A GLIMPS INTO COATING TECHNOLOGIES AND PROCESSES FOR PRESSURE SENSITIVE ADHESIVES

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Abstract:

The rise of water-based pressure-sensitive adhesives (PSAs), particularly acrylic and SBR latex, has led to significant innovations in coating technologies, essential for applications in tapes, labels, and graphics. This article explores the key trends and future developments in popular coating methods, including air knife, Meyer rod, reverse roll, roll over roll, knife over roll, gravure, and slot die coating. Each method is analyzed for its compatibility with water-based PSAs, highlighting their strengths and challenges. Special emphasis is placed on multilayer curtain coating (MLCC), which is emerging as a transformative technology due to its ability to apply multiple adhesive layers, each imparting different characteristic, in a single pass, enhancing product performance and efficiency. While curtain coating offers significant benefits such as customization and reduced material waste, it also presents challenges related to stability and system complexity. As market demand for high-performance, sustainable adhesive solutions grows, advancements in these coating technologies will continue to shape the future of the PSA industry

Introduction

Pressure sensitive adhesives (PSAs) are integral to a wide spectrum of modern applications, ranging from everyday consumer products like tapes and labels to sophisticated solutions in industrial and medical fields. A defining characteristic of PSAs is their capacity to establish a bond with a surface under minimal pressure, circumventing the need for heat, solvent activation, or prolonged curing. This seemingly straightforward functionality is underpinned by a complex synergy of adhesive chemistry, formulation, and critically, the precise and controlled deposition of the adhesive onto a substrate. Consequently, coating technology emerges as a pivotal element in PSA manufacturing, directly impacting the ultimate product performance, consistency, and economic viability.

This article explores the diverse array of coating technologies and associated processes integral to the pressure sensitive adhesive industry. The discussion will center on the fundamental principles of each method, their respective merits and limitations, and their suitability for various PSA formulations and application contexts. The scope encompasses a spectrum of techniques, from established roll coating methodologies to advanced approaches like slot die and curtain coating, alongside a consideration of essential downstream processes such as drying, curing, and quality assurance.

I. Roll Coating Technologies:

Roll coating encompasses a significant category of coating methodologies that leverage rotating rolls to effect adhesive transfer and metering onto the substrate. These techniques are favored within the PSA industry due to their adaptability to a broad range of adhesive viscosities and coating weights, coupled with their proficiency in high-throughput continuous processing. Several distinct roll coating configurations exist, each characterized by unique operational principles and performance profiles.

A. Gravure Coating:

Gravure coating represents a direct method distinguished by its precise coating weight control and capacity for patterned adhesive deposition. Figure 1 describes the different methods of gravure rolls to coat[1]. In gravure coating, an engraved cylinder, the gravure roll, features cells etched into its surface designed to hold a defined volume of adhesive. As the gravure roll rotates through an adhesive pan, these cells are filled, and excess adhesive is removed by a doctor blade, leaving adhesive solely within the engraved cells. Subsequently, upon the substrate web passing between the gravure roll and a counter roll, the adhesive is directly transferred from the cells to the substrate. This mechanism of engraved roll metering and direct transfer affords excellent coating weight control, particularly advantageous in thin coating applications, and enables precise pattern coating for selective adhesive placement. Furthermore, gravure coating demonstrates versatility with both solvent and water-based PSAs, and represents a relatively simple and robust technology. However, gravure coating can exhibit speed limitations compared to other methods, especially at higher coating weights due to the cell filling and emptying cycle. The cost of custom-engraved gravure rolls, particularly for complex patterns, can also be substantial, and potential air entrapment, contingent upon adhesive viscosity and cell design, may introduce coating defects. Applications of gravure coating in PSA manufacturing are diverse, including labels, tapes with specific adhesive patterns, specialty adhesives requiring precise coat weights, as well as protective and decorative films.

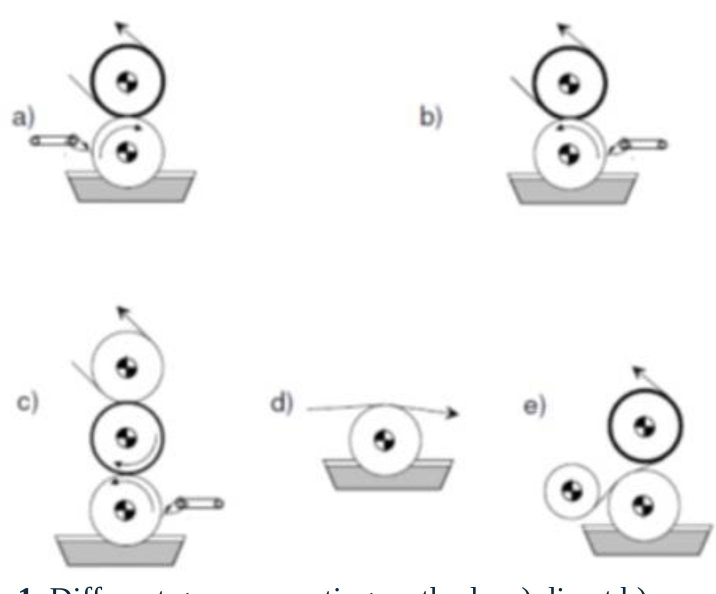

Figure 1. Different gravure coating methods: a) direct b) reverse c) offset d) and e) kiss gravure, doctor blade not shown rolls may rotate either side[1].

B. Reverse Roll Coating:

In contrast to direct methods, reverse roll coating employs an indirect approach, valued for achieving superior film quality and metering precision, particularly well-suited for high-viscosity adhesives and demanding applications. Figure 2 outlines schematic of reverse roll coating method[2]. Reverse roll systems utilize a series of rolls operating synergistically to meter and refine the adhesive prior to substrate application. Typically, a pick-up roll gathers adhesive from a reservoir, followed by a metering roll that accurately regulates adhesive film thickness, and finally an applicator roll that transfers the metered adhesive to the substrate in a reverse direction relative to web movement. This indirect metering and reverse transfer mechanism facilitates excellent film quality and uniformity, as the multi-roll system ensures thorough adhesive mixing and leveling, even with high-viscosity materials. The adjustable gap of the metering roll enables precise coating weight control, and the method proves adept at handling high viscosity PSA formulations, including heated hot melt PSAs. The smoothing action inherent in reverse roll coating also minimizes coating imperfections such as streaks and air inclusions. Nonetheless, reverse roll coating systems present greater equipment complexity and cost compared to simpler roll coating methods. While capable of high speeds, they may exhibit slightly lower throughput than curtain or slot die coating, especially for high-volume production. Moreover, optimal performance necessitates meticulous roll alignment and consistent maintenance to uphold metering consistency. Reverse roll coating finds application in high-performance industrial, medical, and automotive tapes, foam tapes, and other contexts where exceptional coating quality and uniformity are paramount.

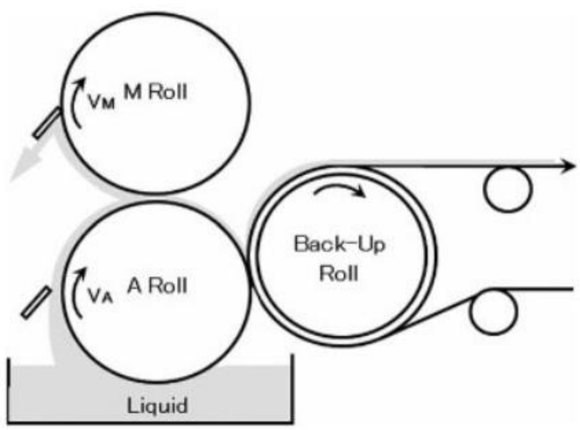

Figure 2. Reverse roll coating head sketch[2]

C. Metering Rod Coating (or Meyer Rod Coating):

Metering rod coating, or Meyer rod coating, offers a comparatively straightforward and versatile direct roll coating technique widely employed for diverse PSA formulations. This method uses a rotating metering rod, typically constructed from stainless steel and wrapped with wire or featuring machined grooves, to control the adhesive layer thickness. Adhesive is applied upstream of the metering rod, and as the substrate traverses beneath the rotating rod, excess adhesive is scraped off, leaving a precisely metered layer defined by the gap between the rod and the substrate. The direct coating and metering rod scraping mechanism results in a simple and cost-effective technology accessible to many PSA manufacturers. Its adaptability to a range of adhesive viscosities through rod exchange and ease of coating weight adjustment further contribute to its versatility. Metering rod coating is also compatible with both solvent and water-based PSAs. However, coating weight control is inherently less precise than gravure or reverse roll methods, especially for very thin or thick coatings. Potential coating defects, such as streaking or ribbing, can arise from improper rod maintenance or viscosity mismatches. Furthermore, it is generally slower than slot die or curtain coating for high-volume production scenarios. Typical applications for metering rod coating include general-purpose tapes, labels, packaging and masking tapes, and applications where adequate but not ultra-precise coating weight control is sufficient. Figure 3 describes various coating configuration for Myer rod[3.]

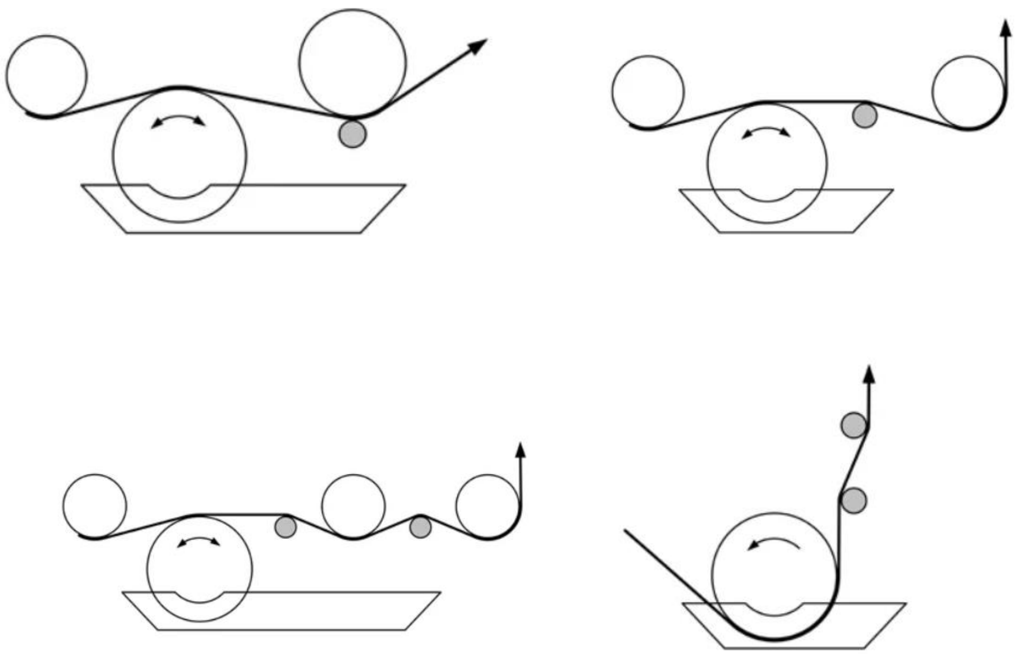

Figure 3. Myer rod coating configurations, single rod, Myer rod with backup rolls, dual rod, two side configuration[3]

D. Knife-Over-Roll Coating:

Knife-over-roll coating shown in figure 4[4] constitutes another direct roll coating approach, particularly suited for thicker coatings and higher viscosity adhesives. In this system, the substrate web passes over a coating roll, which gathers adhesive from a pan. A precisely positioned knife blade, immediately following the coating roll, then doctors off excess adhesive, thereby metering the coating thickness based on the knife-roll gap. This direct coating and knife blade metering method allows for the application of thicker adhesive layers and processing of higher viscosity PSA formulations. The technology is relatively simple and cost-effective. However, similar to metering rod coating, coating weight control is less precise compared to gravure or reverse roll coating. Coating defects such as streaking, knife marks, and uneven coating can occur if the knife is not properly maintained or aligned. It also tends to be slower than slot die or curtain coating methods. Knife-over-roll coating is utilized in the production of foam tapes, double-sided tapes requiring thicker adhesive layers, carpet tapes, and construction tapes, particularly in applications demanding high initial tack and gap-filling characteristics.

The air-knife coating process is depicted in figure 5[5]. In this method, instead of using a knife blade, excess coating material is applied to the substrate and then removed by a high-velocity air jet from the air knife. The interaction between the air jet and the liquid coating film plays a crucial role in regulating the thickness of the coating layer.

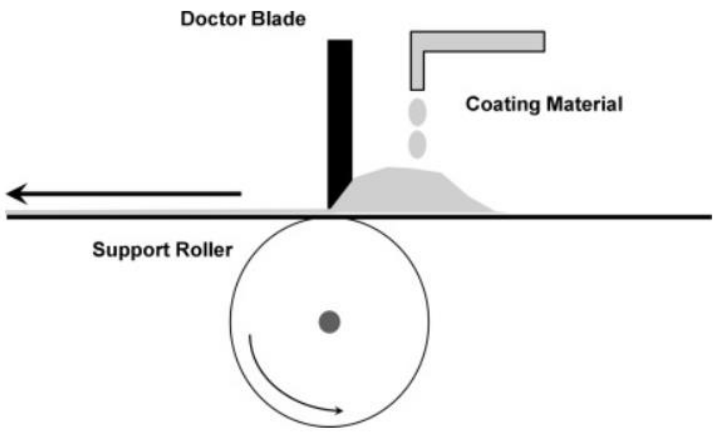

Figure 4. Knife over roll schematic[4]

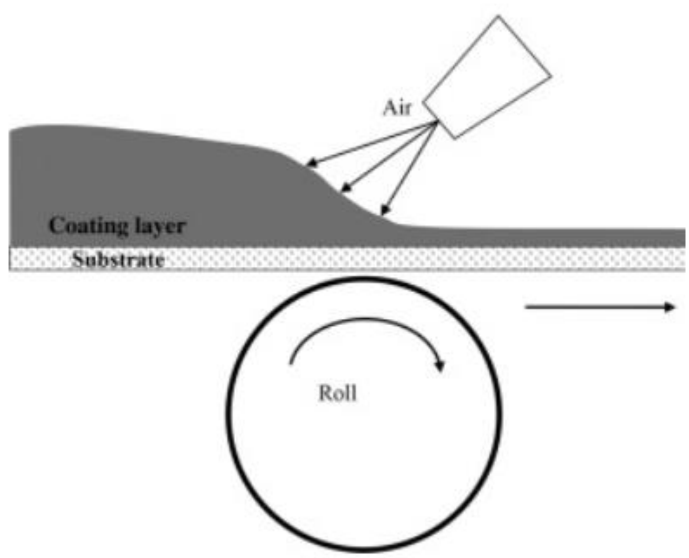

Figure 5. Air- Knife over roll Schematic[5]

II. Slot Die Coating:

Slot die coating, figure 6[6], alternatively termed extrusion or die coating, represents a pre-metered coating technique distinguished by its high precision, uniformity, and suitability for high-speed operation. This method employs a precisely engineered slot die, characterized by a narrow channel with a controlled opening, to deliver a consistent curtain of adhesive directly onto the substrate. Adhesive is pumped under pressure into the die, and the flow rate in conjunction with the die geometry dictates the dispensed adhesive volume, thereby pre-metering the coating weight. For hot melt PSAs, direct extrusion from the heated slot die can be employed where the molten adhesive is directly extruded onto the substrate. This simplifies the process but is limited to hot melt PSA systems only.

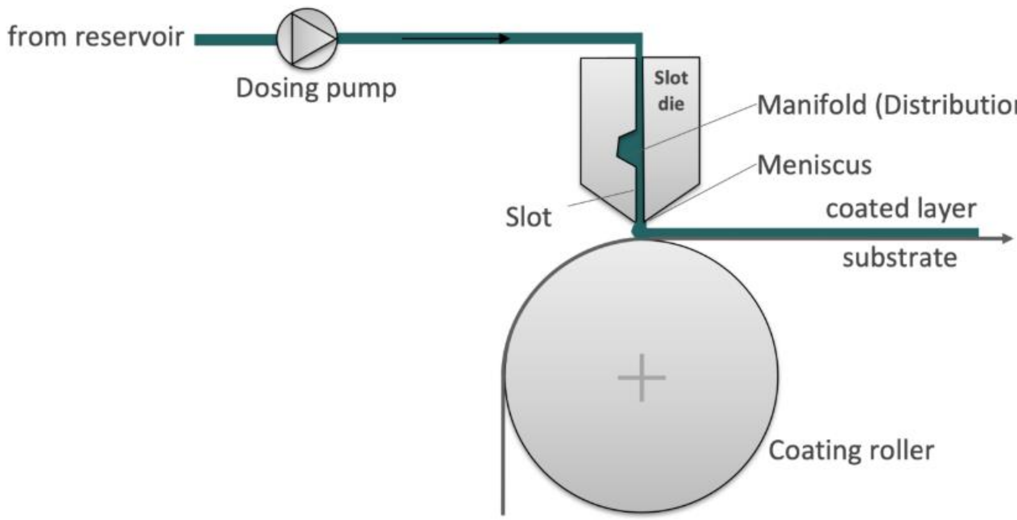

Figure 6. Slot die coating schematic[6]

Slot die coating is often considered a non-contact method, although configurations exist where the die lip is positioned in close proximity to or in contact with the substrate. The pre-metered, slot die extrusion mechanism facilitates exceptionally precise coating weight control and uniformity, leading to consistent PSA product performance. High-speed operation is a key advantage, making it ideal for high-volume PSA production. Being a closed system, slot die coating minimizes adhesive waste and reduces solvent evaporation, enhancing both environmental sustainability and cost efficiency. Advanced die designs can also enable patterned coating capabilities. Furthermore, with appropriate die design and pumping systems, slot die coating can accommodate a wide range of PSA viscosities, including hot melt and radiation-curable systems. The controlled and enclosed nature of the process also reduces coating defects. However, slot die coating systems typically entail higher initial equipment costs compared to roll coating methods. Setup and maintenance are more complex, requiring skilled operators due to the precision engineering of the dies and pumping systems. Viscosity limitations may arise at very high speeds, particularly with extremely viscous adhesives, due to pumping and flow control challenges within the die. Slot die coating finds application in high-performance tapes for electronics, medical, and automotive sectors, optical and display films, high-precision labels, security tapes, and applications necessitating stringent tolerances and exceptional uniformity.

III. Multi-Layer Curtain Coating (MLCC):

Curtain coating, another pre-metered, non-contact technique, is recognized for its high-speed capabilities and ability to apply uniform coatings across wide substrates. In curtain coating, adhesive is pumped through a slot die or specialized manifold to generate a continuous, free-falling curtain of liquid. The substrate web then passes horizontally through this curtain, effectively slicing through the adhesive and becoming coated. Coating thickness is primarily governed by the adhesive flow rate and web speed. The non-contact, free-falling curtain mechanism enables extremely high-speed coating, optimal for very large-scale PSA production. It provides excellent coating uniformity, particularly across wide webs. The non-contact nature of the method minimizes substrate damage and coating defects that might arise from contact with coating rolls or dies. Curtain coating is best suited for lower to medium viscosity PSA formulations, including water-based and solvent-based systems. Material utilization is relatively efficient, although some adhesive loss occurs during curtain formation. However, coating weight control is less precise than slot die coating, as it is more susceptible to variations in web speed and curtain stability. Pattern coating is generally not feasible with standard curtain coating systems, which are primarily designed for full-web coating. Viscosity limitations exist, making it challenging to use with very high viscosity adhesives due to curtain stability considerations. Furthermore, careful environmental control is necessary to minimize air currents and vibrations that could disrupt curtain stability and coating uniformity. Curtain coating is predominantly used for high-volume manufacturing of general-purpose tapes, packaging tapes, labels, and films for large-area applications where speed and coating uniformity are prioritized, such as certain types of masking and commodity tapes.

The curtain coating process involves several key steps to ensure precise, uniform, and stable multilayer coating application. The process begins with liquid storage and pumping, where coating fluids are stored in separate tanks and pumped into the system using precision-controlled pumps that regulate flow rate and material distribution. The next stage is the slide-die delivery system, in which the fluids enter a slide die and are carefully layered before exiting through designated fluid exit slots. These stacked liquid layers travel down the inclined face of the die, forming a free-falling liquid curtain. Maintaining curtain formation and stability is crucial, as the curtain—typically 5 to 20 cm in length—must remain stable with the help of vertical edge guides[7]. Any disturbances can lead to curtain breakup, air entrainment, or non-uniform thickness, compromising coating quality.

Once formed, the liquid curtain impinges onto a moving substrate, labeled the ‘web’, where wetting occurs. The substrate speed and fluid flow rate play a crucial role in coating uniformity. If the substrate speed is too low, a heel of fluid may form, leading to bubble entrapment and streaks. Conversely, a high-speed substrate can trap air pockets under the vertical curtain, reducing adhesion quality. After deposition, the coated material undergoes drying or curing, depending on the composition of the coating. This step ensures that the applied layers achieve their intended functional properties, such as barrier protection, conductivity, or surface modification[7].

One of the most significant challenges in curtain coating is maintaining the stability of the liquid sheet. If the flow rate is too low, the curtain may rupture, causing discontinuous liquid jets, which are unsuitable for coating applications. The stability of the liquid sheet is governed by the Weber number, which represents the balance between inertia and surface tension. Research has established stability criteria for both single-layer and multilayer curtain coating, emphasizing the need for precise control of fluid properties, flow rates, and substrate motion. Additionally, interfacial disturbances within the slide die can impact coating thickness uniformity. When producing an n-layered coating, the liquid film must remain stable as it exits the slide die. Any instabilities at liquid-liquid interfaces can result in wave propagation, ultimately affecting the final coating quality. Proper optimization of fluid properties and process parameters is essential to ensuring a smooth, defect-free multilayer coating.

Recent research by Don Ventresca[8] et-al has explored the potential of Multilayer Curtain Coating (MLCC) as an advanced technique for developing functional barrier coatings for paper and paperboard applications. The study emphasizes the advantages of MLCC in creating coatings that provide resistance to oil, grease, water, moisture vapor, and oxygen, making them particularly suitable for food and packaging applications. Unlike traditional single-layer coating methods, MLCC enables the simultaneous deposition of multiple functional layers, each designed to enhance specific properties, thereby improving overall performance while maintaining cost efficiency. Findings from the study indicate that MLCC significantly enhances barrier properties without the excessive material consumption associated with conventional coating methods. The multilayer approach allows for the precise optimization of material composition, leading to superior protective qualities while ensuring sustainability and recyclability. Given the increasing regulatory and environmental pressures in the packaging industry, MLCC is positioned as a viable alternative to conventional barrier coatings, addressing both performance and eco-friendly requirements.

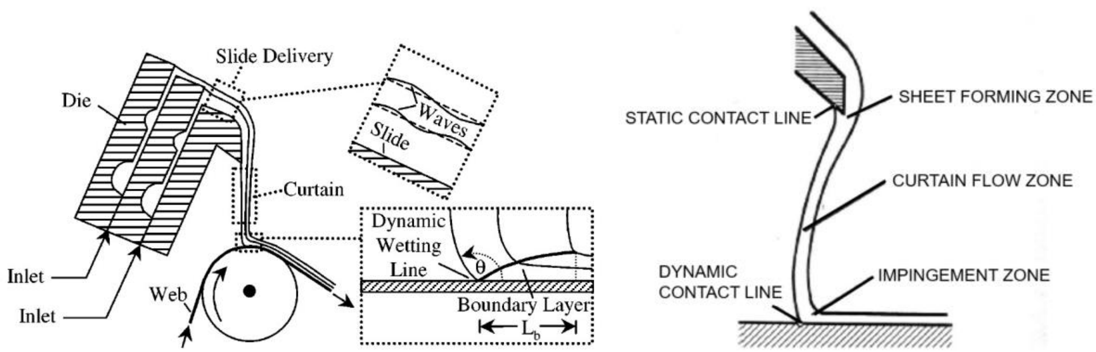

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Figure 7. Schematic of Multi-layer Curtain coating process[7-8].

IV. Other Coating Technologies and Processes Considerations:

Beyond these primary coating technologies, other methods are utilized for specialized PSA applications. Spray coating, involving atomized adhesive application, is employed for complex shapes or discontinuous coatings, offering flexibility but generally lower precision and efficiency for standard web coating. Dip coating, submerging the substrate in adhesive, is used for coating three-dimensional objects or small parts.

Regardless of the coating technology employed, several ancillary process considerations are crucial for achieving desired PSA product quality and performance. Substrate handling systems, encompassing controlled unwinding and rewinding, web tension control, and accurate web guiding, are essential for consistent coating and continuous operation. Drying and curing processes, tailored to the PSA formulation, are critical post-coating steps. Drying ovens are used for solvent and water-based PSAs to evaporate volatiles, while radiation curing (UV or electron beam) is employed for radiation-curable PSAs. Thermal curing may be necessary for certain rubber-based PSAs. Inline quality control measures, including continuous coating weight and thickness measurement, adhesion testing, and automated web inspection systems, are vital for ensuring product consistency and detecting defects. Finally, increasing environmental regulations and safety considerations necessitate solvent recovery systems for solvent-based PSAs, drive the development of water-based and radiation-curable alternatives, and promote ongoing efforts to enhance energy efficiency in coating and drying processes.

In conclusion, the selection of coating technology for pressure sensitive adhesives is a multifaceted decision determined by a combination of adhesive properties, desired product characteristics, production volume, economic factors, and environmental considerations. Roll coating methods offer versatility and remain broadly applicable. Slot die coating provides superior precision and speed, while curtain coating excels in high-throughput uniform coating. Beyond the coating head, careful attention to substrate handling, drying/curing, quality control, and environmental factors is paramount. Continued advancements in coating technologies will be instrumental in the evolution of the PSA industry, enabling increasingly sophisticated and application-specific adhesive products.

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