Effect of drying conditions on the quality of wood-containing lightweight coated paper

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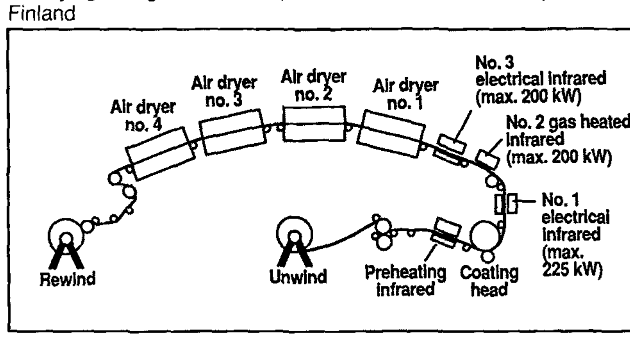
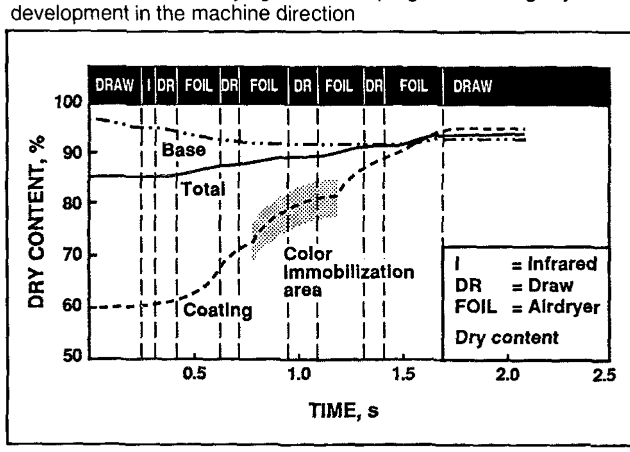
For the least offset print mottling combined with the best print and paper gloss, a drying concept including both infrared and air dryers is recommended. The existence, as well as significance, of a drying critical area is demonstrated.

1. Drying configuration of the pilot coater at Valmet, Jarvenpaa Works, Finland



2. An example of the drying simulation program showing dry content development in the machine direction



It is generally agreed that offset print mottling is linked to coating surface properties like porosity, coating holdout, capillary absorptivity, and binder migration (*1*). One of the major parameters affecting these coated paper surface properties undoubtedly is drying of the coating.

Many experiments and publications have attempted to explain the relationship between offset mottling and binder migration to the surface of the paper. Evidently, drying will induce migration of binders (*2-4*). Some experiments have led to new, exciting findings that the higher the surface binder concentration, the less print mottling appears (*2, 3, 5*). Nonuniform surface distribution of the binders has been reported to produce print mottling due to the uneven paper surface structure obtained (*3, 5, 6*). However, binder migration by itself is considered not to be the only reason for offset print mottling (*7, 8*). For example, excellent correlation between print mottling and mass distribution of the coated layer has been documented (*7*).

Regarding drying and its effect on offset print mottling, it is obvious that the solidification process of the coating color is essential. Fast initial drying in some cases has resulted in less print mottling (*2, 5*). The water penetration into the basestock is also known to affect print mottling (*2, 3*). Both of these dewatering phenomena have resulted in differences in surface binder concentration. Furthermore, a critical solids range drying phase has been suggested to be the key to optimized quality (*9*).

Many studies are contradictory regarding the direct benefits of infrared drying on print mottling tendency. In some cases an infrared located between the coating application and the first air dryer has been reported to have positive effects on printability (*9, 10*). Other reports find nonsignificant differences in mottling tendency with different dryer systems (*2, 11*). All these studies agree about one thing: infrared dryers will improve the overall drying flexibility (*2, 10, 11*).

Many of the publications on coating drying are based upon quite thin material and some compare only a few samples. The purpose of this work, with the help of numerous drying samples, was to determine trends in the drying process that have an effect on the printability (mainly print mottling) of the paper.

Experimental

Basic

The pilot coater used in this study has a web width of 1 m and a maximum speed of 2000 m/min. The drying concept is extremely flexible due to the high total drying

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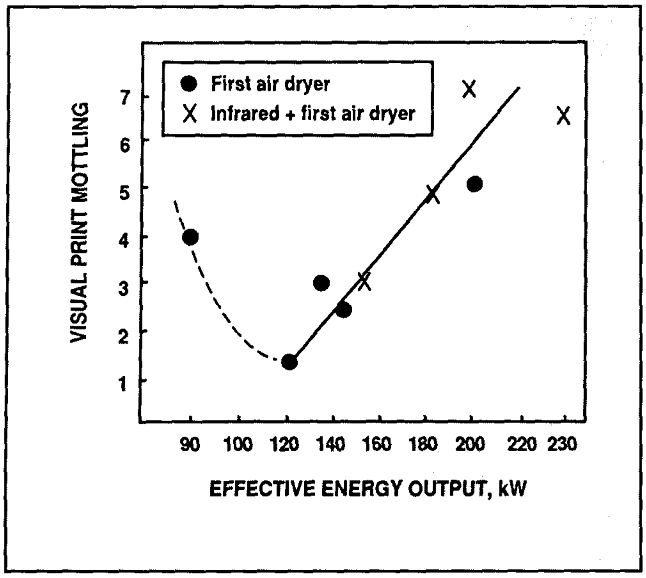
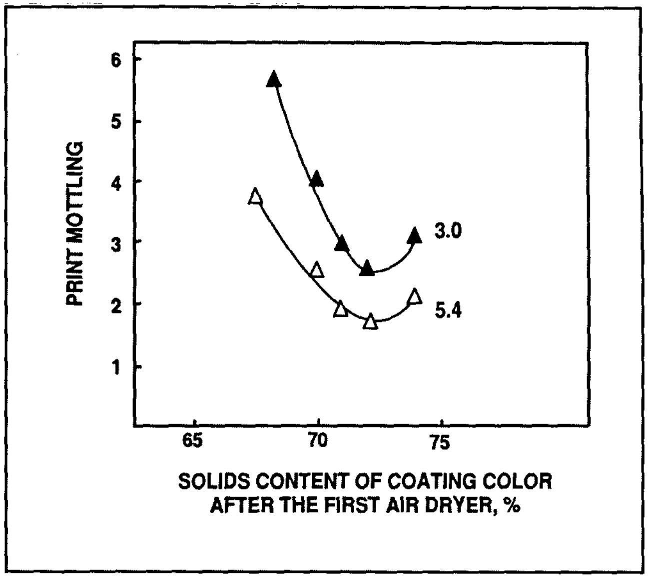
3. Print mottling as a function of effective energy output by the initial dryers



4. Solids content of coating color after the initial dryers (infrared and one air dryer) and its effect on print mottling (by image analyzer)



capacity as well as the many different types of drying elements (**Fig. 1**). The basestock can be preheated by a high-temperature electrical infrared unit to simulate on-machine coating conditions. After the coating application, there are three infrared units, the first and third being electrically heated and the second gas heated. The total nominal infrared output after the coating application was 625 kW/m. The infrared dryers are followed by four double-sided gas-heated floatation air dryers. The length of each dryer is 4 m, maximum air temperature is 320°C, and air velocity is 65 m/s.

A short-dwell coater was used to apply between 8 g/m^2 and 11 g/m^2 coating on a stone-groundwood-based lightweight coated basestock with approximately 40 g/m^2 basis weight and with a moisture varying from 3% to 4.5%. The coating color formulation included SPS clay as pigment and 6/6 pph starch/SB latex as binders. Solids content of the coating color varied between 55% and 60%. The speed of the machine was either 1000 m/min or 1200 m/min. The coated paper was supercalendered at 5-6% incoming moisture at a speed of 500 m/min or 600 m/min.

Besides the normal laboratory tests like coat weight, moisture content, coating solids content, etc., the following paper properties were tested on supercalendered paper: paper gloss (Hunter 75), paper smoothness (Parker Print-Surf 10 and Bendtsen), surface strength (dry IGT), caliper, and density.

All samples were printed on a Roland Favorit 4 four-color sheetfed offset press, with the standard color sequence: black, cyan, magenta, yellow. Print mottling on the printed samples was studied both visually by four different people and in some of the experiments by an image analyzer. The image analyzer, a SEM-IPS with Chalnicon-Pasecon camera, was used to study wave lengths of 3.0, 5.4, and 9 mm.

In one experiment offset printing was used to predict surface strength by utilizing a certain pick test. Both dry strength, using the first print area, and wet strength, using the fourth print area, were tested.

This work involved three experimental runs, all with the same basestock and coating color but with considerable variations in drying configurations and drying profiles. One of the experiments was done on preheated basestock (60-65°C), and the two others were conducted on 15-20°C basestock.

The drying simulation program

Mathematical models for drying of coated paper are helpful when designing drying concepts as well as for predicting what happens during the drying process. This drying simulation program calculates the temperature of the web in the machine direction, moisture content of the coating layer and basestock individually, as well as specific drying rates for each drying element. A typical result of a drying simulation can be seen in **Fig. 2**.

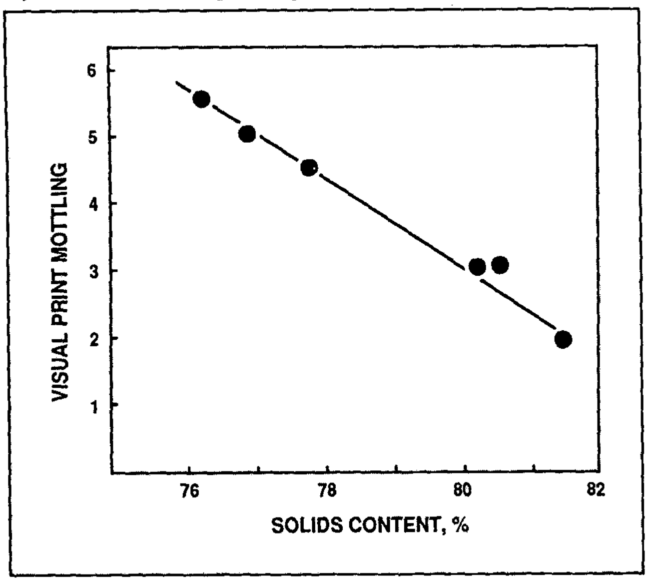
The program is based upon the mass and energy balance equations. Because of differences in basestocks and coating colors, as well as external circumstances, the simulation program includes a variety of parameters that affect the results. The parameters generally describe dryer element efficiencies, properties of coating color and basestock, for example, coating color water retention and basestock absorptivity, heat transfer, etc.

One parameter that plays a vital role in coating drying is the amount of water that is absorbed by the basestock. One way to test this is to scrape off coating after certain contact time periods. This was done on the pilot coater using the same basestock and coating color as in the drying experiment (*12*). Another method is to take on-line measurements on the pilot coater and manipulate the program to give results that match the measured data. This latter method also gives valuable information regarding other essential parameters.

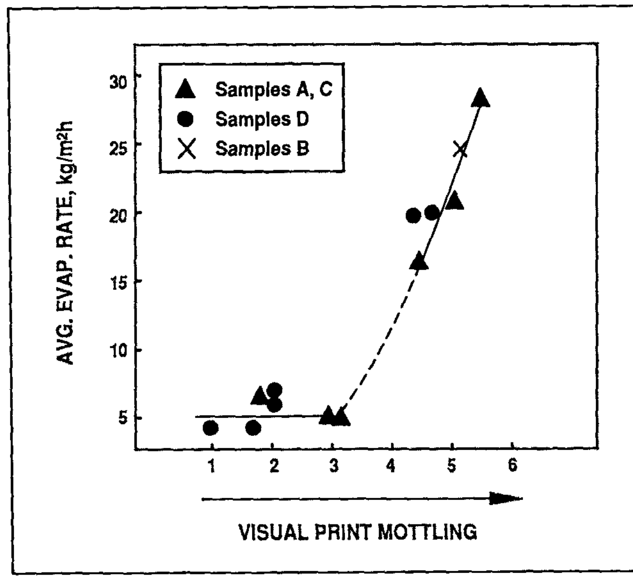
The essential information received by utilizing the program includes:

- Specific evaporation by individual drying elements
- Prediction of color immobilization area (coating color

5. Visual print mottling as a function of the solids content of the coating layer as it enters the high drying rate zone



6. Effect of specific evaporation rate at 78-80% coating solids



solids at certain points within the drying process)

- Water absorption by basestock as well as evaporation from the uncoated side of the web
- Nominal vs. effective energy input (efficiency) by individual drying elements.

Experiments

For a detailed discussion of the experiments, refer to the *TAPPI 1991 Coating Conference Proceedings* (*12*).

Results

Print mottling

The experiments on preheated basestock clearly indicate that the dwell time from coating application up to the first drying element should be as short as possible (<0.15 s) to reduce print mottling. The effect of basestock (liquid) temperature on draining velocity is considerable (*13-15*). However, a coating color possessing fairly good water retention, as in this case with starch as a binder, is likely to be less influenced by differences in basestock temperature (*13*).

Unheated basestock (15-20°C) will allow longer dwell times without risk of print mottling. Even with dwell times up to 0.6 s, samples free of print mottling were produced. This is explained in **Fig. 3**, where print mottling is shown as a function of the amount of initial drying. Samples dried with an infrared dryer located shortly after the coating application showed no less mottling than those without the infrared (dwell time to the first dryer 0.6 s).

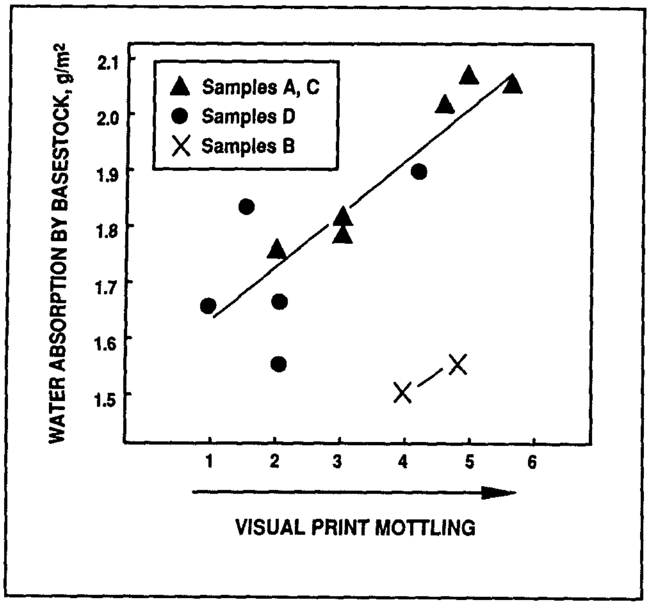
These experiments clearly demonstrate the importance of the initial drying phase, beginning with the sensible heat zone and extending to the beginning of a drying critical phase. The importance of the initial drying phase is illustrated in **Figs. 3 and 4**. Obviously, there will be an optimum initial drying energy input for every drying configuration. The infrared dryers involved in samples described in Fig. 3 were located immediately after the coating application and also prior to the first air dryer. In this specific case, an effective energy output of more than 120 kW overdried the sheet because high drying capacity also prevailed during the drying critical phase. Print mottling evaluated by the image analyzer as a function of solids content of coating color as the sheet left the initial drying phase reveals the beginning of the critical area, which will happen at approximately 73% solids content of the coating color (Fig. 4).

The most significant single drying parameter is undoubtedly the drying critical phase. To determine the end of this phase, a test was run with mild drying conditions before a very abrupt change in energy input. The drying profile was gradually changed by increasing the amount of the initial drying but never to exceed 73% coating solids. In cases when solids content of the coating color was below 81% entering the high energy input phase, print mottling appeared (**Fig. 5**).

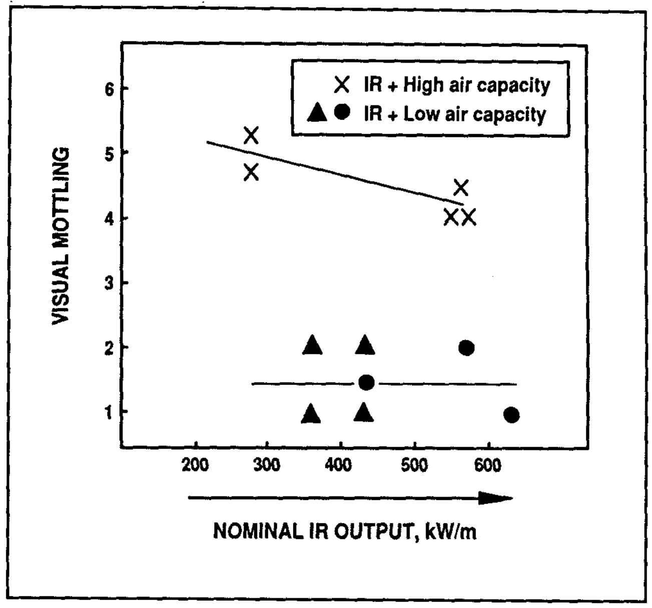
If average specific evaporation rate at the time when the coating solids content reaches 78-80% is plotted as a function of print mottling, a good correlation should be obtained, provided the theory with the critical drying area is correct. This is shown in **Fig. 6** with several different drying configurations. It suggests that an average evaporation rate at the final color immobilization of as low as 5 kg/m²h is needed to reduce print mottling to a minimum.

Water absorption by the basestock up to 81% coating color solids (end of drying critical area) was calculated for all the samples using the drying simulation program. As long as the same drying profile is obtained with mild drying circumstances during the drying critical phase, there is a fairly good correlation between water absorption and print mottling (**Fig. 7**, samples A, C, D). Samples with lower water absorption showed less print mottling. However, in cases where high drying rates are used during drying critical phase, as in samples B, print mottling will occur despite the lower water absorption. This means that the amount of water absorption is definitely not the prime factor controlling print mottling.

7. Water absorption into basestock and connection with visual print mottling



8. Effect of different air-drying capacities following high infrared output on visual print mottling



Regarding print mottling tendency on this lightweight coated paper, the energy source is definitely not a key parameter. **Figure 8** illustrates a comparison between two equal drying configurations including medium to heavy infrared drying. Obviously, high drying capacity of the air dryers during the drying critical area will induce severe print mottling, whereas mild conditions will produce paper almost free of mottling.

Other paper properties

Generally speaking, the other paper properties studied correlate fairly well with print mottling, especially within the same drying configuration.

Print gloss will decrease several units if the coating is dried at higher specific evaporation rates during the drying critical area, whether it is an infrared or air dryer. The existence of an infrared dryer, preferably to deliver sensible heat only, will improve print gloss by several units compared to all-air drying (**Fig. 9**).

The negative effect of high drying capacity in the drying critical area on paper gloss and smoothness is even more pronounced than on print gloss. No significant difference between initial phase, all-air drying, or infrared and air drying could be seen.

The printing pick test clearly indicates a decrease in surface strength (both wet and dry) of the coated paper when extremely harsh drying conditions are prevailing. Generally speaking, there exists no significant difference between initial infrared and air compared to all-air drying, except for a dramatic decrease in dry pick as a result of very intensive initial air drying.

For a detailed discussion of the results, refer to the *TAPPI 1991 Coating Conference Proceedings* (*12*).

Discussion

A basestock with comparatively high water absorptivity and fairly poor formation, together with a coating color including starch as a binder, is a combination which is likely to result in print mottling concerns. These experiments clearly demonstrate that a properly designed drying configuration, together with an optimum drying profile, to a great extent could solve this potential defect.

Having conducted coating drying trials on preheated as well as unheated basestock, the importance of the amount of water absorbed into the basestock is evident. On a hot basestock with higher water absorption, drying has to start sooner after the coating application to be able to decrease the print mottling. However, water absorption is only one of the important issues and clearly not the most dominant parameter.

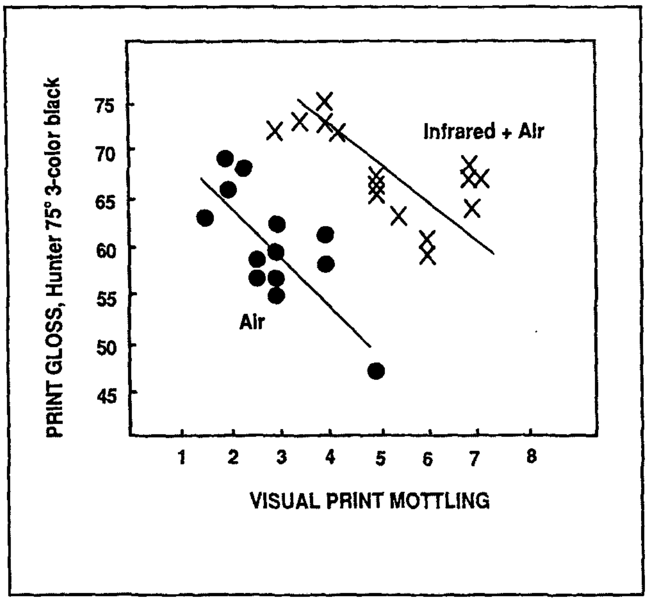
The importance of the initial drying phase on print mottling is evident. A more aggressive initial drying, which also means less water absorption into the basestock, and an earlier coating color immobilization will generate less print mottling.

With the help of the drying simulation program, the conditions in and interaction between the coating layer and the basestock can be predicted. In these experiments a good correlation between print mottling and solids content of the coating layer in certain important locations during the drying process was observed.

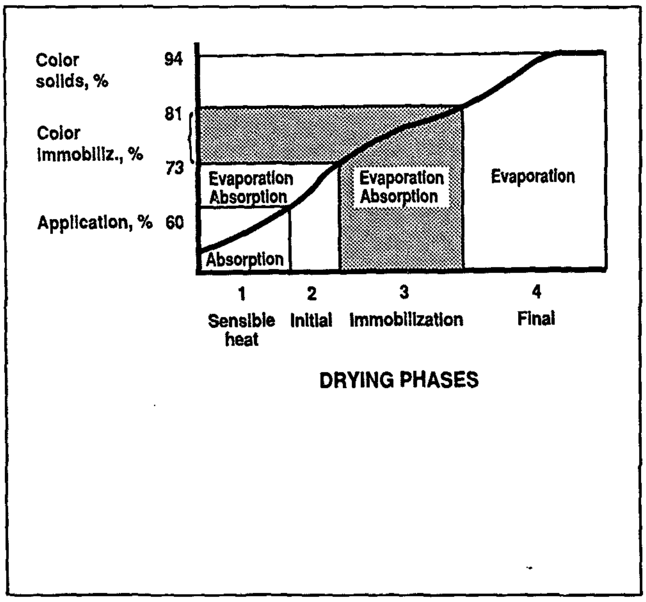
Realizing the significance and location of the drying zone after the initial drying phase undoubtedly is the key to optimized print quality. On this particular basestock and coating color combination, these coating solids numbers were 73% and 81%, respectively. When the coating solids content approaches 80%, a specific evaporation rate of 5 kg/m^2h will result in minimum print mottling and a rate of about 15 kg/m^2h or higher could visibly mean increased print mottling. Drying circumstances, at least within practical limits, in this case did not affect the print mottling after solids of the coating color had reached 81%. A simplified way of describing the drying process, including the essential drying phases, is illustrated in **Fig. 10**.

Some publications have stressed the advantage of the infrared dryers on print mottling. When it comes to these

9. Visual print mottling and print gloss on samples with and without infrared drying



10. Generalization of the coating drying process, including the individual drying phases



experiments and conclusions, no direct benefits can be awarded the infrared dryer. The infrared dryer, mainly because of the physical size, as well as high energy density, is the best solution for rapid delivery of sensible heat and when drying needs to start immediately after coating application, as on hot basestock.

All the other paper properties studied basically show fairly good correlation with the print mottling. Especially good correlations could be observed as the drying configuration remained unchanged. In case of too harsh drying during the drying critical phase, which results in print mottling, decreases in the other quality properties could be seen as well.

From a print gloss standpoint, it is essential to have an infrared dryer as the first drying element. These experiments show print gloss improvements of 2-3 units when the drying concept includes a combination of infrared and air drying as compared to all-infrared or all-air drying. Decreases in print gloss normally are due to differences in surface roughness or local differences in ink absorptivity (*16*).

A concept consisting of infrared and air drying also means improved paper gloss, which will be best if infrared contribution is restricted to sensible heat only.

Surface strength, measured by the printing pick test and dry IGT, generally remained at the same level despite the big differences in drying configurations and profiles. Only in cases of extremely harsh drying conditions, both with and without infrared drying included, remarkable decreases could be observed.

These experiments did not attempt to study the mechanism behind the mottling pattern. However, these printed samples were the subject of extensive work with the intention of studying possible binder migration. No sign of binder migration in these samples was detected (*17*).

Several trial runs on other lightweight coated basestocks but with exactly the same coating color have indicated that the same critical drying phase exists. However, these basestocks had lower water absorptivity, and perhaps even more important, a better formation. The significance of the critical drying phase was obvious but not nearly as decisive as on the base used in these experiments. Furthermore, the critical drying phase was discovered to be shorter and the end coating solids of the critical area lower than what was found in these experiments. This suggests that one reason for the uneven absorptivity by the printing ink might be swelling and shrinkage of fibers, which is reported in the literature (*18*). This might result in differences in mass distribution of the coating layer (*7*).

The final immobilization solids of the coating color used in these drying experiments have been found to be approximately 75- 78%. How to successfully explain the phenomena with the critical solids content of 73% is difficult. By simply touching the coated surface during the run, and by measuring the web temperature, it is clear that the coating layer had not immobilized at the point where the drying critical phase starts. A reasonable explanation could be the theory with local immobilization due to differences in coating layer thicknesses.

As indicated earlier, uneven ink absorptivity is primarily caused by differences in the surface structure of the paper, and the structure seems to develop during the drying process. Therefore, the drying process can most likely strengthen or weaken the effect of the basestock (*17*).

Conclusions

We came up with eight conclusions from these experiments:

1. Drying of the coated paper is one of the key parameters determining the offset print mottling on lightweight coated paper using starch-based coating color.
2. Choice of the right drying profile is more important than the choice of drying configuration (i.e., drying elements).

3. The color solidification process is crucial to optimized drying.
4. The drainage of water from the coating layer into the basestock is assumed to cause swelling and shrinkage of fibers. This is suggested to result in mass distribution of the coating layer. However, drying circumstances during final coating immobilization are more important than the amount of water drained.
5. The significance of having mild drying conditions at a so-called critical drying phase was demonstrated. The critical drying phase was tracked, using the drying simulation program, to solids content of coating color ranging from 73% to 81%.
6. Other paper quality properties like paper and print gloss are also affected by the drying conditions and will generally follow the trend of print mottling.
7. When it comes to print mottling, no actual benefits could be rewarded the infrared dryer. However, some infrared drying will generally improve the print gloss.
8. A combination of infrared and air drying is desirable from an overall print quality standpoint. The infrared should deliver the sensible heat. Air drying should be applied during the drying critical phase.□

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