ELSEVIER

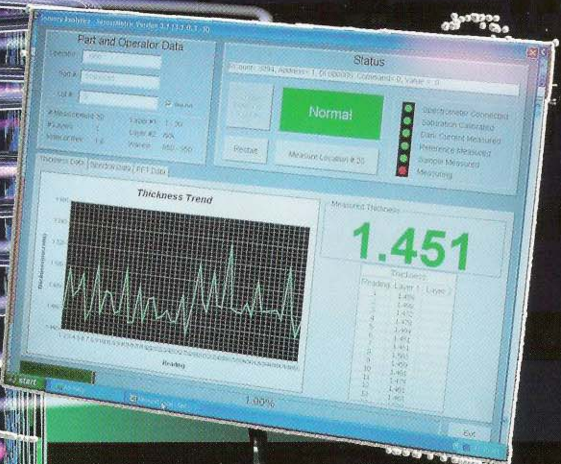
metal finishing

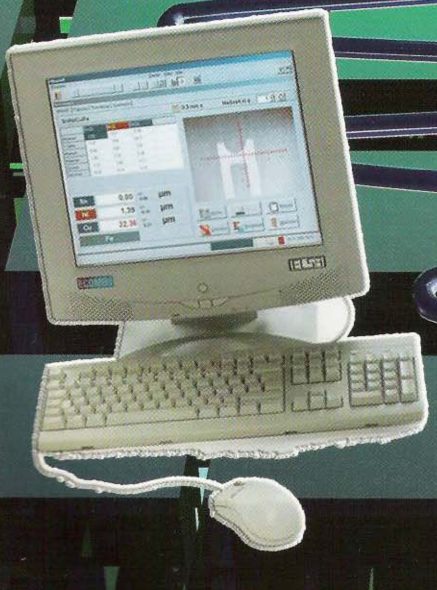
October 2007
Vol. 105
No. 10

The Plating and Coating Industries' Technology Magazine
www.metalfinishing.com

Testing & Control

Advances in thickness measurement offer speed, precision, accuracy.





Measurement Challenges Using XRF Technology

Microhardness Impressions for Characterizing Electrodeposited Nickel

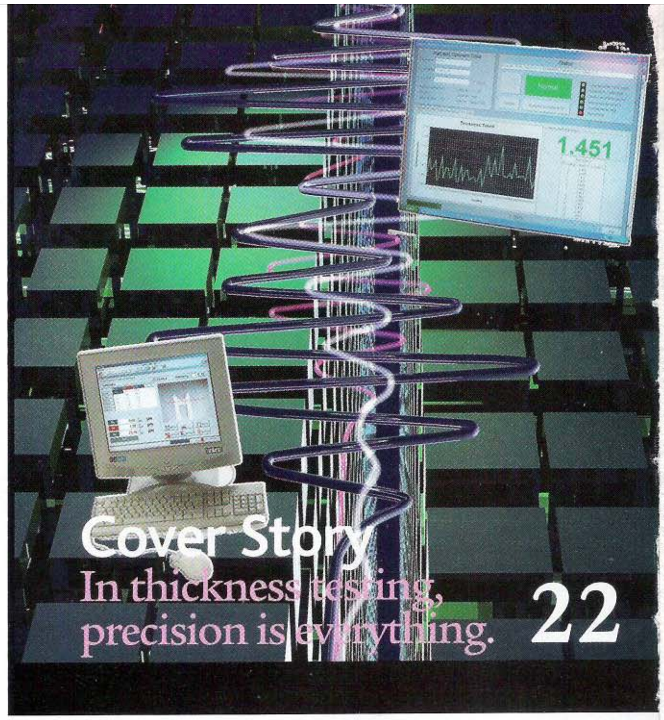
Organic Finishing

Robotics' role in controlling temperature, finish variations

PLATERS/PAINTERS

Profile: Professional Plating

WHAT'S inside



BY MICHAEL R. BONNER, V.P. OF ENGINEERING & TECHNOLOGY, ST. CLAIR SYSTEMS, INC., ROMEO, MICH.

Controlling the Temperature Variable in Spray Painting Processes

A carefully designed temperature control system can improve quality, reduce operating costs.

Many variables are carefully controlled in modern paint dispensing systems. Pressure and flow are automatically regulated, and orifice size is fixed. Where robotics are employed for application, the gun path—including angle to and distance from the surface being painted, as well as speed—can be added to that list. In spite of all this technology dedicated to maintaining consistent performance, temperature-based viscosity variations can upset the careful balance these systems are designed to establish.

Virtually all painters understand the problems that temperature variations cause in the painting process. In the case of spray painting operations, temperature-related viscosity variations can result in significant issues with delivery system performance, resulting in quality problems with film build, color match, surface finish, adhesion, etc. The magnitude of these issues drives most painting operations to institute measures to adjust paint viscosity in an attempt to gain control of their process. This article examines the relationship between temperature, viscosity, delivery system performance, and finish variations, and addresses many of the associated issues with the goal of establishing how the implementation of a carefully designed temperature control system can significantly improve quality while reducing operating costs.

THE ISSUE OF VISCOSITY

It's been long understood that virtually all liquids show some change in viscosity as a function of temperature. Figure 1, taken from an old viscometer data sheet[1], shows that even water—which goes from a solid to a liquid to a gas with very sharp transitions—goes through a viscosity change of nearly 2:1 between 50°F and 100°F.

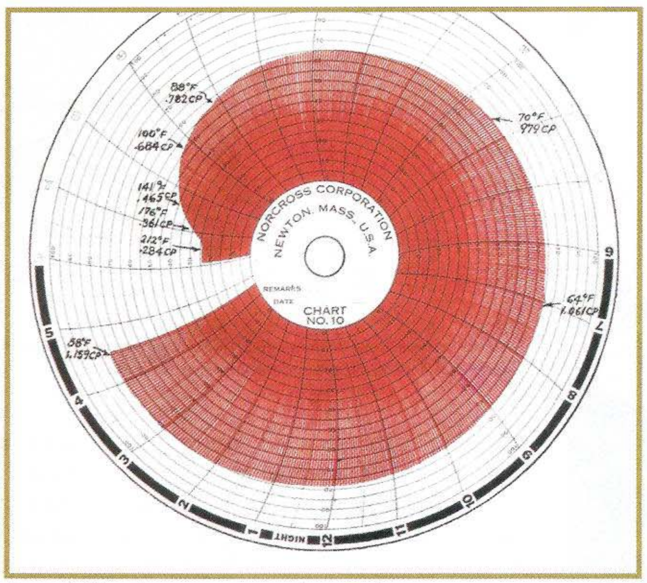


Figure 1: Viscosity vs. temperature for water[1].

Modern paints are no different. Figure 2 shows the viscosity-temperature curve for a selection of common, related paints used in a spray painting operation. This shows the typical non-linear relationship associated with these materials over the normal ambient temperature range. It is worthwhile to note that this characteristic is shared with virtually all viscous liquids and is a physical property, not a defect. As we will see, this is a parameter that can be exploited to improve the performance of the painting process.

In a spray delivery system, paint viscosity will have a significant impact on many system variables, including flow, pressure drop, and atomization characteristics, just to name a few. Each of these can have an impact on the quality of the finish.

In the paint data sheets supplied for a given formulation, the manufacturer will usually provide a reference viscosity, often specified at 77°F (25°C). The supplier will also often recommend the viscosity at which to apply the paint to achieve the desired result. In Figure 2 we see that these colors, all of the same type and formulated for the same operation, display a range of viscosities from 21 to 31 seconds at 77°F. Obviously, these viscosities change significantly with temperature, but there remains a significant difference between colors. If the optimal application viscosity is 20 ±2 seconds, virtually all of these formulations will require some form of viscosity reduction when the paint temperature is at or below 80°F. This is often accomplished through the addition of solvent.

The trend shown in Figure 2 that has caught the eye of most painters is the viscosity appears to stabilize as the temperature increases above 90°F. Figure 3 shows the relationship of the Putty and Warm Beige colors as the temperature is extended above 100°F. Indeed, this shows a significant flattening of the curve with little variation in viscosity above 105°F. This has led some painters to heat their paint in an effort to reach this seemingly stable plateau. There are a number of reasons that this may not be the best course of action.

THE IMPACT OF VISCOSITY ON ATOMIZATION

The most obvious reason for not selecting a paint temperature in excess of 100°F is this elevated temperature may not be the optimal temperature at which to apply the specific formulation. One must always keep in mind that the goal is to create a delivery system that produces the desired finish with regard to film build, color match, gloss, adhesion, etc., from the first piece to the last piece, every time each color is painted.

One of the most significant factors in spray application is consistency of atomization. The orifice size and shape is fixed in any given gun. The atomization produced by this orifice is a function of the flow, pressure, and viscosity of the paint presented to it. For the purposes of this discussion (and in most practical applications) we will assume that the pressure is being held constant by a regulator. Therefore, the only variable to be considered is viscosity.

During atomization, the higher the viscosity, the larger and heavier the droplets become. This generally results in a heavier film build, which is the primary factor in color match. This will also impact flow out and, therefore, surface finish qualities such as gloss. Adequate film build is essential to good finish quality, but excessive film build can have a negative impact on the result. Too much paint on the surface increases paint usage rates and also can result in

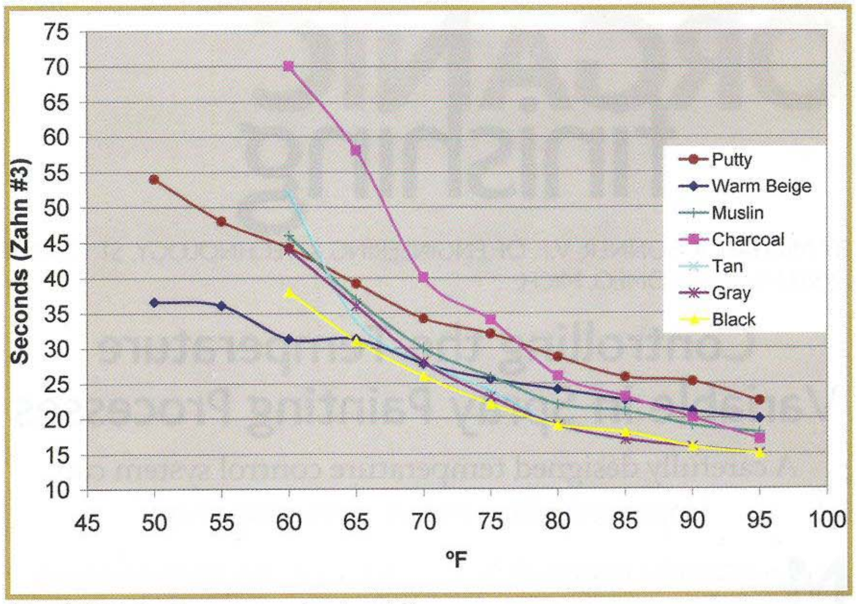


Figure 2: Paint viscosity vs. temperature by color[2].

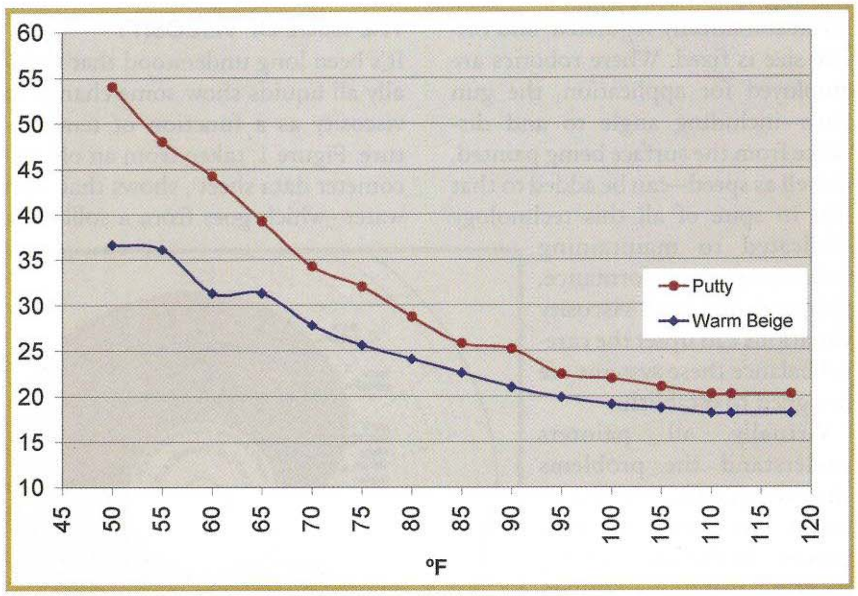


Figure 3: Viscosity vs. extended temperature by color[2].

runs and sags that require rework, both of which add to the cost of the end product. Also often overlooked is the fact that this heavier film build can result in orange peel and solvent pop as the solvent trapped in the film migrates to the surface and escapes during the curing process.

Conversely, the lower the viscosity, the smaller and lighter the droplets become. These lighter droplets are more susceptible to being caught in the booth draft and directed away from their designated target. Even in electrostatic systems this can result in greater overspray and lower transfer efficiencies. This generally results in a lighter film build, which again can have a significant impact on color match. A more subtle effect is the fact that these smaller droplets present more surface area for contact with the air. In the same action that resulted in orange peel and pop in the heavier film builds discussed above, solvent evaporation occurs through the droplet's surface. The rate of evaporation (which increases with temperature) can result in dry spray, with a significant portion of the solvent lost before the droplets even reach the target surface. With insufficient solvent in the paint to facilitate flow-out, gloss suffers. This can also have a negative impact on adhesion. Equally important is that this results in an increase in fugitive emissions and the associated impact on operator safety and environmental concerns.

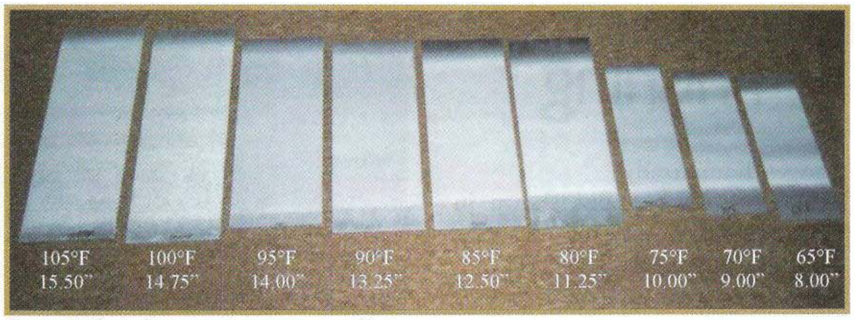


Figure 4: Effect of temperature on spray pattern.

These factors are independent of spraying method with both spray guns and bells producing similar results. In short, consistent atomization is essential to consistency of deposition rate, which is the key to transfer efficiency, color match, surface finish, and adhesion. Atomization is directly affected by viscosity, which is directly related to temperature. Therefore, consistent atomization requires consistent temperature control.

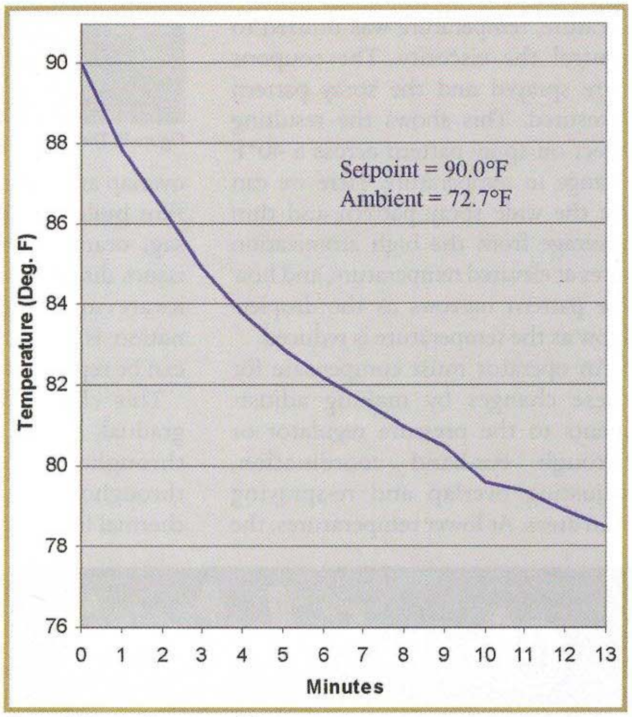


Figure 5: Thermal loss to ambient.

THE IMPACT OF VISCOSITY ON SPRAY PATTERN

Atomization is not the only delivery factor affected by changes in viscosity. Spray pattern is also affected. When all other factors (orifice size, pressure, path, speed, distance, angle, etc.) are held constant and temperature is varied, the pattern dispensed changes dramatically.

To create the coupons shown in Figure 4, orifice, pressure, distance, and angle to the surface were held constant while material was sprayed. Due to the direct relationship already established between viscosity and temperature, temperature was utilized to control the viscosity. The coupons were sprayed and the spray pattern measured. This shows the resulting effect on spray pattern across a 40°F change in temperature. Here we can see the wide spray pattern and thin coverage from the high atomization rates at elevated temperature, and how the pattern narrows as the droplets grow as the temperature is reduced.

An operator must compensate for these changes by making adjustments to the pressure regulator or through eye-hand coordination, adjusting overlap and re-spraying thin areas. At lower temperatures, the overlap area can produce too heavy a film build, resulting in the run and sag, orange peel, and solvent pop issues discussed above. Where robotics are employed, no eye-hand coordination is involved and the problem can be repeated over and over again.

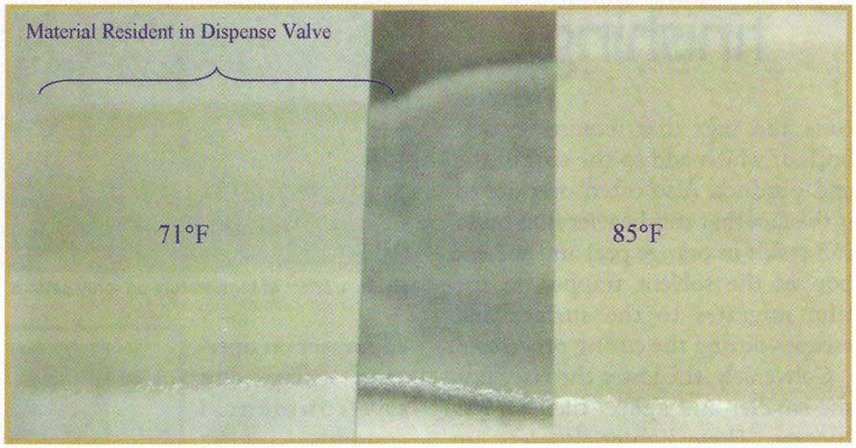


Figure 6: The effect of thermal loss on spray pattern.

This change of viscosity can be gradual, as the temperature climbs throughout the day (or falls throughout the night), or rapid, as thermal losses create uneven temperatures throughout the dispensing system. This is especially true where elevated temperatures are employed.

Figure 5 shows the thermal loss from a dispense valve on a robotic spray system to ambient over time. When the system is allowed to sit idle for more than few minutes (breaks, shift changes, part changes, downtime, etc.), the loss is significant.

Figure 6 shows the effect on the spray pattern when this gun is allowed to reach a 71°F ambient in a system set to run at 85°F. While the lower-temperature material in the valve is being sprayed, the pattern is narrower and the deposition is thicker. As the conditioned material reaches the valve, the fan pattern widens and the film build drops proportionately. The rate of thermal loss increases directly with the ΔT between the surface and ambient, making this situation even more difficult at elevated paint temperatures. This same scenario applies to the supply hose and spray gun in most manual operations and is a short-term, unpredictable situation that is difficult to compensate for, even by an experienced operator. For this reason, many operators will spray the contents of their supply hose to waste after a period of not painting so that this situation will not create a defect. While effective, this quality consideration comes at the cost of increased paint usage and waste disposal.

TO HEAT OR NOT TO HEAT?

There really is no question. Heating is an essential component of any temperature control system. This is most obvious for northern climates where winter temperatures can dip below freezing. Though you may have a warehouse full of paint at room temperature, inevitably the one you need to spray is being unloaded at the dock at a drum temperature of 40°F. Without heating, a lot of solvent will have to be added to get it to a sprayable viscosity.

Though often overlooked, cooling can be just as important. If the drum comes in out of the sun at 100°F and the optimal application temperature is 80°F, no amount of solvent is going to rectify the lower viscosity that will be presented to the painter. The key is to get to the best temperature and stay there.

Most paints are formulated to provide optimal performance at temperatures somewhere between 70°F and 95°F. This is where atomization, flow-out, and solvent evaporation rates are balanced to provide consistent cure, color, finish, gloss, and adhesion properties. Adding solvent can actually interfere with this performance. Herald Cales of Akzo Nobel states, "Reducing the amount of solvent added [provides] additional benefit to the performance of the paint being used. The two major benefits are:

- **Less possibility of having solvent popping or blistering problems.**
- **The addition of too much solvent to certain paints or certain colors of paint may cause color shifts or gloss change..."[3]**

We have already established that heating can be an effective substitute for solvent in reducing viscosity—and it's a lot less expensive. But we must remember that some solvent is necessary to make the paint perform as desired. Obviously, any solvent added to the paint comes out in the oven. In addition to Herald's points above, adding less solvent to the paint can reduce LELs, especially in the first zone. In operations where LELs are the limiting factor, throughput can be increased. Moreover, lower LELs reduce make-up air requirements and the associated heating costs. (But that is an extensive discussion and the subject for another article.)

Suffice it to say that lower cost and improved performance are strong points in favor of heating. Poorly implemented, however, this seemingly simple task can create more problems than it cures. We have already investigated what happens to a system at an elevated operating temperature with unconditioned sections losing temperature to ambient. And in our discussion of atomization we noted that heat causes solvents to evaporate more rapidly, which can lead to dry spray, poor flow-out, and adhesion problems. In recirculation systems, it can also drive the solvent out of the source drum, contributing to the issues many painters have with "partials" carrying problems over from one job to the next.

To reduce physical size and cost, many in-line heaters sacrifice thermal transfer area and, therefore, must use a large ΔT to heat the paint. In contrast, many paint formulations begin to degrade at temperatures above 100°F. Using a heating element well above 100°F to reach set points of 80°F+ will cause localized degradation of the paint where it meets the surface of the heater. This often causes "caking" in the heater itself, but long before that becomes apparent, particles of this degraded paint may appear as "dirt," when they break off the wall of the heater and pass to the spray nozzle and the part.

A well-designed and executed temperature control system will quickly take the paint to setpoint and hold it there. This will be independent of ambient and load changes, and without any possibility of damaging delicate formulations. The goal must be to make temperature a tool—like pressure or flow—just another system variable under our control.

USING TEMPERATURE AS A TOOL

"Being able to control the temperature within a narrow range as paint is being used can be very beneficial. The most obvious benefit is a reduced amount of solvent usage. This is not only more economical for the coater but also reduces the environmental impact and health risks to their employees." (Herald Cales, Akzo-Nobel[3])

Are you listening? This is your paint supplier talking! He's the guy you call when there are problems with your finish. Not that there can't be variation in the paints supplied due to manufacturing tolerances, age, etc. But most modern formulators employ advanced blending controls to assure consistency batch to batch—and do a pretty good job. Doesn't it seem counter-productive to take a paint on which you and your supplier have worked so hard to achieve the performance you need, then immediately change that formulation by adding solvent?

The fact is that the temperature vs. viscosity curve in Figure 2 also varies by color due to differing pigment types and loads. And so even within the same formulation family, different colors will perform differently with the same dispensing system with regard to temperature-based viscosity shifts. As we discussed above, the operator often compensates for these changes with pressure adjustments and eye-hand coordination, as these are the tools they have available to them.

Many so-called "variables" in the delivery system are actually fixed. The pump (usually positive displacement), the supply line and filtration components (and their associated shear and pressure drop characteristics), and the orifice are among these. While the performance of these components will be affected by variations in viscosity, there is nothing that you can do to change them from job to job. Pressure and path are about the only real variables that you have control over in the short term—and pressure is usually a manual adjustment. For most systems, however, temperature is truly variable and continuously changing.

Adding temperature control stabilizes viscosity. Properly implemented, it can also be the easiest to manipulate. It can be the "go-to" tool because it has the greatest impact on all of the other variables and can enable you to strike a balance between system parameters that allow stable, repeatable results.

A BALANCING ACT

As noted, paint viscosity has a significant impact on many spray delivery system variables, including flow, pressure drop, and atomization characteristics. When the viscosity of the paint changes, other parameters in the application process (i.e. pressure, speed, overlap, etc.) must be manipulated to accommodate this variation and produce the desired result. The addition of temperature control to stabilize viscosity places all of these "variables" under control and allows them to be optimized to create an application process that is stable and repeatable, and independent of daily and seasonal temperature swings.

In demanding finishing applications, this balance can be delicate. A Midwest manufacturer of high-end vehicle appearance and performance components found that a 3°F variation in paint temperature resulted in unacceptable orange peel in their Class A finishes. They are not alone: "As part of our ongoing continuous improvement plan at Roush, we decided to take a more aggressive approach to our temperature control in the paint shop. The resulting quality improvement was immediately noted and helped drive our FTC (First Time Capability) up and sustain it where we needed it to be." (Patrick Henterly, Roush Manufacturing[4])

It is clear from this evidence, that the impact temperature has on the quality of the performance of any dispensing system cannot be overstated. The options for process improvement are endless when all of the variables are under control. This is especially true in robotic applications, designed for the express purpose of creating a stable, repeatable process. However, advantages clearly exist for less-automated operations and those utilizing specialty and hard-to-handle formulations as well. In short, this one simple, often overlooked (or haphazardly addressed) parameter can actually be the key to the implementation of a successful, reliable, predictable finishing system.

REFERENCES

1. Water Temperature vs. Viscosity data provided courtesy of Norcross Corporation.
2. Paint Viscosity vs. Temperature data provided courtesy of Sherwin-Williams Corporation.
3. "Temperature Control of Coatings", May 7, 2007 memo, reprinted by permission, courtesy of Herald Cales, Akzo-Nobel Corporation.
4. Letter of recommendation to Chuck Hasse, St. Clair Systems, Inc., reprinted by permission, courtesy of Patrick Henterly, Roush Manufacturing.

BIO

Michael R. Bonner is the vice president of engineering & technology for St. Clair Systems, Inc., a leading supplier of process temperature control equipment for industrial processing systems. For more information, contact the author at MBonner@StClairSystems.com or visit www.stclairsystems.com.