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OPTIMIZING CHEMISTRY AND COATER SETTINGS FOR FASTER DRYING

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Optimizing Chemistry and Coater Settings for Faster Drying

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Abstract

Maximizing line speeds on coating and drying equipment is an obvious approach to improving manufacturing economics. Insufficient drying capacity is often the limiting factor to taking full advantage of the mechanical speed limit on existing coating lines. The addition of extra drying capacity is often both complex and cost prohibitive. This paper will discuss the theories of drying aqueous adhesives and various methods of drying them commercially. We will present strategies for optimizing oven settings and measuring retained moisture and discuss the effect of retained moisture on Pressure Sensitive Adhesive (PSA) performance. The effect of PSA composition on drying will be discussed and a novel, higher solids polymer system will be introduced that can synergistically lead to faster drying.

Introduction

The rate at which an adhesive can be dried is a common limiting factor for increasing line speed of many coating operations. As line speed is optimized, operational costs are reduced and capacity is increased. When production is limited by the drying rate of an adhesive, line speed can be increased by adding additional drying capacity such as more ovens or infrared drying banks. Unfortunately, line redesigns can be expensive both in terms of capital and time loss. Alternatively, changes in oven temperature profiles and air circulation impact drying rates, but most operators have studied these parameters and are well aware of how to adjust them for optimum performance. A final consideration should be the adhesive itself. If its drying rate is improved, higher line speeds can potentially be attained without any modifications to coating equipment. To better understand potential mechanisms of adhesive drying rates, the fundamental steps of drying will be reviewed. The impact of these steps on drying rate will be examined, and alterations in the characteristics of the adhesive that impact drying rates will be discussed. Finally, limited case studies will be presented where drying rates are measured by various lab techniques as well as on a small pilot line. The goal of this work is to demonstrate how various test methods can be used to develop faster drying adhesives as well as provide insight to the relative impact of increasing solids and compositional changes of the adhesive.

As an aqueous adhesive is dried, the material is transformed from a latex dispersion to a coagulated film. Prior to drying, an emulsion is comprised of individual particles that are not touching one another. Generally, these are in the 0.1 to 1 micron particle size range with solids somewhere between 50% and 65%. The balance of the latex is a continuous phase of water that can contain some water soluble material. A schematic of this structure is depicted in the top of Figure 1. At this point, water molecules can readily move throughout the dispersions, migrate to the film surface, and easily evaporate from the surface of the film with little impedance on drying rates. As more and more water is removed, the individual particles will get closer and eventually touch (close packed particles) and the earlier stages of coalescence will begin. Drying starts to slow since water can no longer take a direct path to the surface but will need to move through an ever convoluted path of continuous channels. At some point these channels will start to collapse and ultimately there will be no continuous routes for the water to move to the surface (Compacted particle array). Eventually, water must diffuse through the coalesced adhesive film. Mechanistically, anything that retards the collapse of the continuous channels or increases the transmission rate of moisture through a coagulated film should potentially decrease drying time.

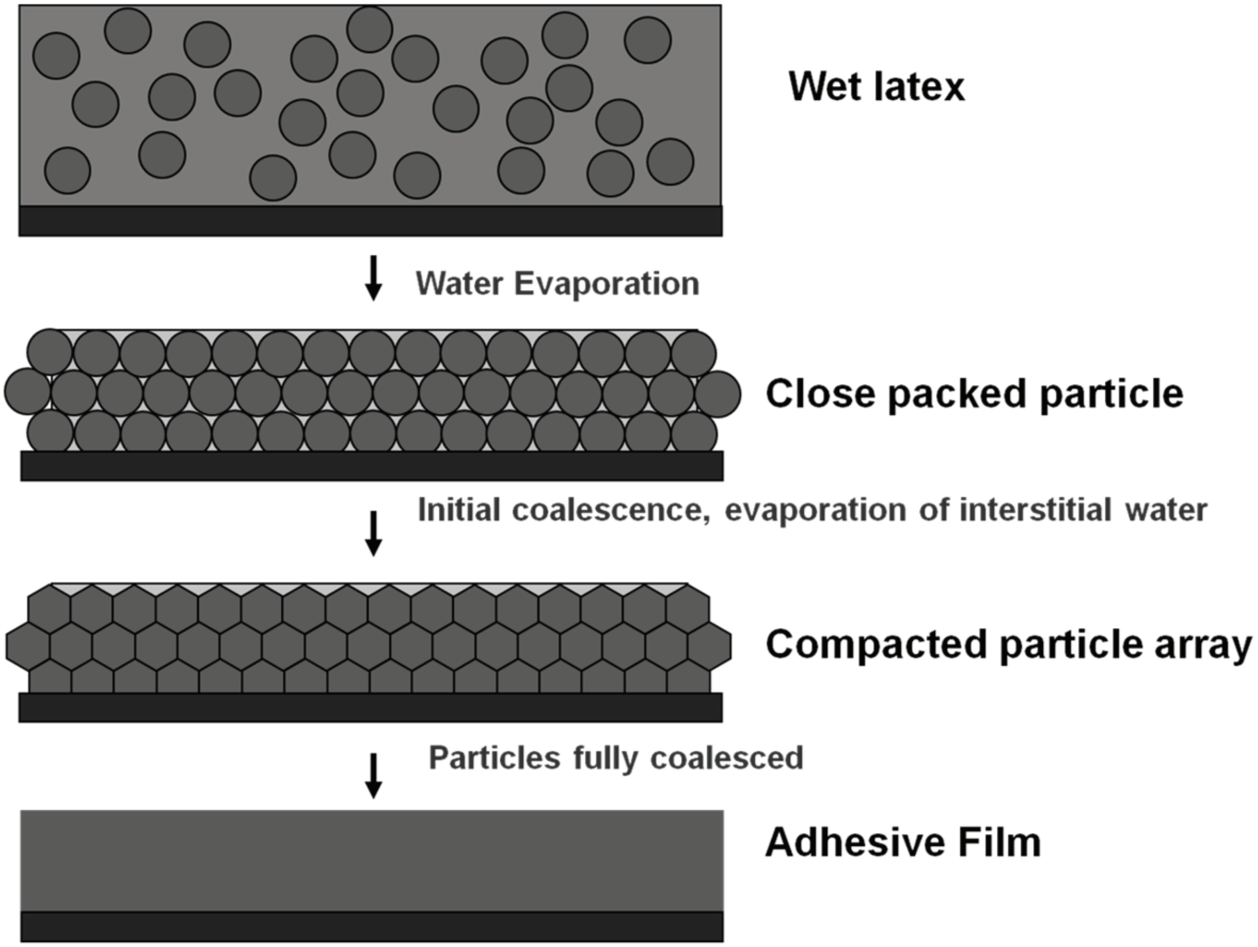

Figure 1. Emulsion structure during drying

In Figure 2, a schematic of a typical drying curve is presented for a fixed oven temperature. Web temperature, as a function of time, is shown in the top half while weight loss, as a function of time, is shown in the bottom half. When a material initially enters an oven, the adhesive is close to room temperature and rapidly increases in temperature as it is heated by the oven (Region I). The rate of weight loss rapidly increases. Evaporation of water is an endothermic process; therefore, the faster the rate of evaporation, the more the film is cooled. Eventually, the heat absorbed from the surrounding oven will balance against the heat it takes to evaporate the water and a steady state condition will be reached. At this steady state the web temperature will plateau below the temperature of the oven and the rate of water loss will be nearly constant (Region II). This condition generally exists prior to the coagulation of the latex particles. As the particles coagulate and continuous pathways for water lessen, the rate of water loss will decrease. The web temperature will gradually climb even higher, owing to a loss of evaporative cooling (Region III). Once the adhesive fully coalesces, any additional water loss must diffuse through the film, which is a relatively slow process. Towards the end of the drying process (Region 4), the last of the water is evaporated and the web temperature will climb toward the oven temperature.

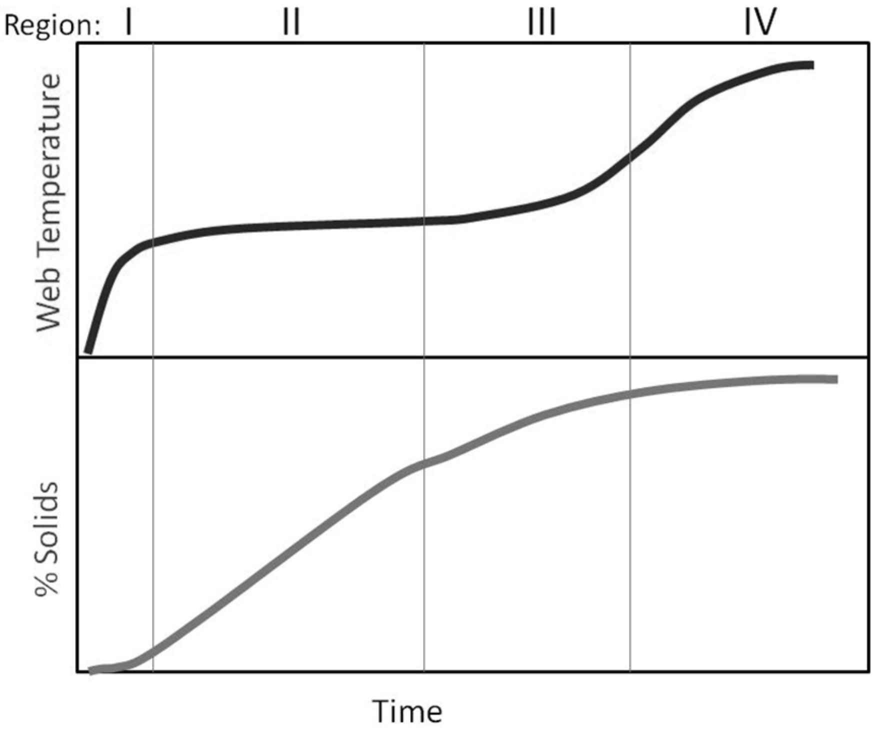

Figure 2. Typical drying profiles

If the emulsion can be designed such that water can more readily migrate to the surface, drying rates can be increased. Alternately, simply having less water in the system, that is higher solids, should increase drying rates since there is less water to evaporate. Because drying rates are also dependent upon the mechanisms cited above, one cannot simply look at the solids content of an adhesive and predict its drying rate. Rates must be assessed in lab studies or from coating line trials. Three laboratory procedures were identified for our studies. One is simply placing a fixed amount of emulsion in a pan and following weight loss as a function of time. Another is to use a commercially available solids analyzer. The final method was to characterize drying on a small pilot line.

The instantaneous rate at which water is evaporated can vary widely throughout the drying process. Unless otherwise specified, the drying rate will be considered to be the time it takes for an emulsion to be transformed to a dried film. This is usually indicated by no additional weight loss with respect to time. In general, fully dried films will have less than 1% moisture content.

Experimental Results

In order to examine compositional effects, three different compositions were selected for this study. Solids effects were also included by adjusting the solids for one of the compositions.

Table 1. Adhesives selected for dying studies

Composition A	53 % solids
Composition A	61% solids
Composition B	53% solids
Composition C	61% solids

Although many other samples were analyzed, this smaller subset displays the trends that were observed. In a first set of drying experiments, identical weights of emulsion were added to a series of aluminum drying pans and then placed in the oven at 80 °C. The pans were removed from the oven and weighed immediately. 80 °C was selected as a drying temperature since it is reasonably close to what is measured for exit web temperatures in many coating operations. The rate of drying was expressed in terms of the grams of water that remain in the pan at any given time relative to the initial weight of the emulsion.

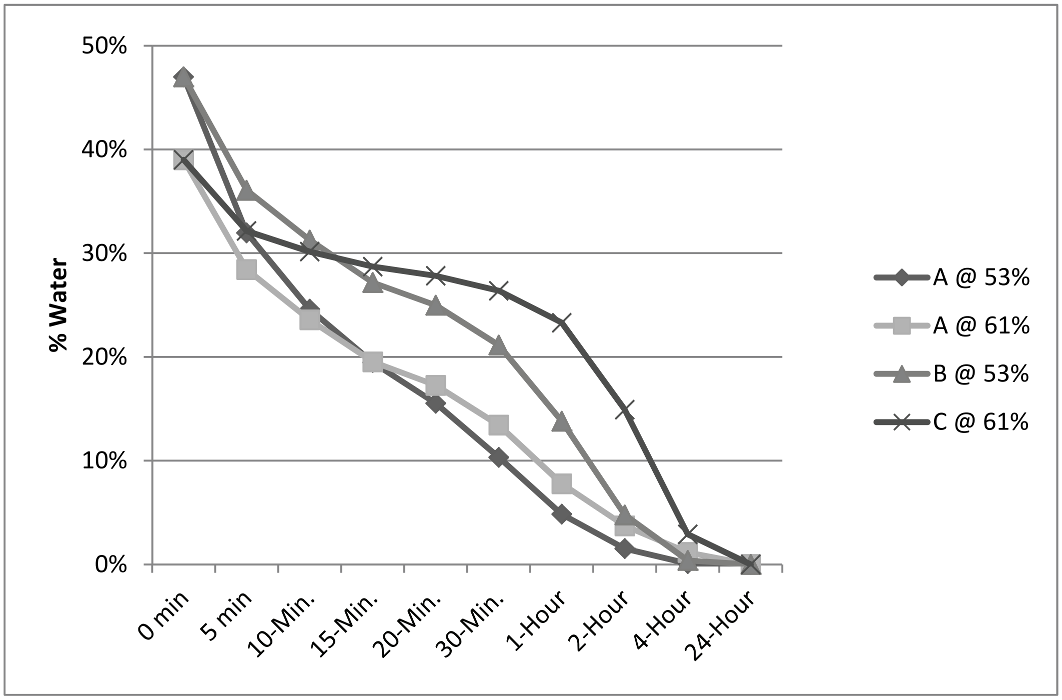

Figure 3. Pan drying of fixed amount of wet adhesive

Based on these results, it is clear that different compositions dry at different rates. C @ 61% dries the slowest, while both samples of composition A dry faster than the others. What may be somewhat surprising is that the two A samples, which are the same composition but different solids, do not display much difference in drying rates, at least for the ranges that were examined. Since the same amount of wet sample was placed in the pan, one might argue that this will result in different dry coat weight. In other words, higher solids lead to a thicker layer through which the water must migrate.

Consequently, a second set of experiments was designed where the amount of wet adhesive that was added was adjusted so that all samples yielded the same coat weight after drying. Even under these modified conditions, results were virtually unchanged. Once again there was little difference noted in the drying rate between the lower solids and higher solids samples of the same chemistry.

In the second set of experiments, samples were tested using a standard solids analyzer (Mettler-Toledo HR83 Halogen). This procedure consisted of placing well separated drops of adhesive on a fiber pad and drying them at 120°C.

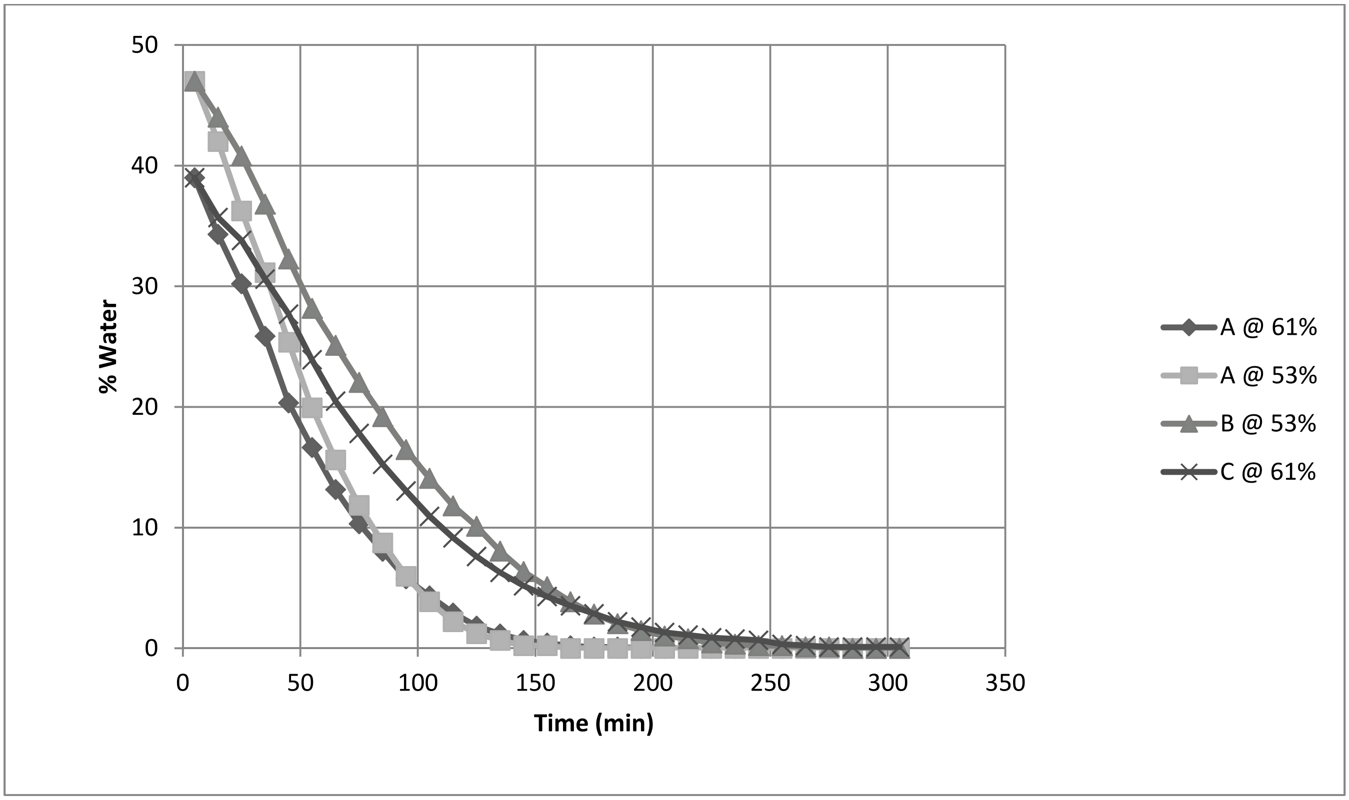

Figure 4. Drying curves from solids analyzer

Based on the data in Figure 4, the two A samples dry the fastest and at a similar rate. Once again, compositional effects dominate over solids effects.

Arguably, the best approach for mimicking the drying rates on production-sized coaters is to employ a small pilot line coater. Drying an adhesive does not directly depend on the line speed, but rather the combination of the dwell time in the oven, the oven temperatures, the air flow, and the humidity within the oven. In the present study, emulsions were coated on an RK pilot coater with two zones of ovens, each 70 cm in length. The ovens were spaced apart by 90 cm so that observations could be made between the zones. Both ovens were set at 80 ^{o}C. Note that at a 10 m/min line speed, the adhesive will be inside the ovens for a little over 8 seconds, which is close to the actual time the material spends in the oven on a full scale production line. For the purposes of this study, all of the adhesives were coated to achieve a dry coat weight of 23 g/m^2 using a wire wound rod coating head and selecting the appropriate rod to give the targeted coat weight. A convenient attribute of the adhesives selected for this study is that they become optically clear very close to the point at which they become dry. With other adhesives, it is possible to be optically clear, yet still have a significant amount of water present. Drying was assessed visually as well as measuring the web temperature after exiting the oven. . Observations were made shortly after existing the first oven (Zone 1 close), shortly before entering the second oven (Zone 1 far), and shortly after existing the second oven (Zone 2). Results are summarized in Table 2.

Table 2: Drying Characteristics on pilot line

PSA	Speed (m/min)	Web Temperature (°C)			Apperance	
		Zone 1 close	Zone 1 far	Zone 2	Zone 1	Zone 2
A @ 53%	7	38	37	74	Clear	Clear
	8	39	37	67	Clear	Clear
	9	37	34	65	Slight haze	Clear
	10	36	35	62	Milky	Slight haze
A @ 61%	7	58	56	77	Clear	Clear
	8	45	46	76	Clear	Clear
	9	46	47	69	Clear	Clear
	10	44	47	68	Slight haze	Clear
B @ 53%	7	41	37	71	slight haze	Clear
	8	36	33	66	milky	Clear
	9	33	32	58	milky	slight haze
	10	36	37	57	milky	milky
C @ 61%	7	59	51	70	milky	Clear
	8	58	49	68	milky	slight haze
	9	53	47	65	milky	milky
	10	52	45	64	milky	milky

Drying rates can be deduced from the line speed at which the adhesive becomes clear. This parallels exit web temperatures except for composition C which will be discussed in more detail below. From slowest to fastest, the samples dry in the following order:

- Sample C @ 61%
- Sample B @ 53% (10% to 15% faster than sample C @ 61%)
- Sample A @ 53% (10% to 15% faster than sample B @ 53%)
- Sample A @ 61% (10% to 15% faster than sample A @ 53%)

Notice that the changes in composition have roughly the same impact as an 8% change in solids content.

Sample C @ 61% also has relatively high exit web temperatures from zone 1, but still has a milky appearance. It also has the largest difference in temperature between the zone 1 close and zone 1 far.

Clearly, this is indicative of poorer diffusion of water through the skin that is formed and poorer evaporative cooling. Hence this one composition has unusually high exit web temperatures in spite of its level of dryness.

Discussion

Although both lab drying techniques show the initial rate of water loss is higher for the lower solids sample (A @ 61% vs A @ 53%), both techniques seem to take about the same amount of time to reach complete dryness. Careful inspection of Figure 2 reveals that although initial moisture is lost at different rates, both samples dry at similar rate for much of the time after this initial "catch-up" period for the lower solids sample. In other words, free water is rapidly lost and once a skin starts to form, in the earlier stages of the drying cure (theoretically, at around 72% solids), most of the curve consists of slower drying, the diffusion limited step.

Consider the case where a given composition dried at two different thicknesses. Since a sample starts to dry and form a skin at the top, there will be more un-coagulated material underneath a skin on a heavier coat weight than a lighter coat weight. Thus, in the heavier coat weight case, a greater percentage of the drying process will consist of water migrating through the skin layer.

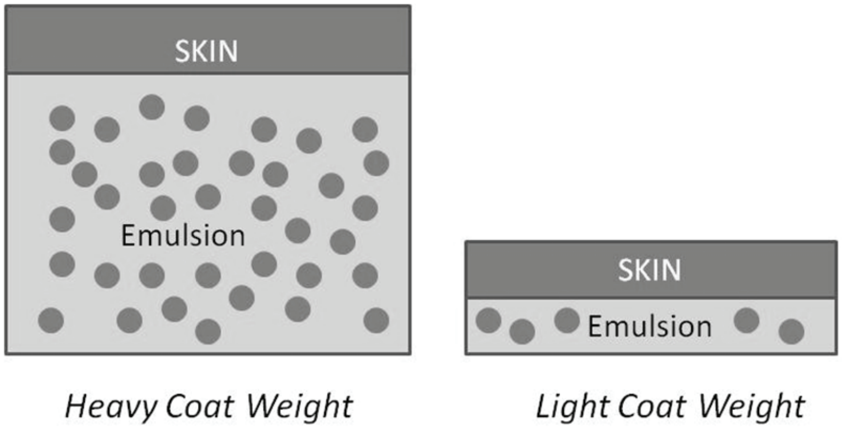

Figure 5. Effect of coat weight on drying

At lighter coat weights, a greater percentage of the drying time will be associated with the evaporation of water from the uncoagulated emulsion, so differences in solids should be more evident. Hence, drying studies in pans and with solids analyzers have more difficulty in discerning difference in drying rates of samples that only vary in solids.

Emulsions tend to dry faster at higher temperatures. However, there is a limit to how high a temperature can be set without running into issues. One of these is that once the adhesive skins, liquid material underneath the skin can start to bubble and form a blister at the surface of the adhesive. Looking at the visuals of composition A and C oven dried at 90^o C, composition C clearly displays more and larger blisters.

A @ 61% C @ 61%

Figure 6. Blistering and Drying

If a material has less of a tendency to blister, drying ovens can be operated at somewhat higher temperatures thereby permitting increased drying rates. Relative humidity and air flow can also be an influence but were outside of the scope of the present study. In addition, how a material blisters also can affect the results of the lab experiments. In the solids analyzer, which was set at 120 ^{o}C, the severe blistering of sample C @ 61% caused much new surface area to be formed and this apparently caused it to dry faster under these conditions than sample B @ 53%, especially at the earlier stages.. This behavior was not noted in drying experiments at 80 ^{o}C.

Conclusion

Optimal drying of a pressure sensitive adhesive can be designed by both adjusting the chemistry of the system as well as adjusting solids. At coat weights typical for most tapes adhesives, both factors come into play where a carefully designed system may be able to be run in excess of 30% faster line speeds than standard systems. Lab tests that are based on drying thick films tend to be more biased to measuring compositional effects. Drying of films with similar coat weights to what is actually run on lines is the preferred method for establishing relative drying rates. For most pressure sensitive adhesive applications, pilot line studies are the preferred approach

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