DATE: January 30, 2013

ORIGINATOR: Michael R. Bonner

TITLE: Process Temperature Control in Modern Coating Dispensing Operations

In modern coating operations, temperature related variations can result in significant quality problems with film build, color match, surface finish, gloss, adhesion, etc.

THE FUNDAMENTALS OF TEMPERATURE AND VISCOSITY

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 goes through a viscosity change of 2:1 between 10°C and 40°C (50°F – 104°F).

Modern coatings are no different. Figure 2 shows the viscosity-temperature curve for a common solventborne paint. This shows the typical non-linear relationship associated with coatings over the normal ambient temperature range. It is worthwhile to note that this is shared with virtually all liquids and is a physical property not a defect. As such, this is a parameter that can be exploited to improve the performance of the coating process.

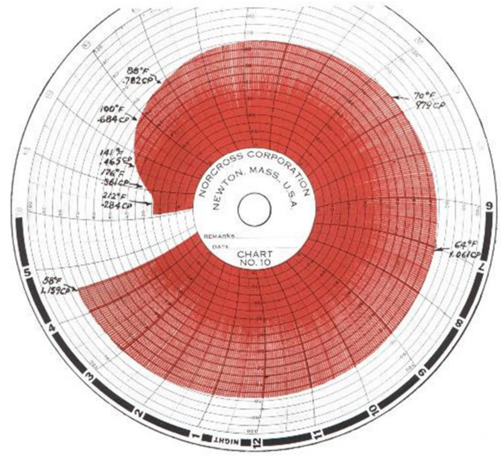

Figure 1: Viscosity vs. Temperature for Water[1]

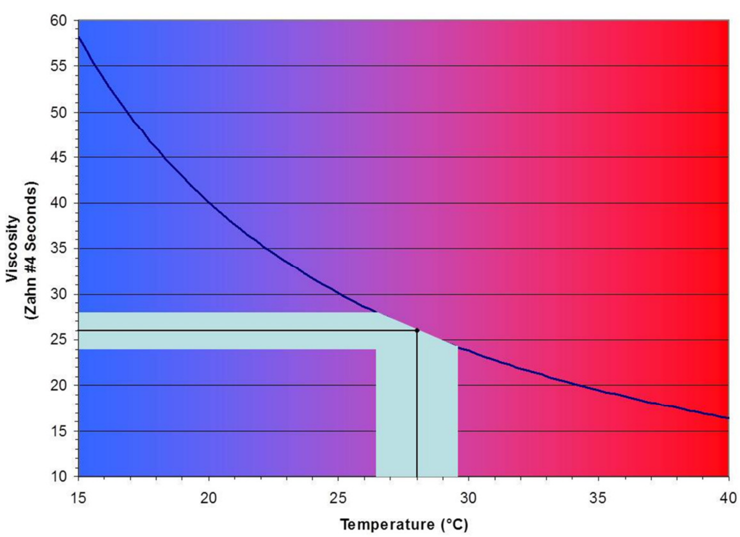

Figure 2: Paint Viscosity vs. Temperature[2]

The optimum coating viscosity for this material (26 ±2 seconds) 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 – 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.

In a system without temperature conditioning, little can be done when the paint is above the 29.5°C (85°F) upper limit and the resulting viscosity is below the 24s lower limit. Other parameters (pressures, speeds, etc.) must be adjusted to compensate. More often, however, the coating temperature is below the 26.5°C (80°F) lower limit and the resulting viscosity is therefore above the 28s upper limit. The most common practice in this instance is to add solvent to reduce its viscosity.

Figure 3 shows the relationship between solvent addition and change in viscosity. From the graph we can see that a reduction of 10s will require the addition of just over 3% of solvent by volume, whereas a reduction of 15s will require the addition of nearly 5%. This amounts to 1.5 gallons and 2.5 gallons per 50 gallon drum respectively. It is important to note that every ounce of this solvent will be driven off in the oven as the paint is cured and so represents excess cost in the process. In addition, too much solvent can cause issues such as blister and pop, orange peel, low gloss, and even off-color. Minimizing solvent addition is a worthwhile objective.

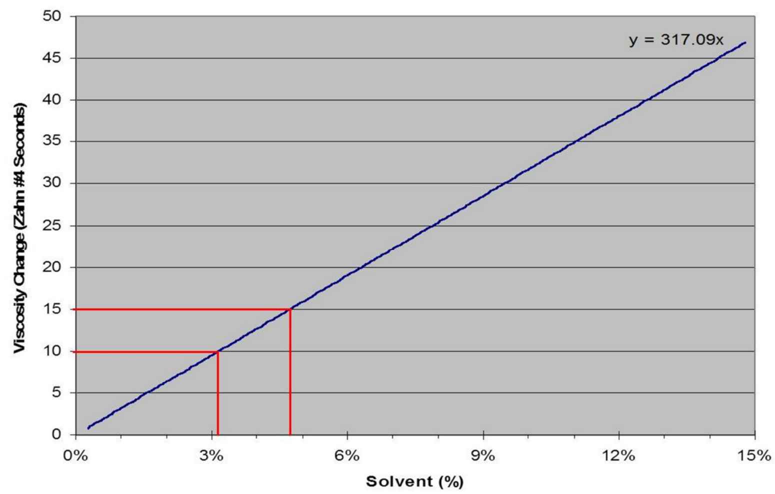

Figure 3: Viscosity vs. Solvent Addition[2]

To correlate temperature to solvent addition, we return to the temperature – viscosity graph appearing again as Figure 4. Here we can see that a 4°C increase in temperature from 16°C to 20°C (61°F – 68°F) produces a 15s reduction in viscosity. Likewise, the next 5°C from 20°C – 25°C (68°F – 77°F) produces an additional 10s reduction in viscosity. Therefore, this 9°C change in temperature (from 16°C to 25°C) has the same effect as adding 4 gallons of solvent to a 50 gallon drum (8%).

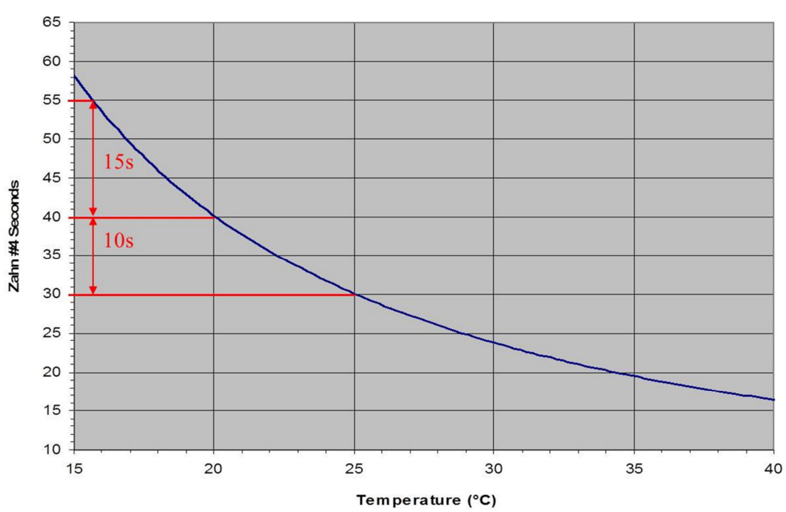

Figure 4: Viscosity vs. Temperature

An important, but often mis-understood fact regarding viscosity is that every paint formulation has its own temperature/viscosity relationship. This is why the paint data sheet for a given formulation provides a reference viscosity, often specified at 25°C (77°F). Figure 5 shows the plots for seven colors, all of the same resin base type, and formulated for the same application. Contrary to popular belief, these display a range of viscosities from 21 to 31 seconds at 25°C (77°F) and each varies quite differently over

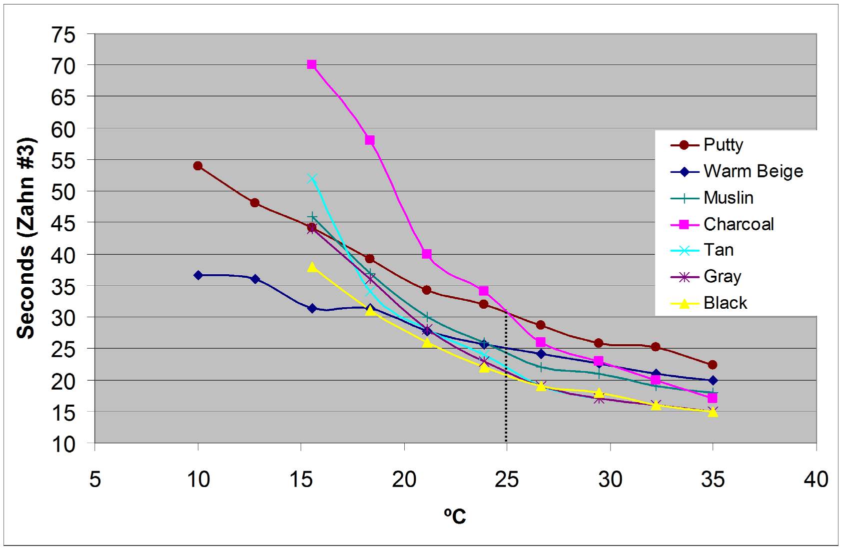

Figure 5: Paint Viscosity vs. Temperature by Color[4]

the same temperature range. To obtain acceptable performance from each color, there must be either changes in the setup parameters of the application system to compensate for these viscosity variations, or the paint must be consistently delivered to the point-of-application at its optimal temperature.

The recent introduction of 100% solids, UV cure coatings has been hailed as a means to reduce solvent use and to allow coating of substrates such as wood and plastic that cannot be oven cured. From a processing perspective, however, these are little different from their solventborne counterparts. These are comprised of an oligomer resin that is quite viscous. To bring that viscosity down to a useable range, a monomer reducer is added. Figure 6 shows the curves for a typical UV cure coating in its pure state, and when blended with reducer at 70/30 and 50/50 ratios.

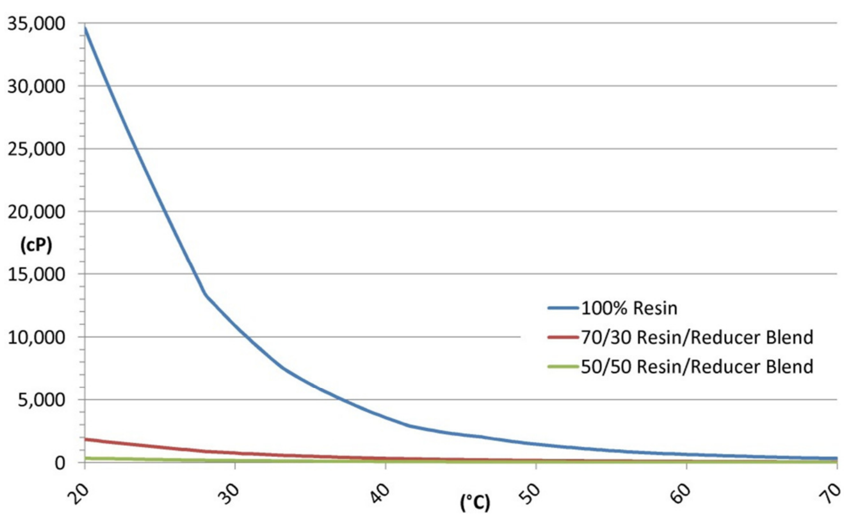

Figure 6: Viscosity of Various Concentrations of UV Cure Resin and Reducer vs. Temperature

Here we can see 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 – 40°C (68°F – 104°F), the solventborne paint in Figure 2 above displays a 2.5:1 change in viscosity, as compared to 10:1 for this UV resin.

As with it's solventborne counterpart the viscosity of the monomer reducer is orders of magnitude lower than the resin and so, has a significant impact on the viscosity of the blend. Though the reduced curves appear quite flat in Figure 6, this is an optical illusion caused by the large vertical scale required to display the entire 100% resin curve. On closer examination, these are all exponential curves and so are much easier to see and compare when we change to a logarithmic vertical scale as shown in Figure 7.

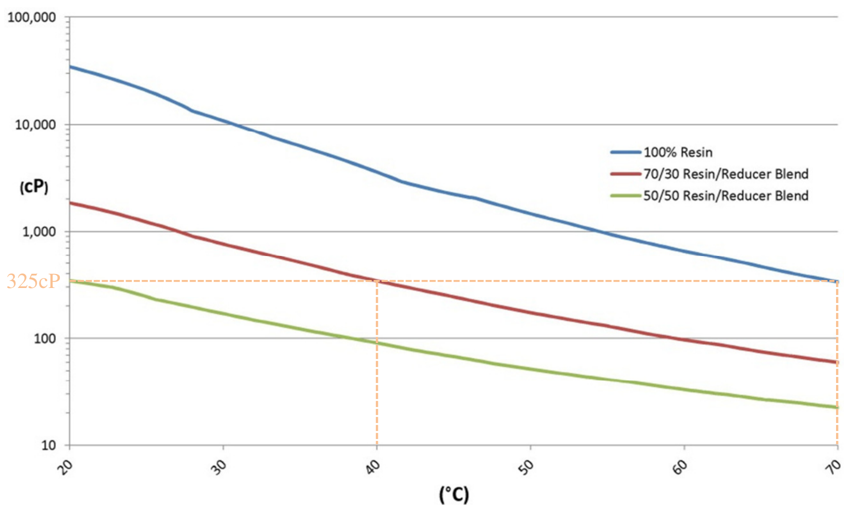

Figure 7: Viscosity of Various Concentrations of UV Cure Resin and Reducer vs. Temperature on a Logarithmic Scale

To demonstrate the similarity between the characteristics of the two coatings, we will make the assumption that we are substituting the 100% solids coating in place of the solventborne coating in the same application and therefore desire to have the same viscosity. A conversion chart reveals that 26s in a Zahn #4 cup is equivalent to 325 cP.

If we place a line at 325cP on this graph, some interesting coincidences appear. First is that the 50/50 blend is at 325cP at 20°C (68°F). Following our assumption, then, we can hold the 50/50 blend at 20°C and make a direct substitution into our process. But, as with solventborne coatings, the goal is to minimize reducer to control costs and improve performance. Following to the right we find that at 40°C (104°F), the 70/30 blend is also at 325cP viscosity. At the extreme, the 100% resin is at 325cP at 70°C (158°F) and could be used without reducer at that temperature, but this is too hot and requires special system design considerations to protect the operators.

With a full understanding of the intractable interdependency between viscosity and temperature in modern coating materials, and the wide variations they create, it is essential to look at their implications in the two most common application processes – spraying and rolling.

SPRAY PROCESSES

With just a sampling shown in Figure 8, there are as many different spray processes as there are engineers to design them. But no matter the details, they all boil down the basic design shown in Figure 9.

Figure 8: Various Spray Processes

In addition to the basic system layout, this shows calculated temperatures at various points throughout the system. Though the temperature may be important at various points throughout the fluid delivery path to maintain a consistent viscosity and to control pressure drop, there is only one temperature that determines the quality of the finish – the temperature of the paint leaving the nozzle. This is the point-of-dispense.

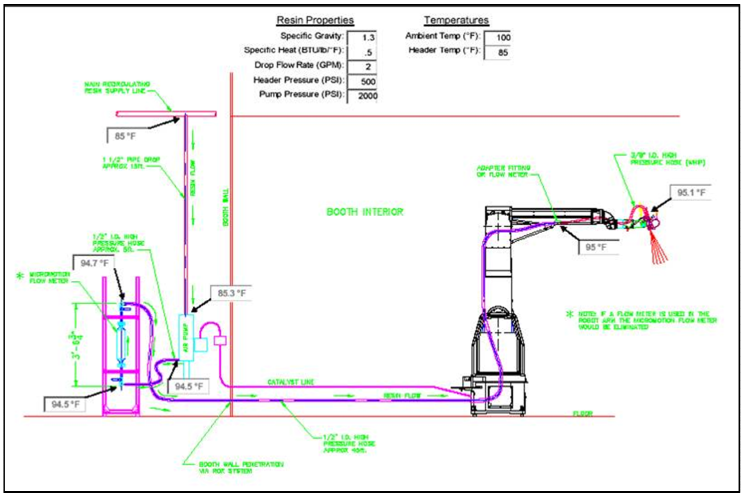

Figure 9: Basic Spray System Design and Thermal Model

Viscosity Impact on Atomization

One of the most significant factors in spray application is consistency of atomization. The orifice size and shape is fixed in any given applicator. 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 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 lower layers of 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 that these smaller droplets present more surface area in 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.

These factors are independent of spraying method with both 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.

Viscosity Impact 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.

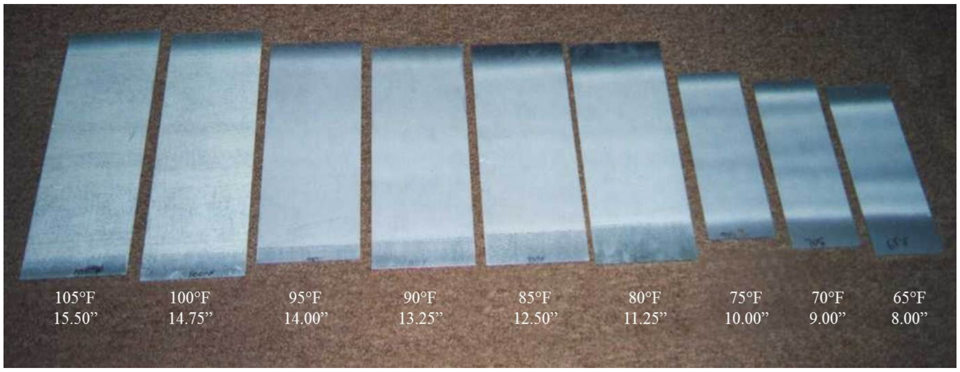

Figure 10: Effect of Temperature on Spray Pattern

To create the coupons shown in Figure 10, orifice, pressure, distance, and angle to the surface were held constant while the coating was sprayed. Due to their relationship, temperature was utilized to vary 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.

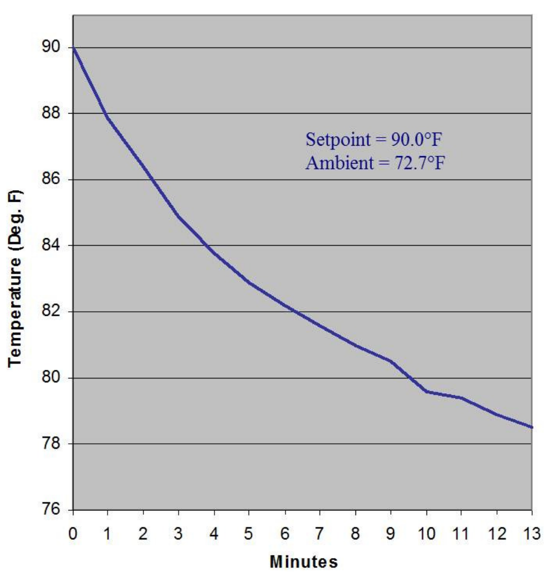

Figure 11: Thermal Loss to Ambient

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

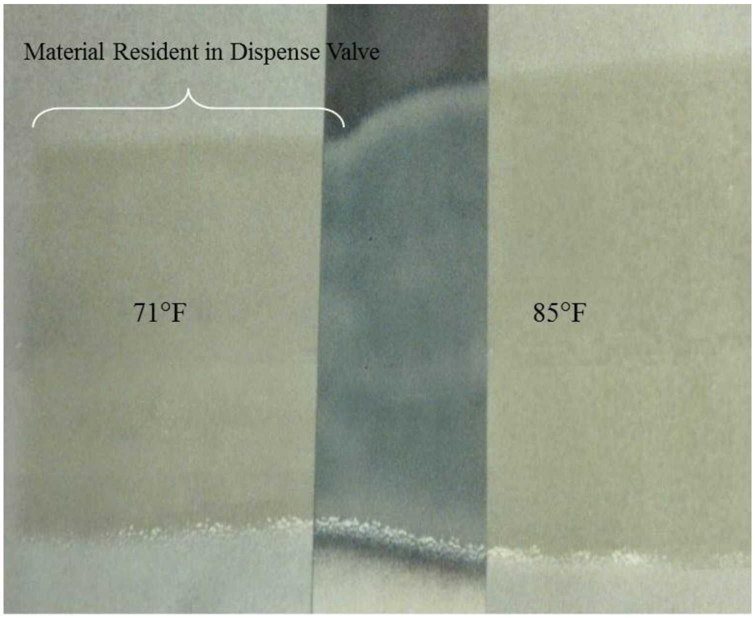

Figure 12: The Effect of Thermal Loss on Spray Pattern

Figure 12 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 heavier. As the temperature 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 is just another of the reasons that heat-only systems often do not produce the expected control. This same scenario applies to the supply hose and spray gun in 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. A robot can be programmed to do the same. While effective, this quality consideration comes at the cost of increased coating usage and waste disposal – both of which increase process cost.

ROLL COATING PROCESSES

As shown in Figure 13, Roll Coating processes also come in all different shapes and sizes. One of the fundamental differences between spray application processes and roll coating processes is that, instead of being sprayed from a single point orifice, the coating is applied all along the width of the face of the applicator roll. Any variation of viscosity (read: temperature) along this path will result in a variation in coating film build. In addition, friction between the rolls generates heat. Therefore, the mechanics of the coating system will endeavor to increase coating material temperature (and thereby reduce its viscosity) throughout the coating cycle. Analysis of such a system requires a different approach to measurement as shown in Figure 14.

Figure 13: Various Roll Coating Processes

Figure 14: Measuring Temperatures in a Roll Coating System

Here we can see that probes are placed in the coating at the nip to sense the temperature variations across the width of the applicator roll. This is the last opportunity to measure the coating prior to application and therefore the best place to take such measurements. We refer to this as the "Thermal Profile" of the nip.

The heating phenomenon is clearly demonstrated in Figure 15, which shows the temperature profile of a roll coating system without temperature control over an hour's time. Plotted here are ambient temperature, drum temperature, and the temperature at eight points across the width of the roll. This graph reveals many interesting details about the roll coating process. The first point of note is that the process temperature rises 10°F while ambient rises just 5°F over the course of this hour. This shows that, because of friction generated heat, controlling the ambient temperature in the booth cannot accurately control the temperature of the coating.

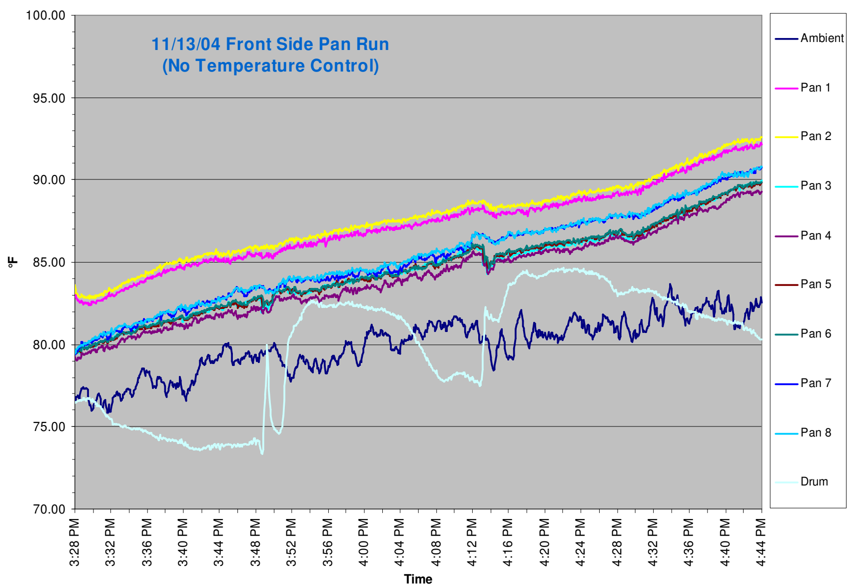

Figure 15: The Effect of Process Friction on Temperature[5]

Above, we showed the impact that temperature has on coating viscosity. Furthermore, remember from our discussion that the total 4s processing range (26s ±2s) translates to a 5°F window from 80°F to 85°F. Even though the coating was at the 80°F lower limit when the process started, the friction in the system moved the temperature twice the allowable temperature tolerance in just one hour, this will require making other adjustments to compensate for the change in viscosity.

An interesting note from Figure 15 is that the eight points across the face of the pickup roller show a significant variation in temperature. This is depicted more clearly in the "Thermal Profile" display in Figure 16. What we cannot see from this graph is that this uncorrected profile displays continuous variation. What we can see from this graph is that this variation exceeds 7°F at times. This means that the total allowable

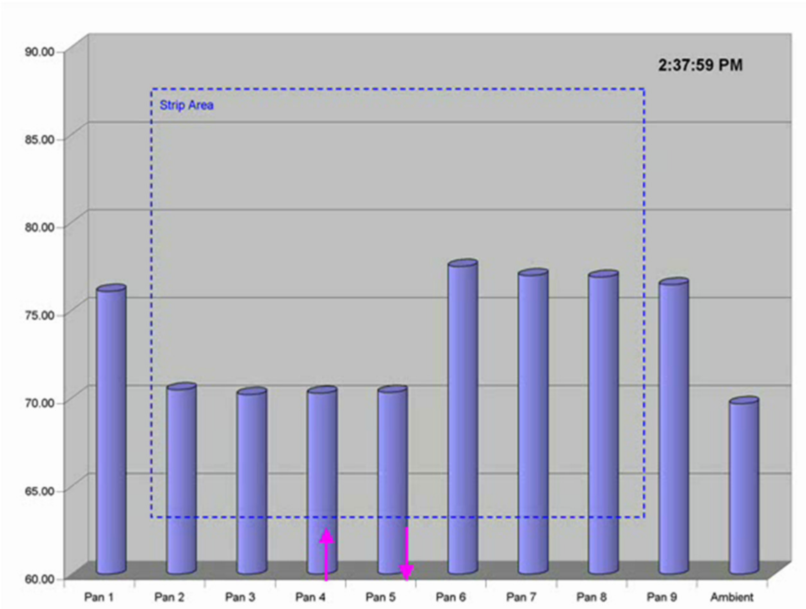

Figure 16: Thermal Profile Variation[6]

temperature tolerance is exceeded by variations across the width of the strip. The result is that portions of the coating across the width will always be outside of the viscosity specification. As shown, this can be a sharp change that cannot be compensated for by simply varying the nip pressure from side to side. To assure adequate film build at all points across the width of the strip under these conditions, it is often necessary to increase the total film build, laying down more material than is actually required in some areas to insure the minimum in others.

This effect on film build is demonstrated in Figure 17. Here we can see that the areas of higher temperature result in lower viscosity which produces a thinner film build, whereas the cooler areas result in higher viscosity and produce a heavier film.

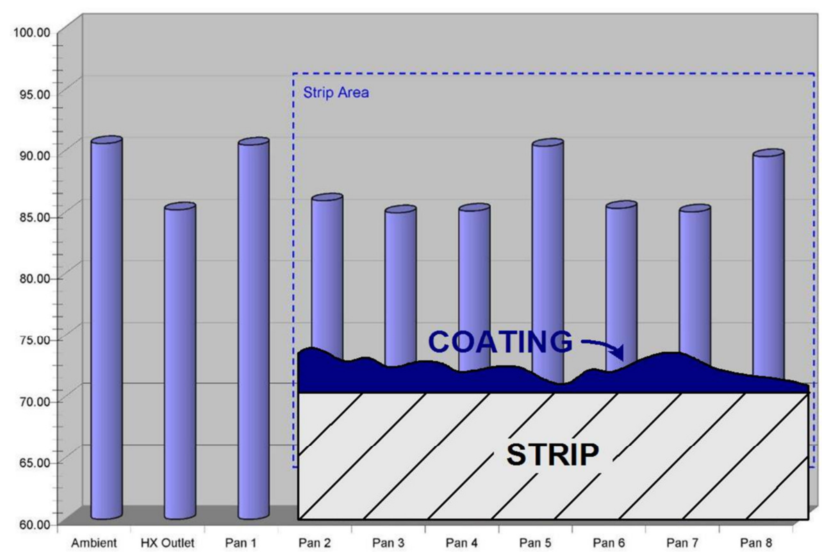

Figure 17: Uncorrected Profile and Effect on Film Build

The goal then must be to reduce variations in viscosity as the coating is being applied to the substrate, but identifying and correcting the factors that create viscosity variation at the point of use can be complex and must be treated on a case by case basis. It is clear however, this can only be accomplished through the careful manipulation of the flow dynamics in the system as well as the supply temperature of the coating.

Figure 18 shows this same system after correction of the thermal profile and the impact on the film build. Here we see that the total temperature variation across the width of the strip has been reduced to about 1°F. This translates to a total edge-to-edge viscosity variation of about 0.8s or just 20% of the total operating window.

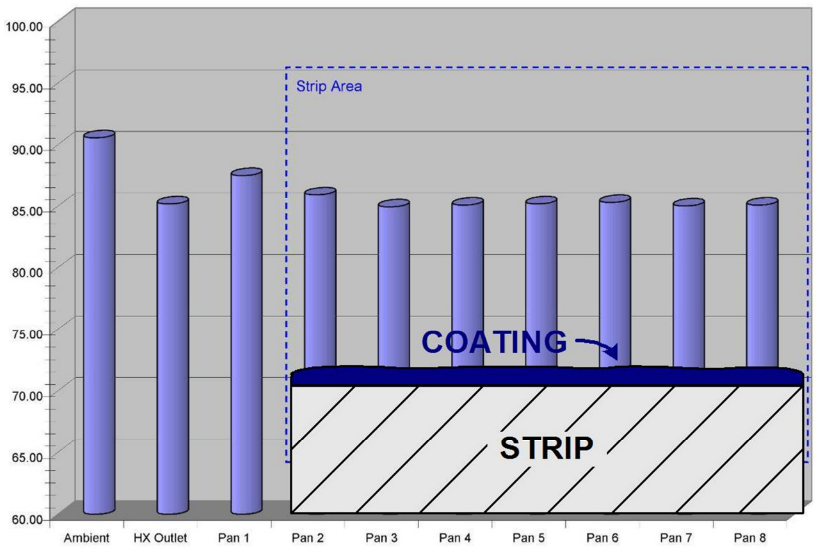

Figure 18: Corrected Profile and Effect on Film Build

POINT OF USE TEMPERATURE CONTROL

In each of these cases it is clear that the solution to the question of how to stabilize the process lies with controlling the temperature of the coating at the point of use. Though the approach for each is unique, the end result is the same – stabilizing the temperature stabilizes the viscosity and helps to bring the process under control.

It is equally important to accurately control the temperature at the optimal value. Often, with modern coatings, that optimal value is well below the ambient temperature. In many cases and in many climates, it is necessary to heat the coating during the cool morning hours and cool it through the warmth of the afternoon. Seasonal temperature variations are generally even more extreme, presenting the same requirements. We have also shown that many systems generate friction as a part of the delivery and application process, this manifests itself as heat which must be removed by the temperature control system. In virtually all modern coating applications, a system capable of both heating and cooling, and of switching seamlessly between the two, is also important.

Recent advances in both methodology and thermal transfer devices make temperature a tool that can be utilized to protect the integrity of the coating and optimize the performance of both the coating and the application process. These new and more efficient means, move temperature control from the bulk supply at the beginning of the process to the point of application, where it can have a more positive impact on the performance of the coating process. This adds another important parameter to the list of those that combine to control the process, and if the parameters of a proven "coating recipe" can all be held constant, the resulting application outcome will be consistent and repeatable.

CONCLUSION

Though modern coatings may be very different chemically from their conventional waterborne and solventborne, oven-cured counterparts; when it comes to dispensing and applying them, the methods employed and their behaviors within those systems are very similar. This is especially advantageous where modern coating formulations can be substituted for older versions to gain significant performance and/or ecological benefits without incurring major rework, downtime and cost in the implementation. In each case, temperature variations result in viscosity variations that undermine the advantages. In fact, modern coating formulations are often even more temperature sensitive than their more conventional counterparts.

Modern temperature control systems utilize innovative methods and devices to assure that temperature-based viscosity variations at the point of application are eliminated and that consistent, repeatable performance can be achieved independent of changes in ambient temperature and/or processing conditions. This turns temperature from an adversary, working against the process, to a tool that can be utilized in conjunction with the other tools (like pressure regulators, speed controls, and the like) to assure that the outcomes of the coating process are completely predictable and advance the goals and objectives of your business.

BIBLIOGRAPHY

1 – Water Temperature vs. Viscosity data provided courtesy of Norcross Corporation.

2 – Paint Temperature vs. Viscosity data provided courtesy of Alsco Metals Corporation – Roxboro, NC.

3 – Material Viscosity vs. Solvent data provided courtesy of Alsco Metals Corporation – Roxboro, NC.

4 – Paint Viscosity vs. Temperature data provided courtesy of Sherwin-Williams Corporation.

5 – The Effect of Process Friction on Temperature data provided courtesy of Alsco Metals Corporation – Roxboro, NC.

6 – Roll Coating Thermal Profile data provided courtesy of Alsco Metals Corporation – Ashville, OH, utilizing Saint Clair Systems' Profile Analysis and Correction System.

Michael R. Bonner is the Vice President of Engineering & Technology for Saint Clair Systems, Inc., a leading supplier of process temperature control equipment for industrial fluid processing systems.