CURTAIN COATING: A SYSTEMS APPROACH

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This paper presents a brief summary of Rohm and Haas Company’s initial investigations into assessing high speed curtain coating technology for aqueous pressure sensitive adhesives (PSAs). It outlines the approach taken, gives a brief discussion of preliminary findings, and describes the impact of specific parameters in achieving good quality coating.

Converters in the pressure sensitive industry continue to focus on optimizing their processes and improving productivity to reduce costs. Better economics may be achieved through improvements in coating operations such as:

- Higher processing speeds
- More consistent and lower coat weight
- Reduced waste
- Improved coating quality

Over the years, incremental improvements in coating head technology have enabled converters of aqueous acrylic PSAs to improve their productivity through higher line speeds and better coating quality. The desire for better coating technology to deliver higher line speeds with reduced coating defects continues today.

- 1980’s: 200 mpm (Roller, Mayer rod, Reverse Gravure,...)
- 1990’s: 600 mpm (Chamber modified Reverse Gravure, Slot die,...)
- 2000’s: 1000 mpm (??)

The higher line speeds achieved with advances in coating head design also require advances in formulating technology for aqueous PSAs to compensate for mechanical instability from shear stress, foam generation and viscosity changes under high shear. For example, current high speed coating equipment, such as reverse gravure and slot die, apply a tremendous amount of mechanical stress on the aqueous adhesive at specific areas on the coating head. Shear rates with these systems can range up to several 100,000 sec⁻¹ at 400 mpm.

For the next step change to line speeds of 1000 mpm or higher, curtain coating offers the advantage of lower shear stress on the adhesive and low foam generation. This reduces the need for additional formulating of the adhesive, resulting in better retention of adhesive properties.

Systems Approach

The approach Rohm and Haas takes to assess a coating technology is based on a “co-supplier/systems approach” which we find is essential to a win-win situation for all in providing a successful product that meets the customers requirements.

To define a “co-supplier/systems” approach, one must look at the specific value chain components that go into providing a quality product to the industry. In this case we looked at the chain
for providing a pressure sensitive coated label or tape. For example, the converter must depend on suppliers of the adhesive, the webs/facstocks, and the equipment. Downstream converting is also part of the chain that must provide materials and processing equipment.

In the case of assessing a new coating technology, we focused on three essential components of the value chain that must work together to provide a win-win situation:

- Adhesive polymer/formulation
- In-line equipment (pump, mechanical defoamer, filters...)
- Coating head

**Adhesive Formulation**

In our program we evaluated several of our pressure sensitive formulated systems by adjusting composition, formulating additives and rheology.

**In-Line Equipment**

This included type of pump and mechanical defoaming device to remove air entrained in the adhesive. These systems are placed prior to the coating head and are helpful particularly in cases where one recirculates the adhesive when coating at very high line speeds.

**Coating head manufacturers**

There is a strong mutual interest for adhesive suppliers and coater manufacturers to work together to help define the future systems for high speed PSA coating. For curtain coating development we established close programs with two major equipment suppliers to the PSA industry.

**Curtain Coater**

A few years ago the curtain coater was introduced to the PSA industry as a coating head technology for aqueous acrylic PSAs having advantages for coating at higher line speeds than currently achievable with reverse gravure and slot-die. Although established already in other industries, it was introduced by major companies of coating equipment as the next high speed coating technology evolution, potentially achieving 1000 mpm and higher.

Advantages presented to the market include:

- No excess liquid
- Less fluid pressure at application
- Contour coating
- Lower foam generation
- Lower Shear

Although there are various configurations such as the slanted die and the vertical die, manufacturers have chosen to present the vertical configuration to the aqueous PSA industry. This configuration is in limited use today in the paper label industry, although high interest will likely drive more installations.

The basic set-up of the vertical die configuration is a chamber with a distribution cavity for the adhesive, the die lip, and side guards. The die lips may be either a fixed lip across the face or a flexible lip that can be adjusted at different points across the face. The side guards define the edge of the curtain and help guide onto the adhesive onto the web. Coat weight is controlled via web speed and adhesive
flow rate, which will vary with pump speed, adhesive rheology, solids, and lip opening. Coating quality depends on the distance from the die to the moving web (vertical gravity drop).

Curtain Coater Assessment
An assessment of both the mechanical and formulation aspects of curtain coating was undertaken to define the critical parameters for successfully producing low defect coating at high speeds. The preliminary work focused on:
- coat weight variation
- release liners (paper or film)
- adhesive formulation variables (surface tension, rheology, etc.)
- vertical die lip set up (flexible or fixed lip)
- range of die lip opening (250 microns to 425 microns)
- minimum and maximum achievable line speeds

In-Line Equipment
One important area of focus was the pump and its impact on the adhesive. As line speed is increased, the flow rate through the pump is increased thereby subjecting the adhesive to higher shear. Whenever higher shear is encountered, the adhesive is more likely to break down and form grit. Shear rates also depend on the cavity design within the pump. We worked with suppliers of various pumps to assess the adhesives under high speed conditions. Two specific pumps we worked with were the lobe and screw pumps.

Our studies showed that adhesives delivered using the lobe pump exhibited up to 100 times less grit formation compared to the screw type pump. This was especially important with tackified systems, where higher grit formation was observed as a result of tackifier mechanical instability. The greater clearance in the lobe design delivered less shear stress and therefore less grit formation even in tackified systems.

Next we focused on foam generation at high speeds. Although curtain coating itself may not generate excess foam, there are still points in the delivery system which can introduce air into the adhesive. This can result in an unstable curtain, dewetting, haze, blistering, and poor coat weight control.

In drop tests with a curtain of adhesive, at flow rates equivalent to coating 21 g/m² at 1000 mpm, we recirculated adhesive through a closed system, generating a considerable amount of foam. Through the use of an in-line deaerating device we were able to achieve a stable curtain, whereas without the deaerator, the foam caused the curtain to destabilize and break.

Three critical coating aspects we focused on during our assessment program of curtain coating at high speeds were:
- Formation of a stable, consistent curtain
- Dynamic wetting/impingement of coating on the web
- Coat weight control
Stability of Curtain

In all systems evaluated we observed that there were four key factors impacting the stability of the curtain:

Surface Tension
Formulated systems varying in surface tension from 28 to 45 dynes/cm were evaluated. The critical area we found necessary to obtain a good stable curtain with our systems and maintain the target coat weight was \(<32\) dynes/cm at \(>500\) mpm. At lower surface tensions, we were able to achieve lower flow rates and maintain a stable curtain. As surface tension increased, we needed a higher flow rate to maintain a stable curtain. Therefore, the range of possible lines speeds is wider at lower surface tension.

Foam Formation
Foam control is a critical factor in having the ability to maintain a curtain. We observed two areas where foam resulted in curtain breaks: at the lip and further down the curtain. Depending on the size of the air entrapped, foam can cause a sporadic disruption in the coating and result in skips on the web. If the foam is extremely small, the curtain is not disrupted; however, the air remained in the coating and did affect the final coat quality. Thus, the mechanical deaerator eliminated both large and small foam.

Grit Formation:
Grit from various sources can lodge in the die lip, cause curtain breaks, and result in unacceptable coat quality analogous to streaks in a slot die coating. In our studies we found that the pump type and the lip set-up were important in reducing grit formation.

Lip Design:
Using a low shear lobe pump, we evaluated both a fixed die lip and an adjustable die lip using several aqueous acrylic PSAs. While both types can be used to produce a stable curtain at high line speeds, an advantage for the adjustable flexible lip design is versatility in coating a range of formulations with varying rheological properties. The fixed lip configuration is generally designed for a specific adhesive formulation.

We found that for lip openings of 250-350 microns shear forces were high enough at line speeds above 300 mpm to form occasional grit and curtain breaks for some formulations. At a lip opening of 400 microns, we were able to produce a stable curtain at flow rates equivalent to 1000 mpm and ran for several hours without grit formation.

Curtain Impingement on Web
After determining the factors necessary to form and maintain a stable curtain in drop tests, we focused on the dynamic wetting/impingement of the adhesives onto a moving web. Increasing line speeds and increasing flow rates displayed different impingement characteristics. As speeds went higher the air/web boundary layer affected the coating. We compared formulations with rheology ranging from Newtonian type high shear behavior to pseudoplastic behavior. Not surprisingly, rheology played a key role in how the adhesive behaved as it was coated onto the web.

Results showed that the adhesives exhibited different behavior at the point of contact onto the high speed web. With various formulations, we observed a “heel” contact (flow of adhesive slightly in reverse direction), a 90° contact, and an “extensional” contact (liquid is pulled beyond the drop point before contacting the web).
We observed different degrees of heel formation, depending on rheology and line speed. A high degree of heeling proved to be unstable with turbulence and air entrainment and resulted in poor coating with streaks and foam. The degree of heeling increases as line speed increases. This could be a result of the shear thinning behavior of the adhesive causing some flow in the reverse direction as the adhesive hits the web. This was exhibited by systems with a high degree of pseudoplasticity, where high shear viscosity is low. Excess heeling also promoted foam formation, resulting in coat weight inconsistencies and poor aesthetics. Our findings showed that a minimum of 100 cps high shear viscosity (10,000 sec⁻¹) is typically needed.

The “extensional” impingement characteristic was observed in systems having higher high shear viscosity (more Newtonian behavior). When high shear viscosity was too high, the adhesive was pulled in the forward direction, thereby creating problems with wetting and contact. This condition forced air into the adhesive from the air/web boundary layer, contributing to foam and inconsistent coat weight control. The high degree of foam was a result of air riding on the web and under the coating at high speeds, disrupting the continuous coating.

The best coating at high speeds was observed with systems having a very slight heel configuration, which can help promote wetting of the web.

Coat Weight Control
Coat weight profile across the web is extremely important to maintain, especially at high line speeds. Other than controlling the impingement behavior through rheology, we found that the die chamber can influence the coating weight profile. We evaluated this property on two different manufacturers’ chamber cavity designs, one having a fixed lip and the other a flexible lip. The flexible lip allows the lip opening to be adjusted across different points of the die. In our studies, the geometry of fixed lip die was not optimized for the rheology of the adhesive.

At high line speeds, the volume of adhesive and shear in the distribution chamber must be optimized in order to have a good coat weight profile. If it is not well designed, one side of the chamber can apply a somewhat different shear on the adhesive which can result in a change in viscosity as it exits the die.

We observed coat weight variation of >10% across the web under conditions where there was an uneven distribution in the cavity. When adjusted for optimum adhesive distribution we found profile variation of <3% was possible. Mechanical adjustments to improve coat weight profile consisted of either modifying the distribution volume in the chamber or adjusting the lip opening in the flexible lip configuration.

Conclusion
Factors influencing the curtain coating of aqueous PSAs are:

**Mechanical**
- Pump type
- Die lip opening
- Die lip type
- Chamber distribution cavity
- Mechanical defoaming

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- Surface tension
- Rheology
- Mechanical stability

From our early assessment of curtain coating technology, we believe it could be a viable coating process for achieving good coating quality at speeds of 1000 mpm and higher and could deliver advantages over traditional coating technology for tape and label applications. A systems approach linking mechanical and chemical optimization is essential in working with this technology to provide a quality product.

Our future efforts in this area will continue to focus on creating economic and quality advantages for our customers. Through joint developments with co-suppliers, we will continue to build in-depth knowledge of curtain coating technology and provide optimized products that stretch the limits of coating speeds for aqueous acrylic pressure sensitive adhesives.