2018 Quarter 2
Vol. 4, No. 2

UV+EB TECHNOLOGY

Global Trends in Automotive Design

Lightweighting with 3D-Printed Foam

PVC Wide-Web EB Curing

Applying UV-Cure Coatings

RADTECH
THE ASSOCIATION FOR UV&EB TECHNOLOGY
Official Publication of RadTech International North America

ON THE COVER

The cover was finished by Royle Printing Company, Sun Prairie, Wisconsin, using a multi-step UV-curing process called Rough Reticulated Strike-Through. First, the 4-color process was laid down and a UV varnish was applied as a spot application in the areas that did not receive the gloss UV treatment (photograph and copy). The UV varnish was cured with UV lights, and then an LED curing system was used to cure the 4-color process inks. A flood gloss UV was applied over the entire cover, which "reacted" to the UV varnish and created the matte varnish – staying glossy in the areas that were knocked out to receive the gloss UV. The final step was a pass under another UV curing system to cure the coating. This process was performed in one pass on press.

FEATURES

DEPARTMENTS

By **Michael R. Bonner**, vice president, engineering and technology, Saint Clair Systems

Guns vs. Bells – What's the Best Way to Apply UV-Cure Coating?

The goal of any finishing operation – whether solventborne, waterborne or UV cure – is to apply a consistent and contiguous coating to the subject part. This coating serves many purposes:

1) To improve the aesthetic appearance of the part.
2) To protect against such things as scratches, corrosion, UV damage, etc.
3) To improve performance in the part's final application – for instance, increasing moisture resistance, reducing aerodynamic drag (i.e. – automobiles, airplanes, rockets), hydraulic drag (i.e. – boats, ships, torpedoes), etc.

There are many ways to apply these coatings, including dipping, brushing, rolling or flow coating, but this discussion focuses on spray operations.

In a spray operation, the coating is atomized into a pattern of droplets and applied to the surface of the part, where the droplets rejoin one another and flow out to form a film. The primary devices used to perform this atomization function are guns and bells.

Comparing guns and bells

Similarities: Because both do the same job, there are many similarities between guns and bells. Both atomize the coating into a cloud, creating a fan pattern that can spread out over the surface of the target part. Both use compressed air to "shape" the fan pattern. Both can be used in electrostatic applications, where the coating particles are charged at a high voltage and the part is grounded to create an "attraction" between the atomized droplets and the part. This helps reduce overspray, gets more of the liquid coating on the part and increases transfer efficiency.

Differences: While both create a fan pattern, Figure 1 shows that the patterns created can be very different. This is due to the differences in the way the atomized cloud is created. We will explore that in detail shortly.

Bells are larger and heavier than guns. This makes guns more suitable to manual spray applications, providing an operator greater control with less stress and fatigue. Bells generally are limited to automated applications. While any coating applicator is susceptible to maintenance and cleaning issues, bells are more complex, with lots of moving parts. In general, bells require more maintenance than guns.

page 40 ▶

FIGURE 1. *Gun[1] vs. bell[2] atomizers*

◀ page 38

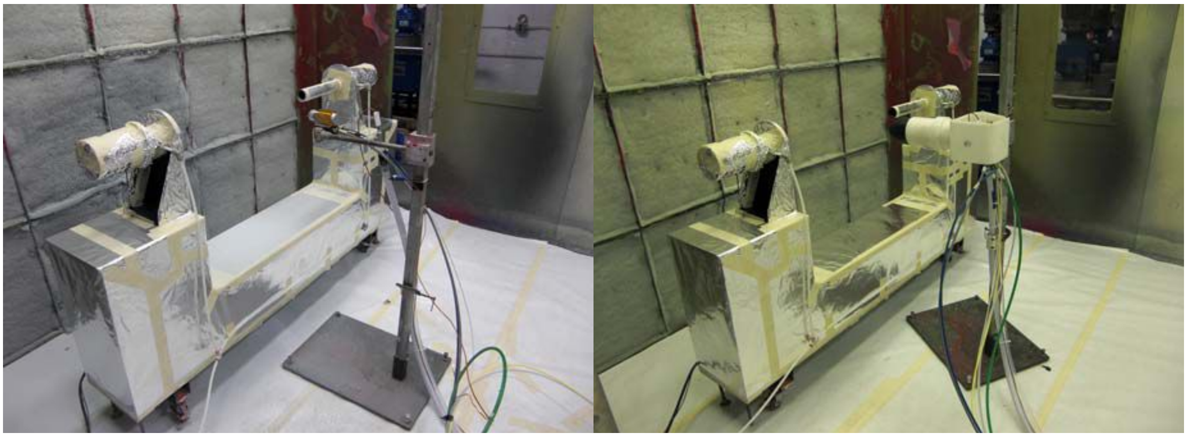

FIGURE 2. *Cloud measurement setups*

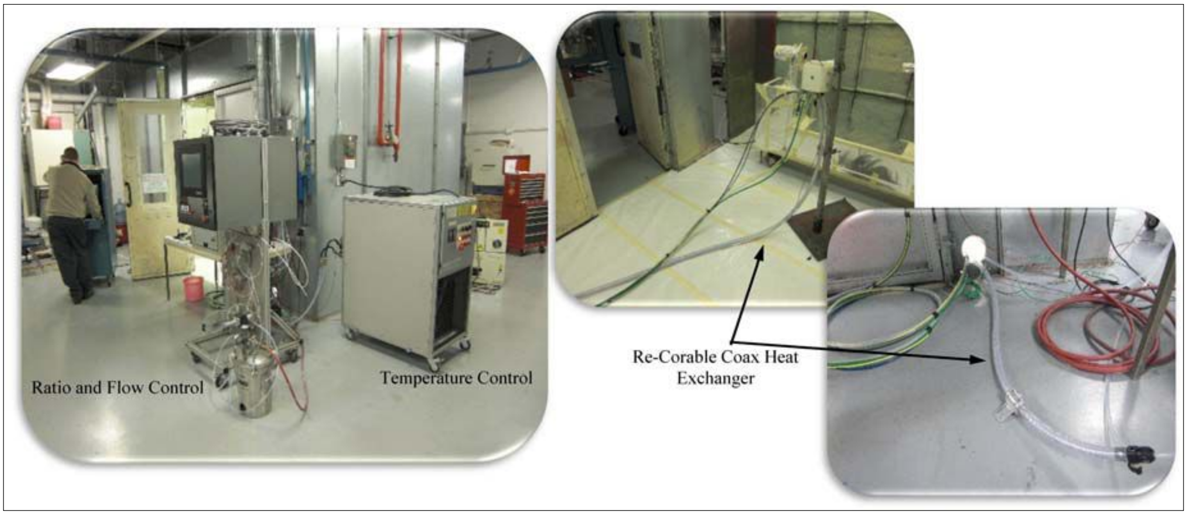

FIGURE 3. *Test control system*

would simply hover adjacent to the part with very little fluid actually reaching the surface. Thus, shaping air is used to "shape" the fan pattern *and* direct it toward the part.

Guns generate shear by increasing the velocity of the fluid stream, then forcing it through a small orifice. Atomization is controlled by the size and shape of orifice and the flow rate of fluid through it, the pressure behind it and the viscosity of fluid. The fan pattern also is both shaped and directed by the shaping air, but because the fluid stream already is moving toward the part when it is atomized, guns create particles with a higher velocity toward the part.

Bells are generally used with lower-viscosity fluids supplied at lower pressure, whereas guns may be better suited for higher-viscosity, higher-pressure applications. This is where we begin to see a distinction in applicator choice for UV cure coatings.

But first, let's get back to atomization …

Atomization

In short, atomization is the result of applying shear, which tears the fluid stream into a cloud of small particles.

The bell's rotating cup shears the fluid by adding force perpendicular to the direction of the fluid stream as it reaches the edge of the cup. The size of the particles is primarily determined by the design of the cup, the flow rate of the coating (which determines the rate at which fluid is delivered to the edge of the cup) and the speed of rotation (which determines the speed of the cup edge relative to the fluid stream). As a result, most of the energy imparted to the particle is perpendicular to the bell and parallel to the part. Without some means of directing the cloud, it

Quantifying the differences

So, how do these differences in atomization affect our day-to-day coating operations? This was put to the test at Carlisle Finishing Technologies' lab in Toledo, Ohio, using its Malvern Particle Size Analyzer to measure the distribution of particle sizes in the atomized cloud for a typical gun and bell, as shown in Figure 2.

To maintain consistency, both gun and bell tests were performed using the same 2K clearcoat. Ratio, fluid flow, atomizing and shaping air all were held constant with a Ransberg RCS system. Ambient conditions were simulated with a Saint Clair Systems (SCS) coating temperature control system implemented with a re-corable coax hose as the heat exchanger. Shown in Figure 3, this system provided accurate control of temperature to the point of dispense in controlled, repeatable steps.

Gun testing

The first tests were performed with the gun setup shown in Figure 2. With all other parameters held constant by the RCS system, temperature was incremented from 65°F to 115°F (18°C to 46°C)

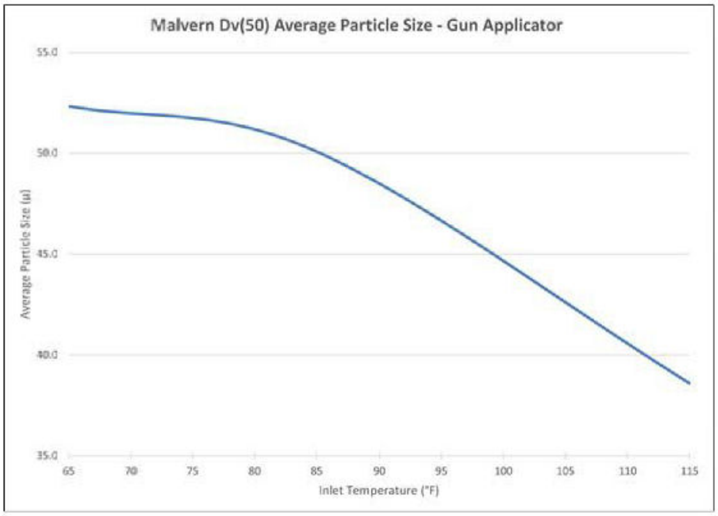

FIGURE 4. *Gun cloud particle size*

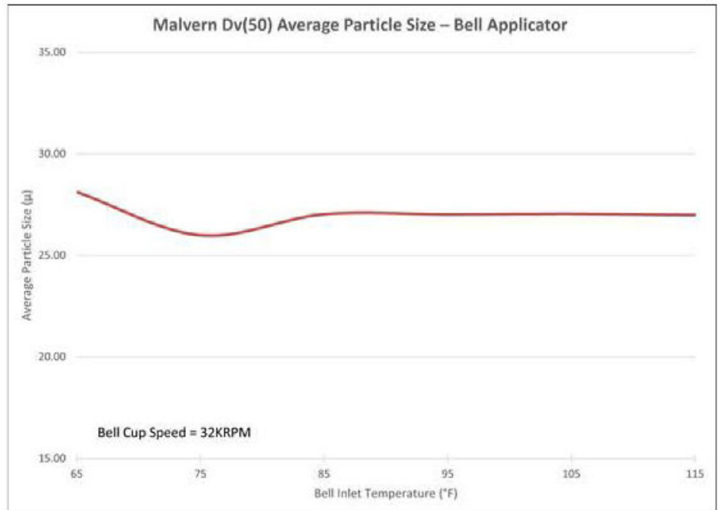

FIGURE 5. *Bell cloud particle size*

to vary clearcoat viscosity. At each step, the resulting Dv(50) average particle size in the atomized cloud was measured using the Malvern.

The results are shown in Figure 4. With all other variables held constant, the average particle size for the gun applicator varied from 52.3µ at 65°F (18°C) down to 38.6µ at 115°F (46°C).

It is reasonable to conclude that the change in atomization is directly related to the change in clearcoat viscosity resulting from the change in fluid temperature.

In addition to variations in particle size, the change in viscosity will affect particle recombination and flow out on the surface of the part. This will have a direct impact on the quality of the finish with regard to film build, gloss, orange peel, etc.

Bell testing

Next, the gun was replaced with a bell. The cup speed was set at 32,000 RPM and, as with the gun, all other parameters were held constant by the RCS system. Temperature was again incremented from 65°F to 115°F (18°C to 46°C) to vary clearcoat viscosity and, at each step, the resulting Dv(50) average particle size in the atomized cloud was measured.

The results are shown in Figure 5. With all other variables held constant, the average particle size for the bell applicator held steady at ~27µ independent of the changes in temperature.

It is reasonable to conclude that bell atomization is not affected by the change in clearcoat viscosity resulting from the change in temperature. This was confirmed by increasing the cup speed from 32,000 RPM to 60,000 RPM at the median temperature of 85°F. This shifted the average particle size from ~27µ to ~16µ.

Though there is no change in particle size as a function of temperature with the bell applicator, the change in viscosity still will affect particle recombination and flow out on the surface of the part – just as with the gun applicator – and still will have a direct impact on the quality of the finish with regard to film build, gloss, orange peel, etc.

page 42 ▶

◀ page 41

Viscosity vs. temperature

Figure 6 shows the viscosity-temperature curve for a common solventborne paint.

The manufacturer states that the optimum coating viscosity for this material is 26 ±2 seconds, which is plotted on the graph to show its relationship to temperature. The entire acceptable viscosity range relates to a 3°C window from 26.5°C to 29.5°C (80°F to 85°F). If the paint temperature is outside of this narrow window, it will be outside of its optimal viscosity range, and either the viscosity must be corrected, or other process parameters must be adjusted to compensate. But, if we can control coating temperature, we can use it as a tool to set and maintain viscosity – thus making viscosity a controlled parameter in our process.

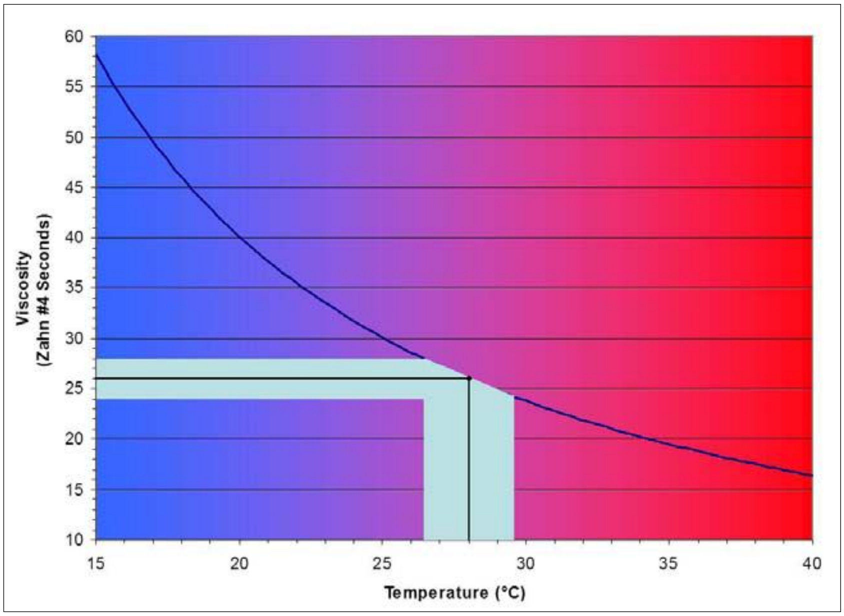

FIGURE 6. *Paint viscosity vs. temperature*[3]

The unique case of UV cure coatings

UV cure coatings have been hailed as a means to reduce solvent use and to allow coating of substrates, such as wood and plastic, that are not conducive to oven curing. The unique case of UV cure coatings comes from the differences in their rheology, yet they exhibit many similarities to their solventborne counterparts. They are composed of an oligomer resin that is quite viscous. To bring that viscosity down to a useable range, a monomer reducer is added. But, as with solventborne materials, this reducer affects the application and curing processes, as well as the performance of the coating on the end product. Therefore, as with solvents, it is desirable to minimize monomers in applied formulations.

Figure 7 shows the curves for a typical UV cure coating in its pure state, as well as when blended with monomer reducer at 70/30 and 50/50 ratios.

This shows the high viscosity of the resin and the dramatic effect of temperature on that viscosity. Looking only at the normal ambient range of 20°C to 40°C (68°F to 104°F), the UV resin displays a 10:1 change in viscosity.

As with its solventborne counterpart the viscosity of the monomer reducer is orders of magnitude lower than the resin and has a significant impact on the viscosity of the blend. Though the reduced curves in Figure 7 appear quite flat, this is an optical illusion caused by the large vertical scale required to display the entire 100% oligomer curve. All are exponential curves, which are easier to compare on a logarithmic vertical scale, as shown in Figure 8.

To demonstrate the similarity between traditional and 100% solids coatings, let's make the assumption that we are substituting this 100% solids coating for the solventborne coating above in the same application process, and therefore desire to have the same 26s viscosity. A common viscosity conversion chart[4] reveals that 26s in a Zahn #4 cup is equivalent to about 325cP.

If we place a line at 325cP on this graph, some interesting coincidences appear. First, the 50/50 blend is at 325cP at 20°C (68°F), suggesting that we could hold the 50/50 blend at 20°C and make a direct substitution into our process. But remember, the goal is to minimize reducer to control costs and improve performance. Following to the right, at 40°C (104°F), the 70/30 blend also is at 325cP and could be substituted directly. At the extreme, the 100% resin is 325cP at 70°C (158°F) and could be used without monomer, but this is too hot for the equipment, the parts and the operators.

Again, this shows that temperature control can be used as a tool, enabling us to vary our formulation to optimize performance. To demonstrate how this affects our choice of atomizer, we also must look at the temperature of the particles when they reach the surface of our part.

Impact of ambient on particle temperature

It is widely believed that it is important to carefully control booth temperature because it directly affects the temperature of the coating as it is being applied. This seems a logical assumption since the atomized droplets are extremely small, which presents a large surface area to the ambient air.

The reality, however, is much different.

While it is virtually impossible to measure the temperature of individual droplets in the cloud, it is fairly straightforward to calculate the change in temperature. Tools have been developed to

page 44 ▶

◀ page 42

perform these calculations quickly and easily to assist coaters in evaluating their process control strategies. An example calculation is shown in Figure 9.

We noted that guns move particles toward their target at much higher speeds than do bells. According to Carlisle Fluid Technologies, bells create particles with speeds ranging from 150 to 300 mm/s, whereas guns create particles with speeds ranging from 300 to 600 mm/s – double that of the bell.[5] Thus, the average time that the particles are in the air ranges from 0.42s to 1.69s. Despite the large surface area presented to the ambient air, this is not a long time to effect a change of temperature.

In this example, the booth temperature is controlled at 25°C (77°F) and the 50/50 blend UV cure coating temperature is held at 40°C (104°F) to stabilize its viscosity. With the high particle velocities created by the gun, the coating only loses between 0.27°C and 0.88°C — always reaching the part above 39°C. Even with the relatively longer air time caused by the lower velocities of the bell, the coating only changes by 1.2°C to 2.7°C — still reaching the part above 37°C. If you are assuming that your coating is being applied at 25°C and it is actually above 37°C, you may find it difficult to make the right decisions to maintain finish quality specifications.

This is why modern, progressive coaters consider coating temperature at the point of application to be more important to finish quality than booth temperature.

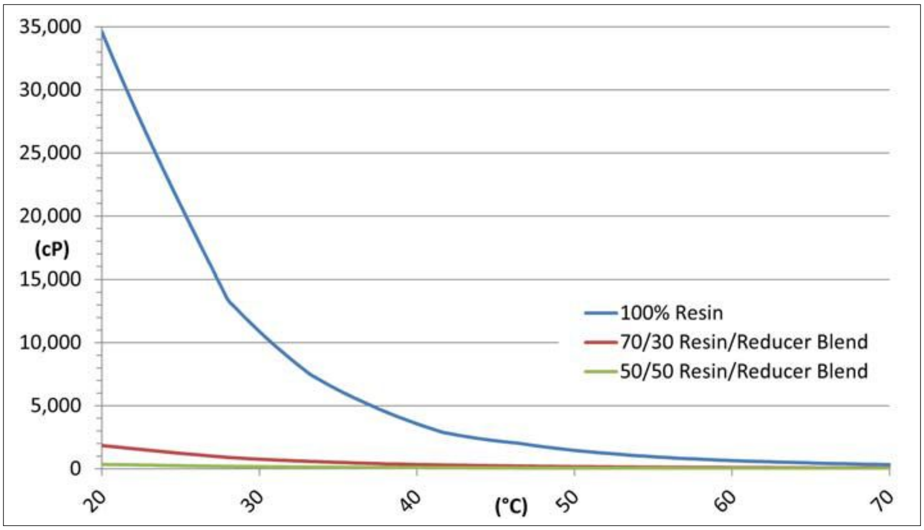

FIGURE 7. *Viscosity of various concentrations of UV cure resin and reducer vs. temperature*

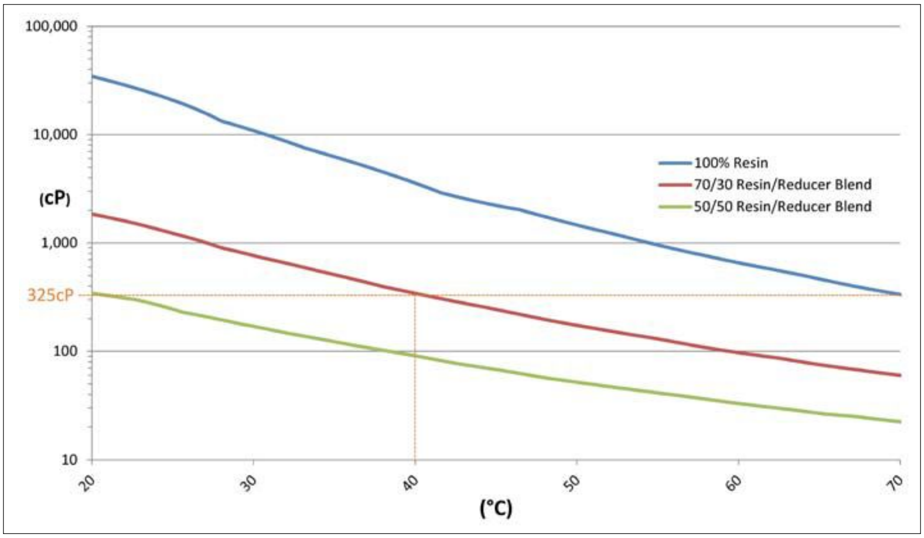

FIGURE 8. *Viscosity of various concentrations of UV cure resin and reducer vs. temperature on a logarithmic scale*

Choosing an applicator

What you are coating – and how you are coating it – are prime considerations in choosing an applicator. While guns are better suited to manual applications than are bells, in robotic applications, each has its purpose. We'll use the automobile as an example.

Why? Because it is considered the "holy grail" of quality in 100% solids/UV cure coatings. The very geometry of the automobile, with deep recesses and gentle, sloping surfaces composed of a wide variety of substrates – with the need for extremely high-quality finishes on both horizontal and vertical surfaces – makes it a combination of all the greatest challenges to a finishing operation.

When choosing an atomizer, the higher velocities and more directional fan pattern of a gun is considered better for "cut-in" – coating areas with deep curves, such as the areas around the doors, trunk, engine compartment, etc. The consistent atomization of bells makes them better suited for large areas with gentle shapes, where surface finish is extremely critical – such as the hood, roof, trunk lid, doors and quarter panels.

Tier I suppliers use guns for deep-form parts (mirror housings and grills), where they need to drive the coating into areas in which a lower velocity would be insufficient — but then use bells for more gentle application to aesthetically important parts, such as bezels, bumpers and facias.

In short, both applicator styles have their place, and it is not uncommon to use them in combination, taking advantage of the

page 46 ▶

◀ page 44

strength of each. But, it's important to understand that neither can overcome the problems created when the coating being delivered to them is out of control. This is especially true with UV-cure materials.

Temperature as a tool

Using temperature as a tool to manage the viscosity fed to your atomizer of choice is especially important in UV-cure coatings for several reasons. First, many UV-cure coatings are 100% solids, so there are no "solvents" to flash off to start the curing process and slow flow-out to hold the coating in place. These coatings will continue to flow at the same rate until exposed to the UV source, at which point the cure is virtually instantaneous. But, this can work to our advantage, as 100% solids coatings will not "shrink" in the cure process: The wet film is applied at the same thickness as the desired dry film. Thus, there is less wet coating available to flow out into a smooth, contiguous coating. Coating viscosity and droplet size (atomization) must be carefully balanced and controlled, especially where Class A finishes are required, to get the proper flow-out at this lower applied volume.

Knowing that temperature remains fairly constant between the atomizer and the part changes our perspective on control at the point of application. This is especially true when we use elevated temperature to reduce the amount of monomer in our blend. Using the example above, when applying the 50/50 blend at 40°C (104°F) to maintain a low application viscosity (to allow use with a bell, for instance), a fairly small reduction in temperature will cause a significant increase in viscosity, due to the steep viscosity vs. temperature curve. If we maintain the booth air and part at 25°C (77°F), we can select the atomizer to allow a smooth, even coating and then depend on the cooling imparted by the substrate to increase the coating viscosity to hold it in place until it is cured. In short, temperature can be used in place of evaporation (flash-off) – which is especially good for vertical surfaces.

Coating Parameters				
Distance to Part:	10	in	254	mm
Thermal Conductivity (*k*):	2.595	BTU in/ft² hr °F	0.374	W/mK
Specific Gravity:	1.200		1.200	g/cc
Specific Heat (*Cp*):	0.500	BTU/lb °F	2.093	J/g °C
U-Value of Air:	0.2	BTU/ft² hr °F	1.136	W/m² °C
Air Temperature:	77.0	°F	25.0	°C
Inlet Paint Temp:	104.0	°F	40.0	°C

	Bell		Gun		
	min	max	min	max	
Particle Speed:	150	300	300	600	mm/s
Particle Speed:	5.91	11.81	11.81	23.62	in/s
Time to Part:	1.69	0.85	0.85	0.42	s
Particle Size (Diameter):	26	28	39	65	µm
Particle Surface Area:	2.1237E-09	2.4630E-09	4.7784E-09	1.3273E-08	m²
Particle Size (Diameter):	1.0236E-03	1.1024E-03	1.5354E-03	2.5591E-03	in
Particle Surface Area:	3.2918E-06	3.8177E-06	7.4065E-06	2.0574E-05	in²
Particle Volume:	5.6159E-10	7.0141E-10	1.8954E-09	8.7748E-09	in³
U-Value of Paint:	5069.95	4707.81	3379.96	2027.98	BTU/ft² hr °F
System U-Value:	0.20	0.20	0.20	0.20	BTU/ft² hr °F
Thermal Gain/(Loss):	-5.8061E-11	-3.3668E-11	-6.5317E-11	-9.0715E-11	BTU
Particle ΔT:	-2.6546602	-1.2325171	-0.8848693	-0.2654503	°C
Particle Temp at Part:	37.35	38.77	39.12	39.73	°C

FIGURE 9. *Particle temperature change calculations*

Conclusion

Each applicator style has its place, and it is not uncommon to use them in combination, taking advantage of the strength of each. The specific methods of atomization and delivery must be matched closely with the coating formulation, and that coating must be carefully controlled when delivered to assure that the atomizer/coating system functions properly. This is especially critical with UV-cure materials. ◆

Acknowledgements

1. Gun photograph provided courtesy of FreeImages.com.
2. Bell atomizer photograph provided courtesy of Carlisle Fluid Technologies.
3. Paint temperature vs. viscosity data provided courtesy of Alsco Metals Corporation – Roxboro, NC.
4. Viscosity conversion data provided courtesy of Norcross Viscosity Controls. http://web.viscosity.com/download-viscosity-conversion-tables
5. Bell and gun particle velocity data provided courtesy of Carlisle Fluid Technologies.

Michael R. Bonner is the vice president of engineering & technology for Saint Clair Systems, Inc., a leading supplier of process temperature and viscosity control equipment for industrial fluid processing systems. For more information, call 586.336.0700 or visit www.stclairsystems.com.

Coating viscosity and droplet size (atomization) must be carefully balanced and controlled...