NEW CURTAIN COATING TECHNOLOGY OFFERS BENEFITS FOR BARRIER-COATED GRADES

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Barrier paper is produced by coating paper with various types of coatings to impart resistance to permeation/penetration of certain types of permeates through it (1-3). A vast array of barrier-coated papers is produced today, from pizza boxes to burger wrappers to corrugated boards. Environmental issues, cost pressures and dwindling profitability are forcing mills to rethink their coating strategies. Coating technology is one the critical areas that leads to radical changes in the barrier coating paradigm (4-5). Most of the current coating processes have some inherent disadvantages, e.g. pinholes, incomplete coverage—especially at low coat weights, base sheet penetration and saturation and non-uniform coating layers (6-8). These limitations push coat weight demand higher. Since barrier coatings are some of the most expensive paper coatings, any improvement would result in substantial savings.

WHAT YOU WILL LEARN

- **How barrier paper is produced**
- **The possibilities for using curtain coating for barrier-coating applications**
- **Why curtain coating is a good fit for barrier coating**

ADDITIONAL RESOURCES

- **Expanded version of this article is available on www.tappi.org**
- **See references at the end of this article**

The theoretical coating layer thickness requirement for barrier applications can be readily calculated from the permissible permeate flow rate, shelf life of the product and permeate diffusion in the barrier layer. In current commercial applications, actual coat weights are always higher to achieve the same permeate flow rate. The actual required thickness of the coated layer depends on the number of imperfections present in the coating layer due to the coating process (6-7). To make up for these process variables, coat weight is generally 40-60% higher than required—defining the need for more efficient coating technology.

Curtain coating has been extensively used by the photographic paper industry for a number of decades and is an emerging coating technology with great potential for the specialty coated paper industry. A curtain coater is a non-contact metering coating method, which provides excellent coverage and a uniform coating layer. The uniform thickness of the coating layer makes curtain coating particularly attractive to specialty paper markets such as barrier coating.

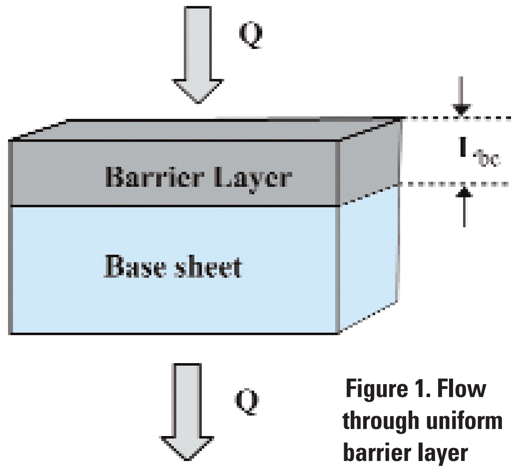

Figure 1. Flow through uniform barrier layer

Curtain coating is a pre-metered type of coating operation, as the coating layer is formed before it comes in contact with the substrate. Curtain coating can be considered as an improved lamination process where a liquid "sheet" and a substrate are merged. As a uniform pinhole-free liquid curtain is formed before it is exposed to the substrate, the integrity of the coating lattice and coverage is virtually guaranteed. Adjustment of the flow rate and substrate speed provides precise control of coating layer thickness. Lower coat weight is required to produce a desired permeate flow rate because the coating layer is free of any imperfections and pinholes.

Let's examine the possibility of using the curtain-coating process for the barrier-coating applications. Curtain coating seems to be most suited for the barrier application since it delivers uniform, pinhole free coating layer with high coverage at low coat weights.

MASS TRANSPORT THROUGH A LAYER

The mass transport of a permeate through a coating layer of thickness L is described by the Darcy's (9) equation,

$$Q = \frac{k}{\mu}\frac{\Delta P}{L}At \qquad 1$$

Here Q is the mass of permeate transferred, A is area, k is the permeability coefficient, (Δp/L) is the pressure gradient across the length of the layer, and t is time (see **Figure 1**).

In use of equation 1 in the barrier application, (Q/t) can be treated as the permissible flow rate of permeate. Thus, Q depends on the tolerable permeation, which in turn depends on the type of product, for example, meat, fish, cookies or vegetables. The pressure gradient (ΔP/L) is proportional to the concentration gradient of permeate across the barrier layer. For gaseous permeates, it is taken as the difference of partial pressures across the barrier layer. For most cases in barrier application (O_2, CO_2, smell etc.), it is taken to be the highest differential across the barrier layer—e.g. permeate is assumed to be saturated one side and absent on the other side. The partial pressure (or concentration) gradient can be altered by changing the thickness L of the barrier layer. Thus barrier layer thickness and permeability coefficient are the only true variables for barrier-coating applications. For relative flow of one gaseous permeant relative to another, the permeability coefficient *k* can be related to the diffusion coefficient *D* and partial pressure *P* of the permeant in the layer as

$$\frac{k}{\mu} = DP \qquad 2$$

The diffusion coefficient relates to the physical characteristics of the layer and the permeate, whereas partial pressure is related to chemical characteristics of the barrier layer and the permeate. Physical characteristics of the layer, such as density, pore size and lattice imperfections in the layer, affect the diffusion rate. These characteristics will, in turn, depend on the binder system of the coating, aspect ratio, and size distribution of pigments, drying condition and any post-coating operation, such as calendering. The solubility of the permeate in the layer is related to chemistry of the layer and the permeate. This includes any chemical reaction, for example hydration, and interactions of surface tension origin. Thus, by closely controlling physical and chemical properties of the surface, permeate flow at the surface can be controlled.

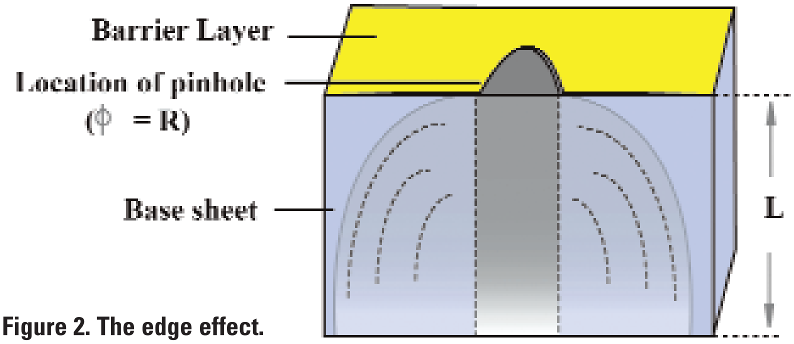

Figure 2. The edge effect.

PINHOLES

Pinholes in the barrier layer or the uncovered areas on the base sheet are the unavoidable features of paper and board coated by conventional processes. They are introduced by various mechanisms, such as insufficient coat weight, overmetering in the coating process, and the type of coating process. The problem is especially acute when operating the coating process at the lower end of its coat weight window. The on-line full text version of this paper (available on www.tappi.org) includes a discussion of the theories and fundamental relationships of the effects of pinholes.

To reduce the probability of pinholes in the coated layer, the two-bump strategy is already in place in paper industry. In the two-bump approach, the total coat weight is applied in two coatings, thus reducing the possibility of pinholes in two layers coinciding, thus eliminating the pinhole. Because of this dynamic, two-bump coating provides a more effective barrier than when coating is applied in one pass.

Because permeation is a concentration-driven diffusion process, the path of the diffusion through a pinhole is not straight across the thickness of the layer, but is in a solid hyperbolic space (**Figure 2**). This is known as the edge effect (10). The edge effect is a significant phenomenon in barrier-coated paper and board.

The effect of the pinhole on failure of the barrier layer is much greater for a thicker base sheet. Thus, a single pinhole can saturate a large area of the base sheet with permeate. This effect is observed in heavily wax-coated corrugated boards. If moisture is the permeate, the board is saturated locally because of a single pinhole, resulting in loss of strength properties in that localized area, leading to catastrophic failure of the board. Pinholes vary in size—as illustrated in **Figure 3.**

Lower pinhole area and base sheet thickness and larger pinhole radius favors the decrease factor. In the case of fluid permeation like water or oils, pinholes can give rise to capillarity. Capillary transport is much faster, almost instantaneous, than the concentration-driven diffusion (11,12). Capillary transport is especially critical for short lifespan products such as convenience food wrapping papers.

CURRENT COATING METHODS

To achieve effective barrier properties, the barrier layer should be of uniform thick-

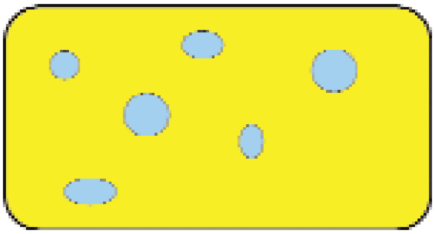

Figure 3. Pinhole size distribution

ness, free from pinholes and provide complete coverage. Pinholes, or insufficiently covered base sheet areas, will have a large impact on the barrier properties. A non-uniform coating thickness layer, pinholes, and incomplete coverage, increases the coat weight demand to achieve the desired permeate transmission rate. Current coating technologies result in the application of a non-uniform coating thickness profile that results in poor coverage at low coat weights. A coating method that provides a uniform layer thickness and good coverage is highly desirable for a barrier coating.

Blade, roll and air-knife coaters are used extensively for barrier-coating applications. Blade coaters are surface coaters, giving an extremely uneven surface profile, **Figure 4.** Surface coaters will have to fill all the valleys on the paper surface before any effective barrier layer can be achieved. Even after filling the valleys, the effective barrier layer thickness is much smaller.

This increases the coat weight demand substantially. Rod coaters are hybrid coaters (surface-contour). Blade and rod coaters operate under larger hydrostatic pressure leading to penetration of coating into the base sheet.

Any material that does not contribute to the effective thickness of the barrier layer can be considered a loss. Blade and rod coaters have very low coverage at the lower end of their coat weight window. This renders them useless for lower-end barrier applications. Air-knife is a contour coater, but because of low viscosity limits on coating color, penetration of coating color into the base sheet can be substantial. This further increases the coat weight demand.

Transfer roll coaters such as metered size presses and reverse roll coaters apply a contour coat, but film splitting tends to increase the occurrence of pinholes.

CURTAIN COATING

Curtain coating is a low-impact true contour coater. Curtain coating can be considered as a lamination process of a liquid film and a substrate. As the free liquid film is formed before it comes in contact with the substrate, the film is pinhole free. This leads to virtually 100% coverage at any coat weight. Previous results (13,14) have indicated that the coverage is almost independent of coat weight. In addition, as a curtain coater is a true contour coater, the coating layer thickness is uniform (**Figures 6 and 7**) and can be easily controlled by manipulating flow rate and web speed (14).

Curtain coating is a low-impact coating process with little hydrostatic pressure. This leads to little or no coating penetration into the base sheet. A uniform coating thickness and no penetration of coating color into the base sheet will lead to substantial reduction in coat weight demand for the same barrier performance. In addition, excellent coverage at low coat weight makes curtain coating especially attractive for short lifespan products.

CONCLUSIONS

The most effective barrier performance is achieved when the barrier layer is uniform in thickness, free of pinholes and coating coverage is complete. Curtain coating is a low-impact true contour coater, making it an attractive coating process for barrier applications. Uniform coating layer, easy and effective control over layer thickness, low impact and excellent coverage make curtain coating a good fit for barrier applications.

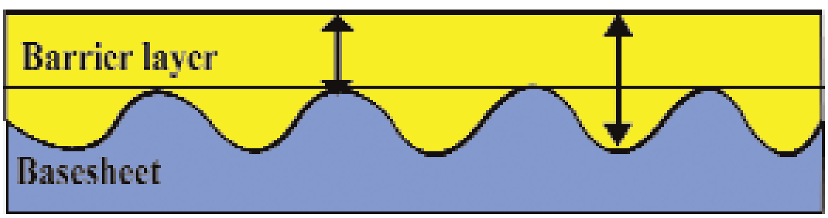

Figure 4. Thickness profile of surface coaters

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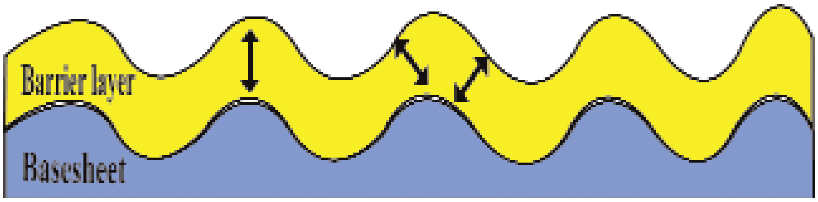

Figure 6. Thickness profile of contour coater

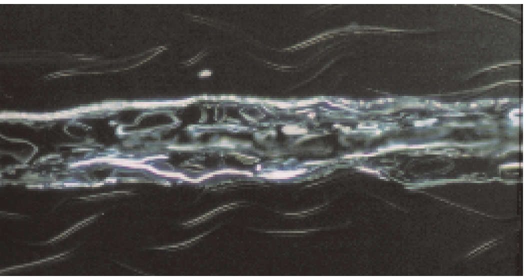

Figure 7. Z-direction cut of curtain coating paper showing coating layer

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