Many factors must be taken into consideration when air-drying parts cleaned with aqueous and semi-aqueous systems. Approaches vary with applications.

Precision Drying Completes Precision Cleaning

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As industries converting to aqueous or semi-aqueous processes tend to focus on the actual *cleaning* aspect of precision cleaning, the often-difficult task of drying has been overlooked and somewhat maligned. As a complete process, precision cleaning demands precision air drying as well – a means of drying a part without sacrificing its cleanliness, so that it remains as clean after drying as it was before.

Various factors must be taken into consideration when air-drying parts cleaned with aqueous and semi-aqueous systems. Most important, the drying process must not recontaminate the part. Contamination may occur if dust, dirt, and other particles are blown onto the surface of the part. Also, if soil, dirt, or chemical residues entrained in surface liquids are not blown off the part, and heat is then applied, these may be baked into the surface of the dry part.

The drying system must dry parts thoroughly and consistently, eliminating the possibility of inadequately-dried parts and the expense of employees sorting out such parts. It must be flexible enough to dry all configurations of parts, from those with blind holes to those of varying sizes and shapes. Finally, the choice of a drying system is entirely dependent upon the application and throughput requirements involved.

This article will offer some solutions to those who now have, or are considering the purchase of, an aqueous / semi-aqueous precision cleaning system and are seeking precision air drying options. Automated and non-automated approaches will be explored.

Despite the fact that manual labor is a "quick fix" to a parts drying deficiency, long-term operating costs, quality control, and safety factors demand an automated system for the majority of cleaning applications.

What is Precision Air Drying?

In any aqueous cleaning system, precision air drying is the process of accelerated parts drying by way of a low-or high-velocity air stream filtered from 0.1 to a maximum of 10.0 microns. Additionally, many precision air drying systems utilize a heat source either in-line with the air being delivered to the parts, or as a subsequent drying zone to flash residual moisture from parts requiring more complex or stringent drying.

Today's precision air blow-off systems are of two basic types – low-impact air velocity and high-impact air velocity – each of which can be coupled with HEPA air filtration.

Impact air velocity is defined as the force of air circulated over the surface of a part. With low-impact air velocity systems, volumes of air are exchanged across the part surface to draw off moisture together with heat, which is evaporating the moisture. High-impact air velocity systems actually strip away the water from the part surface by physically blasting it off.

Although each approach has specific parameters suitable for a specific classification of parts drying (see Figure 1), blow-off systems are often misapplied because the user did not know that other, more efficient or effective methods existed.

Therefore, each application must be thoroughly reviewed to ensure selection of the optimum precision air drying method. Whatever the combination of components, the end result of precision air drying is parts dryness and cleanliness without sacrificing production rates or quality.

Figure 1
Parts Drying Evaluation Sheet

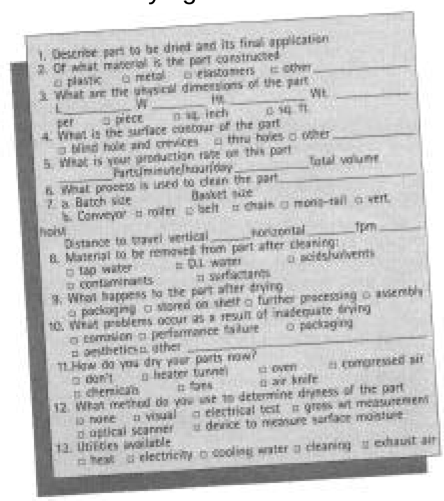
1. Describe part to be dried and its final application
2. Of what material is the part constructed
□ plastic □ metal □ elastomers □ other
3. What are the physical dimensions of the part
L W Ht. Wt.
per □ piece □ sq. inch □ sq. ft
4. What is the surface contour of the part
□ blind hole and crevices □ thru holes □ other
5. What is your production rate on this part
Parts/minute/hour/day Total volume
6. What process is used to clean the part
7. a. Batch size Basket size
b. Conveyor □ roller □ belt □ chain □ mono-rail □ vert. hoist
Distance to travel vertical horizontal fpm
8. Material to be removed from part after cleaning:
□ tap water □ D.I. water □ acids/solvents
□ contaminants □ surfactants
9. What happens to the part after drying
□ packaging □ stored on shelf □ further processing □ assembly
10. What problems occur as a result of inadequate drying
□ corrosion □ performance failure □ packaging
□ aesthetics □ other
11. How do you dry your parts now?
□ don't □ heater tunnel □ oven □ compressed air
□ chemicals □ fans □ air knife
12. What method do you use to determine dryness of the part
□ none □ visual □ electrical test □ gross wt measurement
□ optical scanner □ device to measure surface moisture
13. Utilities available
□ heat □ electricity □ cooling water □ cleaning □ exhaust air

Table 1

Precision Air Drying Methods Available

		BENEFITS	LIMITATIONS
Low-Impact Air Velocity System <= 10,000 FPM		• Low, total energy consumption • Excellent for small batch drying • Low noise levels 75 dBA • No air turbulence • Small space requirements	• Long cycle times • High energy consumption per part • Manual labor needed for loading and unloading carriers • Not made to handle large-scale production rates • No heat rise generated requiring in-line heater or radiant heat • Evaporative process can bake impurities onto part surface • Heated parts may be difficult to handle
High-Impact Air Velocity System 10,000 FPM – 35,000 FPM	PRESSURE BLOWERS	• Low energy consumption per part • Short cycle times • Automated for high-volume productivity • 95-100% of water is sheared off • part surface High impingement decreases frequency of filtration, recharge and disposal of cleaning solutions between wash and rinse zones • No manual labor • Clean dry air • Heat rise to 90 F	• High total energy consumption • Requires large floor space • Sound levels to 85 dBA • High initial equipment cost • Air turbulence • May need to stabilize part • May require additional I.R. heat zone to finish drying
	PRESSURE BLOWERS W/ H.E.P.A. FILTER	• Filters air from 99.9-99.997% efficiency • Guarantees part cleanliness down to 0.1 micron	• High initial equipment cost • Requires additional floor space
	COMPRESSED AIR	• Ideal for small-scale drying of parts w/<6 sq. in. of cross-sectional area traveling single file at <5 FMP • Utilizes existing in-plant compressed air supply	• High energy use • Insufficient for high-volume productivity • Labor intensive • Ineffective for large components • Can recontaminate cleaned part • High sound levels to 90 dBA • May need to stabilize part

Low-Impact Air Velocity

Low-impact air velocity (less than 10,000 FPM) is developed by use of low-pressure industrial fans / blowers with the possible addition of an in-line air heat source for maximum drying efficiency. Because the fan itself generates little or no heat rise, an in-line duct heater (or radiant heat elements) must be used to elevate air delivery to the optimum temperature. This design is most common for batch-type cleaning and drying applications.

Air knives are used with low-impact air velocity to dry parts having a smooth and narrow profile when the throughput speed can be regulated to match the limitations of the low-impact air velocity.

An air knife is a round, square, or formed shaped tube of metal or plastic with holes or slots across the side of its length, spanning the width of the production line. Low- or high-velocity air piped into the tube exits the holes or slots to impact the surface of parts passing by on hoist or conveyor. The impact velocity (not the exit velocity) of the air relative to the part movement determines how much moisture is removed.

In-line heaters are generally not used for these low-pressure (10 to 18 inches water column), high-volume (500 to 1500 CFM) fan / air knife combinations due to the high energy consumption of the heater. Rather, a radiant heat zone (infrared cells in a heat cycle for batch cleaners) is used to elevate the ambient temperature and flash dry parts after the air circulation or air knife zone has done a majority of the liquid removal.

High-Impact Air Velocity

High-impact air velocity (10,000 to 35,000 FPM) can be achieved by use of pressure blowers or compressed air. The blast of air is channeled through air knives or nozzles to blow all liquids off a part's exposed surfaces.

Although abundant in most manufacturing facilities, the most inefficient use of compressed air is parts blow-off. It generally consumes two to three times the electrical drying energy used by a pressure blower for a typical parts drying application. Together with oil and condensate filtration, the increased maintenance costs of a continuously running compressor can be substantial. Manual labor for blowing parts dry after exiting a wash tunnel can be costly as well.

Ideal applicants for compressed air include small-scale drying of parts having less than 6 square inches of cross-sectional area and travelling single file at less than 5 FPM. This would be the maximum part size for a continuous production line where compressed air would be practical.

On the other hand, a pressure blower (of which there are several varieties) has a few distinct advantages over both compressed air as well as the low-impact air velocity designs.

Operation in lieu of electric heaters, the heat rise generated by a pressure blower can be as much as 90 F at a pressure of 120 inches H_20 (4 psi). Air knife noise levels are lower than those of compressed air and, with use of a butterfly valve, impact air velocities can be infinitely adjusted for optimum dryer performance.

High-temperature air delivery systems can be cultivated by recirculating air knife discharge air back thorough the pressure blower, utilizing heat of compression and elevating the discharge temperature from 150 F to as high as 350 F. An infrared heat zone subsequent to the air knife section and at the tall end of the in-line cleaning system will assist in completing the drying process, and provide the necessary heat load for the highest recirculated air temperatures.

Pressure blowers supply clean, dry, and oil-free air for dozens of precision cleaning systems. But, again, certain application limitations (see Table 1) must be considered.

HEPA Air Filtration

While low- and high-impact air velocity may be effective at blowing liquid off a surface, precision air drying demands that the part not be recontaminated once aqueous / semi-aqueous cleaner leaves surface contaminants virtually undetectable. Some of the most critical cleanliness is required where optical particle counters assist quality control.

Available to thwart recontamination, a wide array of inlet and in-line HEPA (High Efficiency Particle Air) filter elements maintain the cleanliness of air a product is exposed to – down to 0.1 microns and with an efficiency range from 99.9 to 99.997 percent. Most industrial-grade filtration of air drying equipment is filtered to 10.0 microns, below which particles are not visible by the naked eye. The filters rated 10.0 microns and above, round-pleated paper or polyester, are readily available and modestly priced.

Generally square-framed elements measuring up to a 24-inch cube, HEPA filters can cost hundreds of dollars to replace after every 2000 to 4000 hours of operation -- a worthwhile expense should you need to achieve the extreme cleanliness these filters provide. But converting to aqueous technologies, avoiding the skyrocketing costs associated with chemical cleaners, will make maintenance costs such as those for the HEPA filter less burdensome.

In order to protect HEPA filter function, filter housings must be constructed to withstand the operating pressures of blower systems up to 4 psi. They must be capable of withstanding washdown and / or sanitizing procedures (before installation and during filter replacements) and also be easily accessible for filter replacement.

HEPA Filter Case History

The Color Printed Imaging Division of Tektronix Inc. (Wilsonville, OR), manufacturer of ink jet heads used in color printers, recently put into production a complete HEPA filtered air drying system as part of a new wash line dedicated to cleaning plates within the ink jet head assembly.

The print head is composed of thin plates that are cleaned prior to assembly. Any particles left on the plates will be included in the finished ink jet head and cause a plug of the 15 mil diameter jet. Since the ink jet heads manufactured by Tektronix are permanent and not disposable, they must be extremely clean.

The Tektronix wash line has two air knife drying sections. The drying set-up consists of two high-speed centrifugal blowers, two HEPA filtration packages, and the air knives. The placement of the filtration package ensures that filtration occurs between the blower outlet and the air knife, thereby preventing any of the system's moving parts from introducing contaminants.

The belt from the wash line runs on SS slide rails to cut particle generation, and the line exits through an enclosure and an automatic sliding window directly into a Class M4.5 (1000) cleanroom.

The air pressures in the cleanroom and the room with the wash line are adjusted to ensure all air movement through the line is from the cleanroom out when the window is open, and that the air supply through the air knives is sufficient to maintain positive pressure inside the dryer end of the wash line, with respect to the room. This arrangement ensures that all air in the dryer end of the wash line is particle-free.

To test the system's effectiveness, a carrier was made to pass silicon wafers through the machine. A wafer surface inspection system from Hamamatsu Corp. (Bridgewater, NJ) was used to characterize the wafers, with its threshold adjusted to create a lower limit of approximately 12 microns or 0.5. mils.

Contamination Monitored

To determine if either the cleaning or drying processes caused contamination, the wafers were cleaned particle-free before being sent through the system. Wafers were also allowed to stand uncovered adjacent to the end of the wash line at the entrance end. Those wafers, measured as controls to show the relative effectiveness of the wash line, showed contaminants.

A final test was run by cleaning the wafer / carrier system with the covers at the dryer section left open to allow "dirty" room air entrain into the system. These parts also showed contaminants. When recleaned with the system closed, the wafer emerged clean and particle-free. Table 2 outlines the results and approximate particle sizes.

The parts used in the manufacture of ink jet heads must not only be clean, they must be dry as well. The processing subsequent to the cleaning is done in an enclosure that must be kept at 20 ppm moisture or less. A DuPont moisture meter monitors the moisture in the gas steam leaving the enclosure. Parts entering the system do not cause a change in the moisture detected.

The final testing involved using a Met One (Grants Pass, OR) laser particle counter to monitor the system's effectiveness at maintaining a clean atmosphere in the wash line. The air quality was measured first with only the belt running, second with the belt and air knives dryers running, third with the entire line running (all pumps, blowers, and DI water), and fourth with the line running and the door to the cleanroom open. Table 3 outlines results.

The system is very effective at cleaning the interior of the wash line, in particular when water is being sprayed. The interior of the line meets Class M4.5 (1000) requirements.

Drying Methods Vs. Throughput

The rate of throughput is fundamental to the final choice of drying system type. As volume increases, so must automation and power if drying is to be adequate and cost-effective. In explaining this relationship, a machined aluminum casting measuring 6 inches cubed with a series of through and blind holes will serve as a hypothetical example.

In a scenario where low production rates exit (200 components per day) and automation is desired, a batch operation of 25 components per hour at eight cycles per day will be adequate. Typically, excess water would need to be removed prior to placing the basket of parts into the drying zone where a low-impact air velocity system evaporates surface water and flash drying finishes the job in a 20- to 30-miunute cycle.

Such a system would use a 0.25- or 0.5- horsepower fan assembly with an electric heater system requiring approximately 5 to 8 kw of electrical energy. Total dryer module power consumption for the lower capacity batch cleaner is 9 kw hour, which at a rate of 25 parts per hour equals 2.7 parts per kw hour.

The advantages of this low-production scenario are low-energy consumption, small space requirements, and low noise levels. The disadvantages are that it requires a certain amount of manual labor for loading and unloading the baskets, the 30-minute drying cycle time is lengthy, and parts heated by drying may be difficult to handle.

Increased Throughput, In-Line

Greater throughput would change everything. If the production rate of the castings increased to 25 parts per minute (12,000 parts per day), the batch cleaning process would not function. This rate would demand continuous throughput from a full in-line conveyorized cleaning system.

The drying cell would entail a high-impact air velocity system composed of blower assembly, air knives, and probably a radiant heating source. A 15- to 20-horsepower, high-pressure blower and 18 kw radiant-heat coil would provide all of the drying power necessary, with the blower providing a natural heat-of-compression temperature rise of 50 F.

The in-line system's drying cycle is now completed in only 30 seconds. Recirculation of this naturally-heated air will accelerate the drying process for increased throughput. Total dryer module power consumption for the high-capacity, in-line cleaner is 33kw hour which, at a rate of 1500 parts per hour, equals 45 parts per kw hour.

In relation to total throughput, an energy-efficient, high-impact air velocity system will have lower total power consumption per part than the low-impact air velocity drying system.

Disadvantages of the in-line systems are the initial equipment and operating costs. Sound levels also increase, as do floor space requirements compared to the low-volume, low-impact air velocity system. Advantages of this high-volume, high-impact air velocity system are that production rates increase to 25 parts per minute, manual labor is eliminated, and the parts finish completely dry.

Table 2
Levels of Contamination

TEST	AVERAGE # OF PARTICLES	APPROX. SIZE
1. Before cleaning	0	-
2. After cleaning	0	-
3. Uncovered in room	3	12 to 36 microns
4. Cleaned with covers opened	9 2	12 to 36 microns 100 to 140 microns
5. #4 Recleaned	0	-

Table 3
Particles / cuft

TEST SCHEME	>0.5 MICRON	>0.5 MICRON
1. Belt only on	28,000	833
2. Air knives on	1967	3
3. Line running	230	0
4. "3" + door open	92	0

Other Practical Considerations

Whether a high- or low-velocity system is used, every drying application involves several practical considerations. For example, how will the part be kept stable?

In the case of low-impact air velocity systems that dry delicate parts processed in batch cleaning operations, turbulence is not an issue. Air is circulated around the parts in an enclosed space, heating to the point where moisture evaporates. This, of course, precludes higher-volume production, which would require an in-line cleaning system and high-impact air velocity drying with other special handling.

However, larger parts with greater surface area (6" x 6" x ¼" high) and others demanding the continuous high throughput of an in-line cleaner require high-impact drying and may indeed be disturbed by a solid wall of air. Such parts are typically transported through both washing and drying cycles on a conveyor while being stabilized in a basket or rack.

A second option would be an opposed conveyor belt that lies over the tops of parts. Such a system both washes and dries the parts, sandwiching them in place to prevent movement or damage, but allowing accessibility for drying.

Another consideration concerns the waster that is blown off the part. In low-impact air velocity systems, drying is primarily a process of evaporation. However, impurities can be baked onto part surfaces if soil, mineral, or chemical residues are entrained in liquids left on the part surface prior to the drying zone.

In the case of high-impact velocity drying systems, water is sheared off of exposed parts surfaces. Water is squeegied off with air and some is atomized, thereby becoming a vapor, increasing the humidity of the drying section of the in-line cleaner. Air knives strip off the bulk of the water (95 to 100 percent), and the radiant infrared heat cells finish the job. In the process, a certain portion of the water is recaptured.

Air knives are often used to minimize the carry-over of water off parts between each wash and rinse zone. Therefore, the high-impingement air velocity system decreases the frequency of filtration, recharging, and disposal of aqueous / semi-aqueous solutions for in-line and batch clean systems.

A final consideration is sound. Sound levels are not a factor in low-impact air velocity dryers. Noise generated with these systems is usually below 75 dBA, which goes hand-in-hand with minimal power for their low throughput. The greater the throughput, the more power necessary and, consequently, the greater the noise.

Therefore, sound levels increase with high-impact air velocity drying systems. Despite this, many of today's in-line cleaners having air knife blowers of up to 30 horsepower are built with acoustical enclosures producing less than 80 dBA.

The Next Step

How dry is dry? The degree of dryness required for a part is directly related to the next step after drying. The part may be integrated with other materials, placed on a shelf, packed into a box and shipped, labeled, coded with ink, painted, coated with preservatives, gathered for further assembly, or quality-tested.

Whatever will be done with the part, it must be dry enough to avoid any problems from moisture. Just as with particulate contamination causing rejects, parts not properly or completely dry cost money, too. Storage of improperly-dried parts can cause a variety of ills. For example, packaging may rot, or appear aesthetically unacceptable and be rejected by the end user. Moisture may damage or corrode the part in transit, leading to defects, and ultimately rejects.

Inadequately-dried parts that will be integrated with others can destroy the end product.

A moist circuit board, for example, will fail electrical testing. Parts that require labeling or ink jet coding will have high reject numbers if faulty drying causes labels to slip and coding to be illegible.

If the drying cycle of a parts cleaner bottlenecks the production line, it costs money. If parts are being rejected because of moisture, it costs money. If labor must continuously blow parts off by hand after the in-line dryer, it costs money.

Current and Future Dryness Measuring Options

Manufacturers of in-line cleaner primarily for the circuit board industry use high-impact air velocity drying systems. They have historically employed a weight measurement standard to determine component moisture content before and after cleaning down to 1/1000 of a gram. Their moisture measurement procedures show that many components are drier coming out of the dryer module than they were prior to cleaning and drying.

For example, these manufacturers monitor drying effectiveness by spot checking one or two printed circuit boards per day to substantiate overall effectiveness of the cleaning and drying system. But, because of the time involved, continuous throughput monitoring is not possible.

The check begins by weighing the part already cleaned and dried. In this example, it weighs 1 pound. The component is then placed in an oven to remove all traces of absorbed moisture. At this point, we will use a hypothetical weight of 0.999 pound. Then it is placed in a room to stabilize, where it absorbs atmospheric moisture. In a few minutes it's reweighed and found to weigh 1 pound again.

Now, the part is run through the washer and dryer module system and remeasured, which in many cases results in a net weight of 0.999 pound once again. This spot check demonstrates just how dry components become during high-impact air velocity drying together with infrared heat zones.

An alternative to the weight measurement procedure, a moisture meter as cited in the earlier Tektronix HEPA discussion, determines atmospheric moisture content of components placed in a controlled environment. Use of this moisture meter, unlike the weight measurement process, allows for checking moisture content in large groups of components to ensure maximum dryness prior to the next process.

For the Tektronix ink jet heads, throughput monitoring is essential because the integrity of the coating process immediately following the dryer depends upon an absolutely dry surface. For the circuit board manufacturer, spot checking of components suffices, since failure rates associated with moisture are typically very low.

Design Meets Demands

An optimum air delivery drying system should remove as much moisture as possible within the allotted time at the lowest energy consumption and for the smallest capital outlay. A careful equipment mix of air source, filtration, and in-line or radiant heat is needed to achieve this goal. Unfortunately, many drying problems have been met with brute force by trying to use more of one component to compensate for a lack of the other. In fact, most drying applications require a little of both.

By complementing an optimum cleaning system with a drying system that will consistently, effectively, and appropriately dry parts in a given application, manufacturers can reduce loss rates, increase throughput, minimize man hours, and achieve maximum quality control.

Numerous configurations of high- and low-velocity systems, sometimes in conjunction with HEPA filtration, can serve the widest spectrum of parts drying needs. A careful evaluation of those needs by qualified experts and a commitment to cost-effective automation will go a long way to solving parts drying challenges.

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