ST. CLAIR SYSTEMS INC.
12427 31 MILE RD.- ROMEO, MI. 48095
Ph. (810) 336-0700 Fax (810) 336-0705

Using Temperature to Stabilize Dispensing Processes:

Applying Lessons Learned by the Automotive Manufacturers to the Composites Industry

The flood of advanced materials developed over the last 20 years has created changes in virtually all of the products that we see and use every day. Nowhere is this more apparent than in the automotive industry. What started with bolted and welded steel, rubber, fabric and glass is now a complex mix of metals, alloys, plastics, composites, sealants, adhesives, etc. It is the use of sealants and adhesives on which we will focus.

Dispensable materials (sealants and adhesives) are now used in the automotive industry to reinforce body panels, seal and smooth seams and joints, diminish noise and vibration, prevent chips and dents, reduce rust and corrosion, etc. In order for these materials to be successful, problems with surface finish, deposition thickness, volume dispensed, overspray, operator exposure, disposal of excess/waste material, etc. all had to be addressed. This has resulted in the development of devices and methods to control all of the variables (temperature, pressure, flow, speed, path, distance, angle, etc.) in the dispensing process.

Of all the dispensing process variables, temperature is the one most often overlooked. Frequently, other variables (like pressure, flow, gun speed, etc.) are altered to compensate for changes in temperature. In the automotive world, however, temperature has shown significant impact in stabilizing dispensing processes, since it affects virtually all of the other variables.

This white paper is the first in a series demonstrating how the lessons learned and tools and processes developed using temperature to address dispensing issues in the automotive industry can be applied to the composites industry to achieve improved results.

In the early days, sealants and adhesives were applied in the auto plants manually, with a spray gun, caulking gun, or brush. These methods were inconsistent at best. This became an issue as the materials and applications began to be used to replace structural fasteners. For instance, when a 2mm bead of heat-curing epoxy was applied around the perimeter of a hood, replacing all welds, inconsistencies in the application could not be tolerated. In order to insure the integrity of the auto body, methods of application had to be developed that would guarantee consistent position and quantity of the material on every part. Enter the industrial robot.

A robot could move an applicator through the same motions time-after-time, maintaining the same path, speed, distance and angle with respect to the surface. The ultimate solution appeared to be simply coupling an industrial robot with a pump and flow gun, fixturing the part, and teaching the right path.

A whole new set of issues arose, however. It became apparent that while a robot could provide the basis of a consistent application in terms of path and speed, there were other variables that needed to be controlled to get a consistent result: orifice size, pressure, and viscosity. For the purposes of this discussion, a fixed orifice system (a common solution for both automotive and composite applications) is assumed.

In a fixed orifice system, variations in pressure and viscosity affect flow, changing the "pattern" of the material being dispensed. For the purposes of this discussion "pattern" refers to the combination of volume, width, thickness, and uniformity of the material after application. Pressure was easily regulated and shot-meters could assure that the right amount of material was dispensed, however, neither of these solutions resulted in a consistent, repeatable pattern of material being applied. While a human operator could adjust for variations through eye-hand coordination or by re-applying over an area that was under-coated or missed completely, a robot had no means of judging or adjusting for these variations. Early attempts at automation still had workers brushing out seams and re-coating areas that had been missed, placing the whole concept of automation at risk.

Similar issues had been dealt with in the paint shop, where exacting standards are the norm. It was known that warm paint is thinner, so it flows faster, increasing problems like sags, runs, and drips, whereas cold paint is thicker, resulting in uneven coverage. For these reasons, virtually all automated paint systems included some form of material temperature control. If the same principles held true for these higher viscosity materials, temperature control would solve the problems with sealants and adhesives. They did. Once temperature control was installed, the systems started performing as intended. The reason is the effect of temperature on viscosity.

It's been understood for some time that virtually all liquids show some change in viscosity as a function of temperature. Figure 1, taken from an old viscometer data sheet reveals that even water, which goes from a solid to a liquid to a gas with very sharp transitions, goes through a viscosity change of 1.7:1 between 60°F and 100°F.

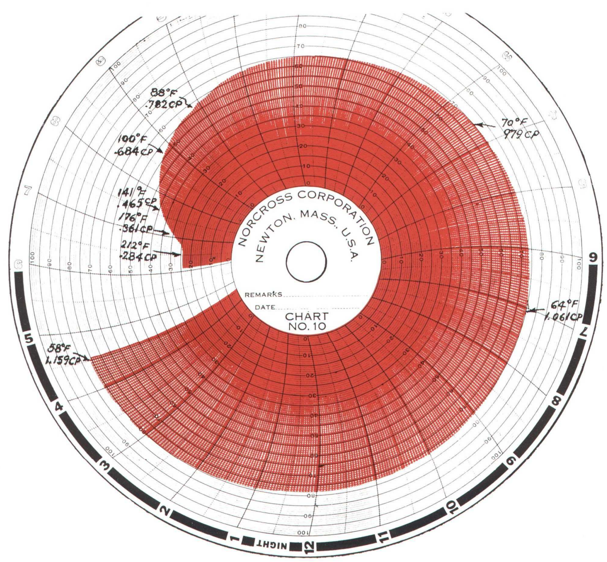
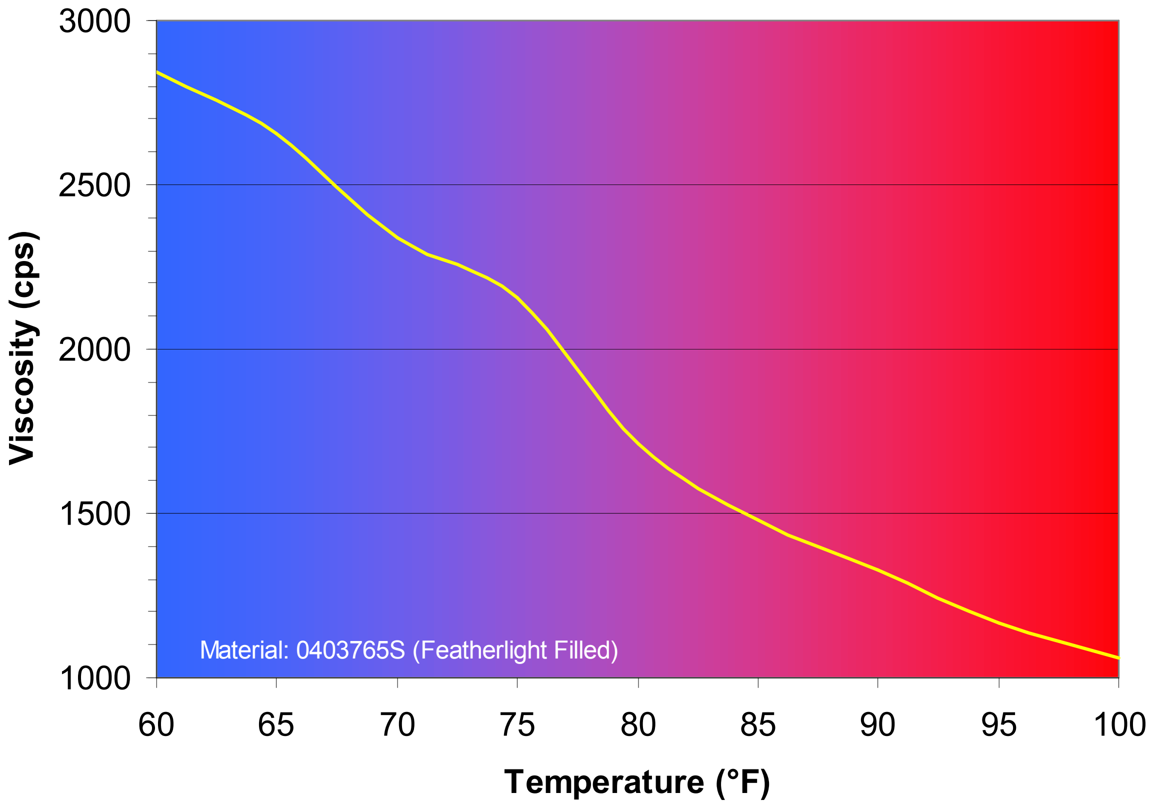


Figure 1: Viscosity vs. Temperature For Water[1]

How does this apply to the Composites Industry?

The effect of temperature is well known among resin suppliers and fabricators alike. Evidence of this can be found on a material specification sheet where viscosity is given at a specific temperature (often 77°F). This is even more obvious if a viscosity vs. temperature curve is provided. Like water, these curves typically exhibit a very sharp change in viscosity over a fairly small temperature range, often falling directly over the normal ambient range. Figure 2 shows the graph for a common resin that exhibits a 200% change in viscosity between 65°F and 90°F.

Figure 2: Typical Viscosity vs. Temperature Curve[2]



The effect of the viscosity/temperature relationship on the dispensing process can be readily demonstrated. When all other factors (orifice size, pressure, path, speed, distance, angle, etc.) are held constant and temperature is varied, the pattern dispensed changes dramatically.

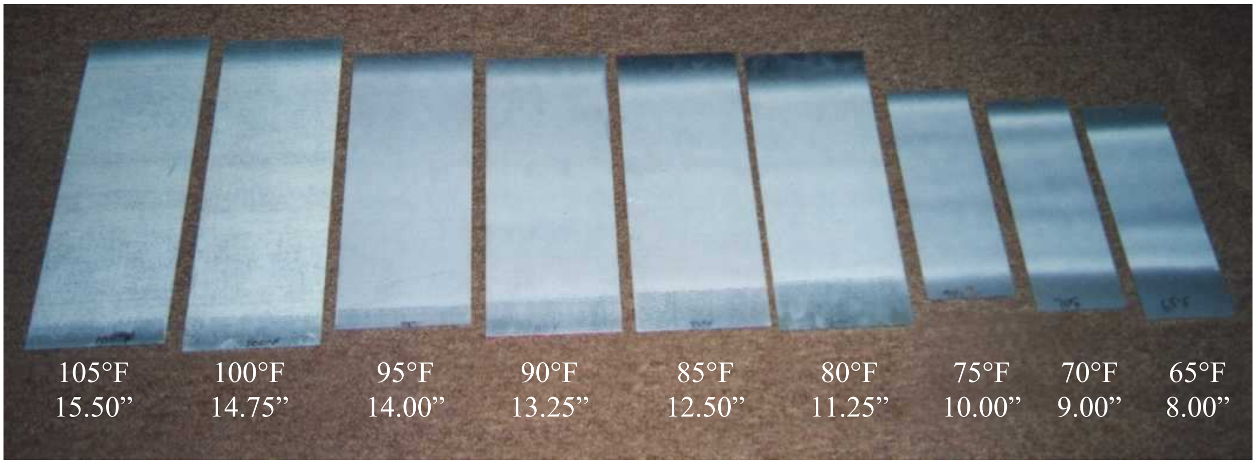
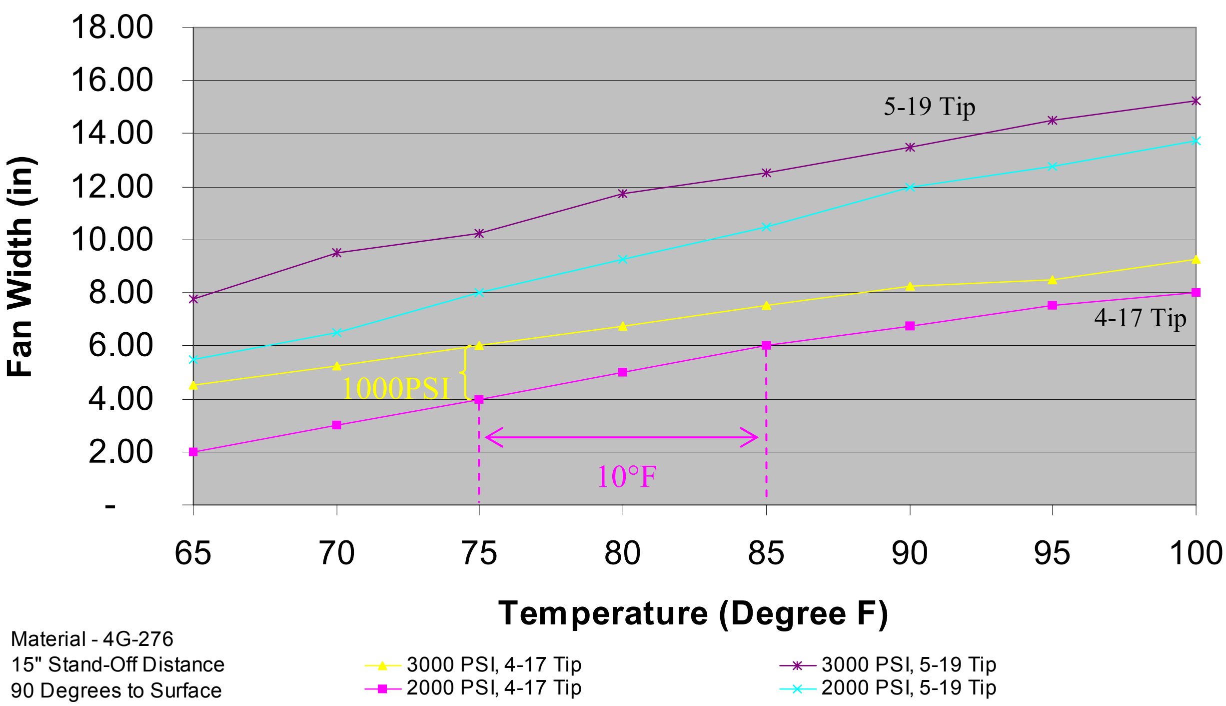


Figure 3: Effect of Temperature on Spray Pattern

For the coupons shown in Figure 3, orifice, pressure, distance, and angle to the surface were held constant while PVC 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. It shows the resulting effect on spray pattern across a 40°F change in temperature. Notice the thin coverage on the 100°F and 105°F coupons; how it smoothes out between 80°F and 95°F; how it grows uneven below 80°F. While the visual impact of this photograph is striking, the results are more easily analyzed when graphed as in Figure 4.

Figure 4: Fan Width vs. Temperature for PVC Anti-Chip



Note the extremely linear relationship between fan width and temperature. The graph shows that a 10°F change in temperature (from 75°F to 85°F) had the same effect on the 4-17 tip as a 1000 PSI change in pressure. This relationship makes temperature an almost perfect control variable.

In his article "The Optimum Composites Shop", Bob Lacovara states, "Controlling temperature is the most important step in gaining a handle on production and quality consistency."[3] He goes on to point out that many fabricators try to address this issue by controlling ambient temperature in their facility. Referring back to Figure 2, there is somewhat of a flat on the curve between 70°F and 75°F. As this is a good ambient temperature for people, it would seem a good operating temperature to choose. It is easy to assume that by installing a large HVAC system to stabilize the plant temperature, the material will exhibit a consistent viscosity. But this ignores many issues. The first of which is the resin itself.

It may be found that spraying a given resin at 80°F – 85°F provides a more even pattern resulting in an improved surface finish (as shown in Figure 3). Another resin may produce a heavier build-up without sagging by spraying at 60°F – 65°F, resulting in increased throughput. A different resin sprayed at 85°F – 90°F on a mold at 70°F may reduce styrene emissions due to faster setup of the suppression medium. Moreover, it may be desirable to use several of these in the same facility at the same time. It is impossible to exploit the advantages of material properties such as these with ambient control alone.

Controlling only ambient temperature also neglects the effect that the spraying system has on the resin.

Unlike water, viscous materials require a great deal of energy to pump from one place to another. Some of this energy invariably ends up in the material as heat. As resin moves through the system, friction between the resin and surrounding surfaces generates more heat. Moreover, when viscous (especially thixotropic) materials shear, the temperatures at the shear interface increase and the viscosity decreases. So, though the ambient temperature may be tightly controlled, it will invariably fail to control the temperature of the resin being dispensed. Standard process control components such as, pumps, regulators, shot meters, filters, etc. all contribute to this phenomenon by adding shear and friction to the resin path. It's simple physics, there are no exceptions.

The result of shear and friction in the common dispensing system then, regardless of ambient temperature, will be to increase the temperature of the resin being dispensed. As you might have guessed from the relationship already established between temperature and viscosity, as temperature increases, the viscosity decreases, which, in turn, decreases the effect of shear and friction. While an in-depth analysis of this effect is a topic for another paper, it is sufficient to say that this will result in a significant change in the spray pattern and overall consistency of the application. Therefore it is also impossible to exploit the various resin properties without controlling the temperature effect of the spraying system on the resin. This cannot be accomplished with ambient control alone.

Fortunately, we can establish that the temperature change due to shear and friction within a system is both linear and repeatable within a given viscosity/temperature range. It is reasonable then, to consider shear and friction as being a constant in a fixed orifice system at any given dispense rate, since dispense rate is a function of pressure and viscosity, and viscosity is a function of temperature.

Controlling the pressure is readily achieved through the use of a regulator and viscosity is directly related to temperature. Controlling the viscosity then, is a function of measuring the temperature in the material path *after* the shear/friction producing devices, then counteracting any change using the appropriate combination of temperature conditioning devices (heat exchangers, etc.) available on the market today. If pressure is held constant, and viscosity (vis-à-vis temperature) is held constant, the spray pattern will be consistent and repeatable. This also demonstrates the importance of choosing the proper control point when designing a dispensing system.

Care must be taken in the design and implementation of the temperature conditioning system, and the location of the control point is not the only critical factor. Often, it is mistakenly thought that short hoses or other devices that connect sections of the system don't have a significant effect on system performance. Nothing could be further from the truth. This can be demonstrated by excluding the dispense valve from the temperature conditioning envelope.

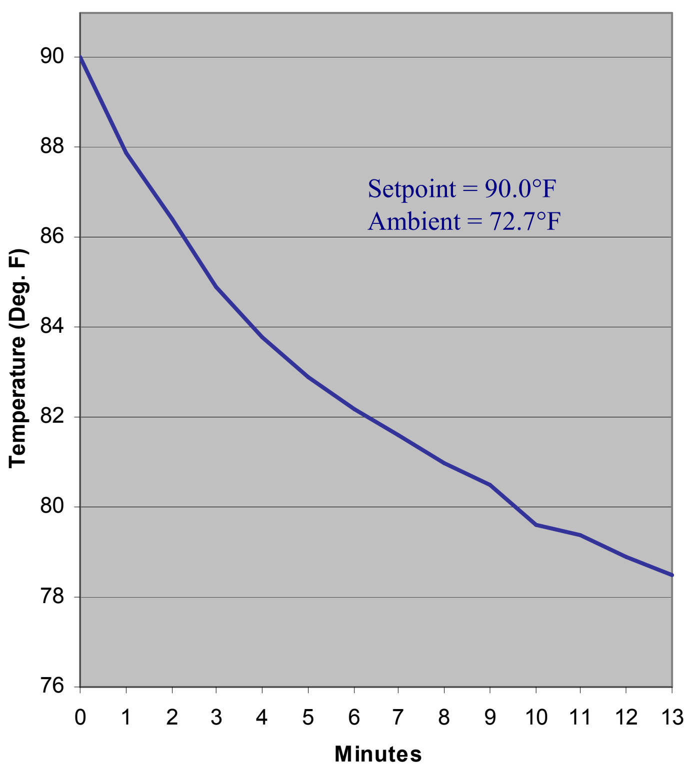


Figure 5: Thermal Transfer to Ambient

Figure 5 shows that thermal transfer from the dispense valve to ambient occurs very rapidly. All appears well under repetitive cycling, but when the system is allowed to sit idle for more than few minutes (breaks, shift changes, part changes, etc.), the effect is dramatic.

Figure 6 shows the effect on the process when the gun is allowed to reach a 71°F ambient in a system set to run at 85°F. Remember that a 10°F change in temperature can have the same impact as a 1000 PSI change in pressure. While the lower, ambient 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 deposition thickness drops proportionately. This is clearly in keeping with the effects demonstrated in Figure 3 and, for most applications, would be considered unacceptable.

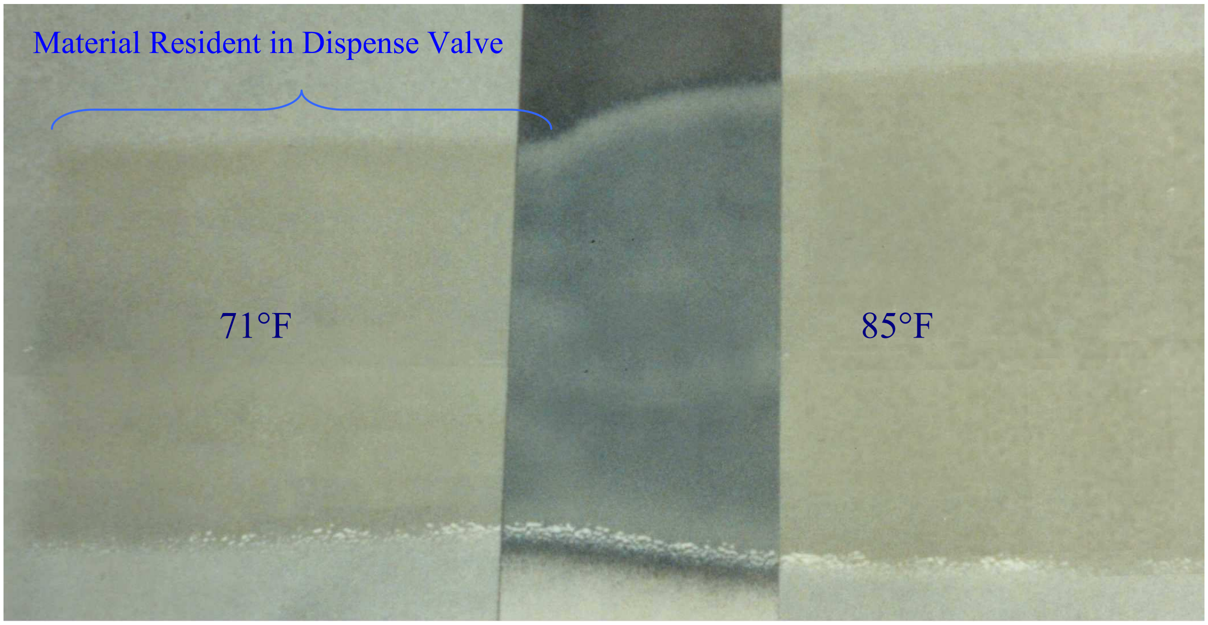


Figure 6: The Effect of Leaving Gaps in the Temperature Control Envelope

Viscosity can offer additional benefits to the dispensing process when all other factors are held constant. From these examples it is easy to see that making temperature/viscosity a controlled parameter adds significant versatility to the system.

It is well established that the higher the viscosity of a fluid, the higher the pressure required to move it through a spraying system. Automotive applications often require materials with viscosities approaching 1,000,000 cps. Though thixotropic, at these viscosities pumping pressures can often reach 5,000 psi. Operating in this range requires expensive hoses and components, which increase system cost. The steep viscosity vs. temperature curves make it possible to reduce system pressures by increasing the material temperature and taking advantage of the resulting reduction in viscosity. This reduces the required operating pressure and therefore reduces the cost of the components and the subsequent wear-and-tear on them. Similar results are possible with composite equipment as well, especially with regard to controlling emissions by reducing gun pressure[4].

Another use lies in the fact that most resins' curing profiles are temperature dependent. Higher temperatures generally result in faster cure times. While this presents an interesting process control opportunity, it can be a double-edged sword. High viscosity materials are often specified to reduce drips, sags, and runs on vertical surfaces, or to increase the deposition thickness of the material. As observed in paint applications, reducing the viscosity of the material can create these problems in the application. This may be offset by reducing the gel time. It can be a delicate balance but provides the opportunity to increase throughput and reduce rework by improving the control of the process and, as discussed earlier, exploiting the natural properties of the resin.

It is clear from this evidence, that the impact temperature has on the quality of performance of any dispensing system cannot be overstated. The options for process improvement are endless. This is especially true in robotic applications, designed for the express purpose of creating a stable, repeatable process, but clearly, advantages exist for less automated operations as well. In short, this one simple, often overlooked parameter can be the difference between the implementation of a successful, reliable, predictable system and an ongoing headache.

BIBLIOGRAPHY

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

2 – Resin Temperature vs. Viscosity data provided courtesy of Cook Composites.

3 – Lacovara, Bob. The Optimum Composites Shop. Composite Fabricators Association, 1996.

4 – Lacovara, Bob. Spray Pressures and Emissions. Composite Fabricators Association, 1997.

Michael R. Bonner is the Vice President of Engineering & Technology for St. Clair Systems, Inc., the leading supplier of process temperature control systems for paints, sealants, and adhesives to the automotive industry.