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Title: “Drying Considerations for Coatings Applied to Thin Films”

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In an effort to maximize profitability in an ever more competitive market, film converters have been forced to address the challenges associated with running faster line speeds, thinner substrates, thinner coatings and wider webs. Within the drying section of a typical coating/laminating machine, these challenges include both web-handling concerns and the drying process itself.

The purpose of this paper is to define some of the key problems associated with the drying of coatings on thin films and to identify the equipment and processing techniques that are typically used to address these challenges. Due to the broad scope of the subject matter, the author will not attempt to identify or discuss at length, the full range of considerations or permutations of variables that may come to play when drying coatings on thin films. Rather, in the interest of time and the desire to provide some realistic and useful recommendations for thin film drying, we will limit our discussion to some of the most frequently encountered challenges and the associated range of potential solutions as they relate solely to (flotation and roll support) convection air drying systems. Finally, for the purposes of this paper, we would like to define thin films as films ranging in thickness from less than 0.25 mils to 3 mils.

Key Factors Affecting Drying of Coatings on Thin Films

The following table summarizes some of the key problems associated with the thin film drying process. Each of these will be discussed in more details in the following sections.

Characteristics that Present Drying Challenges
Film Characteristics
Extensibility
Camber
Baggy Edges
Web Width
Coating Characteristics
Thickness
Viscosity
Cure reqmts.
Machine Characteristics
Length
Width
Air Handling
Tension

Substrate Considerations

Extensibility

Nobody wants to introduce a nice, flat, uniform gauge substrate at the entering end of a dryer and pull out a wrinkled, necked-down string of taffy at the other end. So when dealing with extensible films such as polyethylene and polypropylene, we need to consider several issues.

First, we know that these films are temperature sensitive. Depending on the film properties, they will begin to relax and/or lose stiffness at temperatures ranging from 140-180° F. Therefore, dryer temperatures must be fairly low and this may mean longer dryers.

Secondly, films lose tensile strength as their temperature is raised. Hence, line tensions must be relatively low, to prevent necking down of the substrate when it is heated. At low tensions, web handling can be a concern and problems can be induced by improper air handling, particularly in air flotation dryers. Even in roll support dryers, poor handling of exhaust air (i.e. too high exhaust velocity or pulling exhaust from one side of the web) or for that matter, supply air (i.e. poor cross machine nozzle velocity uniformity or badly aligned nozzles) could create web steering issues or web flutter issues, that result in web or coating defects. Good air handling (both supply and exhaust) is critical when operating under low-tension conditions. (Fig 1 illustrates several recommended air handling design features). Also, when running extensible films, it is important that the dryer is a controlled tension zone, independent of tension requirements in other areas of the machine.

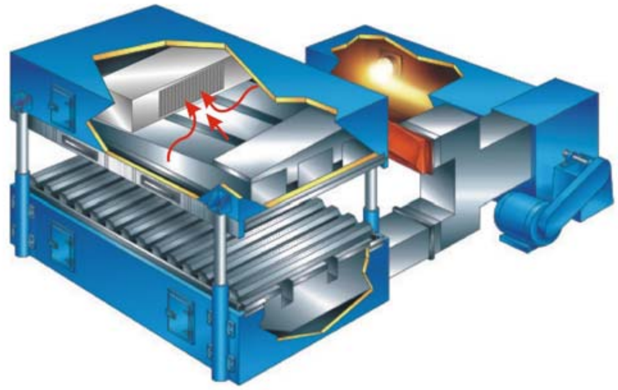

Fig. 1 Uniform supply and exhaust Airflow distribution.

Camber

Web camber is a fairly common manufacturing phenomenon for films produced on tenter-frame systems. Since the web is not straight, it will tend to take its natural curvature over long, unsupported spans. This in turn can present a scenario where the web shifts inside the dryer (sometimes enough to move it off full face contact with idlers or in the case of flotation dryers, outside the edges of the nozzles) resulting in coating or web handling related defects. For thin films, pulling higher tension to mechanically straighten the web may not be possible. Frequently, the only tenable solution is to make the idlers and/or nozzles wider to allow for the shift while maintaining roll contact and/or uniform air cushion contact within the dryer. Naturally, the amount of extra width required will depend upon the extent of the expected camber over the length of the dryer.

Baggy Edges

When dealing with thin films that have baggy edges, special care must be taken (particularly in flotation dyers) to insure that edge flutter does not cause the web to come in contact with the flotation nozzles. This condition can result in the coating 'picking off' on the nozzles, which in turn can create coating defects and dryer cleaning issues. To some extent, this can be addressed with adjustments in nozzle spacing. However, due to the method of web support (i.e. sinusoidal airwave support), there are limits to the amount of clearance that can be allowed before losing control of the wave pattern. For roll support dryers, baggy edges are less of a concern unless the dryer is equipped with bottom-side impingement nozzles in which case turbulence from edge flutter could potentially lead to defects.

Web Width

Wide, thin film webs present a number of drying challenges. All of the conditions discussed above will be amplified in a wider web. This is predominantly due to the fact that wide webs are more sensitive to airflow. Poor air management will cause wrinkling, contact and tracking issues that may not be present with a narrow web. Both cross machine and machine direction airflow distribution as well as impingement velocity uniformity are critical to web handling and drying performance when dealing with wide webs (> 60").

How the supply air is distributed to the nozzles will have a great impact on cross machine airflow uniformity and consequently heat and mass transfer. End fed nozzles tend to perform poorly due to the difficulty of maintaining uniform air velocity over the width of the nozzle. Nozzles fed from the center or from multiple openings in the nozzle tend to hold a more accurate cross machine uniformity profile. (Fig. 2 Illustrates tapered header design used to insure good machine direction airflow uniformity. Fig 3. Illustrates nozzle designs used to improve cross machine airflow uniformity.)

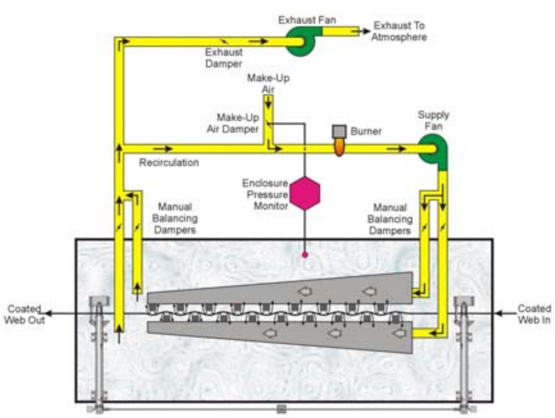

Fig. 2. Tapered air distribution header

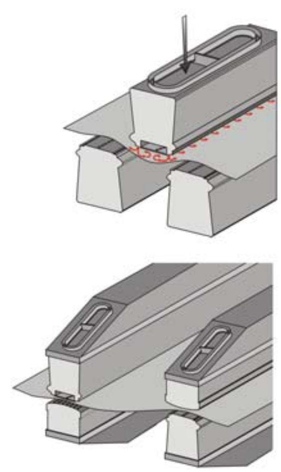

Fig. 3. Air distribution within nozzles.

Likewise, the method of exhausting air from the dryer enclosure becomes even more critical when handling wider webs. If all the air exhausts from one side of the dyer, significant web steering issues can result. Exhaust airflow velocity needs to be controlled, as well, to reduce this effect. (Fig. 4. Illustrates good exhaust flow design characteristics).

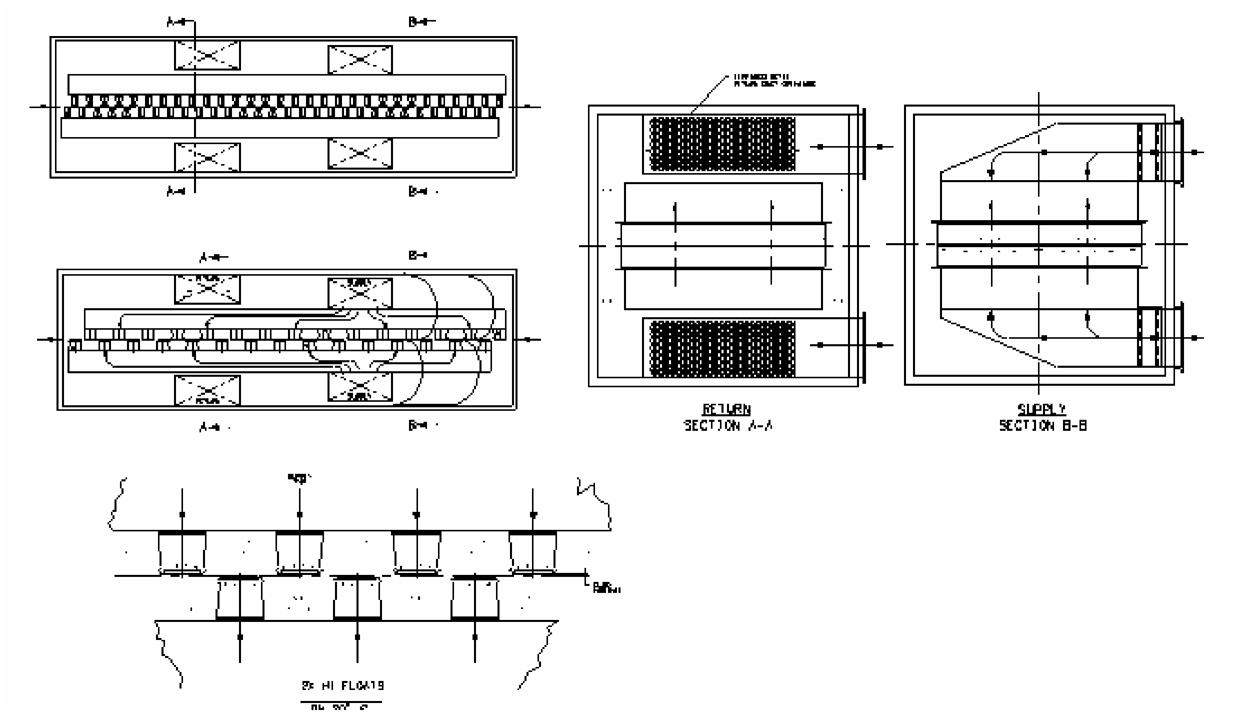

Fig. 4. Design considerations for uniform exhaust flow.

Coating Characteristics

Coating Thickness

Thick coatings on thin films can present problems. As a coating dries, stresses are created in both the coating and the substrate. The coating itself may deform the substrate as it dries (e.g. edge curl on an adhesive coated film). Edge curl can also occur when coated widths are less than the full web width since the drying stresses will vary between the coated and uncoated portions of the web. Again, some of these problems can be addressed via tension control but only if the dryer is a controlled tension zone. Also, flotation dryers tend to limit edge curl since the web is forced into a sinusoidal wave that bends the web in both directions, making the curl more difficult to form. Sometimes, the web must be passed over breaking rolls or an “s- wrap” roll section to mitigate the curl prior to rewinding.

Besides the induced stresses created by thick coatings, there are a number of drying process challenges that need to be addressed. First of all the coating may require a quiet zone (i.e. without direct air impingement on the coating) to allow the coating to flow out evenly and to prevent skinning over of the coating which will tend to reduce mass transfer and diffusion. For solvent based operations, it is important to remember that the dilution air must still be introduced into the quiet zone in sufficient volume to ensure safe operation. In these cases, special nozzle and ductwork arrangements must be used when direct air impingement is undesirable. (Fig. 5. Illustrates a typical quiet zone nozzle and dilution air configuration).

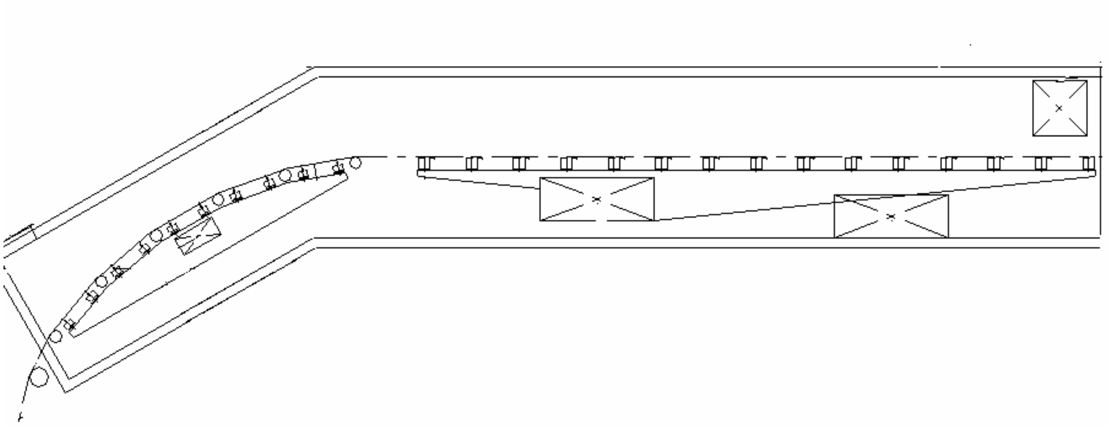

Fig. 5. Quiet zone for controlled evaporation of solvents in thick coatings.

Also, bottom-side heating is often used in quiet zones to provide both gradual heat transfer and sufficient dilution air without directly impinging on the face side of the web. In the case of flotation dryers this can take the form of single-side “airfoil” type flotation nozzles. (Fig. 6. Illustrates another nozzle arrangement typically used for controlled solvent evaporation).

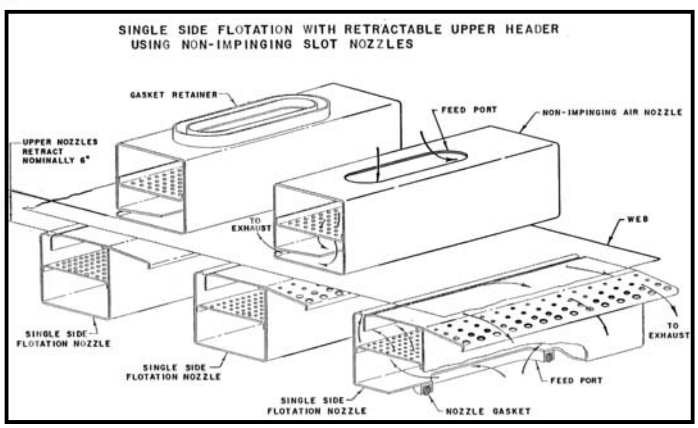

Fig. 6. Single side flotation nozzles combined with dilution air bars.

Thin Coatings and Coating Viscosity

There is no doubt that trends toward thinner coatings have presented challenges to coater equipment manufacturers as they are forced to develop and provide application techniques suited to the coatability of the formulation. But dryability of thin coatings must also be assessed when formulating new coatings.

Lower coat weights leave fewer margins for error. Coating uniformity is important and these coatings may be more sensitive to contamination whereas thicker coatings may be able to “hide” a defect more readily. This often results in the need for clean-room standards both in the coating section of the machine and the dryer itself. For example, optical film coating often requires very high levels of HEPA filtration in dryer air handling systems and the dryer internal construction must be stainless steel with smooth surfaces (i.e. no weld splatter or crevices where dust or other contaminants can collect). Special field cleaning of the dryer and ductwork (post installation) is often required prior to production start-up.

In some cases, thin coatings must be low viscosity formulations in order to facilitate application and achieve uniform coat weights. Low viscosity coatings that must flow out to achieve uniformity are usually quite sensitive to impingement air velocity. In these cases air handling systems in the early drying phase (at minimum the first zone of the dryer) must provide gentle, or in some cases, no direct air impingement, much like the systems described above for thick coatings.

<u>Coating Cure Requirements</u>

Some coating polymers require thermal curing to achieve their intended functional properties. Since thermal curing is a time/temperature-based phenomenon, the dryer "cure section" may need to be very long (particularly if the substrate is a thin, temperature sensitive film like polyethylene or polypropylene). In these cases, when production space is limited, the dryer cure section design may need to be of a multi-pass or accumulator style configuration. If this is the case, then the dryer manufacturer must take into consideration such variables as face roll contact sensitivity, web support methodology, and web steering requirements and maintenance access issues for web-up and cleanability. (Fig. 7. Illustrates one potential accumulator style dryer design configuration).

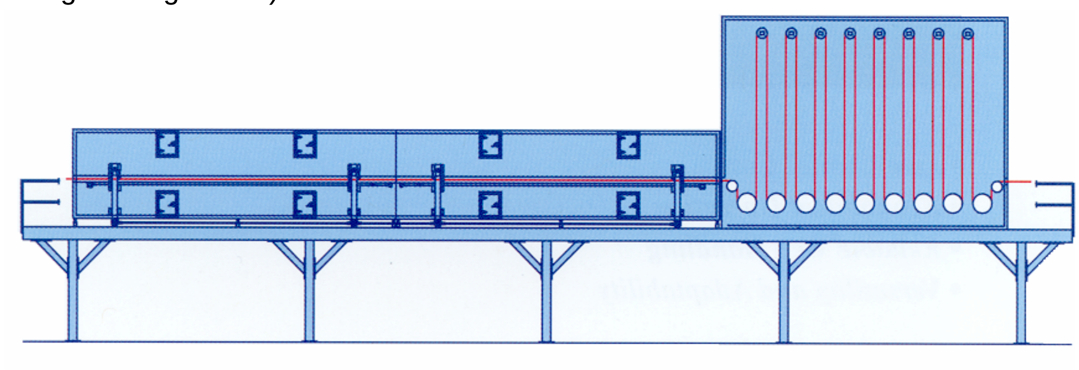

Fig 7. Custom accumulator style dryer used to prevent face roll contact of the coated side of the web.

Machine Characteristics

<u>Dryer Length</u>

Long dryers, whether flotation or roll support, create web-handling challenges when processing thin films. In the case of arched roll support dryers, assuming a 3-4° roll wrap, dryer height may become an issue. Also, depending on the process requirements relative to the importance of scratching or deforming the substrate, rolls may need to be direct or tendency driven. Good roll alignment is critical in long dryers to prevent mechanical steering of the web. Likewise, even though the web is supported on rolls, attention must be paid to air handling (cross web uniformity of the supply and return air) to ensure that the web tracks well through the dryer.

Air handling is even more critical in flotation dryers due to the long unsupported web runs. Non-uniform supply and return airflow can cause the web to track to one side of the dryer. Naturally, web camber, substrate extensibility, baggy edges or lanes, all amplify web-handling issues in a long flotation dryer. Increasing the width of the air flotation nozzles is one method of allowing for some tracking error inside the dryer. Sometimes, mid dryer steering rolls must be used to realign the web (particularly webs with camber issues). Also, for webs that are sensitive to impingement airflow in the early dryer zones, special single-side, flotation airfoils may need to be used to heat the web from the backside.

For thin films that have baggy edges or lanes or films that are not flat (i.e. films with gauge band issues) flotation drying technology may not be suitable. Besides the web tracking issues, webs with the problems mentioned above may have fluttering issues that could result in contact with the flotation nozzles and associated defects and dryer cleaning issues. This is normally only an issue with poor quality substrates.

Air-Handling

As has been previously mentioned, air-handling design is critical to dryer performance in general, but particularly when processing thin films. This is due to the simple fact that thin films are more susceptible to upsets created by contact with high-velocity airflow. This is especially the case when operating under the low tensions that are frequently associated with thin films. In general, converters need to be sure that the dryer manufacturer is addressing the impact of both the air supply and return flow design requirements. The role of return airflow is often overlooked in many dryer designs. Too high exhaust velocities or turbulent return airflow will create tracking problems as well as edge drying defects. Incidentally, this latter defect can also be a problem for converters that run narrow webs on wide web machines.

Tension

Much has been mentioned about operating the dryer section as a controlled tension zone but a few more words may be in order. Tension control of thin films can be a tricky issue particularly with extensible films. Extremely low tension may be required to avoid necking down of the substrate. Again, good airflow management is critical in flotation dryers. If the dryer must become longer to insure evaporation and/or cure requirements are met, then tracking issues may be exacerbated. It is also worth noting that, contrary to some schools of thought, flotation dryers do not induce any added tension within the dryer due to the impingement nozzle velocity. This is due to the fact that the opposing forces used to maintain the web in a sinusoidal wave pattern, are equally distributed in both directions, thus canceling each other out of the equation.

Summary

Drying of coatings on thin films is a science that involves design considerations that go beyond the requirements of processing more robust (thicker), film substrates. This is also true for drying of thin coatings. Whether the dryer is a roll support or flotation design will depend upon the unique requirements of the application. One thing is for sure. A “one size fits all” philosophy simply won’t work. Rather, today’s converter must take extra care to fully communicate the range of chemical, mechanical and functional properties of the products they are seeking to produce on their new or existing coating lines. Existing dryers may need modifications and new dryers may need to be designed for specific process requirements. The better the dryer manufacturer understands the customer’s process and product needs, the better they can customize the dryer design to meet the needs.

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