PERFORMANCE COATINGS INTERNATIONAL

LABORATORIES

COATING APPLICATION METHODS

PCI Lab's Vueguard 901™ high performance chemical coatings can be applied by a variety of conventional application methods. This tutorial provides an overview of four methods -– dip coating, flow coating, spin and roll coating. This information is general in scope; it is the responsibility of the user to determine the suitability of the method for the intended product application. The spray coating method is the most prevalent and all of PCI Labs' Application Notes for each of the **Vueguard 901™** coatings provide full description of that method.

Dip Coating Application

Dip coating is a useful technique when it is desirable to coat both sides of a part with the same coating. The ability to dip coat a part, however, is sometimes limited by the size, shape and/or surface features of the part. For example, extremely large parts or parts that contain holes, protrusions, or other surface irregularities can be difficult to coat by the dip method. However, dip coating is usually well suited for vision, sport, sunglass and safety lens applications.

The basic equipment for a dip coating application includes a dip tank, where parts can be completely submerged in the coating, a closed loop circulation system, which circulates the coating from the tank through a filtering element, and a mechanism to pull the part out of the coating tank at a controlled speed. Dip tanks are usually built using a "tank-in-tank" design. This design allows the coating that is pumped into the tank to overflow over the sides of the inner tank into the outer tank. The overflow, which is collected in the outer tank, is then pumped through a filtering element back into the inner tank. Normally, the dip tank is designed to allow overflow on all four sides of the inner tank. This prevents the possibility of having the coating dry out on a surface that is not continually wetted by the coating solution.

The specifics of the tank design are critical to the proper performance of the coated product. These specifics include tank size, the distribution of flow within the tank, and the flow rate. Tank size also defines the volume of the system. The tank size is defined as the length, width and depth of both the inner tank and the overflow area of the outer tank. The distribution of flow within the tank should be uniform and free of mixing from the bottom to the top of the tank and across the cross section of the tank. The flow rate should allow for a sufficient volume turnover to properly carry debris out of the tank and into the filtering elements of the system. Generally, it is desirable to have a tank design and a circulation system that provide a high tank turnover rate and a smooth, turbulence-free coating solution surface. Similarly, it is desirable to have a part withdrawal mechanism that can accurately and smoothly control the rate of part withdrawal from the coating solution. In addition, it is beneficial to have a withdrawal mechanism that allows the withdrawal rate to be varied continuously as a function of the position of the part during the withdrawal. A means for controlling the temperature of the coating solution is also a beneficial feature for a dip coating system. For controlling the coating solution temperature, it is better to circulate a heat exchange fluid through a heat exchange device rather than trying to circulate the coating through a coil-type-chilling unit. A control temperature range of 15-25°C is suitable for most coating applications

The circulation system should provide a sufficient turnover rate to adequately filter the coating solution. Ideally, the filtration system should consist of two or more filters in series, a configuration that allows for the use of coarse prefilter and finer subsequent filters. The optimum filtering configuration will depend on the coating being used and the rate of circulation through the filters. In general, the circulation rate should be set as high as possible without creating turbulence within the coating tank and without creating a large pressure differential (>10 psi) across the filter elements. A high-pressure differential across the filters can cause coating gels to extrude through the filter elements. The porosity and size of the filter elements can be adjusted to reduce a high pressure differential, although this may also affect the cleanliness of the system.

In any coating application, the amount of coating that is deposited on the part, i.e., the coating thickness is a function of the coating solids, solvent composition, temperature, and viscosity. In a dip coating application, the coating thickness is also a function of the tank flow dynamics, the part withdrawal rate, and the angle of part withdrawal. Normally, it is desirable to keep the coating properties constant and to use the withdrawal rate to control the coating thickness; a fast withdrawal rate will produce a thicker coating than a slow withdrawal rate. Good control over the coating thickness is important to achieve optimum performance of **PCI Vueguard 901**™ products. The coating thickness will affect the abrasion resistance and possibly other performance properties of a product. An optimized coating thickness can be determined empirically, according to the desired performance features of the final coated part.

Flow Coating Application

Flow coating is a useful application when it is desirable to coat only one side of a part or when it is desirable to coat different sides of a part with different coatings. Flow coating can be used on large or small parts, although the technique has some limitations on parts that contain holes, protrusions, or other surface irregularities.

The basic equipment for a flow coating application consists of a support fixture and a delivery system comprising a drip trough, a coating reservoir, a circulation pump, a filtering element and a coating delivery hose. In a typical flow coating operation, such as coating a sheet product, the coating is applied by moving the coating delivery hose from the bottom left hand side of the part, up along the left hand side, then slowly across the top of the part, and down the right hand side. As the coating is deposited on the part, it flows down the vertical surface and eventually covers the entire part. The excess coating solution that drips off the part is collected in the coating reservoir where it is fed back through the filter elements to the delivery hose.

It is desirable in a flow coating application to be able to control the coating delivery rate. In general, it is desirable to “flood” the part with coating, which allows the coating to carry particular debris off of the part and also helps with the adhesion by increasing the coating’s “wet time” on the part.

The circulation system should provide a sufficient turnover rate to adequately filter the coating solution. Ideally, the filtration system should consist of two or more filters in series, a configuration that allows for the use of a coarse prefilter and finer subsequent filter. The optimum filtration configuration will depend on the coating being used and the rate of circulation through the filters. In a typical flow coating application, the circulation rate is limited by the allowable delivery rate. In general, the delivery rate should be set as high as possible, while maintaining flow control and avoiding bubble generation or splatters as the coating flows onto the part. The flow rate should also be adjusted to avoid creating a large pressure differential (>10 psi) across the filter elements. A high-pressure differential across the filters can cause coating gels to extrude through the filter elements. The size of the filter elements can be adjusted to reduce a high-pressure differential, although this may also affect the cleanliness of the system. In any coating application, the amount of coating that is deposited on the part, i.e., the coating thickness is a function of the coating solids, solvent composition, temperature, and viscosity. The coating thickness can also be influenced by the coating environment. Anything that causes the coating to dry quickly, e.g., high coating temperature, high environmental temperature, low humidity, high airflow over the part, high temperature on the part, etc., can contribute to higher coating thickness. In a flow coating application these factors will also add to the normal "wedge effect" which results in a coating thickness gradient. The coating thickness gradient increases from the top to the bottom of a coated part. This "wedge effect" can be significant on a large part.

It is generally most effective to modify the coating solids to make adjustments in coating thickness, while keeping the other coating properties and environmental factors constant. Controlling the coating thickness is important in achieving optimum performance of PCI Vueguard 901™ coatings. The coating thickness will affect the abrasion resistance and possibly other performance properties of a product. An optimized coating thickness can be determined empirically, according to the desired performance features of the final coated product.

Spin Coating Application

Spin coating is a useful application when it is desirable to coat only one side of a part or when it is desirable to coat different sides of a part with different coatings. Spin coating is typically used for small or medium sized parts that are nearly flat and symmetrical in shape. This technique is used extensively to coat ophthalmic lenses and can be used to coat both the convex and concave sides of a lens. Spin coatings also has some limitations on parts that contain holes, protrusions or other surface irregularities.

The basic equipment for a spin coating application consists of a spinning device, a coating delivery device, a collection tank/reservoir, a pump, and a filtering element. The spinning device holds the part securely in place, typically in an inverted position, and allows the part to be rotated at a controlled speed. The coating delivery device dispenses the coating onto the part. The collection tank/reservoir collects the excess coating (the spin-off material). The pump and filtering element circulate the coating back to the delivery device.

In a typical ophthalmic application, an inverted lens is fixed on the spinning device and lowered into the collection tank so that the surface of the lens contacts the coating solution, which is directed by a fountain onto the center of the lens. The lens is usually rotated slowly during this operation to ensure that the entire surface is properly wetted. The lens is then raised out of the coating solution and rotated at a high rate of speed. This rotation spreads the coating evenly across the surface of the part and removes any excess coating from the part. The speed of the rotation (spin rate) and the duration of the rotation can be used to control the coating thickness and can affect the dry time on the coating.

The circulation system should provide a sufficient turnover rate to adequately filter the coating solution. Ideally, the filtration system should consist of two or more filters in series, a configuration that allows for the use of coarse prefilter and finer subsequent filters. The optimum filtering configuration will depend on the coating being used and the rate of circulation through the filters. In a typical spin coating application the circulation rate is limited by the allowable delivery rate. In general, the delivery rate should be set as high as possible, while maintaining flow control and avoiding bubble generation or splatters as the coating is sprayed on the part. The flow rate should also be adjusted to avoid creating a large pressure differential (>10 psi) across the filter elements. A high-pressure differential across the filters can cause coating gels to extrude through the filter elements. The size of the filter elements can be adjusted to reduce a high-pressure differential, although this may also affect the cleanliness of the system.

In any coating application, the amount of coating that is deposited on the part, i.e., the coating thickness is a function of the coating solids, solvent composition, temperature, and viscosity. The coating thickness can also be influenced by the coating environment. Anything that causes the coating to dry quickly, e.g., high coating temperature, high environmental temperature, low humidity, high airflow over the part, high temperature on the part, etc., can increase the coating thickness. In a spin coating application, it is generally most effective to use the coating solids and spin rate to make adjustments in coating thickness, while keeping the other coating properties and environmental factors constant. Good control over the coating thickness is important in achieving optimum performance of **PCI Vueguard 901™** coatings. The coating thickness will affect the abrasion resistance and possibly other performance properties of a product. An optimized coating thickness can be determined empirically, according to the desired performance features of the final coated product.

Roll Coating Application

The "reverse roll coater" is widespread in the coating industry applying various thin films onto a variety of substrates. The metering and application mechanisms employed by this type of coater make it adaptable to this broad usage. To qualify as a true reverse roll coater, two conditions must be met. The first is the requirement for a reverse metering nip (gap). This occurs when the coating must pass between two rolls whose surfaces are traveling in opposite directions. This is illustrated in *Figure 1*.

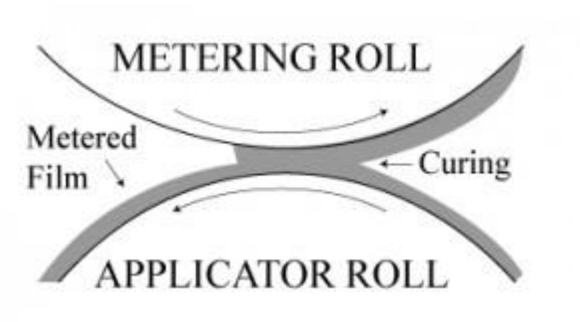


Figure 1

It can be seen from this illustration that the thickness of the metered film will be primarily a function of the clearance or gap between the two rolls. Reverse metering also contributes to smoothness. The opposite approach, forward roll metering, leads to a rougher surface because the coating remains as a single stream for a short distance beyond the nip before separating and following the diverging surfaces of both rolls. The reverse metering action of a reverse roll coater provides a smoother, more uniform metered film by avoiding the film split pattern and the ribbing phenomenon encountered with forward roll metering.

The second requirement for a true reverse roll coater is that of reverse application of the coating to the substrate. In other words, the metered film must be wiped onto the moving substrate by the applicator roll as its surface moves in a direction opposite to that of the web. Again, the film split that occurs when a forward roll applies coating to a moving web is avoided by the reverse wipe.

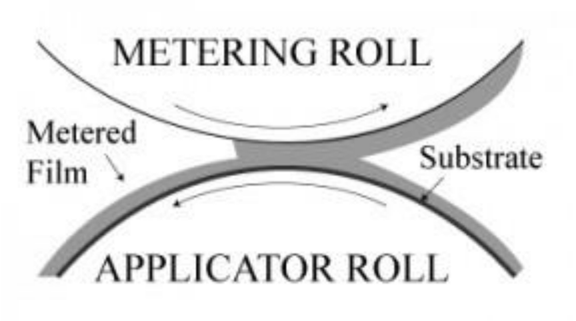
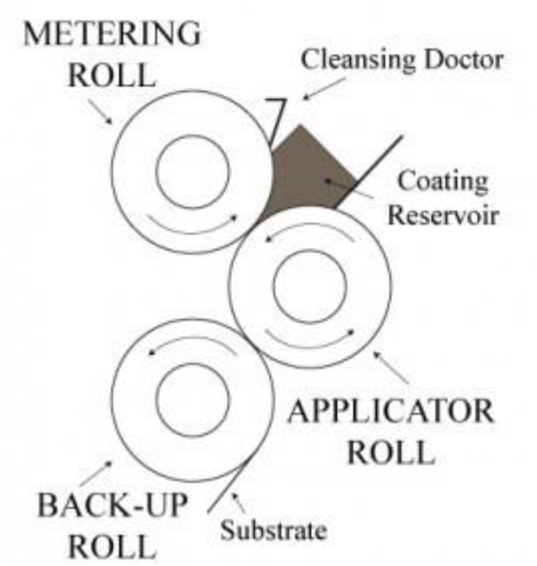


Figure 2

The true reverse roll coater requires a separate metering and application zone, but there is a variation where these two functions are performed simultaneously to produce similar results. This design is illustrated in *Figure 2* and has been referred to as “between the rolls”, “direct metering” and “Level-On” coating. In coaters of this type, the thickness and uniformity of the substrate figures into the metering equation, whereas in the true reverse roll coater, it does not. The true reverse roll coater, in contrast to many alternative coating methods, applies a pre-metered coating of uniform thickness regardless of the variations in substrate thickness. Looking at *Figure 1*, it can be seen that the metering roll carries a layer of coating on its surface as it leaves the metering zone, yet the roll surface is portrayed as being clean and free of any coating residue as it returns. To accomplish this, a cleaning doctor must be employed to clean the metering roll surface as it leaves the metering zone.

Naturally, this device must be positioned so that the doctored coating can be recaptured and reused, since it represents a substantial volume of coating. It must also be positioned and generally constructed to do a very thorough job of cleaning the roll. Failure to do so, results in one of the most common defects found in reverse roll coating-streaks in the coated film, and can lead to other problems as well.

Reverse roll coating appears in two basic forms – the nip fed and the pan fed. The first of these is commonly described as the **3-roll nip fed reverse roll coating**. The third roll in the system is the back-up roll, used to bring the moving web into contact with the applicator roll. In the nip fed design, the metering nip is flooded with coating. The most accepted approach places the metering and applicator rolls at an



angle as illustrated in *Figure 3*.

Figure 3

This approach allows the nip to be flooded utilizing only a minimal amount of coating and virtually all of the coating can be used up by the process at the end of the run. The width of the coating pond is set by repositionable dams contoured to fit into the roll set. This also serves to limit the amount of coating required to properly charge the system in the event the substrate is narrower than the coating rolls. The second approach in current demand is 4-roll pan fed reverse roll coating. This is illustrated in *Figure 4.*

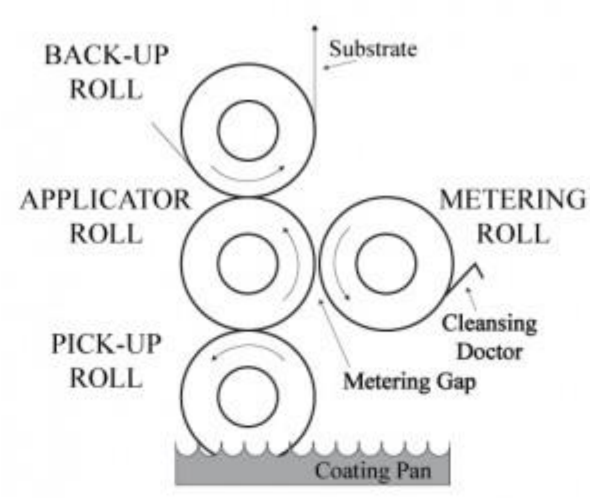


Figure 4

This concept employs a feed pan instead of a coating pond and associated leakage potential. This is an advantage with low viscosity coatings. In order to avoid having the applicator roll running directly in the liquid, a fourth roll, running at a reduced speed, is utilized to pick up the coating and supply the applicator roll. Coaters not utilizing this fourth roll are called **3-roll pan fed reverse roll coaters**. They have generally proven to be limited to low viscosity/speed applications because of the difficulty in getting the high speed applicator roll to wet properly as it rotates through the liquid bath. The fourth roll, as well as the large volume of coating in the pan, can be avoided by supplying a slot feeding device located close enough to the applicator roll that the coating being pumped through the slot is forced onto the applicator.

Reverse roll coating 1) can be used to apply a broad range of coating viscosities, 2) can apply these coatings over a broad range of thicknesses, and 3) can function over an equally broad speed range. Attempts to define limits are only generalizations, because there is interdependency among all these factors, and there are different standards of acceptability that apply in every situation. One unavoidable truth is that reverse roll coating does have a lower limit with regard to film thickness due to the increasing roll that mechanical inaccuracies play as the metering gap dimension is decreased. This seems to have been pushed as far as possible by the narrow web, magnetic tape industry, where metered films under .001″ are applied with good uniformity, but with extreme care.

However, within the mechanical limits of a well-made reverse roll coater, there lies an optimum set of conditions which will provide the smoothest, most uniform film for a given coating application. Otherwise, two well-known defect conditions may appear in metered roll coating. One condition is usually defined as “ribbing”. The other defect is most often described as “cascading. Ribbing lines are oriented down web, and cascading occurs across web. The position of the wetting line affects the thickness of the metered coating and the ribbing and cascading phenomena. The “wetting line” as illustrated in *Figure 5* can be described as the point at which the coating pulls away from the metering roll as it departs the metering gap and travels along with the applicator roll. When the wetting line is located at or near the center of the gap, the metered film thickness is at its minimum (for a given gap setting) and the coating appears the smoothest. If the wetting line is positioned to the outlet or metered film side of the gap, generally the ribbing phenomena is more pronounced. This appears to be related to the shape of the “meniscus” that occurs at the wetting line, and with instabilities arising from forces affecting this shape. The coating thickness can also be expected to increase slightly.

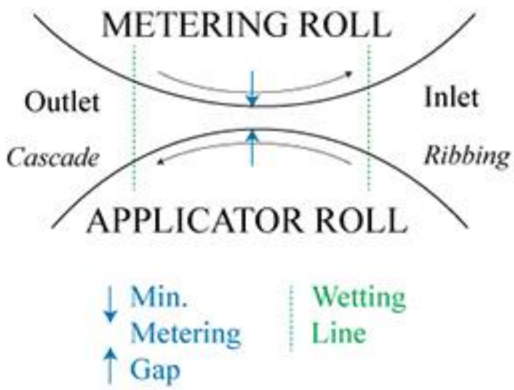


Figure 5

On the other hand, if the dynamic wetting line is positioned on the inlet side of the gap, the onset of cascade occurs, and the coating becomes substantially thicker in an oscillating manner. As the wetting line moves further from the center, the thicker the metered film becomes, until the thickness equals the gap dimension. The most important factor in controlling the position of the wetting line, and therefore, the appearance of the coating, is the ratio of the metering roll speed to the applicator roll speed. The effect of this speed ratio on ribbing or cascade is widely known ~ speed up the metering roll to eliminate ribbing, slow it down to eliminate cascade. The wetting line affects the ribbing and cascading phenomena in reverse roll coating. The most important factor in controlling the position of the wetting line is the metering roll ratio. The second most important factor influencing the position of the dynamic wetting line is the capillary number of the coating. The capillary number is defined as:

$$\frac{\text{Viscosity x Roll Speed}}{\text{Surface Tension}}$$

Increasing the capillary number generally has the same effect as increasing the metering roll ratio, that is, it stabilizes the coating to ribbing. The wetting line moves from the outlet toward the center of the metering gap as the capillary number increases due to the shape of the curve the meniscus can maintain. As the capillary number increases, the liquid supports a more strongly shaped curve that can locate closer to the center of the gap. Still higher capillary numbers can cause the wetting line to locate upstream of the gap, causing the onset of cascade. Since capillary number is directly proportional to applicator roll speed, which itself is proportional to line speed, the implications of this can readily be seen.

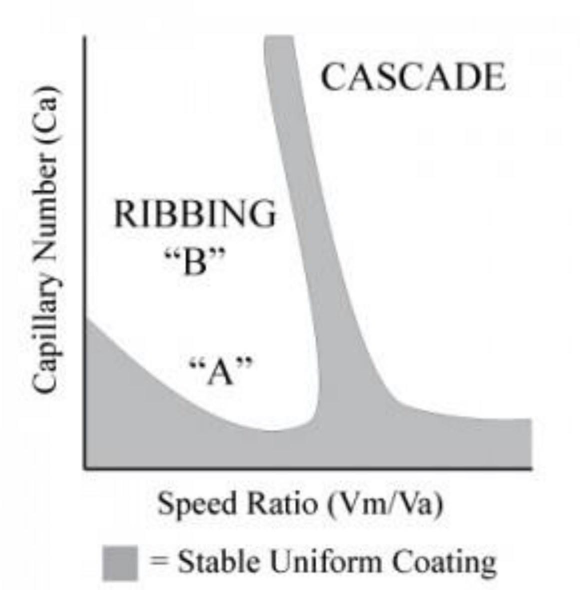


Figure 6

In general, a higher capillary number shifts the optimum metering roll speed ratio to a lower value and vice versa. However, it has been observed that at extremely low capillary numbers, the coating becomes stable to ribbing at a lower metering roll ratio. The concept of eliminating ribbing by lowering the metering roll speed is counterintuitive, but correct. At a higher capillary number, the more conventional adjustment of increasing the metering roll ratio is correct. This phenomena is best illustrated by the following Stability Diagram in *Figure 6*.

Operating under the set of conditions represented by " A " on the diagram (low capillary number, low speed ratio) would produce a ribbed coating. The usual response, increasing metering roll speed, would shift point " A " in a straight line to the right, and no improvement would be seen. However, lowering metering roll speed would soon yield operating conditions in the stable area.

Contrast this with the more conventional speed adjustment required to shift point " B " into the stable area. Also, note how changing the applicator roll speed (strongly associated with production speed) can shift the point in or out of the stable area. The metering gap dimension (along with other factors) can alter the size, shape, or position of the stable region, and generally reduces its area, making it more difficult to achieve acceptable results.

For more information, please contact a PCI Lab's Sales Representative at: (973) 227-5401.