Comparative Design and Performance of Primer Dryers for High-Speed Extrusion Coaters

ABSTRACT

The drying of a low-solids primer for extrusion coaters is accomplished with hot air dryers using "slot-over-roll" and "air bar flotation" designs. At typical line speeds of 200 to 300 m/min, the simplistic configuration of slots-over rolls is effective and nearly as efficient as the flotation approach. As line speeds begin to approach 600 m/min and more, the increased drying loads and air flow dynamics of a fast moving web must be accommodated in both dryer styles. The flotation dryer with air bars on both sides of the web, is able to affect a significantly greater heat transfer coefficient at these higher speeds. Consequently, the flotation dryer can use a lower temperature for drying air and will consume less heating energy. At the higher line speeds, the entrainment of air between the web and the support rollers can create web stability problems for the slots-over-rolls dryer design. The non-contacting nature of flotation dryers negates the adverse interaction with the moving web to provide web stability that is independent of line speed.

INTRODUCTION

The extrusion line common in the flexible packaging materials industry uses a hot air dryer to dry a primer coat in preparation for the subsequent extrusion coating or laminating process. The one-sided water-based coating has a low solids content (2%-3%) that must be dried within plant space that is usually quite limited. As such, the most effective and compact drying devices use high-velocity air impingement technology.

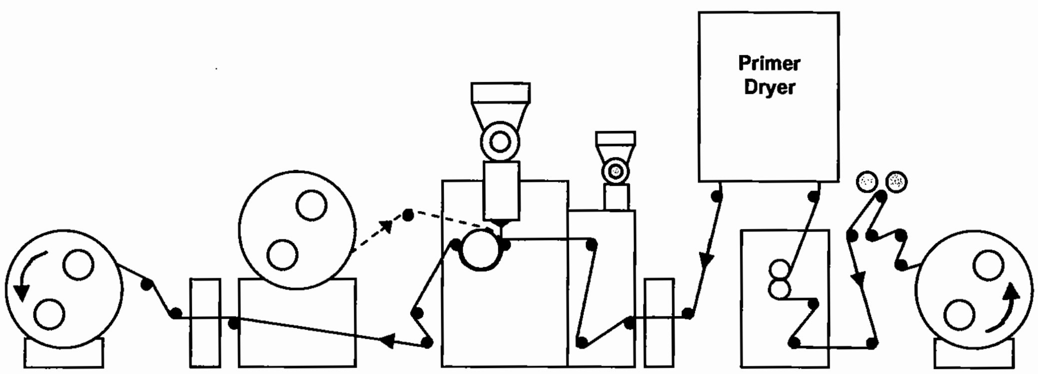


Figure 1: Typical extrusion coating or laminating line

At typical line speeds of 200 to 300 m/min, both the "slot-over-roll" arch dryer and the two-sided flotation dryer are highly effective. At the increasingly higher line speeds that now seem to be approaching 900 m/min, the subtle differences in the mechanics and performance of each drying approach will help to determine which of these methods may be better suited for high-speed production lines.

THE MECHANICS OF DRYING

Drying occurs with the mass transfer or vaporization of the solvent vehicle (water) at the surface of the coating. This mass transfer of the water solvent is a function of the difference in partial pressures existing between the solvent in the coating and the solvent in the surrounding atmosphere. The driving force for creating a higher partial pressure in the coating layer is the application of heat delivered by the hot air. The measure or ability of a dryer to transfer heat energy from the hot air into the coated sheet is called the "*h*" factor; it is essentially the heat transfer coefficient that is measured as J/s-m^2-°K. One of the primary factors affecting the ability to transfer heat energy is the removal of the laminar layer of air that travels with the moving web and serves to "insulate" the coating surface from the outside hot air. The general category of "impingement dryers" refers to the fact that slots, air bars, and hole bars are drying apparatus that will deliver different degrees of air velocity pressure or impingement so as to minimize the laminar air layer and cause heat to be transferred to the coating. The dryer variables that most affect the overall heat transfer ability or *h* factor include

- air velocity
- air volume
- projection (distance of slot/air bar from the web)
- pitch (distance between each slot/air bar)
- air temperature

To preserve the dimensional integrity of the plastic substrates common in packaging, it is necessary to avoid high line tensions and/or high processing temperatures. As such, the air temperature for drying is purposely suppressed and is not the primary drying factor.

"*h*" FACTORS FOR SLOT NOZZLES AND AIR BARS

The "slot nozzle" forces a continuous and directed stream of air across the width of the web through an opening that is usually 2 to 10 mm wide. Because of the concentrated impingement force, an idler or driven roll is often used to support the underside of the web. An "air bar" uses two opposing slots to create an air cushion to float the web about 6 mm above the bar surface while also providing impingement drying air.

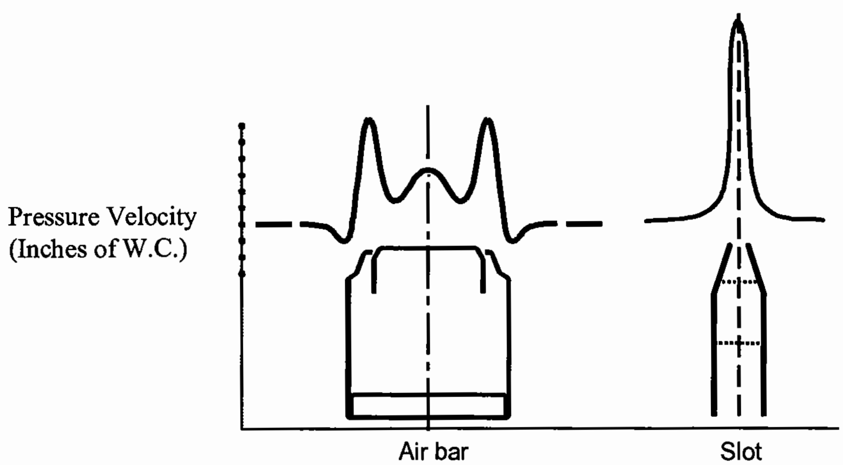
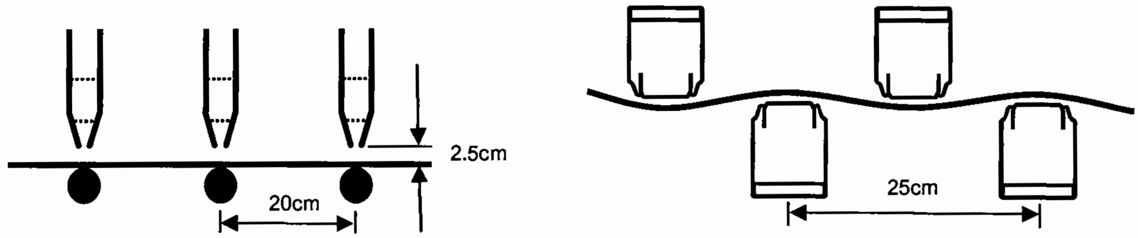


Figure 2: Pressure velocity profiles for slots and air bars

While the physical structure of these two devices determines their inherent ability to transfer heat energy, a slot nozzle or an air bar does not possess a specific *h* factor by itself. It is the physical arrangement of the devices, along with the particular process parameters that defines the *h* factor for a given <u>dryer configuration</u>. That is, it is the drying device (slot or air bar) coupled with the assigned pitch (spacing between devices), projection (distance above or below the web), air temperature, air volume, and air velocity as it exits the device that determines the overall *h* factor for the dryer.

To obtain a relative measure of *h* factor for slot nozzles and air bars, figure 3 illustrates a customary set up for slot-over-roll and flotation drying. The commercial parameters for drying the primer coat for extrusion coaters are typically a pitch of 15-20 cm (slots) and 25 cm (air bars), air velocity of 900 to 3,000 m/min, air temperature of 70-90 ℃, and a projection of 2-5 cm (slots) and 6 mm (air bars). Using these customary settings for pitch and



Slots Over Rolls

h factor = **73** J/s-m^2-°K

Flotation Air Bars

h factor = **108** J/s-m^2-°K

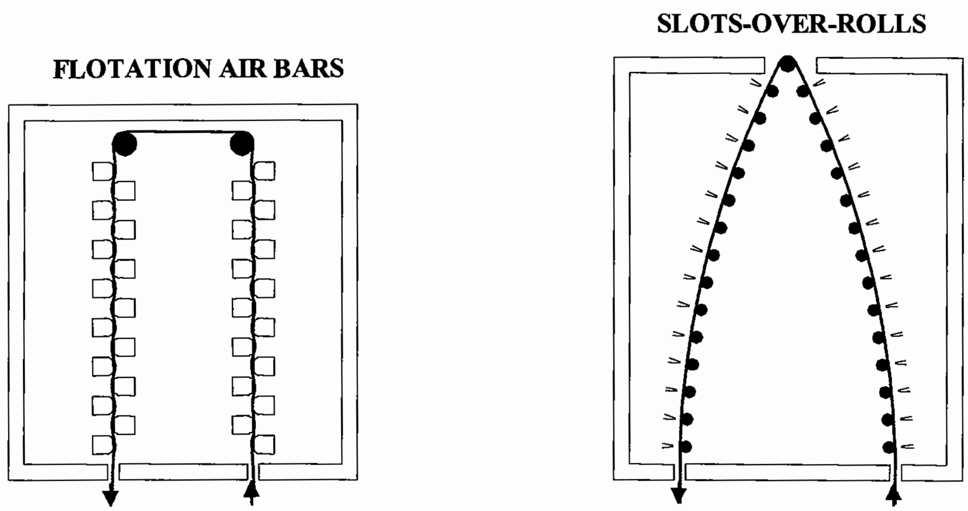
Figure 3: *h* factors with air temperature at 76°C, air velocity at 1525 m/min

identical settings for air temperature, air velocity and force (as measured by blower fan power); the *h* factor for the slot-over-roll configuration is calculated at 73 J/s-m^2-°K and the air bar configuration is 108 J/s-m^2-°K . The notable factors that account for the higher *h* factor for the flotation air bars are the larger surface of the bars over which the heat transfer occurs and the fact that heat is applied on both sides of the web. Although the coating is presumed to be on the top side only, the heat that penetrates up from the web is still a viable and productive source of heat transfer into the coating.

It is illustrative of how the physical set up of a drying device can affect drying performance to note that if the slots shown in Figure 3 were moved closer to the web (i.e. 1.25 cm instead of 2.5 cm) the *h* factor would increase by 22% to 87 J/s-m^2-°K . Again, each drying style possesses an inherent ability to deliver heat energy to the web, but it is the final physical configuration and setting of the process variables that determine the *h* factor of the entire dryer enclosure.

SLOTS-OVER-ROLLS *vs.* FLOTATION AIR BARS

The configuration of an arched slots-over-rolls dryer and a corresponding vertical flotation dryer is shown in Figure 4. For comparative purposes, it is assumed that each dryer is to process a polypropylene web (18 microns) moving at 300 m/min. The substrate is coated with MICA A-131-X primer diluted only with water to form 2.375% solids solution that will yield a dry coating of 0.04 gm/m^2.



DRYER	Eff. Length (m)	Pitch (cm)	Projection (cm)	Air Temp (°C)	Air Vel. (m/min)	Fan Power (Kw)	Heat Load (MJ/hr)	Exit web temp (°C)	Supply volume (std m^3/min)
slots-over-rolls	4.6	18	2.5	85	1,525	7.9	601	37.8	220
air bar flotation	3.8	25	0.6	76	1,350	7.7	549	37.2	230

Figure 4: Drying configurations for slot-over-roll and flotation dryers at **300 m/min**

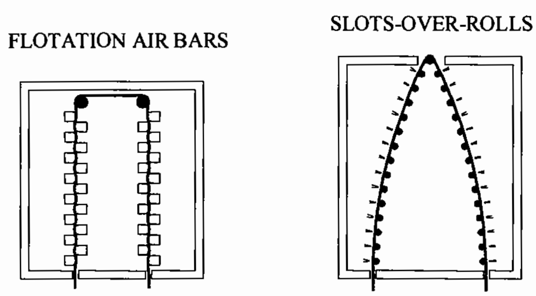
Precision computer modeling is used to establish the end conditions that will best achieve the desired drying performance for each dryer style. Note that by definition, both dryers are putting the same amount of heat energy into the coating in order to achieve the same dry point of the exiting web. Since the flotation dryer possesses a slightly higher *h* factor, it is able to achieve this end point with an *effective length* (length within the dryer enclosure in which active heating and drying is occurring) of 3.8 m versus an effective length of 4.6 m for the slot-over-roll dryer. Again, the favorable difference for flotation drying stems from two-sided heating, two impingement slots per bar, a larger "heat pad" surface and closer positioning to the web surface. Note also that the heat load or joules/hour demand for the flotation dryer was 549 MJ/hr versus 601 MJ/hr for slot-over roll is directly attributed to its higher *h* factor. The lesser energy usage of the flotation style simply means that on a "per foot basis", it is more effective in transferring the available heat energy into the web.

DRYING EFFICIENCIES AT HIGHER LINE SPEEDS

As with most industries, there is an increasing pressure on users of extrusion coaters to get more out of existing assets. Rebuild projects intended to increase coating line throughput by 40-60% are not uncommon. With this in mind, we examine the ability of both the slot-over-roll and flotation drying techniques to function at the higher line speeds.

For this purpose, the above-described dryers are adjusted such that they will dry the same coated web at a new speed of 600 m/min, affectively doubling the drying load. The increased drying load is sometimes addressed by increasing the size of the dryer or using a two-zone dryer arrangement with the first zone at an elevated temperature to accelerate the initial heating and drying rate. However, for this example, the size of the dryer is kept constant to better illustrate what changes must occur in a "speed up" or upgrade situation. In any case, the relative comparison of one-zone or two-zone slot-over-roll and flotation dryers is the essentially the same.

The impact of higher air temperatures and air velocities is nonlinear and dissimilar for both styles of dryer. The computer model selects the theoretical optimum (lowest energy consumption) settings for each dryer.



DRYER	Eff. Length (m)	Pitch (cm)	Projection (cm)	Air Temp (°C)	Air Vel. (m/min)	Fan Power (Kw)	Heat Load (MJ/hr)	Exit web temp (°C)	Supply volume (std m^3/min)
slots-over-rolls	4.6	18	2.5	107	3,050	28.0	1,509	41.1	414
air bar flotation	3.8	25	0.6	85	2,930	29.7	1,277	36.7	488

Figure 5: Equipment designs and parameters for slots-over-rolls and flotation dryers at **600 m/min**

As expected, the slots-over-rolls dryer will require higher levels of air temperature and pressure (air velocity). The use of air at 107 °C is more than the norm, but the exit web temperature will still be below 45 °C.

The flotation air bars actually operate more efficiently at air velocities greater than 2,500 m/min. In hitting this "sweet spot" of heat transfer for the air bar, most of the increased drying capacity is derived from the higher air velocity that more effectively scrubs away the insulating laminar air layer and results in less of a need to increase the temperature of the drying air. In using a relatively lower air temperature for drying, the flotation dryer yields an heat energy usage that is 232 MJ/hr or 15% less than the slots-over-rolls dryer [1,509 MJ/hr (s-o-r) – 1,277 MJ/hr (flotation)].

The improved heat transfer effectiveness of modern dryers should be welcomed news to those who previously might have thought the only alternatives for achieving higher line speeds were to increase the length of the dryer or augment the primer solution. For instance, alcohols are sometimes added to the primer solution as a wetting agent and to enhance the drying rate by lowering the average evaporation temperature. On the downside, the addition of alcohol increases material costs and can pose an environmental emissions concern. With the ability to "turn up" the drying capacity of modern flotation dryers and many of the slot-over-roll dryers, "water only" primer solutions should be usable at any production speed.

AIR FLOW DYNAMICS AT HIGH LINE SPEEDS

Since the moving web does not touch the flotation air bars, the positioning and stability of the moving web is independent of web speed. That is, the passline and cross-machine position of the web will be the same at 0 m/min as it is at 600 m/min.

However, increasingly higher line speeds on slot-over-roll dryers can account for the possibility of unintended "web float". It is well-known that when a web with small to moderate tension runs onto a roll at high speeds, a film of air becomes trapped between the web and the roll. As such, the web rides on the roll with a small clearance, "h_o". The "free floating" caused by the air gap or clearance can result in reduced cross-machine stability, loss of drive friction, and difficulty in winding up rolls.

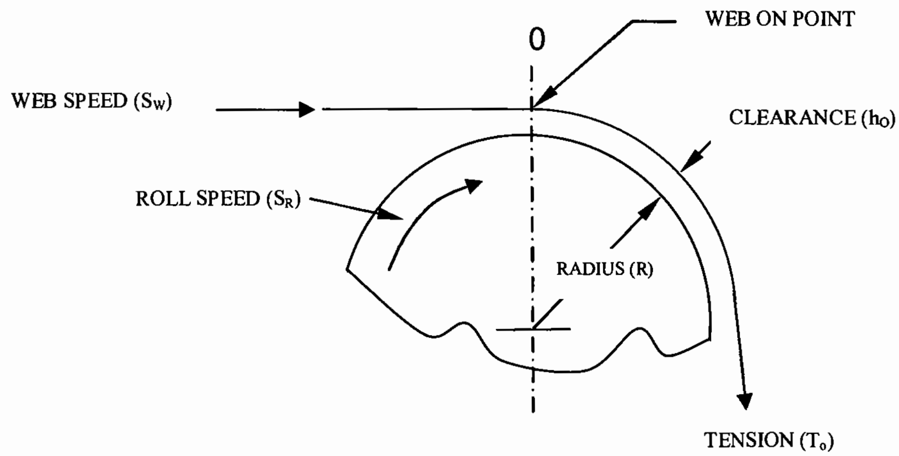


Figure 6: Clearance of web from roll surface at high line speeds

Roisum (1) shows this clearance or gap as:

$$h_o = 0.643\, R \left(\frac{6\mu V}{T}\right)^{\frac{2}{3}}$$

where $V = S_W + S_R$
$T = T_o - B \cdot S_W^2$
B = basis weight (mass per area)
μ = absolute viscosity

Knox and Sweeney (2) have reported the experimental result of:

$$h_o = 3.41\, R \left(\frac{\mu S_W}{T_o}\right)^{\frac{2}{3}}$$

In the arched dryer configuration for extrusion coaters it is uncertain whether "R" should be the radius of the individual idler rolls (approximately 10 cm) or the radius of the arch shape itself (approximately 60-100 cm). Further, the compressing force of the impingement air from the nozzles that will reduce the gap dimension is not addressed in the above equations. However, for this analysis the gap reduction is assumed to be a constant that much like web tension, will reduce h_o until the forces are balanced by the pressure T/R. As such, it can be estimated that with all other variables being equal, the gap, h_o, will vary as the two-thirds power of speed. As a result, the doubling of line speed (say from 200 m/min to 400 m/min) will cause the web/roll gap to increase by 60%. At 600 m/min, the gap will more than double.

The consequences of an increasing air gap are a decreasing of web contact with the roller surface, a tendency for the web to "float" over the roller and a corresponding loss of drive friction. If the rollers are non-driven idler rolls, the loss of drive friction may cause the roller speed to fall below the web speed and thus become a source of scratches or abrasions. To a lesser extent, this will also occur with tendency-driven roller systems.

In extreme cases, the reduced contact of the web on the support rollers will lessen the cross-machine stability of the web. This will become more apparent if the extraction and recirculation of the drying air is unbalanced; that is, biased toward one side of the dryer. With lesser frictional stability provided by the idler rolls, these air currents will serve to "slide" the web to the favored side (usually the side containing the recirculation fan).

CONCLUSIONS

Both flotation and slot-over-roll dryers have proven to be effective for drying a primer coat at speeds below 300 m/min. The *h* factor for flotation air bars is inherently greater than for the slot-over-roll configuration, but the differences are small at these speeds.

In process upgrades aimed at achieving significant speed increases from existing production lines, the performance gap between the air bar flotation dryer and slot-over-roll dryer is greatly increased. As such, a flotation dryer will use a lower air temperature, less physical space, and less energy (gas consumption) per square meter of product.

At line speeds approaching 600 m/min for flexible packaging and 900 m/min for coated papers, the slots-over-rolls dryer may be subject to the negative affects of a fast moving web over a shallow-wrap roll, including cross-machine web instability and scratching caused by roll/web speed differences. The non-contacting nature of flotation air bars results in drying and web handling characteristics that are independent of line speed.

Both the slot-over-roll and flotation dryer designs can be set-up to handle drying requirements for a full range of production line speeds, yet the inherent characteristics of the flotation design would seem to provide a more energy efficient and stable result.

References

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2. Knox, K. L. and Sweeney, T. L., "Fluid Effects Associated with Web Handling", Ind. Eng. Process Des. Div., 10, 201, 1971.

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