result. Air knives are feasible on such a simple shape but are noisy and energy-hungry. The best choice is solvent drying. The photo on the right shows how the vast majority of the water was removed in a brief (five second) immersion in the beaker of solvent. The few droplets that remain are a function the demonstration: the only way to remove the lens from the solvent was to pull it back up, through a layer of water on top of the solvent (just as oil floats on a puddle of water). In a normal industrial environment, the water is removed from the solvent mechanically and the parts come out clean, spot-free and at room temperature.

Doing the Numbers

In general, most solvent cleaning processes tend to be vertical, moving parts up and down in the cleaning system. The requisite hardware is commercially available and only requires a small foot print. The systems operate in much the same method as vapor degreasing equipment except additional water separation and removal capabilities are enhanced.

Entirely self-contained, solvent dryers usually are single-box machines about the size of a large desk or kitchen table. For example, a relatively large Branson dryer costs around $50,000. It holds 50 gallons of solvent and is 90 inches long and 36 inches front-to-back. Operating at 39° C, it uses 6kW of energy in continuous use and about a tenth of that power during “stand-by” mode.

Comparing this to traditional drying systems, infrared heaters, turbo-blowers and air knives are used but their energy consumption is high. The typical aqueous drying station easily can use 5-10 kWh, and that number could double on a bigger system simply because of the increasing size of the motors, fans and compressors.



This close-up shows a simpler version of an industrial solvent dryer. This system uses a three-tier cascade of solvent instead of the vapor degreaser style design shown in Figure 2. In this case, the drying fluid is pumped into the highest chamber of the cascade and it gradually over-flows and tumbles downstream into the two lower chambers. From lowest chamber, the drying fluid is moved to a water separator (not shown). Parts are dried by moving them from the lowest chamber up the cascade, to the progressively more water-free solvent, and removed from the last chamber dry, spot-free and at room temperature. This type of system is an excellent choice when a continuous process (as opposed to a batch process) is desired. The trade-off is higher solvent losses.

These machines also add heat to the surrounding environment which increases the load on environmental systems. The Branson dryer mentioned above will add about 82,000 BTU/hour to the room in which it is operating, but the aqueous system will add nearly 300,000 BTU/hour. The aqueous dryer also will add approximately 15 pounds of water (roughly two gallons) into the air of the plant every hour, which will need to be removed by the HVAC system.

One last consideration is the stand-by power draw. In order to minimize solvent losses, the refrigeration on a solvent dryer should be kept operational at all times, using around 0.5-1 kW per hour. But at many companies the drying ovens are never shut down because of the long delay in re-heating the systems again. These systems will use 2-5 kW of electricity at a minimum, hour after hour, even when no drying operations are being conducted.

A rough estimate from several sources estimates that solvent drying will save a medium-sized plating company $300/month in direct energy costs, compared to other drying technologies. But that’s just the beginning. Other savings, from faster throughput to higher yields and fewer defects all contribute to ever-greater profitability.

Wrap-Up

Some people say that today’s solvents are expensive; maybe too expensive to be cost-effective. I would suggest the issue is not the cost of the solvent, but the cost per-part-dried. Indeed, with energy costs rising and the availability of adequate water supplies becoming a global concern, it makes sense to give solvent drying another look. It might even get your budget back in shape since a properly designed, operated and maintained solvent dryer is one of the safest, most economical and environmentally acceptable ways to dry.

(-end-)

About the Author

Mike Jones is the Vice President of MicroCare Corp., a US-based specialty firm dealing with precision cleaning, coating and lubrication. Today, MicroCare cumulatively has more than 100 years of precision cleaning, drying and vapor degreasing experience. Mr. Jones would like to thank John Hoffman, Ed Mark and Tom Tattersall of MicroCare Corp. for their technical contributions to this report, and also to Wayne Mouser of Forward Technologies, Jon Harmon of Branson Ultrasonics, Bill McCormick of Tiyoda-Serec Corp., and numerous other contributors whose expertise and judgment are incorporated into this article.