How to Improve Cross-Machine Drying Profiles

William R. Henry, President, Advance Systems, Inc.

Abstract

Be it a flotation, roll-support, through-air or infra-red dryer, the ability to produce an even drying profile across the entire width of the web is critical for producing a consistent product and achieving high production efficiency. Existing dryers may have inherent drying deficiencies or may develop uneven drying profiles over time. The cause, effect and resolution of several profile problems are discussed with special emphasis on improvements that can be implemented in existing dryers.

Introduction

Industrial hot air dryers are expected to provide even drying (or curing) in both the machine and cross-machine directions. The cross-machine component is certainly the more difficult to achieve for continuous webs whether they be coated, saturated, laminated or cured. The consequences of unbalanced drying may include edge curl, ridging, sheet breaks due to over-drying, and/or lower throughput due either to off-spec product or slower line speed required to ensure that all parts of the web are dried.

For this discussion, it is assumed that if the wet coating weight and web weight is evenly distributed across the width of the web, then uneven drying would be caused by an uneven cross-machine drying profile. This condition might be due to an inherent design flaw or the result of physical changes to the dryer that occur over time. In either case, significant improvements can be made by defining the deficiency and implementing retrofittable corrections.

It is common to assume that a poor drying profile is the result of a poor air temperature profile in the dryer. Certainly the temperature profile is a major contributor to how evenly the web will dry, however there are other profile variables that will also impact the drying or heating process, including air impingement velocity, air volume and air humidity. Thus, the resolution of a drying profile problem should recognize four key requirements needed to affect even drying, heating, or curing:

1. Creation and delivery of a homogenous mixture of air at the prescribed temperature
2. Even distribution of the air (volume and velocity) across the full width of the web
3. Delivery or impingement of the drying air should be perpendicular to the web surface
4. Removal of the “spent” air away from the web should be in a perpendicular direction

Two common types of dryers are used to illustrate the correction of drying profiles; 1) the “thru air” dryer or oven that will usually employ a conveyor wire to transport the web thru the dryer and allow drying air to pass through the product and the wire, and 2) the “flotation” dryer or oven - a non-contacting impingement dryer used with coated (one or two sides) or saturated webs.

Thorough Mixing of Hot Air

The plenum or "hot box" where the supply air is heated and/or reheated can be a source of uneven air temperatures. Temperature "layers" are most apt to occur because of poor mixing at the heat source (usually a natural gas burner). This is more common when the burner is placed after the recirculation fan in a "push thru" configuration. Placement of the fan after the burner (pull thru) is perhaps the simplest and surest means of ensuring thorough mixing of the re-heated air (Figure 1).

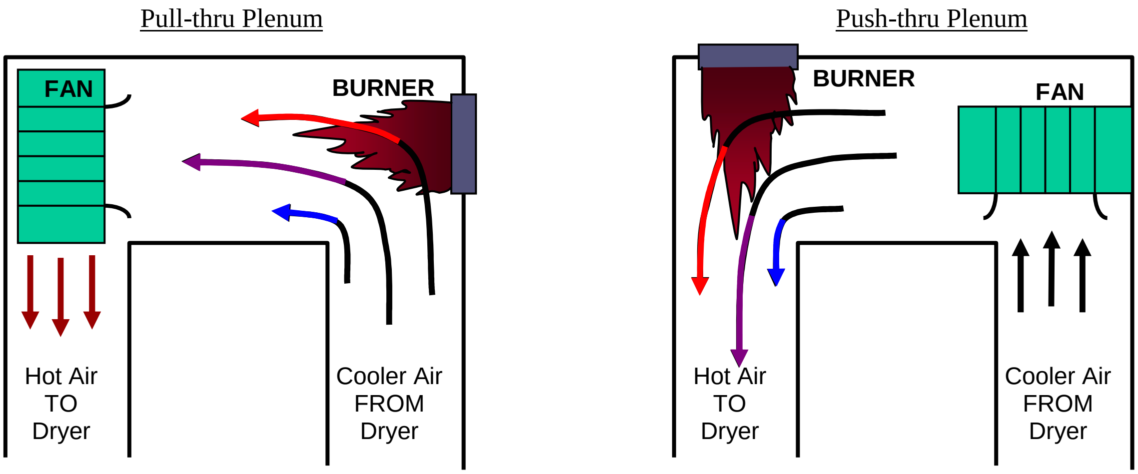

Figure 1. Pull-thru and Push-thru hot air plenums

From the plenum, the next source of uneven heating is the ductwork that carries the air to the dryer box. At the cooler wall surfaces where the air is also moving slower there may be a tendency to develop a distinct temperature profile. Large cross-sectional ductwork with low velocity air is particularly prone to this possibility, i.e. large thru-air dryers for glass mat products (Figure 2) will often utilize recirculation ductwork with a cross sectional area in excess of three square meters.

Figure 2. Seven-zone, glass mat thru-air dryer during installation

A simple and even retrofittable device for eliminating cooler stratified air is a static mixer. A static mixer (Figure 3) is positioned inside of the approach ductwork (usually across the entire cross section) to physically mix the air stream through a series of redirecting vanes that divide, turn and twist the stream to create mixing. Splitter vanes (Figure 4) within a duct elbow serve to "preserve" a given temperature profile while reducing frictional loses.

Figure 3. In-duct static mixer

Figure 4. In-duct splitter vanes

Still other contributing causes to temperature gradients entering the dryer are uneven wall insulation, air leaks into the ductwork, excessive “through-metal” cool spots in the ductwork, and excessively long duct runs from the plenum to the dryer. The best method of pin-pointing these sources of temperature stratification is to measure and compare the air temperature profile across the full width of the supply duct (X and Y dimensions) just after the reheat burner plenum and again just before entrance to the dryer enclosure. A comparison of these profiles should allowed one to determine if a temperature problem originated in the reheating plenum or developed while passing through the approach ductwork.

Even Distribution of Air Volume and Velocity

If one determines that all air is delivered to the dryer at the same temperature yet a poor drying profile still exists, then it may be that the source of the problem is an imbalance of the quantity and/or force of the hot air delivered across the width of the moving web. While these elements are often overlooked, the volume of air delivered to the product (at a given temperature) is directly related to the amount of heat transferred to the web and hence the amount of drying/heating that takes place. That is, if a cubic meter of air at 150 ºC contains 11 MJ of energy, then the solvent evaporation rate will be quite different when a coated web is subjected to 1 m^3 of air versus 2 m^3 of air. As such, the cross-direction profile of air flow or air flow pressure needs to be relatively “flat” so that the full width of the coating on the web is exposed to the same amount of drying energy.

The even distribution of air across the width of a thru-air dryer (drying and curing air passes thru the web itself) is usually established by forcing the air to first pass through a perforated plate located above and across the full width of the web. For flotation dryers, a similar perforated plate is contained inside of each of the individual air bars (see Figure 5). In both cases, the perforated plate creates flow resistance and back pressure which serves to even out the cross-machine air pressure before the air passes through the plate. Using a lesser number of holes and/or holes with a small diameter will create a higher back pressure (i.e. better cross distribution) but with a corresponding need for more fan power to push the air through. Plugging would also become more of a concern as the hole diameter is reduced. Conversely, more holes and/or larger diameter holes will results in less back pressure and a corresponding reduction in required fan power, but also less cross-machine “leveling” of the air flow. As such, the trade off in achieving better air distribution with perforated plates is an increase flow resistance that requires greater fan pressure (i.e. larger fan, larger motor, more electrical power usage).

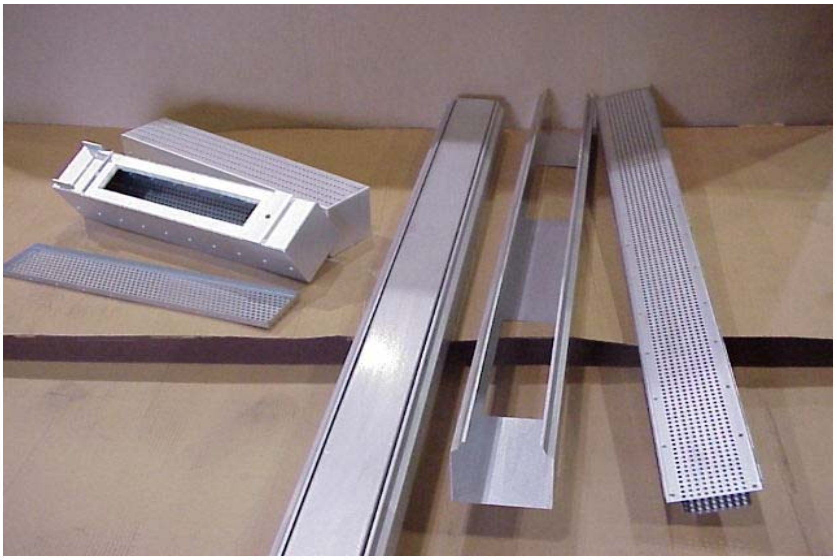

Figure 5. Distribution plates for air bars and hole bars

The relatively “slow and low” air flow used in thru-air dryers is a particular challenge. So, where spacing in the dryer enclosure will permit, it is actually best to have two or more individual air distribution plates located in series and several inches apart. Because of the mixing and redistribution that occurs between the plates, it is more effective for instance, to have two perforated plates with each creating a 1” pressure drop, than to have a single plate creating a 2” pressure drop. The two-plate configuration is also beneficial with light weight webs that are more stable on the conveyor belt when using lower impingement air velocity. The velocity of the air leaving a second 1” pressure drop plate will be considerably less (proportional to the square root of the pressure velocity) than that of a single 2” pressure drop.

Of course, the geometry of the approach ductwork and the dryer enclosure itself will also influence the cross-machine air distribution. These effects are very difficult to predict accurately without the aid of sophisticated computer models. The output of one such model is shown in Figure 6. In this case, the amount of pressure drop on each of two plates and the distance between the plates was varied until the minimum air pressure-velocity profile could be achieved.

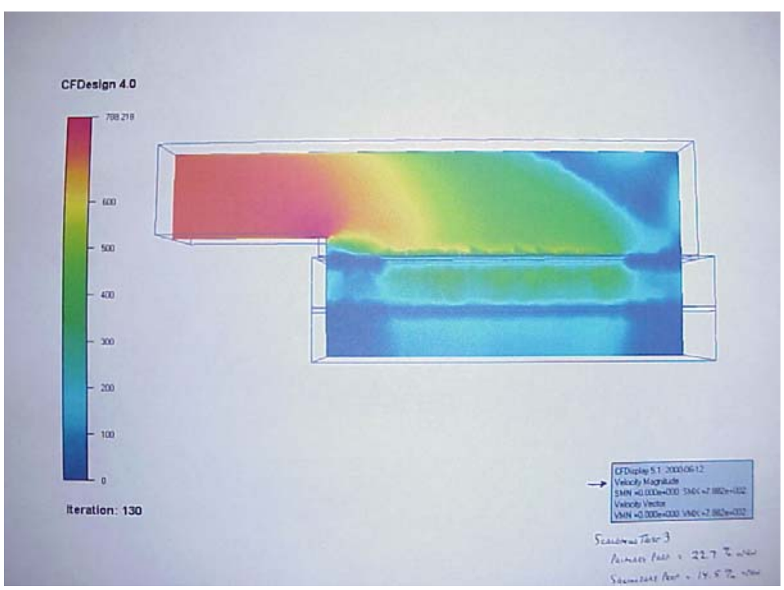

Figure 6.   Computer simulation of air velocities (color coded) from end-fed air supply through two successive perforated plates.

Delivery of Air Perpendicular to the Web Surface

Yet another contributing factor for consistent and even drying is the direction the air is moving when it comes in contact with the web. For the highest transfer of heat energy the air should contact the web at a 90-degree angle to the web surface. Contact at less than a 90-degree angle will lessen the heat transfer (drying power) and may also create a poor drying profile across the web. For example, if the air flow is angled toward one or both edges of the web, that portion of the web will be heated and dried more than other sections of the web. In the case of air bars, the web is in close proximity (about 6 mm) to the air slot and vertical flow is easily attained. However, this close proximity also means there is little margin for error in the cross-machine alignment of the air bars relative to the web. Should the air bar become misaligned due to warping, metal expansion or improper installation, the web will dry faster where the air bar comes closest to the web.

For thru-air dryers that use perforated metal sheets or "hole plates" located several inches above the web, the challenge is not so much alignment as it is establishing vertical air flow. The hole plate design is quite effective in distributing the volume of air, but not as good at establishing air direction. In fact, the hole plate is one extreme for air directional control, with the extended tube being the other extreme (see Figure 7).

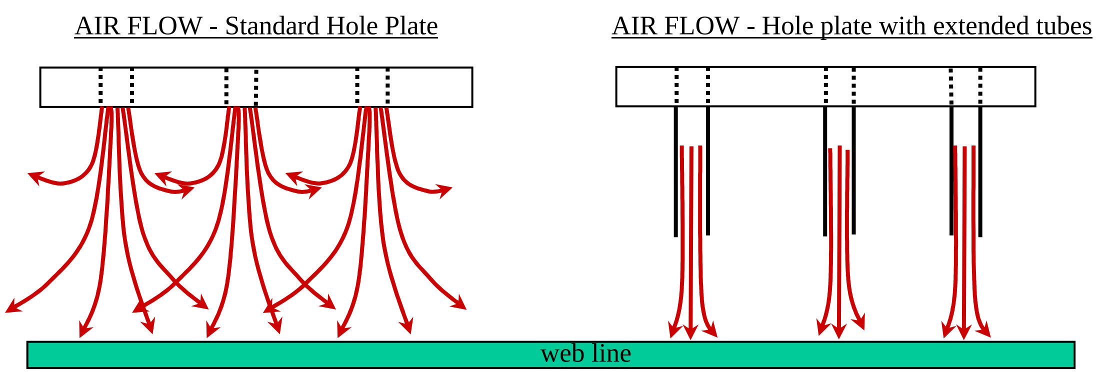

Figure 7. Air flow patterns for standard hole plate versus hole & tube plate design

The most desirable pattern is between these two extremes – a pattern that will spread out to cover the web surface while maintaining a relatively focused direction (Figure 8). In practice, the size, pattern, and shape of the holes are adjusted until the desired pattern is achieved. Figure 9 illustrates a hole pattern trial in which lengths of yarn are arranged in a matrix above an inverted perforated plate. An acceptable result will have the yarn blowing straight up without wavering.

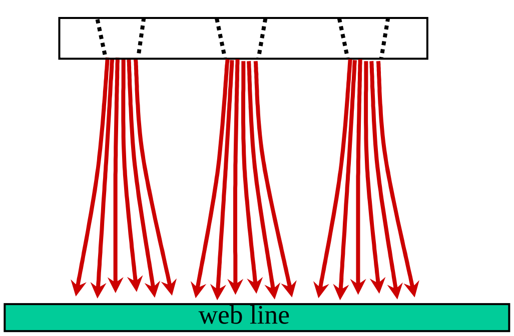

Figure 8. Desired air pattern. Actual hole shape is proprietary and not shown here

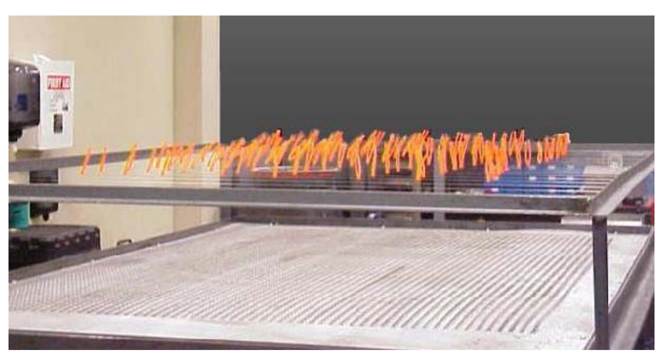

Figure 9. Hole pattern testing

Extraction of Spent Air Perpendicular to the Web Surface

The manner in which the drying air is pulled away from the web can be as important as how it is delivered. Just as non-perpendicular impingement air can "push" the web and/or create a drying bias to a section of the web, non-perpendicular removal of the spent air (a.k.a. extracted, recirculated or exhaust) can "pull" the web and alter the drying profile.

Most commercial dryers will extract air through an exhaust duct on one side of the enclosure. A technique that serves to counter the tendency to pull the air to this "fan side" is to extend the duct into the dryer so that the opening of the duct is positioned in the middle of the web. Even better is to extend the duct the full width of the enclosure and use multiple openings that allow the air to be pulled down and into the duct such that the flow is perpendicular to the web. Note that the duct extension pictured in Figure 10 uses graduated openings. This accounts for the fact that the suction from the fan will be greater on the fan side. By using small openings where suction is high and large openings where suction is low, it is possible to achieve an even draw of air across the entire width of the dryer enclosure.

Figure 10. Extended exhaust duct with graduated outlets

For impingement dryers (flotation, air foils or roll-support) it is also important to extract the air from the same <u>surface</u> of the web that the air is supplied. For example, with a full flotation dryer that has air bars on the top and bottom of the web, there should be separate exhaust ducts for the top and bottom of the web. As shown in Figure 11, "same side extraction" allows the spent air to flow away from the web in a perpendicular fashion directly to the exhaust duct. If only a single exhaust duct is present on either the top or bottom side of the web, at least half of the air must flow around the web. Such a flow pattern could easily cause excessive edge drying.

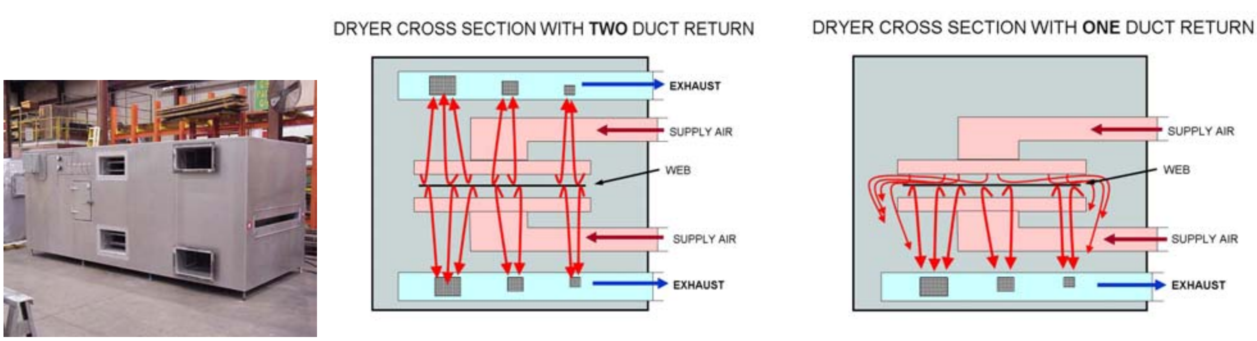

Figure 11. One-zone dryer with two exhaust ducts; illustrations of air flow patterns with two and one exhaust duct

Of course, thru-air dryers to not have this requirement because the air must flow through the web. For thru-air dryers, it is important to set the exhaust draw below the web at a level such that all the air is drawn through the web. Too little draw and the air will begin to flow around the edges of the web and possibly create a dry edge condition. One method applied to thru-air dryers for creating vertical flow of exhaust air thru and away from the web is to use a full-width distribution plate positioned between the conveyor wire and the exhaust duct. This multi-hole "resistor" is very similar in function to the distribution plate used above the web that created the back-pressure that in turn caused the air to be evenly distributed across the full width of the web. A hole plate below the web creates the same type of differential pressure yet now causes the air to be evenly extracted across the full width of the web.

If exhaust duct extenders or extraction distribution plates are not present in a dryer, they can often be retrofitted. If they are already part of the dryer, then one should be aware that regular cleaning and maintenance is needed to prevent plugging of these devices that could otherwise cause uneven air flows and uneven drying.

Identifying the Source of Uneven Drying Profiles

The drying, heating or curing profile of the web is not just a function of air temperature but is also affected by the air velocity, volume and direction of flow. As such, the quantification of both the cross-machine air temperature profile and the cross-machine air flow profiles is the first step in determining what problem may exist and how to resolve it. A *temperature profile* can be attained by indexing a measuring device (usually a thermocouple) across the width of the web. For accurate results, this should be done through a wall tap with all doors closed and the dryer operating at normal production settings. The air flow or more accurately, the *pressure velocity* is measured with a Pitot tube and manometer. As with the thermocouple, the Pitot tube should be indexed across the full width of the dryer through a wall tap. When a conveyor wire is present as with the thru-dryer, a full-width measurement "device" (Figure 12) can be carried on the belt through the entire length of the dryer to obtain both temperature and pressure measurements.

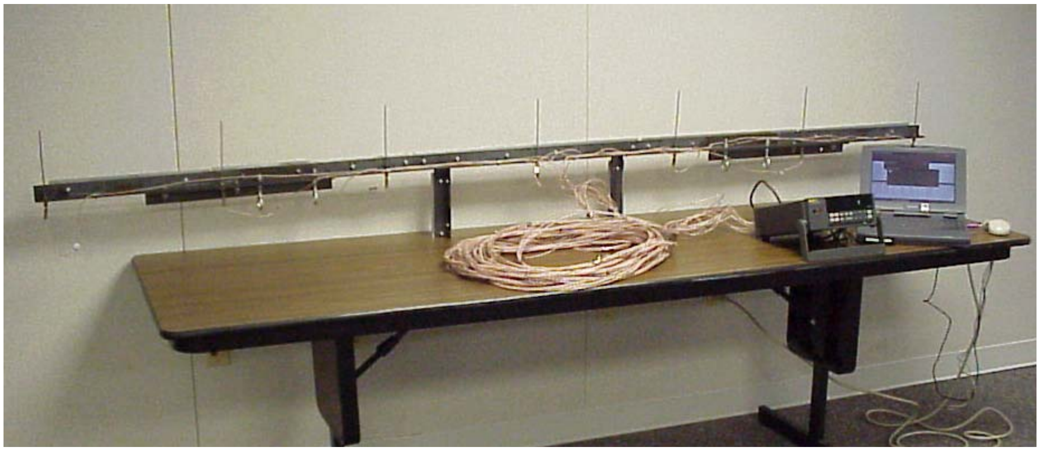

Figure 12: Profile testing rack containing 7 sets of temperature and pressure reading devices

With these profile measurements available, the basic approach to trouble-shooting is summarized in Table 1:

Table 1. Cross-Machine Profile Trouble-shooting

Cross-Machine TEMPERATURE Profile	**Cross-Machine VEL. PRESSURE Profile**	**Action**
GOOD	BAD	Improve distribution via hole plates and duct/dryer geometry changes
BAD	GOOD	Improve air mixing (static mixers) and/or eliminate cold or hot spots
BAD	BAD	First correct air distribution, then retest for temperature profile

Conclusion

Level and stable air temperature profiles in flotation and thru-air dryers can be attained by assuring that the supply air remains thermally mixed and is delivered to the product with even cross-machine velocity and volume. Burner configuration, static mixers, diffusion plates and distributed evacuation of the "spent" air are important factors in achieving the overall result. In new dryers with web widths up to 5 meters, the design criteria described in this report have yielded cross-machine temperature profiles down to ± 1 ºC. While existing dryers may present some constraints based on their physical structure, one should expect that the implementation of these same techniques for improving the *drying profile* will yield comparable results.